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For Public Accounts Committee: Deliberations on the Typhoon Project.

Executive summary.

i. This paper provides an in-depth view of the cost history of the Typhoon aircraft and briefly discusses the relative merit of the major investment in that project compared with the strategic need for other Armed Forces equipments.

ii. It remarks upon the special relationship that exists between British Aerospace systems and MoD/RAF and questions the motives of that relationship in the context of getting the "right bang for the buck" in terms of justifiable defence procurement spending.

Introduction.

1. The statement from the Right Honourable Margaret Hodge MP, Chair of the Committee of Public Accounts, on Tuesday 22nd of February 2011 raised the issue of the Typhoon project: "In 2009-10 the Department had to commit an extra £2.7 billion on the Typhoon project, including the purchase of 16 additional aircraft, to honour its commitments. The resultant cost increase has contributed to the £36 billion gap in the defence budget. We will take further evidence on the Typhoon project in the spring."

2. Putting this in perspective, the balance between our long-term strategic defence needs and how these are not being met by recent rounds of MoD spending is worthy of comment – in particular in relation to the Typhoon project. This paper attempts to present a clear picture of this issue. Unfortunately, this 'picture' has for the most part been kept hidden from the public and from our politicians.

Annex C: Discussion of Reported Statements by British Aerospace Systems.

Annex A, paragraph 2.

https://publications.parliament.uk/pa/cm201011/cmselect/cmpubacc/writev/860/m3a.pdf

1. "Eurofighter is here touting the potential of a navalised development which has already been studied in detail in the UK".

2. **Comment.**

They naturally would not wish to disclose that the formal MoD sponsored studies conducted in the UK came to the conclusion that a viable navalised version of the Typhoon was not a practical proposition.

Annex A, paragraph 4 and 5.

3. "The European type [Typhoon] would receive several new features to support its proposed life at sea. These include a new, stronger landing gear, a modified arrestor hook and thrust vectoring control nozzles for its two Euro jet EJ200 turbofan engines. The latter would enable the fighter to approach the vessel at a reduced speed without restricting pilot vision by requiring an increased angle of attack." "Eurofighter says only localised strengthening would be required on some fuselage sections near the landing gear and to the EJ 200."

4. **Comment.**

a) This proposal appears to be for operating Typhoon in a mode similar to the Russian 'STOBAR' arrangement, where a land based fighter/bomber with a high thrust to weight ratio is launched from a ramp (ski-jump) and recovered at an acceptably low speed using a combination of advanced flight controls systems and vectored thrust. Such a proposal carries significant technical risks, associated with launch, recovery and aircraft design:

i) **Launch Capability**.

The basic requirement for a naval aircraft is to be able to launch from the flight deck under all sea and wind conditions with an operationally effective payload. STOBAR aircraft face severe challenges in achieving this, which are less severe for both CATOBAR (CATapult Operations and Barrier ARrested - as per the US Navy) and STOVL operations, These are set out below.

During any aircraft launch, ramp end speed is crucial (for STOBAR and STOVL, the speed at which the aircraft leaves the deck-fitted ski jump). A CATOBAR aircraft (e.g. F/A-18) relies on the power of the steam catapult to achieve the required speed to generate wing lift. A STOVL aircraft (Harrier or F-35B) leaves the end of the ski jump at a speed below which wing borne flight is possible, but uses vectored engine thrust through its centre of gravity to support the aircraft while it accelerates to wing borne flight speed. Unfortunately, the Typhoon doesn't have a 'powered lift' mode of the flight – that is lift provided by downward facing nozzles -that can replace wing lift below normal flying speed. Nor, critically, does it have reaction controls (thrust nozzles fed by engine air) to control aircraft attitude below normal flying speed. These factors mean that:

It can only sustain flight after launch by wing lift and whatever component of thrust can be generated by a very high angle of flight. This, in turn, generates drag, which means that the aircraft spends longer in the most dangerous phase of flight – immediately after deck launch, and

It runs a severe risk of severely degraded handling qualities as it leaves the deck before full flying speed is reached.

Without a catapult (and BAE acknowledge that the Typhoon cannot use such a device) the aircraft can only achieve higher end speeds by ever longer take off runs, which are in turn limited by nose leg loads on the ramp, or by reducing launch weight – payload. (Looking at the Russian aircraft operations, it is noticeable that they can only carry light weapon loads.)

ii) It should be noted that during the previous UK MoD funded studies, BAE proposed the addition of a reaction control system to Typhoon. Such a modification would involve channelling high-pressure, high-temperature air from both of the engines to the four extremities of the aeroplane, installing the necessary control nozzles, and linking this system to the pilot's control column and the flight control computer system. This would add significant weight and cost to the aeroplane. Critically, such a system would also rob the engines of power at precisely the stage of flight when maximum thrust would be required for safe operation.

iii) If conventional aircraft such as the Typhoon could launch with their normal payload in under 800 feet, ski jumps would be fitted to all expeditionary air bases where take-off weight is constrained by altitude and/or temperature. The reason ramps are not used in this way is because such aircraft cannot benefit from the use of ramps without very considerable modification.

iv) **Landing**.

v) The basic requirement is to be able to land safely and rapidly on the ship, carrying a basic minimum fuel load and also unused weapons, under all conditions, day and night. For a CATOBAR aircraft, this means that the aircraft has to fly controllably on the prescribed approach path some four degrees below the horizontal to the flight deck at a precise, not-to-exceed speed into the arrestor wire – the arrestor wires have a limiting load beyond which they will break. This is an extremely challenging requirement and drives the design of CATOBAR aircraft. The standard USN approach speed is around 130 to 135 knots, which delivers stable approaches and minimum 'trap intervals' (essential when numbers of aircraft are being recovered) at a speed that the arresting cables and engines can cope with. This speed delivers precision approaches, so that the ship needs only three cables for reliable 'traps'. It also allows the aircraft to cope with the 'burble', which is the area of turbulent air immediately behind the ship, through which the aircraft must fly. The four degree downward approach path minimises the 'burble' effects and ensures that the aircraft will not fly into the stern of the carrier if it is pitching. Finally, this approach allows the aircraft, should it fail to engage the wire, or suffer a wire or hook failure, to accelerate immediately and take off again (this is called a bolter) within one second of touching the deck. The T-45 Goshawk, a very small and basic jet trainer, required massive redesign of the entire wing and tail to achieve adequate CATOBAR landings. (BAE are fully aware of these lessons).

Incidentally, a STOVL aircraft gets around all these issues by applying the 'stop, then land' method, but at the cost of carrying the penalty of a powered lift system.

Typhoon is not designed to fly safely in the landing configuration at these speeds at normal landing weights and so the BAE suggestion was that with very advanced flight controls (and possibly vectored thrust?):

(1) The aircraft could be 'over pitched' and
(2) Flared in such a way by the pilot as to arrive at the deck at a low descent rate and lower speeds - essentially, a dynamically manoeuvred landing along a horizontal approach path.

vi) This concept would rely on split-second timing, rapid aircraft manoeuvres in the final seconds of the approach as well as an ability to predict or limit deck motion. It was also unclear how such an approach would deliver precision touchdown points, or how it could be converted into a bolter. In all, such a completely unproven method must be considered extremely risky. The only effective way to reduce some (not all) of the risks would be to reduce landing weight – critically affecting the ability to 'bring back' weapons.

Furthermore, in spite of the proposed changes, the Typhoon pilot's view of the landing sight and deck during the extensive simulator tests carried out continued to be minimal (or in some cases nil, due to the location of the aircraft's fore-planes). This must be considered completely unacceptable if pilot's lives are not to be risked unnecessarily. (It should be noted that despite an extremely tight budget, and a simpler method of landing, the redesign of the RAF Harrier into the Sea Harrier included an elevated cockpit to solve pilot view issues).

It must be concluded that attempting to adopt the completely new and untried technique being proposed by BAE would carry extremely high technical and safety risks that could only be mitigated by an expensive programme of development and trials. See Annex C for a more detailed explanation of some of the issues involved.

vii) As an indication of how critical the landing issues were found to be, the previous studies included a proposal for the ship to be fitted with special RB211 gas turbines to produce an 'updraft blast' of air in the landing area and thereby assist the aircraft to land. Again , this is a completely untried concept –normally, carriers do all they can to keep gas turbine exhaust away from aircraft during landing, to avoid loss of thrust due to hot gas ingestion.

viii) **Structure**.

ix) The BAE assertion that 'localised strengthening' would be required to operate the Typhoon from an aircraft carrier would be challenged by any aircraft designer with experience of naval aircraft, and must be viewed as a grossly optimistic mis-statement of the facts.

Putting an aircraft on to a flight deck at around 135 knots and stopping it in a few hundred feet means taking a great deal of kinetic energy out of the aircraft in a short time through the landing gear and the arresting hook. The resulting loads are measured in tens of tons and have to be transmitted through the airframe to get to the wheels and the hook. This takes metal, and lots of it. (The T-45 Goshawk required around a ton and a half of extra reinforcement to make it carrier-capable.

The F-35C CATOBAR variant of the JSF is the least common of the three variants, with extensive redesign of the structure throughout the entire airframe.)

Moreover, the arresting hook system has to be radically different in design and operation from a land based emergency system (Typhoon's arresting hook will most probably be designed to be thrown away after a single 'trap'.)

Launch loads for a STOBAR design are not as bad as for a catapult launch, but the loads on the nose leg are still non-trivial.

The main challenge for Typhoon is that the basic airframe has been very aggressively pared down to minimum weight. The aircraft suffered a major weight escalation during design, and every part of the airframe was examined again and again for chances to reduce weight (as an example, every nut and screw was pared down to the minimum length and size to save weight – as a result, a single access panel on the fuselage has over twenty different length screws used). The structural modifications required for any effective carrier operations would, without doubt, require a major airframe redesign. An excellent example is the BAE proposal for a redesigned landing gear. The existing design was carefully chosen for lowest weight, least impact on fuel volume, and least interference with under wing stores. The new design would increase all these penalties, and it is not surprising that BAE is proposing the addition of conformal tanks that supposedly have no drag penalty. (If they do not provide lift, they will certainly provide extra weight and drag – giving less range/fewer weapons/ lower combat speed.) The landing gear is in the very core of the airframe, and such a new gear would inevitably lead to a new centre fuselage at least.

x) Finally, during the previous UK studies, BAE proposed that the landing area of the ship's deck should be 'sprung to reduce gear loads'. This quite impractical scheme was an indicator of how tight the airframe loading issues were for any navalised Typhoon, and how little appreciation the Warton team had for maritime aircraft operations. In summary, Typhoon represents a poor starting point for a naval aircraft, and structural modification for naval operations would present massive technical risk which would inevitably carry a major price tag. It strains credulity, and is most unfortunate, that BAE are claiming that this is not the case.

Annex B, paragraph 3.

5. "According to Paul Hopkins, Vice President Business Development (Air) at BAE Systems, simulation tests of a 'navalised Typhoon' show the aircraft can take off and land with full mission payload, including two 'Storm Shadow' cruise missiles, four BVR missiles, two short range missiles."

6. **Comment**.

a) **Simulation**. It would appear that Paul Hopkins' enthusiasm for a 'navalised Typhoon' operational capability from carriers is based upon BAE simulations that do not take into account the realities of flying from the deck at sea (see comments at 14, above).

b) **Mission Payload**.

The feasibility and practicability of the Typhoon returning to the deck and landing with this full mission payload (as well as the extra weight incurred by a major airframe modification and strengthening and the addition of conformal fuel tanks) again calls into question the validity of the internal BAE mission simulation. The F-35C, which is a dedicated naval aircraft design, and much larger than a Typhoon, would not be able to recover to the deck with such a payload. See Annex C.

Annex D: "Hands on" carrier deck landing expertise examines BAE's predictions.

1. Landing on board a conventional aircraft carrier in a fighter aircraft presents significant challenges that are not experienced when operating from an airfield ashore. Deck landing into arrestor wires by day is a high workload, high skill evolution requiring 100% concentration and extremely precise control of speed, aircraft attitude and glide path (in the vertical as well as the lateral sense). Any diversion from the prescribed approach parameters can and does result in various undesirable effects:

a) Too high an approach speed can cause the hooked wire to break leaving the aircraft with not enough residual speed to take off again but too much speed to stop on the deck: resulting in the loss of the aircraft.
b) Aircraft attitude (the angle of attack that the aircraft wings are presented to the air stream) must be accurately controlled. Too high a nose attitude at the prescribed speed will cause the loss lift from the wing surfaces and the aircraft will rapidly sink towards the stern of the ship. Too low a nose attitude will result in an increase in air speed, giving the aircraft to much inertia for the arrestor wire to cope with – and the latter will break.
c) Maintenance of the prescribed glide path as given by the stabilised landing sight is necessary to ensure that the hook does indeed catch a wire. If you are too low on the glide path, the hook can bounce over all the wires (or you may crash into the stern of the ship). If you are too high on the glide slope, your hook will miss the wires.

In other words, the correct air speed, attitude/angle of attack and glide slope must be maintained in a stable fashion all the way down the approach path to the deck.

2. This means that the inertia of the aircraft, both horizontal and vertical, remains constant to the touchdown point: there is no reduction in rate of descent of the aircraft (as with landing on an airfield) and the forces that the aircraft under-carriage has to contain are markedly higher. Some have observed in the past that a carrier deck landing is almost akin to a "crash on deck" – the forces involved are so large. The undercarriage strength also has to take account of the movement of the ship, particularly a pitching deck and "ship heave":

a) The Pitching Deck. With the deck pitching around the ship's centre of gravity in heavy seas a severe upward momentum of the deck can be experienced at the touchdown point. This upward momentum needs to be taken into account in undercarriage strength as it represents to the undercarriage an increased downward force of the aeroplane on touchdown.
b) Ship Heave. This is caused by the ship being moved bodily up and down by heavy seas and has a similar impact on required undercarriage strength to the effects of ship pitch.

3. The prescribed glide path for deck landing (as indicated by the deck landing sight) is, by virtue of simple geometry, steeper than that experienced ashore. On land, the prescribed glide path is 3°. But the land is stationary. With the ship moving at up to 30 kn away from the aircraft on the approach, the deck landing sight it is set at 4° which gives the aircraft an approach path through the air of just 3°. Aircraft handling for maintaining the glide slope is therefore the same for landings ashore and on the deck. It is of course important to recognise that if the ship's deck is pitching 2°, this leaves only 1° of clearance between the aircraft flight path and the stern of the ship. Any reduction in the prescribed glide path and this clearance, through for example the

adoption of a flared landing technique, would therefore be totally unacceptable from a practical and a flight safety point of view.

4. The touchdown area where the tail hook of the aircraft catches the arrestor wire is extremely small and any lapse in concentration can cause pilots to miss the wires completely or, catastrophically, impact the stern of the ship. As if this was not enough, the flow of the wind over the deck often creates a 'burble' just behind the ship. This has to be anticipated by the pilot by applying a small amount of power. Even in calm, benign sea conditions this represents a major challenge to any carrier deck pilot.

5. When an aircraft lands ashore on an airfield it encounters a 'ground cushion' when its height above the ground is at about 10 feet. This condition is caused by the interaction between the flat surface of the ground and the airflow across the aircraft's wings. This automatically causes a reduction in the rate of descent of the aircraft, a side-effect of which is that the aircraft stays airborne longer and touches down further along the runway. If the pilot also reduces rate of descent by flaring the aircraft, the ground cushion effect will be exaggerated and the aircraft will touch down smoothly further down the runway without placing heavy forces on the undercarriage system. Catching a wire using this technique would be extremely difficult if not impossible.

6. When landing on a carrier, with the deck approximately 60 feet above the sea surface, there is no ground cushion. If there was, it would make landing on board more difficult and more dangerous because the essence of a good approach to the deck is to continue the prescribed glide slope all the way to the deck without any reduction (or increase) in the steady rate of descent. This allows the point of impact of the deck hook on the deck to be more precisely achieved – allowing the aircraft to "catch a wire". Any flaring prior to touch down (even the smallest amount) will cause the aircraft to miss the wires. A side-effect of this type of approach is that a heavy force is applied to the landing gear on touchdown and, hence, the landing gear needs to be much more robust (and heavy) than its land-based counterpart. See paragraph 2 above.

7. The arresting hook system appears simple but represents a major challenge for aircraft design. The dynamic interaction between the aircraft and the arresting system at around 135 knots is massive, and reliably bringing aircraft to a halt in around 350 feet is a difficult and dangerous evolution.

8. The "burble" behind the ship, as referred to in paragraph 1 above, can cause an increase in the rate of descent of the aircraft as it approaches the stern of the ship. An obvious danger, this has to be anticipated by the pilot by applying a small amount of power in order to maintain the prescribed flight path to the required impact point of the deck hook amidst the wires. If too much power is applied, the aircraft rate of descent will be reduced and the aircraft will flare, missing the wires.

9. The suggestion in the earlier BAE studies that the Typhoon would be able to make a precisely flown, flared landing on deck is at best highly risky and runs counter to the experience earned in the last hundred years of carrier operations. This places BAE's simulations and assurances in perspective.

10. When you are learning to deck land, one of the golden rules is to always concentrate on the cues given by the deck landing sight and NEVER to attempt to "fly the deck" (which is precisely what a flared landing would require). That is because the landing site is fully stabilised and is positioned so that if you do follow its cues, your hook will catch a wire because you are

maintaining the prescribed steady glide path all the way to the deck. The deck can move considerably in heavy seas and that movement must be totally ignored by the pilot if he is to land on board safely.

11. In rough seas with the ship pitching, rolling and heaving, the challenge becomes much greater. Conducting night deck landings in poor weather represents the most difficult and challenging flying task that any military pilot will face in any environment. In such conditions it is quite impossible for a pilot to “fly the deck” or to employ a flared landing technique. It could be possible that BAE would propose some form of highly assisted or fully automated landing system to take the pilot out of the loop. Again, such a proposal would be extremely risky and carry major development costs.