AERO1560 Assignment 1:

The dH Vampire

Tutorial Time: Thursday 12 - 1pm
Location: Aeronautical Engineering Room N214
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1 Abstract

The *de Havilland Vampire* marks the transition from propeller-driven planes to jet aircraft. The second jet fighter operated by the Royal Air Force, the plane continued to be in service for an incredible 40 years, a testament to its simple, easy to service design and durable plywood-metal construction. Although iconic in the skies due to its twin boom and single-engine structure, the safety record of this plane does not live up to its star reputation, with hundreds of crashes having being reported due to recurring issues with the cockpit design. In saying this, the plane was apparently a beautiful flyer, with smooth controls and incredible manoeuvrability due to its lightweight design and powerful engine. Indeed, much of the current state of aviation and propulsion rests upon the wings of the *Vampire* and its *de Havillard Goblin* jet engine.

Contents

2 Introduction

This section introduces the original design mission for the de Havilland Vampire *aircraft.*

The *de Havilland Vampire* (*'dH Vampire'* or just *'Vampire'*) was one of the first planes of the jet era of aircraft. This plane directly paved the path for the transition between propeller-driven planes and jet aircraft which consequentially led to an onslaught of new innovation and developments in the aeronautical world. The *dH Vampire* was not shy of setting records across its lifetime, being the first Royal Air Force (RAF) fighter with a top speed in excess of 800km/h, the first pure-jet aircraft to land on and take off from an aircraft carrier, and the first jet aircraft to traverse the Atlantic Ocean [1].

Development of the *Vampire* began in 1941 during the Second World War in order to take advantage of the newly-invented jet engine technology, which claimed to allow flight at speeds up to 900km/h. The design specifications submitted to the Air Ministry detailed that the aircraft would be a single-engine, twin boom aircraft with a ceiling of 48000ft and a maximum speed of at least 790km/h. The armament was to include four automatic cannons, and the *Vampire* was to have fuel provision for 1140 litres.

Interestingly, the Air Ministry was not entirely convinced of de Havilland's design. Doubts arose over whether the engineering of the twin boom was possible, and whether the estimations for the airplane's performance were too idealistic considering the use of only one unproven engine. In fact doubts were so bad that the Ministry almost fired the de Havilland company from the project, and were to assign manufacture to Hawker Aircraft (one of the most prominent aircraft developers of the time) — it was only because Hawker Aircraft was preoccupied building another plane that the Ministry allowed de Havilland to produce *Vampire*!

Ultimately the *dH Vampire* proved to be very successful, providing around 30 air forces with their first experience of jet fighter operations. The *Vampire* enjoyed versatile roles during its incredible 40 year service, including as an interceptor, bomber, aircraft carrier fighter, trainer, and night fighter.

This report begins by discussing the key feature of the *Vampire*, its propulsion system, and then delves into its construction, configuration, and safety features.

3 Technical Aspects

3.1 Propulsion System

This section briefly discusses the invention of the jet engine which played a large role in the dH Vampire*'s original design mission, and then discusses the* de Havilland Goblin *('Goblin') jet engine used in the plane's final design.*

During the 1930's, prior to WWII, the aviation industry was looking to develop planes which few farther and faster. The largest hurdle in achieving this was in the piston-powered propeller-driven propulsion system used in aircraft at the time which, although had seen some small improvements over the years such as the addition of the supercharger, was essentially still based on similar mechanics to what the Wright Brothers had used at the turn of the century.

These propeller-driven systems had an inherent flaw in them: their inefficiency at higher speeds due to the propeller tips approaching the speed of sound. The transonic air movement around the propeller would form shock waves at the tips, causing high drag, noise, and structural problems which dramatically decreased propulsive efficiency and could often tear the propeller apart.

It was Frank Whittle who realised that the propeller would have to be replaced with an entirely new type of propulsion system, which he called the jet engine. Essentially, this style of engine relies on a fan which sucks in air from the front, and then compresses the air via a series of static and moving compressor blades. This air is then sprayed with fuel and ignited, releasing a highly pressurised stream of gas out the back of the plane which, according to Whittle's original calculations, would propel the plane at speeds of up to 960 kilometres an hour (he would later find this out to be a severe underestimate). The lack of propeller eliminates the sound barrier issue with propeller-driven aircraft, essentially paving the way for supersonic flight.

Whittle's jet engine, *"Power Jets W.1,"* was completed in 1941. The engine used in the *dH Vampire*, the *'de Havilland Goblin,'* began development in 1941 and thus was heavily modelled around Whittle's design. Although both engines used a centrifugal compressor to provide compressed air to the combustion chambers, there were a few key differences between the two:

- The *Goblin* utilised a single-sided impeller rather than a double-sided impeller.
  - The single sided impeller has the advantage that the air intakes are easily placed in the front cover of the engine instead of being wrapped around the perimeter of the engine.
  - This makes the casing far less complicated as there is no air going around the front to enter through rear intakes.
  - It also allows for the use of the "ram-air effect" which is essentially where the air-intakes are directed forward in order to increase intake pressure.
- The *Goblin* utilised 16 straight-through combustion chambers, rather than Whittle's 10-chamber reverse-flow combustion.
  - Whittle's designs used a reverse flow layout that essentially 'folded' the engine in half, reducing the engine length while also reducing turbine entry temperature. This

- was necessary as the materials available at Whittle's disposal were not strong enough to withstand temperatures greater than 597°C.
  - The *Goblin* was essentially a straightened-out version of the W.1.
  - "Whilst longer than Whittle's layout, it was tidier, easier to produce and maintain and more efficient." [13]

- Improved power output.
  - The original Whittle *W.1.* engine produced 860 pounds of static thrust, whereas the improved *dH Goblin* engine produced 2700.
  - As Butler writes in [4] "The low power output of the early jet engines had meant that only twin-engined aircraft designs were considered to be practical during the early stages of development; however, as more powerful jet engines were quickly developed, particularly Halford's H.1 (later known as the de Havilland Goblin), the practicalities of single-engined jet fighter were soon realised."

One large issue with early jet engines was their fuel consumption. At maximum thrust, the *Goblin* suffered from a fuel intake of 465 Imperial gallons per hour [13], which is approximately 2.1kL per hour — similar to the fuel consumption of a modern-day commercial jet![1]

Figure 1: Frank Whittle's engine. [15]

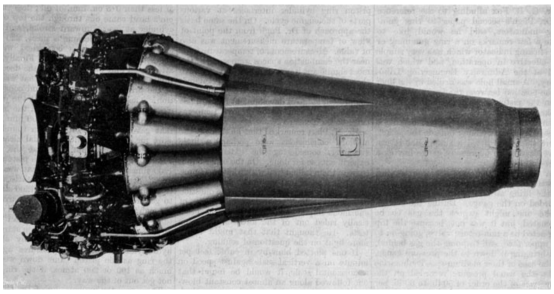

Figure 2: The *Goblin* engine. [24]

[1]If what [13] states is true, then the hourly fuel consumption of the *dH Vampire* at full thrust is similar to the hourly fuel consumption of a modern day twin-jet plane such as the Bombardier Global Express.

3.2 Structural Design and Construction

This section is interested in the physical build of the dH Vampire *including airframe configuration and construction.*

3.2.1 Airframe Configuration

Figure 3: The *dH Vampire*, with its twin boom structure on full display. [7]

Perhaps the most striking feature of the *dH Vampire* is the plane's configuration and design. The *Vampire* is characterised by a small egg-shaped fuselage pod paired with a twin boom tail connected by a single stabiliser (tailplane). The elevator stretches almost the total width of the distance between the two booms, while the vertical rudders and fins were located inline with each boom. The twin boom structure was attached to mid-mounted tapered wings whose roots housed the single engine's air intake. The *dH Vampire* was grounded by a hydraulic tricycle landing gear, including a nose wheel which, notably, due to the lack of ground clearance needed for a propeller, was quite short. The all-metal wings housed ailerons, flaps, and an airbrake, all of which (along with all other flight controls) were actuated through cable connections. A pneumatically operated differential braking system was provided for the main wheels through the rudder pedals, for steering the aircraft on the ground.

A twin boom aircraft is one which contains a singular, short, central fuselage connected to two longitudinal booms which typically run from the wings of the airplane to the empennage (the tail of the plane). This configuration presents certain advantages over a conventional fuselage, primarily the clearance of the engine wake. Engine wake is essentially the disturbance in the air behind a jet engine as extremely hot gases escape its rear. Engineers aim to design planes such that little to none of the body of the plane is in the way of the exhaust escaping the rear of the jet engine, which in the *dH Goblin* engine could be as hot as 800°C [16]. In order to remain inside the bounds of the design brief, which was to produce a single-engined jet fighter, and also ensure the exhaust from the engine was not interfering with any other part of the plane, the use of a twin boom fuselage structure was undoubted. The other option which could be considered is a style employed by the later-produced F-86 Sabre, in which the duct, engine and exhaust system ran the length of the fuselage to the very rear and base of the empennage. However, the use of a twin boom allowed the *dH Vampire* to remain lighter, and perhaps more significantly, it allowed for the intake piping and jet pipe to be kept relatively short, avoiding power loss. One potential issue with the twin boom structure was aeroelastic rigidity and flutter problems, however increasing the power of the engine was placed at a higher priority than this.

3.2.2 Construction

The original design was designated *DH99* and was in fact an all-metal design, however, in response to Ministry of Aircraft Production's recommendations, the design was modified into a mixed wood and metal construction, which was re-designated as the *DH100 Vampire*.

Most of the fuselage (the 'pod' which houses the pilot) was made using a construction method perfected by de Havilland in his production of the *Mosquito* and the *Hornet*, both incredibly successful aircraft of WWII. His method involved 'sandwiching' balsa planks between spruce plywood sheets, and then forming these into shape over mahogany or concrete moulds (more specifically, the shells comprised of 3-ply spruce wood outers with single-ply balsa cores). The *dH Vampire*'s pod was built as two separate parts, which essentially doubled the speed of construction as manufacturers were able to work in parallel.
Once moulded and ready to be bonded together, a "V-groove" was machined longitudinally into the edge of each piece. To assemble these two together, "Aerolite" was used as the assembly adhesive, a urea-formaldehyde gap filling adhesive which is water and heat-resistant, with pressure applied using band clamps to keep the components in place until a full cure. Finally, one the halves were fitted together, they were covered with a heavy cloth for painting (doped madapollam, an extremely fine cotton) [20].

The rest of the *dH Vampire*, including the wings and empennage, was made of aluminium.

The mainplane was made of two separate metal wings with ribs and stringers covered with an Alclad skin. Alclad is a type of aluminium which provides significantly more resistance to corrosion that most aluminium-based alloys for only a small increase in weight, hence extremely popular in aircraft manufacturing.

The fact that still so many *dH Vampire*'s exist in working condition around the world is a testament to the design and construction processes used in the post-War era.

4 Safety Features, Safety Record, and Aerodynamics

This section briefly summarises the main safety issues that were repeatedly found during the dH Vampire*'s long service life.*

Safety features were quite sparse on the post-war *Vampire*, with the aircraft not even being equipped with an ejection seat. There were many crashes and fatalities over the years in the plane, mostly due to recurring issues within the design of the cockpit and the handling of the plane.

The *Vampire*'s cockpit layout was considered haphazard and difficult to use. It was easy to confuse the dive brake and flap levers with the landing gear, and the control column would block vital dials such as the fuel gauges. Certain controls were known to be difficult to move or trigger, such as the low-pressure fuel cock. In this aspect, the *Vampire* lacked ergonomic measures.

The only life-support system provided to pilots was a life jacket, a parachute, an inflatable dinghy, and some stored oxygen for the trip back down to earth — the *dH Vampire* had no ejection seat. Pilots were expected to jettison the canopy, release the seat straps and roll upside down to bail out of the aircraft. This expectation was often impossible to live up to in out-of-control situations, which there were many of. The aircraft, once in a spin, was extremely erratic, losing 4000 feet in the first two turns of a spin. Furthermore, at speeds greater than 70% the speed of sound, the controls began buffeting due to transonic air flow around control surfaces — uncommanded roll and pitch changes would occur, and the plane 'nosing down' randomly would become a prominent issue at speeds above Mach 0.8 [17].

Another repeated issue with the *dH Vampire* was with the windscreen and canopy. Wing Commander R.W. McNair, writing on Aug. 31, 1948, reported: "During recent flights at 25,000 feet for periods up to one and a half hours, I experienced serious deteriorations of vision due to frosting of the inside canopy and windscreen." [13] This issue continued, and ultimately the Institute of Aviation Medicine cautioned against flights in the *Vampire* which were in excess of 38000 feet.

The *dH Goblin* engine, being only the third jet engine in Britain, came with its own safety issues. In modern-day jet engines, the power output can be controlled through the 'mass airflow' into the engine. In the *dH Vampire* however, the Fuel Control Unit (FCU) only allows a pilot to select the amount of fuel sprayed into the combustion chambers. This creates a significant time delay between the pilot actioning the control and the power output being delivered, hence the pilot needed anticipate his thrust needs and feed the fuel in slowly and earlier than necessary. If a go-around was needed great care and patience was required to get the engine 'spooled-up' to full power.

In saying all of this, according to real pilots, flying the *Vampire* was 'a delight.' "Certainly, the *Goblin* first-generation jet engine required some careful throttle handling, and monitoring of maximum rpm and jet-pipe temperature but that was easy to get used to." [13]

A notable aerodynamic feature is how well the *Vampire* was able to glide. From 30000ft, it would take 11 minutes for the plane to reach sea level, only requiring 21 gallons of fuel. In fact the glide rate was so impressive that if an engine flame-out occurred at a great altitude and relight attempts failed, pilots were comforted knowing that they would glide down gently at approximately 1200 feet per minute. This essentially allowed a forced landing up to 90 nautical miles away depending on how high the aircraft is.

In essence, the *dH Vampire* still came with all the flaws and errors a first-generation product comes with. Although laden with technical issues and a stained safety record , the general consensus is still that the *Vampire* was a beautiful and easy plane to fly. This statement is generally backed up by the fact that most *Vampire* planes were transformed to 2-seat trainers in order to help transition pilots into the world of jet aircraft.

5 Operational Requirements

There were no specific operational requirements necessary for the *dH Vampire.* According to [13], the *dH* was easy to handle on the ground, and the take-off and landing could normally be accomplished on a paved or firm grass runway within 3 - 4,000ft.

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6 Part Two

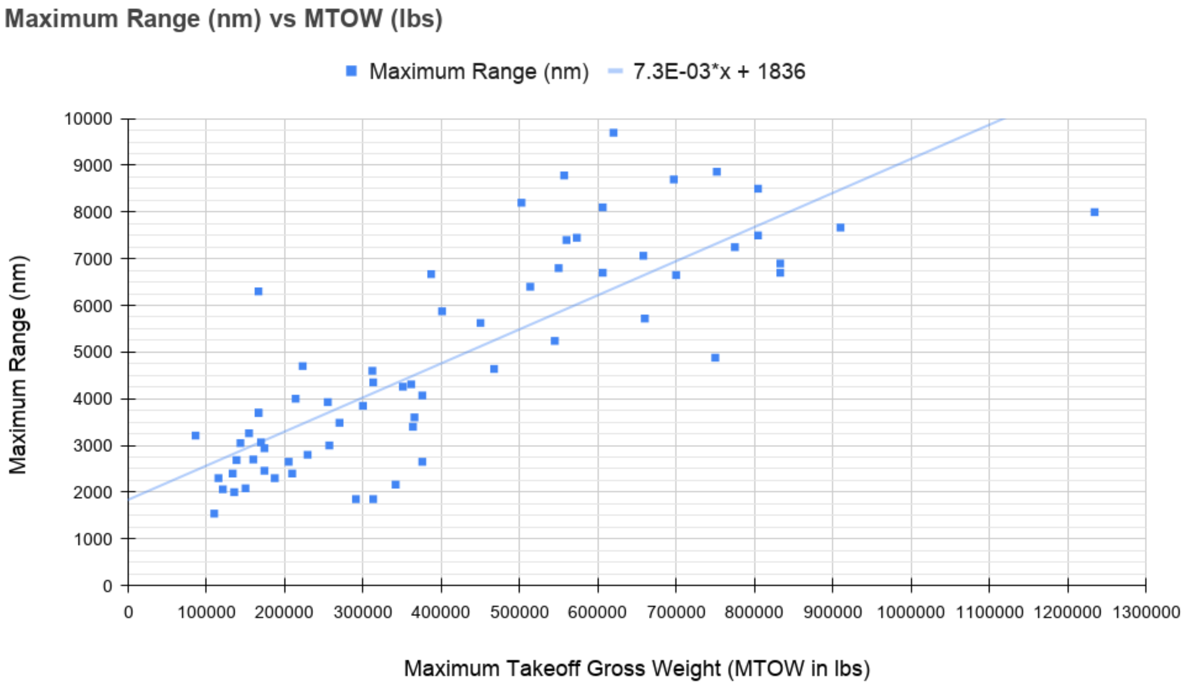
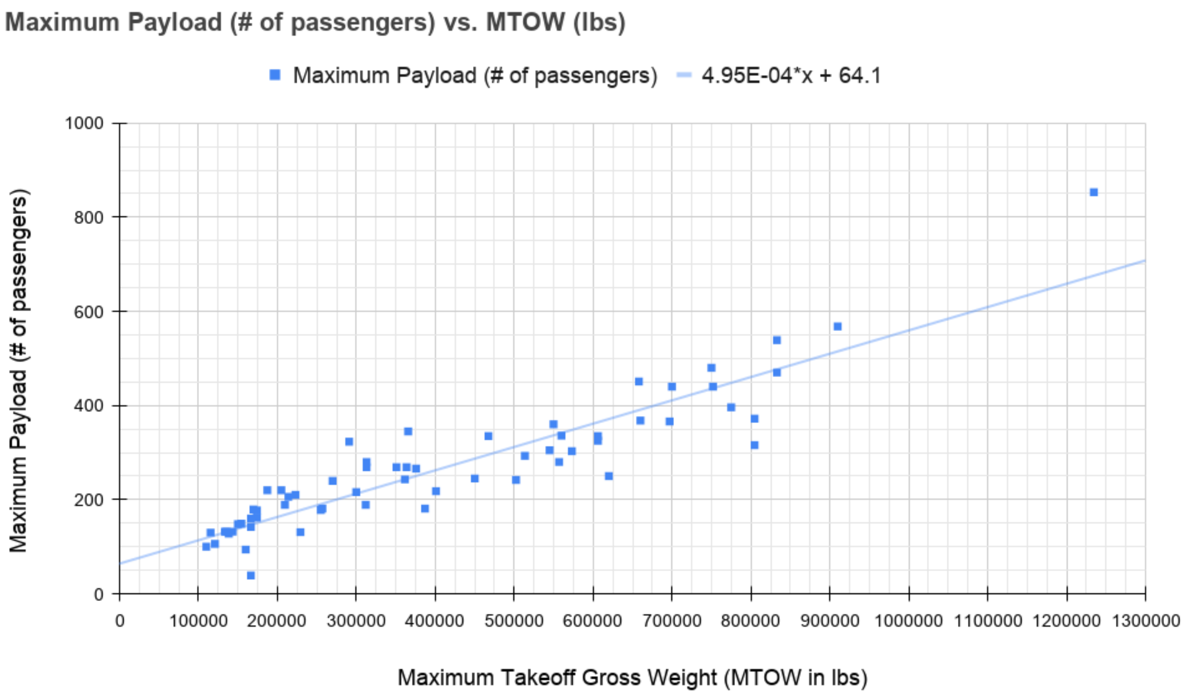


Figure 4: A graph plotting the maximum range (in nautical miles) of each aircraft versus its maximum takeoff gross weight (MTOW in pounds)



[h!]

Figure 5: A graph plotting the maximum payload (max number of passengers) versus its maximum takeoff gross weight (MTOW in pounds)

6.1 Analysis

It is evident from looking at Figure 4 that there is a weak linear positive correlation between the maximum range and MTOW. This is to be expected of course: for an aircraft to travel further, it necessarily requires more fuel, which increases the weight of the aircraft at takeoff.

However, there is a large amount of variance in this graph, including an extreme outlier with a MTOW of 1234600lbs but a range of only 8000nm. This outlier is the A380, and hence such a large deviance from the general trend can be explained by examining the plane's own design mission — a double-decker widebody aircraft suitable for carrying up to 850 passengers is of course going to be much heavier than the average plane.

If we apply a similar slant on other outliers, we can see that because the range is so dependent on other factors such as the aerodynamics, structure, design brief, passenger capacity etc. of the plane, the correlation between range and MTOW will be weak at best, as it varies greatly from plane to plane.

Figure 5, depicting maximum payload vs MTOW presents a much stronger positive correlation. This can be attributed to the tighter correlation between number of passengers and MTOW which isn't as greatly affected by external factors as the prior graph was. The more passengers an aircraft is planning on carrying, the heavier the aircraft will have to be to support not just the weight of those extra passengers, but the extra fuel required for this as well.

6.2 Bogong Moth Airways

Requirement: 312 passengers, 11250nm range.

Looking at Figure 4:

$$y = 7.3 \cdot 10^{-3}x + 1836 \tag{1}$$

$$\text{for } y = 11250 \implies 11250 = 7.3 \cdot 10^{-3}x + 1836 \tag{2}$$

$$7.3 \cdot 10^{-3}x = 9414 \tag{3}$$

$$x = 1289589 \tag{4}$$

i.e. According to Figure 4, the required MTOW would be 1,289,589lbs.

Looking at Figure 5:

$$y = 4{,}95 \cdot 10^{-4}x + 64.1 \tag{5}$$

$$\text{for } y = 312 \implies 312 = 4.95 \cdot 10^{-4}x + 64.1 \tag{6}$$

$$4.95 \cdot 10^{-4}x = 247.9 \tag{7}$$

$$x = 500808 \tag{8}$$

i.e. According to Figure 5, the required MTOW would be 500,808lbs.

These are two very different figures, however by analysing our data further we can reach a more sensible conclusion.

Examining Figure 4, we can see that the plane with the largest range has a MTOW of 620000: this is the A350-900ULR. However, the A350-900ULR only has a passenger capacity of 250.

On the other hand, in Figure 5, we can see that there are many aircraft which can carry a payload of over 300 passengers. However there are not many planes which carry over 300 passengers

and also travel long range.
Hence each graph has its own downfalls which skew the line of best fit. Thus we must examine the data more carefully to reach a sensible conclusion.
The key aircraft family with the longest ranges and a passenger capacity of over 300 is the Airbus A340 and A350 family. The Airbus A340-500 has a range of 8500nm and a max payload of 316, with a MTOW of 804675lbs. To increase this range to 11250nm, considering this means more fuel with a similar passenger capacity, we can do the math on the fuel-per-nautical-mile:

$$804675\text{lbs per } 8500\text{nm} = \frac{804675}{8500} = 94.667 \approx 95$$

i.e. every nm of range requires an extra 95lbs of weight.
Therefore for $11250 - 8500 = 2750$nm more of range, we would require $95 * 2750 = 261250$ more lbs of MTOW. This equates to $804675 + 261250 = 1065925$lbs MTOW.

Therefore the plane would require a MTOW of roughly 1,000,000lbs.

SOURCES FOR PART 2:
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