Naval Aviation

Firsts

ROYAL NAVY

Leading the way in Innovation

LAST HARRIER (GR9) EVER Ski Jump Take Off HMS Ark Royal 24th November 2010

Ski-Jump

In the 1970s Lt Cdr Doug Taylor invented the 'Ski-Jump'. This upwards curving ramp at the forward end of the flight deck ensures that the aircraft is launched on an upward trajectory giving considerable performance gains, including much greater payload and range, than a corresponding flat deck, short take-off. The early trials proved so successful that the Ski-Jump was incorporated into the design of HMS Hermes and the Invincible Class carriers.

FLY NAVY 100

SRVL

Shipborne Rolling Vertical Landing

1909 - 2009

Costing Complex Products, Operations & Support 19 Oct 2011 Dr. Michael Pryce http://www.dtic.mil/dtic/tr/fulltext/u2/a555661.pdf

"...Operations on the Harrier have led to constant discoveries of undercarriage O&S issues that needed to be addressed. Although the main undercarriage was very robust, being designed to operate off base and to take many unusual loads, such as landing while flying backwards, these discoveries were near impossible to predict and meant that the real-world experience of the undercarriage in use differed from the original design spectrum that they were built to meet.

For example, as Burton (1996) reports, seemingly minor differences in the build quality of the ski-jump ramps of the UK's Invincible Class light aircraft carriers seriously affected the life of the undercarriage units, depending on which ship was being operated from. These ship build quality differences were not part of the original design assumptions, or subsequent modeling under-taken for a new ski-jump design fitted to UK aircraft carriers and its effect on the aircraft's oper-ating limits, and led to unexpected, and unexplained, cracking in the undercarriage units.

Upon investigation, down to individual aircraft and mission levels, it was discovered that the undercarriage damage suffered was not particular to the role or mission profile of the aircraft, or to the type of Harrier, but to the particular ship of a class that they were operating from. The damage was expensive to repair, but absolutely necessary in order to avoid a catastrophic failure mode that could not be predicted. Such a failure would lead to loss of an aircraft and likely serious damage to the ship. However, it was avoidable. The issues of the variability of carrier deck design on the class of ships concerned were known to the aircraft design team at least a decade before, with pitting and so forth causing problems on both deck and in the hangar (Brooklands Museum, 1985). However, in the calculation of undercarriage loads carried out during the design of the Sea Harrier, a smooth deck was assumed, based on design rules created by the UK Ministry of Defence (National Archives, 1978)....

...The fact that one of these ships caused damage to aircraft undercarriage units was not catastrophic in this case but, in large part, this was due to the undercarriage being of robust design, thanks to very different original requirements. If the undercarriage had been designed by the assumed loads for the ski-jump, modeled as part of the design and clearance program, it could well have failed in service use, leading to expensive re-design, remanufacture, and modification work for the entire fleet, or to the aircraft carriers. If the simple, baseline assumptions of the nature of ski-jump ramp design had been widened to look at possible worst case scenarios, the issue may have been accounted for earlier, and its costs would not have come as a surprise...."

NPS-AM-09-010

http://acquisitionresearch.net/_files/FY2009/NPS-AM-09-010.pdf

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Acquisition of Capabilities through Systems-of-systems: Case Studies and Lessons from Naval Aviation

Presenter: Dr. Michael Pryce is a Research Associate at Manchester Business School, currently working on a project entitled Network Enabled Capabilities Through Innovative Systems Engineering (NECTISE). He completed his PhD in 2008, which looked at the role of design in the acquisition of STOVL combat aircraft. He also holds a Master's degree in the history of technology and a Bachelor's degree in history. He has worked as a process engineer for GM and in web development.

Dr Michael Pryce
Centre for Research in the Management of Projects
Manchester Business School
Booth Street East, Manchester, M15 6PB
United Kingdom
Telephone Work: +44 (0)161 306 3521
Home: +44 (0)1273 227 046
E-mail: Michael.Pryce@mbs.ac.uk

Abstract

The acquisition community in many nations faces novel challenges with the transition to systems-of-systems, capabilities-based solutions to meet military requirements. Much of the "tribal knowledge" and experience of those in acquisition, both in industry and government, has stemmed from platform-centred development strategies. It is questionable to what extent lessons from these can be applied to systems-of-systems acquisition. How does the acquisition expert trade off platform capabilities against the capabilities of a network of systems that might be composed of new and existing platforms used in new or old ways?

This paper presents case studies from past and present, illustrating such issues, and seeks to draw out lessons from experience that may be useful. It draws on many years of empirical research, undertaken with those involved in addressing such issues in the acquisition community.

Introduction

Much work in the acquisition community, in many nations, has been undertaken in recent years toward achieving enhanced military capabilities through the use of systems-of-systems, network-centric or -enabled capabilities and through life management of these. This work has been motivated by many different factors—evolving threats and military doctrines, changes in technology, force re-structuring, etc. Central to these efforts has been a desire to achieve interoperability of forces, allowing the deployment of capabilities that, hopefully, are more than the sum of their parts.

While much of this work has rightly focussed on the opportunities offered by new, notably digital, technologies, more prosaic (perhaps what could be seen as "old-fashioned") issues also have a significant impact. Capability depends on the interaction of all system components and their differing characteristics. In this paper, the effects of capabilities of such prosaic issues will be explored, with the focus on one of the oldest "systems-of-systems," the aircraft carrier and its aircraft. In a near century of evolution, the aircraft carrier and military aircraft have evolved both independently and together in the face of, and in response to, changing military needs. The success of their evolutionary ability means that they are still seen as providing important capabilities for the long term.

Aircraft and aircraft carriers form symbiotic system for the delivery of capability. A view of aircraft carriers as mere infrastructure, a floating runway and hangar for the aircraft it carries, misses much of its importance. In order to understand how to acquire such capabilities, we need to understand the interactions between the aircraft carrier and its aircraft. In this paper, the prosaic issues that matter in operating aircraft from ships will be illustrated. This is not to diminish the modern need for digital interoperability, etc., but rather to illustrate how matters such as simply being able to move aircraft around the deck and hangar of a ship in an effective manner can have significant effects on capability.

This paper examines the issue from the perspective of the United Kingdom's Royal Navy and its experiences of deploying Short Take Off and Vertical Landing (STOVL) aircraft onboard its carrier fleet over several decades. Current acquisition policy in the UK is concerned with delivering capability using Through Life Capability Management (TLCM). This is defined as, "translating the requirements of Defence policy into an approved programme that delivers the required capabilities, through-life, across all Defence Lines of Development" (MoD, 2009).

The Defence Lines of Development (DLODs) allow for the co-ordination of the development of the different aspects of capability that are needed to create a real military capability. These aspects are:

- Training
- Equipment
- Personnel
- Information
- Concepts & Doctrine
- Organisation
- Infrastructure
- Logistics

It is only by addressing all the lines of development that the acquisition (and sustainment) community can effectively deliver capability to the UK armed forces, through the various force elements (ships, aircraft, army units, etc.), which are then used to create Joint Capability Packages. These are tailored by a force commander to undertake particular missions or tasks, taking into account coalition forces, threats and the overall operating environment. This is shown in Figure 1.

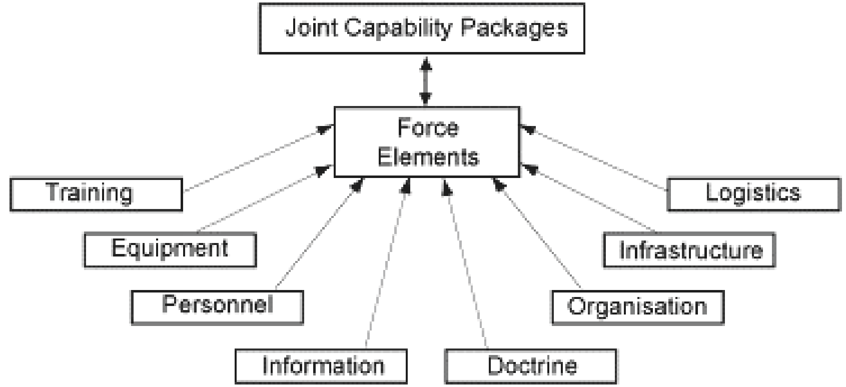

Figure 1. The Role of the UK Defence Lines of Development in the Creation of Capability

The DLODS can therefore be seen as being the primary constituents of capability and forms a useful analytical tool to understand the impact of differing ways of delivering capability. In this paper, we are concerned with the UK Royal Navy's use of STOVL aircraft from its carriers. An illustration of how the choice of STOVL aircraft can impact on the DLODs is shown in Figure 2.

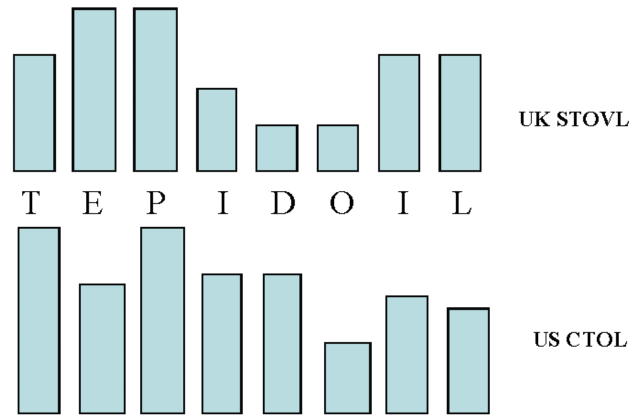

Figure 2. Comparison of UK and US Naval Strike Fighter Costs across the UK Defence Lines of Development
(Stanford, 2008)

This figure illustrates how, for the achievement of a given capability, the costs are allocated for the two examples across the DLODs, due both to the innate differences between two different types of aircraft and also to the differing operational employment of STOVL and CTOL aircraft. The UK STOVL aircraft training costs are lower than for the US aircraft, attributable to the needs of "cat and trap" landings at 140 knots on the US Navy supercarrier. However, the lower warload of the UK STOVL aircraft may account for the higher overall equipment costs while the difference in costs attributable to doctrine is perhaps the most marked, reflecting the greater flexibility of the STOVL aircraft carrier and its aircraft.

While STOVL aircraft may be "easier" to integrate at one level with a ship (with no catapult or arrestor wires and the ability for STOVL aircraft to operate from smaller ships), what this example really illustrates is that the costs are distributed differently for a given capability depending on the nature of the systems used to deliver it. In the case of aircraft carriers and their aircraft, it is important to note that both are complex systems in their own right, with differing design, testing, manufacturing and support approaches. As Andrews (2003) has rightly pointed out, a ship does not have a prototype, unlike aircraft, and therefore, there is a need for the designer to ensure that it is "right first time." However, in the case of an aircraft carrier, it is only once it is operating aircraft, or when a new generation of aircraft are introduced, that it can be determined if the design was indeed right—and that while it may be right first time, it may not be right second time, with new aircraft onboard.

For the acquisition community, the issues attendant on developing and sustaining capability using ships and aircraft in combination present formidable challenges. While traditional approaches to designing them separately may be seen as less than ideal, the rest of this paper will explore how the acquisition process of the past has managed to achieve a large measure of success in doing this, despite being focussed largely around projects rather than overall capability.

Harrier and Invincible Class Experience and Design

One of the main "transformational" military technologies of the twentieth century was the development of aircraft to provide a new dimension to warfare. The impact of aircraft on naval warfare became apparent during World War II, notably in the great battles of the Pacific War, with Japan and the United States relying on aircraft and aircraft carriers as the centrepiece of their fleets. Post-1945, the aircraft carrier continued in this central role in major navies, and helicopters allowed the provision of air power to be extended to smaller vessels and lesser navies.

In the United Kingdom, attempts to sustain a viable force of major aircraft carriers foundered due to budgetary restrictions. Nevertheless, in order to retain a viable naval force, it was recognised (despite considerable inter-service debate) that some form of organic air power was still required to deliver the Royal Navy's key NATO role of anti-submarine warfare in the Eastern Atlantic. This was a highly complex environment with threats from Soviet submarines, surface combatants and aircraft (both land- and ship-based) requiring a mix of capabilities to be able to respond to them.

In order to meet these threats, the Royal Navy was largely forced to adapt the land-based Harrier STOVL strike aircraft to meet their needs. The ability of the Harrier to land on many types of ship had been demonstrated since 1963, from full-size aircraft carriers to the helicopter decks of cruisers. The adoption of the Harrier by the US Marine Corps during the 1970s had led to the regular use of the aircraft from the assault ships of the US Navy, although only those (LPH and LPD) with full flight decks and hangars had Harriers based on them.

The Royal Navy was already planning a fore of anti-submarine warfare (ASW) cruisers during the early 1970s, to operate helicopters only. However, the need for the ships to carry more than six helicopters to meet the submarine threat from the Soviet Union led to the adoption of a "through deck" layout for the ships, essentially a miniature aircraft carrier, and in many ways the same basic layout as the US Navy's assault ships from which the Harrier was already operating. The recognition of the inability of surface-to-air missiles to fully meet the threat of "shadowing" reconnaissance aircraft of the Soviet Navy (providing targeting data for submarine launched anti-ship missiles) led the Royal Navy to push for the adoption of the Harrier to operate from the new class of ASW cruisers, with a small number of the aircraft operating alongside the helicopters. This led to the development of the British Aerospace (BAe) Sea Harrier, which first flew in 1978 (Brown & Moore, 2003).

However, the design of the ships, which became known as the Invincible class, was largely fixed before the decision to develop the Sea Harrier—HMS Invincible was laid down in 1973, while the Sea Harrier was not funded for development until 1978. This meant that, with the Sea Harrier being an adaptation of the land-based Harrier, neither the ship nor the aircraft was designed specifically for the other. For the ship, the hangar, flight deck, maintenance and stores (fuel, weapons, spares) facilities were all designed around the Sea King ASW helicopter. They were also designed "to have the ability to take future VSTOL" (i.e., STOVL) aircraft, with provision made for STOVL aircraft (in terms of some additional space being allocated and with the aircraft lifts) sized for STOVL aircraft. This latter assumed a generation of aircraft in advance of the Harrier, although it led to the assumption that such an aircraft would have similar dimensions to an earlier STOVL project, which had been cancelled while still under development in 1965: the Hawker Siddeley P.1154. The latter had been essentially a larger, faster, more powerful version of the Harrier concept (Andrews, 2009, February 12).

Adapting the Harrier for use in a maritime environment proved relatively straightforward, with new avionics and minor systems improvements in addition to a more noticeable new front fuselage. As the aircraft was relatively small, major modifications such as wing folding were not required, although the radome folded for maintenance access and to reduce the spotting factor. Tie-down lugs were added to the aircraft's undercarriage to secure it to the deck, but, all told, "navalisation" added only an extra 100 pounds of weight. This low figure was largely attributable to the ability of the Sea Harrier to land vertically, so eliminating the need for strengthening to cope with arrested landings, as well as the aircraft's ability to take-off without the need for catapulting, with similar structural "beefing up" obviated (Fozard, 1978).

In place of the catapult, one innovation allowed the Sea Harrier to operate at higher weights from aircraft carriers. This was the "ski jump" ramp, an upwardly curved addition to the end of the flight deck runway that enabled the Sea Harrier to take-off at either lower airspeeds or at higher weights for a given deck run than a "flat deck" take-off. The ramp also offered safety benefits, as it meant that the Sea Harrier should almost always be launched on an upwards trajectory even if the bows of the ship were pointing down, as often happened in heavy seas. Trials on land during the latter half of the 1970s proved the concept of the ramp, and showed that only relatively trivial modifications to the Sea Harrier's undercarriage were required to allow it to use the new "ski jump" technique (Fozard, 1978; Davies & Thornborough, 1996).

The first installation of the “ski jump” on a ship was on the old light fleet carrier HMS Hermes, which was given a 12-degree ramp during a refit and took Sea Harriers onboard for trials in 1979. These trials showed that the concept would work at sea, although it had already been decided to add ramps to the Invincible class during build—although on the first two ships of the class, the ramp was at the lower angle of 7 degrees. This was due to the ships being fitted with a substantial anti-aircraft missile launcher in the bows, the firing arc of which required the lower-angle ramp. This reduced the benefits of the ramp, but still allowed a useful addition in payload or reduction in take-off run for the Sea Harrier (Brown & Moore, 2003).

Once HMS Invincible had been commissioned and began operating Sea Harriers, it became clear that the two systems had not been designed for each other. The dimensions of the ships’ hangar had been defined by two main constraints—the need to change the rotor head of the Sea King helicopter and by the need for the ship’s own gas turbine propulsion system uptakes to pass next to the hangar. This produced a “dumbbell” shaped hangar that was wider at its ends than in the middle section. While this was adequate for the Sea King, the absence of wing folding on the Sea Harrier did mean that they were already approaching the limits of the hangar width in this area. Even greater strains were caused by the Sea Harrier’s support onboard the ship, with perhaps three times as much fuel, spares, etc., required for each Sea Harrier than for each Sea King helicopter. In addition, the need to remove the wing of the Sea Harrier in order to change its engine meant that a specialised hoist was installed in the hangar, with an engine change requiring the aircraft to be trestled and secured to the hangar floor. The entire engine change evolution could take several days, monopolising a major part of the hangar and reducing the scope for aircraft movements in the hangar (Andrews, 2009, February 12; Davies & Thornborough, 1996).

While these limitations were coming to light, there were benefits to using the Sea Harrier onboard the Invincible class. It quickly became apparent that the vectored thrust engine of the Sea Harrier allowed it to “back taxi” under its own power, reducing the requirement for tractors and towing gear and considerably speeding up the process of moving aircraft to and from parking areas on deck. This meant that landing and take-off cycles could be increased, adding to the other benefits of operating STOVL aircraft such as the ability to dispense with “go around” fuel margins, reduced weather minima and high sortie generation rates.

All these aspects were proven of value during the Falklands conflict in 1982, in which the Sea Harrier and Invincible class both proved their worth in a real conflict (Davies & Thornborough, 1996). Subsequently, both were updated, with the Sea Harrier receiving a new weapons system, and the Invincible class adapted with additional weapons and the ablity to operate a larger number of Sea Harriers (and later land-based Harriers). The anti-aircraft missile system was removed from the ships, allowing an increase in deck area and larger weapons magazines for the aircraft, and further operational experience has proven that these adaptations have been valuable.

Figure 3 [next page]. Royal Navy Sea Harriers Operating from an Aircraft Carrier during the Falklands War

*Note the proximity of the deck crews, a problem in later studies for a Sea Harrier successor. (Harrier.org.uk, 2009) [BOLLOCKS - AS IT TURNED OUT]

However, it can be seen from this brief and incomplete history that designing the ships and the aircraft as separate projects—only loosely associated during development—came at a considerable price in terms of reduced efficiency and difficulties in operation. These were offset by the personnel of the Royal Navy and Fleet Air Arm who proved adept at coping with these difficulties. However, the costs of the equipment line of development were considerable, and adding costs in terms of personnel, training and additions to the equipment to overcome deficiencies identified during use was undesirable, as was the in-built high logistics cost of the difficult nature of some Sea Harrier maintenance operations and the confined spaces of the Invincible class hangar.

Sea Harrier Replacement Design and Invincible Class

With the experience of the Falklands War and the emergence of new threats for the Soviet Union (notably the deployment of Soviet aircraft carriers, fighters and long-range maritime strike aircraft), meant that by the early 1980s, the Royal Navy was actively pursuing a Sea Harrier replacement programme, in addition to updating the earlier aircraft. One basic assumption was that such an aircraft would be in service during the lifetime of the Invincible class, so it had to be compatible with those ships. This allowed the opportunity to design new aircraft with the issues of operating from the Invincible class in mind, rather than evolving the aircraft design separately from the ship.

As part of the threat analysis and operational research into how to meet such a threat, work in the UK Ministry of Defence (MoD) into the characteristics of a Sea Harrier replacement showed that supersonic speed would be a valuable asset. In meeting a notional attack from Soviet forces, it was seen that a smaller number of supersonic aircraft could cover the threat than was the case with subsonic aircraft using similar sensors and weapons. For some threats, only supersonic speed in the aircraft could provide an adequate response. This issue of aircraft numbers was important as the relatively small size of the Invincible class (plus the ships' need to also accommodate anti-submarine helicopters) meant that the total number of aircraft carried was unlikely to exceed the number of Sea Harriers the ships could accommodate, about 8 STOVL aircraft (Pryce, 2008).

In industrial studies to develop a Sea Harrier successor aircraft (involving British Aerospace and Rolls Royce), the need to provide supersonic speed led to a number of design issues becoming the focus of much work. The most significant of these was that a much more powerful and energetic engine would be needed than that used in the Sea Harrier. This provided a number of environmental difficulties when operating aircraft onboard ships—as the noise, jet temperatures and velocities could adversely impact the deck environment of the ship as well as the aircraft itself to a significant extent (Pryce, 2008). One result of the work was that it was seen that it may be possible that when supersonic STOVL aircraft were hovering in advance of landing, the deck crew might need to use some form of refuge or shelter as the noise level could induce nausea and possible unconsciousness, and the high velocity jets of the aircraft could readily blow crew members overboard (Brooklands Museum Archive File HSA/SHR/047). Clearly, this would be unacceptable, as the role of the deck crew was to enable aircraft operations (see Figure 3).

The effort to obviate such potential risks in the design stage led to a number of propulsion systems and operating techniques that sought to reduce such adverse effects (Pryce, 2008). However, these brought with them a range of operational drawbacks as well—such as the loss of the ability to "back taxi" and the introduction of engines that were too large for the engine maintenance and storage spaces of the Invincible class. A visit by the aircraft design team from BAe to an Invincible class ship revealed further complications that had not been assumed in their design studies, such as ruts in the hangar deck that could mean that if the nose undercarriage of some designs went into such a rut, the tail of the aircraft could "scrape" the hangar roof—despite the ruts only being an inch or so deep. In addition, it was realised that the highly integrated avionics proposed for some of the new aircraft would require a complete re-arrangement of both the maintenance spaces of the ship and the trade structure of the maintenance personnel (Brooklands Museum Archive File HSA/SHR/047).

While these issues were not faced by all the new aircraft designs proposed (and many of them managed to successfully address the existing problems with the Sea Harrier, such as the difficult engine change evolution), it was apparent that the need for supersonic speed and the innate limitations of the Invincible class would cause problems. In the aircraft design studies, it was to be assumed that the ships were not to be modified with special devices such as deck blast deflectors to accommodate the new aircraft. It was discovered that a key limitation was the strength of the ski jump ramp of the ships, as the new aircraft were much heavier, and that strength limitations of the ramp, as well as in the undercarriage of the aircraft, meant that in some cases the aircraft could not take-off with a full load of fuel or weapons (National Archive File AVIA 6/25876).

While the aircraft designers were wrestling with these difficulties, additional analytical studies in the MoD and in BAe showed that further ship/aircraft interaction-dependent characteristics also provided limitations. With only a relatively small number of aircraft carried by the Invincible class, high levels of availability were essential to meet the threats assumed. While the aircraft could possibly be more reliable than the Sea Harrier, it became clear from assessment work of the deck and hangar movements of the aircraft onboard the ship that critical limitations on availability were imposed on all aircraft designs, with reductions in the number of aircraft actually available for operations disproportionately affected by these limitations (Pryce, 2008; Brooklands Museum Archive File HSA/SHR/047).

For example, the ability of the Sea Harrier to "back taxi" under its own power meant that it was able to move quickly into deck parking spaces. However, the configuration of the propulsion systems of the some of the proposed successor aircraft meant that this was not possible, so they would need to be towed around on deck. While a slower process in itself, the realisation that the turning circle of an aircraft plus tow bar and tractor may be much larger than a Sea Harrier meant that not only were manoeuvres slower, but also required greater free deck area to be carried out. Such free area may not be available as the deck was already congested—with many areas used for more than one purpose (see Figure 4), and a "traffic jam" situation would result. Similar problems arose when the size of the aircraft designs reached a point at which the size limits of the lifts or hangar were approached—narrow margins meant much more careful positioning was required, which the crew were likely to have to do much more slowly. It was realised that while crew training and possibly increase personnel numbers may make it possible ways to ameliorate such matters, it was difficult to accommodate additional crew onboard the ship and impossible to show the extent of training required to ensure high levels of availability (Pryce, 2008; Brooklands Museum Archive File HSA/SHR/047).

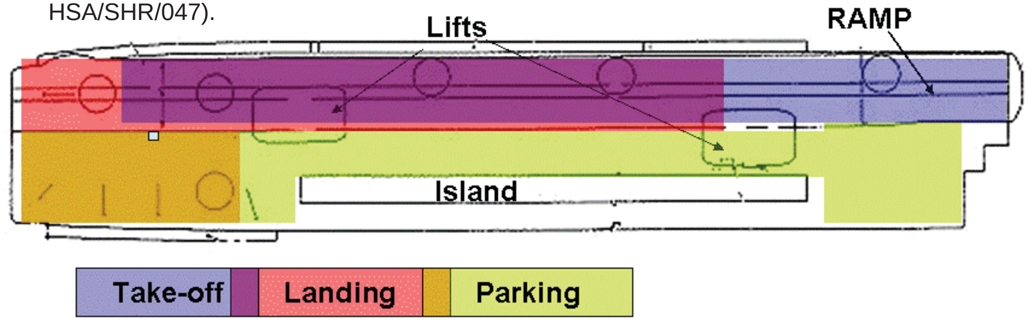

Figure 4. Invincible Class Deck Layout and Uses

(The colours show the different uses of the deck, and how these uses could overlap. An aircraft landing on the deck could slow down take-off operations if it was unable to clear the landing area or to park quickly (Brooklands Museum Archive File HSA/SHR/047).)

Once these ship-dependent aspects of replacing the Sea Harrier were looked into, it became clear that being able to design a new aircraft "around" the Invincible class as it already existed was extremely difficult—as the change in the threat that the new aircraft were intended to meet meant that the aircraft had features that the Invincible class found difficult to accommodate. Attempting to trade-off aircraft performance levels against the deck environment and "traffic" issues on deck also proved extremely difficult, and once wider issues such as the higher fuel/weapon loads of the new aircraft (leading to more frequent replenishment operations) were considered, the work led to the somewhat startling realisation that a new, "better" aircraft could lead to a reduction in capability compared to the Sea Harrier if it had to operate from an Invincible class ship (Brooklands Museum Archive File BAe/PRJ/065—NST.6464).

Harrier/Invincible Experience and CVF/JSF

Although the attempts at developing a replacement for the Sea Harrier foundered during the 1980s, the Royal Navy eventually transitioned to a force of Harrier aircraft operated in conjunction with the Royal Air Force in what is known as Joint Force Harrier. With heavy commitments to operations in Afghanistan, there has been only limited opportunity in recent years to deploy these aircraft aboard the two Invincible class ships still in service, but it is the intention of the Royal Navy to replace these vessels in the next decade with two much larger ships, under the CVF programme.

These vessels are intended to employ the Joint Strike Fighter (JSF), in particular the STOVL F-35B Lightning II version of the JSF. They will, therefore, be able to build upon the experience of STOVL operations at sea built up over many years by the Royal Navy, while at the same time benefitting from being able to design both systems in parallel in order to maximise the capabilities they can provide.

One clear lesson that has been adopted on the CVF programme is that a large ship is helpful in operating even STOVL aircraft, as it gives much more space for moving aircraft around, which has been a problem in past operations and studies. Based on the idea that "air is free and steel is cheap," this appears to be a welcome move, albeit one that may seem to reduce the need for using STOVL aircraft at all. Indeed, the CVF design has been developed so that it can be adapted for the later adoption of CTOL aircraft, including the CTOL version of the JSF. However, this would require not only a significant shift in UK procurement policy but also a re-assessment of all the lines of development for the CVF and JSF. As Figure 2 showed, the costs are distributed differently for the different types of aircraft, although basing them on versions of the JSF should reduce such differences.

Nevertheless, the current plan to deploy STOVL aircraft on the CVF means that the experience built up on the Harrier will be of use. This does not just depend on the service use of the Harrier, but also on research programmes that have used the aircraft. Most notable among these is the VAAC Harrier programme, which has been used to develop the flight control aspects of the STOVL JSF. In the Harrier family, the control of the aircraft was difficult because the pilot had a high work load when hovering the aircraft. For the JSF, the intention is that this can be reduced significantly, requiring much less training and greater flight safety, at the cost of a more complex flight control system.

Tests with the VAAC Harrier have revealed that the control system that came to be preferred from land-based trials needed some modifications when applied at sea (Denham, Krumenacker, D'Mello & Lewis, 2002). In addition, the VAAC Harrier has been used to develop the proposed Shipboard Rolling Vertical Landing (SRVL) technique that will allow the JSF to land at low speeds on the CVF, significantly increasing the "bring back" payload while reducing engine "wear and tear" (Rosa, 2008). While this should allow savings in terms of reduced maintenance as well as operations of the aircraft at higher weights and the deliverance of greater capability, there may be issues to address that may offset these savings in other lines of development, such as training for pilots and deck crew, and the development of additional deck lighting patterns and deck parking arrangements (Hodge & Wilson, 2008).

Further benefits from previous experience with the Harrier, and studies into replacing it, are shown by the adoption of a "ski jump" ramp for take-off. Despite the fact that the CVF is much larger than the Invincible class and that the JSF has a completely different propulsion system, the ramp still gives the same benefits as it did on earlier ships: boosting capability by increasing payloads and enhancing safety, as well as freeing up more deck area for aircraft parking and recovery (Fry, 2008; Rolfe, 2008). ~~This is also assisted by the use of a jet blast deflector~~, the value of which was first indicated in the Sea Harrier replacement studies. Again, despite the larger size of CVF, the area of deck that it frees up for other uses is of great value, as is the enhancement of the safety of deck crew by reducing the chances of them being blown overboard (Morrison, Dockton & Underhill, 2008).

It is possible that the first aircraft to operate from the CVF will be those of Joint Force Harrier, as the ships may undertake trials (or be in operation) before the UK's JSF fleet is ready to come aboard. If so, the experience of decades of Harrier operation will be able to be directly applied to the new ships, while new lessons about the greater capability of the larger ship could be directly related to the experience of using the Harrier onboard the Invincible class. In addition, such an opportunity could allow validation of some of the Harrier-based research work that has helped to underpin the JSF development. Although the equipment line of development subsumes many aspects of such research and technology programmes, there is little doubt that this work has provided a significant contribution to reducing costs across the lines of development.

CVF JBD removed - no benefit - restricts flexibility for STO Distance the WEIGHT

Overview, Conclusions and Further Work

This paper has provided a limited view of the vast subject of operating STOVL aircraft from ships. Its aim has been to illustrate how the experiences of the "prosaic" issues covered matter in delivering capability, and how this capability is a product of the effect of these issues across the Defence Lines of Development.

In summary, it is hoped that this paper has shown that aircraft and aircraft carriers may benefit from being designed with each other in mind, but that they need to adapt to changing operational, technical and other circumstances (budgetary!). The timescale for designing, building and operating aircraft and ships extends over many decades, so it is simply not possible to design to a single "point." Flexibility is an important attribute of both STOVL aircraft and aircraft carriers, with both able to contribute to capabilities independently of each other, but the flexibility of the combined system-of-systems that they deliver when brought together depends on an understanding of how the system functions over time. A key aspect of this is that it is extremely difficult, and probably undesirable, to tailor aircraft and ship designs to each other. This is because the lifecycles of each differ, and it may mean that they are then unable to contribute effectively to capability delivery when operated apart.

It is this difficult issue of optimising platforms as part of a flexible system that confronts acquisition managers. While it may be possible to use standards and protocols to ensure interoperability of digital systems or of weapon pylon attachments and other "lesser" mechanically based systems, at the level of complex, independent systems such as STOVL aircraft and aircraft carriers, it becomes a matter of having (at some point) to abandon the quest for an analytical "optimum" solution and instead to use judgement to decide on the best mix of platform characteristics and interactions to deliver capability. It is then up to the skills and bravery of service personnel to adapt the platforms, and to adapt to using them, in order to deliver a truly flexible range of capabilities using the systems they are given.

In order to support those involved in acquisition that need to use such judgement, as well to reduce the burden on service personnel later on, we will end with an outline suggestion for further research that may prove fruitful. Based on the researcher's own past efforts, and on discussions with practitioners in the field of aircraft and ship design, the researcher would suggest that attempts at understanding the real processes of designing ships and aircraft, understanding how design is done and not just assuming that it is done "by the book," offers a route to providing a basis for sound judgement. Design is a multi-faceted activity: but from an acquisition perspective, it would appear that understanding the early conceptual, or project design, stage matters most. This is because many of the irrevocable decisions about a platform or system are made at this stage, while trade-offs can be made against other platforms and systems—in an attempt to achieve desired capabilities—relatively cheaply in terms of actual expenditures.

However, doing this in isolation would miss important lessons, and it would appear that learning how to link current use of existing systems to the design of future ones would be useful too. If we can see how the assumptions and decisions of yesterday's acquisition experts have come to be used by today's service personnel, perhaps we can learn how to anticipate a little better the needs of the future. Hopefully this paper has made some small contribution to just such an endeavour.

Acknowledgements

The author would like to thank Professor David Andrews at University College, London, for giving up much of his time to help with talk about his experience of working on the Invincible Class. Chris Farara at Brooklands Museum allowed generous access to material there, while the staff at the UK National Archive was helpful in locating much material on the early Sea Harrier replacement studies.

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Ski-jump Harrier

FLIGHT International 20 Nov 1976 http://www.flightglobal.com/pdfarchive/view/1976/1976%20-%202666.html

Use of a curved ramp at the forward end of an aircraft carrier's flight deck could substantially improve the payload of jet V-Stol aircraft. So says Harrier chief designer John Fozard, who gave the Royal Aeronautical Society's R. J. Mitchell Memorial Lecture in Southampton on November 10. It would also bring handling and safety advantages, and could even improve the economics of the ship itself.

The concept was first advanced by Lt Cdr D. R. Taylor in a thesis written at Southampton University in 1973. It is based on the assumption that if the aircraft has enough thrust to accelerate in the initial upward trajectory produced by the ramp, the increased flight time would safely allw a lower launch speed and a lower lift / weight ratio. After building up airspeed all through the part-ballistic trajectory, the aircraft would be able to fly fully self-supported by the time it sunk back to launch height.

The most dramatic improvement, according to Fozard, takes the form of the shorter deck-run allowed by the greatly reduced launch speed. Applying the current Harrier payload trade-off or 66lb per knot of launch airspeed, he says that from a deck-run giving a lift-off speed of 60kt, a 20° Ski Jump would allow the aircraft to carry about 2,000lb more payload than it could at the same launch speed from the same length of flat deck.

From there it is calculated that, at sub-maximum launch weights, the ship need not steam at high speed in calm weather because the ramp would provide the equivalent of about 30kt wind over deck (WOD). Moreover, if the aircraft is lifting off on an upward trajectory of about 20°, it is effectively unaffected by the ship's pitching motion.

Ramps steeper than about 20° are unattractive for two reasons: performance gains start diminishing, and the aircraft on the ramp has to withstand greater undercarriage loads than normal. According to Fozard, if the Harrier's landing gear were not completely redesigned, incremental loading would have to be limited to about 0·5g. The time taken to traverse the Ski Jump is about ten times the design landing impact case for undercarriage struts.

In safety terms, the Ski Jump principle again provides more time for the pilot to jettison his stores or eject as a result of, for example, a failure of the nozzles to rotate on demand at the top of the ramp. There is in any case, according to Fozard, an excellent chance of the aircraft sucessfully completing the transition to wingborne flight with the nozzles fixed out. A fuller appreciation of the principle will appear in an early issue.

"Ski Jump" Harrier

04 Dec 1976

http://www.flightglobal.com/pdfarchive/view/1976/1976%20-%202837.html

http://www.flightglobal.com/pdfarchive/view/1976/1976%20-%202835.html

The principle of using a curved ramp, or Ski Jump as it has been dubbed, for launching jet V/Stol aircraft from ships was described briefly in *Flight* for November 20, page 1468. It was more fully expounded in the Royal Aeronautical Society's R. J. Mitchell Memorial Lecture, given this year by JOHN FOZARD, an executive director at Hawker Siddeley Kingston and chief designer of the Harrier. This article has been adapted from part of that lecture.

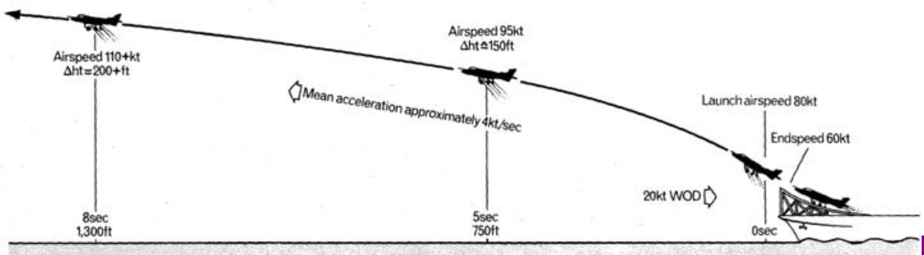
THE SKI JUMP launch proposal (originated by Lt Cdr D. R. Taylor in 1973) took an ancient and very familiar notion—that of increasing the time of flight of a projected body by imparting an initial upward momentum—and applied it to the short take-off of a jet V/Stol aircraft from a deck. Taylor perceived that, given an aircraft having enough thrust to accelerate in an initial upward trajectory, the increased time of flight would enable the vehicle to be launched at a lower speed and with a poorer lift:weight ratio. By building airspeed through all the part-ballistic trajectory (on the upward as well as the downward path) the aircraft could be arranged to fly, fully supported, by the time it had lost height to a level approaching that of the initial launch point.

again to become fully wingborne after a further 15sec or so. The endspeed, deck-run, WOD and other parameters are determined before launch from established data and are functions of aircraft weight and configuration, power, ambient pressure and temperature. In a flat-deck launch, the STO weight is in the region of 25,000lb, 20-30 per cent greater than the VTO weight.

The diagram below shows a Harrier at the same weight as that discussed above. This time, the nozzles are rotated at the top of a curved ramp at a speed considerably less than that in the flat-deck STO. At exit from the Ski Jump there is a resultant forward/downward acceleration of about 0·25g, and the aircraft is clearly not yet flying at this point. With a positive longitudinal acceleration adding several knots airspeed per second, however, lift and drag grow; less of the weight is unsupported (flightpath downward curvature reduced); and the increased flightpath component of the acceleration provides an even better rate of airspeed increase.

The nozzle angle relative to the fuselage remains fixed throughout this phase of the trajectory. We want the pilot

A Sea Harrier Ski Jump short take-off from a curved ramp on the forward end of the ship. Note the low launch speed



Taylor's studies were supported by a few members of the Harrier design team expert in the aerodynamic and kinematic complexities of Harrier powered-lift flight, notably Mr T. S. R. Jordan and Mr W. K. G. Causer. Hawker Siddeley Aviation expressed its early qualified support, but there followed a period of silence while the authorities took stock. Not only was the concept bold—and with a distinct "something-for-nothing" flavour—but also the Sea Harrier programme at this time was unapproved. The Navy and the fixed-wing flat-deck Establishment understandably needed to be extremely cautious.

Limited further in-house work increased HSA's understanding of the potential of the Ski Jump launch technique, and from about mid-1974 we effectively espoused the cause. The active support of a few far-sighted men in MoD Procurement Executive and MoD Navy was aroused and small study contracts were then placed with HSA Kingston, which was by late 1975 championing the concept, convinced of its eventual practicability and the prize it offered.

In a typical flat-deck short take-off (STO), the Harrier has a 90kt endspeed (i.e., relative to the deck) and an airspeed of 110kt (i.e. with a 20kt wind-over-deck, or WOD). At the end of the deck-run the pilot selects the nozzles down, typically to 50° relative to the fuselage, and rotates the aircraft to give 4°-5° greater angle of attack. Launch conditions are set up so that all moments about the c.g. are zero. Most of the aircraft weight is supported by the jets immediately after launch. Once established in vertically unaccelerated flight off the bow of the ship (preferably in practice with a small climb rate rather than truly level), the pilot can start rotating the nozzles aft

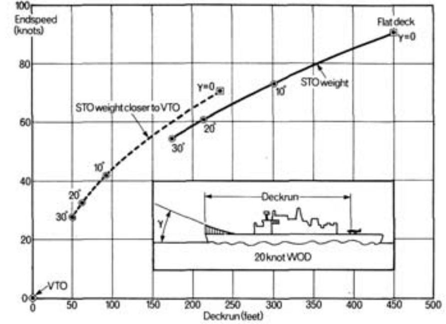
to perform the simplest possible flying task after making the initial configuration change, nozzles down, as he leaves the deck. On the left-hand side of the diagram, the flight conditions are the same as those for the aircraft on launch from a flat deck, and from this point, with greater peace of mind since his wheels are a further 200ft from the sea, the pilot can start rotating the nozzles rearward to transfer all the aircraft weight on to the wings after a further 15sec of standard transition flying.

The most dramatic and immediately evident gain is in the shorter deck-run resulting from the greatly reduced launch speed permitted with the Ski Jump. Applying a payload trade-off of 66lb per knot of launch airspeed, it is apparent that, from a deck-run giving a 60kt exit speed, a Ski Jump of about 20° could enable the aircraft to carry about 2,000lb more payload than it could from the same length of flat deck giving the same launch speed.

It is also obvious that, for many launches at gross weights less than the extended maximum, the Ski Jump ship need not steam at high speed in calm weather because the ramp provides the equivalent of about 30kt WOD. Thus, on average, a significant saving can be made in the use of ship fuel—probably 10 per cent or more.

Any fixed-wing aircraft launched from a pitching deck during the bow-down half of the cycle requires extra launch airspeed to curve the flightpath away from the sea. A Harrier STO deck-roll takes considerably longer than a conventional naval catapult launch. It is therefore on average more difficult to predict bow position (to the extent of about one complete pitch cycle) so as to ensure that the aircraft leaves the deck during the bow-up part of

The performance gains of the Ski Jump are most noticeable for the first 10° of ramp angle. After 20° they fall sharply. The deck-run figures are approximate



the pitching. Clearly, departure on an upward trajectory of about 20° will permit a Harrier to leave the bow at any point in the pitching cycle, almost regardless of the amplitude of the deck motion but within the constraints of practical handling on deck. For comparison, large conventional carriers cease peacetime flying when deck pitch exceeds about $\pm 1\frac{1}{2}$°, that is bow and stern vertical motions in the order of ±10ft.

Bearing in mind that deck-run is a linear function of launch kinetic energy, it is possible to relate STO endspeed to deck length for a particular weight, as shown in the diagram at right. The reducing gains as Ski Jump exit angle is increased are immediately obvious. At STO weights closer to VTO weight than in the examples covered so far, the reduction in deck-run for the first 10° of ramp is startling.

Apart from diminishing performance gains, steep Ski Jumps have other disadvantages. An aircraft negotiating the ramp at deckspeeds up to 100kt must withstand greater undercarriage loads: Without completely redesigning the Harrier landing gear, the incremental normal acceleration on a circular arc-profiled ramp must be limited to about 0·5g if the struts are not to bottom. It is also uncertain at present whether the pilot would perform satisfactorily under accelerations much larger than this—he has to steer accurately and select nozzles down with some precision while actually negotiating the Ski Jump.

The time taken to traverse the Ski Jump is typically 0·5sec, compared with about 0·05sec to absorb the landing impact which usually dictates the strength of all landing-gear struts. Damping, stiffness, recoil, etc, are thus not optimised for the relatively long period of increased vertical load while the Ski Jump is used at STO weight. Unless it were excessively long, a Ski Jump with an exit angle much greater than 20° would therefore require rather more than simply a re-optimisation of the internal oil/gas performance of an existing undercarriage leg.

For all these reasons, attention is focused at present on Ski Jumps with exit angles not much exceeding 20°. They need be no wider than the Harrier STO runway, but since this is asymmetric relative to ship centreline it is probable for practical reasons that the jumps would extend across the full flight-deck width, say 70ft-80ft at the bow of the ship. Only the forward third, say 30ft, of such a 20° profile is likely to prove totally unusable for deck parking, so denial of deck space is not a very serious problem. In fact, the forward third of the ramp does offer additional storage space below the curved deck plating.

A Ski Jump 90ft long and 80ft wide with a typical deck $\frac{5}{8}$in thick, added to an existing ship, would have a plating weight of about 80 tons. If this were doubled to account for the support structure below the curved deck, the penalty would be well under 200 tons of low-cost, welded steelwork, with no systems and no moving parts. In a new ship the ramp plating would replace the flat-deck plating so the only penalty would be in the raised support structure—less than 100 tons of additional steelwork.

Safety is vital in both peace and war, and not only to the pilot. A failure just after launch—catapult or free-run STO—is probably the most critical emergency in flat-deck

The first Hawker Siddeley Sea Harrier is in advanced construction at Kingston. It is due to fly in the autumn of 1977

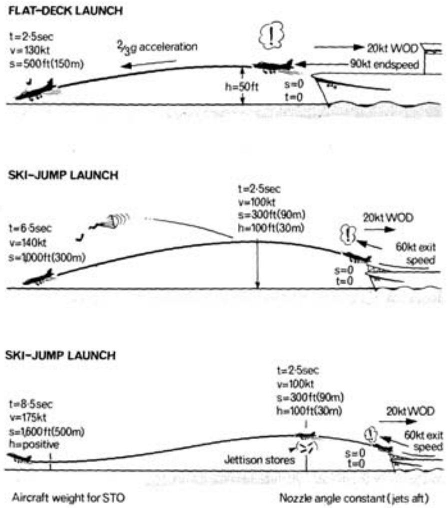
Obi Wan Russell (2-Apr-2011): http://warships1discussionboards.yuku.com/topic/16154/Kuznetsov-video

"Remember when aircraft leave the end of the ski jump, they aren't actually flying yet, flying peed being in the region of 130+knots. Ramp exit speed is around 80 knots, taking a longer run isn't reaaly an option because ramp exit speed is defined as much by undercarriage limits as anything else. Going up ramp puts a lot of stress on the nosewheel, even moreso when the aircraft has a larger payload. In the RN the Invincibles had charts kept aboard showing the required takeoff distance from the ramp needed for a given payload, to ensure ramp exit speed did not exceed 80 knots. [WOD Wind Over Deck needs to be considered also.]

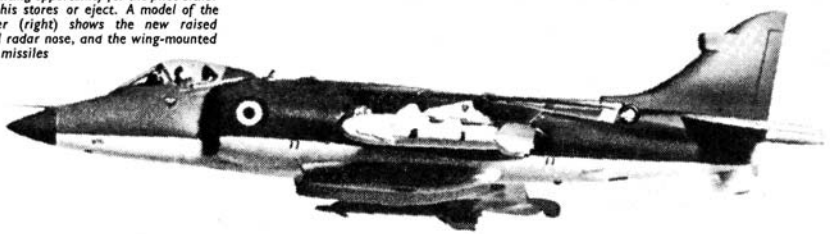
After leaving the ramp aircraft are not yet flying as such, their wings are generating some lift but not enough. The aircraft will have a ballistic component to it's momentum that keeps it moving upwards and forwards, and during this time it is still accelerating. before it reaches apogee and begins to drop back down again it will have reached/ exceded wingborne flying speed (130+knots), will also have reached a minimum of 200ft altitude (compared to a catapult lauched aircraft or a Harrier making a free take-off from a flat decked LHD for example which leaves a 60 ft high deck and stays at that height for several vital seconds) so if there is a problem such as engine failure the pilot will have several vital seconds to decide to eject before hitting the sea."

flying. There is only a remote chance of the Harrier's nozzle-actuation system malfunctioning at the point where the pilot selects nozzles from aft to 50° down. Only one broadly corresponding case has occurred in some 100,000 land-based Harrier STO operations.

If the nozzles do not respond to the pilot's command at STO weight from a flat deck, there is no hope that the aircraft will become fully supported before it strikes the sea. Available vertical forces initially support less than one-third of the weight. The significant numbers associated with the resulting trajectory off a 50ft-high flat deck are shown in the third diagram, right. The aircraft will meet the sea in about 2·5sec, and aeromedical authorities agree that 2sec is the minimum time in which a pilot can respond to a major emergency and eject successfully. Failure of the nozzles to rotate in the same aircraft at 60kt exit speed from a 20° Ski Jump produces the trajectory shown in the centre drawing. Because of the aircraft attitude, some 60 per cent of the weight is initially supported by thrust component plus wing lift. The upward momentum from the Ski Jump again provides increased time, and if the pilot is alert and jettisons his wing stores (several thousand pounds in this STO configuration) there is an excellent chance of the aircraft successfully completing transition to wingborne flight with nozzles fixed aft. In any event, the pilot clearly has ample time to apply for his Martin-Baker club tie, even after the double misfortune of nozzle failure during launch on a pitch-black night.



Emergency trajectories (above right) show the increased time of flight conferred by Ski Jump and the resulting opportunity for the pilot either to jettison his stores or eject. A model of the Sea Harrier (right) shows the new raised cockpit and radar nose, and the wing-mounted Sidewinder missiles



Significantly, the higher the STO weight, the longer becomes the nozzles-fixed-aft trajectory time in a Ski Jump launch—good for the pilot because it is the reverse of his normal experience, in which the higher weights at take-off always bring the most critical and demanding emergency conditions.

The time is increased because the vertical momentum imparted by a given ramp is considerably greater for the higher launch speeds associated with the high weights. In the flat-deck launch, time to sea impact is almost independent of launch weight.

Ski Jump piloting demands, as expressed by HSA test pilot John Farley, must allow a night launch with no external visual cues, and pilot workload must not exceed that in the present flat-deck STO.

The Harrier has a three-axis autostabiliser, but it is single-channel in each axis and of limited authority. An autocontrol system to fly the aircraft through the Ski Jump switchback trajectory originally envisaged by Taylor would need a level of authority and redundancy which is not feasible or economical in this context. Fortunately, HSA investigations have shown that, with practical margins at launch, the aircraft will fly off the peak of the trajectory, thus avoiding extending the "runway in the sky" to the pull-up point, which is much closer to the waves. A vertical velocity component towards the sea is *always* bad at low altitude.

For similar reasons of reducing pilot workload, it was decided to leave the configuration fixed (no nozzle-angle change with speed and height) immediately after launch, until the aircraft achieved vertically unaccelerated flight at the start of the transition. As a result, the most critical phase of the trajectory is shortened and the pilot is asked to function only as a straightforward stick-and-rudder-bar man (a task at which he excels), rather than behave as a pre-programmed flesh-and-blood servo-mechanism (which saturates easily and readily malfunctions).

What is not yet known is precisely how the Ski Jump pilot should fly his semi-ballistic trajectory—fly attitude, or angle of attack, or a director in the head-up display? Is a special pilot aid really needed? Forthcoming simulator work should shortly provide a first answer. This will subsequently be test-flown off a runway-sited ramp, using if necessary a two-seat Harrier carrying an extra safety pilot.

We are moving now into a demonstration phase of the Ski Jump concept, and confirmation by flight-test will be achieved in a year or two—as distinct from half a decade, which is how long a new form of catapult giving comparable performance gains might take to develop and prove. After qualification of the Ski Jump technique in the near future (in terms of ship development), it will be possible to launch Harriers off a total deck-run of about 250ft at weights which currently need over 500ft of flat deck.

In the interim, however, HSA is quite positive that a Harrier could fly today off a ship fitted with a small-angle ramp. Techniques and procedures would be just the same as for the present flat-deck launch. The Harrier would need no changes to permit it to use a 6° ramp, which is worth at least 15kt WOD or endspeed. This would enable 1,000lb more payload to be launched from a given deck-run into a fixed WOD. A 6° ramp would eliminate STO launch hazards in deck pitch motions up to ±2°. It involves no risk and in fact forms an essential feature of Vosper Thornycroft's projected Harrier Carrier (see illustration).

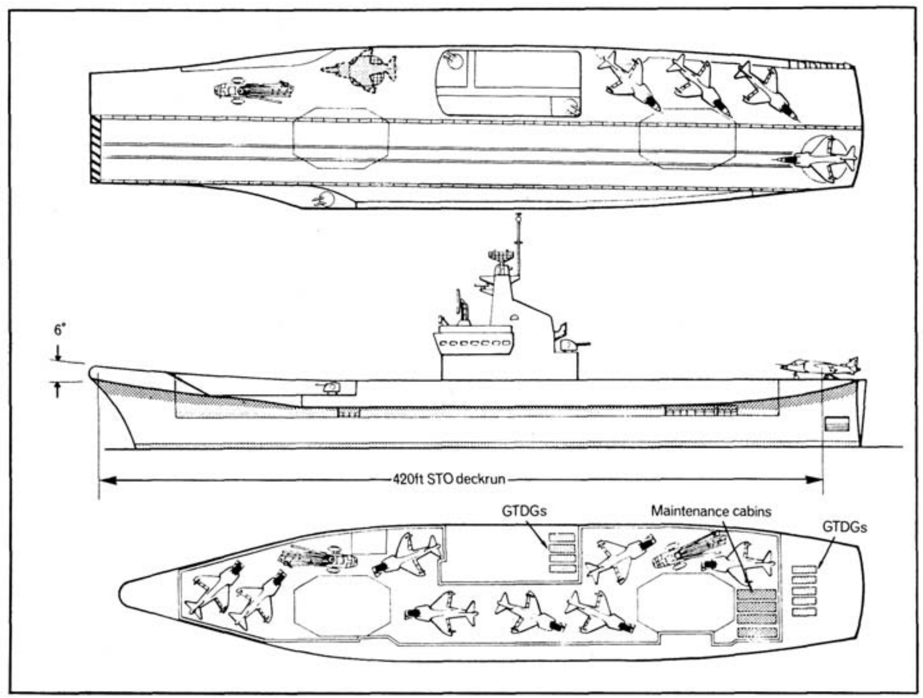
This ship, essentially sized by the flight deck, can be summed up as the smallest and hence most economical vessel able to provide a full and effective Harrier capability at sea. Deck beam is determined by the Harrier runway width plus the width necessary to park aircraft clear of the starboard wingtip safety line. The length is governed by the need for full-load Sea Harrier short take-offs. The forward flight deck has a 6° ramp built in and there is a turntable at the aft end. Deck-run is thereby increased and aircraft need not be pushed backwards, a procedure which prolongs the launch interval. Use of a turntable also avoids the need for across-deck taxiing—reported as the most daunting experience that USMC Harrier pilots have undergone when flying from the USS *Guam* in bad weather (although this old LPH class has a round-bottomed, non-roll-stabilised, single-screw hull).

The Harrier Carrier has a maximum design speed of 25kt. Since this is augmented by the 15kt effective WOD provided by the ramp, in still air the 420ft STO run would yield the same Sea Harrier mission capability as is provided by the longer deck of the RN anti-submarine cruiser HMS *Invincible*. The flight deck forms the roof of a hangar which can house ten aircraft, with the complement ranging from eight Harriers and two Sea Kings/Lynx to eight Sea Kings and two Lynx. This could be extended to a total of 14 aircraft by using the deck park on a 24hr basis while at sea and not just during flying operations.

No doubt the future will see other ship designs promoted as Sea Harrier platforms, including modified merchant ships. This Vosper Thornycroft project, however, has confirmed most emphatically that Harrier jet V/Stol capability will permit a reverse trend in fighting-ship size, manning and cost compared with present-day conventional fixed-wing aviation at sea. The smaller navies of the free world no longer have an economic excuse—particularly since the emergence of the USSR's *Kiev* class—to shrug their shoulders when the future of seaborne air power is discussed.

The Ski Jump, together with its diminutive nephew the ramp, promises a significant practical leap forward. The concept is simple and elegant. None of the problems so far identified can be termed major. All can be readily solved given time and modest funding, and no major changes to existing versions of the Harrier are required. I am certain that by the 1980s the Ski Jump will be providing as great a contribution to high-performance jet V/Stol operations at sea as did the steam catapult, the angled deck and the mirror sight to their generation of fixed-wing naval aircraft. ◘

The proposed Vosper Thornycroft Harrier Carrier is the first ship designed specifically to operate a small number of jet V/Stol aircraft, incorporating a 6° ramp at the forward end of the flight deck



United States Patent [19]

Thorby et al.

SKI

JUMP

[11] **4,441,671**

[45] **Apr. 10, 1984**

[54] **TAKE-OFF RAMPS FOR AIRCRAFT**

[75] Inventors: **Douglas C. Thorby,** Shepperton; **Michael C. W. Sullivan,** Sutton, both of England

[73] Assignee: **British Aerospace Public Limited Company,** London, England

[21] Appl. No.: **442,298**

[22] Filed: **Nov. 17, 1982**

Related U.S. Application Data

[63] Continuation of Ser. No. 188,667, Sep. 19, 1980, abandoned.

[30] **Foreign Application Priority Data**

Sep. 29, 1979 [GB] United Kingdom 7933885

[51] **Int. Cl.**^{3} **B64F 1/04**

[52] **U.S. Cl.** .... 244/63; 244/114 R

[58] **Field of Search** .... 244/63, 104 R, 104 FP, 244/114 R, 116

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Primary Examiner—Trygve M. Blix
Assistant Examiner—Rodney Corl
Attorney, Agent, or Firm—Cushman, Darby & Cushman

[57] **ABSTRACT**

An aircraft take-off ramp, for causing an aircraft with a compressible, shock absorbing and damping landing gear to be so urged from a horizontal path that it follows an initially ballistic trajectory on leaving the ramp, has its profile derived from a notional generally circular arc. The notional arc has its radius selected so that the center of gravity of the aircraft, if its landing gear was incompressible, would follow a desired locus. The derived profile is so modified from the notional arc that during traverse of the ramp the compressible landing gear is compressed so that the center of gravity of the aircraft follows the desired locus.

1 Claim, 9 Drawing Figures

http://www.freepatentsonline.com/4441671.pdf

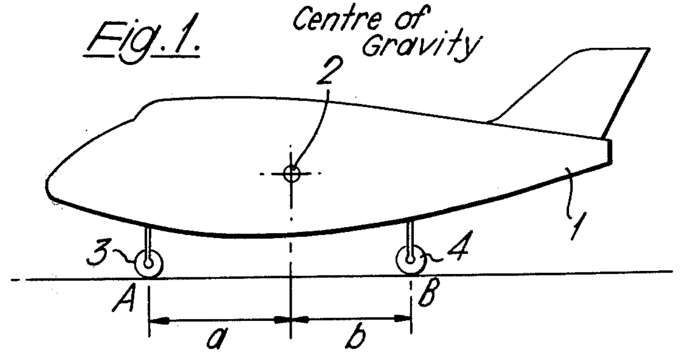
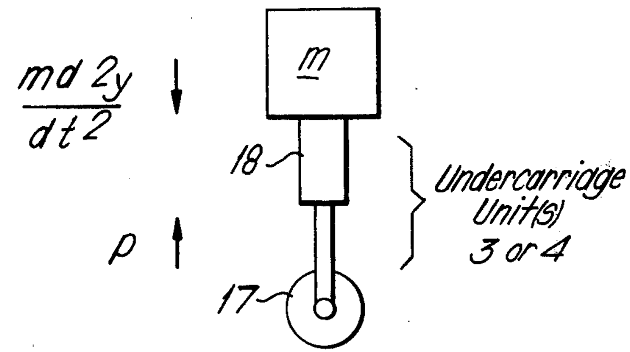
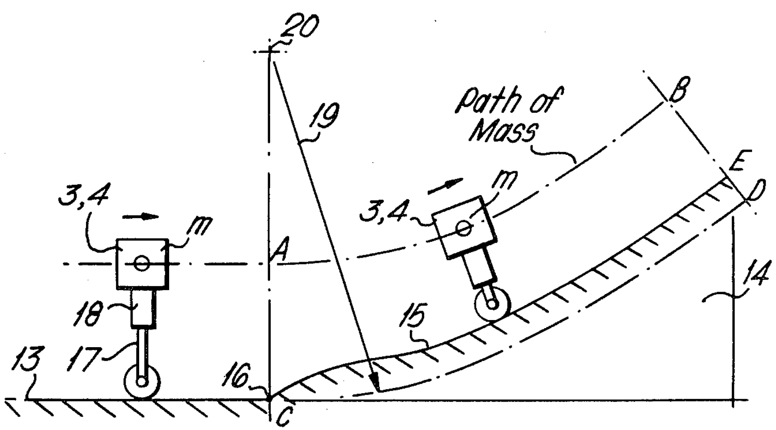


Fig. 2.





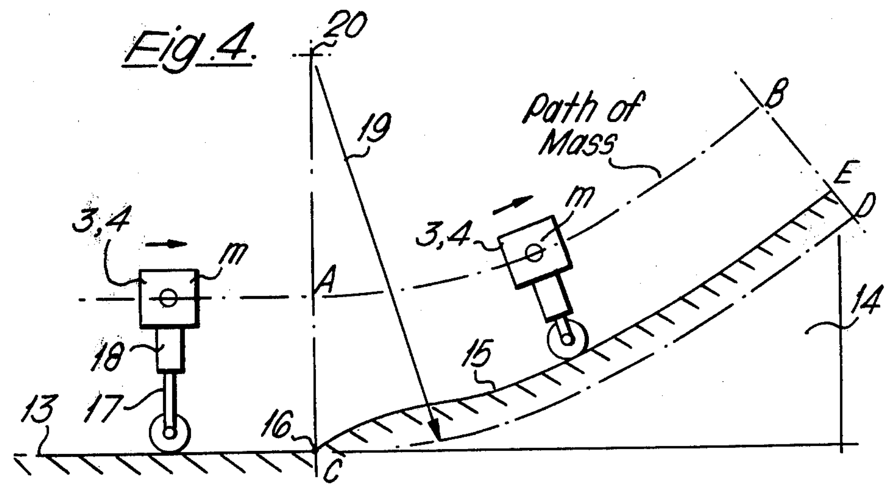


Fig. 3(a)

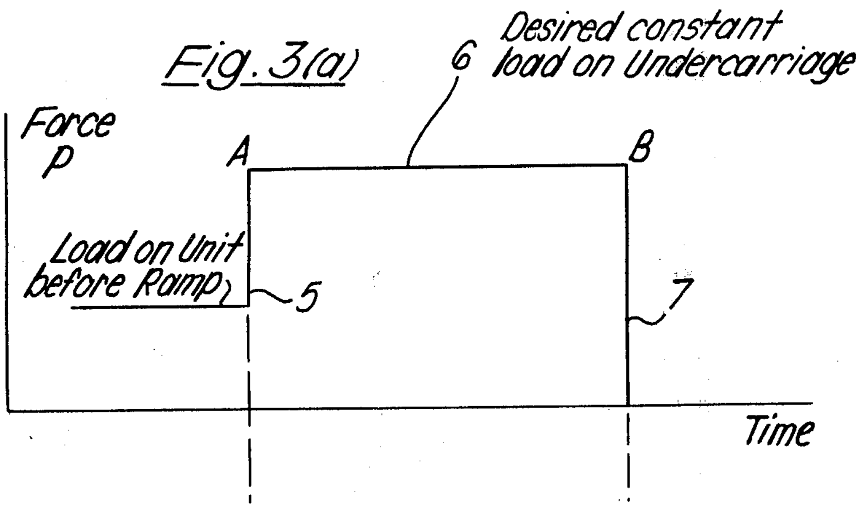


Fig. 3(b).

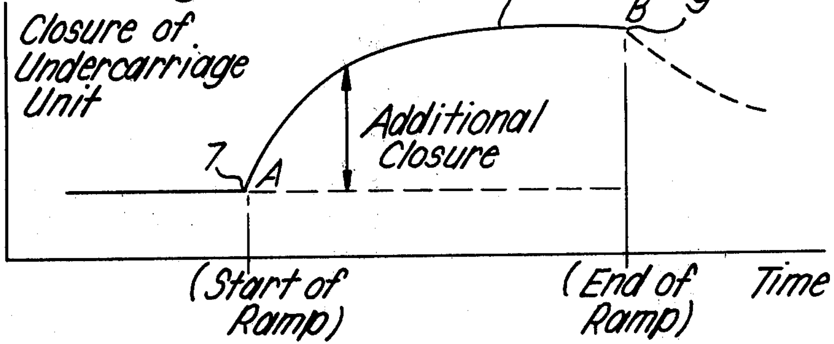


Fig. 3(c).

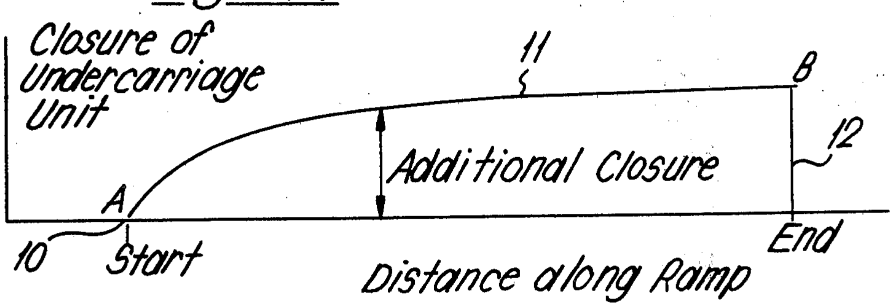


Fig. 5.

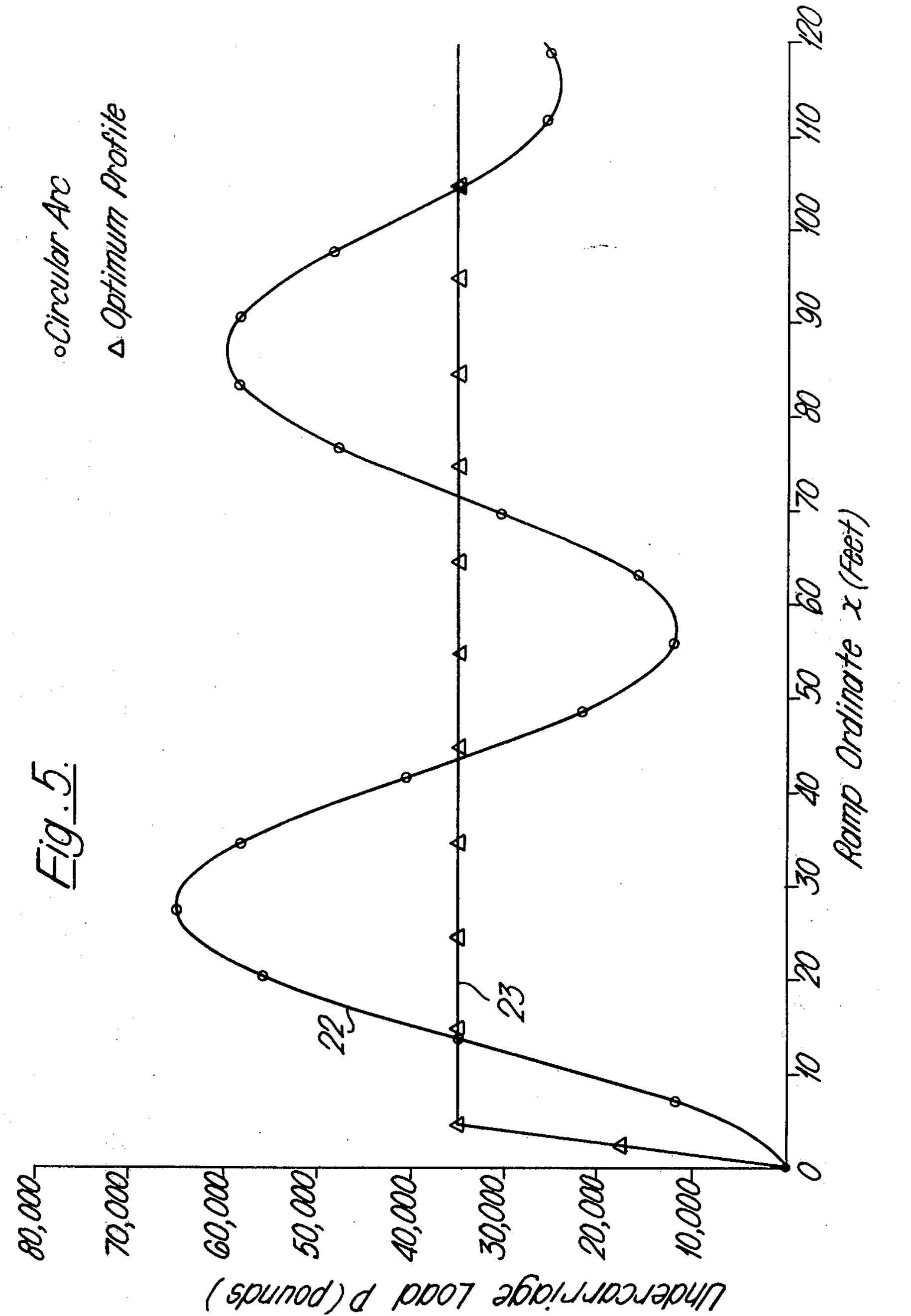


Fig. 6.

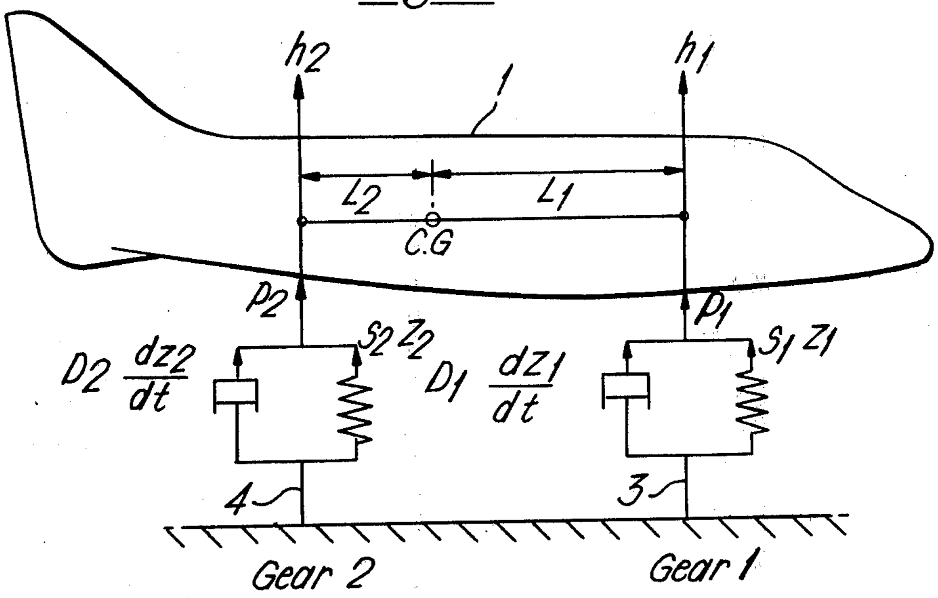
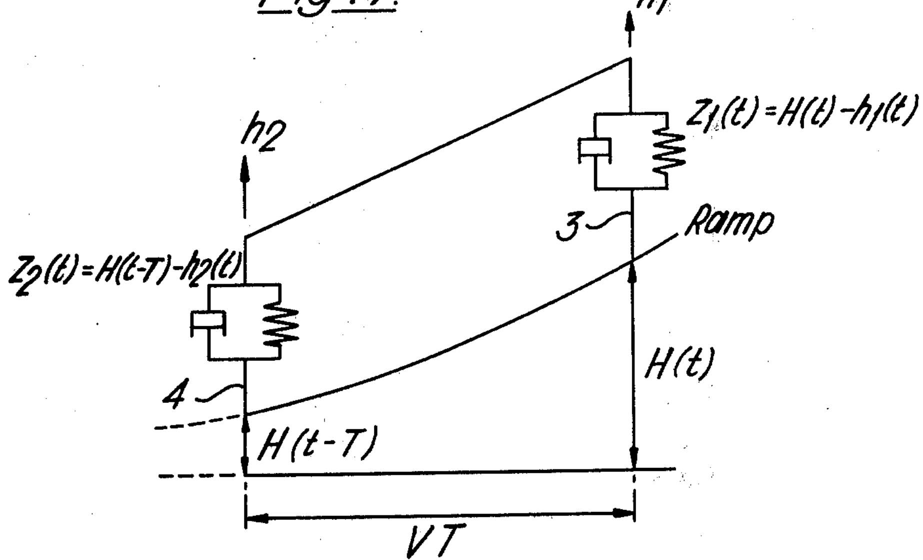


Fig. 7.



TAKE-OFF RAMPS FOR AIRCRAFT

This is a continuation of application Ser. No. 188,667 (now abandoned), filed Sept. 19, 1980.

This invention relates to ramps along which an aircraft travels during take-off to achieve an initially ballistic trajectory on leaving the ramp during which the change to wing borne flight can be made.

Such ramps have particular but not totally exclusive utility when used by aircraft having the ability to deflect their propulsive thrust downward or partly downward; in this case the period of ballistic trajectory is extended by such thrust deflection yielding a relatively long period in which the aircraft can be accelerated to wing borne flight speed. Such ramps enable an aircraft using them to carry additional payload or, alternatively, the take-off distance can be reduced for the same payload.

From purely static considerations, it is found that the ideal profile, that is to say the shape of a take-off surface of the ramp when viewed from the side, is a circular arc. However, ramps having a purely circular arc form in profile are found to cause an aircraft having a compressible landing gear (which inherently constitutes an oscillatory system) to undesirably oscillate in pitch and heave after initial engagement of a ramp. This oscillation is due to the rapid application of centrifugal force. The term "compressible" in this application denotes any landing gear having not only shock absorbers and dampers but also tyred wheels, which also have some compliancy. The term is used in contrast to a notional rigid, incompressible landing gear.

Present ramps, accordingly, have been provided with a transition region for engagement by a landing gear before engagement of the ramp proper so that the centrifugal force was applied relatively gradually. Such a transition region, however, tended to excessively increase the size of the ramp.

It is an object of the present invention to provide an aircraft take-off ramp in which ramp induced oscillations of an aircraft with a compressible landing gear are at least reduced and in which the size of the ramp is not excessively increased beyond that associated with a generally circular arc profile.

According to the present invention an aircraft take-off ramp, adapted to be associated with a generally horizontal take-off surface and for use by an aircraft having a compressible landing gear, such that an aircraft during take-off is so urged from the take-off surface that it follows an initially ballistic trajectory on leaving the ramp, the ramp having a profile so modified from a notional generally circular arc of radius such that the centre of gravity of the aircraft, if its landing gear was incompressible, would follow a desired locus yielding a high, generally constant acceleration, that during traverse of the ramp the compressible landing gear is compressed whereby the centre of gravity of the aircraft follows said desired locus.

The theoretical development of an aircraft take-off ramp is described with reference to the accompanying drawings in which FIGS. 1–4 illustrate a simplified theory and FIGS. 5–8 illustrate a more comprehensive theory.

In the drawings:

FIG. 1 is a side view of an aircraft,

FIG. 2 is a diagrammatic view of a compressible landing gear,

FIG. 3*a* is a graph of load exerted on a landing gear plotted against time,

FIG. 3*b* is a graph of compression of that landing gear plotted against time,

FIG. 3*c* is a graph of compression plotted against distance along a ramp,

FIG. 4 is a diagrammatic side view of an aircraft take-off ramp according to the invention,

FIG. 5 is a graph of landing gear load, that is to say the compressive load on the gear effected by ramp profile plotted against ramp horizontal length,

FIG. 6 is a diagram of an aircraft which may use the ramp, the aircraft being shown in static equilibrium and,

FIG. 7 is a similar diagram illustrating the aircraft travelling along the ramp.

Referring initially to FIGS. 1–4, the theory is illustrated with reference to an aircraft **1** which has a centre of gravity **2**, a forward compressible landing gear unit **3** situated at a distance a from the centre of gravity **2**, and a rearward compressible landing gear unit **4** situated at a distance b from the centre of gravity **2**.

It is possible to apportion the total mass of an aircraft between say the forward landing gear unit **3** and the rearward landing gear unit **4** (bearing in mind that the landing gears **3** and **4** can be groups of landing gears providing each gear of the group is in register with the others of the group when viewed from the side as shown in FIG. 1) so that each landing gear unit is associated with a particular mass. Although this apportionment can be arbitrary without invalidating the theory, it can be exact if the expression $ab=K^2$ where a is the distance of the gear unit **3** from the centre of gravity **2**, b is the distance of the gear unit **4** from the centre of gravity **2**, K is the radius of gyration of the aircraft in pitch, and, $K^2=I/M$ where I=pitch inertia of aircraft, and, M=total mass of aircraft.

Continuing this simple approach, the force P on a single landing gear unit **3** or **4** (as shown with reference to FIG. 2) is equal and opposite to the inertia force, that is to say

$$\frac{md^2y}{dt^2}=P$$

where m is that mass apportioned to the particular gear unit, y is the vertical displacement of the aircraft, and, t is the time interval.

Referring now to FIG. 3*a*, for maximum take-off enhancement, the upward velocity component V imparted to the aircraft must be a maximum, which implies that the upward momentum mv where m is the mass associated with a particular landing gear unit, must also be a maximum.

Upward momentum is essentially the time integral of the upward force P provided by the landing gear. This must not exceed some predetermined value—normally that value which would cause a compressible, that is to say for example a telescopic landing gear leg and tyred wheel to become fully compressed. It follows that the most efficient ramp take-off is obtained when the landing gear force is held constant at the maximum value for the duration of the time the aircraft spends on the ramp. This is to say that the landing gear is effectively compressed to the point of rigidity. As plotted in FIG. 3*a* (upward force P against time) this most efficient ramp take-off is shown at reference 5 which is the start or entry to the ramp and indicates an instantaneous force build-up on the landing gear and a maintained maximum constant force P, referenced 6, until the ramp exit 7 is reached.

Since the inertia force

$$\frac{md^2y}{dt^2}$$

applied by the mass to the landing gear is equal to but opposite in direction to the landing gear force P this also must be constant. The acceleration of the mass m must therefore be constant and the path, that is to say the locus, of the mass m is therefore known—it is a circular arc. This is illustrated in FIG. 4 at A, B.

To continue, noting that the landing gear force must be at a constant maximum whilst the aircraft is upon the ramp for a maximum efficiency take-off, as shown at 5, 6 and 7 in FIG. 3*a*, some way effecting this constant maximum is desirably provided. Referring now to FIG. 3*b*, which for present purposes assumes that at ramp engagement there is no static compression of the landing gear, this constant maximum landing gear force can be achieved by causing the compressible landing gear to become compressed to its fullest extent at a rate depending upon the shock absorbing and damping characteristics of the landing gear itself, that is to say the variation of compression with time. These characteristics are conveniently termed the "closure time history." Thus the desired effect can be achieved by causing the closure time history of the landing gear unit on engagement of the ramp to be that history which gives constant load. This may be determined in two ways:

1. By applying the required force to the actual landing gear unit and measuring the compression as a function of time, and/or
2. by computation.

One way of doing this computation is discussed with reference to FIGS. 5–8 below.

In either case, the graph of FIG. 3*b* is obtained. In this figure, which is a graph of landing gear compression plotted against time, reference 7 is the start of the ramp, and reference 8 is the curve indicating the landing gear compression necessary to effect maximum force during engagement with ramp, reference 9 indicating the exit of the ramp. The compression of FIG. 3*b* is then conveniently replotted against distance travelled along the ramp by the landing gear unit to become one component of the profile of a ramp according to the invention. This is illustrated in FIG. 3*c* where reference 10 is the start of the ramp, reference 11 is the curve of gear compression plotted against distance, and reference 12 is the ramp exit.

To achieve simultaneously both the desired inertia force and a *balancing* landing gear force in one ramp profile, it is evident that the profile component obtained from the closure history of the landing gear (FIGS. 3*b* and 3*c*) must be superimposed upon that component required to give the mass (or rather its centre of gravity) locus, (FIGS. 2 and 3*a*) if the landing gear were rigid, that is to say the circular arc form discussed above.

FIG. 4 illustrates the two profile components superimposed one upon the other. A generally horizontal take-off surface 13 lies in tandem with an aircraft take-off ramp shown generally at 14. The ramp has a take-off surface 15 including an entry edge 16. An aircraft landing gear unit 3 or 4 having an associated mass m, a tyred wheel 17, and a telescopic shock-absorbing and damping leg 18 connecting the wheel with the mass is also illustrated. The take-off surface of the ramp has its profile when viewed from the side formed from the two profile components to which reference has been made above. The first is that which provides the mass m with the locus A, B and is a circular arc C, D shown in broken outline having a radius 19 whose origin 20 is positioned such that the circular arc C, D has its point C at a position of tangency with the horizontal take-off surface 13, the point of tangency C being coincident with the entry edge 16, that is to say vertically below the origin 20, when viewed from the side. For case of incorporation in FIG. 4, origin 20 is shown schematically much closer to take off surface 13 than would be the case in practice; in practice origin 20 would lie at the intersection of lines AC and BD. The second is that which provides the predetermined compression of the landing gear unit 3 or 4 which ensures that the mass m is maintained on its locus A, B. The final corrected profile is C, E being the two coterminous components added together. In effect, the profile C, E is a cam surface of which the thickness increases along its length and the rate of increase of thickness decreases therealong, the cam surface being superimposed on the profile C, D to make the landing gear unit compress such that load transmitted by the gear equals the inertia force on the mass m over the distance C to E. The force and load remain constant, equal and opposite; the landing gear unit compression is therefore non-oscillatory.

In each figure the letters A, B respectively denote the entrance and exit of the ramp.

In FIG. 5 the compressive load effected by an unmodified ramp is shown at 22 whilst the compressive load effected by the ramp of FIG. 4 is shown at 23. As can be seen the unmodified ramp causes an oscillatory load with excessive peaks and troughs whilst the ramp of FIG. 4 causes a steep rise in load within a short distance (say 5 ft.) of ramp engagement by an aircraft wheel. The load rapidly reaches a maximum of constant value and the oscillatory effect is removed.

A detailed method of determining the ramp profile of FIG. 4 whereby the load curve 23 is achieved is now described with reference to FIGS. 6 and 7.

In these figures an aircraft is represented by a body 1 with mass and pitch inertia supported on two landing gear units 3 and 4 similar to those shown in FIG. 4. Basic assumptions are:

That there is vertical equilibrium at the start of a ramp with displacements and loads being defined as increments due to the effect of the ramp.

That changes in aircraft speed, thrust, and aerodynamic loads on the ramp are negligible.

That there is linearity in the sense that (1) equilibrium is satisfied on the undisturbed aircraft and (2) the landing gear units are represented by viscous dampers and linear springs.

These assumptions are not essential, but they considerably simplify the analysis, and lead to an explicit formula for ramp profile according to the invention.

The notation used with reference to the Figures is as follows:

M=Aircraft Mass.
K=Aircraft Pitch Radius of Gyration.
V=Aircraft Speed.
h=Aircraft Vertical Displacement.
S=Landing Gear Stiffness.
D=Landing Gear Damping.
P=Landing Gear Load.
Z=Landing Gear Compression.
H=Ramp Height.
L=Distance of Point of Application of Gear Load from Aircraft Centre of Gravity.

It should be noted the P, h, and Z are incremental changes due to the ramp. Also that for twin landing gear units the leading unit 3 is given the suffix 1, whilst the trailing unit 4 is given the suffix 2.

The Heave and Pitch motions of an aircraft travelling along a ramp can be conveniently defined in terms of the aircraft vertical displacements at the points of application of the loads on the landing gear units 3 and 4.

The equations are:

$$\left\{\frac{K^2}{K^2+L_1^2}\right\} M\frac{d^2h_1}{dt^2} = P_1 + \left\{\frac{K^2-L_1L_2}{K^2+L_1^2}\right\} P_2 \quad \text{(a)}$$

$$\left\{\frac{K^2}{K^2+L_2^2}\right\} M\frac{d^2h_2}{dt^2} = P_2 + \left\{\frac{K^2-L_1L_2}{K^2+L_2^2}\right\} P_1 \quad \text{(b)}$$

and the landing gear compressions are given by:

$$D_1\frac{dZ_1}{dt} + S_1Z_1 = P_1 \quad \text{(c)}$$

$$D_2\frac{dZ_2}{dt} + S_2Z_2 = P_2 \quad \text{(d)}$$

where t=time elapsed from the leading gear encountering the ramp.

The (incremental) deflections due to the ramp are related to ramp profile by:

$$h_2(t+T)+Z_2(t+T)=h_1(t)+Z_1(t)=H(t) \quad \text{(e)}$$

assuming $t \geqq 0$, where T is the delay between the landing gear units 3 and 4 encountering the ramp, and the leading gear unit 3 encounters the ramp at t=0.

The ramp ordinate is given by:

$$X=Vt(X\geqq 0) \quad \text{(f)}$$

where V is aircraft speed assumed constant during traverse of the ramp.

In general it is not possible to control the loads on two landing gear units with a single ramp profile. However, with suitable design features, the two landing gear units can be mathematically reduced to a single landing gear as follows:

If the landing gear units are arranged such that

$$L_1L_2=K^2 \quad \text{(g)}$$

the equations (a) and (b) reduce to those of two independent masses;

$$(G_1M)\frac{d^2h_1}{dt^2} = D_1\frac{dZ_1}{dt} + S_1Z_1 = P_1 \quad \text{(h)}$$

$$(G_2M)\frac{d^2h_2}{dt^2} = D_2\frac{dZ_2}{dt} + S_2Z_2 = P_2 \quad \text{(i)}$$

where

$$G_1 = \frac{L_2}{L_1+L_2} \text{ and } G_2 = \frac{L_1}{L_2+L_1}$$

If landing gear elastic constants in the same proportions as the masses are chosen, that is:

$$S_1 = G_1S\ D_1 = G_1D$$

$$S_2 = G_2S\ D_2 = G_2D$$

where S and D are the total stiffness and damping of the landing gear, the equations for each gear unit are essentially the same and the aircraft may be modelled to have the characteristics:

$$M\frac{d^2h}{dt^2} = D\frac{dZ}{dt} + SZ = P(t) \quad \text{(j)}$$

$$h(t) + Z(t) = H(t) \quad \text{(k)}$$

Individual gear unit loads and displacements are related to (j) and (k) above by:

$$P_1(t)=G_1P(t),\ P_2(t+T)=G_2P(t),$$

$$h_2(t+T)=h_1(t)=h(t),\ Z_2(t+T)=Z_1(t)=Z(t) \quad \text{(l)}$$

and the max total load on the landing gear is given by:

$$[P_1(t) + P_2(t)]_{max} = [G_1P(t) + G_2P(t-T)]_{max} \leqq [P(t)]_{max} \quad \text{(m)}$$

which follows from the definition of G_1 and G_2.

Note that the mathematical reduction of the twin landing gear units 3 and 4 to a single equivalent landing gear is not in principle restricted to the case of linear gear elasticity.

It has been shown in equations (j) and (k) above that with a suitable choice of landing gear design the equations of motion reduce to:

$$M\frac{d^2h}{dt^2} = D\frac{dZ}{dt} + SZ = P(t), \text{ and}$$

$$h(t) + Z(t) = H(t) \text{ where } t \geqq 0.$$

In terms of ramp ordinate X=Vt these reduce to:

$$MV^2\frac{d^2h}{dX^2} = DV\frac{dZ}{dx} + SZ = P(x) \quad \text{(n)}$$

$$h(x) + Z(x) = H(x)\ X \geqq 0. \quad \text{(o)}$$

where V is the aircraft speed. Using these equations there is an optimum solution to the problem of ramp profile design which is given below.

For a rigid landing gear the ramp angle θ (that is to say the angle of the profile to the horizontal at any given point) is given by:

$$\tan\theta = \frac{dH}{dx} = \frac{dh}{dx} = \int_o^x \frac{d^2h}{dx^2}dx = \frac{1}{MV^2}\int_o^x P(x)dx. \quad \text{(p)}$$

The optimum choice of (incremental) landing gear load is a step-function, that is to say:

$$P(x) = 0 \quad X < 0$$
$$= F \quad X > 0$$

where F is the maximum allowable load on the landing gear due to the effects of the ramp. Integration then gives the required profile:

$$H(x) = h(x) = \frac{Fx^2}{2MV^2} \qquad (q)$$

This is a parabolic curve being the linearised version of the circular arc curve which would generate a normal force F on a mass M travelling along the ramp at speed V.

In practice, compression of the landing gear is very small when compared with overall ramp dimensions and the step function landing gear load characteristics may be considered optimum as regards ramp length and height required to achieve a specific ramp angle where the aircraft leaves the ramp. A drawback of the step load arises when aircrew tolerance to rate of change of acceleration or "jerk" is considered.

Differentiating the aircraft equation of motion defined at (j) above gives:;

$$M\frac{d^3h}{dt^3} = \frac{dP}{dt} \qquad (r)$$

and the "jerk" on the aircrew must be less than same limit J, that is:

$$\frac{d^3h}{dt^3} \leqq J \qquad (s)$$

The landing gear load characterisitcs must therefore satisfy:

$$\frac{VdP}{dx} = \frac{dP}{dt} \leqq MJ$$

Where in practice we limit "jerk" at the landing gear stations.

This "jerk" limitation is clearly not satisfied by a step load, and the definition of the optimum landing gear load history must be accordingly changed to:

$$P(x) = 0 \quad X \leqq 0 \qquad (u)$$
$$= \frac{MJx}{V} \quad 0 \leqq X \leqq \frac{FV}{MJ}$$
$$= F \quad X \geqq \frac{FV}{MJ}$$

which satisfies the condition.

Bearing in mind the relatively low acceleration induced by a ramp take-off, the need for a "jerk" limit is somewhat doubtful. However, the form of landing gear load characteristic given at (u) above has an advantage that the resultant ramp profile is continuous in the limit of zero landing gear damping, which is not true for the step load. In practice the linear transition to maximum load could be used to reduce the effect of landing gear damping which is difficult to quantify.

Inserting the optimum landing gear load history defined at (u) above into the equation of motion given at (j) and (k) above the corresponding ramp profile is:

$$H(x) = h(x) + Z(x) \quad X \geqq 0$$

where the aircraft vertical displacement h and the landing gear compression Z satisfy the equations:

$$MV^2\frac{d^2h}{dx^2} = DV\frac{dz}{dx} + SZ = \frac{MJ}{V}x, \quad 0 \leqq X \leqq \frac{FV}{MJ}$$
$$= F, \quad X \geqq \frac{FV}{MJ}$$

Defining four characteristic dimensions for the ramp:

$$a = \frac{FV}{MJ} \quad d = \frac{DV}{S}$$
$$r = \frac{Fa^2}{MV^2} \quad f = \frac{F}{S}$$

the optimum ramp profile is given by:

$$h(x) = r\left\{\frac{1}{6}\left(\frac{x}{a}\right)^3\right\} \quad 0 \leqq x \leqq a \qquad (v)$$

$$r\left\{\frac{1}{2}\left(\frac{x}{a}\right)^2 - \frac{1}{2}\left(\frac{x}{a}\right) + \frac{1}{6}\right\} \quad X \geqq a \qquad (w)$$

$$z(x) = f\left\{\left(\frac{x}{a}\right) \times \left(\frac{d}{a}\right)\left[e^{\frac{-x}{d}} - 1\right]\right\} \quad 0 \leqq X \leqq a \qquad (y)$$

$$= f\left\{1 + \left(\frac{d}{a}\right)\left[e^{\frac{-x}{d}} - e^{\frac{a-x}{d}}\right]\right\} \quad X \geqq a \qquad (z)$$

For the limiting case of a step-function load (a=0) and an undamped landing gear (d=0) the ramp profile is simply:

$$H(x) = \frac{Fx^2}{2MV^2} + \frac{F}{S} \quad X > 0$$

which is the basic parabolic ramp profile for a rigid landing gear considered at (q) above with an added constant, namely the landing gear deflection due to the step load. Note that the ramp is discontinuous at the start.

An example based generally upon the British Aerospace Harrier aircraft but with locked landing gear shock absorbers and dampers is given below. In this case landing gear flexibility arises only from the tyres of the fuselage mounted nose and main gears. Any influence of the wing mounted landing gears is ignored.

The relevant aircraft data is:

M = 20,000 lbs.	(Aircraft Mass)
V = 140 ft./sec.	(Aircraft Speed)
S = 140,000 lbs./ft.	(Total landing gear stiffness)

-continued

D = 1,000 lbs./ft./sec.	(Total landing gear damping)
F = 35,000 lbs.	Maximum Load (due to ramp)
J = 49 g/sec.	Maximum Jerk (due to ramp)
g = 32.2 ft./sec².	Acceleration due to gravity

giving the ramp parameters:

$$a = \frac{FV}{MJ} = \frac{35{,}000 \times 140}{20{,}000 \times 49} = 5 \text{ ft.}$$

$$r = \frac{Fa^2}{MV^2} = \frac{35{,}000 \times 32.2 \times 5^2}{20{,}000 \times 140^2} = .072 \text{ ft.}$$

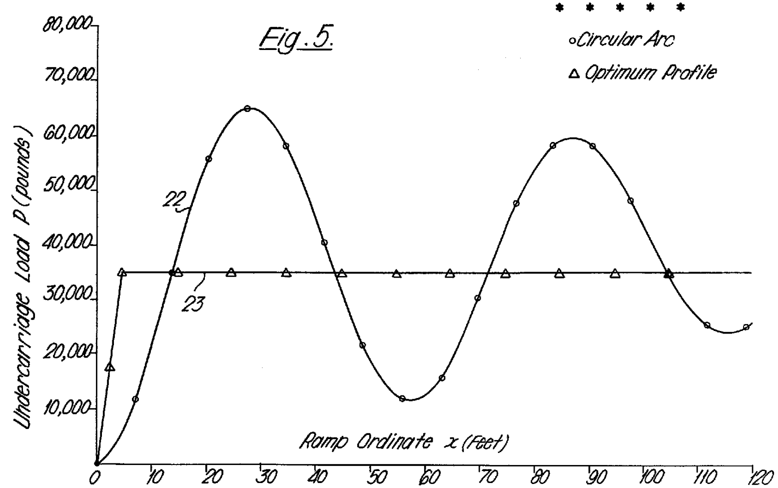
$$d = \frac{DV}{S} = \frac{1{,}000 \times 140}{140{,}000} = 1 \text{ ft.}$$

$$f = \frac{F}{S} = \frac{35{,}000}{140{,}000} = .25 \text{ ft.}$$

The optimum ramp profile is then, when substituting in (V) and (y) above:

$$H(x) = .072\left\{\frac{1}{6}\left(\frac{x}{5}\right)^3\right\} +$$
$$.25\left\{\left(\frac{x}{5}\right) + \left(\frac{1}{5}\right)[e^{-x} - 1]\right\}$$

when 0≦X≦5 ft., and when substituting in (w) and (z) above,



$$H(x) = .072\left\{\frac{1}{2}\left(\frac{x}{5}\right)^2 - \frac{1}{2}\left(\frac{x}{5}\right) + \frac{1}{6}\right\} +$$
$$.25\left\{1 \times \left(\frac{1}{5}\right)[e^{-x} - e^{5-x}]\right\}$$

when X≦5 ft.

These results are plotted in FIG. 4.

The landing gear loads corresponding to the profile of the ramp at the various ordinates along its length are, it will be recalled, given in FIG. 5.

We claim:

1. A take-off ramp for an aircraft having compressible landing gear, said take-off ramp being adapted to be associated with a generally horizontal take-off surface, said ramp having an upper surface profile defined by the superimposition of two coterminous profiles, the first of which being a generally circular arc having an origin positioned such that the arc has a point of tangency with said horizontal take-off surface, the second profile comprising a cam-like surface, the thickness of which increases along its length but the rate of increase of thickness decreasing therealong, the first profile causing a generally constant radial load to be transmitted to the aircraft via said compressible landing gear as it traverses the ramp, the second profile being arranged to compensate for contraction of the landing gear caused by the transmission of said radial load, whereby as the aircraft traverses the ramp it closely follows a generally circular path having an origin substantially coincident with the origin of said first profile, irrespective of the contraction of the landing gear.

* * * * *

CTOL Ski Jump: Analysis, Simulation, and Flight Test

John W. Clark Jr.* and Marvin M. Walters†
Naval Air Development Center, Warminster, Pennsylvania

SKI JUMP INVENTOR

In the past several years, the ski-jump (ramp-assisted) launch concept has received considerable attention within the U.S. Navy. The specific goal was set (and achieved) to demonstrate through flight test the feasibility of, and quantify performance gains from, ski-jump launch of the T-2C, F-14A, and F/A-18A aircraft using a 100-ft ramp with variable end angles of 6 and 9 degs. The analysis, piloted simulation, performance predictions, and flight safety considerations leading to flight test, as well as a comparison of analytical predictions with flight test results for the three aircraft, are discussed. The developed analytical capability, although somewhat conservative, proved to be highly effective in preparation for, and support of, the flight test and in successfully predicting the 40-60% reduction in takeoff distance demonstration in flight test.

http://www.docstoc.com/docs/DownloadDoc.aspx?doc_id=25926285&ref_url=

Nomenclature

a_x, a_z	= body axis accelerations, g (positive forward and down)
F_A	= strut air shock force, lb
F_D	= hydraulic damping force, lb
F_f, F_N	= tire friction and normal forces, respectively, lb
F_s	= strut axial load, lb
F_{sp}	= pilot stick force, lb (positive push)
F_{t_n}, F_{t_s}	= tire loads in strut axes, lb
g	= acceleration of gravity, ft/s^2
I_y	= aircraft inertia, slugs-ft^2
K_D	= hydraulic damping factor, lb/in.^{2}/s^2
$K_{\theta_e}, K_{\dot\theta}, K_{\int\theta}$	= pilot model feedback gains, lb/deg, lb/deg/s, lb/deg-s, respectively
m	= aircraft mass, slugs
m_u	= landing gear unsprung mass, slugs
M	= pitch moment, ft-lb (positive nose-up)
q	= body axis pitch rate, deg/s (positive nose-up)
R	= ramp radius of curvature, ft
s	= landing strut stroke, in., or Laplace variable
u, w	= body axis velocities, ft/s (positive forward and down)
V	= total velocity, ft/s
x, z	= body axis coordinates, ft (position forward and down)
X, Z	= body axis forces, lb (positive forward and down)
θ	= pitch angle, deg (positive nose-up)
θ_e	= pilot model pitch error, deg
θ_r	= local ramp angle, deg
θ_s	= landing gear strut inclination, deg
μ	= rolling coefficient of friction

Subscripts

A/C	= aircraft axis reference
c	= commanded quantity
0	= initial value
ax	= referenced to landing gear axle

Acronyms

GAC	= Grumman Aircraft Co.
McAir	= McDonnell Aircraft Co.
NADC	= Naval Air Development Center
NASA	= NASA Ames Research Center
NTEC	= Naval Training Equipment Center

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*Senior Aerospace Engineer, Flight Dynamics, Aircraft and Crew Systems Technology Directorate. Member AIAA.
†Senior Aerospace Engineer, Aerodynamics, Aircraft and Crew Systems Technology Directorate. Member AIAA.

Introduction

THE ramp-assisted takeoff (ski-jump) concept provides the potential for a passive means of launching aircraft from a confined operational area (ship or short runway) without the need for catapult boost equipment. The past five years have seen considerable effort on the part of the U.S. Navy to verify quantitatively the feasibility of ski jump as a viable means of reducing the required takeoff ground roll for naval conventional takeoff and landing (CTOL) aircraft. This paper will overview the complete development effort: analysis, manned simulation, and correlation with subsequent flight test results.

The ski-jump concept uses a ramp to rotate the aircraft flight path from horizontal to a positive climb angle at forward speed less than that normally required to rotate the aircraft aerodynamically. This early rotation and lift-off provides an initial rate-of-climb and altitude margin that allows the aircraft to accelerate to flying speed while in a partial ballistic trajectory. Reduction in takeoff distance is achieved primarily as a result of liftoff speeds that may be considerably below the stall speed of the aircraft (see Fig. 1). The reader is referred to Ref. 1 for a more detailed description of the segments of a ski-jump trajectory in comparison with a conventional takeoff.

Beginning with an initial, abbreviated (15-takeoff) flight test demonstration using the T-2C in October 1980,[2] the ski-jump program has progressed systematically through detailed analysis, piloted flight simulation, and extensive flight test (Fig. 2) of the T-2C, F-14A, F/A-18A, and S-3A.

This paper details the salient points of the analysis, simulations, and flight tests. A description of the analytical and simulation models is presented along with an outline of the flight test setup and procedures. The aircraft configurations and flight conditions tested are also summarized, with a comparison of the predicted and flight test results presented for these conditions.

Analysis and Simulation

Prior to initiation of flight test, the ski-jump characteristics (structural integrity, stability, controllability, and performance) of each aircraft were analyzed. First, the aircraft performance, control, and loads were predicted for the anticipated ranges of aircraft configurations and flight condi-

LETTERS: Ski-jump Harrier: something...

FLIGHT International, 25 Dec 1976 **LT CDR D.R. TAYLOR**

Sir — "Ski-jump Harrier" (Flight, December 4) mentions a "something for nothing flavour." Misgivings on this score are understandable — I suffered them myself at one stage. As John Fozard has indicated. I began with the realisation that a semi-ballistic trajectory would reduce the launch speeds required. This was in 1969, and at that time I felt that various forms of catapult could provide the initial momentum.

Catapults had to be dropped for a variety of reasons, and it was while I was looking at inclined ramps that I began to worry about "something for nothing." A remark by my wife that one of my sketches looked like a ski-jump provided the analogy which reassured me that I had a simple alternative to the catapult.

But it is one thing to invent some thing and quite another to convince others of its value. I was working alone in my spare time, with no access to Harrier data, and so it was not until 1972-73 at Southampton University and with HSA assistance that I was able to make the concept respectable. It is therefore most gratifying – and rather surprising – that my first rudimentary calculations gave results close to the current predictions.

Why isn't it something for nothing? Because the take-off run to the transition point is longer for a Ski-jump launch than for a conventional short take-off launch. But with Ski-jump the runway is in the sky, of course.

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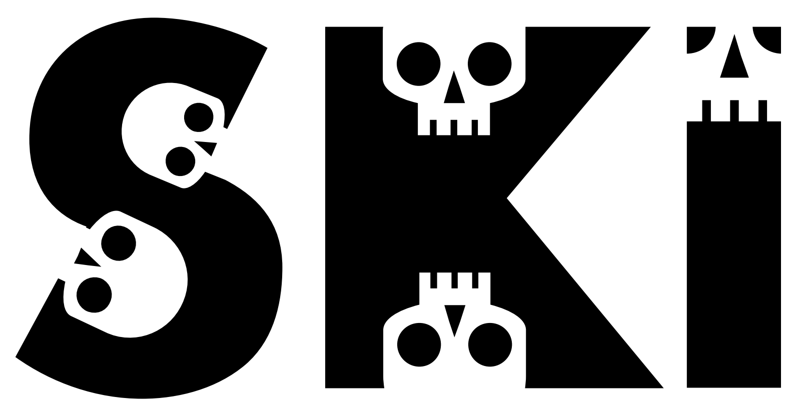
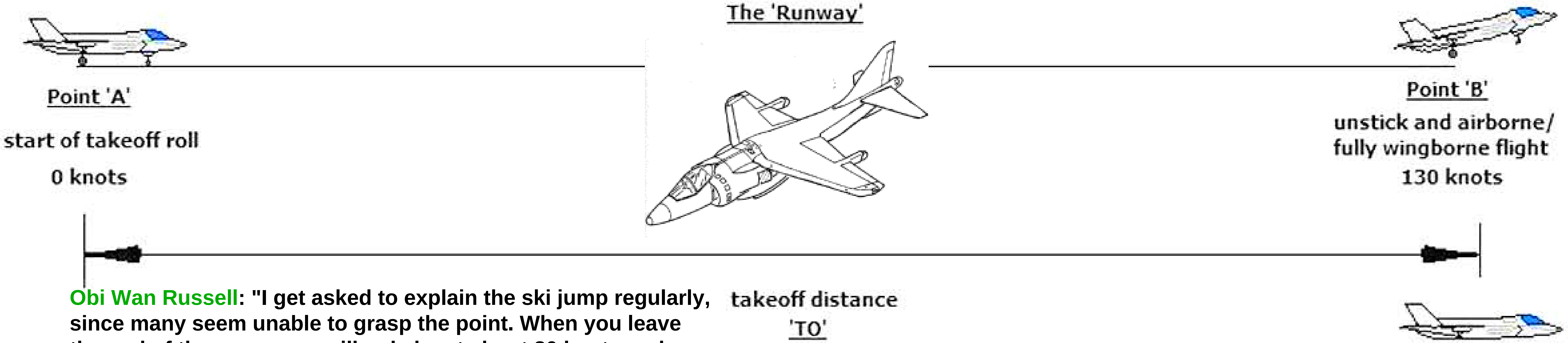
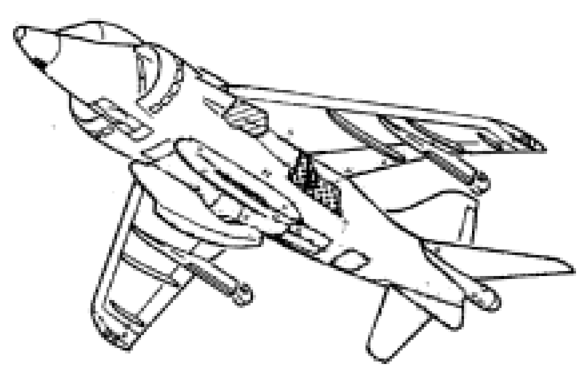


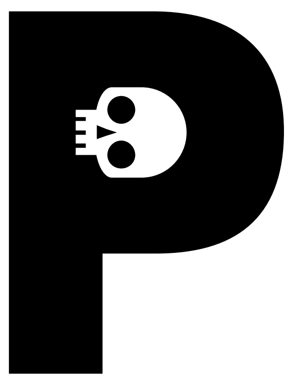
The Ski Jump Explained

Obi Wan Russell 2009

fig. 1

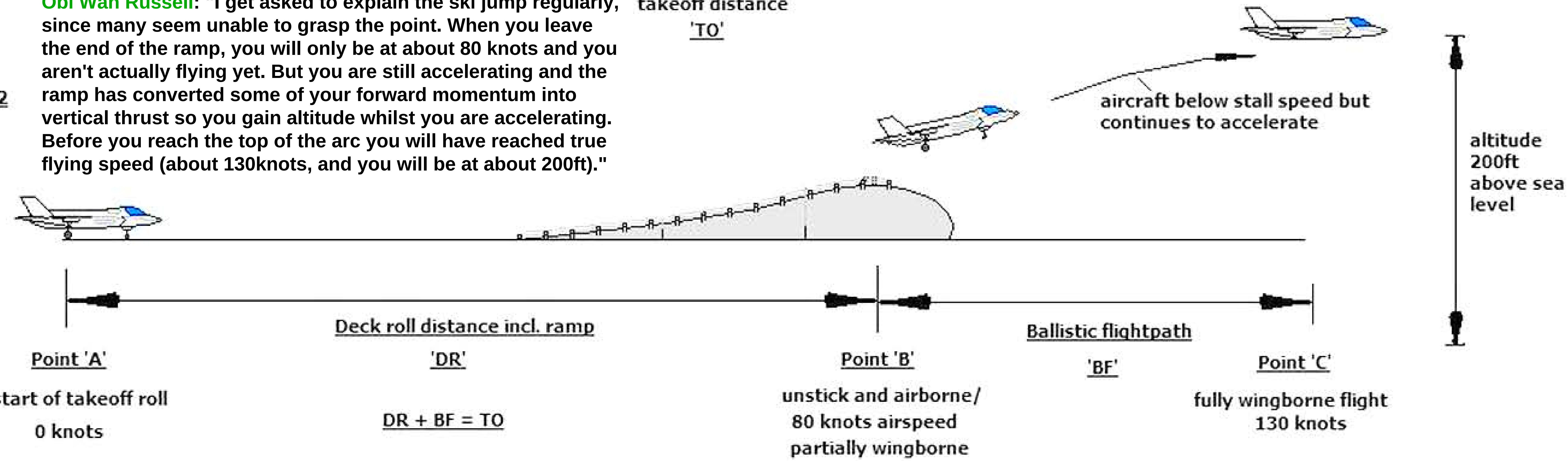


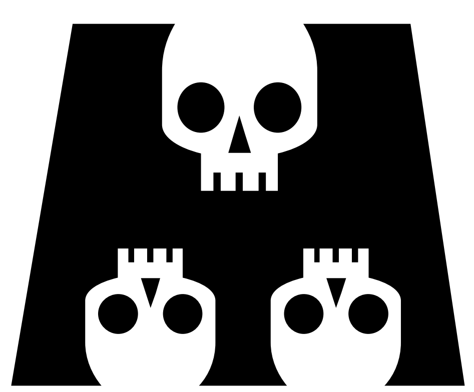




Obi Wan Russell: "I get asked to explain the ski jump regularly, since many seem unable to grasp the point. When you leave the end of the ramp, you will only be at about 80 knots and you aren't actually flying yet. But you are still accelerating and the ramp has converted some of your forward momentum into vertical thrust so you gain altitude whilst you are accelerating. Before you reach the top of the arc you will have reached true flying speed (about 130knots, and you will be at about 200ft)."

fig. 2





The Ski Jump Launch Explained:

In fig. 1 a conventional runway takeoff is shown. The aircraft accelerates down the runway to about 130 knots at which point it has reached fully wingborne flight speed, ie it's wings are generating enough lift to overcome gravity and the aircraft can leave the ground. On land TO could be for example 1500ft of concrete runway or it could be 250ft of catapult track. either way when point B is reached the aircraft is flying.

In fig.2, the distance (TO) is the same, but the aircraft leaves the runway/deck in a much shorter distance, and without catapult assistance. The aircraft leaves the end of the ramp (point 'B') only partially supported by the lift it's wings generate, the support defeiciency is compensated for in aircraft like the Harrier family and the F-35B vectored engine thrust, in the Harrier the nozzles are rotated downwards at 45 degrees on leaving the ramp. If the aircraft was not subject to continued acceleration after leaving the ramp it would arc upwards then fall back to Earth several hundred feet ahead of the carrier. This gives the pilot several extra seconds to react and eject if necessary, improving pilot safety. Otherwise the aircraft follows the arc and continues to accelerate until it reaches fully wingborne flight (point 'C') and flies away normally.

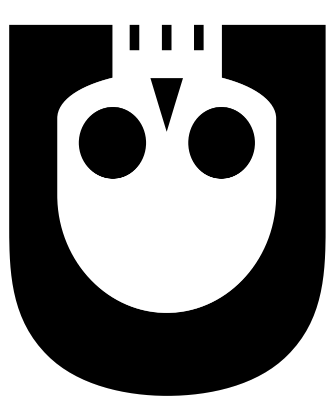
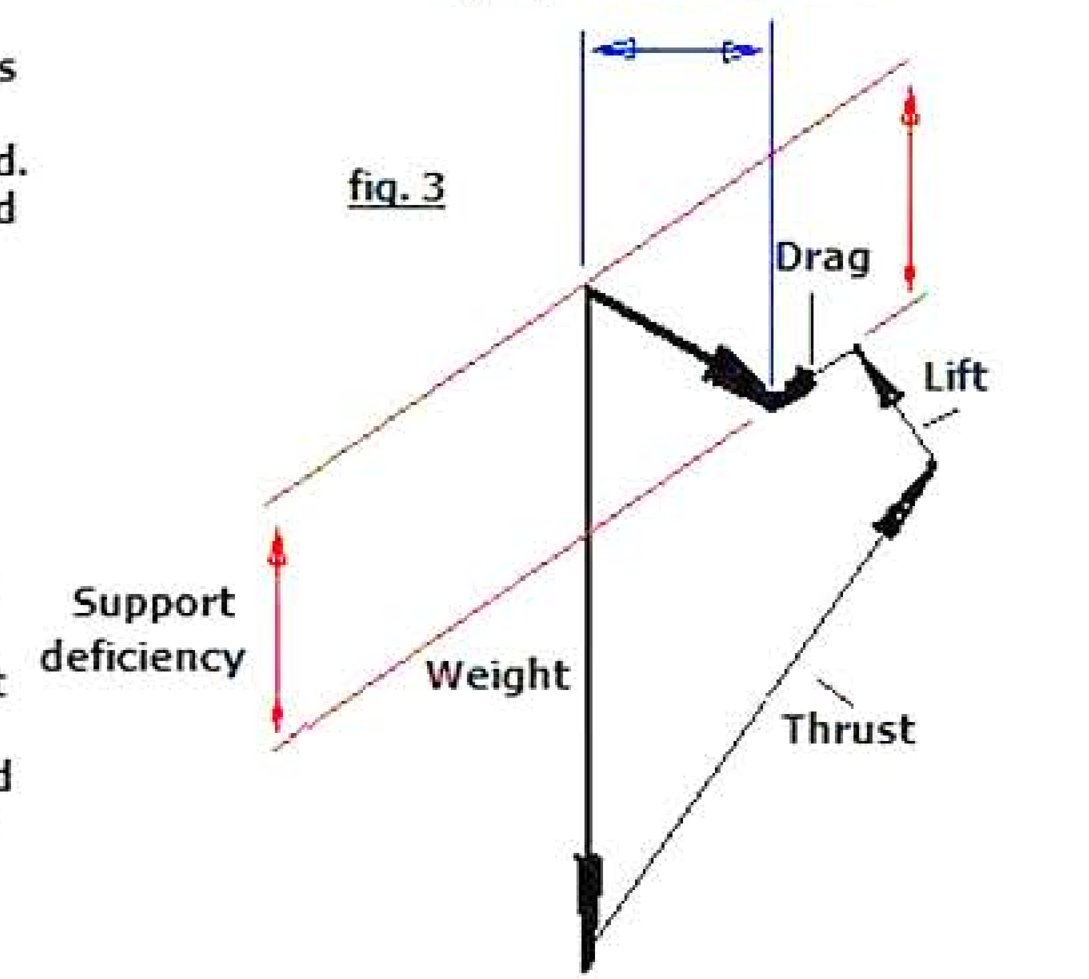
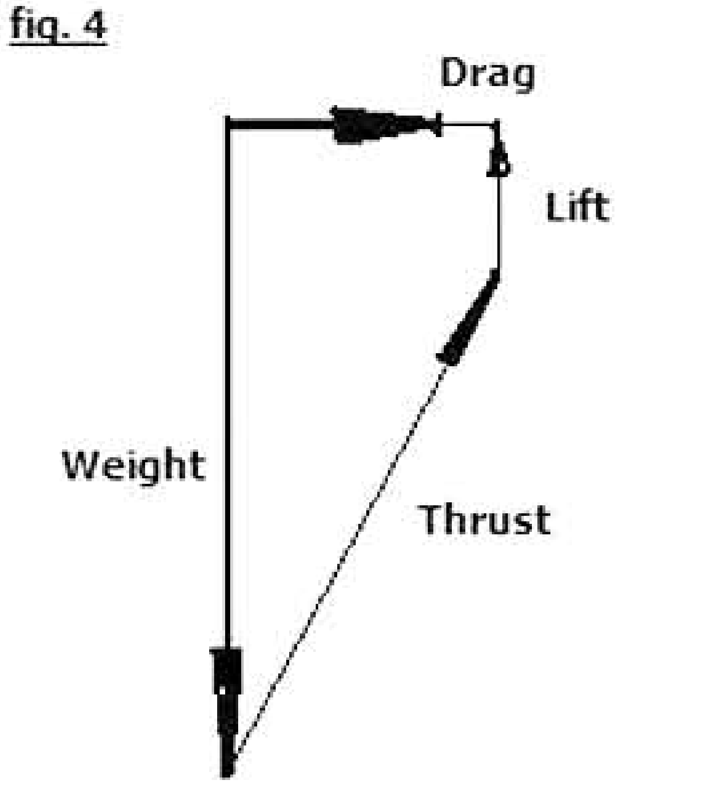


fig. 3

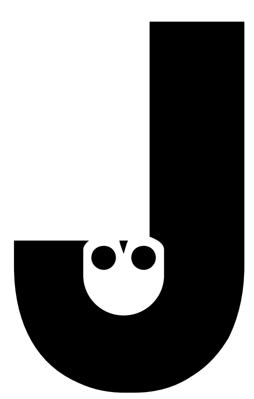


Ballistic (ie Support Deficient) flight trajectory

fig. 4



Lift/Thrust Sustained flight



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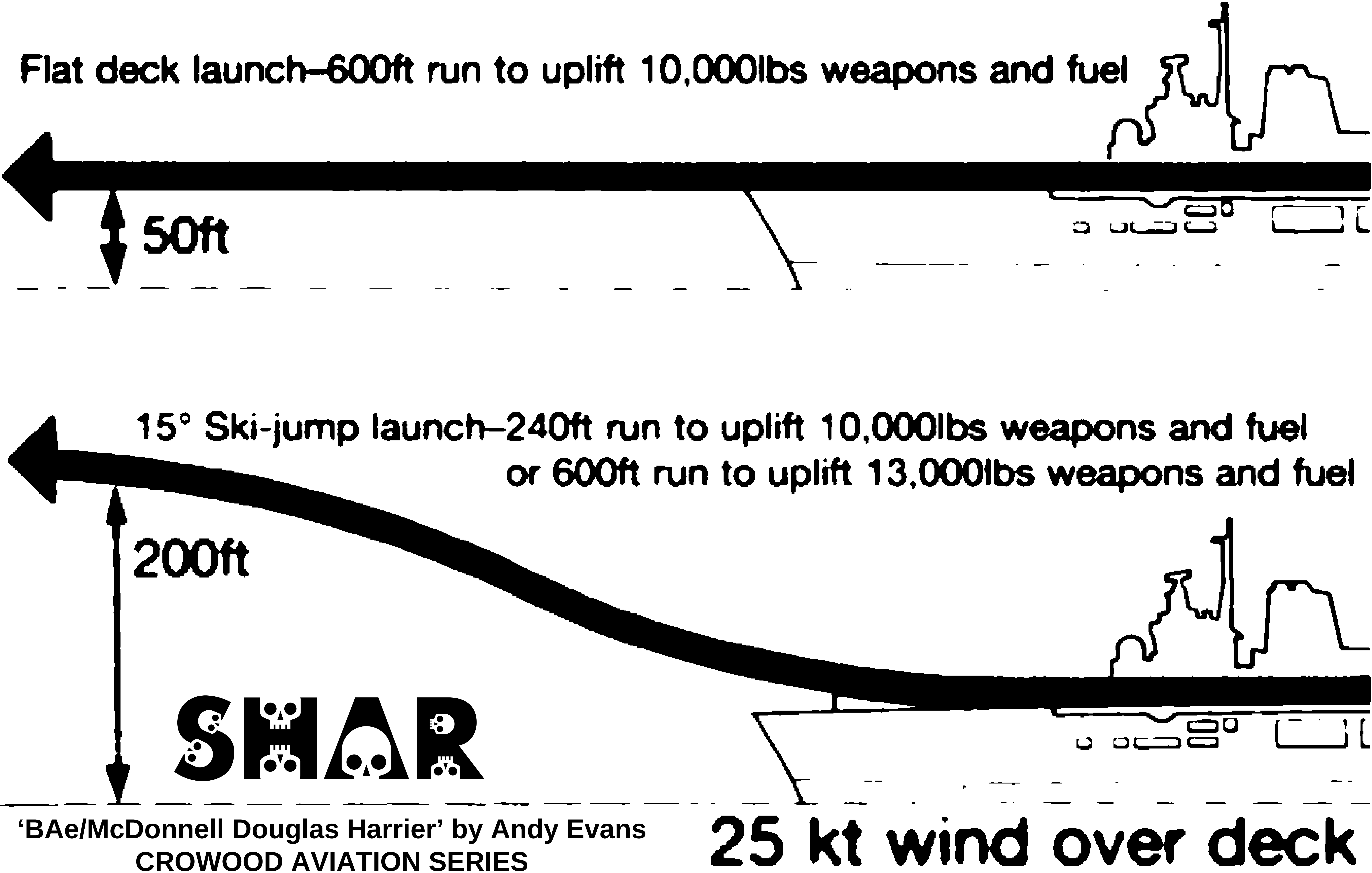
‘BAe/McDonnell Douglas Harrier’ by Andy Evans | CROWOOD AVIATION SERIES **1998**

“...A study which evolved from an idea by a Naval officer, Lt Cdr D.R Taylor. was undertaken at Southampton University in 1972. This was to have a great impact on the Sea Harrier's ability to carry a heavier load direct from the ship, thus increasing its effectiveness. He showed that an appreciable advantage could be gained by launching a VSTOL aircraft from a flat deck with an upward inclined ramp at the end. RAE Bedford undertook to try out the theory, building an adjustable, scaffolded ramp, and between August 1977 and June 1978 tested it at inclinations varying from 6 to 20 degrees. with Bill Bedford making the first 'leap' in XV281, followed by the two-seater XW175. The idea was that the pilot would start a 90ft run, and the ramp would impart a ballistic trajectory to the aircraft, while the pilot would select 35 degrees down nozzle to arrest the aircraft's sink rate as the ‘white line’ at the end of the ramp passed the edge of his peripheral vision, before he gradually moved the lever aft as the aircraft achieved wingborne flight. The gear came up as the aircraft reached 220 kts pulling 12 degrees AOA (angle of attack): a simple yet devastating answer to a big VSTOL headache. Thus for any Harrier take-off weight, the launch speed could be about 25 kts or less than from a flat deck. This also then translates into a 50 per cent shorter take-off run, or more importantly 30 per cent more fuel or weapons can be carried. So conclusive and impressive were the test results that the Navy took the decision to incorporate a ski-jump on the Invincible class carriers, where for reasons of self defence (mainly due to the position of the forward Sea Dart launchers) they were initially set at 7 degrees, but during Hermes's refit her ramp was set at what was considered to be the optimum, 12. The ramps were later revised to a 12-degrees fit on Ark Royal, Invincible and Illustrious....”



'BAe/McDonnell Douglas Harrier' by Andy Evans
CROWOOD AVIATION SERIES

John Farley 25 Nov 2012: “It is easy to misunderstand the benefits of a ‘ski-jump, or inclined ramp, on a ship.

If you run a car or a bike up one you will fly (remain above the height of the level deck) for a while even though these vehicles have no lift generating capability.

If you use an aeroplane that has some lift generating capability you will fly for longer even though you may not have lift equal to your weight. In this case if during the time you fly (thanks to the ski-jump) you can accelerate to a speed where lift will equal weight you have completed your takeoff.

So to obtain the advantages of a ski-jump (with any aeroplane) you need two things:

1. A good t/w [thrust to weight] ratio – very common with many current military aircraft – enabling you to take full advantage of the seconds of flight that the skijump provides.

2. You need to be able to control the aircraft pitch and roll attitude at the (low) ramp exit speed either by good aerodynamics or a reaction control system.”

[Art Nalls would add: “...and a good WOD” (Wind Over Deck)]

http://www.pprune.org/military-aircrew/501297-china-lands-jet-first-aircraft-carrier.html#post7539618

Ski Jumping for STOVL 25 Apr 2014 http://www.pprune.org/military-aircrew/538128-f35-display-uk-year-3.html#post8450029

'ENGINES': ....Ski jumps can be used by both conventional and powered lift (STOVL) aircraft. In both cases, they launch the aircraft into the air below its normal takeoff speed, and the aircraft then spends a period of time in a reducing rate of climb while it accelerates to full wing borne flight, and then climbs away. It's been described to me as a 'runway in the sky'.

However, the two types get very different levels of advantage.

A conventional aircraft (e.g. Flanker, or Fulcrum as used by Chinese and Russia) cannot be launched below normal takeoff speed at max gross TO weight (MGTOW), as the only way they can maintain a safe minimum rate of climb is to adopt a high angle of attack and use engine thrust as best they can. That creates more drag, which delays acceleration, which means lower rate of climb away from the sea. This is why you don't see these aircraft launch with many external stores, and it helps explain an unusually public complaint by a Chinese Navy Admiral over the poor performance of his aircraft.

Conventional ski jumps aren't new, but have usually been discarded due to the inherent limitations I've summarised above.

A STOVL aircraft can launch at much higher relative weights, because it can vector its thrust to the optimum angle to support the aircraft by a combination of wing lift and powered lift so as to deliver the required acceleration and climb out. The angle will be scheduled after launch to move aft as wing lift builds. (Of note, the UK sets a minimum 400 fpm rate of climb as the limiting performance measure for ski jump launches).

Ski jump launch is an extremely effective system for maritime STOVL aircraft, is low workload and safe, as the pilot is guaranteed to be climbing away from the sea, and has more time to react in the event of an engine failure. It also delivers a large improvement in launch weight compared with a flat deck STO.

Oh, and the ski jump was a Royal Navy invention. And the F-35B lift system integration & flight controls design was led by some amazingly talented Brits. And Brits are leading the STOVL flight testing...."

Ski Jumping for STOVL Pt 2 http://www.pprune.org/military-aircrew/538128-f35-display-uk-year-3.html#post8450458

'ENGINES': "...the powered lift system on the F-35B can't vector all the thrust aft like the Harrier does. That's part of the trade off in getting your main propulsion engine located at the rear of the aircraft, where it really belongs for a fighter/strike type aircraft.

The lift fan can vector aft to around 50 degrees: on the X-35 there was a sort of 'pram hood' device that gave further aft vectoring - however, this was replaced in development by a much lighter 'vane box' device (UK designed) which still gave enough aft vector to meet the requirements. These were a set distance for a flat deck STO, and another shorter distance for a ski jump launch. The launch weight was driven by a defined operational scenario.

The roll posts deliver around 2,000 pounds thrust each in balanced operation, but they are turned off during the STO run and switched back on just before launch. This facility was suggested by a very talented RN FAA air engineer, and gratefully adopted during the weight saving programme. Another excellent Brit contribution.

The point overall is that the F-35B meets all its STO requirements, as well as its short landing targets. And it's a much heftier bird than the Harrier — over 55,000 pounds off the ramp...."

‘Engines’ 26 Apr 2014 http://www.pprune.org/military-aircrew/538128-f35-display-uk-year-3.html#post8452299
The ship and the aircraft have proceeded side by side for many years now. At meetings in 2003, the CVF team were demanding a ski jump profile from LM. That profile wasn't available then, but was provided around 2006/7 once the F-35 team had done enough sim work on ski jumps with mature flight control models.

The thing to grasp is that ski jump ops are a low risk area of the F-35B programme. Ski jump launch is not as 'dynamic' as a flat deck STO, & in some areas the F-35B offers less challenges than the Harrier.

‘Engines’ 29 Apr 2014 http://www.pprune.org/military-aircrew/538128-f35-display-uk-year-4.html#post8455995
The landing gear layouts on the Harrier and the F-35 are fundamentally different, especially in the nose leg area. The Harrier has a 1950s style 'bicycle' or 'tandem' layout, & the weight of the aircraft is split almost 50/50 between the aft leg (we called the 'main') & the forward leg (which we called the 'nose leg').

What this meant for Harrier ski jump ops was that the front leg was fairly heavily loaded. We increased the liquid spring pressure for ski jump ops, and the limiting condition was to avoid total closure of the nose leg spring as it reached the end of the ski jump. (The leg started closing as it entered the ramp, & closed steadily as it approached the exit lip).

The F-35 has a more conventional 'tricycle' layout, with the two main gears taking around 90% of the load, the nose leg taking around 10%. The early checks on ski jump profiles & predicted launch speeds showed that the nose leg loads during ski jump launches were well within the highest design load, which was driven (I think) by vertical landings, with an arrival on the nose leg as the worst case, or with high lateral drift. The forthcoming tests at Pax will provide the real data.

Short take-off and vertical landing; a close look at an historical technical breakthrough

Author: Bally, J.J. Date: Oct 1, 1989
Publication: Armada International

Short Take-off and Vertical Landing
A Close Look at an Historic Technical Breakthrough

Vertical take off was not really a new idea. At the beginning of the 1940s, the Germans developed the Bachem 339 Natter, a rocket-engined fighter which took off from a tower just like the Space Shuttle with the help of four solid propellant boosters and was recovered by parachute. Not until the emergence of the jet engine was the concept revived.

From the end of the 1950s onwards, there was a blossoming of several exotic designs whose main merit was to clarify the problem and to "darwinize" potential solutions. Almost every manufacturer had a go, with the exception of Bell, who tackled the problem the other way round and launched research into the tilt-rotor. Thirty years later, Bell's V-22 Osprey is a remarkable example of rewarding tenacity.

The various designs which were tested at the time can be divided into five main families: * The "tail-sitters", which rested on the ground on their tail, taking-off vertically: in the USA the Ryan X-13 (1956) and in France the SNECMA "Atar Volant" (1959). * The "flow-switchers", with twin 2D thrust diverters and aerodynamic "gearing": e.g. the Lockheed XV-4A (1963), Ryan XV-5A (1964) and Rockwell XFV-12A (1978). * Aircraft using pure dynamic lift. Several small, fixed jet engines located in the wing and fuselage provided vertical thrust while the cruise engine installation was conventional: e.g. the Shorts SC-1 (1960), Dassault Balzac (1963), Dassault Mirage IIIV (1966) and Lockheed XV-4B (1966). * Hybrids (lift engines plus a cruise engine supplying vectored thrust), e.g. the EWR VJ-101C (1963), Dornier DO31 (1967), VAC 191B (1972) and the Soviet Yak-36 Freehand (1976). * Pure vectored thrust: e.g. the Bell X-14 (1958), the British P.1127 (1960) and the Soviet Yak-38 Forger (1967).

The prototypes mentioned above are only a few of the numerous designs which were flight-tested. Most of them, at least in the West, were fitted with British engines.

Of all the configurations tested during the past three decades, only two survived and were developed to the production stage: the Soviet Yak-38 Forger and the British P.1127, which gave birth to the Kestrel

such an advantage due to the extra payload it permitted. The British very early on foresaw advantages of the rolling take-off and this is why they developed a simple, reliable and above all very fast-acting (100[degrees]/s) vectoring system.

Where do We Stand Now, Thirty Years On?

Today, with the exception of a few British Harrier units, the NATO Tactical Air Forces still depend on their 2 400 metres-long, paved runways. The number of such suitable airstrips available in Western Europe is well below a hundred. The potential enemy knows their exact position and they are not likely to move overnight. It should not be forgotten that during the past three decades, anti-runway munitions have made tremendous strides. Not only are they now extremely accurate, using submunition-dispensers carried in stand-off guided missiles, the pilots no longer have to overfly the target. What is more, these munitions are now interspersed with a mix of anti-personnel mines intended to slow down or prevent the repair work.

To pretend that airbases can be defended 100% against air attacks at a reasonable cost is another typical example of refusing to face unpalatable facts. Who can say how many runways will still be usable at dusk on D-day? The most pessimistic optimists maintain that even on a cratered runway an undamaged section 500 or 600 metres long can always be found to allow take-offs. Granted. However, the real problem is landing. A modern conventional fighter can take off on a very short strip thanks to its 1 g acceleration at full throttle. But on landing its deceleration is about 0,25 g on a dry surface and never exceeds 0,5 g even when making full use of thrust reversers (only fitted on Tornados and Viggens). While on take-off the pilot can use every foot of the available lenght by releasing brakes at the very edge of the paved surface, the precision of the touchdown point on landing is far from being so accurate, never being less than within about a hundred metres even for a very experienced pilot. By and large, the minimum length required for landing is at least twice that required for take-off.

To close this chapter, it is an odd fact that the only West European countries whose tactical air forces can reasonably hope to survive an all-out war are two neutral powers, Sweden and Switzerland. With a population of 8.3 million people, Sweden maintains 500 modern combat aircraft (France has barely 200 more) sheltered in tunnels and operated from a score of narrow strips scattered in the forests or from highway sections. The 300 Swiss fighters are safely protected in caves dug in the mountains, together with all their logistics. Runways are generally sited in deep, narrow valleys, surrounded by 3,000-metre mountains which provide the cheapest and most efficient protection against air attacks.

At Sea

Even more than on land, gigantism at sea has now become a chronic affliction that leads inexorably to a budgetary and operational dead-end. The well-proven deck-landing system aboard ships has not changed in more than half-a-century, consisting of arresting wires on the deck and a tail hook on the aircraft.

Launching and recovering aircraft at sea still require a strong relative wind over deck, exactly fore-and-aft. The carrier - and her escorts - must therefore constantly change course and speed according to the tactical situation, even if a single aircraft has to be launched or recovered. All this takes time and planning and wastes ship's fuel.

A Carrier Vessel Battle Group (CVBG) at sea is far more vulnerable than it was three decades ago. The threat of new weapons like long-range anti-ship missiles and nuclear attack submarines is such that defending the so-called sanctuary in which the carrier is supposed to move around freely and safely takes up an ever-increasing proportion of its shipborne aviation, in fact considerably more than 50%. Paradoxically on its "attack" carriers, the US Navy spends the bulk of its budget on defensive assets.

The net result of these aberrations is that the "cost-effective" size of an aircraft carrier able to operate modern conventional fighters is now close to 100 000 tonnes at a unit price of roughly $ 4 billion, which is an awful lot of eggs in one basket. At that rate, even the USA can hardly keep up. Former Secretary of the Navy John Lehman's "Maritime Strategy" called for maintaining 15 super-carriers in the fleet, but the actual projected number is already dwindling to 12.

The British Answer

Despite official scepticism and the abandonment of VTOL development by most manufacturers, the British, alone, did not give up. Pragmatic, inventive, stubbornly sticking to their own views and with supreme disregard for outside opinion they casually went their own way. They grasped very early on that thrust vectoring was the right approach.

Incidentally, the basic configuration of the four vectoring nozzles was brought to England by a French engineer, Michael Wibault, who in 1956 approached Bristol Aero Engine (now part of Rolls-Royce) with his Gyroptere design, the ancestor of what was to become the Harrier.

The experimental Hawker P.1127 built on the Gyroptere design first flew in 1960 equipped with a Rolls-Royce Pegasus jet engine. Then came the Kestrel and eventually its production derivative (more than 90%) the Harrier, which entered service in the Royal Air Force in 1969. The Royal Navy joined in much later and rather hesitatingly with the Sea Harrier (a "navalized" Harrier GR3) which only entered fleet service in 1979. But how could the Navy have guessed at the time that the ski-jump take-off technique would so enhance the payload performance of the aircraft? Incidentally, turning the Harrier into Sea Harrier was achieved at a "cost" of only 45 kg in empty weight, as compared with several hundred kilograms for the navalization of a conventional fighter.

Interestingly, the costs of the initial development stage (the first three years on the P.1127 and the first four years on the Pegasus engine) were entirely borne by the manufacturers without any order, grant or subsidy from the government. This was very fortunate for had the government funded the project, it would certainly have imposed its own solution, which at the time was the hybrid concept (separate lift plus lift and cruise engines), and there would today be no Harrier. The programme suffered from the usual inter-services rivalry. At the time, the RAF considered it essential for a fighter to have a speed of Mach 2 and therefore showed very little interest (except that it saw in the Harrier the spectre of the re-emergence of the Fleet Air Arm). When the Navy finally came round to accept the STO/VL concept, it had to take care to conceal its true intentions. HMS "Invincible", the lead ship of a batch of three new aircraft-carriers, was designated "through-deck cruiser" and at the time of her commissioning, the Navy selected a name which no previous carrier had ever borne.

From 1971 onwards, the US Marine Corps ordered a total of 110 Harriers, including eleven two-seaters under the American designation AV-8A to be operated from LPHs and LPDs. For years, the Marines had been trying to achieve the operational self-sufficiency which only the STO/VL could provide. They had nasty memories of the abrupt departure of the Navy carriers at Guadalcanal in 1942, leaving them in the lurch with no air support. Their initial experiences with the AV-8A proved very satisfying and they are now in the process of acquiring a total of more than 300 AV-8Bs, the American version of the Harrier II developed jointly with the UK and now in production in the USA by McDonnel Douglas. A first batch of 72 aircraft was authorized at the rate of 24 yearly in FY 1989, 90, and 91.

The Lessons of the Falklands Campaign

The Harrier is far from being an unproven newcomer. In service for almost twenty years, its various versions had logged more than half-a-million hours of flying time by the end of 1986. During the Falklands conflict in 1982, the 28 Sea Harriers operating from HMS <<Hermes>> and <<Invincible>> shot down 23 Argentinian aircraft, while on the British side not one was lost or even hit in air combat. Ten Harrier GR3s from the RAF, whose pilots had no previous deck training, were also engaged. Four Harriers/Sea Harriers were lost in accidents and five were shot down by the Argentinian ground-to-air defense. The operational attrition rate was never greater than 0.5% per sortie. Aircraft serviceability never fell below an astonishing 85% throughout the campaign.

Appalling weather conditions, which would almost certainly have precluded operating conventional aircraft from a large carrier, very seldom kept the Harriers/Sea Harriers idle on deck. Some were recovered in almost zero visibility (less than the ship's deck-width) or in extreme sea-state conditions with the flight deck moving vertically through as much as 10 metres.

In people's minds, the Harrier is now the symbol of the Falklands campaign, much as the helicopter gunship is of the Vietnam war.

The Harrier: a Few Facts

The non-reheated Rolls-Royce Pegasus turbofan of the Harrier/Sea Harrier/AV-8B has of course been upgraded since that of the original Kestrel. Its thrust is now in excess of 10 tonnes, almost double what it was 25 years ago, but its general architecture remains unchanged. The four nozzles, arranged in a rectangle, two either side under the wing and two further aft, can be rotated through 100 [degrees] from fully aft to about 10 [degrees] forward of the vertical. The control mechanism is simple (a "bicycle-type chain" driven by pneumatic actuators) and fast (100 [degrees]/s). The front nozzles exhaust more than 60% of the air flow (at 360 m/s and 110 [degrees] C), the aft nozzles 40% (at 550 m/s and 650 [degrees] C).

In dynamic flight, the aircraft is controlled in pitch/roll/yaw and trim through the Reaction Control System (RCS) consisting of small, variable-area shut-off valves located at the wing tips and at both ends of the fuselage, fed from HP compressor bleed at about 10 kg/[cm.sup.2] and 400 [degrees]. These valves are controlled by stick and rudder the same way as ailerons, rudder and elevators in aerodynamic flight. They start to operate automatically when the main nozzles are vectored down to 20 [degrees] regardless of airspeed, the pilot having to take no specific action and being in fact unaware of what type of control (aerodynamic or dynamic) he is operating when he moves his stick or the rudder pedals. On the ground, the front wheel of the tandemtype main undercarriage can be steered with the rudder pedals. In the cockpit, the thrust vectoring lever is the only additional control that distinguishes the Harrier from a conventional fighter. Located within the throttle box, the lever has an adjustable stop for short take-off. This allows the pilot to preselect the vectoring angle at the selected lift-off speed or lift-off point, according to the landing run available and other usual parameters (load, wind, temperature, elevation, etc.). The take-off run is then initiated with the nozzles fully aft. When the pilot reaches the selected lift-off speed (or the end of the ramp in a ski-jump takeoff), he slams the nozzle lever to its preselected stop and is airborne, about two-thirds on engine power and one third on wings.

Specific Operating Procedures and Limitations

The Harrier is not a helicopter. In the hover, it is less sensitive to gusts and wind direction. It is less manoeuvrable than a helicopter, particularly in the vertical axis. The aircraft is a bit "sluggish" and hence slower to recover from over-control. Touch-down is not as accurate as in a helicopter but typically within about one metre of the intended point.

On take-off, when applying full throttle, the pilots should be careful not to "drift" on the tyres since the engine takes several seconds to reach its maximum thrust (one aircraft just skidded overboard during the Falklands campaign).

For various reasons, notably due to the design of the tandem-type under-carriage, an aircraft at a weight significantly greater than maximum hover weight cannot be recovered at airspeeds below 70 to 80 knots, thus precluding a carrier landing at this weight without an arresting system. In any case, the gear is not designed for high vertical impact velocities.

The Harrier is not a good glider. Its lift-to-drag ratio is of the order of 3:1. Ejection is the only emergency procedure. Contrary to a widely spread legend, wooden decks (as in the Spanish "Dedalo") do not catch fire due to the hot exhaust jet. On a steel deck, one can walk barefoot from where a Harrier just took off. The Pegasus engine produces no smoke, being a turbofan. Its IR signature is low due to the low temperature exhaust, masked underwing.

"Viffing" and Ski-jump Take-off

Surprisingly and significantly enough, two important operating procedures of the Harrier which are today its two main selling points were initially developed by those that flew them and not by the designer or offical research bodies. It just goes to prove that computers are not about to replace the human brain and that the craftsman's skill can still challenge the best designer. * The first of these is "Viffing" (<<Vectoring In Forward Flight>>) i.e. using

the thrust vectoring control in flight. The development of this technique owes much to the pioneering work done by the US Marine Corps, in particular by the then Major Harold W. Blot (now Brigadier-General and V-22 programe manager) who, in flight at 500 knots on an AV-8A, slammed the vectoring lever to the hover stop, discovering that the deceleration effect was more powerful than any airbrake. (Some RAF pilots are said to have "played" with it before, but kept quiet about it.) Subsequent trials gave this phenomenon the official seal of approval.

"Viffing" has several advantages whose cumulative effects greatly enhance the aircraft's air combat capabilities. * It increases total lift, thus permitting tighter turns. * It generates (even with as little as 20 [degrees] of vectoring) a powerful nose-up trim change, enabling the pilot to bring into his sights an enemy at which he would otherwise have no hope of shooting. * The Reaction Control System, which starts to operate automatically at 20 [degrees] of vectoring, greatly enhances the manoeuvring capabilities in a dogfight. * It produces an extremely powerful deceleration (-2g), enabling the pilot swiftly to shake off a pursuer or missile. * While "viffing", the engine remains at full power, allowing the pilot instantly to reaccelerate when he brings back the vectoring lever to the full back stop.

These various factors combine to give the Harrier a decisive advantage in a dog-fight. Because his flight path is unpredictable, the Harrier pilot is liable to open fire at any moment. In a ground attack, the increased rate of turn through "viffing" enhances survivability and increases the chances of hitting the target on the first run. "Viffing" also provides for easier speed control in a dive and shortens the reaction time in attacking a target of opportunity.

"Viffing" so enhances manoeuvrability in air combat that irrespective of the STO/VL performance, this capability would certainly spin off on conventional fighters if it could be afforded without incurring too heavy a weight penalty. The vectoring mechanism weighs a mere 45 kg. Together with the RCS, the total weight of the systems is in the order of 160 kg, less than 3% of the operational weight empty. Peacetime dummy engagements against various fighter types (F-14, F-15, F-16, F-4, F-5E) showed that the Harrier/AV-8B outperformed them all in "visual initial encounters" by 3:1. Aircraft on both sides were flown by experienced pilots of equivalent training levels. In the contest, the F-16 was the runner-up. * The second technique unforeseen when the Harrier was developed is the ski-jump take-off. Lt. Cdr. Doug Taylor, RN, first proposed this technique in 1973. It seems that his initial concern had been to make a rolling take-off safer on board ships, particularly on a pitching deck. In a large conventional carrier, pitching is quite moderate even in heavy seas. Moreover, a catapult launch is so fast that the flight deck officer can adjust his timing to the pitching of the ship and launch when the deck comes up so as to be sure not to "shoot" on a downwards trajectory. However, the Sea Harrier is designed to operate from relatively small ships, more sensitive to sea states and with shorter pitching periods, and when performing a rolling take-off from a downwards pitching deck it might come dangerously low over water. A ski-jump guarantees that regardless of the pitching angle the initial flight path will be upwards.

The ski-jump take-off procedure is similar to that of a rolling take-off on a short field. Before applying full power, the pilot sets the thrust vectoring lever stop to about 50 [degrees]. The nozzles are vectored fully aft during the deck run but as the aircraft reaches the top of the curved ramp, the pilot slams the vectoring lever to the preselected stop. At this point, the lift is split about one third between the wings and two-thirds the vertical component of the engine thrust. The airspeed is still too low for the aircraft to "fly" but as it arches up and levels off, the forward thrust component builds up speed while the pilot progressively brings the nozzles aft. Typically, the transition takes about 10 seconds to reach 180 knots in normal flight.

Another advantage of the ski-jump is that, should anything go wrong, it gives the pilot more time to eject.

The ski-jump can also greatly reduce the take-off run or, using the same available strip length with a ramp at the end, greatly increase the maximum take-off weight, and hence the payload. Alternatively, the same payload can be flown off from a much shorter field. The gains are roughly of the order of 50% (of load or length). During trials at maximum weight, astonishing end-speeds of 75 knots were recorded on a 12 [degrees] ramp (65 knots less than a "flat" short take-off) and even as low as 42 knots on a 17,5 [degrees] ramp. Ramp settings in excess of 20 [degrees] were not tested for at 20 [degrees] the aircraft sustained a 4 g vertical acceleration and the wheel's oleos just bottomed.

These gains are such that studies are now being made to transfer the ski-jump technique ashore in the form of grid matting strips equipped with a mobile ramp. At sea, the ski-jump is now standard on all new STO/VL carriers.

Jump Take-off and "2D" Nozzles

Ski-jump take-off and "viffing" have now gained so much favor that some aviation circles are anxious to extend their benefits to conventional fighters. Within the framework of the painful A-6 replacement programme for instance, McDonnell Douglas is studying a Super Hornet F/A-18 equipped with "2D" nozzles (i.e. vectorable through an are below the fuselage axis) with reheat and thrust reversers. This would give the F/A-18 some STOL capability, enhance its manoeuvrability and increase its payload and/or endurance. Of even greater interest on that same aircraft, the three legs of the undercarriage would be fitted with powerful actuators which would play a role similar to that of pre-loaded springs. On take-off, at a given speed, they would suddenly expand (nosewheel first for rotation), literally thrusting the aircraft off the ground without having to wait for airspeed to build up and the stick to come into play.

Last May, a US Air Force/McDonnell Douglas team began test-flying an F-15 STOL Maneuver Technical Demonstrator (S/MTD) fitted with "2D" nozzles and thrust reversers, a modified "rough field" landing gear and an integrated flight controls/propulsion system (involving some kind of dynamic attitude control at slow speed). The study contract, awarded in 1984, specifies that the demonstrator should be able to operate from a 450/15 metres strip. Both initiatives confirm that the main purpose of the ski-jump take-off is to get the aircraft airborne sooner than it would otherwise, and this is only possible if control on the three axes is achieved at speeds lower than normal take-off speed.

At sea, arrested landing at high speed has apparently been stretched to its ultimate technical limit, and the ability of designers to invent new aerodynamic gimmicks intended to slow down the approach speed is reaching the point of exhaustion. But the catapult is most likely to survive. It may even gain more favor and see its use extended to land operation.

Performance

The raw performance of the Harrier in terms of speed, payload and endurance does not of course match the F-14, F-15, F-16 and F/A-18. A fair comparison must however take into account their respective capabilities.

The Harrier is often accused of being incapable of lifting its maximum payload in the VTO mode. True. But the Harrier is basically a STO/VL aircraft and the diehards are invited to name a single conventional fighter able to lift its maximum payload on its shortest take-off run. * As for its performance endurance, * the Harrier only burns some 50 kg of fuel in a typical take-off sequence versus 250 kg for a modern twin jet fighter; * the fuel cost of a typical landing sequence is only 70 kg, with no extra allowance necessary for a missed approach; * in a dogfight the Harrier forces his opponent to go over to reheat, without increasing his own fuel consumption; * above all, an almost total disregard of weather conditions at the time of returning to base or to ship allows pilots to draw much deeper on their fuel reserves and thus perform their mission with much greater peace of mind. The typical fuel reserve of a Harrier at the break is in the order of 100 to 300 kg versus 800 to 1200 kg for a conventional fighter. * Payload

In ISA + 15 [degrees], an AV-8B taking-off from a flat 300 metre strip carries 4 tons of bombs with a radius of action of 350 km. It should also be borne in mind that the forward basing capability further reduces the actual range and reaction time to reach the target zone.

At sea, the so-called performance gap between the Harrier and conventional fighters dwindles to such a point as to turn to the advantage of the former, except in interception beyond visual range. Anyone with carrier experience can remember how suddenly the casual routine of launching and recovering aircraft becomes an emergency whenever a pilot reports low on fuel or if the deck is unexpectedly fouled, even in fair weather. In peacetime, captains usually operate within gliding distance of an emergency airbase ashore, which of course breeds bad habits. When the ship is actually way out at sea, safety requires that a ship-based tanker aircraft be kept overhead round-the-clock to help any plane short of fuel.

The Soviet Yak-38F

Spotted for the first time on the "Kiev" in 1976, the Soviet VTOL Yak-38 Forger belongs to the hybrid family. In the hover, the lift is roughly split evenly between its cruise, vectored thrust engine (a pure jet) and two vertical thrust jets situated aft of the pilot, which leads to several inevitable complications.

When the Russians decided to develop fixed-wing shipborne aviation starting from scratch, they deliberately preferred to deploy a rather poor VTO to start with, rather than try to copy the Western saga of catapults and arresting wires. The price paid for this conservative approach is that their four "Kievs" are hybrids, more helicopter-carriers than full-fledged aircraft carriers. It should be noted, however, that the latest Soviet aircraft carrier the 65 000t "Tbilisi" (ex-"Leonid Brezhnev") has a 12 [degrees] ski-jump at the bow and an 8 [degrees] angled deck. "Belt and braces", some will mutter. Though the ship has no catapult, her configuration seems to confirm that the Russians are developing a conventional naval fighter (a derivative of the Su-27 Flanker?) and an improved derivative of the Forger, the STO/VL Yak-41.

The Supersonic Harrier

The Harrier design team very early on undertook the development of a supersonic derivative of the basic aircraft. In 1965, only five years after the subsonic prototype (P.1127) first flew, a supersonic prototype (P.1154) was about one-third completed at Kingston when the British government of the day cancelled the programme.

The main challenge of course was to increase the engine thrust while keeping the original well-tried configuration of four vectoring nozzles. Merely adding an afterburner to the existing engine was out of the question as it would have unbalanced the longitudinal thrust split of the four nozzles in the hover. The original solution for the P.1154 was Plenum Chamber Burning (PCB) i. e. heating the relatively cool fan flow directed through the front nozzles. While the PCB principle was extensively tested on the ground, it never flew. Several other concepts were also investigated including those of a "tandem fan" and RALS (Remote Augmented Lift System), which diverts part of the compressed air flow to the front nozzles.

Whatever configuration may eventually emerge on some future supersonic Harrier, one thing is certain: because the speed of the ejected flow in the hover will be significantly higher, two factors will be of a major concern that are not critical on the existing Harrier: the recirculation of burned hot gases (reducing engine efficiency) and the ingestion of ground debris in the air intakes.

While the development of a supersonic Harrier has officially been shelved for about twenty years, the British have never actually closed the file. In line with their practice, they have quietly, inventively and tenaciously kept on working, particularly on the engine side. The signature in January 1986 of a MoU with the USA for the joint development of an Advanced [i.e. supersonic] STOL aircraft is an indication that they did not come to the negotiation table empty-handed. Nothing has leaked of what is being done (the programme is classified) but the ultimate outcome is fairly certain: the future supersonic Harrier will be Anglo-American.

http://www.flightglobal.com/pdfarchive/view/1980/1980%20-%200091.html

HMS Invincible c.1980

Britain will be the first country to operate a V/Stol carrier when the Royal Navy receives the anti-submarine cruiser Invincible this year. The ship will carry nine Sea Kings and five Sea Harriers

ski jump slope was initially 7°, later increased to 12° for all

WX South Atlantic Quotes: V/STOL: Neither Myth Nor Promise—But Fact

Sep-Oct 1982 Wing Commander John D. L. Feesey, Royal Air Force Air University Review

"...In a remarkable demonstration of the inherent flexibility of V/STOL, RAF Harriers flown by pilots with no previous deck experience operated successfully from naval aircraft carriers and the converted cargo ship Atlantic Conveyor. Sea Harriers frequently landed on the helicopter flight decks of destroyers to refuel, thus freeing carrier decks for other uses. A total of more than 2000 Harrier sorties was flown from aircraft carriers during the conflict, an impressive average of about six per day per aircraft.[2] Any doubts about the effectiveness of the Harrier as a versatile fighter must surely have been removed by its outstanding record in the Falkland Islands War.

note 2: Aviation Week & Space Technology, July 19, 1982, p. 20.

http://www.airpower.maxwell.af.mil/airchronicles/aureview/1982/sep-oct/feesey.html

THE RAF HARRIER STORY - OPERATIONS – GR3

Air Chf Mshl Sir Peter Squire | 2006

"...Incidentally, whilst embarked in Ark Royal in 1971, Ken Hayr had already demonstrated the Harrier's ability to operate from the deck in weather well below the limits for conventional jet aircraft, and this was proven again – several times – during operations in the South Atlantic. In cloud bases of 200 ft and visibility of half a mile, Harriers slowed to 60 knots on the CCA, descended to 100 ft, identified the carrier's wake and motored slowly forward until the superstructure appeared from the gloom, leaving just time to establish a hover alongside FLYCO....

...Landing on the forward spot [of Atlantic Conveyor] in a heavy rolling swell off Georgetown (Ascension) was probably one of the more demanding flying events of our deployment.... However, the use of Atlantic Conveyor as a carrier of aircraft with the ability to launch and recover whilst in transit, is an interesting reflection of the Harrier's versatility...."

http://www.rafmuseum.org.uk.nyud.net/documents/Research/RAF-Historical-Society-Journals/Journal-35A-Seminar-the-RAF-Harrier-Story.pdf

V/STOL SHIPBOARD RECOVERY: "IT'S NOT JUST ANOTHER CARRIER LANDING"

12 Apr 2002 Major A. G. Shorter, USMC

"...In the past, there was seldom a mention of instrument or night recoveries with respect to the Harrier. That is not because these recoveries were not executed early in the aircraft's development; on the contrary, history is replete with examples of Harriers recovering in weather conditions that would have normally grounded CTOL aircraft. This fact is best described by a passage from V/STOL in the Roaring Forties, dealing with the RN's experiences during the Falkland War of 1982:

> 'For much of the task force's time in the South Atlantic, the weather was almost a second adversary. It was not without good reason, in the heyday of the sailing ship, that these ports of the southern ocean became known as the roaring forties. The flight decks of the carriers were moving vertically at times through 30 feet and the weather produced cloud bases typically [down to] 200 feet and often down to 100 feet during flying operations. Visibility was typically ½ nautical mile and often much less. One Harrier recovered to the deck of the [HMS] Hermes in horizontal visibility of 50 meters [on] one notable occasion.
> The time honoured carrier trick of dropping flares at intervals into the ship's wake was used, but it was the Sea Harrier's facility to approach the ship using its internal approach aid & Blue Fox radar at part jetborne [slow] closing speeds of a few tens of knots which

primarily provided the safety and hence the success in bad weather recovery.

No conventional fixed-wing naval aircraft could have operated with adequate safety in such conditions, thus supporting the claim that the greatest military contribution made by the V/STOL and STOVL aircraft is in the vertical landing phase of operation. In the Harrier, this phase is made safer, easier and more flexible than in any other combat aircraft'...."

http://www.dtic.mil/dtic/tr/fulltext/u2/a407726.pdf

Quote: British Aerospace Pamphlet, V/STOL in the Roaring Forties: 75 days in the South Atlantic (Titchfield, England: Polygraphic Limited. 1982), 16.

No cats and flaps... back to F35B?

29th Mar 2012, 10:38 #303

Quote [elsewhere]: 'but would we have been better off in the Falklands with a squadron of Buccs and and one of F4s?' | John Farley answers:

"Of course. But only if they could have been operated. The Wx down there [South Atlantic] was grim especially the vis and flying up a line of floating flares until you get to the ship is not something a Bucc or F4 pilot would want to do. Over and over sens-ible people seem to ignore the incredible value of being able to slow right down when landing. Unless you have tried it perhaps you cannot grasp how (relatively) relaxed this makes you feel even if you literally have ony two minutes fuel. (Just think how bored you are watching somebody near you sit in a hover for two minutes).

Not wishing to flog a dead horse but one night I was doing visual circuits round Foch with a French naval aviator in a civil reg two seater (no HUD or stabs) somewhere in the Bay of Biscay. We got to landing fuel but I succumbed to the plea for one more circuit. On the downwind leg the ship vanished. They called to say they had driven into a patch of low stratus and could not see the masthead light from the deck. I asked for a radar line up and ranges every half mile and told my French mate not to let me go be-low 100 ft. I kept slowing down and gingerly stepping down on the VSI and altimeter until we found the ship about one length astern. After landing I bollocked said mate for not mentioning we were now below 100ft.

Honestly, ship motion and vis that would rule out an arrested landing are not of concern if you can hover."

http://www.pprune.org/military-aircrew/478767-no-cats-flaps-back-f35b-16.html

Flying the Sea Harrier: a test pilot's perspective

20 Apr 2009 Peter Collins, Flight International

"Royal Navy Cdr Nigel "Sharkey" Ward and the Royal Air Force's David Morgan gained their place in British military folklore by flying the navy's British Aerospace Sea Harrier FRS1 fighter with distinction during the 1982 Falklands War. Flight International's UK test pilot Peter Collins offers a rare insight on flying the "SHAR", having sailed south aboard the rapidly completed aircraft carrier HMS Illustrious as the combat action drew to a close.

Freshly posted to Germany as an RAF Harrier GR3 ground-attack pilot, Collins was recalled to the UK after the war broke out and diverted to the Fleet Air Arm for a short tour flying the Sea Harrier. Type conversion was con-ducted with 899 NAS at RNAS Yeovilton in Somerset between June and July 1982. "My first memory is of my first FRS1 familiarisation flight, including 'Ski Jump' launch," says Collins. "The FRS1 cockpit wasn't like the GR3's at all, with the engine and critical aircraft systems instrumentation on the left [rather than the right], to allow space for the Blue Fox radar display. There was no Sea Harrier T-Bird [two-seat trainer] and no simulator training; just a quick cockpit self-assessment in the last FRS1 left in the UK. And then go: taxi up to the very bottom of the ramp, gaze upwards at what looked like Mount Snowdon (the ramp was set at the maximum angle of around 18°), remember some words of wisdom from somewhere, pause, slam the throttle, depart the lip, take nozzles and fly away. Piece of cake!"

Collins then moved aboard HMS Illustrious – aka "Lusty" – with 809 NAS for the voyage to the South Atlantic. The vessel arrived in the Falkland Islands Protection Zone in late August, with its SHARs flying combat air patrol sorties to plug a gap until a new landing strip could be completed for the RAF. Recalling one experience, Collins says: "It was a perfect day, but Lusty was heaving in a massive swell and the flight deck was pitching through 6°. I manoeuvred into my launch position while Flyco [Flying Co-ordination] had a think about it. Through my forward canopy the entire world alternated from completely bright blue to completely bright green (the sea was alive with plankton) as the ship pitched through more angles than I had ever seen before. Refusing the launch is mutiny: it has to be done by the pilot slamming the throttle as the deck starts to pitch down. Thankfully Flyco scrubbed the launch!" Illustrious returned home after two months of duty, with Collins having logged a total of 66 deck landings. "I am immensely proud of my short time with the Fleet Air Arm," says Collins. "I wish them every continued success as a uniquely professional element of our fighting services."

http://www.flightglobal.com/articles/2009/04/20/325254/flying-the-sea-harrier-a-test-pilots-perspective.html

Corbett Paper No 13

The interoperability of future UK air power, afloat and ashore: a historical analysis

Jan 2014 Tim Benbow and James Bosbotinis

"...18 May [1982]: Four Harrier GR3s cross-decked from Atlantic Conveyor to Hermes (the other two aircraft were unserviceable and joined Hermes subsequently). On 19 May, four additional Harrier GR3s deployed to Hermes with the aid of air-to-air refuelling, bringing the number of Harriers aboard Hermes to ten, alongside 14 Sea Harriers.

Three of the pilots from 1(F) Squadron had prior experience of landing on ship; Squadron Leaders Bob Iveson, Peter Harris and Tim Smith had previous experience via the US Marine Corps. The Squadron had prior to its deployment undertaken some ski jump training at Royal Naval Air Station Yeovilton and, whilst embarked on Atlantic Conveyor, joint ground training with personnel from 809 NAS.

For the most part, no major problems were encountered with integrating 1(F) Squadron aboard HMS Hermes. This was because the Squadron:

> ...joined a well-founded **airfield** [?] that was experienced in the safe operation of Harriers in poor weather and with a fully worked up Air Department optimised for the environment. They were supported and trained by the existing carrier system. They also had the benefit of dovetailing with the RN's 800 Sqn, who provided deck briefings and an intensive work-up package. Their minds were firmly focussed upon the dangers of operating from a ship.

http://www.kcl.ac.uk/sspp/departments/dsd/research/researchgroups/corbett/corbettpaper13.pdf http://i842.photobucket.com/albums/zz349/ontheroger/jump2.jpg

“I was TAD from VS-32 to FOF-3 as the S-3 (Viking) Liaison Officer. We didn’t get into Vestfjord, but Airops just outside were quite colorful. Watching a SHAR mis-time his roll and fly through a wave (totally, and I mean totally, submerged) after he jumped off that pointy-end ramp thing-a-majingy was quite an experience. Especially when Wings (their Airboss/CAG equivalent) turned and looked up at me, stogie belching, and remarked:

“Well Yak, that’s gonna f!€k up the bloody corrosion effort!” Old Phantom driver he was.”

http://www.neptunuslex.com/2010/12/15/final-flight/comment-page-1/#comment-663784

Old Hairier Driver Retort:

“1) you can't "mis-time" to that extent.
2) a Sea Harrier flying through water is impossible
3) if a Sea Harrier was still on the ski-jump as the wave broke over the bow it might look spectacular, but the aeroplane would still be primarily in the air and going upwards relative to the surface.”

Flying the Sea Harrier: a test pilot's perspective By Peter Collins, Flight International 20/04/09

http://www.flightglobal.com/articles/2009/04/20/325254/flying-the-sea-harrier-a-test-pilots-perspective.html

"Royal Navy Cdr Nigel "Sharkey" Ward and the Royal Air Force's David Morgan gained their place in British military folklore by flying the navy's British Aerospace Sea Harrier FRS1 fighter with distinction during the 1982 Falklands War. Flight International's UK test pilot Peter Collins offers a rare insight on flying the "SHAR", having sailed south aboard the rapidly completed aircraft carrier HMS Illustrious as the combat action drew to a close.

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‘Initiation into the Ski-Jump Club’

The Harrier Development Story

John Farley OBE AFC CEng 02 May 2000

“...In 1977 ski jump trials were carried out, initially from a land-based ramp that was adjustable from a 6 to 20 degree exit angle. This showed great improvements were possible with regard to performance, handing, safety and ship pitch motion limits when compared to flat deck ship STO's....”

http://www.harrier.org.uk/history/history_farley.htm

RAE Bedford adjustable ramp

RAF GR3 Pre-Falklands War Work Up 1982

http://www.rafmuseum.org.uk.nyud.net/documents/Research/RAF-Historical-Society-Journals/Journal-35A-Seminar-the-RAF-Harrier-Story.pdf

Run & Jump!

Aircraft ski jumps interested the military for two reasons. The Air Force and Marines wanted a way for aircraft to operate from the short stretches of runway remaining after airfield bombing attacks. The Navy and Marines wanted a way to reduce the length of carrier flight deck needed for an aircraft to become airborne—without the aid of a catapult. The Air Force decided not to use ski jumps, but the Navy proceeded with the idea. During the late 1970s and early 1980s, the Naval Air Test Center (NATC) performed ski jump tests at NAS Patuxent River using the T-2, F-14, F/A-18, and AV-8 Harrier.

The Marine Corps tested an instrumented AV-8B Harrier II on the Spanish aircraft carrier Príncipe de Asturias *(R-11) in December 1988. Then-Major Art Nalls, USMC, reported a Harrier at its maximum weight could takeoff in 400 feet instead of 750 feet on a flat deck.*

However, the ski-jump design has drawbacks: the forward part of the flight deck is no longer available for parking aircraft and there is less space available for moving aircraft around on the already crowded carrier deck. In addition, the upward push of the ski jump also means that aircraft structures may need to be stronger to bear the extra launch loads. This could lead to aircraft that weigh—and cost—more.

Ski Jump Testing at Pax River

The T-2 Buckeye flew 112 ski jump takeoffs in July of 1980. Takeoff distances were reduced by than more than 50% using ramp angles of 6 and 9 degrees.

The Grumman F-14 Tomcat flew 28 times from a ski jump at NAS Patuxent River in 1982, but never achieved maximum takeoff capability because of single-engine operating concerns.

http://api.ning.com/files/xEh6B1KdSWQzOLt*6ObkI-o0BM3q-SWX-dPNkEiSNU4zPiQadlI1LZc25fyGf9FsagaZJyoSrzjuoPESusZ4iYKXtOXO6wOC/KneeboardWinter2014reduced.pdf

Flight tests showed that the basic theory was sound: all aircraft tested took off in significantly shorter distances than they could from flat decks. But except for the AV-8 Harrier, none of these aircraft ever flew from ski-jump-equipped carriers.

The F-35B VSTOL (Vertical/Short Take-Off & Landing) version of the Lightning II Joint Strike Fighter (JSF) will soon take its turn on a new ski jump at NAS Patuxent River. These tests will support the Marine Corps and JSF partner nations Great Britain and Italy, which operate carriers designed with ski jumps.

The Harrier ski jump at NAS Patuxent River as seen from the air (left). The Harrier is seen leaving the ski jump from a head-on position (center). Cameras mounted underneath the Harrier's fuselage provided close-up views of how the landing gear behaved during launches off of the ski ramp (right).

The McDonnell F/A-18A first flew from a ski jump on 26 September 1983. It flew 91 ski jump tests at ramp angles of 6- and 9-degrees and achieved takeoff distance reductions of 66%.

The McDonnell Douglas AV-8 Harrier was tested on a 12-degree ski jump for suitability on small-deck carriers in July 1979. It was flown by Capt. Russ Stromberg, USMC.

http://api.ning.com/files/xEh6B1KdSWQzOLt*6ObkI-o0BM3q-SWX-dPNkEiSNU4zPiQadlI1LZc25fyGf9FsagaZJyoSrzjuoPESusZ4iYKXtOXO6wOC/KneeboardWinter2014reduced.pdf

http://upload.wikimedia.org/wikipedia/commons/d/de/YAV-8B_Harrier_testing_a_ski_jump.jpg

Operation Ski Jump was the test taking off of a Marine Corps YAV-8B Harrier aircraft, from a specially built ramp was constructed by the Bridge Co., 8th Engineer Support Bn., 2nd Mar. Div., Fleet Marine Force, Camp Lejeune, N.C. Location: NAVAL AIR STATION PATUXENT RIVER, MARYLAND (MD) UNITED STATES OF AMERICA (USA)
Date Shot: 1 Jul 1979

"...The important difference between a ski jump and a flat deck is that the heavier the aircraft, and the higher the wind over the deck, the greater the advantage of using a ski jump.

The aircraft takeoff performance was so dramatically improved that the heaviest Harrier ever flown from any ship – 31,000 pounds gross weight – was launched from Asturias with only a 400-foot deck run. The 31,000 pounds equals the maximum gross weight capability of the AV-8B. To put this In perspective. a "typical" AV-8B with a close air support ordnance load of full fuel, full water, guns, and 12 MK-82 bombs would weigh only about 29,000 pounds. On a typical 59-degree Fahrenheit day, with 35-knot winds over the deck, this load could be launched from a 300-foot deck run with a 12-degree ski jump. The same ordnance load would require the entire 750-foot flight deck of an LHA...."
Harrier Operations on a Ski Jump by Major Art Nalls, USMC, Naval Aviation News, May – June 1990

http://www.history.navy.mil/nan/backissues/1990s/1990/mj90.pdf

USMC tests Ski-Jump

INITIAL Ski-Jump trials by the US Marine Corps have been completed successfully using a British Aerospace AV-8A Harrier. Fairey Engineering delivered the ramp, which was ordered in February, to the US Naval Air Test Centre at Patuxent River, Maryland. Ramp angle for the trials was 12°. USMC Capt Russ Stromberg flew the AV-8A, carrying out an initial conventional take-off for comparison with the Ski-Jump launch. Using the ramp reduced the take-off run from 900ft to 370ft but "since it was the first time, I did not push the plane or the distance might have been shorter," Stromberg added.

The ramp was assembled at Pax River by 30 Marines working with advisors from the British company. Construction took 18 hours, but the use of pre-assembled sections would reduce this to four hours in the field. The ramp surface consists of three Medium Girder Bridge single storey girders supporting standard deck units with outriggers to increase overall width from 12ft to 34ft. In the field the ramp approach would also be made of deck units, eliminating the time needed to pour and set concrete. The Ski-Jump components can be air-lifted by helicopter.

The Fairey Engineering ramp was demonstrated at 15° at the 1978 Farnborough Show and later bought by the Marine Corps for more than £50,000 (see *Flight* March 3, page 618).

At the higher ramp angle Harrier endurance can increase 50 per cent.

http://books.google.com.au/books?id=-UT7MDTeKj8C&pg=PA357&lpg=PA357&dq=Patuxent+River+Ski+Jump&source=bl&ots=HTfeZRBxNa&sig=LYp-2F86BiMUdtERatZmZQ4vv7Q&hl=en&ei=iHBsTOauHYPJcfO7yXA&sa=X&oi=book_result&ct=result&resnum=2&ved=0CBcQ6AEwATgK#v=onepage&q=Patuxent%20River%20Ski%20Jump&f=false

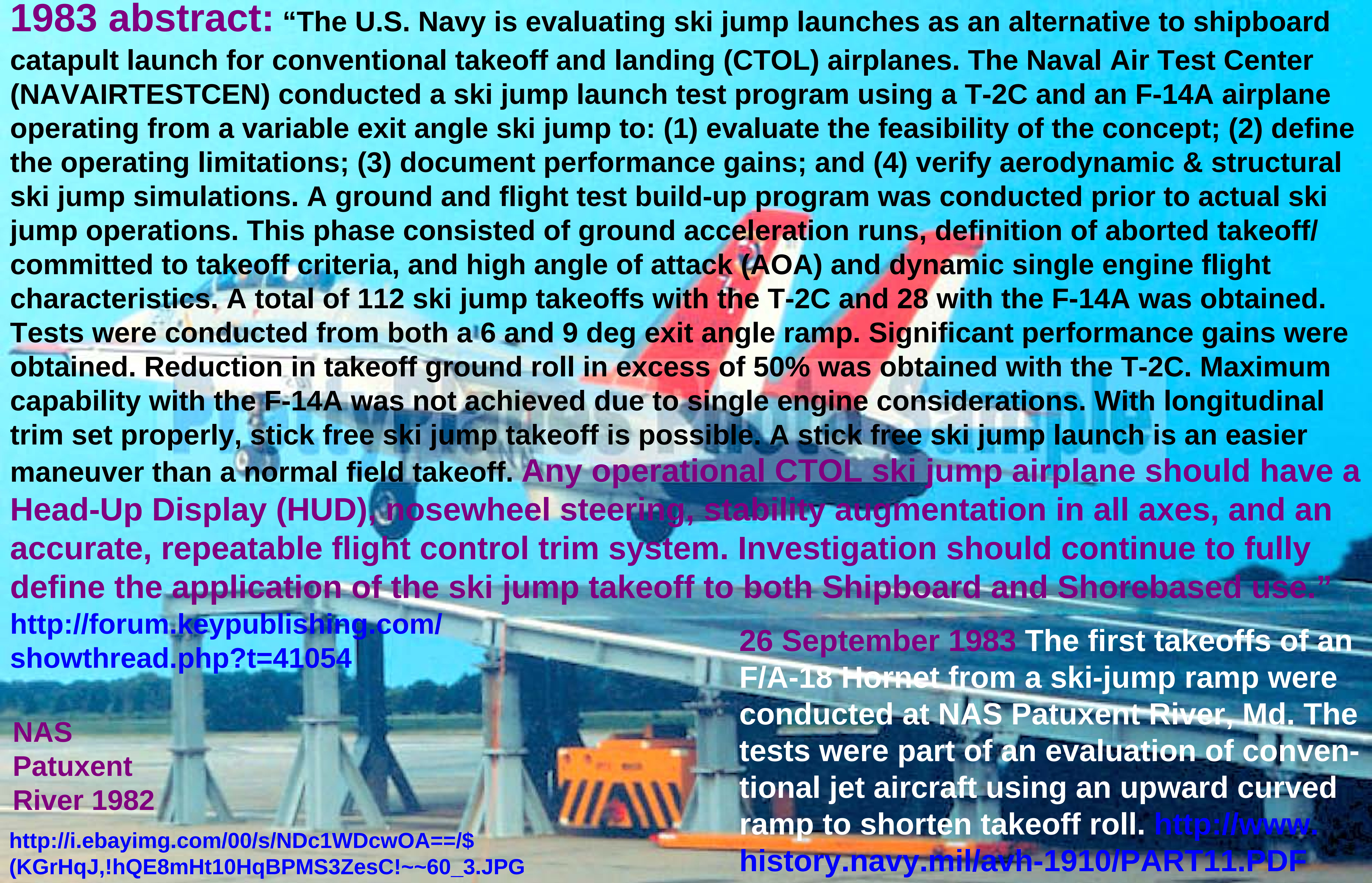
The design of a sea control ship was an attempt to develop an inexpensive ASW carrier, but proponents were never able to convince Congress that the ship would have a worthwhile role. The VSS design that followed was similar in outline but longer, with Harpoon cannisters on the fantail, twin propellers, and a deck-edge elevator. A modified SCS with a British "ski-jump" ramp incorporated in the bow was launched in May 1982 in Spain.

central issue is vulnerability. No small ship is likely to be survivable as a large one. However, in the face of nuclear weapons, any one of which can destroy even a large carrier, it can be argued that the VSS force can preserve a larger fraction of its air power against a given level of attack. It is also often argued that, given their independence from catapults and arresting gear, VSTOL aircraft aboard a large carrier can greatly reduce that ship's vulnerability to disabling damage from conventional hits.

Proposals were repeatedly made for VSS construction. For example, the Congress almost funded conversion of a helicopter carrier to an SCS in FY 79. The Senate Armed Services Committee added $40 million for such a conversion and $25 million for the design of a new type of VSTOL carrier, as well as $70 million for long-lead items for a sixth LHA (see chapter 17) to more than replace the LPH withdrawn for SCS duty. All of these items were deleted from the FY 79 bill finally passed after President Carter vetoed the original version (which had included a large-deck nuclear carrier). However, interest in limited carriers persists, some proponents of large-deck ships wanting medium-capability carriers of about 40,000 tons in addition. For example, in the fall of 1978 Rear Admiral George Jessen of the Naval Air Systems Command pointed out that modern jet fighters had such high thrust-to-weight ratios that they, like the VSTOLs, would benefit from ski-jump takeoff—thus catapults might be dispensed with (or at least considerably reduced in size and power) aboard a sufficiently fast (for wind-over-deck), long carrier. Tests of this concept began in 1982 at Patuxent River with T-2J and F-14 aircraft. See Next Pages for 1980 start date

In FY 82 testimony, navy representatives reported that a VSS III (a hardened VSS) was well-enough advanced for translation to contract design, but that the more exotic light (40,000 tons) ski-jump carrier would not be at the same stage until about 1985.

U.S. aircraft carriers: an illustrated design history By Norman Friedman



1983 abstract: **"The U.S. Navy is evaluating ski jump launches as an alternative to shipboard catapult launch for conventional takeoff and landing (CTOL) airplanes. The Naval Air Test Center (NAVAIRTESTCEN) conducted a ski jump launch test program using a T-2C and an F-14A airplane operating from a variable exit angle ski jump to: (1) evaluate the feasibility of the concept; (2) define the operating limitations; (3) document performance gains; and (4) verify aerodynamic & structural ski jump simulations. A ground and flight test build-up program was conducted prior to actual ski jump operations. This phase consisted of ground acceleration runs, definition of aborted takeoff/ committed to takeoff criteria, and high angle of attack (AOA) and dynamic single engine flight characteristics. A total of 112 ski jump takeoffs with the T-2C and 28 with the F-14A was obtained. Tests were conducted from both a 6 and 9 deg exit angle ramp. Significant performance gains were obtained. Reduction in takeoff ground roll in excess of 50% was obtained with the T-2C. Maximum capability with the F-14A was not achieved due to single engine considerations. With longitudinal trim set properly, stick free ski jump takeoff is possible. A stick free ski jump launch is an easier maneuver than a normal field takeoff. Any operational CTOL ski jump airplane should have a Head-Up Display (HUD), nosewheel steering, stability augmentation in all axes, and an accurate, repeatable flight control trim system. Investigation should continue to fully define the application of the ski jump takeoff to both Shipboard and Shorebased use."**

http://forum.keypublishing.com/showthread.php?t=41054

26 September 1983 The first takeoffs of an F/A-18 Hornet from a ski-jump ramp were conducted at NAS Patuxent River, Md. The tests were part of an evaluation of conventional jet aircraft using an upward curved ramp to shorten takeoff roll. http://www.history.navy.mil/avh-1910/PART11.PDF

NAS Patuxent River 1982

http://i.ebayimg.com/00/s/NDc1WDcwOA==/$(KGrHqJ,!hQE8mHt10HqBPMS3ZesC!~~60_3.JPG

“The McDonnell F-/A-18A first flew from a ski jump on 26 Sep 1983. It flew 91 ski jump tests at ramp angles of 6- and 9-degrees and achieved takeoff distance reductions of 66%.”

http://defesa.forums-free.com/tejas-indiano-t164s50.html & http://ic.pics.livejournal.com/al_datr/31048754/728630/728630_original.jpg

NAVAIR

USN F/A-18 Hornet

New Light Combat Aircraft to be custom made for [INDIAN] NAVY by Leena Dubey 07/07/2010

http://www.stockwatch.in/new-light-combat-aircraft-be-custom-made-navy-27995

"The Light Combat Aircraft (LCA), now to be a part of the Indian Naval fleet India's first indigenous aircraft is all set to make its maiden flight this October.

The aircraft was first developed for the Indian Air force, and reworked on to then be included in the naval fleet. A new structural design was required to better able the aircraft to land and take off a carrier. The aircraft has been designed to take off at a distance of 200 meters with a ski jump and land at a distance of 90 meters. The aircraft will use avionic systems, flight controls, and a GE-F404 engine similar Indian Air Force Light Combat Aircrafts. However, the flight control technology will be redesigned in order to provide a greater reduction in landing approach speeds.

The aircraft will be deployed in 2015 alongside the aircraft carrier being built in the Cochin shipyard. The aircraft is scheduled to take systems integration tests, ground runs, taxi trials and eventually flights before it is deemed ready for deployment. The aircraft has been developed under the Aeronautics program of the Aeronautical Development Agency (ADA) and will use a U.S. made machine. It has been designed to make "ski jump" take offs and arrested landings on aircraft carriers.

Shore based test facility, at the naval air base in Goa, will rum simulated take offs and landing runs for the aircraft. Mr. Antony said that this facility is already being used to train pilots flying the MiG-29K fighter jets, bought from Russia, which are also to be deployed abroad aircraft carriers."

http://www.nhhs.org/src/nhsTimeline1980.htm

1980 July 31--A T-2C Buckeye was successfully launched from a fixed-angle, three-degree ski jump at Naval Air Test Center, Patuxent River, Maryland. This launch was the first part of feasibility demonstrations to evaluate the use of ramps for takeoffs by conventional, as opposed to V/STOL aircraft.

http://www.dtic.mil/ndia/2007test/Fischer_SessionH4.pdf

26 September 1983

The first take-offs of an F/A-18 Hornet from a ski-jump ramp were conducted at Patuxent River

STOVL Air Power | The Ramps, Roads, and Speedbumps to Exploiting Maneuver Air Warfare Major Charles R. Myers, 01 April 1996

"Amphibious Ships http://www.dtic.mil/dtic/tr/fulltext/u2/a527872.pdf (50 Kb) Page 7

The most significant contribution that the Navy could make to STOVL air and helicopter-borne power projection is adding a ramp (ski jump) to all Tarawa- and Wasp-class amphibious assault ships. The technology is proven and for return on investment relatively inexpensive. A ramp not only improves dramatically a STOVL aircraft's takeoff performance, it facilitates concurrent fixed- and rotary-wing operations afloat. Of all countries that operate STOVL aircraft (the United States has more STOVL aircraft and ships to employ them than anyone) the United States is the only country without a ramp-equipped STOVL assault ship. Now is the time for ramps...."

& on page 9: "...The skeptics insist that ramps will displace landing spots. Tests prove otherwise. On a 12 degree ski jump approximately 150 feet long, the slope gradually increases from zero up to 12 degrees at the bow. The first half of the ski jump has a slope no greater than that of an LHA during wet-well operations with the well-deck flooded – both Harriers and helicopters can land on it...." [Major Art Nalls, USMC, "Why Don't We Have Any Ski Jumps," U.S. Naval Institute Proceedings, November 1990, 81.]

The ramp not only bolsters a STOVL aircraft's combat payload to its maximum and enhances fixed- and rotary-wing interoperability, it provides a margin of safety to the pilot in emergency situations. The upward vector off the bow offers the pilot extra precious seconds to handle takeoff emergencies and an expanded ejection envelope if required. The price of one saved STOVL aircraft, and potentially the pilot's life, would probably fund several ramps on amphibious ships. The Navy and Marine Corps need ski jumps on the big-deck amphibious ships...."

Harrier Operations on a Ski Jump

by Major Art Nalls, USMC, Naval Aviation News, May – June 1990

"In December 1988. a detachment from the Naval Air Test Center (NATC), Patuxcent River, Md., conducted a flight test program matching up a Spanish aircraft carrier, Principe de Asturias, and the U.S. Marine Corps AV-8B Harrier II vertica/short takeoff and landing attack aircraft. The flight test results were nothing short of amazing. Takeoff performance of the AV-8 was dramatically improved, as well as safety and the potential for true Harrier/helicopter interoperability. All of this was realized from a single device with no moving parts – the ski jump.

For Shipboard takeoffs, the AV-8 does not use a catapult like other conventional aircraft. The AV-8 pilot simply aligns the aircraft with the short takeoff line on the flight deck. On the launch officer's signal, he slams full power and accelerates. When he reaches the bow, the pilot rotates his four engine ex-haust nozzles downward. The combination of engine lift from the nozzles and wing lift allows the aircraft to fly. The amount of deck run is determined for each takeoff and varies primarily as a function of aircraft gross weight, wind over deck, and ambient temperature. The most limiting factor in Harrier takeoff gross weight capability is the deck run available. It is currently limited in U.S. amphibious ships to 750 feet on the Tarawa-class amphibious assault ship (LHA) and approximately 800 feet on the new Wasp-class multipurpose amphibious assault ship (LHD).

What makes this Spanish carrier so different from any U.S. ship is the additlon of an upwardly curving surface on the ship's bow, called a "ski jump." Based on an original U.S. design for sea control that was never constructed, Asturias was built in Spain and delivered to the Spanish Navy in May 1988. In December of that year, the United States was given the unique opportunity to perform, for the first time, a complete shipboard flight test program using instrumented AV-8Bs on an operational ski jump up to the gross weight limits of the AV-8B.

Ski jump operations are not entirely new. Since the mid-1970s, the British have routinely employed ski jumps on their Harrier carriers. but they fly the Sea Harrier, which is a variant limited to roughly 25,000 pounds gross weight. NATC also performed a brief flight test evaluation of the YAV-8B on a land-based ski jump in the late seventies, but a land-based ski jump is limited to the ambient winds (low wind over deck) and the YAV-8B was basically an AV-8A with an AV-8B wing and was still limited to 23,000 pounds gross weight. These operations were far too limited in maximum gross weight and wind over the deck, which are where the real advantages of the ski jump become apparent.

For years, it was thought that

the performance improvements in the AV-8B were so substantial over the AV-8A that a ski jump was unnecessary. It's true that the AV-8B clearly out performs the -A, but the aerodynamic improvements that make the AV-8B superior also make it ideally suited for ski jump operations: excellent slow-speed handling qualities, rapid acceleration, and improved vertical/short takeoff and landing capability. The important difference between a ski jump and a flat deck is that the heavier the aircraft, and the higher the wind over the deck, the greater the advantage of using a ski jump.

The aircraft takeoff performance was so dramatically improved that the heaviest Harrier ever flown from any ship – 31,000 pounds gross weight – was launched from Asturias with only a 400-foot deck run. The 31,000 pounds equals the maximum gross weight capability of the AV-8B. To put this In perspective. a "typical" AV-8B with a close air support ordnance load of full fuel, full water, guns, and 12 MK-82 bombs would weigh only about 29,000 pounds. On a typical 59-degree Fahrenheit day, with 35-knot winds over the deck, this load could be launched from a 300-foot deck run with a 12-degree ski jump. The same ordnance load would require the entire 750-foot flight deck of an LHA.

Any flight deck in front of a Harrier is unusable for any other flight ops until the AV-8 is airborne. On the other hand, any flight deck behind the Harrier can still be used for concurrent heIo/MV-22 Osprey operations. If the deck run can be shortened from 750 to 300 feet, a valuable 450 feet for concurrent flight ops is acquired – an important consideration in amphibious operations. For all practical purposes, the 820-foot flight deck of an LHD could be utilized like two completely separate ships – the front 400 feet for Harrier launches and recoveries, and the back for completety separate and concurrent helo/MV-22 ops.

Another important aspect of ski jump operations is the inherent safety over a flat deck launch, after which the aircraft is only 60 feet (height of the flight deck) above the water for the accelerating transition to airborne. With a ski jump, the Harrier ALWAYS has a positive rate of climb due to the incline of the ramp. The accelerating transition begins at approximately 150 to 200 feet, vice 60 feet [ASL]. This altitude cushion is a considerable increase in safety should the pilot encounter any emergency.

This NATC flight test program served to highlight the significant performance improvements in takeoff capability and safety that could be realized by the addition of a ski jump to our existing amphibious ships for the AV-8B. In fact, every navy in the world that operates Harrier carriers uses ski jumps, except one: the United States. Rarely before has such a dramatic increase in performance been achieved from a device with no moving parts."

http://www.history.navy.mil/nan/backissues/1990s/1990/mj90.pdf

Guests Visit HMS Illustrious, Get Sneak Preview of War Game 23 Jul 2007

John J. Kruzel, American Forces Press Service http://www.defense.gov/news/newsarticle.aspx?id=46816

“...brought the special guests and media members to HMS Illustrious to see the joint task force’s inner-workings as it prepares for the war game. On the flight deck, we watched as Marine aviators in Harrier jets readied to blast off the “ski jump.” Cutting through the deafening engines were British and American members of the flight line, working in concert to direct the assault aircrafts & speaking in hand signals.

As Harriers whizzed by spectators, then up and off the ramp, the engines bathed us in hot combusted jet fuel, which felt like sticking your face before a scalding oven and ripping the door open. Thickly-padded headphones couldn’t damper the lion’s roar of takeoff that rocked the flight deck and jostled onlookers’ viscera.

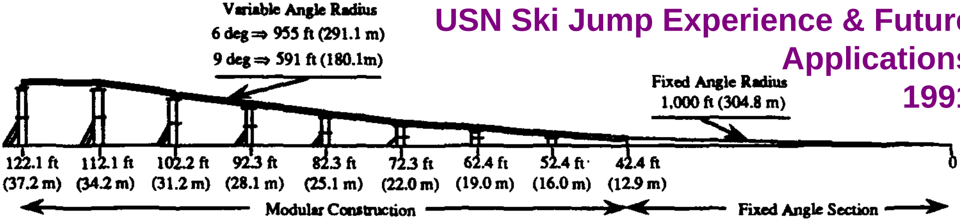
In stoic terms, Marine aviator Maj. Stephan Bradicich, of the Marine Attack Squadron 542 “Tigers” described the drama involved in taking off from the short runway. “When you’re flying off a ship like this and you’re looking 300 to 400 feet in front of you and then, all of a sudden, you’re dropping off the end of the boat, there’s a little apprehension,” he said. “But the kick in the butt when you throw the power in the corner is absolutely phenomenal in the Harrier. “Particularly with the ski jump on this ship,” he said. “When you hit the end of the boat you’re going up fast.”...”

"...[Art Nalls] was the project officer for the ski-jump testing aboard ship. The first ship was the Italian Navy Garibaldi, with a 6 deg ramp, designed specifically for Harriers. The ship must have been designed by someone who had never actually been aboard a fighting ship - centre deck elevators, centre hangar bay with passages round the outside, fuel lines running round the ship perimeter, no deck-edge scuppers and no lights – but it does look good! Anyway, we did the tests and provided the launch bulletin for them. The second ship was the Spanish Navy Principe de Asturias with a 12 deg ramp. This had a much better configuration being based on the unbuilt US designed Sea Control Ship sponsored by Admiral Zumwalt, USN.

The ski-jump so impressed me that I authored several technical papers and was a huge advocate for the USMC to push the USN to install it in our amphibious ships (LHDs). We could then use the single flight deck as essentially two runways; the helos launching from the stern, the Harriers from the bow. There is nothing that can be loaded on a Harrier that it can't take off with from 400 ft with 15 knots wind over deck – absolutely nothing – and the flight deck is 800 ft long on the LHDs. Doubled take off performance, increased inherent safety from the launch trajectory and no moving parts. Seemed like a no-brainer to me but the USN didn't want to jeopardise their big deck carriers. I even attempted to orchestrate a cross-deck operation with the Russian ski jump ship Tiblisi.

Towards the end of my flight testing career I conceived and got official approval to take a test team to Russia to explore the YAK-141 supersonic VSTOL fighter and to fly and report on the YAK-38 Forger. I was the first western TP to do this."

USN Ski Jump Experience & Future Applications 1991



9 Degree Ramp Depicted

Distance Along Ramp ft (m)	Ramp Height ft (m)		Distance Along Ramp ft (m)	Ramp Height ft (m)	
	6 deg	9 deg		6 deg	9 deg
0	0	0	82.3 (25.1)	3.88 (1.18)	4.40 (1.34)
42.4 (12.9)	1.16 (0.35)	1.16 (0.35)	92.3 (28.1)	4.81 (1.47)	5.62 (1.71)
52.4 (16.0)	1.68 (0.51)	1.71 (0.52)	102.2 (31.2)	5.85 (1.78)	7.02 (2.14)
62.4 (19.0)	2.30 (0.70)	2.44 (0.74)	112.1 (34.2)	5.85 (1.78)	8.58 (2.62)
72.3 (22.0)	3.03 (0.92)	3.33 (1.01)	122.1 (37.2)	---	8.58 (2.62)

Figure 10
Ski Jump General Arrangement

http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA244869&Location=U2&doc=GetTRDoc.pdf

AIRCRAFT OPERATIONS FROM RUNWAYS WITH INCLINED RAMPS (SKI-JUMP) 1991

http://handle.dtic.mil/100.2/ADA237265

Elijah W. Turner

ABSTRACT

The use of inclined ramps to launch aircraft from short runways is proposed as a possible solution to the runway denial problem in Europe. Past efforts to launch aircraft in this manner, including a very successful program conducted by the US Navy to launch the T-2C, F-14, and F-18 aircraft, are reviewed.

An analytical study was conducted for the launch of the F-16, F-15, A-10, A-7D and F-4E from inclined ramps. The takeoff ground roll, stabilizer trim setting, landing gear loads and flight trajectory are reported. The F-15 was selected as a candidate aircraft for a USAF flight test program to be patterned after the Navy program and additional studies were performed. Perturbations in center of gravity, thrust, and ramp exit angle were investigated.

A ramp contour was designed for launch of the F-15, F-16, A-7D and A-10 which minimized the length and height of the ramp while maintaining the landing gear loads below 90 percent of their design limit.

1.2 Ski-Jump Launch

The use of inclined ramps for launching aircraft has been recognized for some time. A NACA report in 1952 proposed the use of an inclined ramp on aircraft carrier decks to improve the takeoff performance of aircraft (Ref. 1). The ramp proposed in the 1952 report had a radius of curvature of 50 feet and a rise of 1.73 feet. Whereas fighter aircraft launched from a flat deck normally sink as much as 9 feet below the deck, analysis indicated that the addition of a ramp would eliminate the altitude loss.

In 1974 a British Commander wrote his masters thesis on launching the Harrier aircraft from inclined ramps (Ref. 2). This report started an effort that resulted in launch test of the Harrier from enclined ramps in 1977.

About the same time, the US Navy was considering a smaller class of aircraft carriers that would not use steam catapults to launch aircraft. This program generated an analytical effort in 1979 followed by a flight test program to launch the T2C, F-14, and F-18 aircraft from inclined ramps. A metal ramp was constructed that could be modified to give ramp exit angles of 3, 6, and 9 degrees. The ramp was 112.1 feet long and 8.58 feet high at the exit when configured for the 9 degree exit angle, measured from the horizontal. A total of 112 launches of the T-2C, 28 of the F-14, and 91 of the F/A-18 were made. The minimum ground roll for the F/A-18 was 385 feet at a gross weight of 32,800 lbs. This ramp effectively reduced the takeoff roll of the F-18 by more than 50 percent.

2.3 Ski-Jump Launch Criteria

When the Navy first considered using inclined ramps, the objective was to reduce or eliminate the aircraft sinking below the carrier flight deck after launch. This same criteria could not be applied to testing of the T-2C, F-14 and F-18 because they were launched from a ramp that began at ground level. Sinking below the flight deck would be equivalent to sinking below ground level. The criteria that was finally selected by the Navy were that there should be no loss of altitude. The aircraft leaves the ramp with a vertical velocity imparted by the upward contour of the ramp. The speed, however, is below the minimum level flight speed, so the aircraft is not able to maintain its upward velocity. The vertical velocity decreases as the aircraft accelerates and at some point the degradation is stopped. This results in no loss of altitude, and puts the aircraft in level flight at an altitude of 30 to 50 feet. Thereafter the aircraft accelerates upward. The successful launch criteria that were selected was to allow the aircraft to leave the ramp at the lowest speed for which the vertical velocity would degrade to a value no lower than zero.

WORLD NEWS

Ski-jump Harrier FLIGHT International, 20 November 1976

http://www.flightglobal.com/pdfarchive/view/1976/1976%20-%202666.html

Use of a curved ramp at the forward end of an aircraft carrier's flight deck could substantially improve the payload of jet V-Stol aircraft. So says Harrier chief designer John Fozard, who gave the Royal Aeronautical Society's R. J. Mitchell Memorial Lecture in Southampton on November 10. It would also bring handling and safety advantages, and could even improve the economics of the ship itself.

The concept was first advanced by Lt Cdr D. R. Taylor in a thesis written at Southampton University in 1973. It is based on the assumption that if the aircraft has enough thrust to accelerate in the initial upward trajectory produced by the ramp, the increased flight time would safely allow a lower launch speed and a lower lift/weight ratio. After building up airspeed all through the part-ballistic trajectory, the aircraft would be able to fly fully self-supported by the time it sunk back to launch height.

The most dramatic improvement, according to Fozard, takes the form of the shorter deck-run allowed by the greatly reduced launch speed. Applying the current Harrier payload trade-off of 66lb per knot of launch airspeed, he says that from a deck-run giving a lift-off speed of 60kt, a 20° Ski Jump would allow the aircraft to carry about 2,000lb more payload than it could at the same launch speed from the same length of flat deck.

From there it is calculated that, at sub-maximum launch weights, the ship need not steam at high speed in calm weather because the ramp would provide the equivalent of about 30kt wind over deck (WOD). Moreover, if the aircraft is lifting off on an upward trajectory of about 20°, it is effectively unaffected by the ship's pitching motion.

Ramps steeper than about 20° are unattractive for two reasons: performance gains start diminishing, and the aircraft on the ramp has to withstand greater undercarriage loads than normal. According to Fozard, if the Harrier's landing gear were not completely redesigned, incremental loading would have to be limited to about 0·5g. The time taken to traverse the Ski Jump is about ten times the design landing impact case for undercarriage struts.

In safety terms, the Ski Jump principle again provides more time for the pilot to jettison his stores or eject as a result of, for example, a failure of the nozzles to rotate on demand at the top of the ramp. There is in any case, according to Fozard, an excellent chance of the aircraft successfully completing the transition to wingborne flight with the nozzles fixed out.

A fuller appreciation of the principle will appear in an early issue.

May 1991

3. RESULTS - MULTIPLE AIRCRAFT

3.1 Ground Roll for 9 Degree Ramp

This analysis was performed to determine the reduction in ground roll for each aircraft from ski-jump launch and to compare the improvements from one aircraft to another. For each aircraft, three gross weights were selected to cover the practical operational range of each. The lightest gross weight was for a clean aircraft with a moderate fuel load as might be used for evacuating an airbase. The heaviest gross weight was representative of a moderate fuel and bomb load suitable for an attack mission. An intermediate gross weight was also evaluated to better define the trends. The ramp profile was the Navy Ramp at Patuxent River Naval Air Station in the 9 degree configuration. It was 138 feet long and 10.3 feet high at the exit.

3.3 Design of 9 Degree Optimum Ramp

The objective of this analysis was to determine a ramp contour that would permit the launch of all five Air Force aircraft at a combat gross weight without exceeding 90 percent design limit loads. Ramp length and height were minimized. The result was a ramp 178 feet long and 14.2 feet high at the exit. The ramp is steep at the beginning in order to raise the gear loads rapidly to near the 90 percent limit. The curvature is then decreased to prevent overshoot, followed by an increase to give the aircraft a high pitch rate at the exit. Figure 5 shows the gear loads from all five aircraft plotted against position on the ramp. Using this type of presentation, segments of the ramp were identified where the curvature could be increased (or decreased) in order to maintain the gear loads at a high level without exceeding the limit.

5. CONCLUSIONS

1. The F-16 and F-15 are candidate aircraft for ski-jump launch of Air Force aircraft. Reductions in the ground roll of more than 50 percent can be expected.

2. The F-4E aircraft can not be launched using the same piloting technique as the F-15 and F-16 aircraft. Forward stick will be required to arrest the aircraft pitch at the optimum attitude, thus requiring considerable piloting skills. It is improbable that the F-4E aircraft can be safely launched from a ski-jump.

3. A ski-jump ramp with a 9 degree exit angle, contoured so that the F-16, F-15, and A-7D aircraft at combat gross weights can be launched without exceeding 90 percent of design limit landing-gear loads, will be approximately 180 feet long and 14.4 feet high at the exit.

Using Simulation to Optimize Ski Jump Ramp Profiles for STOVL Aircraft

http://handle.dtic.mil/100.2/ADA378145

Introduction

Ramps have been used for many years aboard the Navy ships of many countries to reduce takeoff run distance and wind-over-deck (WOD) requirements, as well as to increase the aircraft takeoff gross weight capability over that of a flat deck carrier. Under the Joint Strike Fighter program, an effort has been funded to evaluate various ramp profiles and ramp performance optimization methodologies. Results of these evaluations will be used with an advanced STOVL aircraft to provide the maximum benefit to takeoff performance, while not becoming a design driver for landing gear or adversely affecting ship designs.

The Boeing AV-8B Harrier is a true STOVL aircraft, in that it routinely performs short takeoffs and vertical landings. This allows operations from ships not equipped with catapults or arresting gear and that are considerably smaller than the US large deck carriers. This unique capability is obtained through a group of variable angle nozzles for vectored lift and a reaction control system for stability and control, which uses engine bleed air to provide thrust through several small nozzles located on the aircraft.

Many foreign navies operate Harriers from ships equipped with smooth profile ramps. The US Navy has conducted many ship and shore-based tests of smooth and segmented (flat plate) ramp profiles over the years to demonstrate the performance advantages of a ramp-assisted takeoff. Much of this work serves as the basis for our research initiative.

Preliminary Work

The first step was to collect data from prior flight tests to validate the AV-8B landing gear model. The test data were incomplete because the test aircraft did not have sufficient instrumentation to measure gear/store loads and accelerations. Therefore, criteria were developed which enabled us to compare predicted gear load trends and instead of actual gear and structural loads.

<u>Preliminary Criteria for Ramp Optimization</u>

1. The landing gear shall not compress to full closure at any point during the takeoff. Harrier flight tests have been conducted to within ½ inch of full closure with no adverse results.
2. Investigate a segmented ramp versus a smooth profile ramp, and how it could be used with the existing structural and operational requirements of the aircraft. If so, what is the maximum angle change between segments that can be tolerated by the aircraft and aircrew?
3. Resonance effects from segmented ramps on landing gear and wing mounted stores are unknown, and efforts should be taken to break up or reduce these loads.

Preliminary Results

Preliminary simulation runs have been completed. Test results indicate that the segmented ramp concept shows great promise and could allow ship designers options in building retractable or reconfigurable ramp designs for future STOVL capable ships. Segmented ramp takeoff performance is not diminished as compared with a smooth ramp. Initial results indicate that segmented ramp profiles can be modified to keep the gear loads well within their structural limits. Since the velocity of the aircraft remains fairly constant while it is on the ramp, an equally distributed (same length) segment pattern generates a recurring load on the landing gear at each joint. If the frequency of these inputs is close to the natural frequency of the gear, or transmitted through the aircraft structure to a wing store, a resonance condition could be excited. This will be investigated at in more detail in the coming months.

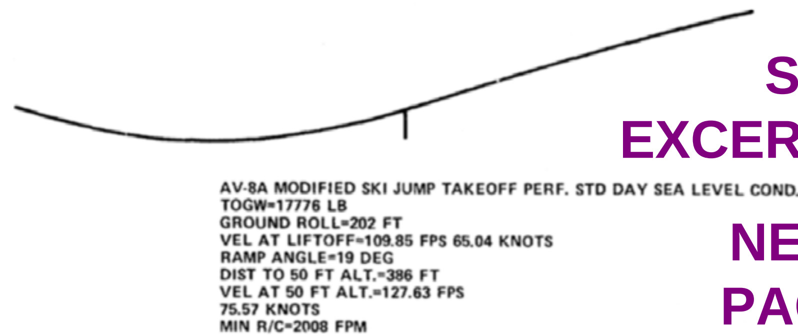
Preliminary Conclusions

The smooth and segmented ramp profiles have demonstrated significant performance gains over a field or flat deck ship takeoff. Work will continue over the next several months to expand and refine the optimization criteria and investigate various ramp profiles and quantify their benefit to aircraft performance.

Ski Jump Takeoff Profile with Limited Takeoff Roll

	End-to-End MGB Ramp			Conventional Ramp		
TOGW (lb)	18,374	18,604	19,304	18,374	18,604	19,304
Liftoff Distance (ft)	260	260	260	282	279	292
Ramp Exit Velocity (knots)	70.2	70.5	69.4	71	70	71
Distance to 50-ft Alt. (ft)	482	480	495	502	501	521
Min. R/C (ft-min)/Distance to Min. R/C (ft)	833/700	877/701	589/703	1,146/-	1,135/-	1,051/-

SHORT TAKEOFF PERFORMANCE USING A GRAVITY ASSIST SKI JUMP



Modified Ski Jump with Initial Downhill Slope Extended

SEE EXCERPT NEXT PAGE →

CONCLUSIONS

A modified or gravity assist ski jump ramp shape was generated through an application of the calculus of variations. The modified shape employs an initial down run which takes advantage of gravity to maximize acceleration and energy at the beginning of the takeoff.

The gravity assist ramp provided for considerable improvement in AV-8A takeoff performance over what could be achieved with the conventional ski jump. The ground roll was reduced by up to 30 percent and the distance required to climb to a 50-ft altitude was reduced by up to 20 percent while providing the same liftoff velocity and maintaining better than the recommended minimum rate of climb.

http://handle.dtic.mil/100.2/ADA126456

Short Takeoff Performance Using a Gravity Assist Ski Jump

http://www.dtic.mil/dtic/tr/fulltext/u2/a126456.pdf (1Mb) by Roger J. Furey 1983 March

"ABSTRACT: A modified or gravity assist ski jump is developed, through an application of the calculus of variations, to provide for the shortest takeoff roll for a thrust vector control type vertical or short takeoff and landing (V/STOL) aircraft that will maintain a better-than-minimum required rate of climb. As a means of comparison between the resulting modified and a conventional ski jump, the equations of motion are programed to model the takeoff performancer using a ski jump. The results of this model are found to compare well with Naval Air Test Center ski jump test results of the AV-8A aircraft. A comparison of the standard and gravity assist ski jump shows a reduction of 30 percent in required ground roll and 20 percent in distance to a 50-ft altitude, while maintaining a better-than-minimum required rate of climb, with the modified ramp. A simple modified ramp, using a pair of standard multiple girder bridging (MGB) ramps, is shown to provide similar improvements in takeoff performance."...

&

"...While the performance benefits to be gained through the use of the ski jump have been demonstrated, it seems reasonable that, as in the case of an actual skier, an assist from gravity in the initial downhill run prior to the ramp entry would provide for greater initial acceleration and thereby further performance gains. The current report is an effort to determine what the ski jump shape should be in order to provide for a maximum payload with the shortest takeoff roll. The payoff would include smaller ships platforms from which such aircraft could operate...."

CONCLUSIONS

"...The purpose of this report has been to present results which are necessarily preliminary in the sense that a limited number of variables have been evaluated. Although such an arrangement of ski jump ramps may be physically challenging, the challenge is no greater than the single ski jump ramp first presented...." EXCERPTS from Previous Page PDF (on the right hand side of the page)

CARRIER SUITABILITY OF LAND-BASED AIRCRAFT

José-Luis Hernando and Rodrigo Martínez-Val Universidad Politécnica de Madrid http://www.icas.org/ICAS_ARCHIVE/ICAS2012/PAPERS/167.PDF

"Abstract

The paper describes the first steps of a study aimed at assessing the modifications that should be introduced in ground-based combat airplanes to make them compatible with aircraft carriers designed with ski-jumps & arresting devices. The present analysis includes operational and performance aspects, & describes the complexity of the take-off and approach/landing manoeuvres, identifying the key variables intervening in such manoeuvres. A last section is devoted to summarise the most critical features for carrier suitability....

...4 Final considerations

The present paper has described the take-off and approach/landing manoeuvres, as they are performed on aircraft carriers equipped with ski-jumps and arresting mechanisms. The operations are very different from those on ordinary runways, for the size and longitudinal motion of the deck, for the pitch and heave displacements of the carrier, and for the potential interference between the carrier superstructure wake or the rough sea generated air turbulence and the approach glide path. The findings include the following critical items:

- The thrust-to-weight ratio at take-off must be appropriately matched to the available deck length & the ski-jump geometry, including wind-on-deck effects;
- The approach speed must be compatible with wind-on-deck & the available landing distance to completely stop the airplane after engaging the last arresting pendant;
- The thrust-to-weight ratio at approach must be high enough as to allow fast acceleration and safe lift-off should the airplane hook failing engaging the arresting pendants.

Obviously, since the present paper only describes the first steps of the study there are other important aspects that will be addressed in future works. They include, for example:

- Very fast control to give the pilot full authority on the aircraft after the semi ballistic jump at the end of a hands-off take-off;
- Suitable aircraft attitude during ground runs, that may require meaningful modifications of the nose landing gear; and
- Rear fuselage modifications to fit the arresting hook, as well as structural reinforcements to withstand the hook transmitted loads."

Ski-jump take-off for light combat aircraft Tejas

http://www.dnaindia.com/india/report_ski-jump-take-off-for-light-combat-aircraft-tejas_1401783

"Bangalore: The Naval Air Station in Goa is quietly readying a first-of-its-kind facility in India for flight tests on the light combat aircraft (LCA) Tejas naval variant. The shore-based test facility (SBTF), when fully-operational, will be the third such test facility in the world after the US and Ukrainian navies. "After the initial flight tests, we will shift all action to SBTF. The ramp for the take-off area will be ready by the last quarter of 2011 and the landing area in 2012. A full-fledged telemetry unit is also coming up in Goa," sources in the Indian Navy told DNA.

The sources said the SBTF simulates an aircraft carrier with ski-jump take-off and arrested recovery landing wherein the incoming aircraft is brought to a standstill after touchdown when a hook attached to its underbelly engages a taut arrester wire placed across the landing path. "It's recreating a ship on the shore. The one that's coming up in Goa is based on the Indigenous Aircraft Carrier (IAC) that's being built at Cochin Shipyard. The SBTF is constructed with the same measurements of IAC," sources said. All the specialised equipment for the facility is being supplied by the Russians, while the steel structure is being made by Goa Shipyard and civil engineering work by R&D Establishment (Engineers) in Pune."

by Anantha Krishnan M / DNA June 27, 2010

Small Leap for LCA (Navy) - A Giant Leap for Indian Naval Aviation 01 Jan 2015 HH/RAJ

http://www.noodls.com/view/51E4C1A2CD76E831735242503B6F94ED5785861F?1861xxx1420153489#sthash.HBWAQM8C.dpuf

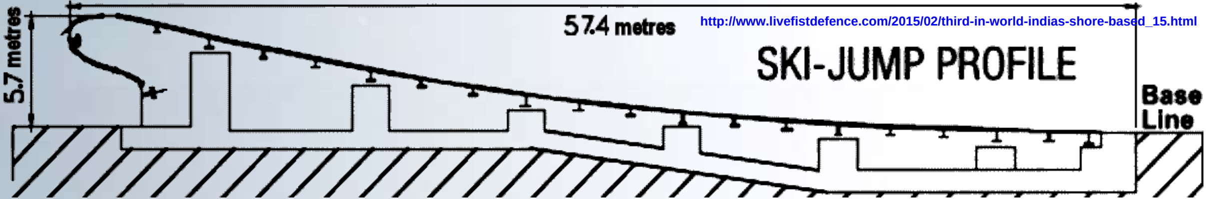
"It was a defining moment when LCA (Navy) Prototype 1 (NP1), the first indigenously designed and developed 4th plus generation combat aircraft designed to operate from the decks of air-craft carriers, took-off majestically from Ski-Jump facility of Shore Based Test Facility at INS Hansa in Goa yesterday. Piloted by Commodore Jaideep Maolankar, the Chief Test Pilot of National Flight Test Centre, the aircraft had a perfect flight with results matching the predicted ones to the letter. The launch was orchestrated by the Test Director Cdr J D Raturi and Safety Pilot Capt Shivnath Dahiya supported by GpCapt Anoop Kabadwal, GpCapt RR Tyagi and Lt Cdr Vivek Pandey. The readiness and availability of aircraft for the event was made possible through the relentless effort of HAL, ARDC under the aegis of Mr P S Roy the Executive Director.

Dr Avinash Chander, SA to RM, Secretary DDR&D DG DRDO congratulated the LCA Navy program team and said, "With today's copybook flight of LCA-Navy from the land based ski-jump facility we see our own indigenous combat aircrafts soon flying from the decks of our aircraft carriers." Congratulating the team Dr Tamilmani, DS & DG Aeronautics, said "A complex task of Ski Jump of NP1 Executed beautifully".

LCA (Navy) is designed with stronger landing gears to absorb forces exerted by the ski jump ramp during take-off, to be airborne within 200 m as against 1000m required for normal runways. It's special flight control law mode allows hands-free take-off relieving the pilot workload, as the aircraft leaps from the ramp and automatically puts the aircraft in an ascending trajectory. The maiden successful, picture perfect launch of NP1 from ski jump at Shore Based Test Facility at Goa is a testimony to the tremendous efforts put in by scientists and engineers to design the Naval aircraft, its simulator (that helps pilots to know well in advance how the aircraft will behave on ski jump) and the flight test team that timed the whole event to near perfection. It can be stated with conviction "The indigenous Indian Naval Carrier Borne Aviation program has been launched, literally from the Ski-Jump"

The LCA Navy program team of ADA (Aeronautical Development Agency) is jubilant on achieving the remarkable feat that is the culmination of several years of design, flight test, simulation and management effort with significant contributions from a number of DRDO laboratories. The teams were ably supported by the certification agency, CEMILAC and the quality assurance agency, CRI (LCA). INS Hansa, the Naval Air Station played the perfect host to achieve this significant milestone. The design teams guided by Program Director ADA Shri P S Subramanyam have ensured that all systems meet the stringent requirements of Carrier borne aircraft. Cmde C D Balaji (Retd) as Project Director LCA (Navy) and it's Chief Designer has been at the helm of affairs right from the concept phase. The team led by Dr Amitabh Saraf indigenously achieved the flight control laws that take care of the problems encountered by a fly by wire aircraft undertaking a Ski Jump Launch.

The Shore Based Test Facility (SBTF) has been created to replicate the aircraft carrier with a Ski Jump for take-off and arresting gear cable for arrested landing; by ADA with the participation of the Indian Navy, Goa shipyard, CCE (R&D) West, Pune, R&D Engg (E) Pune and the Russian agencies providing the design support and specialized equipment."



"The SBTF's 57 x 16 metre ski-jump is parabolic and assembled at a 14-degree angle, constructed using steel, concrete and a 10mm steel plate on top. The ski-jump tops off at 5.71 metres at the launch point."

"...ADA says the AoA (Angle of Attack) after ramp exit reached 21.6 degrees... For a ski-jump launch, the final design intent is to have a zero rate of climb after ramp exit to get the best performance of the aircraft," says Balaji...." http://tejas.gov.in/IOC-Brochure.pdf

http://2.bp.blogspot.com/-9JwDXoUjrO0/VOCXZLF42dI/AAAAAAAAYHc/QFLEAvjQ3Oo/s1600/sbtf1.jpg

"The Indian SBTF, a replica of 'Nitka', will be equipped with a 14 degree ski-jump located at the end of a taxi-track, on a 150 foot high cliff overlooking the sea." http://www.vayuaerospace.in/images1/The_LCA-NAVY.pdf

LCA Navy Maiden Ski Jump Details & Analysis 21 Dec 2014 http://defesa.forums-free.com/tejas-indiano-t164s60.html

"LCA Navy's maiden ski jump take-off at SBTF at INS Hansa on December 20, 2014 was a milestone event, not because it happened (Ski jump take-off are as old as the Harriers!), but because it happened in hands-off automated take-off mode! Yes, LCA Navy feature hands-off take-off using ski-jump to ensure smooth transition to stable flight, and hands-off landing with steady AOA, autothrottle approach, flareless touchdown, and arrester hook engagement. During take-off and landing the pilot is required to only give steering inputs to stay on the center line.

According to a DRDO press release on the test flight, Naval Prototype 1 (NP-1) - piloted by Commodore Jaideep Maolankar, the Chief Test Pilot of National Flight Test Center - had a perfect flight with results matching the predicted ones to the letter. The flight validated the hands-off take-off algorithm of the Flight Control Software (FCS). NP-1 attempted the ski-jump after a 300-m roll in clean configuration presumably with full internal fuel.

A safe take-off required 150 knot at a climb rate of 6.4 degrees. But, the aircraft achieved higher acceleration with a climb rate of around 11 degrees. In the tests ahead, NP1 will progressively reduce the length of its take-off roll and increase payload. INS Vikramaditya, which could one day base LCA Navy, has a total deck length of 273-m. The maximum take off length available is between 160-180 metres.

The ultimate goal for the LCA Navy program is to demonstrate a full load take-off with 90-m roll. Five more ski-jump take-offs are planned in the current series of tests.

"Based on the test points achieved, we will schedule the next leg of trials," DRDO Director-General (Aero) Dr K Tamilmani told OneIndia.com. According to Tamilmani, NP-1 will start arrester hook landing trials within 6-8 months. It's pertinent to remember that LCA Navy is in Phase-1 of its development, which involves using a LCA Mk-1 modified to take off using a ski jump and perform arrested landing. Phase 1 is a technology development and demonstration phase.

In Phase 2, LCA Navy will be certified for carrier operations using aircraft built in the Tejas Mk2 configuration, powered by GE-414-INS6 engine with a max thrust of 22,000 lbs. Only Phase 2 aircraft will participate in carrier operation certification, with Phase 1 aircraft being reserved exclusively for SBTF operations."

Indian Navy Fighter RFI: Lockheed To Respond With Both F-35B & C

28 June 2010 Shiv Aroor http://www.livefistdefence.com/2010/06/indian-navy-fighter-rfi-lockheed-to.html

"Lockheed-Martin plans to respond to the Indian Navy's recent RFI for a new generation carrier-based fighter with two parallel dockets on the STOVL F-35B and the carrier variant F-35C. While it was initially thought that the F-35B would be the variant offered (since it appeared a logical replacement for India's Sea Harrier jump jets), Lockheed-Martin Biz Development (India) VP Orville Prins told me and a few other journalists today that Lockheed-Martin is conducting simulation and analysis studies to support the team's supposition that the F-35C -- built for a steam catapult launch off aircraft carriers -- is also capable of short take-offs from ski-jumps. The simulation and analysis will take into account various stress and strain parameters. The RFI to Lockheed-Martin simply requested information on the F-35 as a potential future carrier-based asset for the Indian Navy, and did not specify a variant. While LM has provided the Navy with programme-level briefings it will shortly begin a round of technical briefings on both the F-35 variants it plans to offer...."

Top LCA-Navy Team In Russia For Talks, Aug 3, 2010 By Anantha Krishnan M.- BENGALURU

http://www.aviationweek.com/aw/generic/story_generic.jsp?id=news/awx/2010/08/03/awx_08_03_2010_p0-245338.xml&topicName=India

"A high-level naval delegation from the Aeronautical Development Agency (ADA) — the government makers of India's much-anticipated Light Combat Aircraft (LCA) — is in Russia for contract negotiations and issues related to the program's shore-based test facility (SBTF). A senior official from the Defense Research & Development Organization (DRDO) told AVIATION WEEK that the team is being led by Satish Babu, the financial advisor to DRDO chief V.K. Saraswat, who also is ADA's director general. LCA Navy Program Director C.D. Balaji is also on the ADA team. "The team is currently holding contract negotiations with Russia's Rosoboronesport," the DRDO official says. "The talks are mainly revolving around SBTF, that's coming up at the Naval Air Station, Goa, to flight-test LCA naval variants." A naval prototype of the LCA was officially rolled out by Indian Defense Minister A.K. Antony on July 6.

The SBTF would be the Indian navy's first such facility.

"Building the SBTF in Goa is a huge technological challenge for ADA and the Indian Navy, and Russian help is critical. It will have to be an exact ship-on-the-shore facility based on India's Indigenous Aircraft Carrier [IAC] being built at Cochin Shipyard," the official says. "The measurements are the same as IAC and it must have all equipment to simulate an aircraft carrier with ski-jump and arrested recovery. Hence, the current project review being undertaken with the Russians is crucial in many ways."

The SBTF is critical to the program because ADA will be conducting carrier suitability tests for LCA-Navy in Goa after the initial flight trials for the current two prototypes are completed in Bengaluru. ADA hopes to have the ramp for the takeoff area ready by the end of 2011 and the landing area completed by 2012. A full-fledged telemetry unit is also being constructed in Goa as part of SBTF."

"...Shore Based Test Facility (SBTF) to simulate an aircraft carrier with ski-jump and arrested recovery is being set up at the Naval Air Station at Goa. The ski-jump facility is expected to be ready by the last quarter of 2011 and the landing area a year later. Goa Shipyard Ltd is handling the complete structural work, system integration and operations. R&D Engineers and CCE(R&D) west Pune are handling the civil works. Specialised equipment supply is from Russia in order to have the same configuration as on the Vikramaditya...."

http://www.indian-military.org/news-archives/indian-navy-news/815-lca-navy-programme-director-s-speech-on-np-1-roll-out-day.html


INS Hansa / NAS Goa
15°23'N 73°52'E
W — E
Airport type, Naval Air Station; Operator, Indian Navy; Location, Dabolim, Goa, India; RW 08/26
Elevation AMSL: 184 ft / 56 m
http://en.wikipedia.org/wiki/INS_Hansa
Main Runway East / West
Arrestor Gear & 'Mirror'
Ski Jump; on Cliff Top above Sea 150 feet below
SBTF
S E A
Image © 2015 DigitalGlobe
© 2015 Google
Works Office, INS Hansa
1335 ft
2002
Imagery Date: 11/6/2014 15°22'31.65" N 73°49'25.43" E


‘Restraint System’ is 200 metres from the Ski Jump


https://www.scribd.com/document_downloads/255723461?extension=pdf
“...It’s recreating a ship on the shore. The one that’s coming up in Goa is based on the Indigenous Aircraft Carrier (IAC) that’s being built at Cochin Shipyard. The SBTF is constructed with the same measurements of IAC,...”
http://www.dnaindia.com/india/report_ski-jump-take-off-for-light-combat-aircraft-tejas_1401783
INS Hansa/NAS Goa Indian Navy Shore-Based Test Facility (SBTF)

Navy to begin expansion at Dabolim [Goa] - Times of India, The, Feb 21, 2010

http://findarticles.com/p/news-articles/times-of-india-the/mi_8012/is_20100221/navy-expansion-dabolim-goa/ai_n50193350/?tag=rel.res2

“PANAJI: The Indian Navy has decided to go ahead with its expansion plans at the Dabolim airport. Preparations are under way to build a Shore Based Test Facility (SBTF) which will be used by its Light Combat Aircrafts (LCAs) and MiG 29K fighter jets.

The SBTF, which is being set up at the naval station INS Hansa, is meant to train fighter pilots before they attempt take-off and landing on aircraft carriers.

Giving mediapersons a brief synopsis a day before the MiG 29Ks were inducted into the naval air arm, Commanding Officer (CO) of the INS Hansa, captain Surendra Ahuja, said that the SBTF in India will be only the second of its kind in the world, with Russia being the only other country to have this facility.

Ahuja also outlined the Navy's expansion plans for several new facilities at the airport, where three additional hangars and two simulators will be built.

Work on constructing a 1,255 m strip is also underway for the SBTF facility he added. A feature of the project will be the ski-jump facing the seafront. This ski jump will be a replica of the same facility available on board the mother ship for the MiG 29Ks - the INS Vikramaditya - which is being refitted and which will only sail by December 2012.

Since the MiG-29K's flight operation on the aircraft carrier will be in the Short Take Off But Arrested Landing (STOBAR) configuration, two wire arresting systems are also being set up at the INS Hansa naval base.

"The STOBAR system will help arrest both the LCAs and the Mig-29Ks safely," he said.

He said that India is the second country in the world to have a 'wire arresting' system, besides Ukraine. American aircraft carriers carry out such operations by using a 'catapult' system, he added.”

LCA naval version achieves milestone 20 Dec 2014

Chethan Kumar,TNN http://timesofindia.indiatimes.com/india/LCA-naval-version-achieves-milestone/articleshow/45587509.cms

"BENGALURU: The first prototype of the light combat aircraft (LCA) Tejas' Naval version — LCA NP-1 — completed its maiden flight as part of the carrier compatibility tests at the shore-based test facility INS Hansa in Goa at 12.34pm on Saturday. LCA-Navy is the second Ski Take Off But Arrested Recovery (STOBAR) carrier-borne aircraft in the world, after a Russian deck based aircraft. And, this will be the only Carrier borne Fighter aircraft in the Light category. The flight in Goa comes more than two years after the aircraft completed its maiden flight on April 27, 2012. Attempting to build such an aircraft for the first time, the Indian Navy and team LCA even got help from the United States Navy, which audited the aircraft in the initial stages.

"...The US Navy Carrier Suitability Test Team conducted audits of our test findings which has been very beneficial for us given the fact that this is India's first attempt at developing a carrier-borne fighter," a senior official involved with the project said. The aircraft designed to operate from the decks of air-craft carriers, on Saturday took off from Ski-Jump facility of INS Hansa. Piloted by Commodore Jaideep Maolankar, the Chief Test Pilot of National Flight Test Centre (NFTC), the aircraft had "a perfect flight with results matching the predicted ones to the letter," a note said.

LCA (Navy) is designed with stronger landing gears to absorb forces exerted by the ski jump ramp during take-off, to be airborne within 200-m as against 1,000-m required for normal runways. Its special flight control law mode allows hands-free take-off relieving the pilot workload, as the aircraft leaps from the ramp and automatically puts the aircraft in an ascending trajectory.

The Shore Based Test Facility (SBTF) has been created to replicate the aircraft carrier with a Ski Jump for take-off and arresting gear cable for arrested landing; by ADA with the participation of the Indian Navy, Goa shipyard, CCE (R&D) West, Pune, R&D Engg (E) Pune and the Russian agencies providing the design support and specialized equipment.

Role of the Aircraft: * Air to Air * Air to Sea * Air to Ground | Dimensions: * Span : 8.2m * Length : 13.2m * Height : 4.52m "

LCA team gets first naval variant 03 May 2012 Chethan Kumar http://bharat-rakshak.com/NEWS/newsrf.php?newsid=18278

"The Indian Navy, Aeronautical Development Agency (ADA), Hindustan Aeronautics Limited (HAL) and the others that constitute Team LCA (light combat aircraft) have been successful in getting the first prototype of the LCA naval variant LCA-NP 1 airborne. The next challenge star-ing in the eye will be to evolve a testing methodology to check the compatibility of the aircraft on the Indian Navy carriers.

The Indian Navy, along with ADA, has sought the help of the United States Navy to share its expertise while resolving some of these issues, although the US will not have full privy to the design and development of the indigenous aircraft. "With the US having over half-a-century of experience in developing and maintaining carrier-borne aircraft, we are getting valuable help from to resolve issues, especially with the undercarriage and related problems," a source familiar with the developments said.

Sources in the Navy said the US Navy is not being paid for the consultancy as the arrangement is a government-to-government arrangement. "We only take care of their travel accommodation and other requirements," a source said. Under the memorandum of understanding signed for the purpose, the US consultancy will not cover design-specific or commercial aspects. It is specifically for carrier-borne operations and they are also helping Team LCA with crucial technologies like the ski jump take off and arrest landing –– technologies that make the LCA naval version a great asset for the Indian Navy –– allowing it to take off from vessels during war and other counter-insurgency operations and land back on them.

Speaking to Deccan Herald, ADA Chief P S Subrahmanya said: "The US Navy Carrier Suitability Test Team is, in fact, conducting audits of our test findings which has been very beneficial for us given the fact that this is India's first attempt at developing a carrier-borne fighter."

Naval variant of LCA Tejas to undergo tests in Goa soon

Vishwas Kothari, TNN 29 Mar 2014

PUNE: The naval variant of light combat aircraft (LCA) 'Tejas' will soon undergo carrier compatibility tests at the newly commissioned shore-based test facility at the Indian naval base INS Hansa in Goa, the LCA's programme director Kota Harinarayana told TOI on Friday.

"Before we go to the ship, we have to do something on the ground that is similar to the ship," Harinarayana said, while pointing out that the shore-based test facility is primarily a ramp – similar to the ones on aircraft carriers – which facilitates ski-jump take-off and arrested landing of a naval aircraft. "The aircraft will go to the test facility in a month's time," he added.

"Apart from enabling carrier compatibility, the new facility will aid certification of the LCA naval variant, which is critical to the LCA's future induction in the Indian Navy," he said.

The LCA (Navy) is India's first indigenous effort to build a carrier-borne naval fighter aircraft, a vital ingredient in the Navy's expansion plans. It is designed to operate from future indigenous aircraft carriers that the Indian Navy plans to acquire.

Harinarayana is regarded as the chief architect of the LCA programme, which was launched in 1980 as part of the plan to replace the Indian Air Force's (IAF) ageing fleet of MIG-21 aircraft. He spoke to TOI on the sidelines of a talk on 'Aircraft designing in India', jointly organised by the Centre for Advanced Strategic Studies and the Aeronautical Society of India. Former vice-chief of air staff Air Marshal (Retd) Bhushan Gokhale chaired the event.

In December 2013, the IAF gave its operational clearance to the LCA Air Force variant and also cleared the same for full-scale production at the Hindustan Aeronautical Limited facility in Bangalore, Harinarayana said. "We expect the aircraft to be rolled out for induction into the Air Force later this year and hopefully the IAF will raise an independent squadron for the LCA," he said.

He said, "The IAF has placed an initial order of 40 LCAs which are to be delivered over the next four to five years. We have their (IAF's) commitment for another 80 to 90 LCAs in future. The Air Force and Navy collectively require 200 LCAs."

Harinarayana added that the LCA had also evinced keen interest from foreign countries. "However, our immediate focus is on meeting the Air Force and Navy's requirement for the next three years. Supply to foreign countries remains a part-commercial, part-diplomatic matter, and may still take some time to come through. The priority for now is to enhance the production capacity and to continue working on the LCA Mk-II variant, which is expected to go operational in four to five years following flight and other tests."

He conceded that both LCA variants will work on the imported GE-404 engines as it will take some more years for the indigenously developed Kaveri engine to be ready for use in these aircraft. "We still have to fully achieve the reliability and performance of the Kaveri engine. We have tested for 50 hours' flying in a transport carrier, but we still have to improve," he said.

Apart from enabling carrier compatibility, the new shore-based test facility will aid certification of the LCA naval variant, which is critical to the LCA's future induction in the Indian Navy.

http://timesofindia.indiatimes.com/India/Naval-variant-of-LCA-Tejas-to-undergo-tests-in-Goa-soon/articleshow/32872152.cms

India's 1st indigenous aircraft carrier taking shape at Kochi 09 Oct 2014

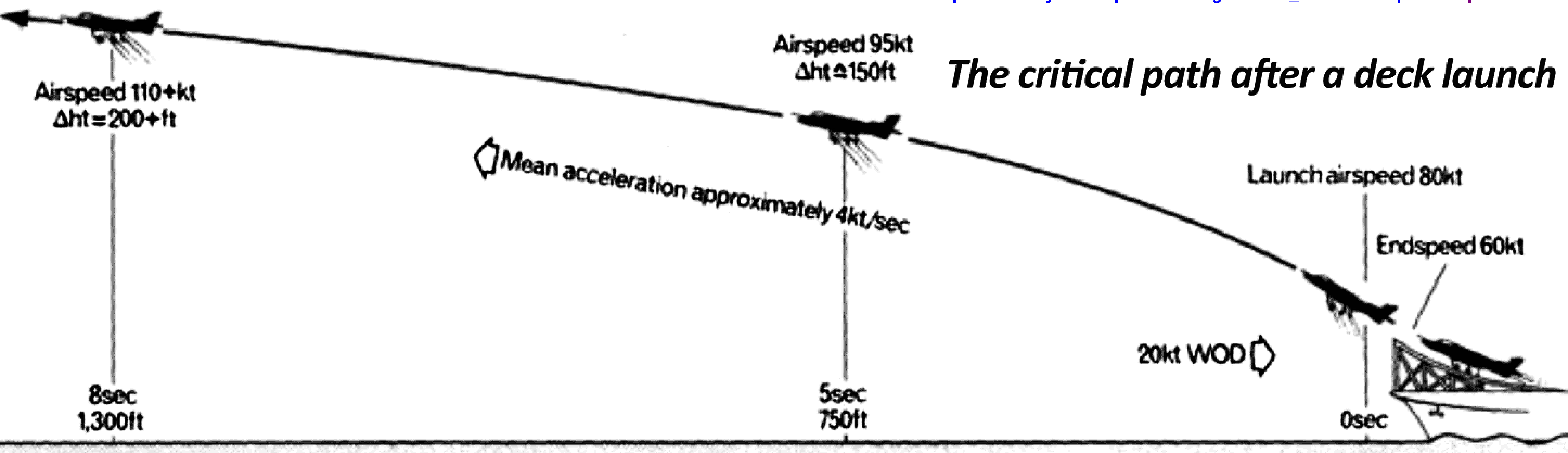
Press Trust of India http://www.business-standard.com/article/pti-stories/india-s-1st-indigenous-aircraft-carrier-taking-shape-at-kochi-114100900936_1.html

“India's first indigenous aircraft carrier was taking shape in the Cochin Shipyard Limited at Kochi, one of the nine Defence PSUs in the country, where 85 per cent of the work relating to its hull are complete, a senior official said here today. "Around 85 per cent of the hull is complete and 90 per cent of the fabrication is over. 85 per cent of the erection has been over," Commodore K Subramaniam (Retd), CSL Chairman and Managing Director told reporters on the sidelines of a function organised by the CII. Interacting with journalists in the sidelines of a CII- organised conference on 'Approach to Integrated Maritime Systems' here, he said many elements of innovations were being incorporated in the building of the aircraft carrier.

"For instance, the Navy wanted a 14 degree ski-jump in the ~~foxle~~ [foc'sle = forecastle] of the ship for easy taking off of fighter planes, for which a big piece of iron had to be welded, which was also trimming down the ship to the front. "We have employed a big piece of iron in the hull area, which will function as a buoyant, which has made the keel of the hull float horizontally. Likewise, we have made many innovations in the building."

Replying to a query, he said the degree of indigenous equipment in the aircraft carrier was very high, barring the aviation, for which the county was dependent on Russia. "We can say around 80 per cent of the ship is indigenous."....”

http://www.vayuaerospace.in/images1/The_LCA-NAVY.pdf Graphic Below



Indian Navy Light Combat Aircraft to soon begin test flights 11Jul 2014

IANS http://ibnlive.in.com/news/indian-navy-light-combat-aircraft-to-soon-begin-test-flights/485214-3.html

“New Delhi: The naval variant of India's indigenous light combat aircraft (LCA) is due to soon begin ramp trials. Avinash Chander, scientific adviser to the Defence Minister and Director General Defence Research and Development Organisation (DRDO), told India Strategic magazine (www.indiastrategic.in) that the LCA-Navy had already done more than 25 test flights from a runway. As these were successful and met the designated parameters, the aircraft will now be deployed at a naval base in Goa to commence ramp flights, probably after the monsoon. Goa, on the Arabian seafront, has a major naval air station, INS Hansa, where the MiG-29Ks for Indian aircraft carriers are also located.

The station has a 14-degree ramp along with necessary testing sensors and paraphern-alia to monitor the flights and was specifically built as part of the indigenous LCA-Navy develop-ment programme. But as it is a national naval asset, it is shared by the MiG-29Ks for training pilots and flight tests. Both the aircraft need the same degree in the ramp, matching the one on INS Vikramaditya, acquired from Russia, and INS Vikrant, now being built at the Kochi shipyard.

Chander said that the flight tests are being conducted with LCA Mark-I to prove certain technologies and to familiarise the naval pilots with them. One aircraft is operation-al, another is on the anvil and a third will son be available to complete the trials. After that, for full weaponised operations aboard carriers, will come the LCA Mark-II powered by GE 414 engines, according to India Strategic.

The naval variant, being tested from the HAL airport in Bangalore, has a bigger undercarriage that Hindustan Aeronautics has built to facilitate deck landings. The development programme is coordinated by a one-star naval pilot.”

Pragmatic progress

While the air force despairs of the indigenous fighter's development, the navy's longer-term approach could prove to be a masterstroke

ATUL CHANDRA BENGALURU

Since the last Aero India in 2013, the torturous development of the Tejas fighter for the Indian air force and Light Combat Aircraft (LCA) for the navy has continued. But while the outlook for the Tejas Mk2 remains uncertain, the navy's pragmatic approach towards the LCA programme could see India's future carrier fleet operating a capable light fighter.

The Defence Research and Development Organisation has been bullish about the LCA while the air force has treated the programme with benign neglect, understanding that it will have to look abroad for war-winning capability. Meanwhile, there has been a studious "we have to make this work" approach from the navy team.

The LCA Navy programme began in 2003, when the government approved the development of a carrier-borne fighter aircraft on the understanding that converting the air force version to meet naval requirements would take about seven or eight years. The LCA Navy Mk1 was intended to demonstrate carrier suitability and compatibility and achieve initial operational clearance (IOC).

But by the time the first navy prototype (NP1) made its maiden flight in April 2012, it was obvious that no matter what was done, basing the LCA Navy on the Tejas Mk1 would always be a sub-optimal solution. However, the programme continued to be of great help in terms of developmental flight testing, validation of important concepts and pilot training.

REWORKING

The second navy prototype, NP2, is expected to make its maiden flight by 31 March this year. An indigenously-built aircraft carrier, to be named INS *Vikrant*, will not be ready until the end of 2018 and two-year carrier suitability trials involving navy Mk1 aircraft are scheduled for completion by 2020/2021.

In an example of long-term planning lacking in many of India's indigenous programmes, the navy is now looking at a substantially reworked navy Mk2 variant instead of tinkering around with short-term fixes. Although it will have the same control surfaces, basic wing structure, fin and rudder, it is practically a new aircraft.

The navy Mk2 design will be optimised to reduce supersonic and subsonic drag and have bigger intakes. A new centre fuselage will "provide additional volume to accommodate the landing gear from the start and free up space in centre fuselage and increase internal fuel volume significantly", an official closely associated with the programme tells Flightglobal.

Both the air force and navy plan to use the General Electric F414 to power their Mk2 air-craft, helping to reduce landing gear weight by 300-350kg (660-770lb) – all existing Tejas aircraft use the less powerful F404.

An increased fuselage length will also allow for better maintainability and improved distribution of equipment. The preliminary design review (PDR) is to be concluded next year, followed by an aggressive two-year schedule for the detailed design phase.

The air force received its first series produc-tion example Tejas Mk1 in January, signalling the first step towards operational exploitation of the type in service. However, the air force appears to be losing patience with the Tejas. Retired Air Marshal M Matheshwaran, who stepped down as deputy chief of integrated defence staff in 2014 and is now strategy advisor to Hindustan Aeronautics' (HAL) chairman, says: "The LCA has become an avenue for technology development. At the end of the day, the weapon system as envisaged by the air force is nowhere in sight."

Looking beyond the Tejas Mk1, Matheshwaran says that "for the Tejas Mk2 to become a major frontline fighter for the IAF, there would have to be major aerodynamic changes."

PATIENCE

Development work continues on the Tejas Mk1, which is slated to obtain final operation-al clearance (FOC) by December 2015. HAL is to build the first 20 Tejas Mk1 aircraft to the IOC standard, and these will later be upgraded to the FOC standard. As things stand, the air force will not see a full squadron of Tejas Mk1s operational until 2019, while the first operational Tejas Mk2 squadron is at least a decade way. ▪

OneIndia Special: NLCA NP-1 outperformed our expectations, says ADA

09 February 2015

Dr Anantha Krishnan M http://www.oneindia.com/india/oneindia-special-nlca-np-1-outperformed-our-expectations-says-ada-1647622.html

Bengaluru, Feb 9: The first prototype (NP-1) of the Naval Light Combat Aircraft (NLCA), which had a ski-take off from the Shore Based Test Facility (SBTF) in INS Hansa in Goa on December 20, 2014, outperformed the expectations of its designers and engineers. In an exclusive interview to OneIndia, his first after the historic flight of NP-1, NLCA Programme Director Cmde C D Balaji (Retd) said that NP-1 gifted a 'welcome bonus' at SBTF.

"There are many uncertainties and potential surprises when you attempt something for the first time. We had built in a detail plan after looking into all major possibilities of a failure. Accordingly, we wanted to have a minimum climb angle of 5.7 degrees during the first attempt," Balaji told OneIndia ahead of the forthcoming Aero India 2015.

With Lady Luck finally giving company to the NLCA designers at Aeronautical Development Agency (ADA) and Hindustan Aeronautics Limited (HAL), the NP-1's performance seems to have lifted the spirits of the entire team.

"We got an unexpected bonus in terms of NP-1's excess performance and the actual minimum climb angle was in excess of 10 degrees. It is welcome bonus for an aircraft that has been so often derided for lack of thrust, and this excess will be accounted for in future launches as well," a satisfied Balaji said.

ADA Chief P S Subramanyam too agrees with Balaji while sharing inside details of the NP-1's performance. "The Goa campaign turned out to be a memorable one for all of us. It is inspiring when an aircraft performs more that what was expected during its flight evaluation stages. NP-I's performance was better than anticipated in comparison to estimates earlier made purely based on its flight tests at Bangalore," says Subramanyam.

There are more prototypes to be added to flightline

Balaji said to meet the full missions requirements stipulated by the Indian Navy, three more prototypes will be rolled out in future. "We have a new programme with a higher thrust engine sanctioned under the LCA Navy Mk2 phase. It is aimed minimising the constraints of LCA Navy Mk-1. It will have significant changes in design to improve aerodynamics, landing gear & arrester hook optimization, structural design optimization, updated sensors, avionics and Flight Control System among others," says Balaji.

Interestingly, Balaji, the soft-spoken captain of the NLCA project had to bear the brunt of the Navy, Ministry of Defence and the media for the delays the project entered in the last couple of years.

The landing gear mass of the LCA (Navy) Mk-2 aircraft is likely to be reduced by 200-250 kg, albeit being capable of a higher take off mass. Prototypes likely to come from this Mk-2 flightline are NP-3 and NP-4 (both fighters). From the existing resources ADA has already begun the work for the third NLCA prototype which will be designated as NP-5, a trainer. Balaji says all trainers will be from the Mk-1 flightline.

ADA insiders tell OneIndia that the newly-appointed HAL Chairman T Suvarna Raju has promised all help for the NLCA project. "HAL Chairman was waiting to receive the NP-2 after it touched down during his maiden flight on February 7, 2015. His presence has inspired the entire team," says an official in ADA.

NP-1 to undergo minor changes

ADA says the wealth of data collected from the maiden ski-jump mission has been fully analysed. "The areas needing attention have been identified. The CLAW (Control Law) and Flight Control System (FCS) software will be updated for higher performance. The Nose Landing Gear (NLG) extension was faster than predicted. Minor modifications to the NLG will also be done," says Balaji.

“The skijump test last December [2014] showed the aircraft can get airborne from the carrier deck within 200 meters (660 ft.), compared with 1,000 meters for a conventional runway takeoff.”

http://aviationweek.com/Tejas

http://tejas.gov.in/IOC-Brochure.pdf

When compared to NP-1, one major addition on NP2 is the presence of a Multi-Mode Radar (MMR). The aircraft performance is expected to be similar to NP-1. "The focus on sensor and weapon capability demonstration will be on NP-2," says Balaji.

Critical observations from the last trials

ADA says the AoA (Angle of Attack) after ramp exit reached 21.6 degrees which augers well for utilisation of even greater angles of attack for launch. "The maximum all up weight that an aircraft can be launched at is the primary determinant of its operational capability as it dictates the quantum of weapons and fuel that the aircraft carries.

For a ski-jump launch, the final design intent is to have a zero rate of climb after ramp exit to get the best performance of the aircraft," says Balaji.

More action lined up in Goa from March

Once the FCS software upgradation and minor rework on NLG is completed, NP-1 will hit Goa for the next phase of the campaign in March 2015. It will continue its ski-jump launches to progressively reduce margins till final performance levels are achieved. "Also, it is planned to initiate activities towards arrested recovery starting with dummy approaches on the landing area, ‘taxi-in' arrester hook engagements on to the arrester wire at the SBTF and final flight engagement," says Balaji.

ADA hopes to get a suitable slot for NLCA NP-1 during the upcoming Aero India 2015. "We are working on the slots available. It is likely that NP-1might fly," adds Balaji.

Maiden Ski Jump of LCA Naval Prototype - 1 (NP-1) Published on Dec 31, 2014 LCA Tejas

“Full 1080p HD Video - The first prototype of the light combat aircraft (LCA) Tejas Naval version - LCA NP-1 completed its first flight as the part of the carrier compatibility tests at the shore-based test facility in Goa.”

Slow Motion and Various Views Inside & Outside A/C

https://www.youtube.com/watch?v=dB73FdERNBA

Second naval Tejas prototype conducts maiden flight 08 Feb 2015

Greg Waldron http://www.flightglobal.com/news/articles/second-naval-tejas-prototype-conducts-maiden-flight-408812/

The second prototype of the naval variant of the Hindustan Aeronautics (HAL) Tejas Light Combat Aircraft (LCA) has conducted its maiden flight. The 35 minute sortie of the aircraft, designated NP2, took place on Saturday 7 February from HAL's Bengaluru production facility, says the airframer in a statement. "The event marks the growth of the indigenous LCA (Navy) programme, aimed to achieve carrier compatibility technology demonstration, including arrested landing and ski-jump take offs, initially from the shore-based test facility at Goa."

The first flight of NP2 follows the successful ramp-assisted takeoff of the first naval Tejas prototype, NP1, from the Goa facility on 20 December [2014], adds HAL.

NP2 incorporates a number of improvements over NP1. The aircraft can accept incremental improvements related to carrier landing aids, auto-throttle, as well as improved internal and external angle of attack indicators. NP2 is also the lead aircraft for arrestor hook integration. The HAL statement indicates that NP2 also has strengthened landing gear over NP1, a key design element for aircraft carrier landings. NP2 also has one seat, while NP1 has two.

Both aircraft, however, are powered by the General Electric F404 engine. For carrier operations at sea, the aircraft will receive the more powerful F414 engine, which will also power the Tejas Mk II.

New Delhi has two aircraft carriers, the Viraat and Vikramaditya. Formerly the HMS Hermes, the Viraat operates BAe Sea Harriers and helicopters. It is likely to be retired in the coming years. The short take-off but arrested recovery (STOBAR) Vikramaditya was formerly the Russian carrier Admiral Gorshkov. After years of the delays the carrier, which operates RAK MiG-29K aircraft and Kamov Ka-31 helicopters, it entered service in 2013.

New Delhi is also producing another STOBAR equipped carrier, the Vikrant, indigenously. She is expected to enter service in 2018 or afterwards. A follow-on carrier could be equipped with catapults, which would greatly improve the payload of fighters operating from its deck, and allow the use of fixed wing airborne early warning & control (AEW&C) aircraft, specifically the Northrop Grumman E-2D Hawkeye."

A Turnaround For India's First Indigenous Fighter

Feb 13, 2015 Jay Menon
Aviation Week & Space Technology

...The second prototype of a carrier-capable version being developed for the Indian navy, the single-seat aircraft NP-2, made its first flight on Feb. 7 from HAL's airport in Bengaluru. The initial two-seat prototype, NP-1, first flew in April 2012 and in December logged the first takeoff from a ski-jump at the Shore-Based Tests Facility (SBTF) in Goa.

NP-1 was mostly grounded for the better part of a year following its maiden flight, to fix several structural and technical issues, mainly with the undercarriage. The weight of the landing gear had to be reduced and movement of the leading-edge vortex controls corrected. These movable surfaces were added to the delta-wing LCA to reduce carrier approach speed. NP-2 has a redesigned landing gear.

"[NP-2] addresses several systemic deficiencies observed while making progress on flight-test of NP-1. It incorporates most avionic hardware components promised to the customer," says HAL Chairman T. Suvarna Raju. NP-2 has been designed to accept modifications incrementally for carrier-landing aids such as a new air-data computer, auto-throttle and external/internal angle-of-attack lights.

The second prototype is the lead aircraft for integration of the arrestor hook, as well as Rafael Derby beyond-visual-range air-to-air missiles and tactical data link. "The inclusion of NP-2 into the LCA flight-test stable is a significant milestone in the indigenous carrier-borne aircraft development program," says Raju.

The LCA-Navy is India's first effort to develop a carrier-borne fighter and is to be deployed on India's indigenous aircraft carrier INS Vikrant, replacing the navy's Sea Harriers and operating alongside MiG-29Ks. **The ski-jump test last December showed the aircraft can get airborne from the carrier deck within 200 meters (660 ft.), compared with 1,000 meters for a conventional runway takeoff.** LCA-Navy is heavier than the air force version and has a fuel-dump capability to reduce weight for arrested landings.

"The LCA-Navy is designed with stronger landing gear to absorb forces exerted by the ski-jump ramp during takeoff," says K. Tamilmani, chief controller of aeronautics R&D at India's Defense Research & Development Organization. A special flight-control law allows hands-free takeoff from the ramp, reducing pilot workload and automatically putting the aircraft on a climbing trajectory. A second phase of SBTF tests will involve arrested landings, he says.

At 8.5 tons, the Tejas is light for a single-engine multirole supersonic fighter, but it is heavier and lower performing than planned. So development has begun on the larger Mk. 2, with a more powerful General Electric F414/INS6 engine in place of the Mk. 1's GE F404/INS20. GE Aviation says it will begin delivering F414s to India next year, with first flight of the Tejas Mk. 2 expected in 2017.

http://aviationweek.com/Tejas

Su-33 (Su-27K/T-10K) particulars:

* empty weight : 43,210 lb / 19,600 kg
* max. internal fuel : 20,940 lb / 9,500 kg
* standard internal fuel : 11,795 lb / 5,350 kg
* max. ordnance load : 14,330 lb / 6,500 kg
* max. AtoA ordnance load : 7,055 lb / 3,200 kg (8 x R-27E + 4 x R-73)
* thrust with A/B : 2 x 28,220 lbst / 12,800 kgp

Su-33 (Su-27K / T-10K) T-O weights :

* with standard internal fuel : 55,100 lb / 25,000 kg
* with standard internal fuel, 2 x R-27E, 2 x R-73 : 57,320 lb / 26,000 kg
* with standard internal fuel, 8 x R-27E, 4 x R-73 : 61,730 lb / 28,000 kg
* with max. internal fuel, 2 x R-27E, 2 x R-73 : 65,920 lb / 29,900 kg
* with max. internal fuel, 8 x R-27E, 4 x R-73 : 70,990 lb / 32,200 kg

Su-33 (Su-27K / T-10K) with 14.3° ramp and max. A/B :

* 345ft ground roll @ 61,730lb T-O weight
* 345ft ground roll @ 65,290lb T-O weight with 7kn WOD
* 640ft ground roll @ 70,990lb T-O weight with 15kn WOD

source : Su-33 Naval Saga
by Andrei Fomin, Moscow 2003 (in Russian)

MiG-29K (9.41) particulars:

* empty weight : 27,340 lb / 12,400 kg
* max. internal fuel : 11,460 lb / 5,200 kg
* max. ordnance load : 12,125 lb / 5,500 kg
* thrust with A/B : 2 x 19,480 lbst / 9,000 kgp
(for T-O : 2 x 20,720 lbst / 9,400 kgp)

MiG-29K (9.41) with 14.3° ramp and max. A/B :

* 345ft ground roll @ 39,000lb T-O weight
* 640ft ground roll @ 49,400lb T-O weight

source : Mikoyan MiG-29
by Yefim Gordon, Midland Publishing, 2006

http://www.global-military.com/wp-content/uploads/2010/05/Su-27-series-aircraft-in-the-land-sliding-Yanliang-flight-deck-jump.jpg

"...The J-15 prototype made its maiden flight on Aug. 31, 2009 and performed the first takeoff from a land-based ski-jump in May last year [2010]. The aircraft is scheduled to become operational by 2015, operating on China's new, indigenous built carriers...."

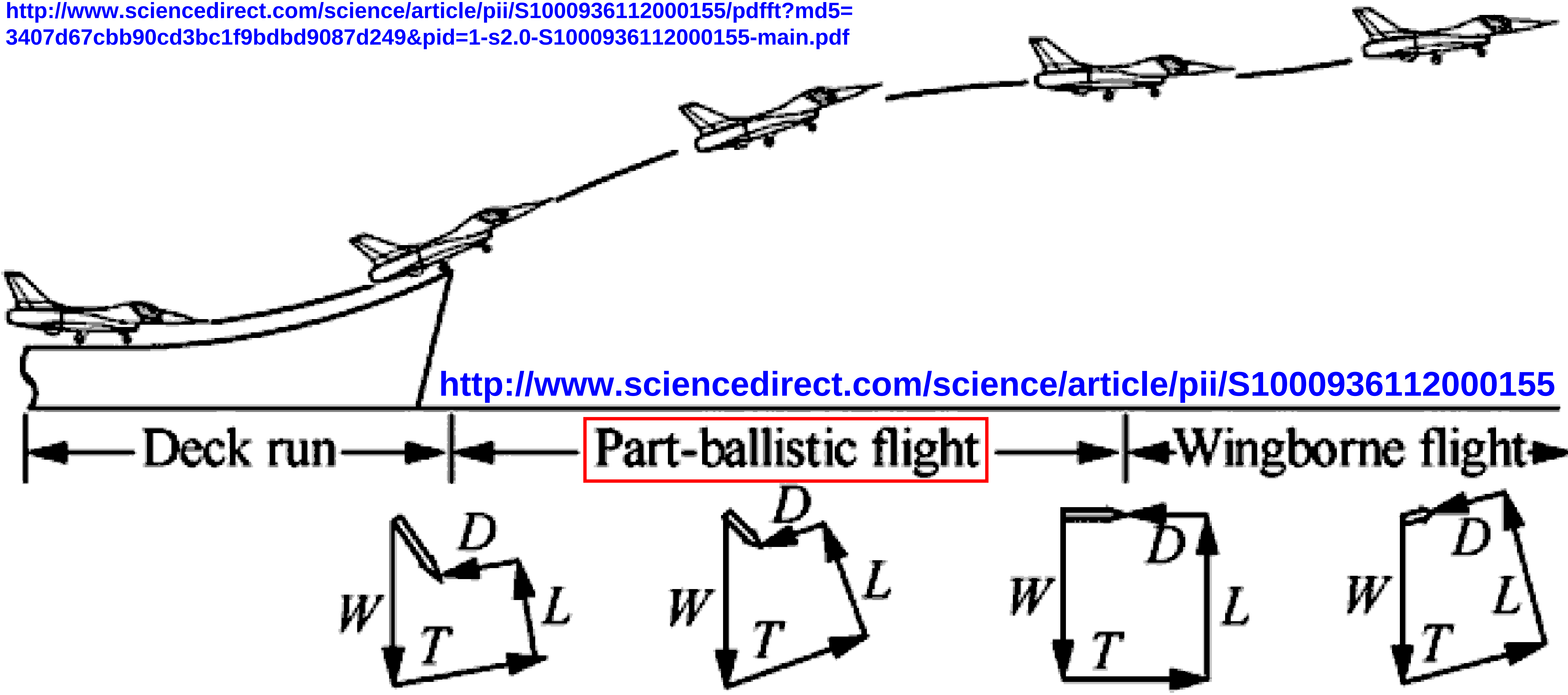
http://defense-update.com/wp/20110426_j-15_unveiled.html?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+DefenseUpdate+%28Defense+Update%29

J-15 prototype was finished, China started aircraft carrier pilot training

http://www.global-military.com/j-15-prototype-was-finished-china-started-the-aircraft-carrier-pilot-training.html

"According to 21, reported the latest issue of the Canadian "Chinese Defense Review" magazine, said China has launched aircraft personnel training project, training centers may be located in Huludao. The article said that as China's first ship-borne fighter aircraft F-15 manufactured prototype, China will build test base for the Navy, similar to Ukraine's Navy carrier fighter NITKA as test center. Reported that China's naval pilot training center, carrier-based fighter aircraft flight test center is most likely located in Liaoning Huludao area. Huludao already have, "Chinese Navy Flight School," which is the famous 91 065 troops. Navy helicopters, bombers, transport aircraft pilot training in this. Han and that the future China is likely to fly in the Naval Academy's structure, the building of carrier-based fighter aircraft flight test center, there may be an independent building a new naval flight test center. But Huludao Xingcheng, Jiyuan Navy land-based aircraft carrier construction of the airport did not find signs of the runway test center. Han and the founder of Ping Kefu said, "building a new trial airport is very expensive, equal to land the aircraft carrier construction. At present, only Ukraine, United States, the existence of such a test center." At the same time that the Chinese F-15 fighter flight carrier is facing difficulties because there is no Navy pilots in the flight test center where, in Shaanxi, the Air Force Flight Test Center Yanliang J-15 only testing flight control systems, radar, weapons use and so on."

http://www.sciencedirect.com/science/article/pii/S1000936112000155/pdfft?md5=3407d67cbb90cd3bc1f9bdbd9087d249&pid=1-s2.0-S1000936112000155-main.pdf



Multi-body dynamic system simulation of carrier-basedaircraft ski-jump takeoff

Schematic of carrier-based aircraft ski-jump takeoff

Multi-body dynamic system simulation of carrier-based aircraft ski-jump takeoff

2011 Wang Yangang, Wang Weijun, Qu Xiangju http://www.sciencedirect.com/science/article/pii/S1000936112000155/pdfft?md5=3407d67cbb90cd3bc1f9bdbd9087d249&pid=1-s2.0-S1000936112000155-main.pdf

Abstract: The flight safety is threatened by the special flight conditions and the low speed of carrier-based aircraft ski-jump take-off. The aircraft carrier motion, aircraft dynamics, landing gears and wind field of sea state are comprehensively consider-ed to dispose this multidiscipline intersection problem. According to the particular naval operating environment of the carrier-based aircraft ski-jump takeoff, the integrated dynam-ic simulation models of multi-body system are developed, which involves the movement entities of the carrier, the aircraft and the landing gears, and involves takeoff instruction, control system and the deck wind disturbance. Based on Matlab/Simulink environment,the multi-body system simulation is realized. The validity of the model and the rationality of the result are verified by an example simulation of carrier-based aircraft ski-jump takeoff. The simulation model and the software are suitable for the study of the multidiscipline intersection problems which are involved in the perform-ance, flight quality & safety of carrier-based aircraft takeoff, the effects of landing gear loads, parameters of carrier deck, etc....

...The effects of a moving carrier-based aircraft on an aircraft carrier motion are negligible as the mass of the aircraft is near-ly three orders of magnitude less than the aircraft carrier. Therefore the carrier motion is independent of the carrier-based air-craft and regarded as an input of the multi-body dynamic system (MBDS)....

...**3.5. Flight instruction and control module:** The LSO is responsible for the safety of the carrier-based aircraft takeoff. Be-fore the deck run, the aircraft is attached to the flight deck by the holdback fitting to enable the engine to run up to full power. After the pilot signals the LSO that it is ready, the commander will make a right judgment by considering carrier motion, air-craft characteristics and flight mission, etc. If the takeoff decision is made, the LSO will give signals immediately to the launch oper-ator to release the wheel gear, and the carrier-based aircraft will then start rolling and complete the takeoff process. Otherwise a right time shall be waited for. The time decision-making system for carrier-based aircraft launching is shown as Fig. 3....

...**7. Conclusions:** The simulation modeling of carrier-based aircraft ski-jump takeoff is complicated. This paper builds the relatively complete system model of carrier-based aircraft ski-jump takeoff to resolve the problems of the coupling among multi-motion bodies and flight environment, as well as the problems of the cooperative instructions control. This system model takes into account three main effects: the coupling of carrier, aircraft body and the landing gears; the influences on the carrier motion by sea state and on the flight by the induced wind field; the influences on the aircraft flight by the cooperative instruct-ions control among deck commanders and pilot. Two simulation examples show that the system model can describe the dyn-amic characteristics of all the movement bodies reasonably. It has practical significance for the multi-disciplinary intersect problem in the design of carrier deck, design of landing gears and aircraft body. This system model can be used to analyze the influencing factors of flight safety comprehensively, such as flight environment, human decision-making control, etc., which is supposed to play an important role in flight training.”

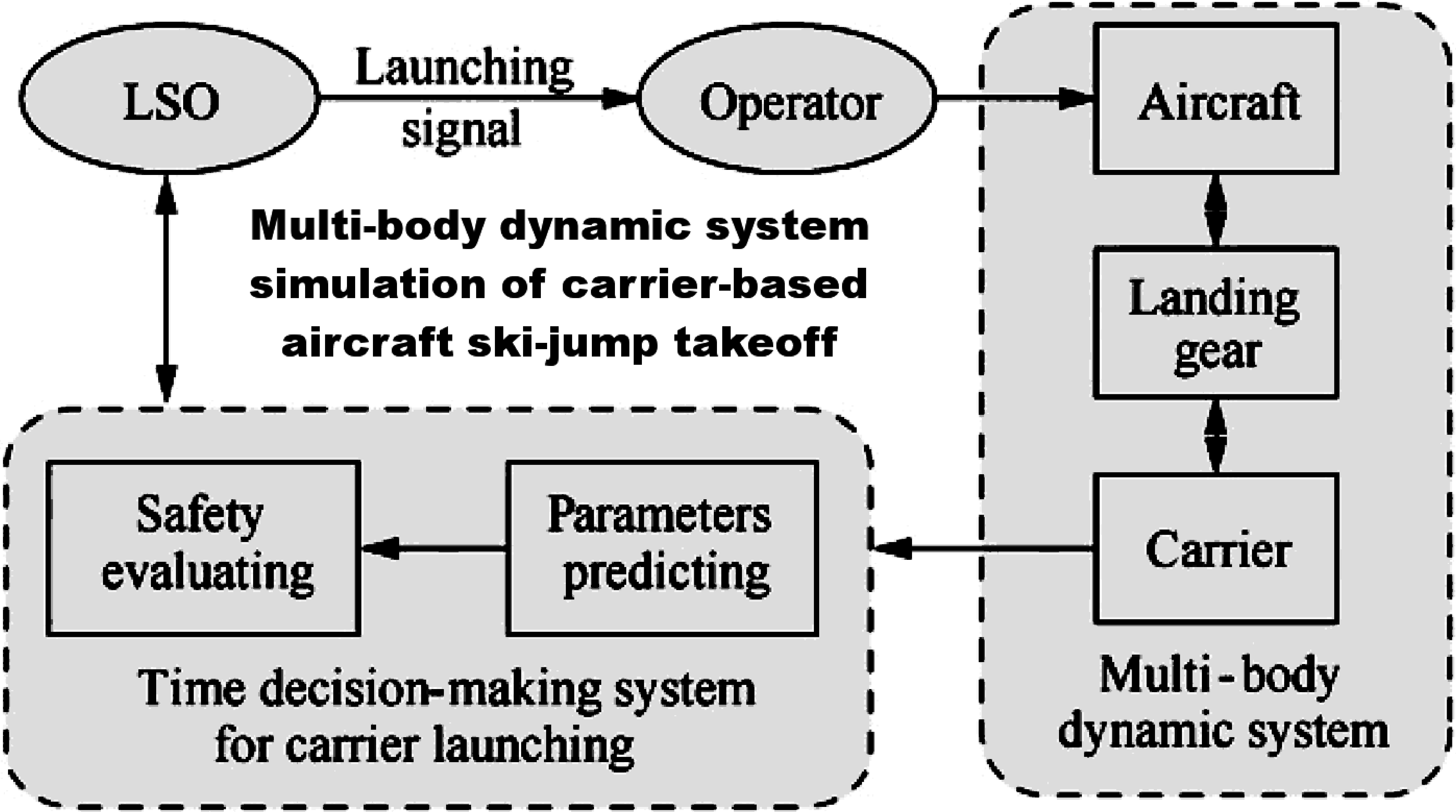


Fig. 3 http://www.sciencedirect.com/science/article/pii/S1000936112000155/pdfft?md5=3407d67cbb90cd3bc1f9bdbd9087d249&pid=1-s2.0-S1000936112000155-main.pdf

Time decision-making system for carrier-based aircraft launching

New Chinese Ship-Based Fighter Progresses — Apr 27, 2011 By David A. Fulghum

http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=defense&id=news/asd/2011/04/27/02.xml&headline=New Chinese Ship-Based Fighter Progresses

"Beijing is revealing pictures of its Shenyang J-15 Flying Shark design that is intended to populate the decks of its first aircraft carrier. The J-15 is based on the J-11B, Shenyang's unlicensed and indigenously adapted version of the Sukhoi Su-27 Flanker, and resembles its Russian equivalent, the Su-33 shipboard version, with a foreplane, folding wings, arrester hook and reinforced landing gear. Like the Su-33, the J-15 is designed to take off from a ski jump rather than a catapult. There are some differences from the Su-33, including more complex trailing-edge flaps and advanced Chinese avionics. The unlicensed adaptation has been a source of friction with Moscow, says Douglas Barrie, senior fellow for military aerospace with London's International Institute for Strategic Studies. The J-15's canards replicate those on the Su-33, indicating its flight control system is at least similar, Barrie says. Moreover, "a mock-up of the J-15 was seen carrying a dummy anti-ship missile, suggesting the J-15 may be intended to have a strike role from the outset, while the Su-33 was an air-to-air design." The heavy shipborne fighter will be yet another piece in the foundation of a ship-based force that can project power at sea, far from China's shore defenses. They are expected to be first based on the former Russian Varyag aircraft carrier. The first pictures were taken at Shenyang Aircraft Industry Corp.'s No. 112 factory.

The design features exterior missile rails and a wide-angle holographic head-up display similar to those on the company's J-11 fighter. There are competing claims about the aircraft's capability. Russian's Ria Novosti news service called it inferior to the Su-33, but Chinese officials say the Su-33's avionics are obsolete, so they have installed locally made sensors, displays and weaponry. While based structurally on the Su-33, the aircraft features avionics — including an advanced anti-ship radar — from the J-11B program. Deployment is expected no earlier than 2016.

Analysts and aircraft watchers in China say the aircraft's first flight was made on Aug. 31, 2009, powered by a Russian-supplied AL-31. Ukraine is the source of China's Su-33/Flanker D, U.S. analysts agree. "Russia's carrier training is done in Ukraine at Saki, and for years there was one of the first prototype Su-33s sitting there," one of the analysts says. "It disappeared a few years ago and likely ended up in China. The most recent photos of the J-15 show that they are either already entering low-rate initial production or close to it. I expect these [LRIP aircraft] to move to the training facilities soon and begin the long road to carrier qualification."

The first takeoff from a simulated ski jump was conducted on May 6, 2010.

The program began after a Su-33 prototype was acquired from Ukraine in 2001. China offered to buy Su-33s from Russia as recently as 2009. A Ukrainian court convicted a Russian man in February of conspiring to give the Chinese details of a Crimean air base that had been used to train Su-33 pilots to take off from a carrier's ski jump ramp, according to the New York Times.

In Huludao, a navy installation on China's northeast coast, workers are said to have built a rough clone of the Crimea test center, complete with a ski ramp for short takeoffs. "There are lots of photos of a [dry, ground-based] carrier training facility that has a static flight deck for crew training," the U.S. analyst says. "The facility is shaped like a carrier, with the dormitories and classrooms below the flight deck. It already has both a Flanker mock-up and a helicopter [onboard] to qualify deck and maintenance crews for carrier operations. Another facility at Xian has the ski jump for carrier takeoffs and the arresting gear network for landings. We expect to see these J-15s do a lot of work there."

Taiwan intelligence officials say the aircraft carrier — thought to be slated for a training role — could make its first voyage by the end of the year. The warship has been docked in China's eastern Dalian harbor, where it has undergone extensive refurbishing since 2002. "The carrier is also interesting in that it appears to be fitted with a close-in [Club-type cruise missile] weapons system," Barrie says.

U.S. intelligence analysts agree with the Taiwanese officials. "Just last month we started seeing the powerplants firing up, showing they are getting really close to going to sea trials sometime this year, [perhaps] as soon as this summer," the U.S. analyst says. "They've also discussed a second carrier [indigenously built] using the knowledge gained from their work on the one they bought from the Russians."

"This Google Earth Image shows an air-field outside Xian, in China's Shaanxi province, for pilots to practice take-offs and landings as if they were flying carrier-based aircraft. The tip of the runway, shown at top right, is warped up at an **angle of 14 degrees** just like an aircraft carrier to assist take-offs." http://www.asahi.com/english/TKY201008180284.html

http://www.east-asia-intel.com/eai/2009/08_26/list.asp

Photos of Chinese aircraft jumps point to continued development of carriers

"Satellite photographs have revealed for the first time that China has constructed a ski-jump aircraft carrier launch system at an in-land base, an indication that Beijing is moving ahead with plans for strategic naval power projection forces. The ski-jump ramp was located at Xian-Yanliang — a high- altitude location about 500 meters above sea level. A ski-jump style launch system is used on some Russian carriers. U.S. carriers use steam piston driven jet launchers."

http://www.east-asia-intel.com/eai/2009/Images/skij1.jpg

Beijing admits it is building an aircraft carrier

BY KENJI MINEMURA 17 December 2010 http://www.asahi.com/english/TKY201012160435.html

"BEIJING — China has officially admitted for the first time that it has embarked on an aircraft carrier building program, part of a grand strategy to "build itself up as a maritime power."

A report published by the State Oceanic Administration says the country's leaders decided last year to back plans to build China's first aircraft carrier. The Chinese government & military had kept the program under wraps until now.

The annual national ocean development report says that asserting China's power at sea is "indispensible to accomplishing the great resurgence of the Chinese people."

Chinese military sources said initial plans had called for launching a conventional powered carrier with a displacement of between 50,000 & 60,000 tons in 2015. But, with construction progressing quickly, the launch of the first Chinese-made aircraft carrier now appears to be set for 2014.

Construction has already begun at six military-affiliated companies & research institutes in Shanghai and other locations.

The plan calls for a nuclear-powered aircraft carrier to be launched by around 2020.

Meanwhile, the Varyag, a Soviet-era Kuznetsov-class aircraft carrier bought from the Ukraine, is undergoing repairs in the north-eastern port of Dalian and is expected to be pressed into service as a training vessel from 2012.

The Chinese military is developing a fighter jet to be used on its new carrier & 50 pilots have begun land-based training.

Facilities to train the pilots in landing & taking off at sea are being constructed at Xingcheng, Liaoning province, & Xian, Shaanxi province, & a full-scale model of an aircraft carrier has been completed in Wuhan, Hubei province, to test radar systems.

The report, written by a research institute affiliated to the State Oceanic Administration, sketches a strategy for expanding the reach of Chinese sea power and strengthening its ability to protect its maritime interests.

As part of that strategy, the report says, the Chinese military "came out in 2009 with a vision and plan to construct aircraft carriers." It also maps out a longer-term drive to build China into a mid-level maritime power by 2020, able to counter challenges & threats at sea.

The report indicates that possessing aircraft carriers is seen not only as necessary to compete with the United States, but also as a way to heighten patriotic sentiment in China.

Military sources said the Chinese leadership decided in April 2009 at an expanded meeting of the Communist Party's Politburo to give the go-ahead to the aircraft carrier building program.

But there appears to have been a tug-of-war within the Chinese regime about publicly announcing the program. Initial plans to announce the program were put off because of concerns that it would fan concerns in neighboring nations about the Chinese military threat.

However, the military has been insistent that the construction plan should be announced. The report by the State Oceanic Administration, an agency of China's land ministry with close ties to the Chinese Navy, may have been a convenient vehicle for that lobby.

All the aircraft carriers will likely be based at Sanya, a South China Sea port on the southern tip of Hainan Island."

Lianshan, Huludao?

In Huludao, a navy installation on China's north-east coast, workers are said to have built a rough clone of the Crimea test center, complete with a ski ramp for short take-offs.

"There are lots of photos of a [dry, ground-based] carrier training facility that has a static flight deck for crew training," the U.S. analyst says. "The facility is shaped like a carrier, with the dormitories and classrooms below the flight deck. It already has both a Flanker mock-up and a helicopter [onboard] to qualify deck and maintenance crews for carrier operations. Another facility at Xian has the ski jump for carrier takeoffs and the arresting gear network for landings. We expect to see these J-15s do a lot of work there."

http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=defense&id=news/asd/2011/04/27/02.xml&headline=New Chinese Ship-BasedFighter Progresses

"...[gave] Chinese details of a Crimean air base that had been used to train Su-33 pilots to take off from a carrier's ski-jump ramp, says the New York Times. In Huludao, a navy installation on China's northeast coast, workers are said to have built a rough clone of the Crimea test center, complete with a ski ramp for short takeoffs...."

http://www.aviationweek.com/aw/blogs/defense/index.jsp?plckController=Blog&plckBlogPage=BlogViewPost&newspaperUserId=27ec4a53-dcc8-42d0-bd3a-01329aef79a7&plckPostId=Blog%3a27ec4a53-dcc8-42d0-bd3a-01329aef79a7Post%3ae0019bc5-e488-488d-a55d-56cf54ed6ad4&plckScr

Russian sold secrets for China's first carrier—Ukraine sends him to prison

By Reuben F. Johnson – The Washington Times – Monday, February 14, 2011

http://www.washingtontimes.com/news/2011/feb/14/russian-sold-secrets-for-chinas-first-carrier/

"KIEV | Ukrainian authorities have imposed a six-year prison term on a Russian man convicted of spying for China who was assigned to steal military secrets for Beijing's program to build and operate aircraft carriers.

The Russian national, Aleksandr Yermakov, was blocked from attempting to transfer to China classified data that would have significantly accelerated the Chinese army's effort to field its own operational aircraft carrier, according to reports in the Ukrainian newspaper Segodnya and other news outlets.

China's military announced last year that it had begun construction of its first aircraft carrier, confirming Pentagon and U.S. intelligence reports that Beijing was seeking the power-projection platform that requires highly skilled pilots who can take off and land from the relatively short space of a carrier deck at sea....

...China's intelligence service directed Yermakov to steal classified information about Ukraine's Land-based Naval Aviation Testing and Training Complex, or NITKA, its Russian acronym, according to reports.

The facility is in the Crimea near the city of Saki and was built when Ukraine was a part of the Soviet Union. It remains the only training complex of its kind in the world.

The NITKA base is vital for states that operate one of the Russian-designed carriers equipped with ski-ramp takeoff decks, instead of the flat decks used on U.S. and French aircraft carriers.

The only two ski-jump carriers are the Russian navy's Admiral Kuznetsov and its sister ship, the Varyag, acquired by China from Ukraine in 1998 and initially announced in China for use as a floating casino. Russia continues training its pilots in Ukraine while building a similar facility in the Krasnodarsky Krai region of Russia that is expected to be completed in 2012....

...Chinese military officials have been quoted in China's state-run press as saying they plan to create a carrier-naval aviation capability; but "the Chinese need their own NITKA" for training their own carrier pilots, according to Ukrainian news reports, "and they have already begun building their own complex."

U.S. intelligence officials said the first indications of China's plan for building aircraft carriers were land-based short takeoff and landing drills going back a decade.

The Chinese are building a massive carrier pilot training base at Xingcheng, in the northeastern province of Liaoning. Other facilities for training of carrier personnel and engineering support specialists have been built in Xian, Shanxi province. The Xingcheng facility has features that duplicate the design of NITKA in Ukraine."

Chinese Naval Aviators Proliferate http://www.strategypage.com/htmw/htnavai/articles/20100817.aspx

“August 17, 2010: The Chinese Navy Air Force is now training its own fighter pilots (or "aviators" as they are known in the navy), and training them to operate from aircraft carriers. In the past, Chinese navy fighter pilots went to Chinese Air Force fighter training schools, and then transferred to navy flight training schools to learn how to perform their specialized (over open water) missions. Now, operating from carriers, and performing jobs carrier fighter pilots perform, has been added to the navy fighter pilot curriculum. It was only a year ago that China announced its first class of carrier aviators had begun training at the Dalian Naval Academy. The naval officers undergo a four year course of instruction to turn them into fighter pilots capable of operating off a carrier. The Russians warned China that it may take them a decade or more to develop the knowledge and skills needed to efficiently run an aircraft carrier. The Chinese are game, and are slogging forward.

For over five years now, China has been developing a carrier version of the Russian Su-27, calling it the J-15. There is already a Russian version of this, called the Su-33. Russia refused to sell Su-33s to China, when it was noted that China was making illegal copies of the Su-27 (as the J-11), and refused to place a big order for Su-33s, but only wanted two, for "evaluation." China eventually got a Su-33 from Ukraine, which inherited some when the Soviet Union dissolved in 1991. The first prototypes of the J-15 have been under construction for two years, and the aircraft is believed to have taken its first flight in the last few months. The Russians are not happy with this development. Russian aviation experts have openly derided the J-15, casting doubt on the ability of Chinese engineers to replicate key features of the Su-33. That remains to be seen, as the Chinese have screwed up copying Russian military tech in the past. But the Chinese have a lot of experience stealing foreign tech, so the J-15 may well turn out to be at least as good as the Su-33 (which Russia itself has stopped using as too large and expensive). Earlier this year, Google Earth revealed a Chinese air base where a mockup of the aircraft carrier Shi Lang (formerly the Russian Varyag) flight deck had been constructed. Here, Chinese carrier pilots will begin their training in the difficult task of landing on a carrier.

At the same time, the Shi Lang was moved into dry dock, apparently to install engines and other heavy equipment. It was only a year ago that this ex-Russian aircraft carrier, Varyag, was renamed the Shi Lang (after the Chinese general who took possession of Taiwan in 1681, the first time China ever paid any attention to the island) and given the pennant number 83.

The Varyag is one of the Kuznetsov class carriers Russia began building in the 1980s. No one is sure exactly what plans the Chinese have for the Shi Lang, despite the years of work. Currently, it's believed that the carrier will eventually be used to train the first generation of Chinese carrier aviators and sailors. Or maybe not. No one who really knows anything about the plans for the Shi Lang is speaking up. All is observation (from a distance, but good pix are numerous) and speculation.

The Varyag has been in a Chinese shipyard at Dailan since 2002. While the ship is under guard, it can be seen from a nearby highway. From that vantage point, local military and naval buffs have noted the work being done on the ship. A few obvious signs of this work are visible; like a new paint job (in the gray shade used by the Chinese navy) and ongoing work on the superstructure (particularly the tall island on the flight deck.) Many workers can be seen on the ship, and material is seen going into (new stuff) and out of (old stuff) the ship. Shipyard workers report ever tighter security on the carrier, and stern instructions to not report details of what is happening on the carriers.

Originally the Kuznetsovs were to be 90,000 ton, nuclear powered ships, similar to American carriers (complete with steam catapults). Instead, because of the high cost, and the complexity of modern (American style) carriers, the Russians were forced to scale back their plans, and ended up with 65,000 ton (full load) ships that lacked steam catapults, and used a ski jump type flight deck instead. Nuclear power was dropped, but the Kuznetsov class was still a formidable design. The thousand foot long carrier normally carries a dozen navalized Su-27s (called Su-33s), 14 Ka-27PL anti-submarine helicopters, two electronic warfare helicopters and two search and rescue helicopters. But the ship can carry up to 36 Su-33s and sixteen helicopters. The ship carries 2,500 tons of aviation fuel, allowing it to generate 500-1,000 aircraft and helicopter sorties. Crew size is 2,500 (or 3,000 with a full aircraft load.) Only two ships of this class exist; the original Kuznetsov, which is in Russian service, and the Varyag.”

Defense Strategies 20 Jul 2013

Without an appropriate military power, a small state is on the mercy of neighboring big states; which senses its sovereignty is under threat...

http://defensetiger.blogspot.com.au/2013/07/plan-naval-aviation-training-facility.html

PLAN Naval Aviation Training Facility

The People's Republic of China is in the process of jump starting a complete carrier aviation industry and capability for the People's Liberation Army Navy (PLAN), and doing it in relative short order. Nations like the United States, which commissioned it's first aircraft carrier, CV-1, USS Langley in 1922, have been operating carriers and establishing their doctrine through war and peace over the last 91+ years. China is attempting to pull it together in less than two decades.

INTRODUCTION

This development has occurred over the last 10+ years as the PRC purchased, transported to Dalian Shipyards, and then completely refurbished and refit the former Russian Carrier, Varyag, into their own, modern short-take off but barrier arrested (STOBAR) carrier, CV-16, the Lianoning. The Chinese had studied numerous carrier designs before this, including the older Austalian Carrier, HMAS Melbourne, and two of the older Russian Kiev class carriers which they had purchased to scrap and/or create theme parks out of them.

Towards the end of the construction/refit of the Liaoning, the PRC created an entire mockup of the carrier, from the hanger deck up, and set it atop a large research building on Lake Huangjia near Wuhan. This facility has continued to be developed and is now called the Wuhan Naval Research Institute. Deck handling, logistical considerations, armament and weapons handling, and hanger placement and movement of aircraft can all be researched and trained upon at this facility, which will be the object of a seperate article.

Shortly therafter, the PLAN announced and then displayed and flew the prototype of a new carrier strike fighter, the J-15, which is an indegenous, modernized version of the Russian SU-33 aircraft. This aircraft, in conjunction with the trials and commissioning of the Liaomning has now started Low Rate Initial Production (LRIP).

But simply having a carrier and having some fighters does not equate to carrier aviation. The individuals flying and maintaining the aircratf must also be developed, significantly trained, and steeped in carrier aviation doctrine, policy, and procedure. This is not an immediate process. It takes many years, and takes significant investment.

The PRC, and the PLAN in particular are in the process of making that investment.

After the commissioning of the Chinese carrier, the Liaoning, within a few months she departed the Dalian shipyards which gave her birth, and sailed to a new naval base that had been constructed for her near Qingdao on the East China Sea. This is her new home port, or home base, which was constructed at significant cost for the carrier and her escorts. This is a significant facility and will also be the object of another seperate article.

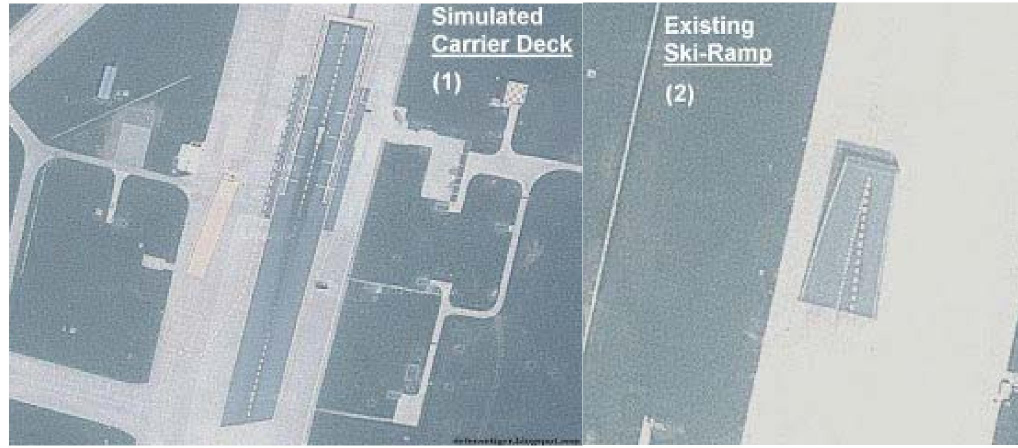
THE NEW NAVAL AVIATION TRAINING FACILITY

Throughout this later period, a new aviation facility and air base was being constructed on the shore of the Bohai Sea across from Dalian and well north of Tianjin. This base is a dedicated naval aviation training facility for the airwing personnel who will operate and maintain aircraft off of the Liaoning, and off of future carriers as well.

Here are the location of the four facilites discussed. The new Naval Aviation Training Facility, the Dalian Shipyards, the new Naval Base near Qingdao which is the home port of the new Chinese Carrier, and the Wuhan Naval Research Institute:

These features include all of the following:

1. A Simulated Aircraft Carrier Flight Deck



This has been laid out on a portion of the runway for the naval strike fighters, jet aircraft trainers, and helicopters to practice landing on. A close look at the "deck" indicates regular use from ongoing practice/training.

2. An existing Ski-Jump Ramp:

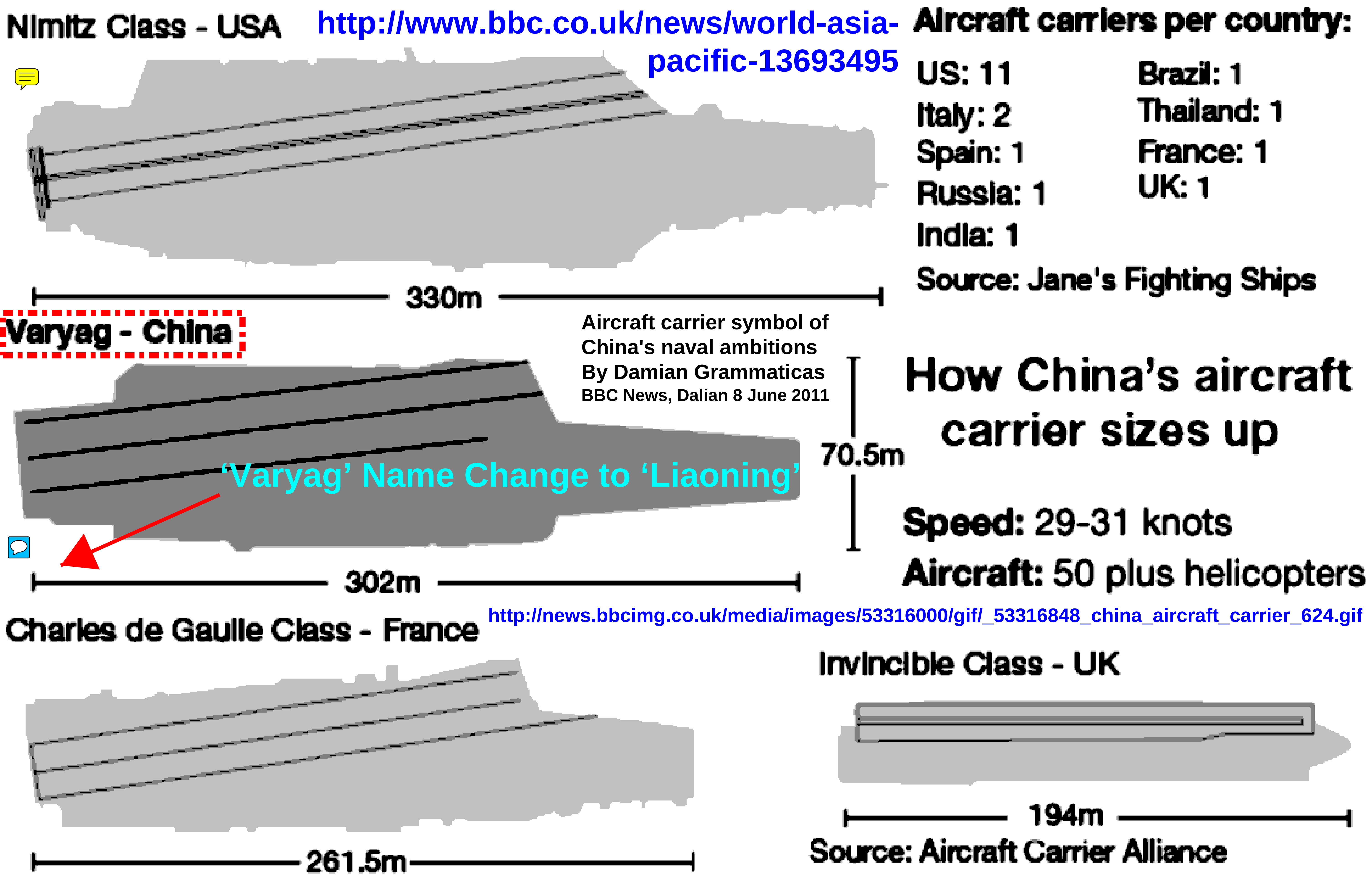
This ramp is an exact replica of the STOBAR ramp on the Liaoning and is being used to train pilots to take off ith the assistance of the ramp.

3. A New Build Ski-Jump Ramp:

This is a second ski-ramp for even more pilots to train off of. This indicates an increase in the tempo of the training/practise that will be going on at the base, training future carrier pilots for the PLAN carrier(s). If we focus on the new Naval Aviation Training Facility itself, we find a large naval air base, still under construction, with numerous major features:

http://www.bbc.co.uk/news/world-asia-pacific-13693495

Aircraft carrier symbol of China's naval ambitions
By Damian Grammaticas
BBC News, Dalian 8 June 2011



http://news.bbcimg.co.uk/media/images/53316000/gif/_53316848_china_aircraft_carrier_624.gif

China: First display of J-15 from carrier 14 Nov 2013 http://www.pprune.org/military-aircrew/527504-china-first-display-j-15-carrier.html#post8152130

'Engines': "...this way of operating aircraft (often called STOBAR – Short Take Off Barrier Arrested Landing) was looked at in detail during CVF requirements development. It was also looked at by the USN many years ago (in the 70s, I believe).

The basic issue with it is that you get relatively poor launch performance with CTOL aircraft. The key to ramp launches is that you fly off the deck going upwards, which means you have more time to accelerate to a speed where you start flying at a positive rate of climb.

Any aircraft has to attain a ramp exit speed that allows it launch at an acceptable initial sink rate, plus it has to be controllable. That sink rate will be driven solely by wing lift and whatever thrust if can get by being pitched up - although that will in turn cause significant drag. That will delay the ability of the aircraft to accelerate to normal climb out speed. For a conventional aircraft with aerodynamic controls, and no thrust vectoring, a ramp launch will not be achievable at anything like MGTOW off a runway. In fact, probably quite a long way below. The sort of thrust/weight ratios used for flying displays are quite a long way away from what you get when fully loaded for a strike mission, or even air defence work.

A STOVL aircraft (e.g Harrier, F-35B) has a couple of massive advantages off the ramp. The first is that they have a control system that works at flying speeds down to zero, so they don't have to rely on control surfaces. The second is that they can launch in a powered lift mode, where they can vector their thrust through their CG. That means that they can launch at well below aerodynamic stalling speed, & then progressively shift thrust aft as wing lift builds up. Sea Harrier typically had ramp end speeds of around 85 kts.

The 'vanishing chocks' are used to allow the aircraft get into full reheat at higher weights before they start rolling, to try to get the best ramp end speed they can. At higher weights, the effect is minimal. Harrier did look at using a 'hold back' for deck launches, but it was realised that the gain was not worth the complexity.

Bottom line is that CTOL ramp launches are not going to deliver the sort of payloads (fuel & weapons) that operational air arms require. This is basic physics and is not solved by marketing. Ask the 'Sea Typhoon' salesmen after a few quiet beers. The Chinese have recently gone public with some fairly severe criticisms of their aircrafts' performance off their new carrier, which seems to confirm the point...."

China Has Plans For Five Carriers – Jan 5, 2011 By Richard D. Fisher, Jr.

http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=defense&id=news/dti/2011/01/01/DT_01_01_2011_p71-272520.xml&headline=China Has Plans For Five Carriers

China's People's Liberation Army is assembling the production & basing capacity to make its aircraft carrier program one of Asia's largest military endeavors.

A plausible near-term projection for China's aircraft carrier ambitions was revealed in two 2009 articles in Japan's Asahi Shimbun newspaper, which featured rare access to Chinese military and shipbuilding sources. The sources noted that China would first build two non-nuclear medium-sized carriers similar to the 50,000-ton ex-Soviet/Ukrainian Project 1143.5 carrier Varyag being rebuilt in Dalian Harbor. These carriers would start initial construction in 2009. Beginning in 2020 or soon after, two 60,000-plus-ton nuclear-powered carriers would follow, based on plans for the Soviet-designed but never built Project 1143.7 Ulyanovsk class.

This would mean a likely fleet of five carriers by the 2020s, including Varyag, which entered a phase of accelerated reconstruction in 2009. Work surrounding this carrier is also serving to create the development and production infrastructure for future carriers. Since mid-2005, Varyag's reconstruction has been documented by images from Chinese military fans on dozens of web pages.

In April 2009, Varyag was moved from its Dalian berth to a nearby drydock. Surrounding the drydock are large ship-component construction hangars, from which the next carriers may emerge. By April 2010, the ship was berthed outside the drydock. Since the move the hull has undergone degaussing, likely in preparation for the now-visible outfitting of a new naval electronics suite. This suite will include four arrays for Chinese-developed naval phased-array radar and new rotating-array radar. Emplacements for the electronic warfare suite are visible.

A "Sinicized" model of a Varyag-like carrier, built in 2003 by students at Harbin Technology Institute, which does carrier development work, indicated it would carry a heavy fixed armament of YJ-63 long-range antiship cruise missiles, vertically launched medium-range surface-to-air missiles (SAMs) and Type 730 30-mm. close-in weapon systems (CIWS). Last November, however, Internet imagery indicated it might carry a lighter weapons suite. It will be the lead platform for the short-range FL-3000N SAM, similar to Raytheon's SeaRAM, though it carries 24 missiles. The imagery shows that Varyag will carry four FL-3000N launchers and at least two Type-730 30-mm. CIWS.

Varyag's air wing is becoming visible. Chinese Internet sources reported that the first flight of the Shenyang Aircraft Corp.'s copy of the Sukhoi Su-33 was in August 2009, and by early 2010 Internet imagery and a video confirmed Shenyang had copied the Su-33. Since 2005 Russian sourceshave insisted to this writer that China could not copy the Su-33, as it was a radical modification of the Su-27SK design. By 2009, these sources anticipated China would purchase an upgraded Su-33 as it developed its own version with a Chinese-designed WS-10A turbofan. In 2010, an Asian source said the PLA might not be pleased with its Su-33 copy, and would consider buying the Sukhoi-built version. Since 2005, negotiations have been held up over Russia's insistence that China buy a profitable number, around 40.

It is now expected that Shenyang will perfect its Su-33 copy, which will feature the latest Chinese-designed active phased-array radar, and new 5th-generation air-to-air missiles and long-range antiship missiles, such as an air-launched version of the YJ-63, with a range of 600-plus km. (373 mi.). Varyag may start its service with a multirole fighter more capable in some respects than the Boeing F/A-18E/F.

In 2010, Internet images appeared of a new airborne early-warning and control radar array of the size needed for a carrier aircraft. This followed a 2005 partial image of a turboprop-powered AEW&C. In October 2009, Internet images emerged of possibly retractable AEW&C radar on a Chinese Z-8 helicopter, which may form part of the initial air wing.

The PLA is also building escort ships for its carrier fleet. In the autumn of 2009 it appeared that two Chinese shipyards were building two new destroyer classes, but their configurations and equipment are not apparent. The PLA is expected to build up to 18 modern Type-065A air-defense frigates. Two new Type-093 nuclear-powered attack submarines (SSNs) have been built, and a more capable Type-095 SSN is expected.

When it enters service around 2015, the Varyag and its sisters, plus escorts, may be located at a recently constructed naval base near Sanya on Hainan Island.

Chinese Carrier Pilots Train with Brazilian Help

May 2009 http://informationdissemination.blogspot.com/2009/05/more-on-varyag-news-from-brazil.html

“Nelson Jobim, the Minister of defense for Brazil. “I think the important part is that Jobim is going to China this fall to basically finalize a deal that will allow Chinese naval pilots to train from Sao Paulo. You can see a little bit about the Sao Paulo aircraft carrier in its Wikipedia Page. I think it's kind of interesting that they chose Sao Paulo, because it's basically the only aircraft carrier with catapult and not serving for a country that current has military embargo on China. US will obviously not let PLAN train on its carriers and French navy probably will not either due to the embargo. I guess it shows that China is looking to build a CATOBAR carrier pretty soon. Otherwise, there really isn't any need to train on Sao Paulo right now. On the other hand, it's kind of curious that China is also planning to use NITKA training center, because that's probably preparing pilots for STOBAR carrier. Obviously, PLAN would be able to do more realistic training on Sao Paulo, but it would only have limited training schedule on Sao Paulo compared to NITKA. So, it looks like PLAN is just covering all the basis with its plans. On the whole, my guess is that Varyag will probably not equip any catapult, but the home built carriers will.

The other interesting part is that PLAN actually told Brazil that its building multiple carriers for power projection. We also heard a while back where a PLAN officer joked with USN about splitting power in Pacific Ocean (and I think there are definitely elements in PLAN that thinks this way). Also a couple of years ago, I remember reading Admiral Keating saying that PLAN officials were very forward about their intention to build aircraft carrier in private conversations (this was at a time when China was still sort of denying their aircraft carrier ambitions). I think this kind of conversation really contrasts with Chinese government's official statements. It seems like PLAN officers are more relaxed and transparent with their intention in private conversations through military exchanges than their civilian bosses are willing to be. In the past couple of years, I've seen many politicians and military personnel complaining about lack of reciprocal invitations from PLA after they had been fairly transparent toward visiting PLA delegation. I really think that PLA is still learning how to be more open with their intentions and such. And it is clear that contacts with other countries are helping them to build trust and understanding the importance of transparency. We are seeing PLA becoming more transparent recently (with its white paper and the 60th anniversary review). Only positive military engagements can direct PLA to become more transparent and reduce likelihood of a conflict.”

Lineup of 36 aircraft on China's Liaoning carrier revealed 28 Aug 2014 Cao Weidong

http://www.wantchinatimes.com/news-subclass-cnt.aspx?id=20140828000110&cid=1101

“China's first aircraft carrier, the Liaoning, can carry four Z-18J airborne early warning (AEW) helicopters, six Z-18F anti-submarine helicopters, two Z-9C rescue helicopters, and 24 J-15 shipborne fighter jets, the Chinese-language Shanghai Morning Post reported on Aug. 28. Cao Weidong, senior colonel and researcher at the People's Liberation Army Naval Research Institute, said the aircraft carrier could gain the upper hand in any potential battle for air or sea supremacy. The lineup may differ for various missions, however. The full lineup of 36 aircraft shows that the "PLA Navy's era of aircraft" has arrived, the report said.

On the tail of the Z-18F helicopter is the image of a sea eagle sprawling its talons, which suggests that the aircraft's mission is to seek out and attack enemy submarines, according to the paper. Cao said it is common practice to mark aircraft with physically tough and fierce animals to "show the spirit of bravery of the pilot and the craft itself." The helicopter has a shipborne sea search radar that enables 360-degree detection and is equipped with dipping sonar and the report speculated that it can carry 32 sonobuoys.

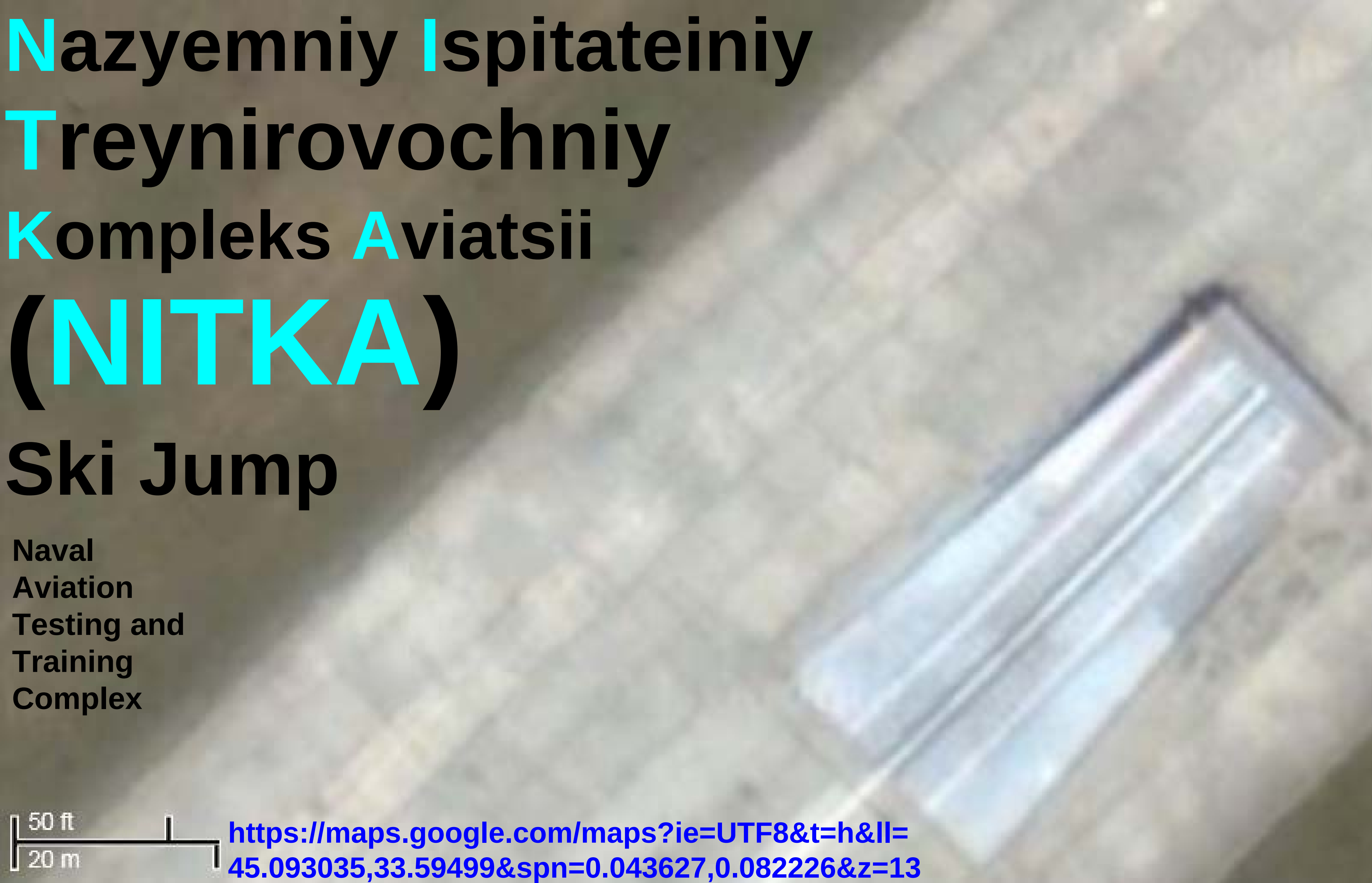
China is faced with a grave threat from the US, which owns the most advanced nuclear submarines, as well as Japan's Maritime Self-Defense Force, the report said. Countries operating in the South China Sea, particularly those engaged in territorial disputes with China, have also been strengthening their naval forces, putting pressure on China, said the report. The Z-9C helicopter's ZLC-1 radar can detect up to a range of 150 meters, while the Z-18F helicopter is equipped with four 7K anti-submarine torpedoes and four YJ-91 missiles.

"In offshore combat, we are mainly faced with challenges to defensive military operations," said Cao. "We need to power up anti-submarine capability to prevent offshore detection from potential opponents and to prevent a mine blockade."”

'NITKA', Ukraine, Crimean Peninsula

Nazyemniy **I**spitateiniy **T**reynirovochniy **K**ompleks **A**viatsii (**NITKA**) Ski Jump

Naval Aviation Testing and Training Complex



https://maps.google.com/maps?ie=UTF8&t=h&ll=45.093035,33.59499&spn=0.043627,0.082226&z=13

Russia, Ukraine Revise Nitka Facility Lease 2012 August 20

http://en.rian.ru/mlitary_news/20120820/175327497.html (RIA Novosti)

"Russia and Ukraine signed on Monday a protocol on amendments to an agreement on the rent of facilities on Ukraine's Crimean Peninsula for training of Russian carrier pilots. In line with a 1997 bilateral agreement, Russia occasionally uses the Nitka Naval Pilot Training Center in Ukraine as the only training facility for its carrier pilots. "During a meeting of a subcommittee [of the Russian-Ukrainian Interstate Commission], the sides signed a protocol on the use of the Ukrainian Nitka training facility by the Russian military," Russian Defense Minister Anatoly Serdyukov said.

The new protocol envisions monetary payment for the use of Nitka facilities, an unrestricted range of naval aircraft used for training and testing, and the possibility of sharing the center with third parties. Under the original agreement, Russia remunerated Ukraine for the use of the Nitka facilities with spare parts for Su-family naval fighter jets, which were the only type allowed to operate at the center. Russia & Ukraine were the only countries to use Nitka.

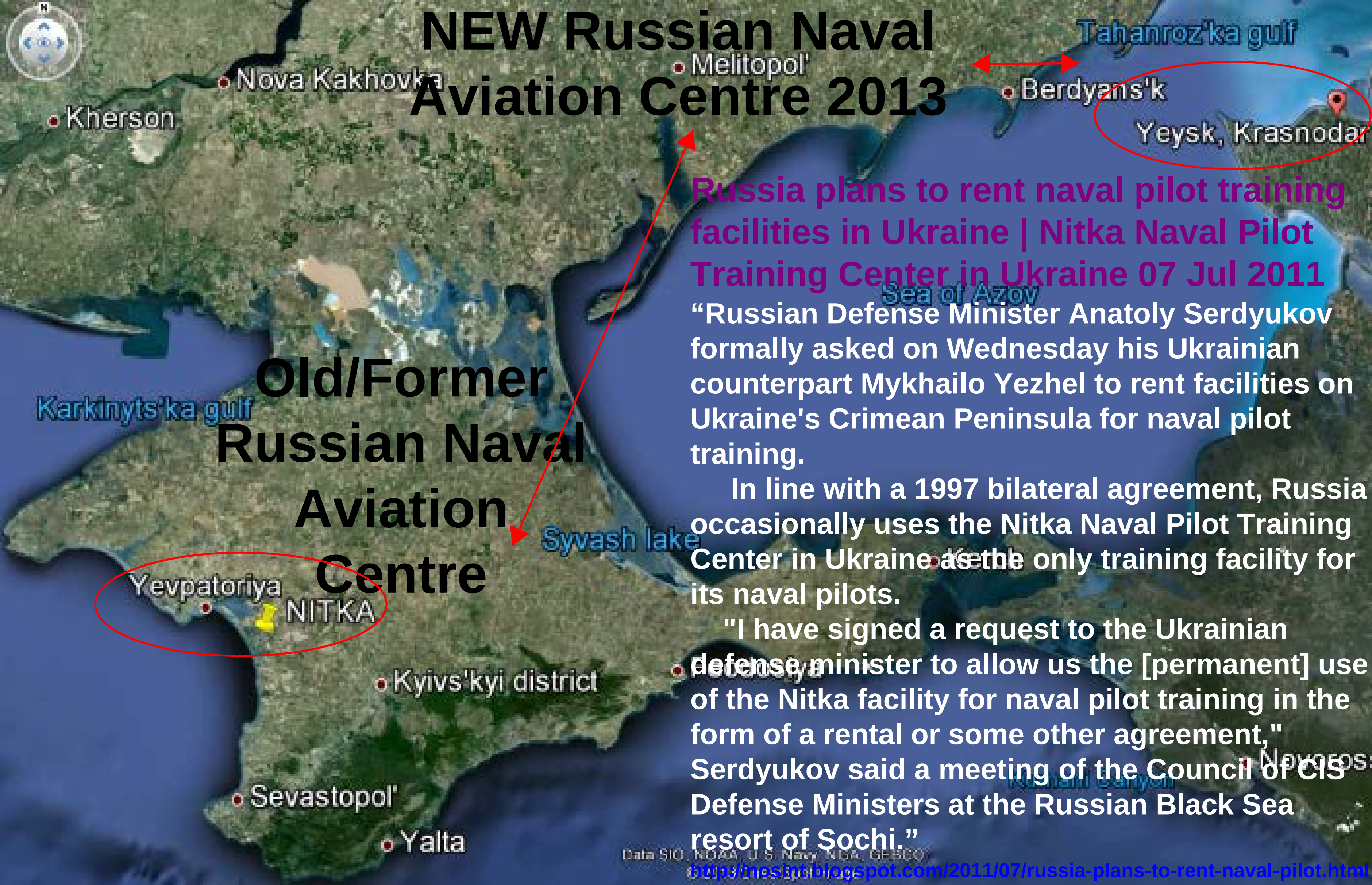
The Nitka Center was built in the Soviet era for pilots to practice their skills in taking off from and landing on an aircraft carrier's deck. After the collapse of the Soviet Union in the early 1990s, the facility remained under Ukrainian jurisdiction.

The center provides naval aviation training facilities such as a launch pad, an aerofinisher, a trampoline, a catapult launching device, a glide-path localizer, a marker beacon, and an optical landing system. Serdyukov earlier said the Russian Defense Ministry pays about $700,000 annually for the rent of the Nitka Center and is willing to upgrade this facility.

Russia, which has only one aircraft carrier - the Admiral Kuznetsov - is aiming to finish drafting plans for a new nuclear-powered aircraft carrier for its Navy by 2018."

NEW Russian Naval Aviation Centre 2013

Old/Former Russian Naval Aviation Centre



Russia plans to rent naval pilot training facilities in Ukraine | Nitka Naval Pilot Training Center in Ukraine 07 Jul 2011

“Russian Defense Minister Anatoly Serdyukov formally asked on Wednesday his Ukrainian counterpart Mykhailo Yezhel to rent facilities on Ukraine's Crimean Peninsula for naval pilot training.

In line with a 1997 bilateral agreement, Russia occasionally uses the Nitka Naval Pilot Training Center in Ukraine as the only training facility for its naval pilots.

"I have signed a request to the Ukrainian defense minister to allow us the [permanent] use of the Nitka facility for naval pilot training in the form of a rental or some other agreement," Serdyukov said a meeting of the Council of CIS Defense Ministers at the Russian Black Sea resort of Sochi.”

http://nosint.blogspot.com/2011/07/russia-plans-to-rent-naval-pilot.html

Russia to Open Carrier Pilot Training Site by Fall

15 Mar 2013 http://en.ria.ru/military_news/20130315/180041642.html

"MOSCOW, March 15 (RIA Novosti) – A new Russian carrier-deck pilot training site will be ready for operation by fall, the Federal Agency for Special Construction Work confirmed on Friday, replacing a Soviet-era base in Ukraine which Kiev has said it may lease to other countries. "The construction work there is effectively complete. I believe aircraft will start flying there in August or September," Grigory Naginsky, head of the Federal Agency for Special Construction Work (Spetsstroi) said. Former Russian Navy chief Adm. Vladimir Vysotsky had previously said the training facility in the city of Yeisk, on Russia's Black Sea coast, should be complete by 2020.

Earlier in March, Ukrainian First Deputy Defense Minister Oleksandr Oleinik said Ukraine, which does not operate fixed-wing ship-borne naval aircraft, was considering leasing out its Nitka training site in Crimea to other countries. Under a 1997 bilateral agreement, Russia occasionally uses Ukraine's Nitka Naval Pilot Training Center, the only land-based training facility for its carrier-based fixed-wing pilots. At present, the site is only used by Russia on a short-term basis to train Northern Fleet carrier pilots, who fly Su-33 naval fighter jets and Su-25UTG conversion trainers for Russia's sole carrier, the Admiral Kuznetsov.

The Nitka Center was built in the Soviet era for pilots to practice taking-off and landing from aircraft carrier decks. After the collapse of the Soviet Union in 1991, the facility remained under Ukraine's control. The center provides facilities such as a launch pad, a catapult launch device and arrester wires, a glide-path localizer, a marker beacon, and an optical landing system. The Russian Defense Ministry has previously asked the Ukrainian Defense Ministry to lease the site to Russia. Ukraine's then-Defense Minister Mykhailo Yezhel supported Russia's request. However, a firm deal for the Russia lease option was not clinched, Oleinik said earlier this month, so the Ukrainian Defense Ministry was looking at other options for using it.

"India and China are the obvious potential candidates for this," Douglas Barrie, air warfare analyst at the London-based International Institute for Strategic Studies, said earlier this month. India is awaiting delivery of a refurbished Russian aircraft carrier which will operate Russian MiG-29K fighter jets. China only has one carrier, from which naval aircraft were seen operating for the first time last year, and has little experience of fixed-wing naval operations. Most other aircraft carrier operators either use short take-off/ vertical landing (STOVL) aircraft whose crews would not need a facility like Nitka, or have their own such facilities, or use only ships for training.

Under the original agreement, Russia traded use of the Nitka facilities for spare parts for Sukhoi-family naval fighter jets, which were the only type allowed to operate at the center. Russia and Ukraine were Nitka's only users. In August, Russia's then-Defense Minister Anatoly Serdyukov said Russia and Ukraine had signed a protocol on amendments to that agreement, setting out payment for using the site, unrestricted use of a range of naval aircraft for training & testing, & the possibility of sharing the center with third parties. The Russian Defense Ministry said last year it was paying about $700,000 annually to rent Nitka and was willing to upgrade the facility. Russia, which has only one aircraft carrier – the Admiral Kuznetsov – is drawing up plans for a new nuclear-powered aircraft carrier for its Navy by 2018."

CVF ski-jump ramp profile optimisation for F-35B http://www.raes.org.uk/pdfs/3324_COLOUR.pdf Feb 2009

A. Fry, R. Cook and N. Revill, THE AERONAUTICAL JOURNAL FEBRUARY 2009 VOLUME 113 NO 1140

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The ski jump ramp works by imparting an upward vertical velocity and ballistic profile to the aircraft, providing additional time to accelerate to flying speed whilst ensuring it is on a safe trajectory. This additional time is manifested either in a reduced take-off length for a given weight, or increased weight (i.e. launch performance) for a fixed take-off distance as in a ship based STO.

The additional performance does not come for free, with a significant increase in landing gear loads above those of a standard take off (which are very low compared to a landing). The increase represents the energy transferred to the aircraft as it translates up the ramp; and if the angle and curvature of the ramp are increased to obtain greater performance benefit, so are the loads. This is tolerable up to a point because the gear strength is defined by landing events and thus has the ability to accept the increased take-off loads, but loads act as an upper boundary on permissible ramp size, as illustrated in Fig. 5.

The ideal landing gear vertical load time history for a ski jump ramp STO is sketched in Fig. 6, with a rapid increase to a steady maximum where the area underneath the curve represents the energy imparted by the ramp. However, the actual loads are different, and reflect the complex dynamic response of the gear components as they enter and travel up the curvature of the profile.

References 1, 2 and 3 describe in further detail the principles behind the ski jump and its advantages as part of a STO manoeuvre compared to a flat deck launch and the design of the profile is described later.

It should be noted that non-STOVL aircraft can benefit from a ski jump manoeuvre, as illustrated by the Russian use of ramps with conventional type aircraft from their carriers. STOVL aircraft are unique however because of the flexible and complex manner in which the thrust and control effectors generate combinations of thrust and forward speed in conjunction with the speed dependent wing lift...."

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At the core of a ski jump performance analysis is the assessment of whether a launch case is achievable or not. The minimum safe launch is defined where the ramp exit speed does not result in any rate of descent during the trajectory until the aircraft has transitioned to fully wing-borne flight. This results in the launch profile shown in Fig. 8, with an inflection point at which the crit-eria for a successful launch are assessed.

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CVF ski-jump ramp profile optimisation for F-35B

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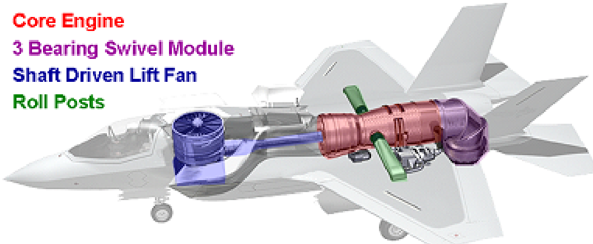
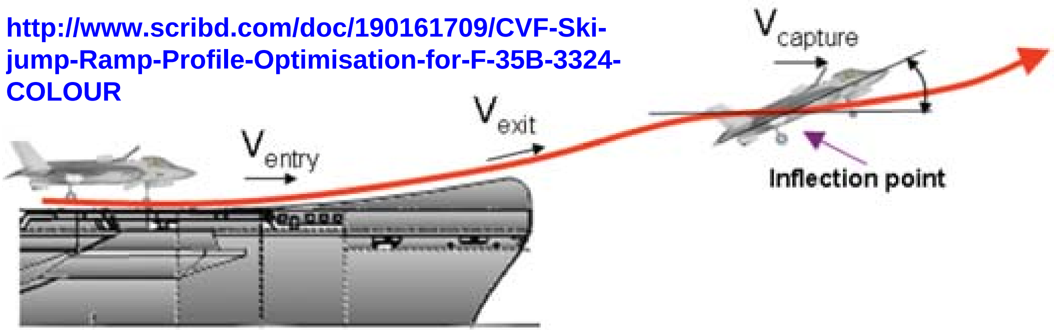
A. Fry, R. Cook and N. Revill
anthony.fry@baesystems.com

BAE Systems
Warton
UK



THE AERONAUTICAL JOURNAL FEBRUARY 2009 VOLUME 113 NO 1140

http://www.scribd.com/doc/190161709/CVF-Ski-jump-Ramp-Profile-Optimisation-for-F-35B-3324-COLOUR



ABSTRACT

This paper presents a summary of the principles and processes used to design a ski-jump ramp profile for the UK's Future Aircraft Carrier (CVF) optimised for the Joint Strike Fighter (JSF).

The paper includes an overview of the CVF and JSF programs, a history and summary of the ski-jump ramp and the principles of its use in the shipborne Short Take-Off (STO) manoeuvre.

The paper discusses the importance of defining optimisation boundaries including specified objectives, aircraft configurations and environmental conditions. It then demonstrates the process of balancing the design drivers of air vehicle performance and landing gear loads to achieve an optimum profile. Comparisons are made between the proposed candidate CVF ramp profile and the current in service ski-jump design as designed for the Harrier family of aircraft.

The paper briefly covers some of the important issues and factors that have been experienced when a theoretical profile is translated into a physical ramp fitted to a ship, principally the effects on aircraft operations due to build and in-service variation from the nominal profile.

NOMENCLATURE

3BSM	3 Bearing swivel module
ACA	aircraft carrier alliance
CG	centre of gravity
CTOL	conventional take-off and landing
CV	carrier variant
CVS	anti submarine carrier (descriptor for the *Invincible* class of ships)
CVF	UK future aircraft carrier project
CVFIST	CVF integration support team
DEFSTAN	UK MoD defence standard publication
Dstl	Defence Science and Technology Laboratory
EC	environmental condition (e.g. Hot/ISA day)
JCA	UK joint combat aircraft project
JSF	Joint Strike Fighter
SDD	system development and design phase
STO	short take-off
STOVL	short take-off and vertical landing
TJSF	Team JSF

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1.0 THE JSF AND CVF PROGRAMS

1.1 Overview of the JSF program

Team JSF (TJSF) comprises Lockheed Martin, BAE Systems and Northrop Grumman and will produce the JSF aircraft in three variants: conventional take-off and landing (CTOL); carrier based variant (CV); and a short take-off and vertical landing (STOVL) aircraft. This paper deals with the STOVL aircraft, designated F-35B, which is currently selected by the UK as its Joint Combat Aircraft (JCA), to be operated by the Royal Navy and Royal Air Force replacing the existing Harrier fleet.

1.2 overview of the CVF programme

The Future Aircraft Carrier (CVF) programme is managed by the Aircraft Carrier Alliance (ACA), an industry and government consortium, and will produce two new carrier vessels entering service from 2014 to replace the existing Invincible class of ships and is illustrated with the F-35B in Fig. 1.

These carriers will act as the UK's mobile air-base, operating and supporting a wide variety of aircraft in support of UK expeditionary operations – obviating the need to rely on other countries co-operation. The embarked air group will primarily consist of JCA but will also include Airborne Surveillance and Control, Maritime, Support, Attack and Battlefield helicopters depending on the mission.

In the Carrier Strike role, up to 36 JCA will be embarked, capable of operating in all weathers, day and night; providing a long range strike capability in addition to air defence and offensive support to the fleet and ground troops.

1.3 CVF integration support program

This program and team was established as part of TJSF and tasked to provide existing and newly generated engineering information to support the ACA in the integration of F-35B with CVF.

Figure 1. Artists impression of CVF and F-35B.

Figure 2. F-35B and its STOVL Propulsion and Lift System.

Although the ramp is physically part of the ship and responsibility for its manufacture and installation lies with the ACA, its profile is entirely based on the aircraft characteristics and for this reason the development of a profile optimised for the F-35B was conducted by the CVF Integration Support Team (CVFIST) on behalf of Team JSF in 2006 and 2007.

1.4 F-35B STOVL lift and propulsion system

The F-35B has a number of unique elements that facilitate its STOVL capability, and these are critical in the optimisation of a ski jump ramp profile for the aircraft. A basic description of the layout and function of the lift and propulsion system is shown in Fig. 2 and described below:

- a Lift Fan driven by a shaft from the main engine which provides vertical lift through a variable area vane box nozzle using louvered vanes to vector thrust between vertically downwards and partially aft.
- a three-bearing swivel module (3BSM), which vectors the main engine exhaust thrust from the core engine through vertically downwards to fully aft – the latter being the default for conventional mode flying.
- roll nozzles, ducted from the engine and exiting in each wing providing roll control and vertical lift. These are closed off during the initial portion of the short take-off (STO) in order to maximise forward thrust from the main engine, opening towards the end of the ramp in order to provide control and lift during the fly out.

2.0 THE SKI JUMP RAMP

2.1 Background and history of the ramp

The ski jump ramp was conceived by a Royal Navy officer in the 1970s and subsequently developed by the UK services, industry and Government as a way of increasing the STO launch payload for the Harrier. It has since become an integral part of embarked operations for UK and most foreign Harrier operators.

The first operational ramp was fitted to HMS *Hermes* (see Fig. 3) in 1979 and was a 12 degree ramp; as defined by the angle to the horizontal of the tangent at the last point on the profile.

The Invincible class of Anti-Submarine Carriers (CVS) were modified during building to accommodate the Sea Harrier aircraft and were completed with a 7 degree ramp in the early 1980s. This lower angle was chosen to avoid obstructing the firing arcs of the Surface to Air Missile system fitted to this class although giving less launch performance benefit. Due in part to the success of the Harrier in the 1982 Falklands war these ramps were replaced by a larger 12 degree design later in the 1980s. The ships and their ramps have given valuable service to the UK through to this day with successive generations of the Harrier family, as Fig. 4 illustrates.

Figure 3. HMS *Hermes* with first 12° ski jump ramp.

Figure 4. HMS *Illustrious* with retrofitted 12° ramp.

2.2 Principles of the ski jump

The ski jump ramp works by imparting an upward vertical velocity and ballistic profile to the aircraft, providing additional time to accelerate to flying speed whilst ensuring it is on a safe trajectory. This additional time is manifested either in a reduced take-off length for a given weight, or increased weight (i.e. launch performance) for a fixed take-off distance as in a ship based STO.

The additional performance does not come for free, with a significant increase in landing gear loads above those of a standard take off (which are very low compared to a landing). The increase represents the energy transferred to the aircraft as it translates up the ramp; and if the angle and curvature of the ramp are increased to obtain greater performance benefit, so are the loads. This is tolerable up to a point because the gear strength is defined by landing events and thus has the ability to accept the increased take-off loads, but loads act as an upper boundary on permissible ramp size, as illustrated in Fig. 5.

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3.0 RAMP DESIGN PROCESS

Figure 7 illustrates the overall concept adopted for the design of the CVF ramp and this was strongly influenced by the documentary evidence and guidance from previous ramp design tasks. References 4 to 7 and the acknowledgements reflect drawing on past experience and knowledge, and the team's contribution was to then optimise it to the F-35B aircraft using TJSF analysis tools.

4.0 REQUIREMENTS

4.1 Defining optimisation parameters

An essential first step in the process was to specify criteria that would bound the task and provide measures for driving the design and evaluating its success. Without having these to reduce the design space to manageable boundaries, optimising for the 'best' ramp could be equated to 'how long is a piece of string ?'.

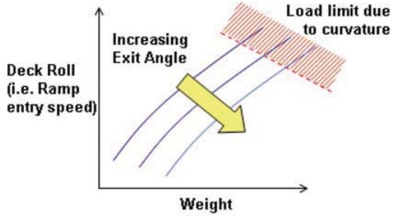

Figure 5. Ramp design drivers.

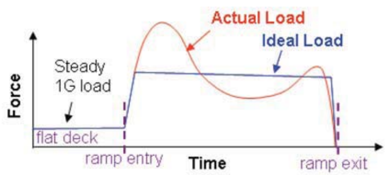

Figure 6. Ideal and Actual Ramp Landing Gear Vertical Load Profiles.

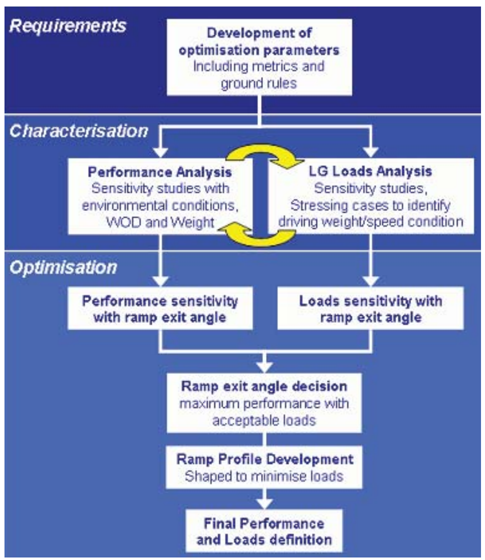

Figure 7. Ramp Design Process.

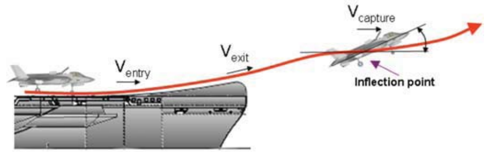

Figure 8. Ski-jump launch profile.

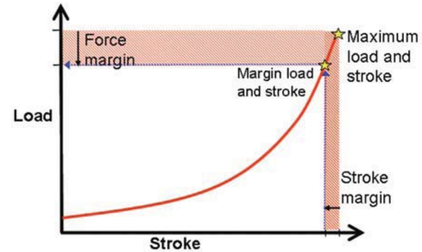

Figure 9. Landing gear loads/stroke margin.

Reference 8 details the work performed by Dstl to examine the key factors and CVF/JCA requirements which influenced this task, in particular, development of the key performance and loads cases in terms of aircraft configurations and environmental conditions which formed the customers objectives. Other ground rules such as take off distances, maximum ramp length and height constraints, wind over deck speeds (WOD) and ship motion factors were also generated prior to the main analysis which was based on legacy experience with Harrier analysis, TJSF SDD best practice, and sensitivity studies of performance and loads to identify sensible values and ranges.

Previous assessments considered pilot view of the sea and deck as well as handling qualities which were found to be benign for ski-jump STOs and since they do not drive the design of the ramp, are not discussed further.

4.2 Safe launch metric

At the core of a ski jump performance analysis is the assessment of whether a launch case is achievable or not. The minimum safe launch is defined where the ramp exit speed does not result in any rate of descent during the trajectory until the aircraft has transitioned to fully wing-borne flight. This results in the launch profile shown in Fig. 8, with an inflection point at which the criteria for a successful launch are assessed.

There are two safe launch criteria derived from legacy STOVL experience that are used on the JSF program, of which the more stressing is adopted: (a) subtracting a margin from the WOD and requiring zero sink rate (known as Operational WOD); and (b) using the full value of WOD but requiring a defined positive rate of climb. Both also require a threshold forward acceleration.

4.3 Landing gear loads metric

In a ski jump STO event, the gear axle load is almost entirely in the vertical direction represented by F_z. Additionally, because the rate of application of load is relatively slow in comparison to a landing event, the load and stroke can be considered to approximately track the airspring force/displacement curve as shown in Fig. 9.

The maximum load and stroke are defined by the limit load and bottoming stroke of the landing gear, but it is necessary to set an optimisation metric below this in order to generate an engineering margin.

This margin primarily accounts for variation between the mathematical profile derived during the analysis and the 'as-built' steel structure that flexes with the operation of the ship and can develop a permanent deformation. Legacy experience is explicit that this build and in-service physical variance can result in gear load increases of a severity requiring operational performance restrictions.

Graphically illustrated in Fig. 9, the load margin is obtained by specifying a minimum remaining strut stroke in the worst loading case based on legacy experience, applying this to the load/stroke curve and using the resulting load/stroke point as the metric against which launch cases are assessed.

5.0 CHARACTERISATION

5.1 Performance

The sensitivity studies initially used the existing CVS ramp profile as a baseline, and showed that the high weight configurations at higher ambient temperatures were the most stressing in terms of what payload capability was achievable. Figure 10 displays a performance characterisation at different environmental conditions (EC 1 to 4) with the CVS ramp, and showing the target configuration (weight) is achievable bar the most stressing condition.

A nominal case from which comparisons could be made against past and baseline predictions of performance was developed, as were a range of weight cases in order to provide the on-ramp schedules of control effectors (nozzle angles, thrust split and elevator angle) for use in the landing gear loads analysis. The effects of varying WOD and aircraft CG were also investigated.

For the F-35B, optimum scheduling of thrust and control effectors is a vital component of maximising the performance benefit of a ski jump ramp and this was assumed possible based on SDD practice. Optimum scheduling after leaving the ski-jump was achieved using a theory developed by Dstl and outlined in Ref. 9.

5.2 Loads

For loads, the gear response on entering the ramp is essentially a function of energy, i.e. mass and speed, and it was necessary to investigate a range of weight and speed cases in order to identify the worst case in order to then use that as a 'working' case for the optimisation phase. This balance is not intuitive since the highest weights are only achievable with higher WOD speeds and the gear loading may be offset by the additional wing lift. The opposite case, at lighter weight but with excess deck run and thus high entry speed, was included for balance.

The sensitivity to changes in the control effector scheduling was investigated in order to understand how changes to these to optimise for performance can impact loads – as were centre of gravity (CG) variations, different WOD speeds, use of external stores (for their aerodynamic drag increment effect on speed, forces and moments) and different methods of modelling the strut internal pressures.

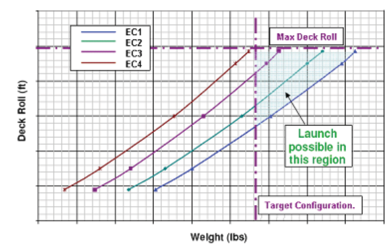

Figure 10. Launch envelope for CVS ramp.

To account for ship motion due to the sea state, a delta was added to the value used for gravity (ΔG). This is a legacy approach and replaces the huge matrix of pitch, roll and yaw attitudes, velocities and accelerations of the ship and aircraft with a single factor.

Figure 11 shows the main gear axle load for the worst weight and and speed case at 1G and 1+ΔG, using both short and long ramps of the same exit angle as a way of examining the effect of ramp curvature on gear loads.

This phase of the work demonstrated that for the worst case launch the CVS ramp would breach the load metrics applied, but also indicated that using additional length, thus reducing the curvature, could alleviate this.

6.0 OPTIMISATION

This phase centred on the selection of a ramp exit angle and the shaping of the ramp profile to achieve this.

6.1 Performance

Analysis showed that performance is affected primarily by the exit angle, with diminishing aircraft performance returns from increasing exit angle. Figure 12 shows the trend of launch benefit 'flattening off' as the exit angle increases above the CVS datum.

This flattening off is more severe than seen in legacy Harrier analysis, but exists due to the fundamental differences in the F-35Bs STOVL propulsion system. For the F-35B, with increasing ramp exit angle, the nozzle vector angles and thrust split (between lift fan and core) required to trim the aircraft mean the propulsion system is not operating at the point at which maximum total system thrust is generated, thus reducing the air path acceleration. At higher weights the acceleration reduces below the minimum threshold, as shown in Fig. 13.

This lower air path acceleration results in the initial post-exit increased height rate benefit of higher exit angles being washed out to approximately the same as lower exit angles by the end point of the analysis, as demonstrated in Fig. 14.

This balance is indicative of the complexity of optimising the performance, other factors including the need during the STO manoeuvre to angle the core nozzle downwards slightly in order to offset the lift fan vertical thrust (since its aft angle is restricted) and ensure a minimum nose gear load for adequate steering.

6.2 Loads and exit angle decision

Using the loads metric as an upper boundary achieves the most efficient ramp, as defined by imparting the maximum upward momentum without exceeding the loads metric. A range of ski jump ramps were created using the longer version of the CVS angled ramp as a template to design higher angled ramps. Figure 15 shows the nose and main peak gear loads generated.

From this it can be seen that the nose gear is well below the metric for all angles, and that a maximum exists for the main gear.

The maximum exit angle dictated by the gear loads is 12·5 degrees, slightly greater than the CVS angle, and was selected as the ramp exit angle for the following reasons:

- The loads are at their maximum tolerable threshold as defined by the metrics.
- The level of performance derived from this angle is comparable with the requirements.
- CVS ramp performance capability is achieved, but with acceptable loads.

6.3 Ramp profile design

Having identified a suitable exit angle, effort was then focussed on developing a detailed profile. A ski jump ramp can be characterised as having three distinct parts, as illustrated in Fig. 16.

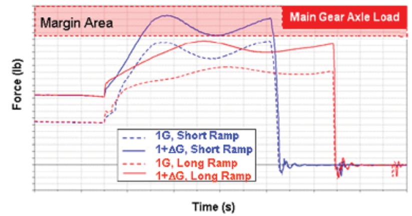

Figure 11. Axle loads for long and short ramps, 1 and 1+ΔG.

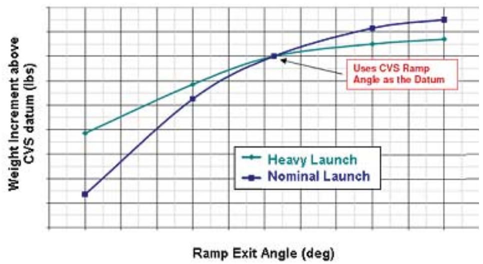

Figure 12. Performance variation with ramp exit angle.

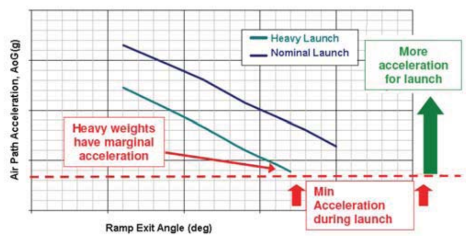

Figure 13. Air path acceleration against ramp exit angle.

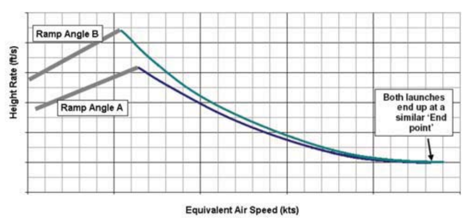

Figure 14. Height rate against air speed for varied ramp exit angle.

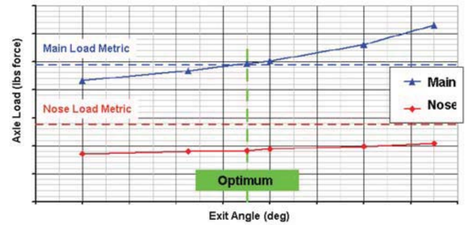

Figure 15. Gear load variation with ramp exit angle.

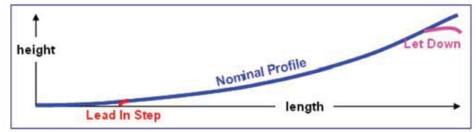

Figure 16. Elements of a ski-jump ramp profile.

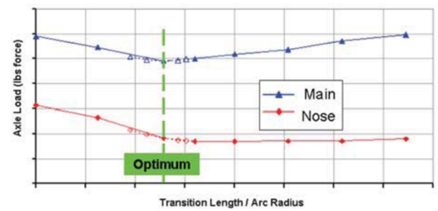

Figure 17. Gear Loads against ramp profile index.

The method used to generate the nominal profile was that of a cubic transition into a circular arc, consisting of a fixed transition length and a fixed radius of curvature, an approach common in engineering disciplines, e.g. railway track transitions from straight sections into corners and aerodynamic streamlining. Geometric relationships are used to match the tangency at the end of the cubic transition curve with the start of the circular arc. Overall height and length are outputs and creating a ramp to satisfy constraints in these requires iteration. The key advantage is that the curvature can be controlled in two easily understood and modifiable variables that relate directly to the profile and loads.

There are alternative ways of generating the nominal profile, described in the references, but the 'cubic plus transition' was deemed the most effective. Trials with other methods proved them to be significantly more complex to use with no observable benefits.

The lead-in step intersects the nominal profile allowing the section prior to this, which consists of negligible height (and thus of minimal benefit whilst also being difficult to manufacture) to be eliminated so the length freed up can be used for a higher radius of curvature. The resulting load spike at the step is within load limits and actually aids the overall process by rapidly increasing the load towards the steady maximum as in Fig. 6, which also reduces the peak of the overshoot on ramp entry, particularly for the nose gear.

The let down was added to previous ramps when it was discovered that the rapid unloading of the gear at ramp exit caused loading problems and there was a requirement to provide a section of ramp that would restrain the gear from uncompressing too quickly. Note that the CVS 12° ramp is actually now 11·26° as a result of converting the last section of the ramp to a let down – and entailing a slight performance reduction.

6.4 Profile development

This looked at a large number of ramp profiles using a wide range of transition length and arc radius values, of which the key conclusions were:

- Short transition lengths produce high load overshoot peaks and oscillations on the first part of the ramp. These outweigh the benefit of reduced loads from the higher circular arc radius later in the ramp.
- Long transition lengths produce much lower initial load peaks, but to remain within the overall design length the circular arc radius has to be increased, producing a counteracting load peak.

The combined effect of varying transition length and circular arc radius is to vary the concentration of curvature in different parts of the ramp. With both of these linked by the requirement to fit an overall length constraint, it was necessary to combine transition length and circular arc radius into a single variable, and in Fig. 17 this is plotted against the peak gear loads for the ramps that demonstrated broadly acceptable loads.

The minimum point in each curve represents its optimum, and it is clear that it differs for the nose and main gears. With the main gear identified as driving the ramp optimisation (see Fig. 15) – then it is from this optimum point that the detailed profile is derived.

6.5 Quartic profile

The use of a polynomial equation to represent the ramp profile is reflected in that the transition is a cubic and the circular arc a quadratic. The use of a single cubic or quartic equation to define a profile was mentioned previously as a method but, although unsuccessful in direct application, the effort did highlight the advantage that a curve to a quartic equation has a smoother variation of curvature and offers the advantages of a less oscillatory load profile and a lower peak. A least squares fit method was used to convert the optimum cubic transition plus circular arc profile to a quartic curve, and the variation of curvature is plotted in Fig. 18.

This demonstrates the subtle change in curvature, and Fig. 19 shows the significant change in gear loads resulting.

In addition to the slight reduction in peak gear loads, the load trace exhibits beneficial features with less oscillatory behaviour and a marked turndown towards the end of the ramp. The latter is of considerable value as it eliminates the new load peak being generated in the original profile. Note also that the nose gear sees a slight increase in both peak load and its oscillatory tendencies, although there is still a large margin available.

6.6 Lead in and let down

Figure 19 also shows the rapid load increase at the ramp entry and the lead in, in this case a rounded step. Assessment of different sized steps, as well as using much longer lead-ins was conducted with little or no difference noted. A decision was taken to use a similarly sized step as the CVS ramp on the grounds that this approximated the diameter of runway arrestor wires used for trampling analysis in the main SDD program and which show similar acceptable loadings.

The let down was designed as an ellipse, blending from the tangent at the end of the nominal profile to the horizontal, where it would interface with the proposed aerodynamic fairing that sits ahead of the ramp.

7.0 CANDIDATE RAMP DEFINITION

The CVF candidate ramp was defined as a 12·5 degree angled ramp with the profile achieved by combining a nominal profile based on a quartic fit to an optimum cubic transition plus circular arc, a rounded step lead in and an elliptic let down. Definitive performance and landing gear loads data were generated to demonstrate the resulting capability and compliance with the metrics.

8.0 OTHER RAMP DESIGN ISSUES

In addition to the single event performance and loads analysis used to optimise the ramp profile, other aspects were considered for CVF ramp optimisation:

- Cyclical loading: fatigue impact was assessed and found to be significantly lower for the candidate ramp than a CVS ramp.
- Weapons physical clearance: to ensure that the carriage of bulky external stores (e.g. stand-off missiles or fuel tanks) does not result in parts of these breaching minimum clearance distances due to the curvature of the ramp. Worst case store loadings with combinations of fully flat tyres and compressed struts confirmed no clearance breaches.

8.1 Manufacturing

The ramp profile must be transformed into a physical structure, and to do this build tolerances on the candidate profile are required. Figure 20 illustrates the elements of the ramp profile and the issues related to manufacturing.

As discussed earlier, a margin was applied to the loads metrics in order to account for variations between the mathematical profile derived during the analysis and the 'as-built' structure. To ensure this margin was sufficient and to provide the ship builders with useful guidance regarding build tolerances, analysis was conducted on each of the elements and issues:

- Segment size: this is the discretisation of the ramp when specifying ordinates and represents the size of each flat plate that forms the curve. Increasing segment length raises the angle between each plate leading to load spikes.
- Co-ordinate accuracy; this represents the accuracy to which the theoretical curve is converted into a set of 'design-to' points at an accuracy level appropriate for manufacturing, with loads affected due to the change in angle between each point.
- Bumps and dips: These are variations from the 'design-to' profile when designed, fabricated, installed and subject to usage, which result in raised and/or sagged parts of the ramp. A modified DEFSTAN approach (Ref. 10), using bump/dip depth and length parameters based on legacy experience was utilised to produce a suitable build tolerance.

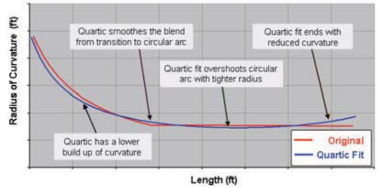

Figure 18. Variation of curvature against length for original cubic transition plus circular arc, and quartic fit.

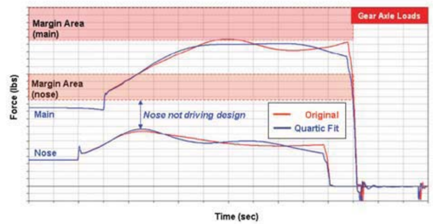

Figure 19. Main and nose gear loads for original and quartic fit.

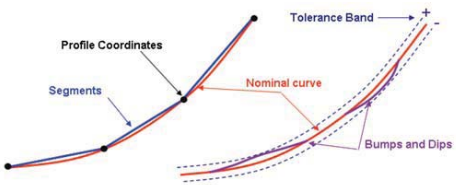

Figure 20. Ramp profile, manufacturing elements and issues.

9.0 CONCLUSION

The paper has covered all the principles and processes used in designing a candidate ski-jump ramp profile for the CVF, optimised for the F-35B.

With loads metric eventually dictating the choice of exit angle and the ramp profile shape, this demonstrates the importance of developing and defining the optimisation metrics.Compared to the CVS ramp, the candidate ramp offers comparable performance but with acceptable loads.

The key issues involved in converting a mathematical profile to a physical structure have been explained.

The team and customer are now taking this profile forward as part of the continuing integration of the F-35B aircraft onto CVF.

ACKNOWLEDGMENTS

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Martin Rosa Dstl
Steve Solomon Lockheed Martin

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Patuxent River Naval Air Station, Maryland, USA

"'Ski jump' trials of the Lockheed Martin F-35B Lightning II Joint Strike Fighter are expected to take place in 18 months' time at US Naval Air Station (NAS) Patuxent River in Maryland. The tests will see if the F-35B can fly from the take-off ramps to be fitted to the UK Royal Navy's two new Queen Elizabeth-class future aircraft carriers (CVF), but BAE Systems F-35 test pilot Graham Tomlinson told Jane's that he expects such take-offs to be far more straightforward than those from flat deck aircraft carriers."

http://articles.janes.com/articles/Janes-Defence-Weekly-2010/JSF-ski-jump-tests-due-in-2011.html

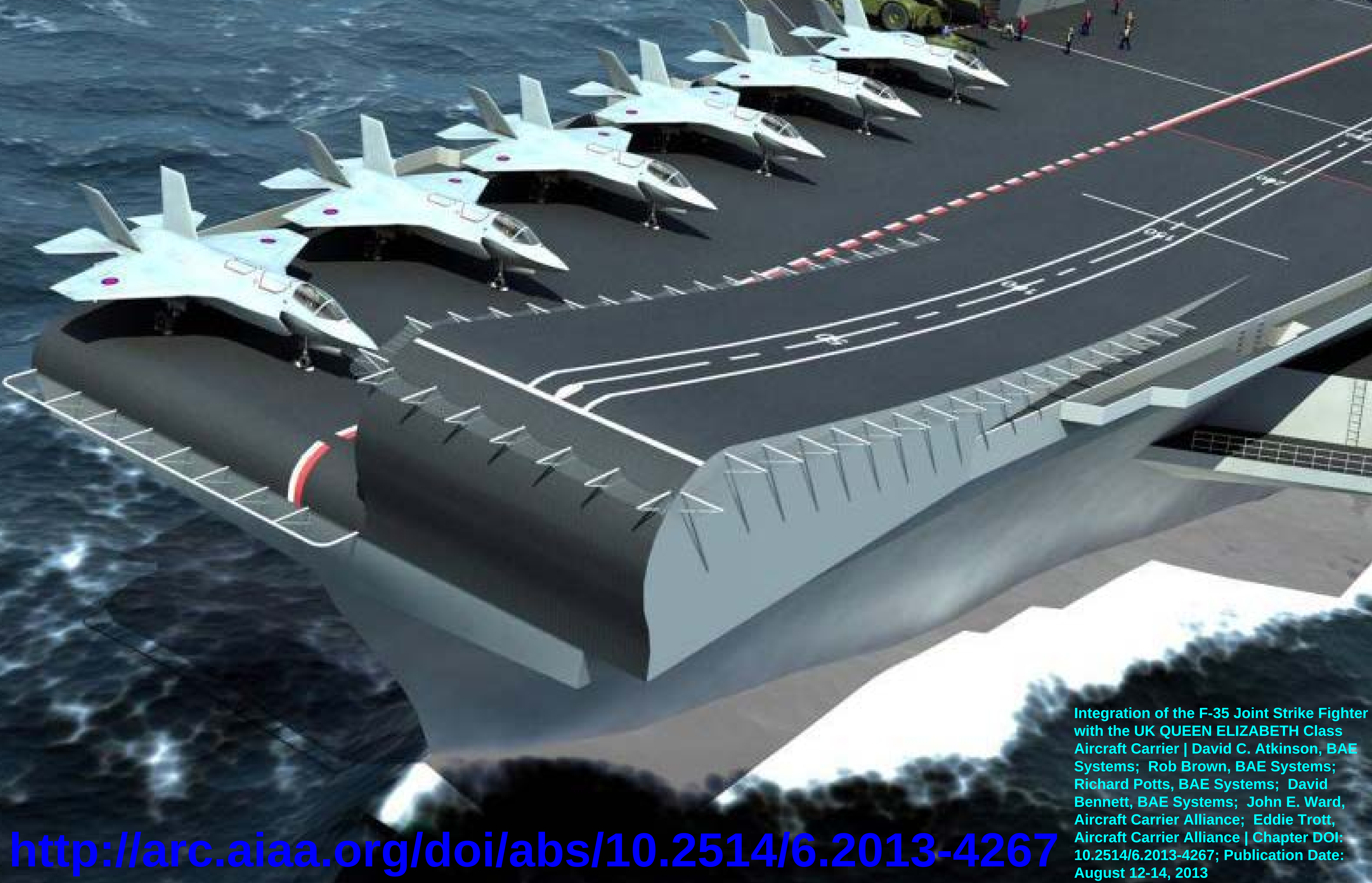
CVF ski-jump ramp profile optimisation for F-35B

A. Fry, R. Cook and N. Revill, FEBRUARY 2009 VOLUME 113 NO 1140: http://www.raes.org.uk/pdfs/3324_COLOUR.pdf

"...1.4 F-35B STOVL lift and propulsion system

The F-35B has a number of unique elements that facilitate its STOVL capability, and these are critical in the optimisation of a ski jump ramp profile for the aircraft.... and described below:

- **a Lift Fan driven by a shaft from the main engine which provides vertical lift through a variable area vane box nozzle using louvered vanes to vector thrust between vertically downwards and partially aft.**
- **a three-bearing swivel module (3BSM), which vectors the main engine exhaust thrust from the core engine through vertically downwards to fully aft – the latter being the default for conventional mode flying.**
- **roll nozzles, ducted from the engine and exiting in each wing providing roll control and vertical lift. These are closed off during the initial portion of the short take-off (STO) in order to maximise forward thrust from the main engine, opening towards the end of the ramp in order to provide control and lift during the fly out...."**



Integration of the F-35 Joint Strike Fighter with the UK QUEEN ELIZABETH Class Aircraft Carrier | David C. Atkinson, BAE Systems; Rob Brown, BAE Systems; Richard Potts, BAE Systems; David Bennett, BAE Systems; John E. Ward, Aircraft Carrier Alliance; Eddie Trott, Aircraft Carrier Alliance | Chapter DOI: 10.2514/6.2013-4267; Publication Date: August 12-14, 2013

Using Simulation to Optimize Ski Jump Ramp Profiles for STOVL Aircraft Dec 01, 1999

Greg Imhof and Bill Schork | Naval Air Warfare Center/Aircraft Division | Air Vehicle Department | Patuxent River, MD

Abstract for AIAA Modeling and Simulation Technologies Conference 14-17 August 2000 Denver, Colorado http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA378145

Introduction

"Ramps have been used for many years aboard the Navy ships of many countries to reduce takeoff run distance and wind-over-deck (WOD) requirements, as well as to increase the aircraft takeoff gross weight capability over that of a flat deck carrier. Under the Joint Strike Fighter program, an effort has been funded to evaluate various ramp profiles & ramp performance optimization methodologies. Results of these evaluations will be used with an advanced STOVL aircraft to provide the maximum benefit to takeoff performance, while not becoming a design driver for landing gear or adversely affecting ship designs.

The Boeing AV-8B Harrier is a true STOVL aircraft, in that it routinely performs short takeoffs and vertical landings. This allows operations from ships not equipped with catapults or arresting gear and that are considerably smaller than the US large deck carriers. This unique capability is obtained through a group of variable angle nozzles for vectored lift and a reaction control system for stability and control, which uses engine bleed air to provide thrust through several small nozzles located on the aircraft.

Many foreign navies operate Harriers from ships equipped with smooth profile ramps. The US Navy has conducted many ship and shore-based tests of smooth and segmented (flat plate) ramp profiles over the years to demonstrate the performance advantages of a ramp-assisted takeoff. Much of this work serves as the basis for our research initiative.

Preliminary Work

The first step was to collect data from prior flight tests to validate the AV-8B landing gear model. The test data were incomplete because the test aircraft did not have sufficient instrumentation to measure gear/store loads and accelerations. Therefore, criteria were developed which enabled us to compare predicted gear load trends and instead of actual gear and structural loads.

Preliminary Criteria for Ramp Optimization

I. The landing gear shall not compress to full closure at any point during the takeoff. Harrier flight tests have been conducted to within 1/2 inch of full closure with no adverse results.

2. Investigate a segmented ramp versus a smooth profile ramp, and how it could be used with the existing structural and operational requirements of the aircraft. If so, what is the maximum angle change between segments that can be tolerated by the aircraft and aircrew?

3. Resonance effects from segmented ramps on landing gear and wing mounted stores are unknown, and efforts should be taken to break up or reduce these loads.

Preliminary Results

Preliminary simulation runs have been completed. Test results indicate that the segmented ramp concept shows great promise and could allow ship designers options in building retractable or reconfigurable ramp designs for future STOVL capable ships. Segmented ramp takeoff performance is not diminished as compared with a smooth ramp. Initial results indicate that segmented ramp profiles can be modified to keep the gear loads well within their structural limits. Since the velocity of the aircraft remains fairly constant while it is on the ramp, an equally distributed (same length) segment pattern generates a recurring load on the landing gear at each joint. If the frequency of these inputs is close to the natural frequency of the gear, or transmitted through the aircraft structure to a wing store, a resonance condition could be excited. This will be investigated at in more detail in the coming months.

Preliminary Conclusions

The smooth and segmented ramp profiles have demonstrated significant performance gains over a field or flat deck ship takeoff. Work will continue over the next several months to expand & refine the optimization criteria and investigate various ramp profiles and quantify their benefit to aircraft performance."

VIDEO

F-35 Pilot talks from the deck of the QEC Carrier BAE Systems 14 Jul 2014 BAE Systems' F-35 Pilot Peter Kosogorin talks from the deck of the QEC Carrier.
https://www.youtube.com/watch?v=9bq0mVk_3qc

Carrier countdown 30 June 2014 Tim Robinson

“...Not your father’s ski-jump

The QE-class’s ski-jump, too, has been carefully designed and engineered from the beginning — drawing on BAE’s Harrier heritage. Says Atkinson: “We had to go back into the archives and talk to people who had actually been involved with trials with the Sea Harrier and Harrier to make sure we understood the history of ski-jump ramp development. The aircraft carrier ski-jump is a UK innovation and something the UK is very proud of.” The QEC’s ski-jump is longer (200ft) than the Invincible class (150ft) and designed so that the aircraft has all three (including the nose) wheels in contact right up until the point where the aircraft leaves the deck — giving positive nose wheel authority throughout. Additionally, the F-35Bs smart flight control system ‘knows’ when it is going up a ramp and will pre-position the control surfaces and effectors to launch at the optimum angle to avoid pitch-up or down....” **http://aerosociety.com/News/Insight-Blog/2300/Carrier-countdown**

http://farm8.staticflickr.com/7369/9929674624_53b0df94ae_o.png

Blue Sky OPS 26 April 2012 AIR International F-35 Lightning II http://militaryrussia.ru/forum/download/file.php?id=28256

Mark Ayton spoke with Peter Wilson, a former Royal Navy Sea Harrier pilot and now STOVL lead test pilot at NAS Patuxent River

...Pilot's View

The author was keen to hear what the F-35 is like to fly particularly at takeoff which always shows dramatic acceleration. Peter Wilson explained: "The take-off itself is unremarkable, in afterburner the aeroplane accelerates dramatically, but it's comparable with legacy fighters, and very weight dependent."...

...Nine Hops

During STOVL testing in February 2010, Peter Wilson flew nine sorties from NAS Patuxent River in about four hours, all of which were less than 5 minutes in duration. Each sortie carried a relatively low fuel load allowing Peter to take off, and fly around for a brief period to ensure the fuel was at the right level in preparation for a landing test. "The highlights on the day were the take-offs. I took off as slow as 50 knots [92km/h] with the STOVL mode engaged, accelerated out to the normal pattern speed of 150 knots [276km/h], turned downwind, and positioned ready for a vertical landing," he said....

...F-35B Take-off Options

The F-35B STOVL variant has a range of take-off options using different modes to suit the basing. Take-offs from a ship, with either a flat deck or one with a ski jump, are also possible with a mode for each scenario. These are short take-off scenarios that can be achieved at speeds as low as 50kts with a deck or ground run of no more than a 200ft (60m). In the same mode, a take-off as fast as 150 knots is possible if the weight of the aircraft requires that speed. If the aircraft is light it can take off at a slow speed and faster when heavy.

Take-off at speeds as low as 5, 10, 15, 20kts (9, 18, 27 and 36km/h) are also possible, each of which is effectively a vertical take-off while moving forward. There are different ways of rotating the aircraft in STOVL mode, including the usual 'pull on the stick'. Other ways are by pressing a button or programming a ground distance required after which, the aircraft control law initiates the rotation and selects the ideal angle for climb-out.

F-35Bs BF-01 and BF-02 are the only B-models currently undertaking STOVL testing and therefore performing take-offs in STOVL mode. Peter Wilson commented: "We have found a remarkable similarity between BF-01 and BF-02 which gives us the confidence to move on and get more aeroplanes [BF-04 followed by BF-03] into STOVL mode very soon." At the time of closing for press in mid-April the first vertical take-off had not taken place....

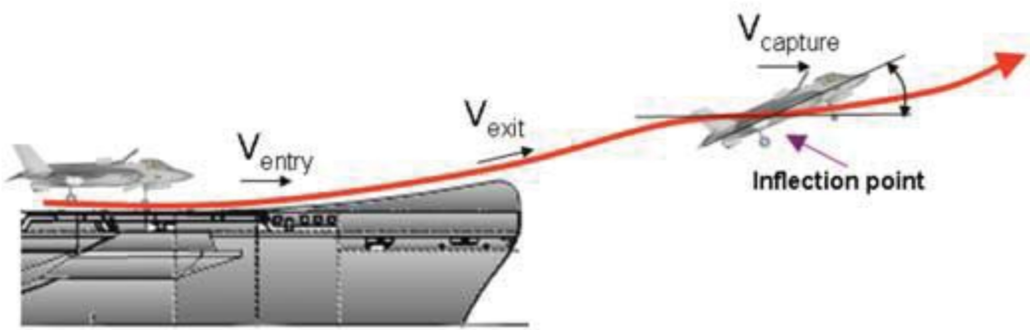
..."It is important for people to understand the reason that this aircraft exists is not as a science project set around take-off and landing, it exists to bring the most amazing range of sensors that have ever been put together on a single aeroplane, and deploy it to the battlefield reliably and repeatedly."

II. Ski Jump Ramp

The ski jump ramp was conceived by a Royal Navy officer in the 1970s and subsequently developed by the UK services, industry and Government as a way of increasing the STO launch payload for the Harrier[1,2,3]. It has since become an integral part of embarked operations for UK and most maritime STOVL operators. The QEC was designed with a ski-jump ramp from the outset and the shape of the ramp was designed to be optimal for the F-35B STOVL JSF.

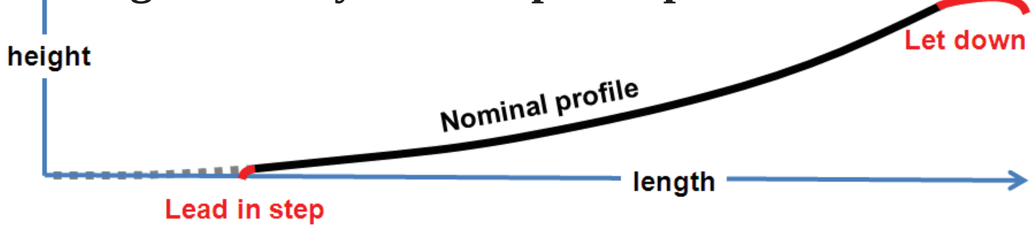
The ski jump ramp works by imparting an upward vertical velocity and ballistic profile to the aircraft, providing additional time to accelerate to flying speed whilst ensuring it is on a safe trajectory after launch, reducing risk from mis-timed launches with regard to ship motion, reducing pilot workload and giving the pilot more time to diagnose any issues compared to a flat deck STO. The upwards trajectory at ramp exit also allows either a reduction in take-off length for a given weight, or increased weight (i.e. launch performance) for a fixed take-off distance. The additional performance does, however, increase landing gear loads above those of a flat deck STO. The loads increase represents the energy transferred to the aircraft as it translates up the ramp; and if the angle and curvature of the ramp are increased to obtain greater performance benefit, so are the landing gear loads. This is tolerable up to a point because the gear strength is defined by landing events, the landing loads from which far exceed flat deck STO loads, therefore the landing gear has the ability to accept increased loads at take-off, but these must be carefully controlled because they act as an upper boundary on permissible ramp size and the ramp's shape needs to be optimized to control the loads across the range of launch weights, speeds and conditions. The minimum safe launch speed is defined where the ramp exit speed does not result in any rate of descent during the trajectory until the aircraft has transitioned to fully wing-borne flight. This results in the launch profile shown in Fig. 2, with an inflection point at which criteria for a successful launch are defined and assessed.

Figure 2. Ski Jump Ramp Launch



Two safe launch criteria derived from legacy STOVL experience have been used for JSF ski-jump launch, of which the more stressing is adopted: (a) achievement of zero sink rate having taken a margin from the WOD (known as Operational WOD); and (b) achieve a defined positive rate of climb using the full value of WOD. Both criteria also require a threshold forward acceleration. Optimisation of the QEC ski-jump ramp design (Fig.3) is described in Ref 4. The optimal QEC ramp was assessed to be a 200 foot long 12·5 degree angled ramp with the profile achieved by combining a nominal profile based on a quartic fit to an optimum cubic transition plus circular arc, a rounded step lead in and an elliptic let down (Fig. 4). Performance and landing gear loads data has been generated to demonstrate the resulting capability and compliance with the loads metric, which is defined by consideration of the maximum load and stroke at the limit load and bottoming of the landing gear after allowing for an engineering margin.

Figure 4. Key Ski Jump Ramp Features



Bumps and plate sags result in increases of loads beyond those achieved on an idealized ramp profile, see Fig. 5. The initial loads analysis, performed using commercially available dynamic software, assumed values for the maximum bumps and plate sags, placing them at the worst credible positions on the ramp, i.e. where peak loads occur in the idealized profile. The QEC ski-jump ramp has been built as accurately as possible using conventional shipbuild techniques, however there are practicalities associated with ship-build that results in deviations from the pure mathematical profile and it is important to check how they compare to the design assumptions; for example, the detail of how the entry to the ski-jump ramp interfaces with the slightly cambered flight deck. The CAD model of the ski jump ramp has been used to define the shape of features such as ramp entry, light fittings in the QEC ski-jump ramp and to allow actual weld positions to be used to place bumps, plate sags and/or steps in the dynamic model (Fig. 6). The dynamic model will be further updated with data from laser mapping of the ramp after the ship has been floated up and the analyses will be re-run to confirm that the loads metrics continue to be met for the defined launch conditions and therefore enable the launch parameters for QEC ski-jump launch to be fully defined to high confidence, ready to be verified by flight tests during Lightning/QEC First of Class Flight Trials (FOCFT).

http://arc.aiaa.org/doi/abs/10.2514/6.2013-4267

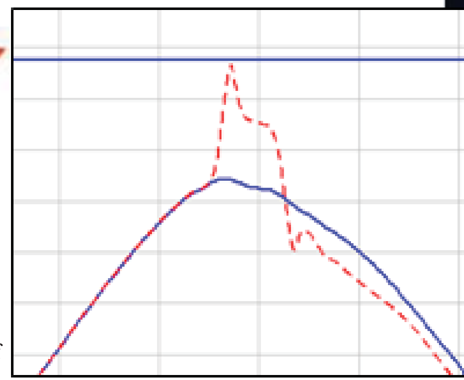


Figure 5. Potential Load Oscillations at a Step

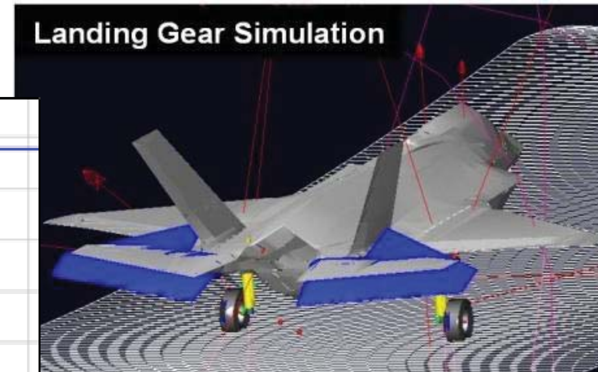


Figure 6. Dynamic Analysis of Launch Loads

Integration of the F-35 Joint Strike Fighter with the UK QUEEN ELIZABETH Class Aircraft Carrier

A ski-jump ramp, being a curved surface, consumes deck area that could otherwise be used to park aircraft or operate helicopters. A further major consideration for integration of a ramp has therefore been its width, because it needs to be as wide as possible for launch safety purposes while avoiding excess width to preclude aircraft parking on the starboard side of the ship. The QEC ski-jump ramp has been designed to ensure that the aircraft will safely launch, with margins, when the aircraft stays within the STO launch safety lines, the criteria for which have been carried forward from previous UK fixed wing aircraft carriers.

RAMP UP Deck-mounted ski-jump assembly marks key step toward U.K. carrier-based JSF operations, Aviation Week & Space Technology / 19 Aug 2013 pp.33-34

"As a new phase of ship-borne testing of the F-35B Joint Strike Fighter gets underway on the amphibious assault vessel USS Wasp, British shipbuilders are assembling the ski-jump launch ramp on HMS Queen Elizabeth - the first of two new JSF-dedicated aircraft carriers for the Royal Navy.

The 200-ft.-long ramp is the longest ever fitted to a carrier and, like the Queen Elizabeth-class carriers (QEC) themselves, is the first of its type to be purpose-designed from the outset for F-35 operations. Angled at 12.5 deg., the ramp will be 20-ft. high and is designed to reduce the required deck roll on takeoff by up to 50%, or allow an increased payload of up to 20%. The ramp achieves this by boosting vertical velocity, giving the aircraft a ballistic launch profile that provides it with additional time to accelerate to flying speed.

However; the ski ramp imparts added loads on the landing gear during launch and, because these can be increased by even small variations in the surface of the ramp or by the interface with the deck, developers are paying special attention to the build tolerances. David Atkinson, who leads JSF/QEC integration activities for BAE Systems, says the requirement for build accuracy is even greater than for previous ski jump designs because the F-35 has a wide tricycle gear. This makes it more exposed to variability than the narrower footprint of the tandem main gear of the Harrier, for which the concept was originally conceived in the 1970s. In addition, the center section of the carrier deck is cambered to prevent pooling of water, further complicating the interface with the ramp.

"You have to allow for the effect of deck-plate bumps and sags, and when the ship is floated up we will go over it with laser mapping to measure the actual tolerances achieved in build," says Atkinson, who was speaking at the American Institute of Aeronautics and Astronautics Aviation 2013 conference in Los Angeles. The ramp has been designed by BAE and Lockheed Martin, rather than the shipbuilders, and is configured with two curves. The initial entry or "cubic" curve leads to a let-down or "ellipse" section that provides the launch point for the aircraft. The ramp's makeup provides a positive climb rate and no more than a zero sink rate if wind-over-deck conditions are less than expected...."

"...Onboard the Queen Elizabeth aircraft carriers, the aircraft would take off at its maximum weight of nearly 27 tonnes using a UK-developed ski-jump,..." 2204.62lbs = 1 tonne 59,535lbs = 27 tonnes [Wing Commander Hackett explained]

http://content.yudu.com/A219ee/ETSWin12/resources/20.htm ETS winter 2012_13 LIGHTNING STRIKES

http://2.bp.blogspot.com/-zLM6-NPZRyE/U0AFvxfVZjI/AAAAAAAAC0I/b8hcjBArqts/s1600/9929674624_636076b854_k.jpg

"...The 300-tonne section of ramp, which is 64 metres long and 13 metres wide, is the final exterior piece of the aircraft carrier to be fitted. At its highest point, the take-off ramp is 6 metres above the flight deck, which will allow aircraft to be propelled into the air. The pictures come on the same day as MOD announces that a fourth Lightning II Joint Strike Fighter aircraft has been ordered from Lockheed Martin. The UK has already taken delivery of 3 Lightning II jets and Royal Navy and RAF pilots are training on the aircraft in the USA. This fourth jet, which is specially designed to be a test aircraft, will help boost the on-going training available...."

https://www.gov.uk/government/news/royal-navy-aircraft-carrier-ramping-up

The final section of the flight deck of HMS Queen Elizabeth has been fitted onto the Royal Navy's new aircraft carrier 11 Nov 2013

http://www.flickr.com/photos/qeclasscarriers/10797672293/sizes/o/in/photostream/

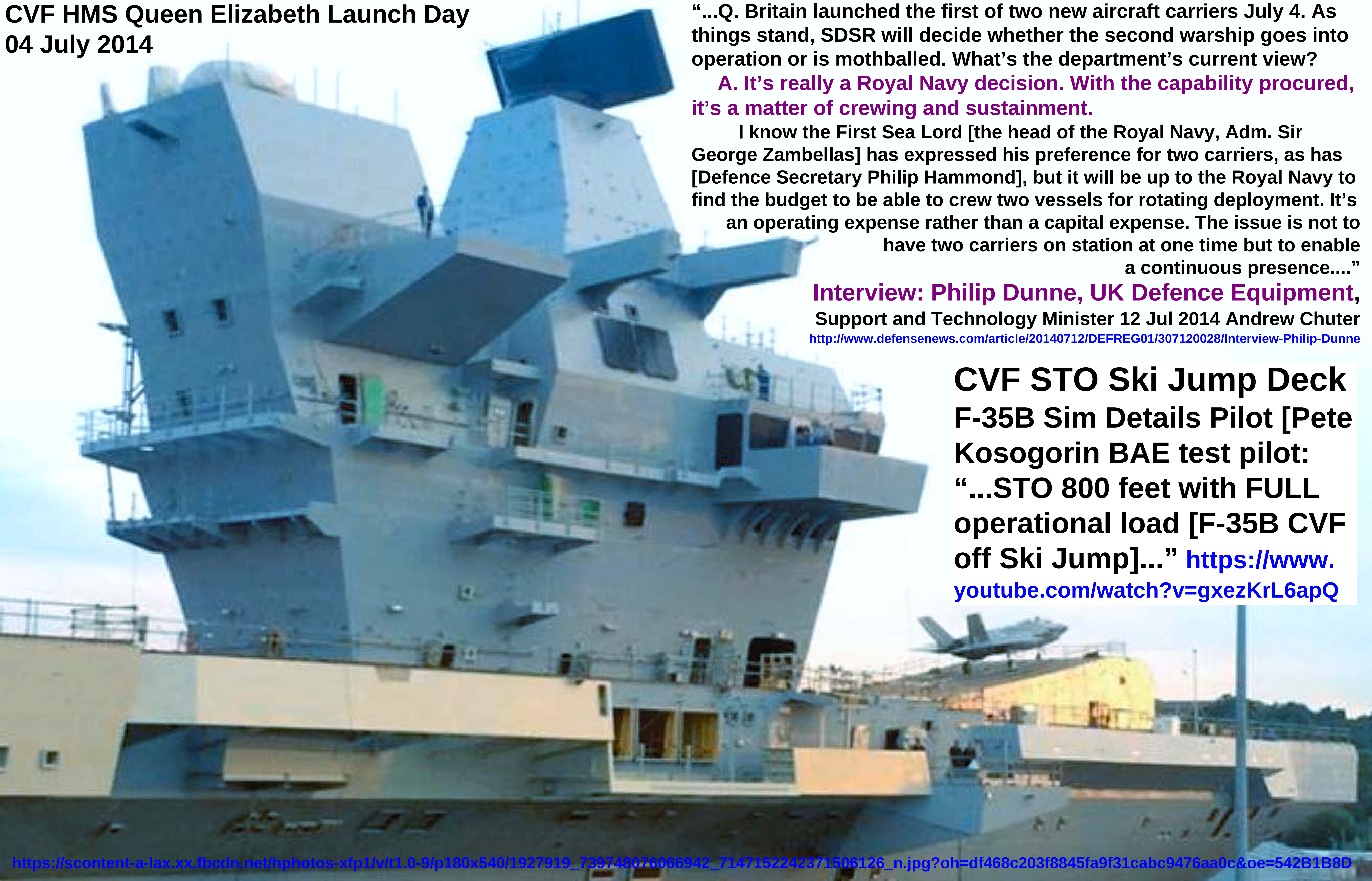
Start of a momentous year for Carrier project 3 Feb 2014 David Downs

"...On the upper deck, the catwalks around the edge of the flight deck are being prepared and will shortly be painted with a heat resistant paint scheme. This will survive the thermal effects of the exhaust of an F35 jet while hovering on the approach to a vertical landing. This work also entails application of the thermal metal spray coating to the edges of the flight deck. This coating system will later be applied across the whole flight deck....

...Meanwhile recognising that access to the ship and craneage is much easier while the ship is in the dry dock, served by the Goliath crane, than when afloat in the non-tidal basin, the chance is being taken to install anything that might be difficult to do later. This includes the platform at the stern for the SPN 41 Precision Approach Radar, the seating's for the Glide Path Cameras and some CCTV cameras. It looks like 2014 is going to be another busy but very interesting year."

http://www.theengineer.co.uk/home/blog/guest-blog/start-of-a-momentous-year-for-carrier-project/1017934.article#ixzz2sGrXdsvd

CVF HMS Queen Elizabeth Launch Day 04 July 2014



"...Q. Britain launched the first of two new aircraft carriers July 4. As things stand, SDSR will decide whether the second warship goes into operation or is mothballed. What's the department's current view?

A. It's really a Royal Navy decision. With the capability procured, it's a matter of crewing and sustainment.

I know the First Sea Lord [the head of the Royal Navy, Adm. Sir George Zambellas] has expressed his preference for two carriers, as has [Defence Secretary Philip Hammond], but it will be up to the Royal Navy to find the budget to be able to crew two vessels for rotating deployment. It's an operating expense rather than a capital expense. The issue is not to have two carriers on station at one time but to enable a continuous presence...."

Interview: Philip Dunne, UK Defence Equipment, Support and Technology Minister 12 Jul 2014 Andrew Chuter
http://www.defensenews.com/article/20140712/DEFREG01/307120028/Interview-Philip-Dunne

CVF STO Ski Jump Deck F-35B Sim Details Pilot [Pete Kosogorin BAE test pilot: "...STO 800 feet with FULL operational load [F-35B CVF off Ski Jump]..." https://www.youtube.com/watch?v=gxezKrL6apQ

https://scontent-a-lax.xx.fbcdn.net/hphotos-xfp1/v/t1.0-9/p180x540/1927919_739748076066942_7147152242371506126_n.jpg?oh=df468c203f8845fa9f31cabc9476aa0c&oe=542B1B8D

[CVF/F-35B] The Influence of Ship Configuration on the Design of the JSF

Ryberg, Eric S. Feb 2002: http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA399988

"...UK OPERATIONAL NEEDS

The UK requires a Future Joint Combat Aircraft (FJCA) that will be a stealthy, multi-role aircraft to follow on from the Sea Harrier FA1, Harrier GR7, and Harrier T10 operated by the Royal Navy (RN) and Royal Air Force (RAF). The aircraft must be capable of sustained air defensive counter air, suppression of enemy air defenses, combat search and rescue, reconnaissance, and anti-surface warfare missions. While the STOVL JSF is to be evaluated for basic compatibility with INVINCIBLE-class (CVS) carriers, it is unlikely that the aircraft will ever be deployed aboard CVS for any extended periods. Instead, the UK Ministry of Defence (MoD) has initiated development of a future aircraft carrier (CVF) scheduled to enter service at or about the same time as its JSF. The CVF program is currently in its concept development phase, and the ship will be designed for compatibility with the shipboard JSF variant, CV or STOVL, that will be procured for use by the UK's joint air forces. The UK's selection of JSF variant is scheduled to occur during the first half of 2002...."

"...Unlike the CV variant, the JSF STOVL variant did not have a spot factor requirement levied upon it. Instead, the ORD specified a spotting requirement in operational terms. The USMC operators required that it be possible to park a total of six STOVL variants aft of the island on an LHA or LHD, such that none fouls the landing area and that any one of them can be moved without first moving any other. This requirement constrains the STOVL variant's wingspan to be no more than 35 ft...."

"...TAKEOFF RAMP COMPATIBILITY [out of date info on ski jump - a new ski jump constructed at PaxRiver in May 2009 replicates CVF]

Since the UK is a customer for JSF, the STOVL variant will be designed to be compatible with the 12 deg short takeoff (STO) ramp, or ski jump, found on the bows of ~~INVINCIBLE~~ class ships. An aircraft performing a ramp-assisted STO experiences an increased normal load factor, the result of centripetal acceleration applied as the aircraft traverses the curved ramp. While the benefit to aircraft takeoff performance is predominantly a function of the inclination angle at ramp exit, the load on the aircraft is a function of the ramp's radius of curvature, coupled with the geometry and dynamics of the aircraft landing gear.

In the design of JSF, structural analyses indicated that the loads predicted for a STO off ~~INVINCIBLE's~~ 12 deg ramp were less severe than other design conditions such as high sink rate landings and rolling over deck obstacles. Hence, the ramp takeoff does not act as a structural design driver. However, changes in ramp profile that lessen its radius of curvature such as an increase in exit angle for a fixed-length ramp, or a decrease in the length of a ramp with the same exit angle, may cause the STO ramp takeoff to become the most severe ground load contributor. Future ships incorporating ramps should account not just for takeoff performance benefits added by the ramp, but also for the impact of added ground loads on any aircraft to use the ramp. Use of high fidelity aircraft simulations would allow the ramp profile to be "tuned" for a particular launch scenario, such that the ramp design maximizes aircraft performance gain while minimizing the impact of added ground loads...."

FEDBIZOPPS.GOV

17 -- Ski Jump Ramp

Solicitation Number: N00421-05-R-0119
Agency: Department of the Navy
Office: Naval Air Systems Command
Location: Naval Air Warfare Center Aircraft Division Pax River

Solicitation Number: N00421-05-R-0119

Notice Type: Presolicitation

Synopsis:
Added: July 8, 2005

https://www.fbo.gov/index?s=opportunity&mode=form&tab=core&id=f47e237486e35645cbb89120d6fe6724&_cview=0

The Naval Air Warfare Center, Aircraft Division (NAWCAD) intends to award a sole source contract to Williams Fairey Engineering Limited (WFEL), P. O. Box 41 Crossley Road Heaton Chapel, Stockport Cheshire SK4 5BD England. This sole source award will be made to design, fabricate, deliver, and provide analysis and set-up documentation for a Ski Jump Ramp in support of flight test operations of the F-35B Short Takeoff and Vertical Landing (STOVL) Joint Strike Fighter (JSF) aircraft, which weighs approximately 62,000 lbs. A Ski Jump is used to assist STOVL aircraft during shipboard takeoffs. This land based Ski Jump will be used to exercise the F-35B STOVL JSF prior to conducting shipboard testing. The contract requires expertise in the design of structures to withstand the complex dynamic loads imparted by a STOVL aircraft during Ski-Jump Takeoffs and in the design and production of structures that limit the risk of Foreign Object Damage (FOD) to an aircraft. The requirement involves design, production, and delivery of equipment, analysis, and documentation products to provide a Ski Jump Test Capability. A sole source acquisition is required under the authority of FAR 6.302-1 and 10 U.S.C. 2304(c)(1) due to WFEL's unique experience in Ski Jump structures, specialized production expertise, and critical appreciation of aircraft-compatible design requirements. The anticipated period of performance is one base year with one option year. The base year of the contract will be for the design of the ramp. The option year of the contract will include fabrication, testing, and delivery of the ramp, consultation during the initial ramp set up, as well as analysis and documentation. All interested parties may identify their capability and respond to this requirement. The Government will consider all capability information received prior to the closing date of this synopsis. Information received will be considered solely for the purpose of determining whether to conduct a competitive procurement. A determination by the Government not to compete the proposed contract based upon responses to this notice is solely within the discretion of the Government. No phone inquiries will be entertained. Responses shall be made in writing by email, U.S. mail, or facsimile to the attention of Jason Lawson using the contact information provided in this synopsis.

Contracting Office Address: Department of the Navy, Naval Air Systems Command, Naval Air Warfare Center Aircraft Division Pax River, Building 441 21983 Bundy Road Unit 7, Patuxent River, MD, 20670

Place of Performance: Patuxent River, MD20670

WFEL set to soar after latest American deal
10 October 2008

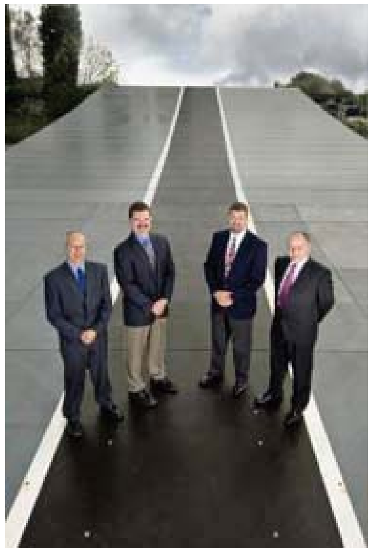
http://www.wfel.com/news/wfel-set-to-soar-after-latest-american-deal/

WFEL, the Stockport-based defence engineering company, has completed a major new order for the US Department of Defense.

The business, based in Heaton Chapel, is about to ship a 250 tonne ski jump ramp to the US where it will be used by pilots testing the new F-35 Joint Strike Fighter (JSF). The aircraft is the product of the JSF Programme, which has been under development by the US Military since mid-90s, and involves nine other Western militaries worldwide.

The ski jump – the first of this type to be built anywhere in the world – was designed to replicate the runway of an aircraft carrier. It will enable the JSF to be tested on land, potentially saving the military millions of pounds.

WFEL, already a global leader in the design and manufacture of tactical military bridges, has made a strategic move to expand its engineering expertise into new military sectors with the ski jump.



(L to R) Greg Roney WFEL
Tom Chaillou and Tom Briggs
F35 Integrated Test Forum
Ian Wilson WFEL

Designed, developed and manufactured by WFEL, the $3.7 million (£2 million) jump is the brainchild of engineer Greg Roney.

http://www.wfel.com/news/archive/

A team from US Defense travelled to Stockport this week to see the finished product before it is deconstructed and shipped to Maryland. Once there, it will take just two weeks to re-assemble.

Tom Briggs, from the US Defense F-35 Integrated Test Force, said: "We've worked with WFEL for many years and knew they had the intellectual capital, as well as quality manufacturing processes, needed to deliver a challenging and bespoke project like this."

The company's chief executive, Ian Wilson, is also in talks with other militaries signed up to the JSF project.

Ian said: "The JSF will be one of the most advanced military aircraft ever made and we are proud to support the development team in achieving one of their key milestones, both on time and on budget . We have a long history of applying our specialised design and manufacturing skills to high quality and technically challenging products where deliverability and reliability are paramount and this project has been no exception.

Ski Jump Comparison:
150 ft length/15 feet high = Invincible Class whilst 200 ft length/20 ft high is CVF Class

http://ww2.dcmilitary.com/stories/070909/tester_28153.shtml

"The mock ski-jump is 150-feet long, with a 15-foot high "lip" for aircraft launch. These shore-based ski-jump takeoffs will be conducted at varying airspeeds prior to the first UK ship detachment with the F-35B."

A jump ahead

http://www.janes.com/images/assets/271/54271/DSEi_Show_Daily_Day_1.pdf 2015

The Lockheed Martin F-35B Lightning II supersonic short take-off and vertical landing aircraft made aviation history in June, when it took off at the Naval Air Station (NAS) in Patuxent River, Maryland, from a WFEL ski jump, the first of its type to be built anywhere in the world.

This first ever launch from a ski jump marked the start of an initial testing phase to demonstrate the aircraft's ability to take off and land safely, with the US-UK team continuing the trials over the summer before the first shipboard ski jump launch from HMS *Queen Elizabeth*.

Designed, developed and built by WFEL, a leader in the design and manufacture of tactical military bridges, the £2 million jump was the brainchild of engineer Greg Roney. **It is a 250-ton land-based structure that replicates the runway of aircraft carriers operated by the British and Italian navies, both of which will be acquiring the F-35B.**

WFEL chief executive Ian Wilson said: "We have a strong heritage in applying our specialised design and manufacturing skills to high-quality and technically challenging products. We made a strategic move to expand our engineering expertise with the ski jump after consultation with the US military, whom we've been working with since the 1980s."

GÜNTER ENDRES

Peter Wilson, test pilot and ski jump project lead, added: "Aircraft BF-04 performed well and I can't wait until we're conducting F-35 ski jumps from the deck of the *Queen Elizabeth* carrier. Until then, the de-risking that we're able to achieve now during phase I of our ski jump testing will equip us with valuable data we'll use to fuel our phase II efforts."

The F-35 Lightning II is a single-seat, single-engine, strike fighter that incorporates low-observable (stealth) technologies, defensive avionics, advanced sensor fusion, internal and external weapons, and an advanced prognostic maintenance capability.

F-35B STOVL: http://www.pprune.org/military-aircrew/478767-no-cats-flaps-back-f35b-51.html 2nd Jun 2012

'Engines'

"The UK F-35B is required, and is perfectly able to, use a 'STO' technique to get airborne. The pilot will select 'powered lift' mode before it starts its take off run, & the aircraft will be partially jet borne & partially wing borne when it leaves the ramp. At the appropriate point as it flies away, the pilot selects back into 'conventional flight' mode.

The landing gear is fine. What you see on the video is the tyre flexing. The Harrier nose leg was massive because it was a 'bicycle' gear layout with the nose wheel taking around 50% of the weight of the aircraft. The F-35 has a conventional gear, with the front leg taking around 10% of the load. Oh, and I can testify that Harrier landing gears (outriggers & nose legs both) flexed plenty during deck ops. Stopped them breaking.

&

The last few feet as a jet powered lift aircraft nears a surface are both complex and critical. There is the ever present risk of Hot Gas Ingestion (HGI) as well as quite complex flow around and under the aircraft that can lead to 'suck down' and/or loss and deterioration of control.

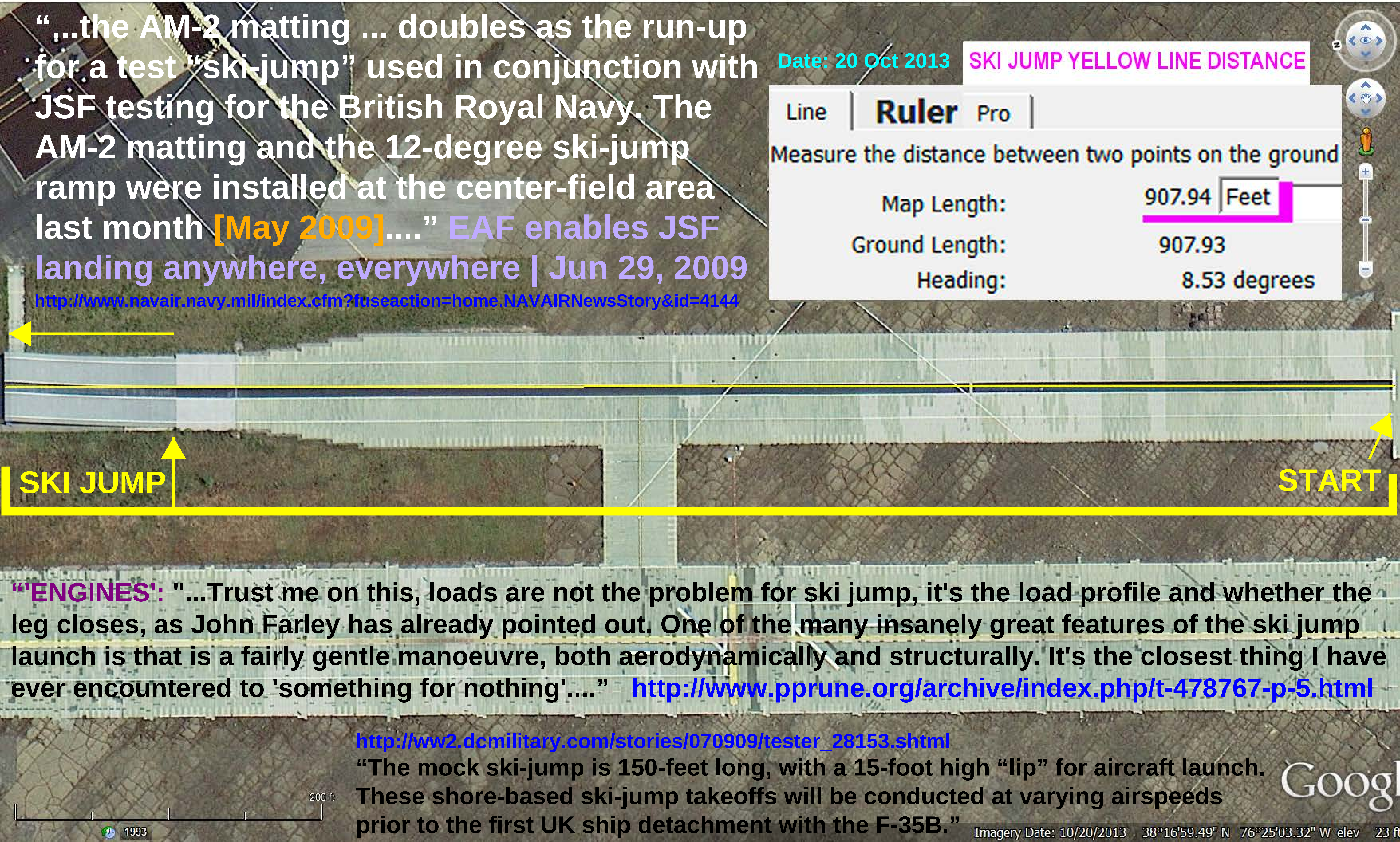
The Harrier had some quite challenging characteristics in this area, although the fact that it was able to enter service without much artificial stability augmentation was a great achievement by the people who designed it. You probably know that a key to this was controlling the 'fountain' of air generated under the aircraft, hence the use of strakes, airbrake and on the AV-8B, a separate air dam.

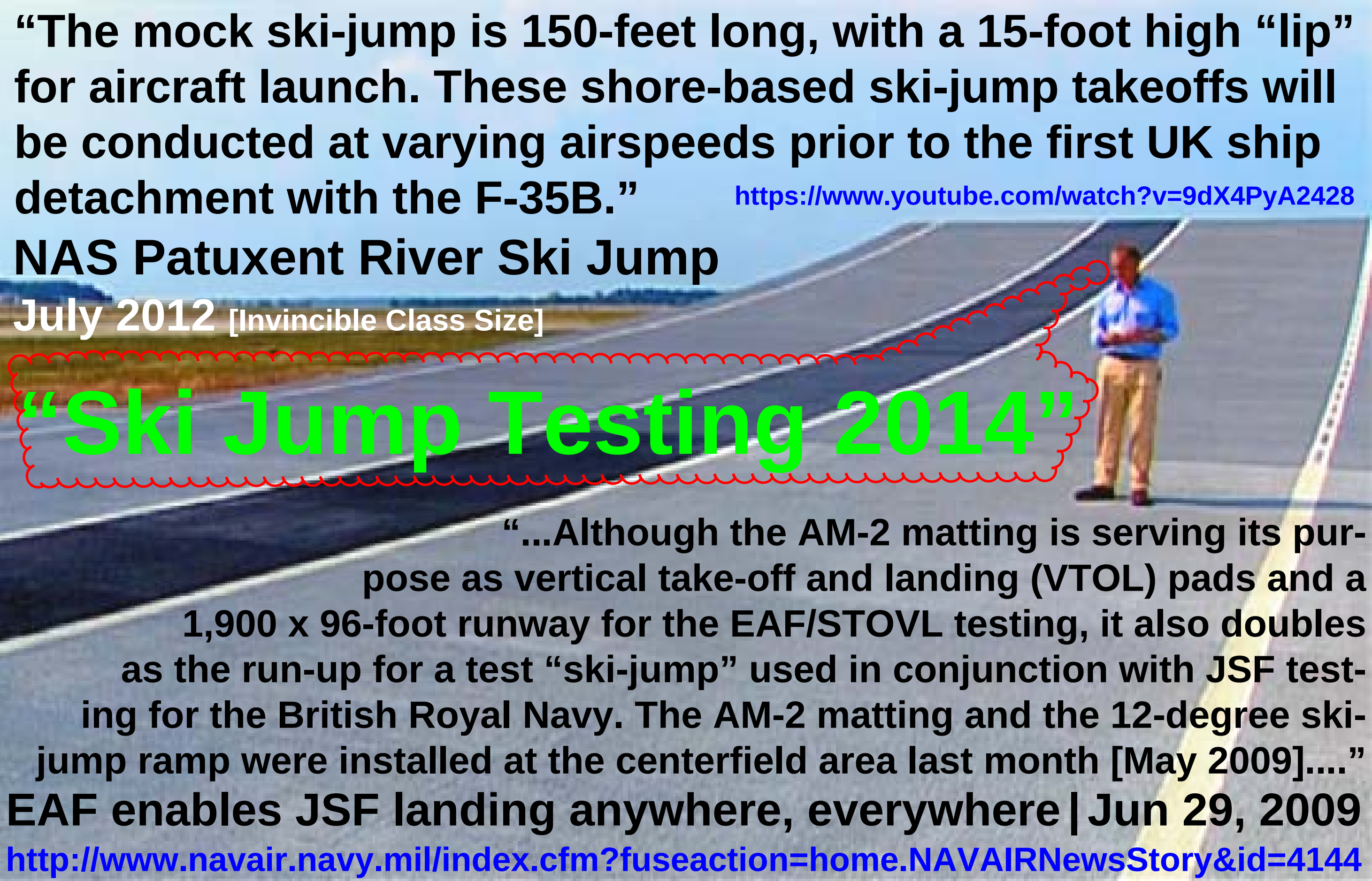
The best way to avoid problems in this area for the Harrier was to land 'firmly', and so get through the critical 'near to ground' area as fast as practicable. Hence the sometimes firm landings. Although it's worth noting that the vertical velocity of these was still way less than is normally used in 'cat and trap' operations.

Fast forward to F-35B. The team have used design tools and test rigs that didn't exist in the 60s when the Harrier team did their work. That has given the F-35 team a much better understanding of how the jet operates close to the ground, and this has paid off. You'll see from the videos that they are using the in-board weapon bay doors as 'strakes' during vertical landings.

Another major difference from Harrier are the flight controls. F-35B has a 'rate command' system, which reduces pilot workload, but it did, in the early days, lead to some 'rebound' on landing – look up some of the X-35 videos that are out there. This appears to have been solved now."

NAS Patuxent River Ski Jump + Run Up being in total 908 ft from right to left





"The mock ski-jump is 150-feet long, with a 15-foot high "lip" for aircraft launch. These shore-based ski-jump takeoffs will be conducted at varying airspeeds prior to the first UK ship detachment with the F-35B." https://www.youtube.com/watch?v=9dX4PyA2428

NAS Patuxent River Ski Jump

July 2012 **[Invincible Class Size]**

"Ski Jump Testing 2014"

"...Although the AM-2 matting is serving its purpose as vertical take-off and landing (VTOL) pads and a 1,900 x 96-foot runway for the EAF/STOVL testing, it also doubles as the run-up for a test "ski-jump" used in conjunction with JSF testing for the British Royal Navy. The AM-2 matting and the 12-degree ski-jump ramp were installed at the centerfield area last month [May 2009]...."

EAF enables JSF landing anywhere, everywhere | Jun 29, 2009

http://www.navair.navy.mil/index.cfm?fuseaction=home.NAVAIRNewsStory&id=4144

Pax River Prepares for F-35 Lightning II Joint Strike Fighter

http://somd.com/news/headlines/2009/10716.shtml NAVAIR Oct 29, 2009

"PATUXENT RIVER NAVAL AIR STATION (Oct. 29, 2009) - A new jet aircraft will soon be calling Naval Air Station (NAS) Patuxent River home. The F-35 Lightning II, Joint Strike Fighter (JSF) will arrive from Fort Worth, Texas to continue its System Development and Demonstration (SDD) testing efforts at NAS Patuxent River. Since early 2002, NAS Patuxent River has been getting ready for the arrival of the F-35 with the addition of new facilities and equipment required to support the testing of this new aircraft....

...The F-35B and F-35C will be tested and developed at NAS Patuxent River, which will host a total of eight aircraft at the peak of the testing program.

The Centerfield Complex will be used to test these capabilities including vertical landings on pads mimicking those found on land and on the LHD class of ships; short-distance takeoffs using the ski jump which is similar to those found on U.K. carriers; and flight performance testing on the EAF. Expeditionary Airfields are mobile systems that allow U.S. Marines to quickly build functioning airfields in mission critical areas that do not support a standard-use airfield. These areas allow the JSF to perform missions in any terrain. Additional testing activities to occur at NAS Patuxent River include carrier approach and landing flights, software and aircraft systems development, and aircraft certification testing.

The JSF SDD program operations at NAS Patuxent River are expected to continue through 2013 although the F-35's presence at the Naval Air Station will likely extend well into the future. Aircraft equipment and systems requirements continually evolve, resulting in the continued need for follow-on test and evaluation."

Pax ski jump readied for future F-35B Lightning II launches 22 May 2014 Sarah Ehman

Atlantic Test Ranges Business Communications http://www.dcmilitary.com/article/20140522/NEWS14/140529960/pax-ski-jump-readied-for-future-f-35b-lightning-ii-launches

"Thanks to a partnership between the Atlantic Test Ranges (ATR) and the F-35 Lightning II Pax River Integrated Test Force (ITF), the Joint Strike Fighter took one step closer this Spring to making its debut on international ships. The Pax River ITF partnered with ATR's Geomatics and Metrology team to perform a high fidelity survey of the shore-based ski jump at Naval Air Station Patuxent River's center airfield. The survey is a prerequisite to future F-35B flight testing by the Pax River ITF, the United Kingdom and Italy. The shore-based ski jump at centerfield was built in the United Kingdom, divided into sections, then transported and reassembled at Pax River.

"Launching off our Pax ski-jump paves the way to F-35Bs launching off our international partner ships that feature ski-jumps," said Bob Nantz, the Pax River F-35 ITF external environment and performance lead. "The significance of the Pax ski-jump shape is connected to aircraft loads & performance modeling. Ideally, the loads will never limit the launch weight or speed, thus allowing the maximum performance benefit."

Together, Fred Hancock, Sung Han and Warren Kerr, each with ATR Geomatics and Metrology, employed electronic differential leveling and total station measurement techniques to check for drift in construction and determine precise deviations in both vertical and horizontal components of the ramp. "We captured hundreds of elevation readings, determining the relative vertical difference between points," Hancock said. "We also obtained precise angular distance measurements to determine if the ramp edges were parallel to the center line. This helped us to know whether the ramp was at all skewed." Hancock noted that the team achieved readings accurate to within one millimeter — approximately the thickness of a credit card. "The razor-sharp accuracy of the Geomatics team's survey is a key part of the process leading to future ski-jump operations at sea," Nantz said."

http://www.dcmilitary.com/storyimage/DC/20140522/NEWS14/140529960/AR/0/AR-140529960.jpg

"U.S. Navy photo/Jennifer Amber The Atlantic Test Ranges Geomatics and Metrology team, from left, Fred Hancock, Sung Han and Warren Kerr survey the ski jump ramp that was assembled at Naval Air Station Patuxent River in 2009 to document potential deviations from the original design plan."

JSF programme to proceed with UK-specific land-based carrier trials

Gareth Jennings 09 Jul 2012 http://www.janes.com/events/exhibitions/farnborough-2012/news/july-10/JSF-programme-proceed.aspx

“The Program Office for the Lockheed Martin F-35 Lightning II Joint Strike Fighter (JSF) is to shortly commence UK-specific trials for carrier operations of the short take-off/vertical landing (STOVL) variant F-35B, it was announced at the Farnborough Airshow 2012. Speaking on 10 July, BAE Systems lead STOVL test pilot Peter 'Wizzer' Wilson said that 'ski-jump' launch trials will begin at Naval Air Station (NAS) Patuxent River, Maryland, in the near future, while work on the shipborne rolling vertical landing (SRVL) is also ongoing. "A 'ski jump' is in place at Pax River that is based on the one [formerly fitted to HMS] Illustrious," he said, adding: "If we can get a few launches in over the next 12 months or so to help de-risk the programme, that would be something that [the UK Ministry of Defence (MoD)] would be interested in."

Wilson said the advantage of the 'ski jump' launch method is in the extra time it gives the pilot on take-off. "The real benefit is one of timing. Once airborne you are flying upwards rather than horizontal, and this gives you extra time to think if something should go wrong," he explained. In addition, Wilson noted that the 'ski jump' saves approximately 100 to 150 ft of deck run over the standard 'flat top' carrier deck. "Everything we have seen in modelling is that [the 'ski jump'] is the best way to get this aircraft airborne," he said.

Wilson noted that the lift-fan door behind the cockpit does not affect the aircraft's handling when open for the landing and take-off phases of flight. "There are no issues in terms of drag," he said. "We can open [the door] up to speeds of 250 kt and you don't feel a thing in the cockpit."

With regard the SVRL landing technique, which is designed to increase the aircraft's fuel and/or weapons bring back capacity, Wilson said that the Program Office is continuing the support the UK-specific work in this field, although he added that the UK government has not yet decided if it will adopt this technique on the two Queen Elizabeth-class ships (CVF) when they enter service....”

Ship Shape — F-35/QEC simulator

SEPTEMBER 2014 PAUL E EDEN

"…Pete 'Kos' Kosogorin, a BAE Systems F-35B experimental test pilot, recently visited HMS Queen Elizabeth, under construction at Rosyth, Fife. Standing in the ship's flying control center (FLYCO) he commented: "It's really exciting because it looks so familiar. I can see how vast, how wide and how long the deck is, and it looks familiar because of the simulator work we've been doing at Warton, in terms of integrating the F-35 into the ship using the shipborne rolling landing technique, the normal vertical landing and short take-off operations. That simulation work is part of a wider carrier integration effort at Samlesbury and Warton that has allowed us to find efficiency and savings in the design of the carrier, its deck, the array and the systems that assist the pilot in approach and landing."

A member of the F-35 Integrated Task Force at Naval Air Station Patuxent River, Maryland, for the past four years, Kosogorin explains more about the simulator's role: "The sim work hasn't just been about developing the flight controls software in the aircraft, it's also about finding out how to fly and carry out certain maneuvers, and working out various flying techniques, such as shipborne rolling vertical landing. We've brought together a cross-section of individuals to do that, from very experienced Harrier pilots to US Navy conventional F-18 pilots, and also Royal Navy and other air force pilots who have no shipborne or STOVL [short take-off/vertical landing] experience, to ensure the design is optimized for all levels of ability and all levels of scale."

HARRIER LEGACY

Comparisons are frequently made between the F-35B and the Harrier; they are usually misleading. But in the case of BAE Systems' F-35/carrier flight simulator, earlier work with the legacy jet and Invincible class ships has helped lay the foundations for Warton's 21st century simulator design. As David Atkinson, F-35 Carrier Integration Lead at BAE Systems, explains, the result is a flexible system with capabilities beyond F-35B: "We've been conducting flight simulation at Warton for over 50 years for many projects, including simulating Harriers operating from the recently retired Invincible CVS class. The F-35/carrier flight simulator has been developed to support the integration of the F-35 to the QE class ships. It is, however, capable of simulating F-35C to aircraft carriers with catapults and arrestor gear, and has been used for assessment of various flight control developments for F-35C to CVN and, while the UK was considering a CV-converted QE class ship, for F-35C to QE."

Unlike the more familiar full mission simulator, the F-35/carrier sim focuses on the near-ship environment, primarily for the assessment of launch and recovery operations, including circuits around the ship. It uses a Lockheed Martin F-35 six-degrees-of-freedom mathematical model validated against extensive flight test data; a QEC ship motion model provided by the Aircraft Carrier Alliance (ACA), based on tank test data; and a computational fluid dynamics (CFD) ship-airwake flowfield that is being further developed and validated by the University of Liverpool.

Realism has been further enhanced by the recent addition of a landing signal officer's (LSO) station. The LSO's role will be similar to that aboard an Invincible class ship, but according to Atkinson there will be "a larger workstation and more sophisticated situational awareness aids and information displays".

Describing the simulator's design and how the LSO station is integrated, Atkinson continues: "From a physical point of view it has a hydraulic motion platform within a dome and uses motion-cueing algorithms to enable the pilot to feel aircraft motion in a very realistic way, despite remaining very firmly on the ground. High-specification projectors are used, with a very high-resolution projector for the pilot's forward field of view. It has a second projected screen display to represent part of the FLYCO – the LSO workstation, at which a pilot can operate as an LSO, interacting with the pilot flying the simulator, while watching the aircraft maneuver in real time. The combined motion simulator and FLYCO representation have proved very valuable while developing maneuvers, operating procedures and display layouts."

SIMULATOR AMBITION

Allowing pilots to fly F-35B approaches in cooperation with an LSO, as they will on the real carrier at sea, is already delivering immense value to the program, but Atkinson says that the simulator is scheduled for much greater capability. "Our ambition is for the simulator to be used for wider purposes than pilot and LSO interactions…."…

…Work to date has driven modification and refinement in carrier flight deck design, aircraft design and operational procedures. "We've conducted a number of trials to develop the F-35B to QEC vertical landing, ski-jump launch and shipborne rolling vertical landing maneuvers and the supporting systems; visual landing aids (flight deck lights, glidepath indicators), F-35B helmet mounted display symbology, LSO situational awareness aids and standard operating procedures.

"We've helped the MoD and the ACA optimize and gain confidence in their designs and likewise for some changes we've made to the F-35B, to allow shipborne rolling vertical landings to be conducted. These are unique to the QE class and involve a rolling vertical landing onto the ship's 'runway' with 30 to 40kt of overtake, allowing increased bring-back weight performance for the aircraft, which should pay dividends on operations," says Atkinson….

…Over more than a decade of work, Warton's F-35/carrier simulator has identified and helped fix various issues, as well as facilitating the safe expansion of the operating envelope. "The QE class has an immense flight deck with state-of-the-art visual landing aids," says Atkinson. "The F-35 is a hugely capable 5th generation aircraft that pilots find easy to fly to a ship and we believe that there are lots of good ways to operate the F-35B to a ship the size of the QE, with our role being to optimize the designs and procedures to maximize performance. We've identified a few issues and concerns through the simulation work, but thankfully it also provides an ideal environment to visualize problems, explain them and rapidly show how potential solutions would work. Between the MoD, ACA and ourselves we have identified and resolved a number of issues over the 10 plus years that we've been working together using the Warton simulator."…

…The potential of Warton's F-35/carrier simulator to begin the definition of a future training syllabus even as its test work continues is obvious and Atkinson confirms its role, not only in pilot training, but also for flight deck crew: "We have already used the simulator to inform the training syllabuses and help our customers understand the benefits of immersive simulation to their training processes for the pilot and LSO. What is abundantly clear is that simulation technology is here to stay and continues to increase its role in development and training based on cost-effectiveness and an ever-increasing ability to emulate the real world."

See Next Page

300 Take-off run in feet from QEC for lightly loaded F-35B

800 Take-off run in feet from QEC for fully loaded F-35B

AEROSPACE TESTING INTERNATIONAL
September 2014

Roles **F-35B Lightning II**

http://www.raf.mod.uk/equipment/f35jointstrikefighter.cfm

The F-35B Lightning II will place the UK at the forefront of fighter technology, giving the Royal Air Force a true multi-role all weather, day and night capability, able to operate from well-established land bases, deployed locations or the Queen Elizabeth Class Aircraft Carriers.

Engines: Pratt & Whitney F-135-600 **Thrust:** 40,000lbs

Max speed: 1.6Mach

Length: 15.6m

Max altitude: 50,000ft

Span: 10.7m

Aircrew: 1

Armament: Paveway IV, AMRAAM, ASRAAM

maximum weapon payload of 6 Paveway IV, 2 AIM-120C AMRAAM, 2 AIM-132 ASRAAM & a missionised 25mm gun pod

Future Armament: Storm Shadow, SPEAR, METEOR, 25mm Gun Pod

The Lockheed Martin F-35 Joint Strike Fighter will be known in UK service as the Lightning II. Lockheed Martin is the prime contractor but the UK is the only Level 1 partner with the US. A number of British companies, including BAE Systems and Rolls-Royce will have significant industrial work-share in construction and development of the aircraft. The Lightning II will provide UK Defence with a 5th Generation (low observable, supersonic, enhanced data fusion), multi-role, all weather, day and night aircraft that will have the ability to operate from land bases as well as the Queen Elizabeth Class carriers, the first of which is due to accept Lightning II onto her deck in 2018. This basing flexibility will give UK Defence a truly joint expeditionary Combat Air capability well into the 2030's. The RAF is the lead service for the operation of Lightning II and, like the Harrier before, the Joint Lightning II Force will be manned by both RAF and RN personnel.

Lightning II has been designed from the outset to carry out a wide range of mission types, able to use its very low observable characteristics to penetrate Integrated Air Defence Systems and strike a number of types of targets. In a permissive environment, Lightning II is able to carry weapons on external pylons, as well as in the internal weapon bays. This will allow a maximum weapon payload of 6 Paveway IV, 2 AIM-120C AMRAAM, 2 AIM-132 ASRAAM and a missionised 25mm gun pod.

The Lightning II design applies stealth technology manufacturing techniques and, to minimise its radar signature, the airframe has identical sweep angles for the leading and trailing edges of the wings and tail, and incorporates sloping sides for the fuselage and the canopy.

The advanced sensor suite of the Lightning II is the greatest step-change in capability that the UK has not previously possessed. The APG-81 is an Active Electronically Scanned Array multi-function radar with Synthetic Aperture Radar and Ground Moving Target Indication capabilities. Targeting information can also be supplied by an Electro-Optical Targeting System, which provides long-range detection and precision targeting by employing thermal imaging, laser tracking and marking. 360 degree situational awareness is aided by the Electro-Optical Distributed Aperture System. Lightning IIs advanced mission systems will also provide navigation information, missile warning and infrared search and track capabilities.

Lightning II will place the RAF at the forefront of fighter technology and will give it a true multi-role aircraft that will surpass the majority of other weapons systems in production today, or envisaged in the foreseeable future. Lightning II and Typhoon aircraft will make up the Fast Jet elements of Future Force 2020....

Powering the Lightning II

April 2012 Chris Kjelgaard

"...According to Jones, the roll posts themselves are variable-area nozzles which are situated in the lower part of each inner wing section and act to provide roll control for the F-35B while it is in hover mode. In order to do this, the roll-post ducts direct bypass air from the engine to the roll posts, which drive the air out through the bottom of each wing. In the F-35B, 3,700lb (16.46kN) of thrust in the form of bypass air is directed out to the two roll posts while hovering.

Each roll-post assembly features a pair of flap-type doors in the bottom of the wing, controlled by the FADEC. Jones says these titanium doors are controlled by rotary actuators which allow fully variable opening, providing a degree of thrust variability and directionality so that the pilot can control roll while hovering. He says Lockheed Martin's original X-35 concept demonstrator featured doors between the engine casing and the roll-post ducts which could be closed when the aircraft was not hovering, but in production aircraft there are no such doors and bypass airflow is constantly sent to the ducts. The only way to control roll-post thrust is via the flap-doors in the bottom of the wing...."

http://militaryrussia.ru/forum/download/file.php?id=28256

Jumping Jack Flash

July 2014 unknown author
AIR International F-35 Special Edition

"...STO-ing...

...There are three ways to conduct a short take off (STO) in the F-35B: stick STO, button STO – and auto STO. "That's a completely automated way to STO the aircraft off the flight deck. You punch in a distance and the aircraft will auto rotate to its optimal fly-out condition. It's all based on distance: we know where the aircraft is spotted [before it starts its take-off run] and where it should start its actual rotation," explained Rusnok. "Unlike a Harrier, which launches off the end of the ship flat, the F-35 rotates at about 225 feet from the bow, sits on two wheels until it gets to the end of the ship and actually takes off, a much different process to a Harrier. From a pilot perspective, you lose some sight of the front of the ship; in a Harrier you can see all the deck. But that's all part of optimising a 35,000lb aeroplane to get off the ship compared to the Harrier, which is only 16,000 to 25,000lb."

With stick STO the pilot controls the take-off by pulling back on the stick, holding it there and then rotating to the optimal pitch angle to fly off. In button STO, the pilot uses a trim switch which rotates the aircraft when pushed in, activating it when the aircraft passes the yellow STO rotation line positioned 225 feet from the bow of the ship.

"That was a temporary marking applied on the flight deck for this trial and is now being permanently installed on the ship with lighting," explained Rusnok. "It's based on optimising the performance of the aircraft and its flying qualities, so we can get the aeroplane off with the maximum amount of nozzle clearance and performance. The STO line is our visual cue to either pull the stick aft or hit the button; or if you're on automated STO you should start seeing the aeroplane's flight controls moving by the line, otherwise the pilot can intervene and pull back on the stick. We've never had to intervene."

The pilot also has command of the throttle. Two power setting options are available for take-off: Mil STO and Max STO, as Maj Rusnok explained: "When you taxi to the tram line you stay in mode one, the conventional flight mode. You convert the aircraft into mode four, the STOVL flight mode, and it takes about 15 seconds or so for the doors to open up and the lift fan to engage.

"Then you push the throttle about halfway up the throttle slide into a detent position at about 34% engine thrust request. It sits there and you check the engine gauges: if the readings are okay you slam the throttle to either Mil or Max position and then release the brakes simultaneously. Pushing through to max is like an afterburner detent. But it's not an afterburner – you can't go to afterburner in mode four.

"It's a very fast acceleration. The closest we would spot from the bow is 400 feet, so about 175 feet before we would actually start rotating the aeroplane [at the STO rotation line]; so very, very quick."

One of the big test points for DT I was to ensure adequate nozzle clearance in all the different test conditions. The engine nozzle swings down and back up during the take-off in accordance with inputs from the aircraft control laws.

"It's all automated," said Rusnok. "The pilot is not in the loop whatsoever – either they're pushing the button and letting the aeroplane do its own thing or pulling back on the stick to help it. Monitoring systems cue when something is wrong, so you have to rely on them to keep you safe because the flight controls are being moved unbelievably quickly."

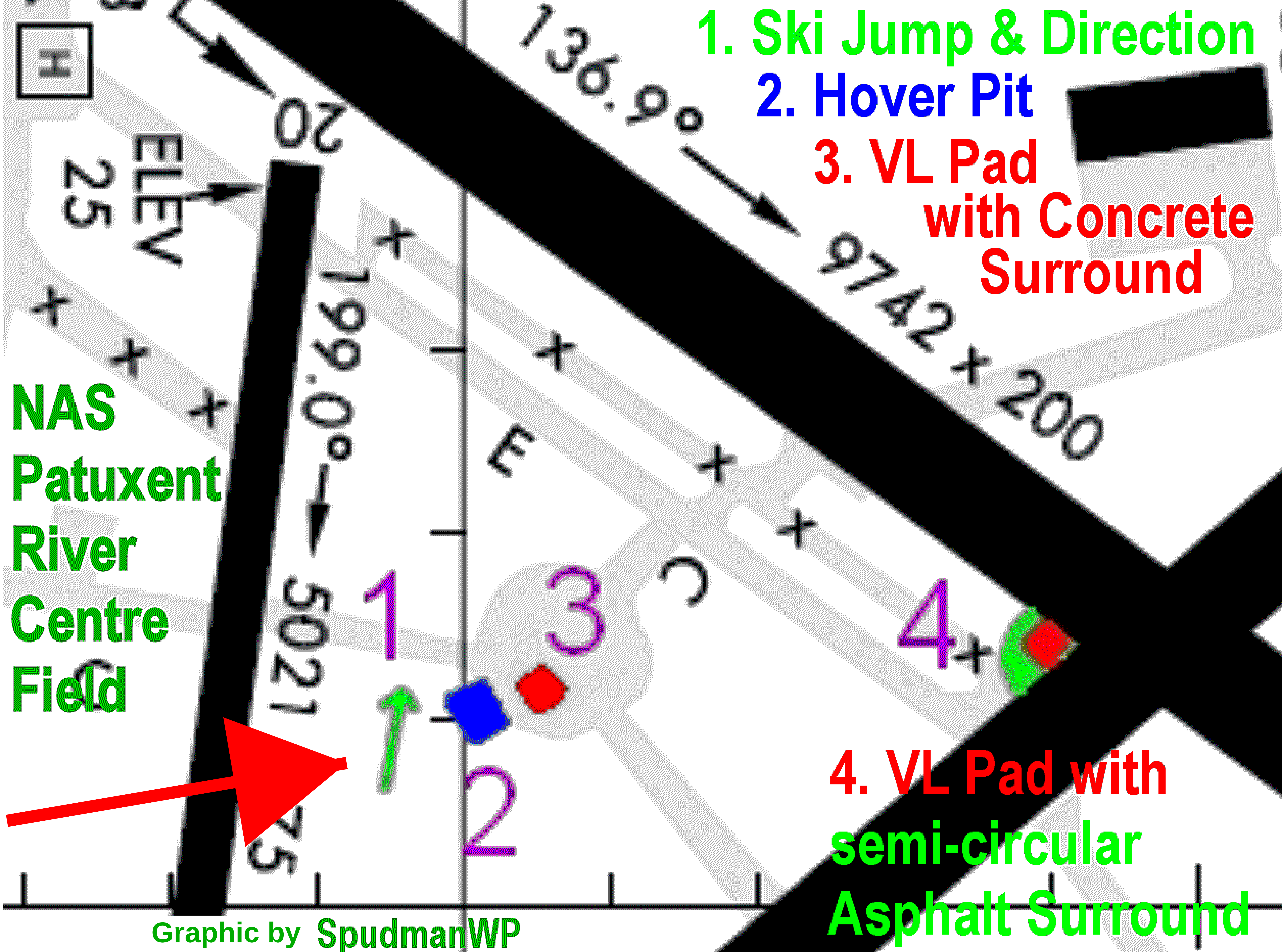
Maj Rusnok said the take-off was very much like that ashore, with very little sink off the end of the deck. "The aeroplane is ridiculously powerful in STOVL mode. Just raw, unadulterated power."

Forum: F-35 Lightning II AV-8B/ Expeditionary (F-35B) Basing on AM-2 Matting Exercise

http://www.f-16.net/index.php?name=PNphpBB2&file=viewtopic&t=16017&postdays=0&postorder=asc&highlight=paxriver&start=30

http://www.f-16.net/attachments/swppaxrivervlpadsskijumphoverpit_200.gif

PAX RIVER Centre-field 'Ski Jump' SPOT



EAF enables JSF landing anywhere, everywhere

29 Jun 2009 Press Release Number: E200906291

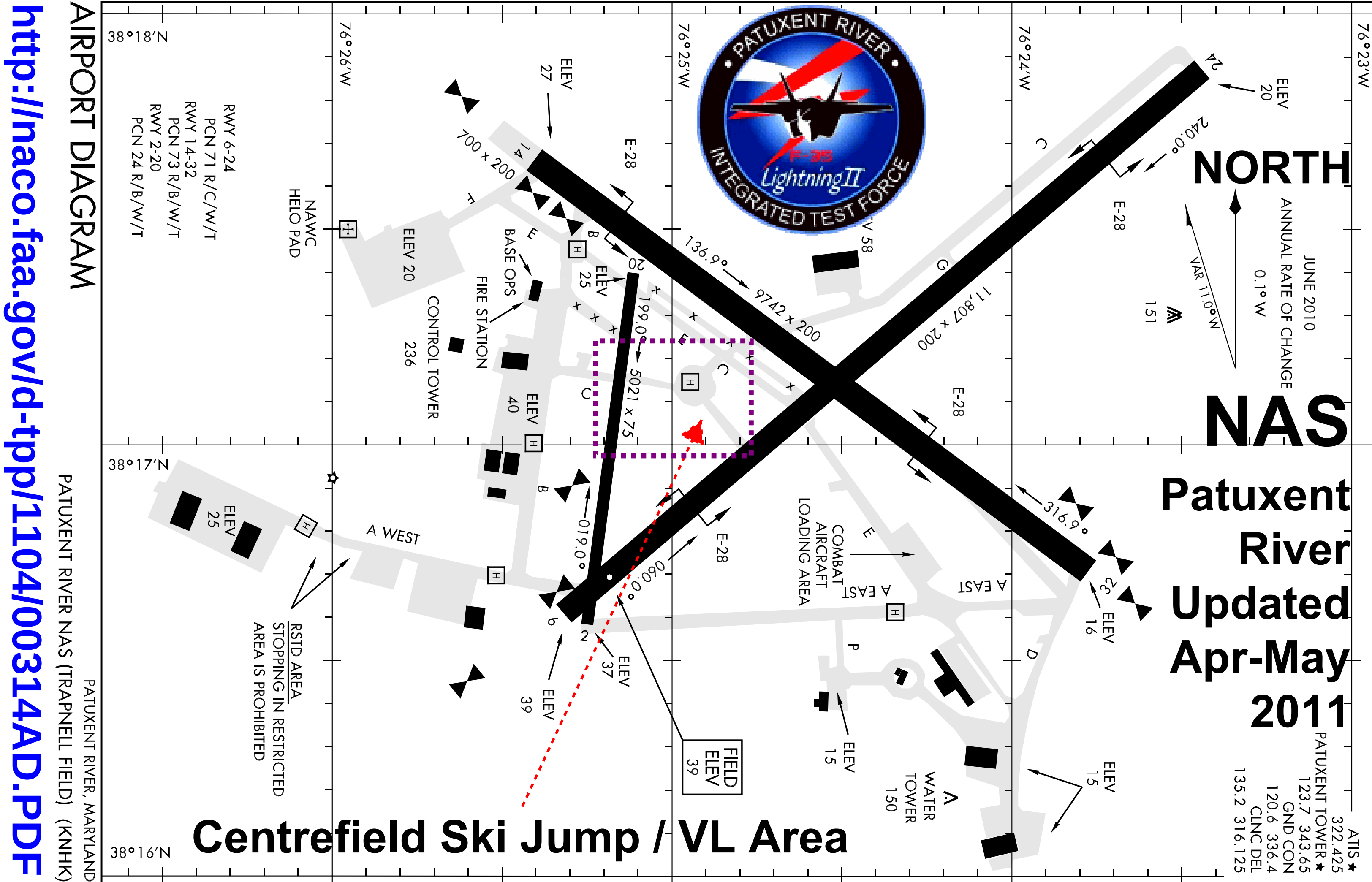
http://www.navair.navy.mil/press_releases/index.cfm?fuseaction=home.view&Press_release_id=4144&site_id=15

"PATUXENT NAVAL AIR STATION, Md. -- Marine Wing Support Squadron 274 gave engineers help in April to lay the first expeditionary landing site for the F-35B Lightning II Joint Strike Fighter for short takeoff/vertical landing (STOVL) capabilities testing. Expeditionary Airfields are mobile systems that allow Marines to quickly build functioning airfields in areas without airfield support. EAFs are built using AM-2 matting: aluminum panels which are assembled in a brickwork pattern to form runways, taxiways, parking sites and other areas required for aircraft operations and maintenance. These EAFs allow the JSF to perform missions in any terrain that does not support a standard-use airfield in mission-critical areas.

"This joint testing is a significant step for the Aircraft Launch and Recovery Equipment program," said ALRE Program Manager Capt. Randy Mahr. "The JSF and EAF have an integral relationship in expanding our capabilities and success on the battlefield. The EAF's AM-2 matting is battle tested, dependable and versatile. It's exactly what we need for our expeditionary landing and take-off platforms." Although the AM-2 matting is serving its purpose as vertical take-off and landing (VTOL) pads and a 1,900 x 96-foot runway for the EAF/STOVL testing, it also doubles as the run-up for a test "ski-jump" used in conjunction with JSF testing for the British Royal Navy. The AM-2 matting and the 12-degree ski-jump ramp were installed at the centerfield area last month. "NAVAIR is excited about our involvement in the JSF program, said Mike Jiavaras, ALRE's EAF team leader. "Knowing that the first time this aircraft demonstrates its impressive VTOL capabilities will be on an expeditionary airfield raises the level of pride the team has in our program and in support of the warfighter."

The ski-jump ramp is used by British Her Majesty's Ship (HMS) Invincible-class carriers for launch of STOVL aircraft, such as the Harrier GR7A, & is located on the forward-end of the flight deck. JSF program experts explain that the ski-jump is a more fuel efficient way for aircraft take-off. However, the drawback is that it does not allow larger aircraft such as the E-2D Advanced Hawkeye, F/A-18E/F Super Hornet and the EA-18G Growler — future carrier deck-mates with the JSF, the needed distance for launch and recovery. The mock ski-jump is 150-feet long, with a 15-foot high "lip" for aircraft launch.

These shore-based ski-jump takeoffs will be conducted at varying airspeeds prior to the first UK ship detachment with the F-35B. "We are extremely excited about getting the first of eight F-35's to Patuxent River beginning this summer. The first aircraft to arrive, a STOVL aircraft designated BF-1, will use test facilities we have built to test and verify the unique warfighting capabilities the STOVL variant brings. We look forward to supporting the long-standing traditions of expeditionary warfare capabilities for the next 50 years of Marine Corps aviation," said Capt. Wade Knudson, acting deputy program executive officer and program manager for F-35 Lightning II development."



NAS
Patuxent River
Updated Apr-May 2011
Centrefield Ski Jump / VL Area
AIRPORT DIAGRAM
http://naco.faa.gov/d-tpp/1104/00314AD.PDF
PATUXENT RIVER NAS (TRAPNELL FIELD) (KNHK)
PATUXENT RIVER, MARYLAND
RWY 6-24 PCN 71 R/C/W/T
RWY 14-32 PCN 73 R/B/W/T
RWY 2-20 PCN 24 R/B/W/T
PATUXENT RIVER INTEGRATED TEST FORCE
F-35 Lightning II
NAWC HELO PAD
ELEV 20
BASE OPS
FIRE STATION
CONTROL TOWER 236
ELEV 40
A WEST
A EAST
RSTD AREA STOPPING IN RESTRICTED AREA IS PROHIBITED
FIELD ELEV 39
COMBAT AIRCRAFT LOADING AREA
WATER TOWER 150
JUNE 2010 ANNUAL RATE OF CHANGE 0.1°W
VAR 11.0°W
ATIS 322.425
PATUXENT TOWER 123.7 343.65
GND CON 120.6 336.4
CLNC DEL 135.2 316.125
9742 x 200
11,807 x 200
5021 x 75
700 x 200
38°18′N
38°17′N
38°16′N
76°26′W
76°25′W
76°24′W
76°23′W

Jumping Jack Flash

July 2014 unknown author
AIR International F-35 Special Ed.

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AIR International
F-35 Special Edition July 2014

Stepping-Stones

Tony Osborne AVIATION WEEK & SPACE TECHNOLOGY 08 SEP 2014

"...Particular emphasis has also been placed on how the F-35 will launch from the Queen Elizabeth's ski jump, which gives the aircraft valuable vertical impetus, allowing for greater takeoff weights as well as a positive rate of climb. The F-35B's flight control logic has been written for the Queen Elizabeth's new 12-deg. jump, which at 200 ft. long, is some 50 ft. longer than that used on the Invincible-class carriers.

With the aircraft lined up for takeoff, the pilot presses the short-takeoff-and-vertical-landing (STOVL) switch, activating the lift fan and rear nozzle. The lift fan is fully operational within 15 sec. The F-35B uses the same process and partially opens its weapons bay doors, which help provide more lift. [Perhaps it was meant that this is for the VL?] As the aircraft hits the ski jump, its flight control logic recognizes it is on the ski jump anduses the rear nozzle to keep all three wheels on the ground. The aircraft should be airborne at around 90 kt.

"It's a luxurious way to get airborne,'' says Wilson. "The pilot simply uses the pedals to keep the aircraft straight, and the aircraft recognizes the presence of the ski jump." Test pilots have tried out the ski jump only in the simulator, but that work has been very valuable in addressing early concerns about the ground clearance between the ski jump and rear nozzle...."

AVIATION WEEK & SPACE TECHNOLOGY 08 SEP 2014

F-35 B/C TESTING

Program http://www.jsf.mil/program/prog_field_nawcad.htm

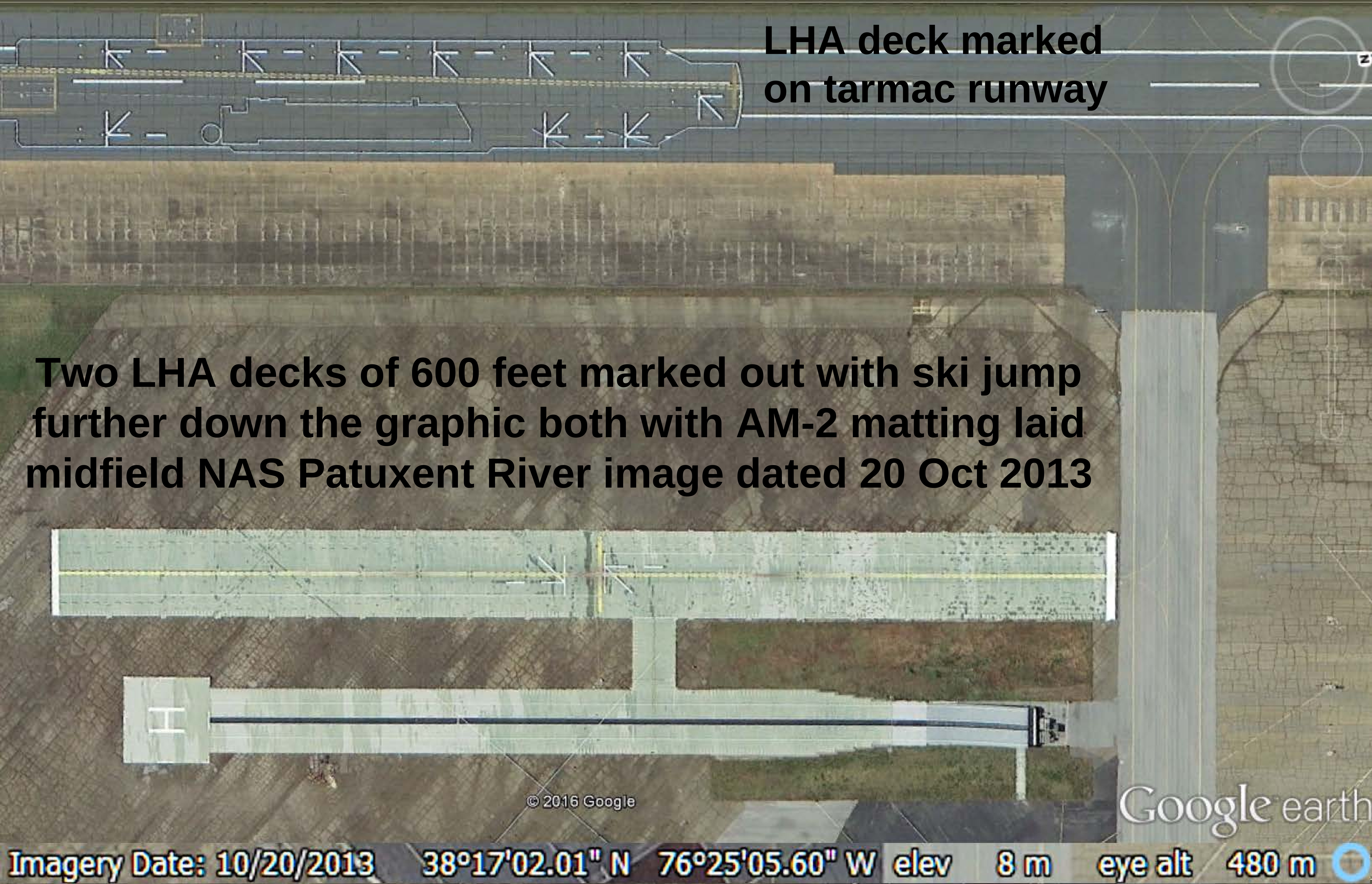
Field Activities > Patuxent River Naval Air Station, Maryland

The Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River Maryland, is the Navy's research, development, test and evaluation (RDT&E), engineering and fleet support center for air platforms. Patuxent River is also home to the Naval Air Systems Command (NAVAIR). Ranges at Patuxent River include extensive inshore and offshore operating areas to support the full array of testing required for a new air platform. The airfield test facilities include a land based TC-7 catapult and MK-7 arresting gear and other unique test facilities geared toward the evaluation of weapon systems designed to operate in a shipboard environment. **Also Mid-Field Ski Jump & EMALS from Dec 2010**

NAWCAD provides approximately 220 Work Years (FY05) of critical engineering expertise to virtually every Integrated Product Team within the JSF program. Major efforts include the standup of facilities to support a total contractor and government F-35 test team of approximately 700 personnel. All Carrier and STOVL F-35 variant test airplanes will be developed at Patuxent River, totaling nine aircraft at peak. Unique F-35 tests to be conducted at Patuxent River include land based catapult and arrestments, STOVL vertical and short takeoff and landing tests, expeditionary airfield operations, the full range of aero-sciences envelope expansion, mission systems development and weapon certification testing.

The Lockheed Martin X-35C and the Boeing X-32B were both tested at Patuxent River during the JSF Concept Demonstration program. The X-35C is currently on display at the Patuxent River Naval Air Museum, and the X-32B will be prepared for display by March 2005.


N
NAS Patuxent River
Centrefield Ski
Jump & VL Pad
82 ft
1993
Imagery Date: 10/20/2013
38°17'05.56" N 76°24'58.94" W
SKI JUMP LEFT


LHA deck marked
on tarmac runway
Two LHA decks of 600 feet marked out with ski jump
further down the graphic both with AM-2 matting laid
midfield NAS Patuxent River image dated 20 Oct 2013
© 2016 Google
Google earth
Imagery Date: 10/20/2013 38°17'02.01" N 76°25'05.60" W elev 8 m eye alt 480 m

British pilot is first to test F-35B ski-jump launch

BAE Systems plc Manufacturing Group | June 24, 2015 http://www.onlineamd.com/british-pilot-tests-f35b-jump-062415.aspx

Washington – The launch took place at Naval Air Station Patuxent River, Maryland, on June 19, 2015, from a land based ski jump and marks the start of an initial testing phase expected to last two weeks. The trials demonstrate the aircraft's ability to take off safely and effectively from a ski-jump ramp similar to that which will be used on the UK's new aircraft carrier. Ski-jump ramps provide the aircraft with an upward flight path meaning the aircraft can take off from the available distance with a greater payload, which means more weapons.

BAE Systems test pilot Pete Wilson said: "It's always exciting when you get to do something in aviation for the first time. We spend literally years planning these 'firsts', with hundreds of hours in the simulator as the event gets close, but even with all the preparation the test team remains focused on the potential that something unexpected might happen. As is usually the case, the jet performed as expected and it was a real pleasure."

BAE Systems plays a key role in the design, development and manufacture of both the aircraft and the aircraft carrier, and also leads the work to ensure that both are integrated seamlessly for the UK customer. These recent trials continue to inform the F-35 program and the BAE Systems engineers involved in it on both sides of the Atlantic. That includes BAE Systems flight test engineers based in the U.S. and engineers in Lancashire helping to develop and test the latest technologies for the aircraft.

In Warton, Lancashire, UK, the data from the flight trials will be used to further improve the models used in a unique simulation facility. Using the latest cutting edge technologies, engineers have developed a simulator that allowed pilots and engineers to fly the F-35 from the deck of the Queen Elizabeth carrier before either are available. This facility remains at the heart of developing a carrier strike capability for the UK.

Globally, some 3,000 BAE Systems people work on the **F-35** program. From the UK, BAE Systems is responsible for the production of each and every rear fuselage and tails set. Along with manufacturing aircrafts sets for each of the three variants, the UK business produces carrier wing tips for the carrier variant and nozzle bay doors for the short take off and vertical landing variant. The Company also plays a key role in flight test, vehicle and mission systems, life support system and prognostics health management integration. BAE Systems Inc. in the US adds further key capabilities to the F-35 portfolio in the areas of electronic warfare, advance apertures, advanced counter-measure systems, vehicle management, and active inceptor systems.

The F-35B is designed to operate to and from aircraft carriers which means being able to operate from very short runways. Although U.S. ships have flat decks, British and Italian aircraft carriers that are planning to operate F-35B incorporate an upward sloped ramp at the end of the runway, which is right at the bow of the ship. The term "ski jump" has been adopted over the years because it invokes a feeling of leaping into the air.

F-35 Lightning II

Pax River Integrated Test Force

Public Affairs Release – 2015 06 19

http://www.jsf.mil/news/docs/20150619_SkiJump.pdf

F-35B COMPLETES FIRST SKI JUMP LAUNCH

An F-35B Lightning II completed the first ramp-assisted short take off to test the aircraft's compatibility with British and Italian aircraft carriers.

"This test was a success for the joint ski jump team," said Peter Wilson, BAE Systems F-35 test pilot and U.K. citizen, who flew the 19 June mission at Naval Air Station Patuxent River, Maryland. "The aircraft performed well and I can't wait until we're conducting F-35 ski jumps from the deck of the Queen Elizabeth carrier."

Two F-35 partner nations use ramp-assisted short take offs for their carrier operations as an alternative to the catapults and arresting gear used aboard longer U.S. aircraft carriers. The shorter U.K. and Italian carriers feature an upward-sloped ramp at the bow of the ship. Curved at its leading edge, a ski-jump ramp simultaneously launches aircraft upward and forward, allowing aircraft to take off with more weight and less end-speed than required for an unassisted horizontal launch aboard U.S. aircraft carriers.

The F-35B's design allows it to automatically position the control surfaces and nozzles for takeoff; a unique capability compared with previous short takeoff and vertical landing aircraft. Such automation frees up pilot capacity and provides an added safety enhancement.

"The control laws on the F-35B are designed to make the task of taking off and landing at the ship much easier than for previous STOVL aircraft," said Gordon Stewart, flying qualities engineer representing the UK Ministry of Defence. "For ski jump launches, the aircraft recognizes when it is on the ramp and responds by positioning the control surfaces and nozzles automatically for takeoff and climb. This was our first chance to demonstrate these new control laws using a land-based ski jump. We'll be using these results - along with those from future testing - to help us prepare for the first shipboard ski jump launch from HMS Queen Elizabeth."

“The F-35 Lightning II Pax River Integrated Test Force from Air Test and Evaluation Squadron (VX) 23 conducted the first-ever ski jump of an F-35B Lightning II short take-off/vertical-landing (STOVL) variant June 19. During flight 298, BAE test pilot Peter Wilson launched aircraft BF-04 from a land-based ski jump located aboard NAS Patuxent River. This test is the first of a series of U.K. ski jump events scheduled for 2015. Lockheed Martin photo by Andy Wolfe.”

SLOW MOTION 1st F-35B Ski Jump Launch 19 June 2015
https://www.youtube.com/watch?v=ihpNrDriZrc

A Message from Lorraine Martin 22 Oct 2015 LM

"...Ski Jump testing at Pax River is ongoing, and the team is really doing some amazing work. They completed nine successful takeoffs from the ski jump platform. Throughout the testing they found some challenges to overcome and work, but the team has done a great job of working through those challenges. They have to complete eight more tests to finish up phase one testing. It’s exciting to see images of the F-35B taking off from the ski jump, and I know the U.K. and Italy are also excited about this testing and the capabilities it brings to their countries...."

https://www.f35.com/assets/uploads/documents/16409/f-35_weekly_update_10_22_15.pdf

F-35B First Ski Jump Test NAS Patuxent River, MD June 19, 2015
VIDEO: https://www.youtube.com/watch?v=pIO5K-fUMzQ

https://www.f35.com/assets/uploads/images/15850/ski-jump-news__main.jpg

Navy’s new F-35 jump jet flies from trademark ski ramp for 1st time

[19] 23 June 2015 https://navynews.co.uk/archive/news/item/12935

“Veteran test pilot Peter ‘Wizzer’ Wilson took off in an F-35B using the jump – identical to those fitted on the Royal Navy’s new carriers [not true]. This is the moment years of complex calculations, computer simulations, planning, training & testing pays off for the Navy’s jet of tomorrow.

This is the first launch [19 June 2015] of the F-35B Lightning II using a ski jump ramp – exactly as it will do when launched from flight deck of HMS Queen Elizabeth and Prince of Wales. Naval reservist and BAE Systems test pilot Peter ‘Wizzer’ Wilson guided his state-of-the-art strike fighter BF-04 down the runway at the US Navy’s Pax River air base, about 45 miles from the American capital, where the ramp has been built to pave the way for Royal Navy carrier operations.

“It’s always exciting when you get to do something in aviation for the first time,” said Peter. “We spend literally years planning these ‘firsts’, with hundreds of hours in the simulator as the event gets close, but even with all the preparation the test team remains focussed on the potential that something unexpected might happen. As is usually the case, the jet performed as expected and it was a real pleasure. “I can’t wait until we’re conducting F-35 ski jumps from the deck of the Queen Elizabeth-class carrier."

Ski jumps were fitted to the RN’s generation of Harrier carriers to give the jets more lift with less speed than a conventional flat flight deck. The concept has been retained with the Queen Elizabeth class – although the ‘replica’ ramp has been built in Maryland, not Yeovilton. On the new carriers the structure rises about six metres (20ft) above the normal deck.

Two weeks of initial trials are being carried out with the data gathered fed back by the test team to engineers and designers, including those at Warton in Lancashire where F-35 simulators help pilots ‘fly’ from the deck of HMS Queen Elizabeth – before they do it for real from 2018 onwards.”

Salty Dogs & Funky Jets

October 2015 Mark Ayton

...Ski Jump Trials

Her Majesty's Ship Queen Elizabeth (R08) is fitted with a ski jump like no other: a new design tailored to be used by very expensive new aircraft. Launching a 60,000lb F-35B off a ski jump requires some serious maths, engineering and testing.

The F-35B ski jump test campaign should have started in March of this year, but was delayed due to brutal sub-zero temperatures and snow that blighted Patuxent River at the time. Aircraft BF-01 was originally assigned to conduct the ski jump events but was unable to remain at Pax while the weather improved. It was already scheduled to deploy to Edwards Air Force Base, California to conduct wet runway and crosswind testing.

The test programme comprises two phases, the first of which eventually began on June 19 when BAE Systems test pilot Peter Wilson conducted the first take-off using the ski jump at Pax with F-35B BF-04. Sqn Ldr Edgell told AIR International: "Phase 1 is a risk-reduction phase designed to highlight any significant hardware or software updates that may be required prior to commencing the bulk of testing. It comprises 29 ski-jump launches.

"Phase 1 will ensure our models and predictions are correct. If anything needs addressing we can do so in a timely fashion and then go into the 140-sortie Phase 2."

The ski jump used on HMS Queen Elizabeth has a curved leading edge designed to simultaneously launch an F-35B upward and forward with a greater take-off weight and less end-speed than required for an unassisted horizontal launch aboard an LHD-class amphibious assault ship, such as USS Wasp (LHD 1).

The reader may be surprised to learn that the ski ramp built at Pax River is based on the type used on the Invincible-class aircraft carriers which is a little bit shorter (50ft) and slightly shallower (0.5º) than the ramp on Queen Elizabeth-class carriers. Sqn Ldr Edgell explained: "The Pax River ramp design process dates back to 2005 but, at the time, the Queen Elizabeth ramp profile was not known. Analysis conducted in 2005 showed we simply needed to use a ramp with a profile that allows us to stay just under the predicted F-35B ultimate loads and the Invincible-class ramp achieved this."

Pax River's ramp allows the test team to make adjustments for different profiles and encompass everything below the ultimate loads of the aircraft. "Though the verification of our models during phases 1 and 2 we can tweak the control laws to work off other types of ramp, none of which are the same," said Sqn Ldr Edgell. When the aircraft comes off the end it is ballistic and accelerates to the fly away air speed, typically 10-20kts higher than launch speed, and therefore reduces ground roll.

"There's a fine line between ensuring we have suitable gear loads and fly away speed," explained Sqn Ldr Edgell.

"We want lots of margin on both of those. To achieve margin for gear loads we need to be slow, i.e. start right at the bottom of the ramp. To achieve margin on minimum fly away speed we need to start towards the back of the run-up. We blend the two aspects together and meet in the middle to gain the safest launch spot. For the very first sortie, our spotting distance will be conservative and will launch the jet off the end of the ramp straight into a previously flown flight condition."

Such regimes have been flown several times during short take-offs at the field and STOVL departures.

Sqn Ldr Edgell explained an interesting fact about the take-off : "You can be lined up three, four, five hundred feet back from the start of the ramp and as you slam the throttle forwards, **the jet doesn't know it's about to go up the ski jump.** It waits for certain triggers to alert it to the fact it's going off the ski jump, at which point its flight control system moves the horizontal tails and the nozzles into the optimum position. It needs to hit 45 knots going up the ramp.

"The throttle needs to be above 65% ETR, with 6 degrees of attitude and a pitch rate of 6 degrees per second. At that point it moves all of the effectors into the right place. Bear in mind the ski jump at Pax is only 150 feet long, so the aircraft hits all of those parameters with less than 100 feet remaining. **By the time it goes off the edge of the ramp all the surfaces and the nozzles are at the optimum position, the aircraft rotates up to the optimum pitch attitude to fly away.** It's pretty clever stuff."

Sqn Ldr Edgell described the launch process: "You slam the throttle and guard the stick. There is no input on the stick required. As the aircraft moves down the tramline of the deck you track the centre line with your feet, just like any other carrier deck take-off, but there's no pitch input required. The jet flies away. It's effortless." In the event of any kind of malfunction, the pilot takes control and manually flies off the edge of the ramp, which is why he must guard the stick during the roll.

There is no significant part for the pilot to play in the take-off – the result of a design philosophy to minimise the pilot's workload. **A good example is tracking the centreline on a rolling pitching deck at night. That's a challenge in a Harrier but in the F-35B it's his only task so he should do a much better job.** The administrative burden on the pilot has been significantly reduced: in this situation to an effortless level.

Phase 2 will introduce cross-winds, external stores, asymmetry, minimum performance (minimum deck) launches from the bottom of the ramp, and simulated performance degradation all to increase the aircraft's flight envelope in Block 3F configuration. That's imperative work for the UK which will undertake first-in-class flight trials on HMS Queen Elizabeth in the final quarter of 2018…"

Air International OCTOBER 2015 Vol.89 No.4

'John Farley' and 'Engines' on Ski Jumps

http://www.pprune.org/military-aviation/424953-f-35-cancelled-then-what-317.html#post9021527

'John Farley' 23 Jun 2015:

http://www.pprune.org/military-aviation/424953-f-35-cancelled-then-what-317.html#post9021527

"**Re ski-jumps,** it does not take much thought to realise that the ramp delivers any aircraft into free air in a nose up attitude and climbing. This saves the pilot having to arrange all of this when departing from the flat. Indeed back in 1977 when the boffins thought I was exaggerating how easy a jump was compared to a flat takeoff, I gave them the next record with a straight line on the tailplane and aileron traces for 35 secs after crossing the end. At the debrief they showed me the traces and apologised for the instrumentation drop out on the tailplane and aileron channels. I said "It was not a drop out I was not touching the stick - can you have a lower workload than doing nothing?"….

&

Incidentally, if you look at any video of a B flat deck takeoff and watch the tailplane activity crossing the end and compare that with the tailplane activity off the ski-jump you will notice that even modern flight control systems find life easier from a ramp."

&

'ENGINES' 23 Jun 2015:

http://www.pprune.org/military-aviation/424953-f-35-cancelled-then-what-317.html#post9021824

"Perhaps I can help out a bit here. What I can't do is improve on **JF's** succinct and 'spot on' comments about ski jump takeoffs. They are, by some distance, the lowest workload way of getting a combat jet into the air. The flat STO presented many more challenges to the F-35B team, and the lack of aft control surface movement shows how straightforward the evolution is.

However, it's a lot more than 'straightforward'. It's a little surprising, given that this is a pilots' forum, how few people mention the significant advantages it delivers. Firstly, operational: the ski jump will allow the F-35B to launch on task with at least another ton and a half of fuel and/or weapons. That's a ton (or two) of pure military goodness. Secondly, safety. As JF points out, the aircraft leaves the jump nose up and climbing without the pilot having to do anything. If anything does go wrong, the pilot has many more precious seconds to dump stores/jump out. At night, or in bad weather, or from a pitching deck, that's also a lot of goodness.

I do understand why some posters think this looks like a 'pucker' heavy evolution, but it's really, honestly, not. Every Harrier pilot I worked with said that it was a complete non-event. What's really amazing is that these gains come without penalty to the aircraft, which is fairly rare. The Harrier needed no mods to do ski jumps, save extra servicing checks on the nose leg. The F-35B has needed none. The flat deck STO drove the design, the ski jump came basically free.

Oh, and don't forget that it's another brilliantly simple and effective naval aviation idea from the UK's Fleet Air Arm. Respect.

JTO: Yes, the aft nozzle is definitely moving. I am not familiar these days with the F-35B control laws. but I would guess that what is happening here is that the aft nozzle is being left as far 'up' as possible to get to ramp exit speed in the shortest time (and distance), then programmed 'down' after ramp exit to support the 'fly away' profile. The Harrier did this manually, with the pilot selecting nozzles down to an adjustable 'STO stop' as it neared the ramp exit. F-35B does this for him/her.

For those that might not be familiar with the way a ski jump STO works, the key thing to 'get' is that the aircraft leaves the ramp BELOW flying speed. So the rate of climb starts to decay after ramp exit, depending on how much wing lift and jet lift is being provided. However, the aircraft is still climbing. As it accelerates, wing lift increases and jet lift can be reduced by altering the angle of the propulsion system's nozzles. At some point after ramp exit, the aircraft reaches an 'inflexion point', and the rate of climb starts to increase again. That distance between the end of the ramp and the 'inflexion point' is essentially a 'free runway in the sky' - around 1 to 1.5 km, depending on launch weight, temperature and other factors. That 'free runway' delivers the payload improvement.

The UK legacy performance limit for Harrier ski jump STOs was a minimum ROC of 400 feet per minute at the 'inflexion point'. Other nations have different limits.

A powered lift aircraft can 'schedule' (adjust) wing and jet lift so as to maximise the payload that can be delivered from the ramp. It can also be controlled well below wing borne flying speeds. Unfortunately, conventional aircraft can't do either of these. They have to launch at a speed at which they can fly controllably on wing lift alone. Their only option (with all thrust already applied) to arrest ROC decay is to apply more pitch, which increases drag, which slows the aircraft, which… you probably get the picture. That's why the STOBAR option, being used by the Chinese and others, is, in my view, always going to be severely limited in effective payload…."

PITCH RATE QUESTION IS ANSWERED on the next page 318:

http://www.pprune.org/military-aviation/424953-f-35-cancelled-then-what-318.html

F-35 Control Law 'Tweaked' To Correct Ski-Jump Takeoff Anomaly

29 Jun 2016 Angus Batey

WARTON, U.K. — Unexpected effects of undercarriage on aircraft balance were the reason for the slow start in testing the F-35B's "ski-jump" takeoff capability.

According to BAE Systems' lead STOVL test pilot, Pete "Wizzer" Wilson, the anomaly caused an unanticipated pitch-up when he carried out the first takeoff from the land-based ramp at NAS Patuxent River, Maryland, June 19, 2015. **After the same phenomenon occurred on the second flight from the ramp, ski-jump tests were paused while a fix was developed, which involved amending the control law.**

"We discovered some minor differences between the offline models we were using to predict what the performance would be and what the airplane actually did," Wilson says. "It was the balance of the airplane, and the thing that was incorrect was the contribution of the landing gear as we exited the ski jump. If you get the landing gear contribution to the balance wrong, then your assumptions about what you need to do with the propulsion system will also be wrong. Once we discovered what the correct gear contributions were, through flight test, we could then tweak the assumptions that went into the control law that balanced the airplane correctly as it came off the ski jump."

A discrepancy had been anticipated in some early computer modeling of the interaction between the jet and the ramp.

"We discovered very early on that the actual shape of the physical ski jump has a very big impact on what happens to the airplane when it leaves the deck at the end of the ski jump," Wilson says. "We knew that subtle changes in the shape of the ski jump would have an impact on that, and so we tried to design the control law for what we felt was a really good compromise, knowing that it's got to be able to cope off multiple ski jumps."

The question of flying from different ski jumps applies not just to the different ramp profiles adopted by the aircraft

carriers of the U.K. and Italy, which will use this technique to launch their carrier-borne F-35Bs — the U.K.'s Queen Elizabeth Class carriers have a 13-deg. ramp while the Italian Cavour's ramp is 12 deg. — but also to different individual ramps built to the same design.

"Land-based ski jumps are going to be subtly different from the Queen Elizabeth [the U.K.'s first carrier]," Wilson says. "Queen Elizabeth and [sister ship] Prince of Wales should be identical—we hope they will be—but there may be minor differences. And then there's the Cavour. So we were looking for a balanced design [to the control law] that would recognize any type of ski jump and be able to cope equally well regardless of the precise profile."

Wilson argues that discovering and solving the discrepancy is a perfect example of the purpose and value of flight testing.

"For some period of weeks there was a bit of uncertainty, and then we discovered what we needed to tweak," Wilson says. "You just put a huge amount of effort into it, you find a way through it, and you solve it. The engineers have done a great job. Being a flight-tester, there's nothing more I like than to find something that the engineering couldn't predict. It makes my job worthwhile."

A total of 31 ramp takeoffs have now been completed, with more to follow next year. The most recent flights have been expanding the center-of-gravity and weight envelopes.

"We've done takeoffs as heavy as 50,000 lb.," Wilson says, "and we've been highly successful through that. We've done weapons coming off the ski jump, we've done crosswinds, we've done some tailwinds, we've done some pretty strong headwinds. We've done a reasonable cross-section, albeit only 31, so it's not enough to say that we're good yet. We have another program of ski jumps coming up inside a year from now — well in advance of going to the [Queen Elizabeth] for the first time — and by the end of that period we'll be super-confident to take it to the ship."

http://aviationweek.com/awindefense/f-35-control-law-tweaked-correct-ski-jump-anomaly

How it Works: An F-35B Ski Jump Takeoff

https://www.f35.com/in-depth/detail/how-it-works-and-f-35b-ski-jump-takeoff

July 02, 2016

For more than 30 years, the UK has used the ski jump for carrier operations as an alternative to the catapults and arresting gear used aboard U.S. aircraft carriers. The shorter UK carriers feature an upward-sloped ramp at the bow of the ship. Curved at its leading edge, a ski-jump ramp simultaneously launches aircraft upward and forward, enabling takeoffs with more weight and less end-speed than required for an unassisted horizontal launch aboard U.S. aircraft carriers.

With the partnership between the Lockheed Martin and the UK's BAE Systems, the design of the F-35B has incorporated the ski jump takeoff capability from the very beginning.

HMS Queen Elizabeth is the first of two Queen Elizabeth Class aircraft carriers equipped with a ski-jump ramp, charged with maintaining security for the UK and overseas, increasing the UK's ability to project maritime and air power and responding to crises worldwide.

HMS Queen Elizabeth is an impressive 280 meters, or nearly 1,000 feet, in length, and displaces up to 65,000 tons of water. It is so big that each of its two propellers weigh 33 tons. With the ability to move 500 miles a day, it can react quickly to situations across the globe.

The UK will declare F-35 maritime Initial Operational Capability in 2020. When the new carrier comes into service, the F-35B will dominate the skies for decades to come. Squadron Leader Andy "GARY" Edgell, RAF, is the first UK military pilot to complete a takeoff from the ski jump with an F-35B.

"The performance of the jet has been great. As the pilot, I have to do very little to accomplish a perfect ski jump takeoff," commented Edgell. "I push the STOVL [short take off vertical landing] button to convert to Mode 4, push throttle to mil and use the pedals for minor directional inputs to remain on centerline."

The F-35B automatically positions the control surfaces and nozzles for takeoff, a unique capability compared with previous STOVL aircraft. Such automation frees up pilot capacity and provides an added safety enhancement. The aircraft treats the take off just like a regular short take off until it recognizes the six-degree per-second pitch rate and six-degree pitch angle about half way up the ramp. The horizontal tails and nozzle then automatically maneuver downward, and the vane box does not budge. The vane box sits directly under the lift fan and directs the airflow to allow for the proper lift off the surface.

"As the jet travels up the ski jump it automatically makes the necessary adjustments to the nozzle and control surface deflections. With the F-35 automatically adjusting for the optimum takeoff, the pilot is free to adopt more of a supervisory role, monitoring for any off-nominal behavior and ready to immediately take full control, if necessary," said Edgell. "Virtue of the superb F-35 STOVL handling qualities, the low pilot workload during launch and recovery from an aircraft carrier enables the pilot to focus more on the operational task at hand and less on the administrative aspects of the flight."

The F-35B represents the first STOVL aircraft with the ability to go supersonic, and it will change the way the UK defends their country for many decades. The next phase of this testing will continue to expand the takeoff envelope and eventually add stores both internally and externally. Adding more stores highlights the advantage of using the ski jump as the weight increases to an eventual fully loaded F-35B. The testing at NAS Patuxent River is proving the F-35B can operate from a ski-jump carrier and be a powerful force for the UK when they begin deployments in the 2020s.

Farnborough 2016: F-35B completes initial phase of land-based ski-jump trials

Peter Felstead, Farnborough - IHS Jane's Defence Weekly **13 July 2016**

http://www.janes.com/article/62226/farnborough-2016-f-35b-completes-initial-phase-of-land-based-ski-jump-trials

The initial phase of land-based ski-jump testing for the F-35B short take-off/vertical landing (STOVL) variant of the Lockheed Martin Joint Strikes Fighter has been successfully completed at Naval Air Station (NAS) Patuxent River in Maryland in the United States, laying a key foundation for first-of-class flight trials with the UK's future Queen Elizabeth-class (QEC) aircraft carriers.

Briefing journalists at the Farnborough International Airshow on 12 July, David Atkinson, BAE Systems' F-35/QEC integration manager, said the flight trials were "critical to validate a lot of the work that has been done through modelling and provide the certification-quality evidence that's needed to allow service pilots to operate from the ship". BAE Systems is under contract via the F-35 Joint Program Office to perform the ski-jump trials work.

Following on from the first F-35B take-off from a ski-jump ramp at NAS Patuxent River, performed by aircraft BF-04 on 19 June 2015, another 30 take-offs were made over the course of the next 12 months by aircraft BF-04 and BF-01.

Describing the parameters of the ski jump tests in the same briefing, Pete 'Wizzer' Wilson, the STOVL lead test pilot for the F-35 programme at NAS Patuxent River, said, "We've done weights up to full fuel and full internal stores; forward/mid/aft centre-of-gravity positions; a range of ramp exit speeds up to 95 KCAS [knots - calibrated air speed]; line-up distances from 315 to 620 ft; and we've done mil and max power [non-afterburning and afterburning] launches: a total of 31 in all. So we have successfully executed the initial phase of the F-35 ski jump testing; this is a very significant milestone from our perspective."

Wilson explained how "an awful lot is happening in a very short amount of time, about a second's worth", when an F-35B takes off from a ski jump: a process that is effectively automated and "cognitively simple for the pilot" in comparison with taking off in a Harrier jump jet.

Peter 'Wizzer' Wilson, the F-35 programme STOVL lead test pilot, undertaking ski-jump trials at NAS Patuxent River in 2015. Source: BAE Systems

Centerfield Short Take Off/Vertical Landing (STOVL)

The Centerfield STOVL (Short Takeoff/Vertical Landing) was completed in 2009, to support the developmental testing of the Joint Strike Fighter (JSF) F-35B STOVL aircraft. Located in the centerfield area at NAS Patuxent River, the STOVL Centerfield Facility consists of an AM-2 Expeditionary Airfield (EAF), an AM-2 Vertical Takeoff and Landing (VTOL) pad within a painted LHD deck outline, a Ski Jump, and a grated Hover Pit.

The EAF and VTOL Pad AM-2 surfaces are representative of current US Marine Corps austere/forward deployed basing capabilities. These surfaces will be used to test F-35B compatibility during Short Takeoff (STO), Vertical Landing (VL), and Slow Landing (SL).

50 ft less long & 5 ft less tall but similar to the CVF ski jump profile

The Ski Jump, built to match the profile of the UK HMS Invincible Class Ships, will provide a land-based test site for unique ship compatibility. The Hover Pit was constructed during the X-32/X-35 concept demonstration phase of the JSF Program and has supported operations with British Sea Harrier aircraft.

The Hover Pit also provides a means to perform STOVL mode engine runs without ground effects by ducting exhaust thrust away from the aircraft through a series of vanes below the top grating of the pit.

Centerfield STOVL

http://www.navair.navy.mil/nawcad/index.cfm?fuseaction=home.content_detail&key=99E8E3FA-3C12-4BCC-A905-6838819A5C10

Title: The STOVL Joint Strike Fighter in Support of the 21st Century Marine Corps

Author: Major Ben D. Hancock, United States Marine Corps (1997)

Thesis: The potential basing flexibility and firepower that the Joint Strike Fighter (JSF) offers the Marine Corps in support of Operational Manuever From the Sea (OMFTS) will not be realized with the doctrine, mindset, and equipment that currently determines how we operate and support STOVL jets on amphibious ships and ashore in an expeditionary environment.

Background: In the 21st Century the JSF will replace both the F/A-18 and the AV-8B as the USMC fulfills its goal of an all-STOVL aviation component. STOVL aircraft increase basing flexibility which is fundamental to the expeditionary nature of the Marine Corps and provides the foundation for improved responsiveness. OMFTS seeks to avoid establishing a traditional logistics base ashore and the majority of firepower, to include aviation, will remain afloat and only go ashore if necessary. This means that the JSF will operate primarily from naval ships versus land bases. The JSF will be a far more capable aircraft than the AV-8B, but if the shipboard environment that it operates in is one which remains marginalized and biased against effective fixed-wing operations, we will not fully realize the JSF's firepower and flexibility.

Forward basing tactical aircraft reduces the distance to the battlefield and improves response times and aircraft surge rates. Operating jet aircraft from dispersed sites is a big logistical challenge. The Marine Corps does not have enough equipment to supply significant amounts of fuel and ammo to maneuver units. Relying almost exclusively on aviation to supply forward bases will place an enormous burden on already limited vertical lift capability. Recommendations: The Navy-Marine Corps team must develop and refine STOVL employment concepts that includes ramps (ski jumps) and smaller EAFs and it must fund the hardware and structural improvements that allow STOVL aircraft to operate in their intended environment. If we envision maintaining a primarily sea-based approach to conducting operations and we require responsive day/night air support in all-weather conditions, then we need to fundamentally change how we operate fixed-wing jets off amphibious ships. The most significant contribution that the Navy could make to STOVL air and helicopter-borne power projection is adding a ramp to all LHA/LHD class amphibious ships. A dedicated "JSF carrier", such as an LHA/LHD with a ramp and updated radars, would serve as the optimum mobile forward base.

Although the most effective means of employing the JSF would be to base it ashore as soon as possible, it should remain sea based for as long as possible where it can be more easily provided with fuel, ordnance, and maintenance without becoming a logistical burden. Seabasing may remain the best means of enhancing sustainability and reducing vulnerability.

STOVL Jet Value: With the acknowledged limitations and historical employment of the Harrier in mind, we will now examine the value of STOVL jets to the Marine Corps. The Harrier, and the JSF that will replace it, is the only jet that deploys with USMC MEU's as dedicated fixed-wing aircraft that are "owned" by the MEU commander. According to Brigadier General Blackman the Harrier makes the MAGTF complete. "Harriers are another tool for the MEU Commander, they don't provide 24 hour capability under all conditions, but they do bring additional capability and flexibility to the MEU." Blackman contends that you cannot always count on the Carrier Battle Group being there with fixed-wing support when you need them and it may be overkill (may be perceived as too threatening or offensive in delicate political situations) for some scenarios. Colonel Richard F. Natonski, USMC, a recent commander of the 24th MEU commented on the availability of the CVBG in support of the MEU:

"We didn't see the Enterprise CVBG for the entire deployment. We didn't have any integration of the CVBG and the ARG/MEU. The CVBG spent 90 days in the Persian Gulf and during that time the only fixed-wing air we had were our AV-8Bs and the aircraft landbased in Aviano, Italy.

General Blackman supports the STOVL JSF, but only if it brings F/A-18 type performance and capability. "I think that if you had the same survivability, reliability, and maintainability as the F-18 with all the same or better capabilities, and the jet was STOVL, then you have the best of both worlds."

Colonel Conry also supports the all-STOVL aviation concept. He believes that it is part of our MAGTF ethos and that we should stay committed to it. Colonel Conry is a big supporter of STOVL jets and says that "the real strengths of Harriers are the flexibility that they bring and that they have USMC painted on them. You don't have to worry about overfly rights or basing rights. We need to be able to rely on ourselves and the Harrier is a complimentary asset to the MAGTF."

VI. Conclusion

The potential basing flexibility and firepower that the STOVL Joint Strike Fighter offers the Marine Corps in support of OMFTS will not be realized with the current doctrine and equipment that determines how we operate and support STOVL jets on amphibious ships and ashore in an expeditionary environment. Although the JSF will to be able to perform all of the missions currently flown by both the AV-8B and F/A-18 and do them better, the Marine Corps cannot just buy the aircraft without also having the ability to support it properly or to maximize its potential.

It is clear that many of the current problems faced by STOVL aviation are external to the aircraft. The Navy-Marine Corps team must develop and refine STOVL employment concepts that will optimize the basing flexibility of the JSF. Marginally supported aboard amphibious ships and difficult to support ashore in a true forward based scenario, some of the AV-8B's problems will be inherited by the JSF unless the Navy and Marine Corps provides the necessary doctrine, equipment and commitment to eliminate or reduce these problems. The Marine Corps believes in STOVL fixed-wing tactical aircraft, we now need a STOVL aircraft that performs as well as the F/A-18 or better. If the engineers, designers and the Marine Corps are right, the STOVL Joint Strike Fighter will be that aircraft.

http://www.globalsecurity.org/military/library/report/1997/Hancock.htm

STOVL Air Power - The Ramps, Roads, and Speedbumps to Exploiting Maneuver Air Warfare

Major Charles R. Myers Conference Group Ten, April 1, 1996 http://www.dtic.mil/dtic/tr/fulltext/u2/a527872.pdf

Amphibious Ships Page 7

The most significant contribution that the Navy could make to STOVL air & helicopter-borne power projection is adding a ramp (ski jump) to all Tarawa- & Wasp-class amphibious assault ships. The technology is proven and for return on investment relatively inexpensive. A ramp not only improves dramatically a STOVL aircraft's takeoff performance, it facilitates concurrent fixed- & rotary-wing operations afloat. Of all countries that operate STOVL aircraft (the United States has more STOVL aircraft & ships to employ them than anyone) the United States is the only country without a ramp-equipped STOVL assault ship. Now is the time for ramps...."

& on page 9:

"...The skeptics insist that ramps will displace landing spots. Tests prove otherwise.

On a 12 degree ski jump approximately 150 feet long, the slope gradually increases from zero up to 12 degrees at the bow. The first half of the ski jump has a slope no greater than that of an LHA during wet-well operations with the well-deck flooded – both Harriers and helicopters can land on it.10..." [Major Art Nalls, USMC, "Why Don't We Have Any Ski Jumps," U.S. Naval Institute Proceedings, November 1990, 81.]

The ramp not only bolsters a STOVL aircraft's combat payload to its maximum and enhances fixed- and rotary-wing interoperability, it provides a margin of safety to the pilot in emergency situations. The upward vector off the bow offers the pilot extra precious seconds to handle takeoff emergencies and an expanded ejection envelope if required. The price of one saved STOVL aircraft, and potentially the pilot's life, would probably fund several ramps on amphibious ships. The Navy and Marine Corps need ski jumps on the big-deck amphibious ships.

Unquestionably, an LHA and LHD could never replace an aircraft carrier in total air power projection or air space dominance; however, if task organized properly, either could greatly augment it....

& on page 12:

"...Sea-based platforms are not the only places where ramps are effective. The Marines must focus on their employment once phased ashore. An all STOVL aviation component provides the Marines an opportunity to double its current EAF capability by simply installing ramps at each end. Today's typical 4,000-foot EAF would decrease to less than 2,000 feet using ramps, yet still provide a maximum gross weight takeoff capability to STOVL aircraft. Additional EAF matting provides vertical landing spots and parking space if needed. More over, ramps provide almost limitless EAF locations wherever there is a straight quarter-mile stretch of road or highway. Korea and Sweden, for example, have designed much of their highway systems for use as conventional runways. A STOVL aircraft requires a mere fraction of that if augmented with light-weight, high-strength modular ramps. Smaller EAFs provide several advantages. A reduced footprint makes it less susceptibile to targeting and the chance of being hit. Reduced construction time, especially when a road or highway is used as the runway, maintains operational tempo...."

Naval Air Systems Command
Program Executive Office
Tactical Aircraft Programs

News Release

NAVAIR
PEO (T)

Contact: Marcia Hart-Wise
Phone: (301) 757-7178
marcia.hart-wise@navy.mil
www.navair.navy.mil

News Release: E200906291 29-Jun-09

EAF enables JSF landing anywhere, everywhere

http://www.navair.navy.mil/press_releases/index.cfm?fuseaction=home.view&Press_release_id=4144&site_id=15

PATUXENT NAVAL AIR STATION, Md. -- Marine Wing Support Squadron 274 gave engineers help in April to lay the first expeditionary landing site for the F-35B Lightning II Joint Strike Fighter for short takeoff/vertical landing (STOVL) capabilities testing.

Expeditionary Airfields are mobile systems that allow Marines to quickly build functioning airfields in areas without airfield support. EAFs are built using AM-2 matting: aluminum panels which are assembled in a brickwork pattern to form runways, taxiways, parking sites and other areas required for aircraft operations and maintenance.

These EAFs allow the JSF to perform missions in any terrain that does not support a standard-use airfield in mission-critical areas.

More Next Page

"This joint testing is a significant step for the Aircraft Launch and Recovery Equipment program," said ALRE Program Manager Capt. Randy Mahr. "The JSF and EAF have an integral relationship in expanding our capabilities and success on the battlefield. The EAF's AM-2 matting is battle tested, dependable and versatile. It's exactly what we need for our expeditionary landing and take-off platforms."

Although the AM-2 matting is serving its purpose as vertical take-off and landing (VTOL) pads and a 1,900 x 96-foot runway for the EAF/STOVL testing, it also doubles as the run-up for a test "ski-jump" used in conjunction with JSF testing for the British Royal Navy. The AM-2 matting and the 12-degree ski-jump ramp were installed at the centerfield area last month. **May 2009**

"NAVAIR is excited about our involvement in the JSF program, said Mike Jiavaras, ALRE's EAF team leader. "Knowing that the first time this aircraft demonstrates its impressive VTOL capabilities will be on an expeditionary airfield raises the level of pride the team has in our program and in support of the warfighter."

The ski-jump ramp is used by British Her Majesty's Ship (HMS) Invincible-class carriers for launch of STOVL aircraft, such as the Harrier GR7A, and is located on the forward-end of the flight deck. JSF program experts explain that the ski-jump is a more fuel efficient way for aircraft take-off. However, the drawback is that it does not allow larger aircraft such as the E-2D Advanced Hawkeye, F/A-18E/F Super Hornet and the EA-18G Growler - future carrier deck-mates with the JSF, the needed distance for launch and recovery.

The mock ski-jump is 150-feet long, with a 15-foot high "lip" for aircraft launch. These shore-based ski-jump takeoffs will be conducted at varying airspeeds prior to the first UK ship detachment with the F-35B.

"We are extremely excited about getting the first of eight F-35's to Patuxent River beginning this summer. The first aircraft to arrive, a STOVL aircraft designated BF-1, will use test facilities we have built to test and verify the unique warfighting capabilities the STOVL variant brings. We look forward to supporting the long-standing traditions of expeditionary warfare capabilities for the next 50 years of Marine Corps aviation," said Capt. Wade Knudson, acting deputy program executive officer and program manager for F-35 Lightning II development.

EAF enables JSF landing anywhere, everywhere

Press Release: E200906291 29-Jun-09

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http://www.navair.navy.mil/press_releases/index.cfm?fuseaction=home.view&Press_release_id=4144&site_id=15

CVF Ski Jump is 200 feet & 20 feet high

AM-2 MATTING

AM-2 aluminum matting, an evolution of the pierced steel planking used in World War II, was adopted by the Air Force in 1965 for use in nearly all bases in South Vietnam. AM-2 matting was used in expediting airfield construction by eliminating the time required for placing Portland cement or asphaltic concrete pavement. AM-2 mats were 1.5-inch thick aluminum alloy panels, 12-foot-by-2-foot, each weighing 144 lbs. Half mats, 6-foot-by-2-foot, were also used. A nonskid ferrous coating was factory-applied to the wearing surface. Mats were fastened together by interlocking connectors and secured with locking bars. Mats could be laid on the ground or a subsurface of soil-cement after required grading and leveling. The life of the surface could be extended by waterproofing the soil with a polyethylene membrane or impregnated asphaltic material prior to laying the aluminum mats. The matting rested directly on a two-ply nylon membrane which was resistant to abrasion and JP-4 fuel. Panels were laid in a staggered brickwork configuration with the longer 12-inch dimension perpendicular to the main direction of traffic. The system was designed for 1,600 passes of a 27,000-pound single wheel load at 400 p.s.i. tire pressure (approximately the weight of an F-4B).

AM-2 matting-surfaced areas of a typical installation included a 102-foot-by-10,000-foot runway, a 48-foot-by-10,000-foot main taxiway, four 48-foot-by700-foot cross taxiways, and a 570-foot-by-1,900-foot parking apron totaling nearly 3 million square feet -- an amount sufficient to build a 2-foot wide footpath between San Francisco and Los Angeles.

The use of aluminum matted offered many advantages over Portland cement and asphaltic concrete. It eliminated the need for concrete aggregate (which often was not readily available to combat airfield sites) as well as the equipment, work, and time required to crush the aggregate, prepare the mix, dig foundations, install forms, and place the concrete. Procuring, delivering, and setting up crushing and batching plants in South Vietnam took as long as five months. AM-2 matting required only the equipment to deliver the 2,000-pound pallets and could be laid entirely by hand.

Aluminum matting provided a valuable tool for the construction of airfields in forward or remote areas. In combat landing operations, matting made it possible to construct jet airfields when and where construction would otherwise be impossible. AM-2 matting is available today to make rapid repairs of bomb-damaged runways.

Matting Installation

The most effective method of laying matting was to use four-man crews -- two men to place the mat panels, one to place the locking bars and spacer bars, and one to assist with a crowbar and mallet as needed. The jobs were rotated among the crew during the shift to minimize fatigue. An additional crew of approximately twenty South Vietnamese laborers disassembled the AM-2 bundles. Air Force personnel operated the lowboys, forklifts and the cranes for matting resupply. Placement crews, backed up by labor units, could lay over 500 linear feet of runway (50,000 square feet) in a 9-hour shift.

Because of the hot weather in Southeast Asia, matting teams often found their productivity on the runway limited to a few hours during the day. Heat reflections from the aluminum matting sent air temperatures soaring to 125°F making it nearly impossible to touch the even hotter AM-2 panels. Night work, therefore, was the answer, and although heat was still a factor, the men could operate effectively for longer periods. Work on operational runways was also accomplished at night to avoid interfering with the flying mission.

http://www.nationalmuseum.af.mil/factsheets/factsheet.asp?id=1270

"...The Navy has added approach speed as a service specific key performance parameter. The threshold for approach speed is 145 knots with 15 knots of wind over the deck. This must be possible at Required Carrier Landing Weight (RCLW). The RCLW is the sum of the aircraft operating weight, the minimum required bringback, and enough fuel for two instrument approaches & a 100nm BINGO profile to arrive at a divert airfield with 1000 pounds of fuel. The minimum required bringback is two 2000 pound air-to-ground weapons & two AIM-120s. The Navy further requires that the CV JSF be capable of carrier recovery with internal & external stores; the external stations must have 1000 pound capability on the outboard stations & maximum station carriage weight on the inboard."

"The USMC has added STOVL performance as a service specific key performance parameter.

With two 1000# JDAMs and two internal AIM-120s, full expendables, execute a 550 [now 600] foot (450 UK STOVL) STO from LHA, LHD, and aircraft carriers (sea level, tropical day, 10 kts operational WOD) & with a combat radius of 450 nm (STOVL profile). Also must perform STOVL vertical landing with two 1000# JDAMs and two internal AIM-120s, ~full expendables, & fuel to fly the STOVL Recovery profile.

The Marine Corps has used the more limiting deck launch, rather than a simple expeditionary airfield, to frame its requirement."

F-35 Variants — Maneuverability		Threshold	Objectives
Corner Speed	CTOL/CV	F-16 like	F/A-18 like
Instantaneous G	STOVL (At 15K feet)	+7.0 320 KCAS	+7.5 305 KCAS
Sustained G	CTOL CV STOVL (At 15K feet/.8 Mach)	+5.3 +5.1 +5.0	+6.0 +6.0 +6.0
Sustained G Mil Power performance at 30K ft ≤0.9M	CTOL[1]	Sustained 30 degree bank turn 1000 fpm climb (straight and level).	Sustained 45 degree bank turn 2500 fpm climb (straight and level).
Acceleration:	CTOL CV STOVL (At 30K feet/0.8 to 1.2 Mach)	≤ 55 sec ≤ 65 sec ≤ 65 sec	≤ 40 sec ≤ 45 sec
Ps	STOVL (At 15K feet/0.8 Mach)	550 feet/sec	
G at Maneuver Weight	CTOL[2]	+9.0/-3.0 (Mach ≤ 1.05) +7.0/-2.0 (Mach > 1.2)	
	CV	+7.5/-3.0 (Mach ≤ 1.05) +6.5/-2.0 (Mach > 1.2)	+8.0/-3.0
	STOVL	+7.0/-3.0 (Mach ≤ 1.05) +6.0/-2.0 (Mach > 1.2)	+8.0/-3.0

1. Configuration: 2 x empty external 370 gallon tanks internal fuel for 540nm combat radius, 4 x JDAM Mk-84, 2 x AIM-120, gun with 150 rounds. Airspeed ≤0.9M.
2. With 60% of internal fuel load required for 540nm combat radius and JDAMs jettisoned/released.

KPPs = Key Performance Parameters

USN & USMC Land & STO KPPs

Scorecard: A Case study of the Joint Strike Fighter Program by Geoffrey P. Bowman, LCDR, USN 2008

0.4Mb PDF

http://www.f-16.net/f-16_forum_download-id-14791.html