Analysis of Wing and Tailplane Structures

ON THE BOEING 747-400 AND DE HAVILLAND TIGER MOTH DH82

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Abstract
This report aims to analyse the wing and tailplane structure of the De Havilland Tiger Moth DH82 and the Boeing 747-400 noting the basic layout, arrangement and associated design features. Without going into significant detail there is discussion on how these structures affect the aerodynamics and efficiency of each aircraft providing a basis for direct comparison of requirements with respect to their intended purpose. It should be noted that the description of aircraft structures is derived from firsthand observations of said aircraft.

Introduction
In comparing the Boeing 747-400 and the De Havilland Tiger Moth DH82 the rapid technological progress within a period of only sixty years can be examined through a comparison of the largely unchanged fundamental structures that underpin flight. As the development of supersonic airlines continues it is worthwhile looking back on how exactly aeronautical engineering has morphed the primitive biplane into the commercial behemoth that is the 'Queen of The Skies'.

The 747-400 was the most famous iteration of the incredibly popular 747 series, with a distinct, recognisable figure the jumbo jet was so large the wingspan exceeded the entire length of the Wright brothers first flight in Kitty Hawk, North Carolina. It revolutionised travel for mass-market and accelerated globalisation to what it is today, ferrying more people, more freight faster than ever around the world.

The DH82 Tiger Moth while not as famous as the Jumbo was also widely produced, serving as a recreational aircraft and later repurposed to train Commonwealth pilots for war. It developed a reputation for being easy to fly, reliable and low maintenance surging in popularity in the United Kingdom and it's territories.

De Havilland Tiger Moth DH-82

Layout and Structure
In this section the following characteristics of the DH82 are presented:

- Layout
- Basic features
- Wing and tail configuration
- Wing bracing
- Operation of control surfaces

The De Havilland Tiger Moth DH-82 is of the biplane design consisting of a low wing attached level with the lower fuselage and an upper parasol-like wing. These wings are braced by two parallel interplane struts on either side and are pin-jointed to a 'centre section' as shown in figure 1. The centre section is mounted forward of the cockpit by two cabane N-struts cross braced diagonally by cables. As shown in figure 2 the wings are staggered where the upper wing is slightly forward of the lower wing. They can be classified as swept back wings with a small dihedral angle. The overall shape of the wing is rectangular with a relatively large camber owing to the generally slower speed of biplanes.

Extensive use of cabling is present between interplane struts and fuselage with the purpose of bracing the wings during various phases of flight. On both port and starboard sides there are a pair of cables extending from the top of the interplane struts and converging to a point where the lower wing meets the fuselage slightly forward of the front cockpit seat, similarly another pair of cables extend from the bottom of the interplane struts converging to the top of the rear part of the N-struts of the centre section mounting, see figure 2. Both pairs of cables form a triangular shape and are braced at the intersection by a long thin bar. Furthermore the interplane struts themselves are braced by a single cable extending from the bottom of the forward strut to the top of the aft strut on each side.

Thicker cables were observed extending aft from either side of the forward section of the fuselage near the front cockpit to the tail control surface through actuating levers as shown by figures 3, 4 and 5. The cables for the elevators extend from just forward of the empennage emerging from the internal structure. As shown on the sketch, both sides of the control surfaces are connected by external cables to maintain the tension as cables are incapable of withstanding compressive forces allowing surfaces to flap uncontrollably in flight if only a single cable was used. The conventional tail is held by two cables per side while the elevators only use one (per side).

Design Features

In this section the following characteristics of the DH82 are presented:

- Materials used in frame and skin construction
- Joining method
- Size of structures
- Surface finishes
- Inspection and maintenance

The tailplane and wings of the Tiger Moth are composed largely of a timber frame covered in treated fabric. This includes the leading and trailing edges of the wings including ailerons however the construction of wing tips below the skin are of hollow metal construction, likely to tubes. The empennage is also of wood and fabric construction but uses similar hollow metal tubing for the tail and elevator trailing edges.

The joining method used to bind the frame to fabric appears to be rib-stitching followed by some form of doping to ensure that the fabric is stretched taut around the wings preserving the aerofoil geometry and preventing wrinkling or damage that would induce drag. There is evidence of outer coats applied to the doped fabric giving it a reflective appearance along with the paint job.

The low top speed of the DH82 and biplanes in general is conducive to less airflow over control surfaces, resulting in lower responsiveness of control movements. Hence arises the need for control surfaces i.e. ailerons, tail and elevators with proportionately larger surface areas and corresponding thickness to provide strength. As shown on the tailplane diagram the tail and elevators are of relatively large size relative to the overall size of the aircraft.

With regard to inspection given the external location of many components and the relatively small size of the aircraft it is easy to conduct a brief inspection of the exterior by examining the fabric skin for tears, cabling for fraying and simply feeling through the fabric for signs of damaged members. For internal examinations there are inspection rings scattered around the aircraft allowing access for closer inspection.

Boeing 747-400

Layout and Structure

In this section the following characteristics of the DH82 are presented:

- Layout
- Basic features
- Wing and tail configuration
- Wing bracing
- Operation of control surfaces

The 747-400 is of the monoplane design with a conventional low wing cantilever, it has a tapered swept back shape such that the chord decreases further along the wing. The wing has considerable length proportional to the size and weight of the 747-400, using large outboard ailerons and elevators for greater low speed control and smaller inboard ailerons and elevators for stability during high speed manoeuvres as shown in figure 6. Additionally anti-shock bodies are used to reduce drag at higher cruising speeds while also serving as trailing edge flap tracks. The wing incorporates Krueger flaps on the leading edge underneath the wing which rotate about an axis at the leading edge of the wing to increase the camber of the aerofoil, producing a higher coefficient of lift. The trailing edge flaps produce the same effect however are considerably larger, triple-slotted flaps.

On the upper surface spoilers are present to degrade the lift of the wing and produce drag when landing or descending. The inboard ground spoilers deploy fully on landing while the outer flight spoilers have variable deployment angles that can be operated separately (i.e. differential control) and can supplement aileron roll control in flight. Winglets are used at the extremities of the wings to reduce induced drag caused by wingtip vortices. The tailplane is of the conventional type as shown in the drawing below and the vertical stabiliser extends a significant height upward resulting in greater rudder authority at lower speeds. Specifically the tail has a split-rudder at the trailing edge with an upper and lower rudder as illustrated on figure 7, these operate in a similar fashion to the inboard and outboard ailerons and elevators as the upper rudder exerts a larger twisting force further from the structurally stronger fuselage creating a large moment.

Design Features

In this section the following characteristics of the DH82 are presented:

- Materials used in frame and skin construction
- Joining method
- Size of structures
- Surface finishes
- Inspection and maintenance

The outer skin of 747-400 are made of sections of aluminium alloy which are joined to the frame by rows and columns of rivets. These rivets sit flush with the skin of the aircraft reducing skin friction and overall parasitic drag. The overall surface finish excluding the flush rivets is smooth and aerodynamic to decrease the more pronounced effect of drag at higher speeds.

With respect to maintenance and inspection, progressive maintenance occurs every few days wherein visual checks for cracks are completed however these are primitive and cannot detect microscopic cracks as a result of fatigue. This can result from the flexing of the wing or application of control surfaces. X-ray testing is used to detect cracks and corrosion however is done on an infrequent basis due to the inherent danger of radiation. Once cracks have been identified but are within specified limits, mechanics bolt a plate on top of the cracks becoming the new exterior skin for the plane. Regardless the sheer size of the 747 makes inspection and maintenance no easy task given the quantity and location of components.

Comparison

747-400 Requirements:

- Commercially viable transport of passengers and goods
- Ability to transport passengers and goods within a restricted timeframe

DH82 Requirements:

- Cheap and low maintenance for civilian recreational use
- Easy to fly for basic training and civilian flight
- Highly manoeuvrable for training and aerobatics

Very little points of similarity exist between the De Havilland Tiger Moth DH82 and the Boeing 747-400. This is predominantly due to the completely different time periods of conception and the intended purpose for the aircraft. The DH82 was intended as a civilian recreational aircraft and later repurposed for entry-level flight training for the RAF and Commonwealth forces during WW2. The 747-400 is a commercial airliner with the sole purpose of transporting passengers in a profitable manner for airlines. The differing aims for each aircraft translate to vastly dissimilar technical specifications of the wing and tailplane structure as shown below:

	747-400	DH82
Frame	Aluminium	Timber (mostly)

Skin	Aluminium	Treated Fabric
Joining Method	Flush Riveted	Rib stitching
WING		
Number of Wings	1	2
Vertical Wing Location	Low	Low + High
Dihedral Angle	Positive	Positive
Planform	Swept back tapered	Swept back rectangular
Bracing	Cantilever	Dual strut braced
Stagger	N/A	Positive
Flaps	Triple-slotted	N/A
Krueger Flaps	Yes	N/A
Spoilers	Ground and Flight	N/A
Aileron sets	2 (inboard and outboard)	1
Engine Mountings	2 per side	N/A
Winglets	Yes	N/A
Control Surface Operation	Hydraulic	Mechanical Cable
TAILPLANE		
Type	Conventional T	Conventional T
Split Rudder	Yes	N/A
Split Elevator	Split (inboard and outboard)	Conventional
Control Surface Operation	Hydraulic	Mechanical Cable
Taildragger wheel	N/A	Yes

Most of the technical differences in wing and tailplane structure arise from the different speeds that the two planes operate at. The 747-400 cruises at extremely high speeds relative to the DH82 hence requires a wing with variable aerofoil geometry through high-lift devices, a set of inboard control surfaces and spoilers to ensure that it is safe and efficient at all speeds. It also incorporates materials that are capable of greater wing loading and stress allowing for large wingspans to support the massive weight of the aircraft. These wings can allow for multiple engine mountings and fuel storage which the weaker timber frame and fabric skin of the DH82 cannot support. The single low power engine of the DH82 meant a monoplane structure could not produce enough lift at the speeds it was capable of and the extra wing loading may cause the failure of weaker materials resulting in the slower, less efficient biplane design. However this allowed for greater manoeuvrability and no need for high-lift devices contributing to the low maintenance and easy to fly aim of the aircraft.

Conclusion

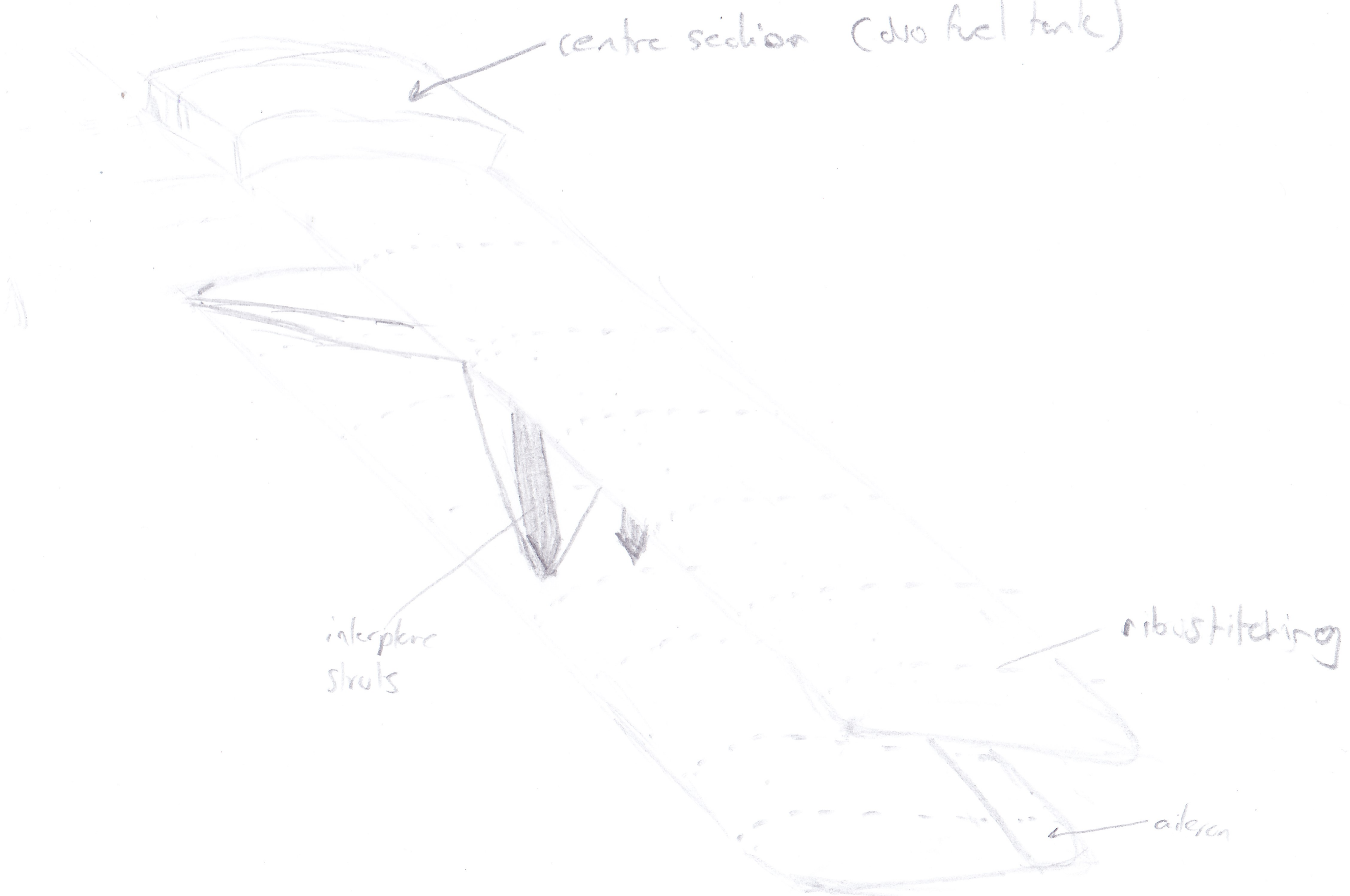
From the discussion of the layout and design features of the wing and tailplane structures of the Boeing 747-400 and the De Havilland Tiger Moth DH82 the advancement of aviation in a small timescale can be appreciated. The varying purpose for building an aircraft is illustrated as no mass-market airliner existed during the conception of the DH82 which was available only to the rich or for military training.

Appendix

De Havilland Tiger Moth DH-82 wing structure 1

"ISOMETRIC" VIEW

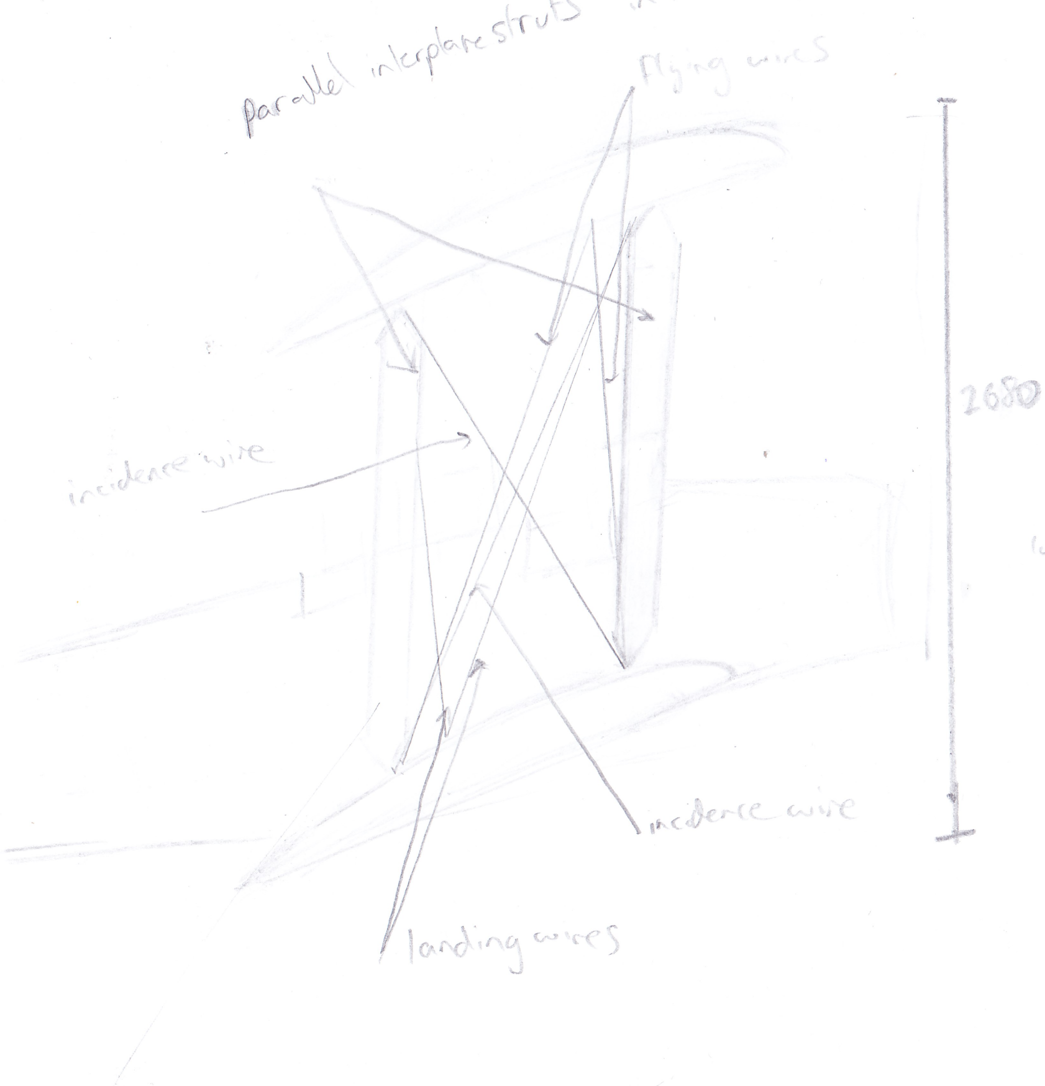
FIGURE 1



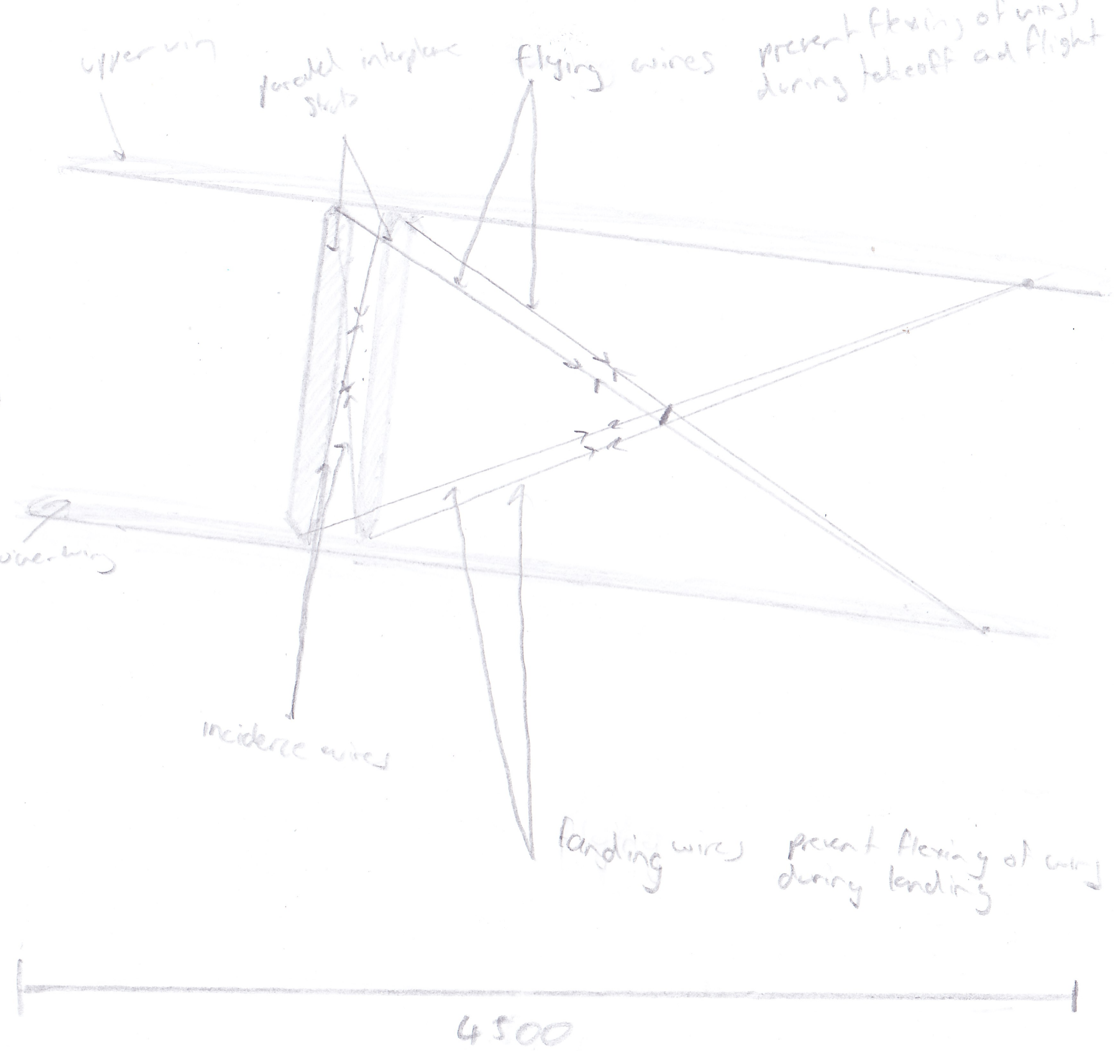
De Havilland Tiger Moth DH-82 wing structure 2

FIGURE 2

SIDE VIEW

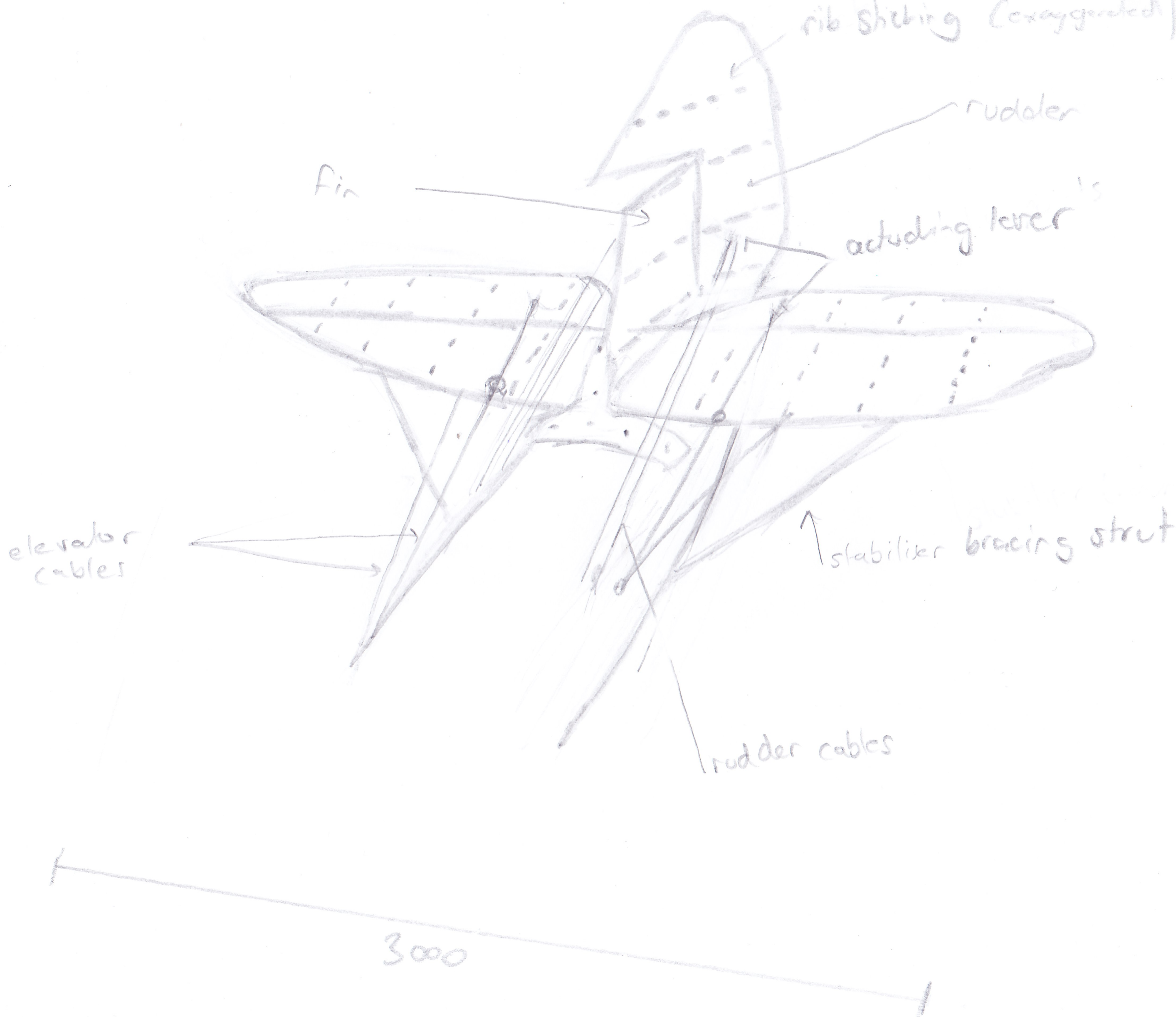


FRONT VIEW



De Havilland Tiger Moth DH-82 Empennage

FIGURE 3



[De] Havilland Tiger Moth DH82 Empennage Close-up

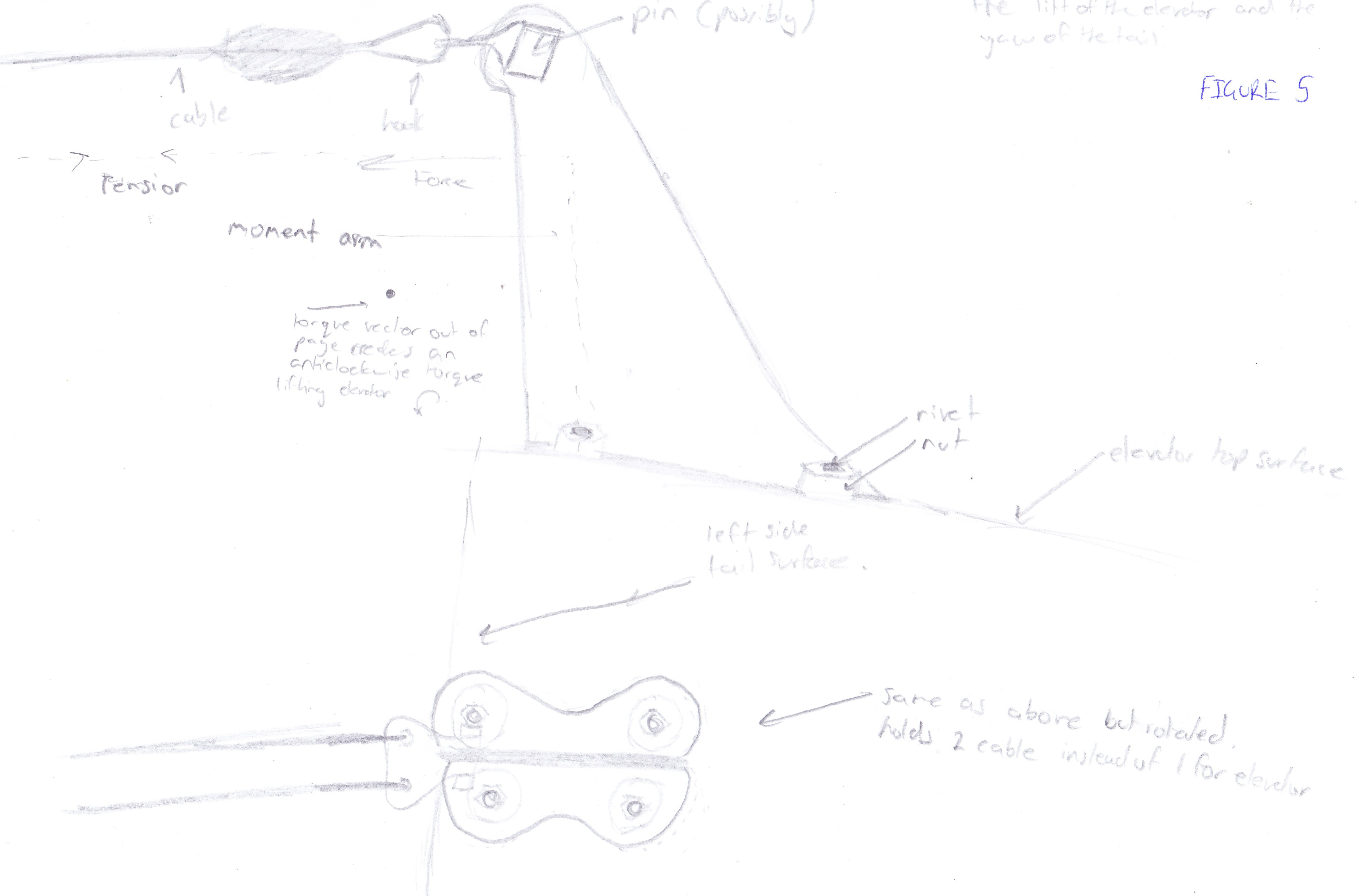
FIGURE 4

De Havilland Tiger Moth DH82 Actuating levers Empennage

Load Path

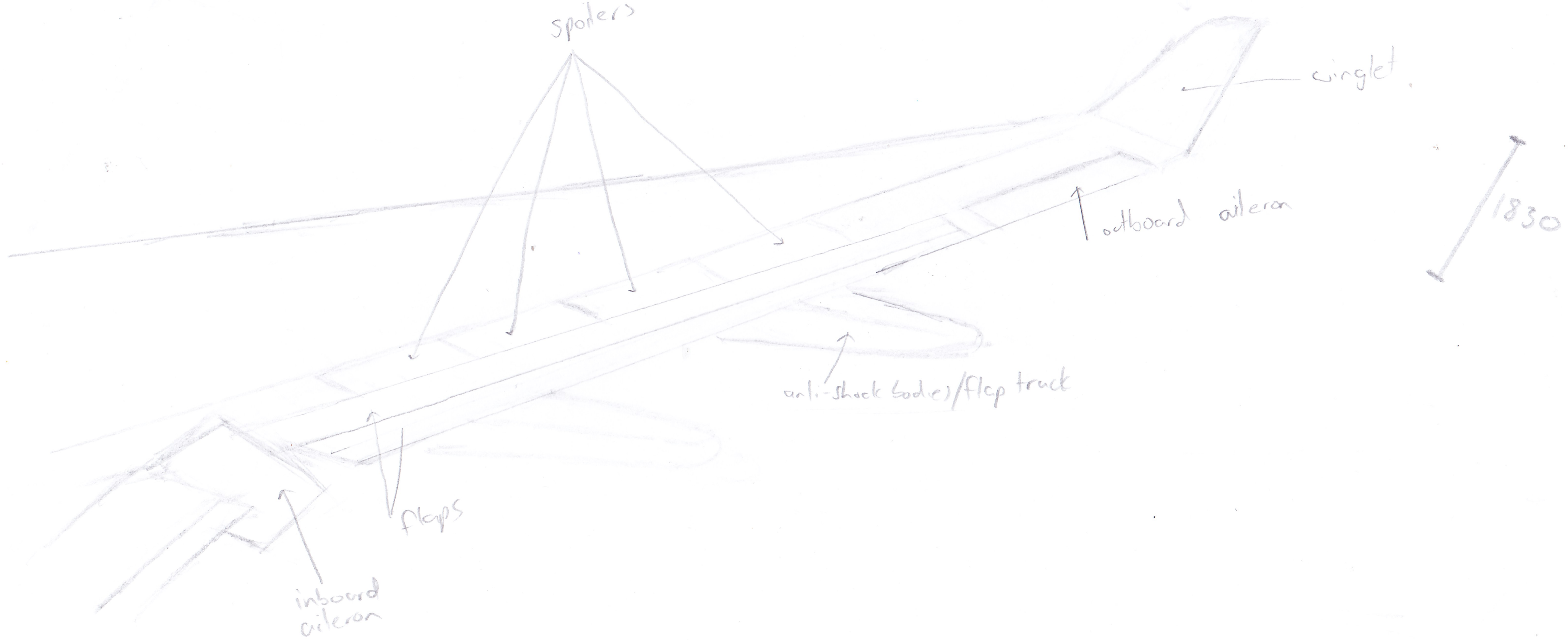
- tension in the cable creates a moment about the actuating lever varying the lift of the elevator and the yaw of the tail

FIGURE 5



Boeing 747-400 outboard Wing Section (Right)

FIGURE 6



Boeing 747-400 Empennage.

FIGURE 7