Single minded

Experienced Harrier test pilot John Farley evaluates control concepts being considered for STOVL variants of the JSF

JOHN FARLEY/**DERA BOSCOMBE DOWN**

PILOTS FROM TWO Joint Strike Fighter (JSF) teams have been evaluating new pilot control concepts using a unique flying testbed. The trials are part of the UK's contribution to the JSF design effort and capitalise on the country's unrivalled experience with short take-off and vertical landing (STOVL) operations.

The UK Defence Evaluation and Research Agency's (DERA) Bedford and Boscombe Down sites are researching the best way for pilots to control future STOVL aircraft. Their primary tool for this work is the oldest British Aerospace Harrier flying. First flown in 1969, XW175 was one of two development two-seaters to be produced.

Thirty years later, and now known as the VAAC (Vectored thrust Aircraft Advanced flight Control) Harrier, this airframe boasts the most capable system for studying control concepts for powered lift aircraft available on both sides of the Atlantic. As a result, test pilots from the Boeing X-32 and Lockheed Martin X-35 JSF concept demonstration teams recently participated in tests at Boscombe Down.

When the Harrier first entered squadron service with the Royal Air Force in 1969 the big news was that V/STOL was possible using a single extra lever, which the pilot used to control the direction of the engine thrust. No electrics, no computers – just a lever.

Today, should we view this nozzle lever as the control of choice or as a liability? The facts suggest it is both. Properly used, the two left-hand controls – throttle and nozzle lever – provide a remarkable capability. But moving one when you mean to move the other can result in an almost instant accident.

A major disadvantage of the Harrier is that, when the aircraft is slowing down to the hover,

The oldest flying Harrier is a key development tool for next generation STOVL

there is a peak of workload while the pilot manually feeds in engine lift to substitute for decaying wing lift. Doing this at night, low over the water, in poor visibility while approaching a moving ship, is arguably the highest workload facing a service pilot today. This results in weather minima for Harrier vertical landings of 200ft (60m) cloud-base and 0.9km (0.5nm) visibility, while helicopters are cleared to 100ft and 0.5km.

The message is clear: although Harrier-type STOVL can be operationally invaluable, it is costly in training and accidents and has more restrictions than do helicopters in bad weather. That is why DERA is searching for the best way to simplify the STOVL pilot's task.

For this new trial, pilots are asked to evaluate a range of cockpit inceptors and control laws

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http://www.flightglobal.com/pdfarchive/view/1999/1999%20-%202360.html

Jump to talk (excerpts in note)

while flying from 220kt (405km/h) to a vertical landing. An inceptor is anything the pilot holds or moves to control an aircraft in flight. The rear cockpit of XW175 can be fitted with a wide range of left- and right-hand inceptor options.

PILOT COMMANDS

The inceptors input the pilot commands to a flight control computer which then chooses the appropriate aircraft motivators – tailplane, aileron, rudder, flap, throttle, nozzle – to satisfy those commands. The overall characteristics of the chain of events, from pilot input to aircraft response, is determined by control law software in the computer.

In this aircraft, the rear pilot can select the control law used by the simplex flight control computer while in flight. It can vary gain settings while the system is engaged – useful when tuning a particular handling characteristic. When engaged, the computer has 100% authority over all the aerodynamic, reaction and engine motivators except the airbrake.

VAAC work will lead to the deletion of the nozzle control lever (inboard of the throttle)

The VAAC team realised it had to make the experimental control system non-safety critical. Its starting point was a two-seater with a safety pilot in the front with standard Harrier controls. But with a computer having 100% authority over everything, things could go out of control so quickly that no safety pilot would have time to see the problem, disengage the system and recover.

The solution was the independent monitor (IM), a separate computer which knows the characteristics of the Harrier airframe and can recognise when its limits are being approached. It can then disconnect the experimental control system and hand the aircraft back to the safety pilot in a flyable condition.

DERA's VAAC project pilot, Flt Lt Justin Paines, spent three years designing the recent trial, which involved eight visiting pilots each flying six sorties. Four of the pilots had never flown the Harrier. I flew after a briefing from Paines, followed by a visit to the DERA research simulator at Bedford.

The trial focused on decelerations from 220kt to the hover, followed by a vertical landing (VL) on a designated spot. The piloting task was tightly defined, with acceptable and desired limits of position for the hover and VL indicated by lines painted on the ground. Following each manoeuvre, the pilots were required to rate the task using the industry standard Cooper-Harper handling qualities scale.

Three main control modes were under evaluation as well as further options on what method the pilot used to make final adjustments

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Adjusting the throttle while slowing to a hover is a high-workload task

to aircraft position once in the hover. The chosen right hand inceptor for all modes was a centre stick, taken from the former Experimental Aircraft Programme (EAP) technology demonstrator.

The most radical mode under test is known as Unified. Here the pilot pulls back on the stick to go up and pushes forward to go down, regardless of airspeed. When flying on the wing, if the pilot centres both the stick and throttle, the aircraft holds the existing speed, bank attitude and climb or dive angle. In the hover, centralising everything maintains the existing hover height, position and heading.

Such hover characteristics are the stuff of dreams for every Harrier pilot – although, as discussed later, experienced Harrier pilots may be critical of Unified.

Given that no Harrier or helicopter pilot pulls back on the stick to go up when in the hover, the second major option under assessment was the aptly (if awkwardly) termed Mode Change mode. At its simplest, this requires the pilot to select either a conventional flight or hover mode of control. In hover mode the pilot controls height with the left hand. It is to be expected that this mode will be well liked by trained Harrier pilots. The down side is the inherent risk of pilot error whenever a selection is required or available.

The third mode is Fusion. In essence this is like flying a highly augmented Harrier that has automatic selection of nozzle angle. Flying on the wing is similar to a conventional fast jet, but after decelerating in the circuit the pilot uses the throttle to control height and the stick to control speed through attitude, as with a helicopter. Nozzle angle is controlled by the system.

Extensive research by NASA, using a variety of hovering vehicles, including Harriers, has established that pilots like an X-Y controller for making final adjustments to a hover position before descending to a VL. When the stick is used for this you just move the top towards where you want to go and the aircraft slides that way, then as you approach the position you desire just centre the stick and the aircraft stops moving. What could be nicer?

Termed Translational Rate Control (TRC), this system has the drawback that it stops the stick being used for any other purpose in the hover, such as a height or flight path controller. It also raises issues about how and when to switch the stick modes. Because of this, the VAAC Harrier enables pilots to fly TRC using three inceptor options: stick position or thumb operated slew-type buttons fitted on top of the throttle and stick. All options were being evaluated in this trial.

SURFACE GUSTS

For our flight Paines was concerned that the gusty 25kt surface wind put the hover area downwind of the hangars. In his experience this increased the chances of the duplicated sideslip and incidence vanes sending noisy signals to the IM, resulting in frequent and annoying trips of the system. I saw such activity as a heart-warming indication that the IM was going about its business.

When I first flew the VAAC in 1994, the experimental system had little authority over the lateral and directional axes. Additionally, the IM had not been cleared below 100ft, preventing a VL from the hover. I therefore expected to find things much improved.

Following standard Harrier procedures, we strapped in and Paines got us started. In less than a couple of minutes we were taxiing. During the taxi I followed instructions to set up the Digital Harrier (DH) control law – software replicating the handling of a normal 1969 two-seat Harrier to provide a datum from which to look at the new ideas. Paines warned me that the law had not been modified to take account of the different throws and forces of the Experimental Aircraft Programme stick and so the combination provided the worst-flying Harrier ever.

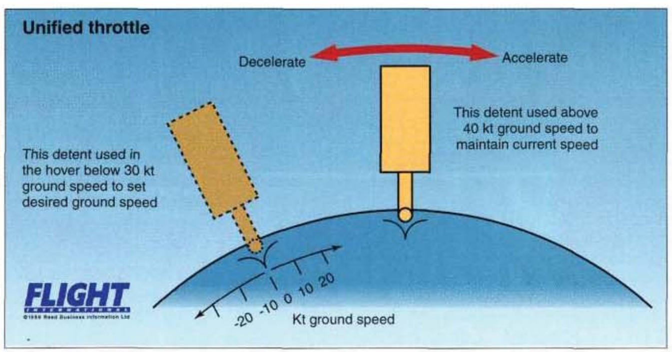
Paines, as safety pilot, got us airborne into the circuit from a short take-off. Then, after synchronising the front and rear flap and throttle inceptors, I engaged DH. Sadly, as predicted, I found myself flying an aeroplane that was all too easy to overcontrol and halfway round finals I let the angle of attack pass the IM limit of 12° and the system dumped.

Paines put us on the ground and when we next got airborne I had the Manual Thrust Vector mode selected. This made the two main left-hand inceptors act as they do in a Harrier, but with the stick providing synthetic and benign fast jet handling. This is being offered to the evaluation pilots as a baseline.

After the next short take-off, I engaged the Unified mode; fitted in a modified circuit round a GKN Westland Sea King on long finals; included a late jink to avoid overflying a lone house; continued decelerating to the hover; re-engaged following a sideslip trip; pushed the stick forward and went lower when I meant to move forward; and eventually did a VL. Not entirely satisfied with my performance I asked if I could try Unified again.

Next time things went much more as planned. In the hover, I even managed to make myself stop moving the stick and allow the system to hold a steady attitude. The voice recording of me saying "This is nice" was an understatement. I also managed a few seconds in TRC mode, controlling hover position by using the slew-type button on the throttle.

Paines performed a vertical take-off and I had a longer look at TRC from the throttle. Then, having set up the desired descent rate at 100ft before the VL, I clicked a trigger on the front face of the stick. This locked in the descent rate and saved me having to hold the stick forward to keep us coming down. As a result, I had the novel experience of being responsible for a Harrier hover and VL while hands off for much of the time.



Now at fuel minimums, it was time to return to the flight line. Paines asked for a hot refuel, which produced a bowser and the largest fire truck I have ever seen. The crew chief asked for the nozzles to be put down 30° and at idle power they plugged in the hose and gave us 1,600kg (3,500lb) of fuel. This ground equivalent of in-flight refuelling avoided a shut down.

I flew the next deceleration in the Fusion mode. The thumb wheel on the left-hand inceptor is easy to use to control the deceleration. During hover manoeuvring I blotted my copybook by leaving the wheel just outside the detent so we crept forward a bit. Since I was busy looking at flying a different law on the stick, it required the patient voice from the front to speak up before I twigged the problem.

A further circuit in Fusion allowed me to see that holding the aircraft flat in the hover and moving backwards and forwards on the thumb wheel was not such a good control option as using attitude to adjust position in the way the designers intended.

Our final circuit was made using Mode Change. The important new feature here was that I was able to try using TRC with the stick as the inceptor. In flight it was even more impressive as a natural way to adjust hover position than it had been in the simulator.

I had expected the VAAC Harrier to handle better than it did in 1994, but the level of improvement still surprised me. Comparing the sortie with my first flight in the Hawker P1127 (in 1964), it was clear how far the designers have come. In 1964 every trip required more skill than I really had, plus a full measure of luck. Today this Harrier flew best when I took my hands off.

CONTROL OPTIONS

Choosing the best control strategy for the JSF will not be a choice between black and white. There are pros and cons to all the options available in the VAAC Harrier.

Operational pilots succeed by honing their skills to compensate for the shortcomings of their aircraft. An experienced service Harrier pilot, who has learned to operate two left-hand levers, is proud of this. It is asking a lot to expect him to vote to give it up.

A research pilot, on the other hand, is trying to improve aeroplanes. His job is to bring an open mind to new ideas and assess their value in reducing pilot skill requirements and the risk of pilot error. A research pilot is therefore more likely to vote for change.

Unified is very much the "clean sheet" approach. Fusion, on the other hand, offers a highly augmented close relative of the Harrier three-inceptor concept that could appeal to those preferring a middle road.

When I flew the Phase 1 VAAC aircraft in 1994, I believed that Unified was the way to go. This experience of Phase 2 has strengthened those views because, with all axes available and the ability to fly a VL, the system can be truly used as its designers intended. It means throwing away what has served the Harrier force well, but future JSF pilots are in school now and know nothing about Harriers, so they they will have nothing to unlearn.

How to adjust hover position is also important. Having tasted TRC I would not wish to give it up. The issue is how to combine these two benefits without compromising either.

I view decelerating to a hover and accelerating back to wingborne flight as real flying tasks. I want to command those with my right hand and I never want to think about changing something while I am flying. But, and it is a big but, I do not feel the same about adjusting a hover position, which I see as no big deal. Therefore, I would be happy to use TRC for this using a slew-type button with my left thumb. Then, if I need urgently to get up and away from the hover, I can instantly (and instinctively) pull back on the stick in the normal way.

"This research is of crucial importance to future STOVL fighter aircraft. The objective is no less than lives saved and taxpayers' pounds and dollars conserved," Paines says. "Once the trial is complete, it will be for industry to use the research results in conjunction with platform specific criteria to build a safe, low workload STOVL fighter for the 21st century."

The choice of piloting solution for the production JSF STOVL variant is an interesting dilemma. Will it be a conservative development based on proven Harrier piloting techniques? Or will it be a brave new world, where the military pilot accepts his job is done as he turns away from the target – and allows the scientists and research pilots to decide the easiest and safest way to recover the aircraft back at base? My money is on the operators specifying the former, but my vote is for the latter. ❑

CONTROL LAWS

UNIFIED

Above 40kt ground speed the stick commands the rate at which the flight path changes. Relaxing the stick to the centre position when the aircraft is flying level maintains height. In a climb or dive, relaxing the stick maintains the existing flightpath angle. As the aircraft decelerates through 40kt, the stick response blends to become a height rate control by 30kt. In the hover, with stick centre commanding zero height rate, Unified appears to the pilot as a height hold.

When flying up and away, lateral stick commands roll rate. This blends between 130kt and 100kt to become a closed-loop roll attitude control, so that relaxing the stick to centre below 100kt commands wings level. Above 40kt groundspeed, the rudder pedals command sideslip. Decelerating below this speed they blend to a yaw rate command by 30kt, providing heading hold in the hover with feet central.

A throttle-type left hand inceptor, incorporating two detents, commands longitudinal acceleration. Putting the inceptor in the centre detent holds the current speed. Acceleration or deceleration is selected by moving the lever forward or aft of the detent, with full travel demanding maximum available performance.

Decelerating through 35kt starts a blend and below 25kt the aft detent commands zero ground speed. Either side of the aft detent gives the pilot a closed loop control of ground speed up to 30kt forwards or backwards.

MODE CHANGE

In conventional flight Mode Change provides the same features as Unified, but following selection of hover mode the throttle commands height rate. The lateral and directional controls remain as in Unified.

FUSION

Fusion mode is really for those pilots who like to fly an approach where power is primarily controlling flightpath (as opposed to an approach where the stick is the primary control of flightpath and throttle is used to set speed).

In Fusion, the left hand throttle controls flightpath rate at all speeds down to 60kt ground speed, when it starts blending to height rate control below 50kt, providing a height hold when placed in the centre detent in the hover. Speed control is by a thumb wheel on the side of the throttle, which commands longitudinal acceleration or deceleration, again with a centre detent for holding the current speed, analogous to a highly augmented Harrier nozzle lever.

Like the throttle, the stick also controls flightpath rate but only down to 120kt where it blends by 60kt airspeed to become a longitudinal acceleration control through pitch attitude. Above 120kt, given that the pilot needs to hold the stick for lateral control, the throttle action becomes redundant. Lateral and directional controls are the same as in Unified.

VACC Harrier Story: http://www.wingweb.co.uk/aircraft/Harrier_VTOL_Jump-Jet_part4.html

"Another experimental evaluation program focused on the Harrier has been conducted by the British military researcher establishment. This program is focused on making STOVL flight simpler for the pilot, and involves a modification of the second T.2 prototype with the tortured designation 'Vectored-thrust Aircraft Advanced flight Control (VAAC)'.

The VAAC Harrier is intended to consider solutions to the 'three hands' problem of flying the type, where the pilot must handle throttle, stick, and nozzle angle lever during takeoff and landing. The VAAC Harrier was fitted with a new cockpit and control system to allow the aircraft to be flown by pilots without special training.

The control system was installed by the Cranfield Institute of Technology, Britain's foremost academic institution for aviation research. The T.2 was delivered to Cranfield in 1983, the modified aircraft made its first flight in 1985, & Cranfield handed it back to the Royal Aircraft Establishment for tests in 1986.

The aircraft still looks like a normal T.2 externally, except for the replacement of the cannon pods with featureless pods containing test avionics. The rear seat was given the new layout, while the front seat retains the old T.2 control layout. This allows the aircraft to carry a test pilot in the back seat and a 'safety pilot' in the front seat who can take over if the new control system does something outside of the script.

The VAAC Harrier was designed to be easily modified to allow testing of different cockpit layouts, control systems, and software, and it has been through many modifications. As of 1995, the program came under the jurisdiction of the new British 'Defence Evaluation & Research Agency (DERA)', which absorbed the RAE, though DERA has now been disbanded into two new organizations, a commercial organization named 'QinteQ' and a government organization named the 'Defence Science & Technology Laboratory (DSTL)'. It is unclear which organization inherited the VAAC Harrier.

The VAAC Harrier is strictly an experimental program and was not intended as a prototype for another Harrier update as such. However, it has proven extremely useful for evaluating technologies to be used in the F-35 JSF."

http://myweb.tiscali.co.uk/hawkerassociation/hanewsletters/hanewsletterpdf/hanewsletter024.pdf

"...Dunsfold was where V/STOL became an everyday event. There things could be regularly seen that other organisations had been trying for years to achieve. Another very important flight test programme had been the VAAC Harrier. To overcome the Harrier problem of having three pilot's hand operated flight controls (stick, throttle & nozzle lever) which gave different results in V/STOL & conventional flight, & only two pilot's hands, which inevitably led to occasional confusion & accidents, the RAE pushed for a simpler arrangement applicable to more complex ASTOVL propulsion concepts. DB Harrier T2 XW175 was fitted with an adjustable digital flight control system in the front cockpit with the conventional system retained in the rear for a safety pilot.

Over 23 years of flight testing, simulating numerous control concepts, the inceptor strategy was defined. Here there are but two pilot's hand controls or inceptors; stick & throttle. No matter which flight regime you are in, pulling the stick back makes you go up, pushing it forward, down. This British system is in the F-35B & will allow any current military pilot to fly the aircraft easily. In fact, a PPL holder has flown the VAAC Harrier from VTO to VL with no practice...."

SLD: As a Harrier pilot, could you comment on the potential arrival of the F-35Bs? | 17 Jul 2011 [at Eglin AFB]

Col. Tomassetti: It is ultimately disappointing constantly to see in the news all of the things that the F-35B hasn't been able to achieve yet or can't do & people completely missing what we've already achieved.

The fact is that we have a STOVL airplane that every pilot who has flown it says that it's easy to fly. In 60 years of trying to build jet airplanes and do this, we've never ever been there before. We've never had a STOVL airplane that was as full spectrum capable as it's conventional counterparts. We've never done that before in 60 years of trying.

It's an amazing engineering achievement; [what] we've already accomplished is completely being missed by some observers." http://www.sldinfo.com/?p=21300 **[Colonel 'Art' Tomassetti [USMC] flew the X-35B on the STO - Supersonic - VL mission a decade ago, 30 July 2001. Now he is vice-commander 33rd Fighter Wing Eglin.** http://www.lockheedmartin.co.uk/news/archive/55.html**]**