AERO1560 Assignment 2:

Tracker and Tiger Moth

Tutorial Time: Thursday 12 - 1pm
Location: Aeronautical Engineering Room N214
Tutor's Name: Anne Bettens

STUDENT ID: 510415022

Contents

1 Introduction **1**
1.1 The Grumman Tracker 1
1.2 de Havilland Tiger Moth 1

2 Layout, Structure and Design Features **2**
2.1 Grumman Tracker 2
2.1.1 Folding wings 2
2.2 de Havilland Tiger Moth 3
2.2.1 Positive-stagger wings 3
2.2.2 Differential aileron control setup 3
2.2.3 Wing structure 4
2.2.4 Wing-to-fuselage attachment 4

3 Comparison **5**

References **6**

A Sketches **7**

1 Introduction

This section introduces the original design missions for the Grumman Tracker *and* de Havilland Tiger Moth *aircraft.*

1.1 The Grumman Tracker

Up until the late 1940s, anti-submarine warfare (ASW) was largely conducted through two separate categories of aircraft - the ‘hunter’ and the ‘killer.’ The ‘hunter’ aircraft - commonly known as marine patrol aircraft (MPAs) or a ‘guppy’ – would usually be equipped with state-of-the-art submarine detection technology such as radio detection and ranging (RADAR), magnetic anomaly detectors (MAD), and disposable sonobuoys. Their aim was to locate and track the submarine, and then to relay this information back to base (usually an aircraft carrier) so that a ‘killer’ or ‘scrapper’ aircraft with a more substantial weapons system could carry out some offensive strategy. In fact, many MPAs did not even carry any armament at all. The major drawback of this strategy, which ultimately led the US Navy to commission the *Grumman Tracker*, was the overuse of already limited carrier space. Hence, the *Grumman S-2 Tracker (G-89)* was the first purpose-built, ASW aircraft able to carry out both hunter and killer operations on a single airframe.

1.2 de Havilland Tiger Moth

The *de Havilland Tiger Moth* is one of the most famous and popular trainer aircraft ever produced, primarily used for ab-initio training (initial training for military pilots) in the Royal Air Force during WWII. A trainer aircraft is a special class of aircraft with additional safety features on board, such as tandem flight controls (for both an instructor and trainee) and a simplified cockpit arrangement. The *Tiger Moth* helped trained over 90% of the Royal Australian Navy’s Fleet Air Arm in the 1940s, with about 1,000 *Tiger Moth*s produced at the Australian De Havilland Bankstown factory. It is also the first and best-known aircraft to utilise differential ailerons.

This report discusses the key design features of both the *Vampire* and *Tiger Moth*, but specifically their wing and tailplane structure.

2 Layout, Structure and Design Features

2.1 Grumman Tracker

This section briefly discusses some of the major structure and design features of the Grumman Tracker.

The *Tracker*'s design is unremarkable for the most part — two propeller-driven radial engines attached underneath the monoplane's tapered high wing, with a tricycle undercarriage and a conventional tail. The most interesting structural feature of the *Tracker* are the foldable wings, a hark back to the naval carrier roots of the plane. The ability of the wings to fold upward and inward hydraulically from outboard of the engine nacelles, with the wing fold 'skewed' so the two wings would overlap each other when folded, allowed (in theory) twice as many planes to sit on the same aircraft carrier, decreasing the wingspan of the *Tracker* from 22.13m to just 8.33m folded. See sketches 1 and 2.

The cantilever tail unit is an all-metal structure, with the rudder split vertically into two sections. The forward section is actuated hydraulically only during take-off, landing and single engine operation to increase the rudder area. See sketch 3.

Control surfaces on the *Grumman Tracker* include large Fowler-type flaps, spoilers and outer wing leading-edge slots.

Another interesting piece of equipment employed on the *Grumman Tracker* is the 70-million-candlepower searchlight installed on the starboard wing. See sketches 4, 5 and 6.

2.1.1 Folding wings

To combat the issue of limited carrier space, engineers tried various designs for a folding wing plane. Originally they tried to put hinges in the wing itself to simply fold the tips up, however this decreased the structural rigidity of the extended wing. It was Leroy Grumman himself who designed the first successful folding wing design in aviation history. Grumman engineered a folding wing on a 'skewed axis' – a pivot set in the wing root that projected outwards and backwards into the moveable portion of the wing. Initially Grumman's design relied on hydraulic cylinders, however this increased weight by a large factor and so a lighter manual system fitted with safety locks was selected for production. See sketches 7 and 8.

This design was built into the design of the *Grumman Tracker*, with two wings which would fold vertically upwards and then back over the fuselage of the body on a diagonal axis such that both wings could lie next to each other.

2.2 de Havilland Tiger Moth

This section briefly discusses some of the major structure and design features of the Tiger Moth.

The *de Havilland Tiger Moth* is a two-seat tandem biplane light aircraft. It is powered by a de Havilland Gipsy III 120 hp engine, a four-cylinder piston engine driving a two-bladed wooden propeller. The undercarriage consists of two main wheels and a tail wheel. The aircraft's structure is primarily fabric-covered metal and timber.

2.2.1 Positive-stagger wings

The biplane's wings have a positive stagger. The main reason for this was the need to improve access to the front cockpit. Recall that the *Tiger Moth* was designed from the ground up to be a trainer aircraft, and hence the training requirement specified that the front seat occupant had to be able to escape easily, especially while wearing a parachute. Originally the plane's design had no stagger between the wings, however the access to the front cockpit was then severely restricted due to the proximity of the aircraft's fuel tank directly above the front cockpit, and the rear cabane struts for the upper wing. Hence the final design included a positive stagger with swept back wings to maintain the same centre of lift.

2.2.2 Differential aileron control setup

To generate lift, we pitch the nose of the plane upwards, increasing the angle of attack of the wing moving through the air. As this angle increases, a difference in pressure between the top and the bottom of the wing, and hence lift, is produced. The by-product of this system is induced drag, which itself is proportional to the amount of lift produced. Now, usually the amount of lift that each half of the wing creates is equal. However when ailerons are deflected up or down to produce roll, the upwards-deflecting aileron produces less lift, whereas the downwards-deflecting aileron produces more. Hence, the upwards-deflecting aileron also produces less drag and vice-versa for the other side. This unequal drag causes the airplane slip through the air sideways, a phenomenon called adverse yaw.

This was a large issue, making aircrafts difficult to control especially at low speeds. It was Geoffrey de Havilland himself who invented the differential aileron in order to combat adverse yaw, and was first implemented on the *Tiger Moth*. The system combats adverse yaw by rigging the ailerons such that the down-going aileron deflects less than the up-going one.

The implementation of differential ailerons on the *Tiger Moth* is incredibly simple, which is one attribute to the plane's overall success. Each aileron is operated by a circular bell-crank which is flush with the wing (the *Tiger Moth* only had aileron's on the lower wing). The aileron pushrod — literally a rod which pushes or pulls the aileron up or down — is attached to the circular bell-crank at a 45 degree angle towards the back of the plane (NW on a compass). The result of this set up is that the anticlockwise movement of the bell-crank to 'push' the ailerons upwards (going to SW on a compass) has a much larger effect in the vertical axis than the clockwise movement of the bell-crank to 'pull' the ailerons downwards (going to NE on a compass). It was this incredibly simple design with trigonometry at its heart (the pushrod essentially acting as a sine function along the bell-crank, the 'y-coordinate' of the unit circle) which established the *Tiger Moth* as the plane which revolutionised ailerons [1].

2.2.3 Wing structure

The *Tiger Moth*'s wings are predominantly manufactured from timber with a fabric covering. They were externally braced through the use of flying wires, landing wires, incidence wires and interplane struts. The wings had no flaps at all, and ailerons only present on the lower wings. The lower wing attaches to the fuselage at the same attachment point used for the undercarriage shock strut and the flying wires (Joint A). Refer to sketch 9.

Both the top and bottom wings had a similar structure, with the only difference being the presence of ailerons in the lower wings. Both are comprised of two solid timber spars and numerous timber ribs, with three sets of internal bracing wires. Refer to sketch 10.

2.2.4 Wing-to-fuselage attachment

Both lower wing forward attachment point Joint A fittings are secured to the fuselage by two specially-designed upper attachment bolts and two fuselage lateral tie rods. The tie rods pass through the lower fuselage structure and are secured and held in tension by nuts against the Joint A fittings at both ends. See sketch 11. Note that the tie rods are internal and are depicted with dashed lines.

The upper attachment bolts were designed to transfer vertical loads in shear from the Joint A fitting into the fuselage. The tie rods transferred the loads pulling the wings away from the fuselage in tension through the fuselage. A compression strut that ran parallel to the tie rods provided support to the fuselage for landing, ground and inverted loads. See sketch 12.

3 Comparison

These two planes are quite disparate in almost every way, and most of this can be understood by referring back to the original design missions for both of these aircraft.

Recall that the *Tracker* was am American post WWII plane designed for anti-submarine warfare (ASW). Thus, by nature of its design (as explained in section 1.1), the plane must be heavy and capable of carrying large amounts of armament and equipment such as RADAR, MAD, and searchlights. The *Tracker* also required a crew of 4 in order to fly and operate equipment such as the disposable sonobuoy. It followed a common all-metal monoplane construction. By extension, the plane required decently-powerful engines not just to maintain flight, but in accordance with its double 'hunter' *and* 'killer' duties, be relatively fast and efficient. Each Wright radial piston engine was capable of producing upwards of 1500 horsepower each. A large range would be key to the aircraft's success, travelling many kilometers searching for submarines before returning to its carrier, which once again is a feature unique to the *Tracker* - its use on aircraft carriers. Initially commissioned precisely for this use, the plane's iconic feature are its folding wings which collapse from 22.13m to just 8.33m (less than the width of the *Tiger Moth*!).

Compare this to the small and nimble *dH Tiger Moth* designed as a trainer aircraft pre-WWII, 22 years prior to the *Tracker*. The plane only carried a crew of 2 in tandem and carried no armaments or special equipment, powered by a comparatively meagre 130 horsepower engine. Perhaps the most exciting feature (much simpler than the *Tracker*'s folding wings!) is the *Tiger Moth*'s differential ailerons — the first place to implement such a design.

Below is a table summarising this info.

Table 1: Key facts compared between *Grumman Tracker* and *dH Tiger Moth*.

	Grumman Tracker	**dH Tiger Moth**
Origin	United States	United Kingdom
Year	1954	1932
Crew	4	2
Production Run (units)	1284	8868
Wingspan (m)	22.13	8.9
M.T.O.W (kg)	11860	830
Power (hp)	3050	130
Range (km)	2170	485

References

[1] Colin Cutler. *How The Tiger Moth Helped Revolutionize Ailerons*. 2014. URL: https://www.boldmethod.com/blog/2014/02/how-the-tiger-moth-helped-introduced-differential-ailerons/.

[2] Greg Goebel. *Grumman Tracker, Trader, & Tracer*. 2021. URL: http://www.airvectors.net/avtraker.html.

[3] *Grumman and Paperclips*. URL: http://heroicrelics.org/info/grumman-paperclip/paperclip.html.

[4] *Heritage: Grumman Tracker*. URL: https://www.faaaa.asn.au/heritage-grumman-tracker/.

[5] *In-flight break-up involving de Havilland DH82A Tiger Moth, VH-TSG*. 2013. URL: https://www.atsb.gov.au/media/5750718/AO-2013-226%5C%20final.pdf.

[6] David D Jackson. *Grumman Tracker*. 2017. URL: https://www.grummantracker.com/index.htm.

[7] Jane's. *Northrop Grumman (Grumman) S-2 Tracker*. 2020.

[8] Thomas A. Michelhaugh. *Wing-Folding Mechanism of the Grumman Wildcat*. 2006. URL: https://www.asme.org/wwwasmeorg/media/resourcefiles/aboutasme/who%20we%20are/engineering%20history/landmarks/238-grumman-wildcat-sto-wing-wing-folding-mechanism.pdf.

A Sketches

List of Figures

1	Grumman Tracker wing folding mechanism.	8
2	Grumman Tracker left wing & engine.	9
3	Grumman Tracker tailplane.	10
4	Grumman Tracker starboard searchlight.	11
5	Grumman Tracker starboard searchlight (close-up).	12
6	Grumman Tracker 70 million candlepower searchlight.	13
7	Grumman Tracker wing folding mechanism.	14
8	Grumman Tracker wing folding mechanism.	14
9	Wing layout of dH Tiger Moth	15
10	Tiger Moth wing structure (interior).	16
11	Tiger Moth lower wing attachment.	17
12	Tiger Moth front view of Joint A.	18

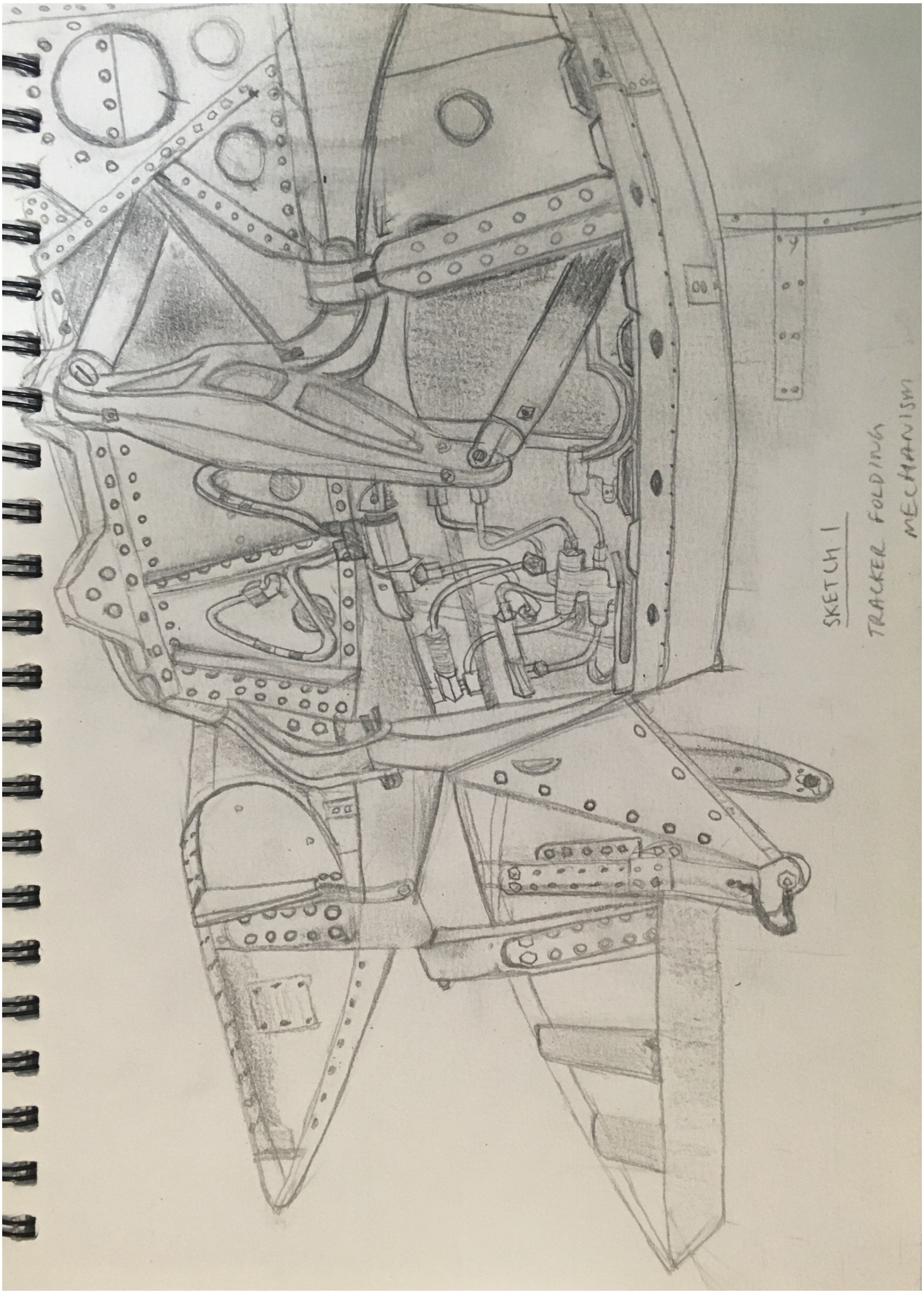

Figure 1: Grumman Tracker wing folding mechanism.

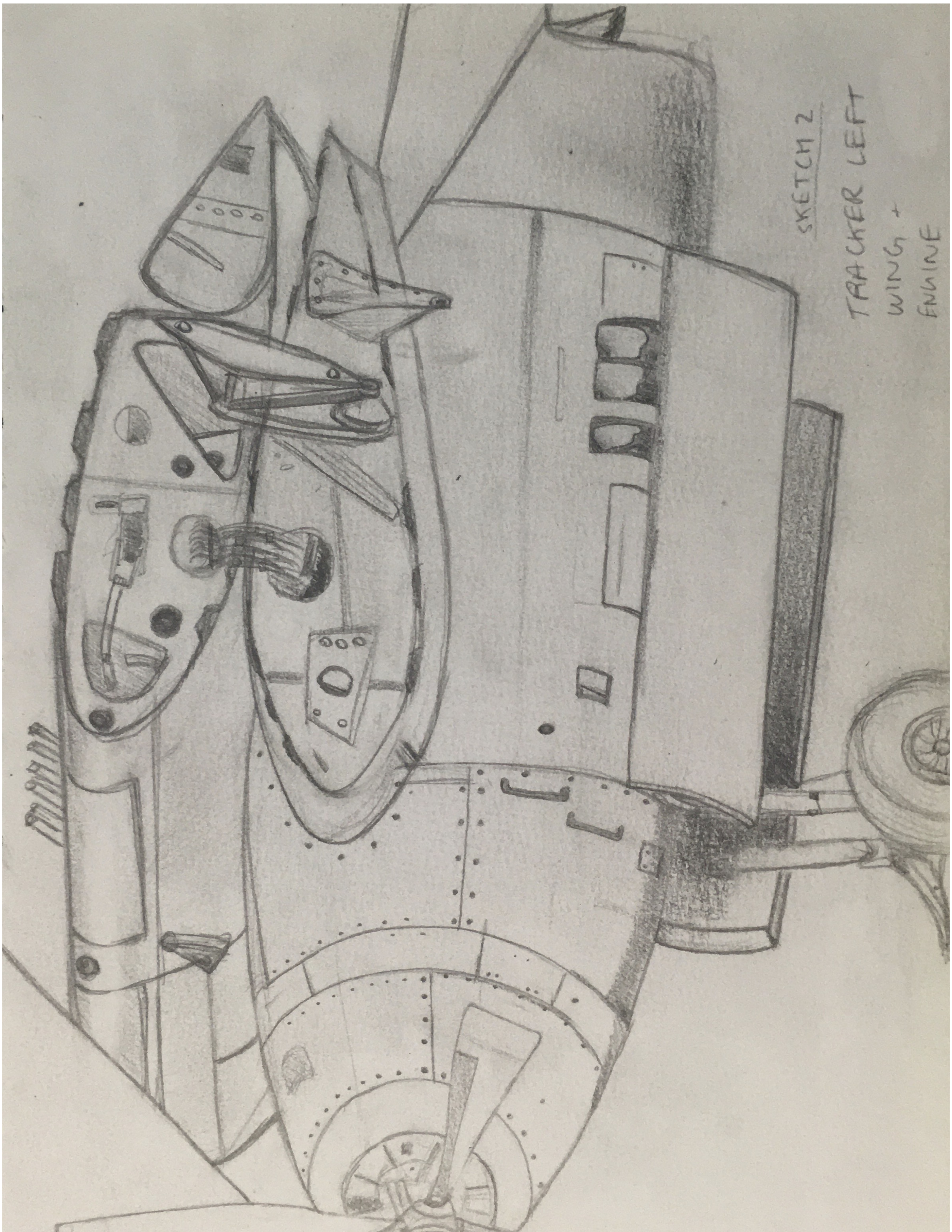

Figure 2: Grumman Tracker left wing & engine.

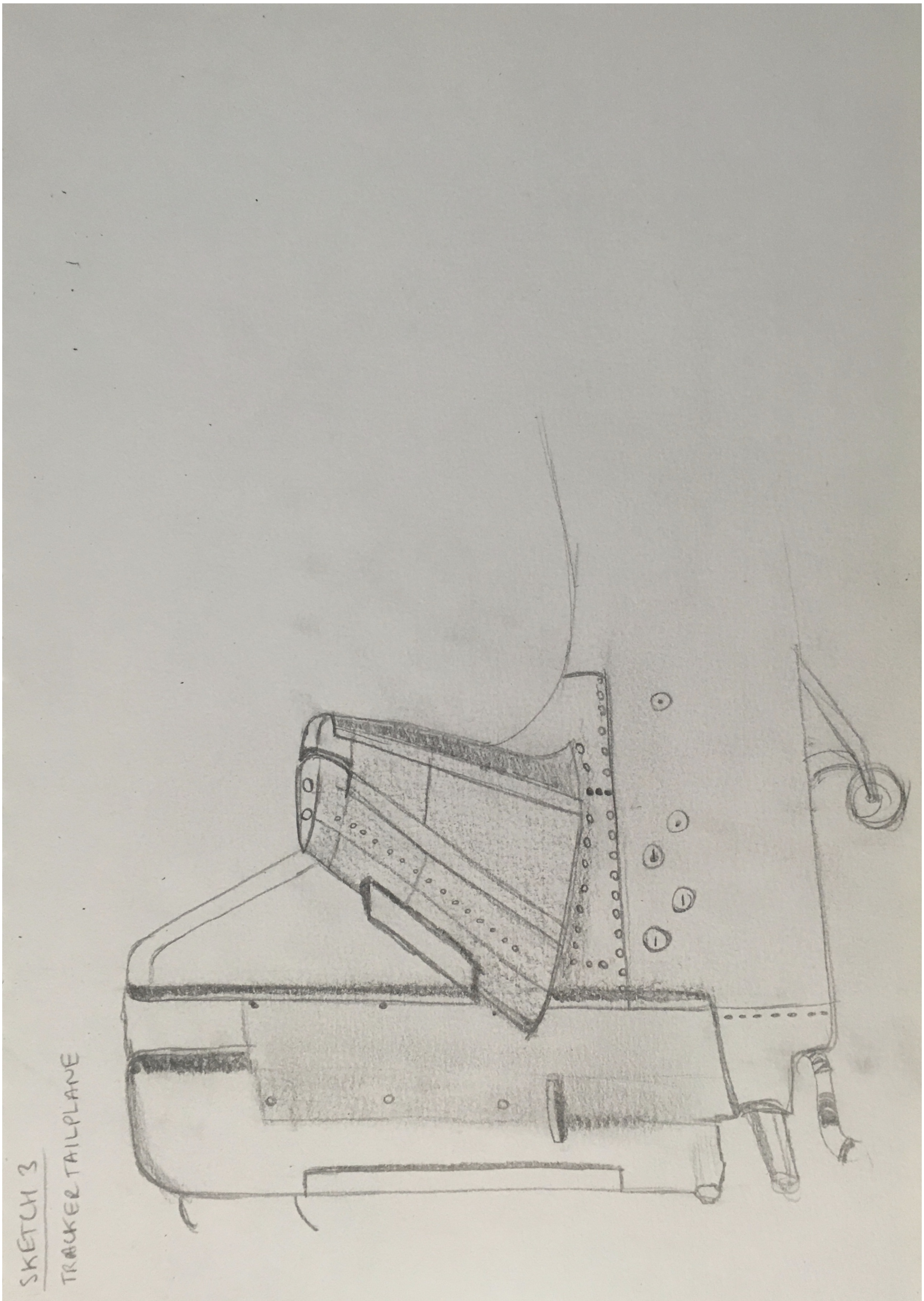

Figure 3: Grumman Tracker tailplane.

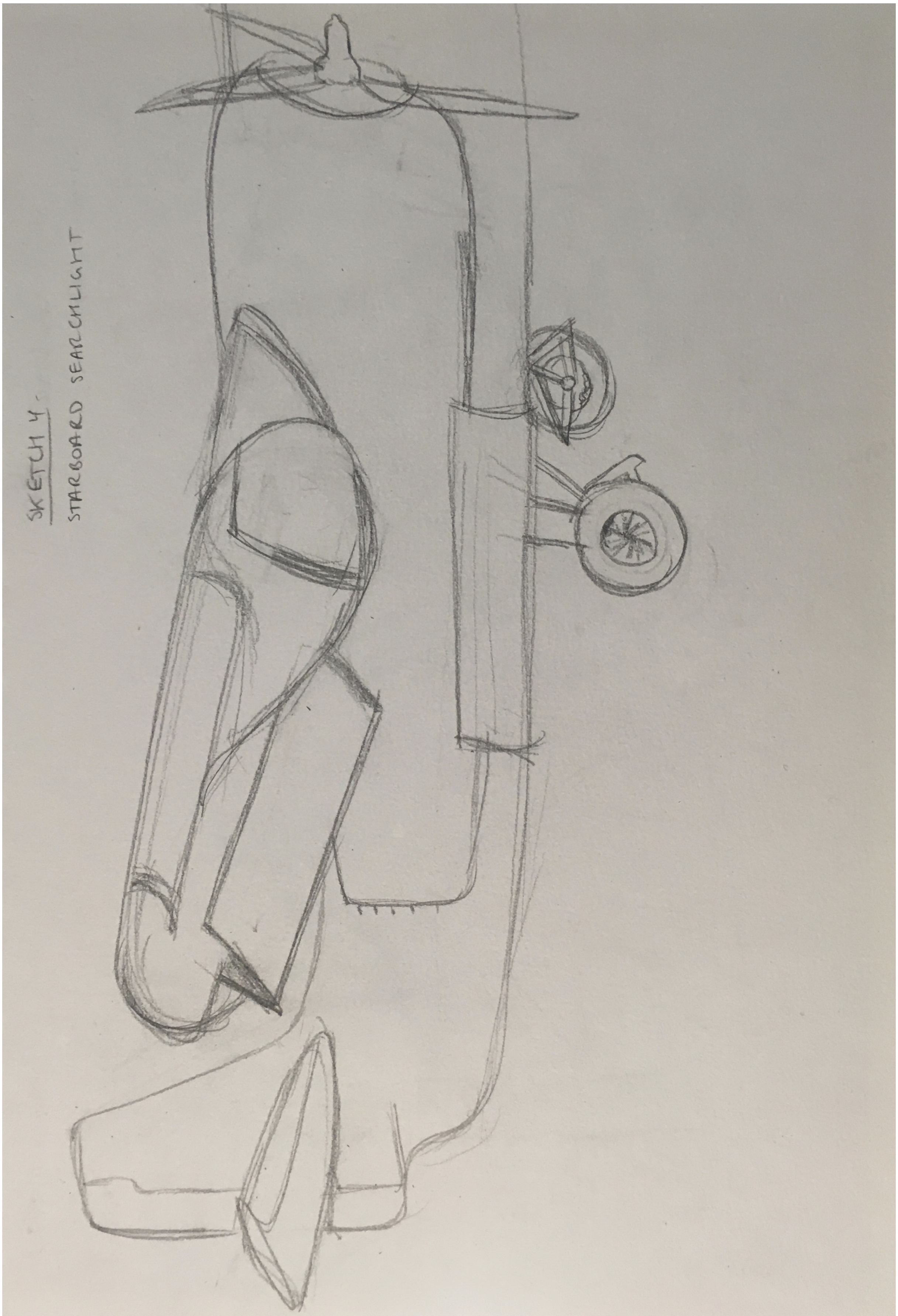

Figure 4: Grumman Tracker starboard searchlight.

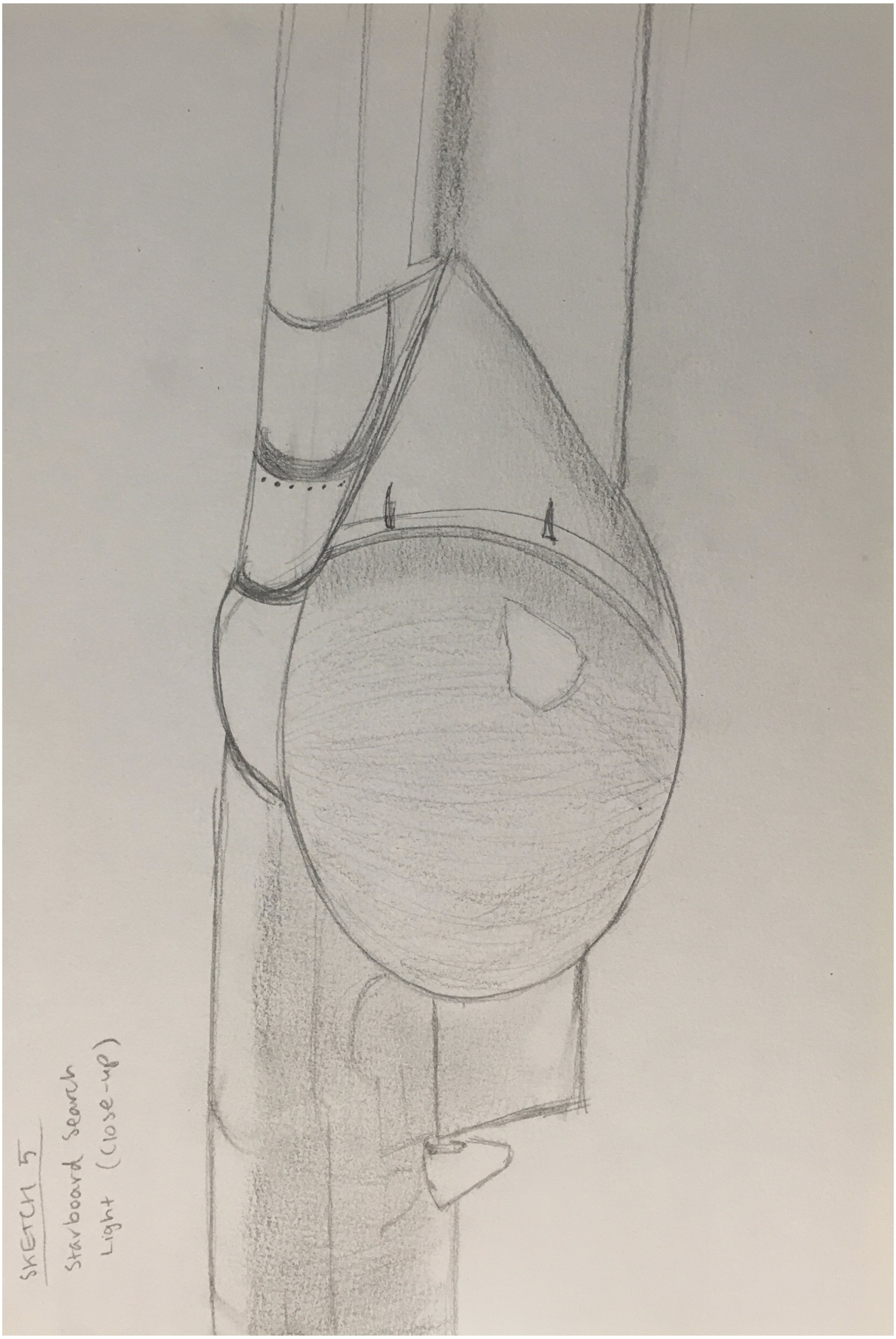

Figure 5: Grumman Tracker starboard searchlight (close-up).

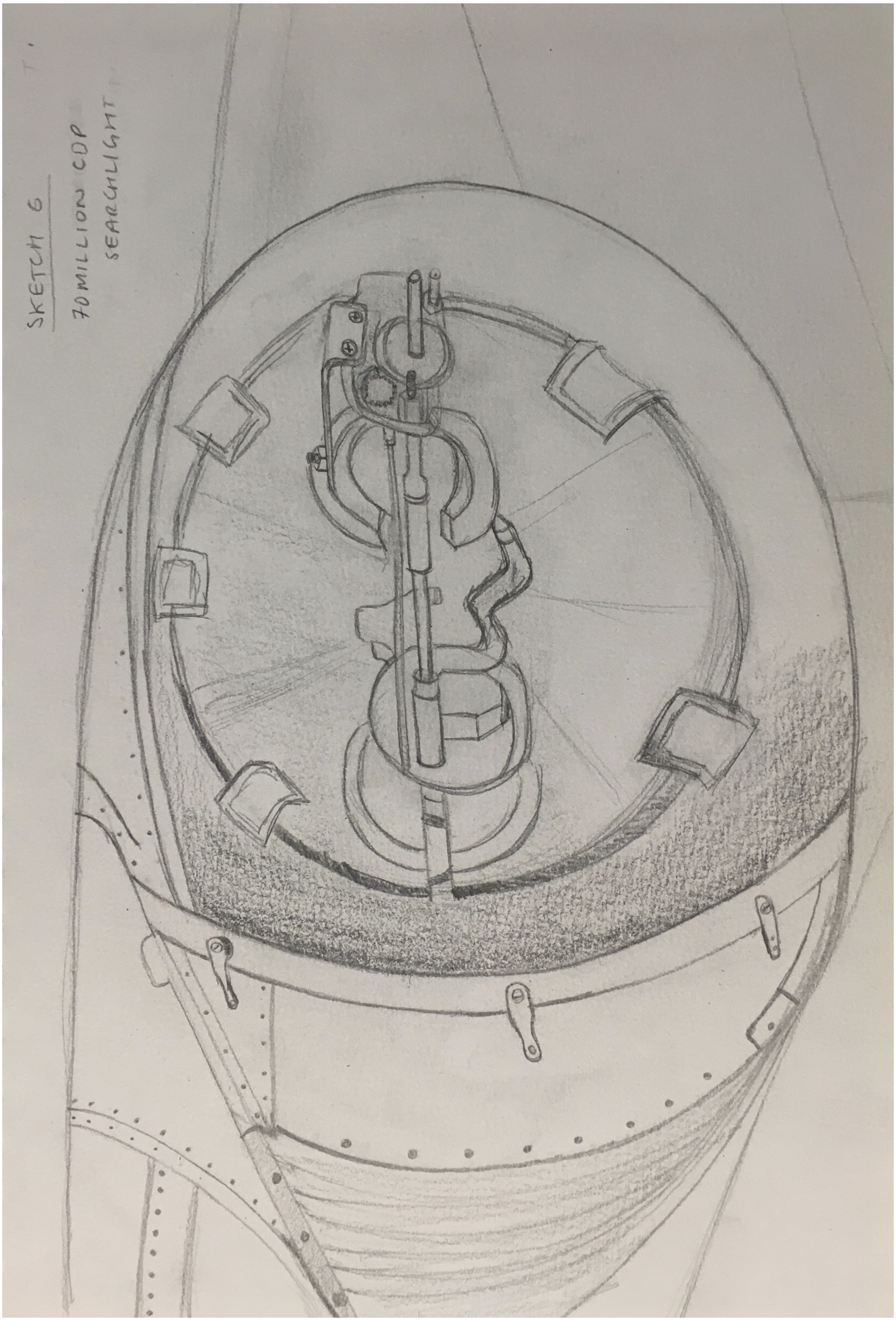

Figure 6: Grumman Tracker 70 million candlepower searchlight.

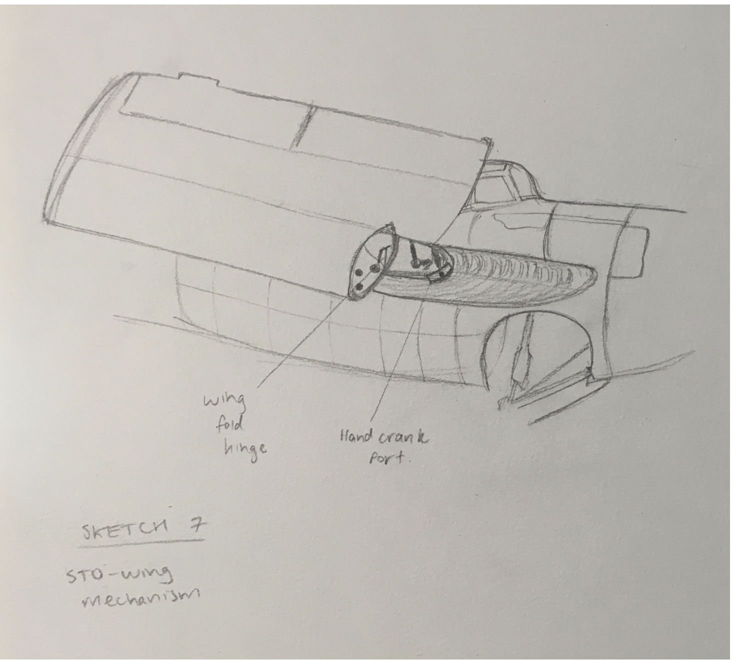

Figure 7: Grumman Tracker wing folding mechanism.

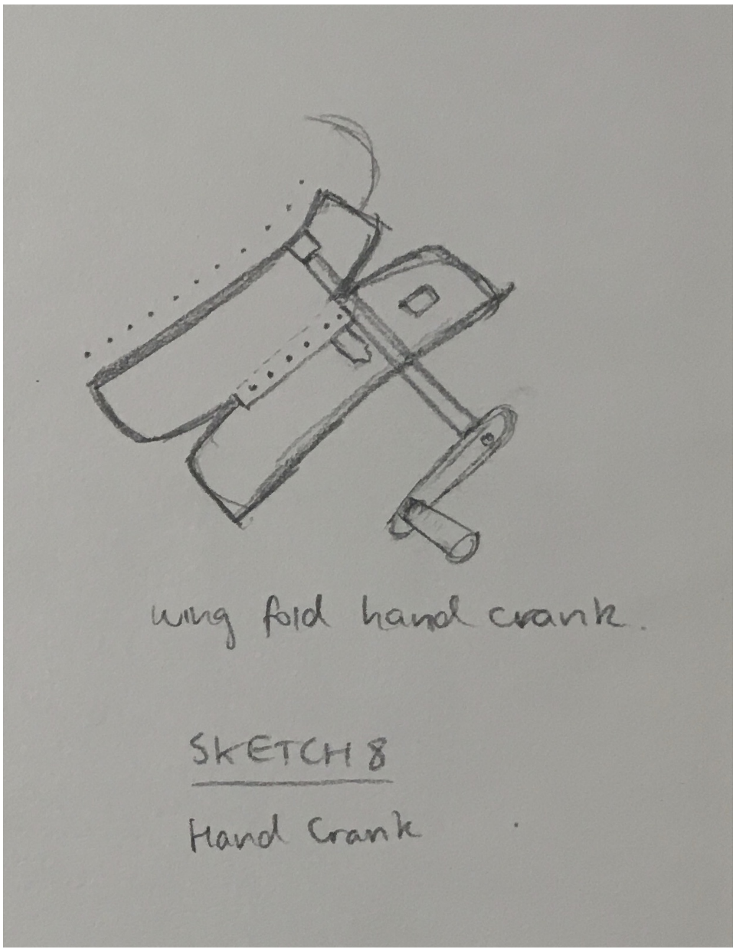

Figure 8: Grumman Tracker wing folding mechanism.

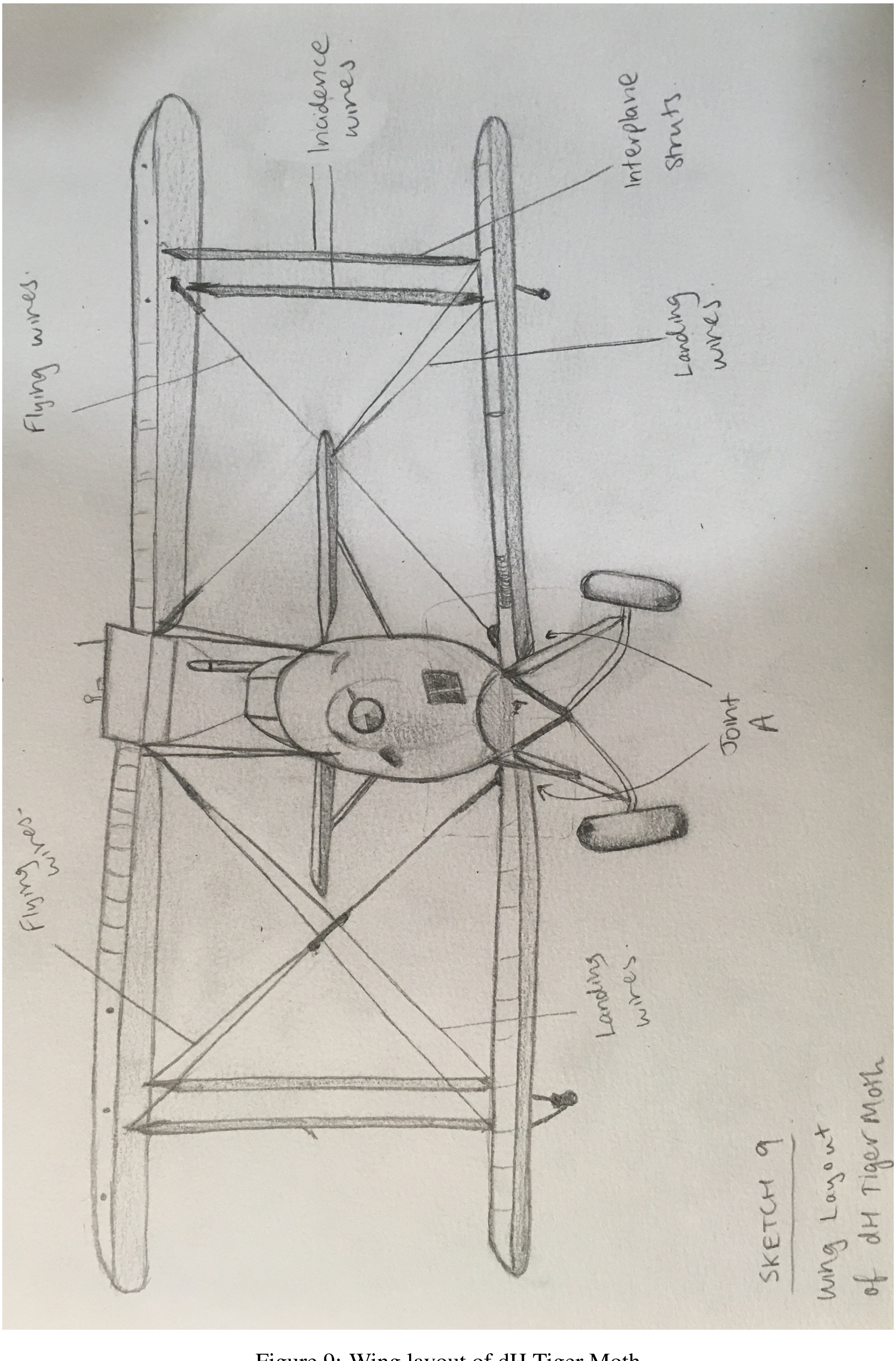

Figure 9: Wing layout of dH Tiger Moth

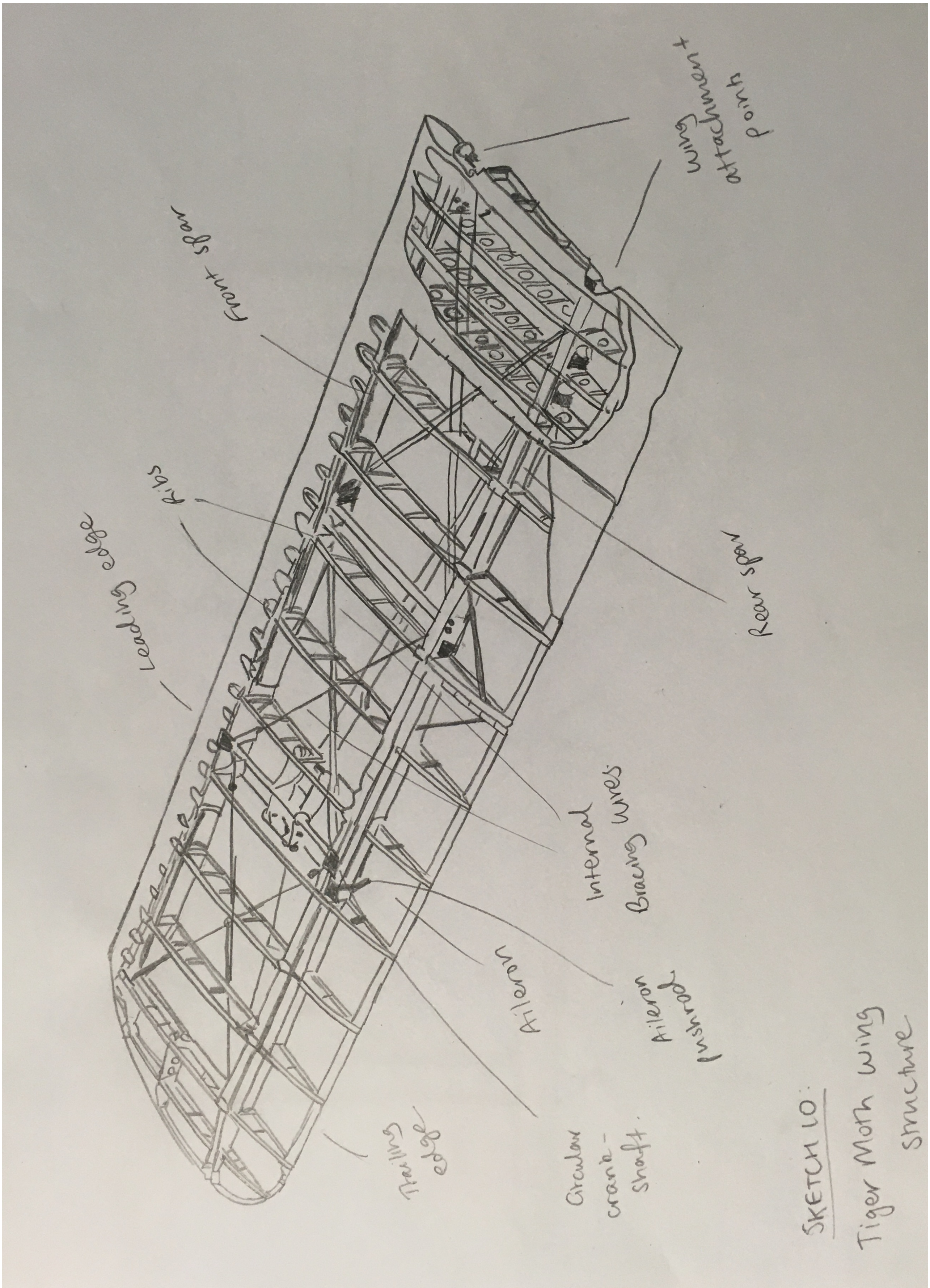

Figure 10: Tiger Moth wing structure (interior).

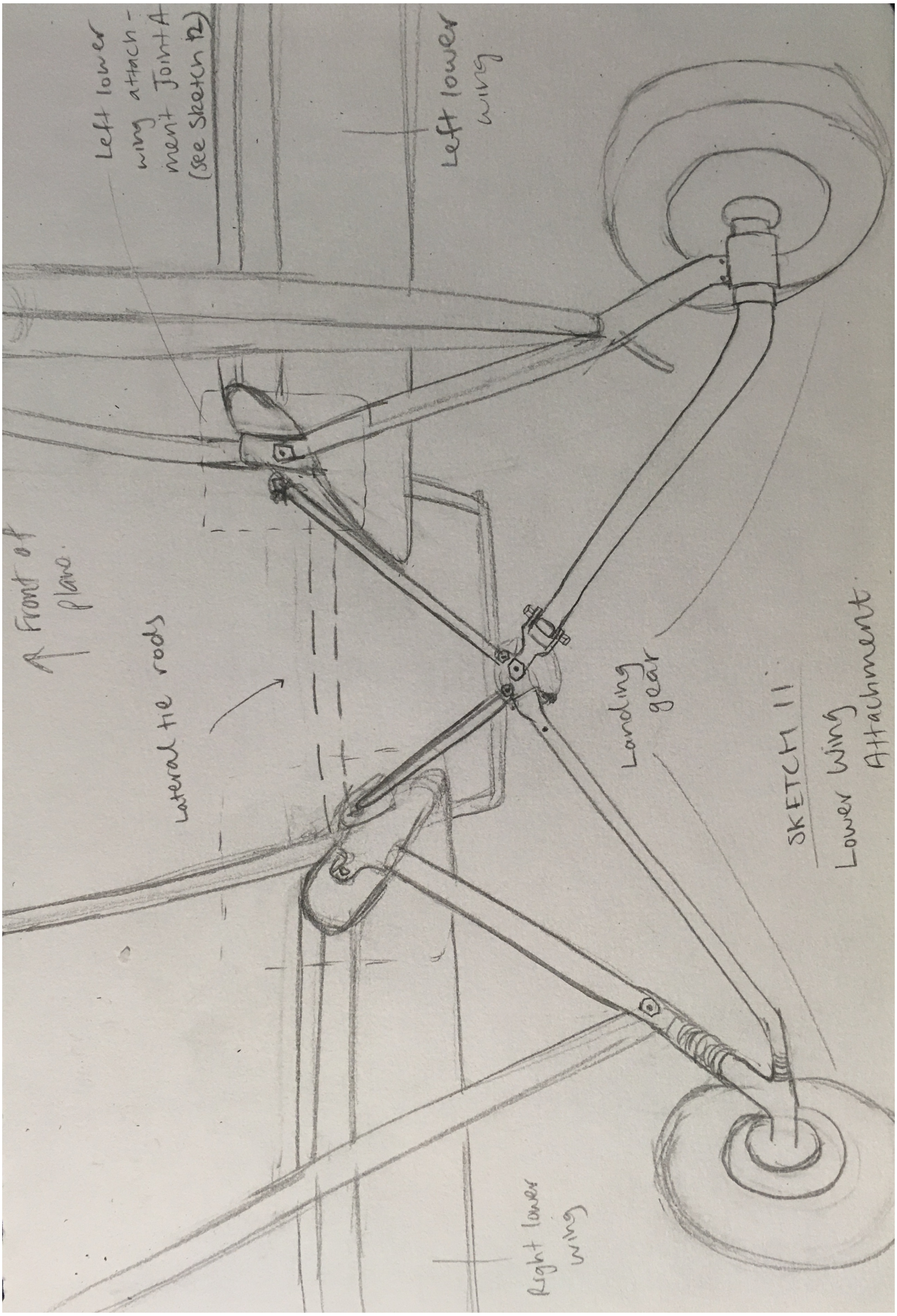

Figure 11: Tiger Moth lower wing attachment.

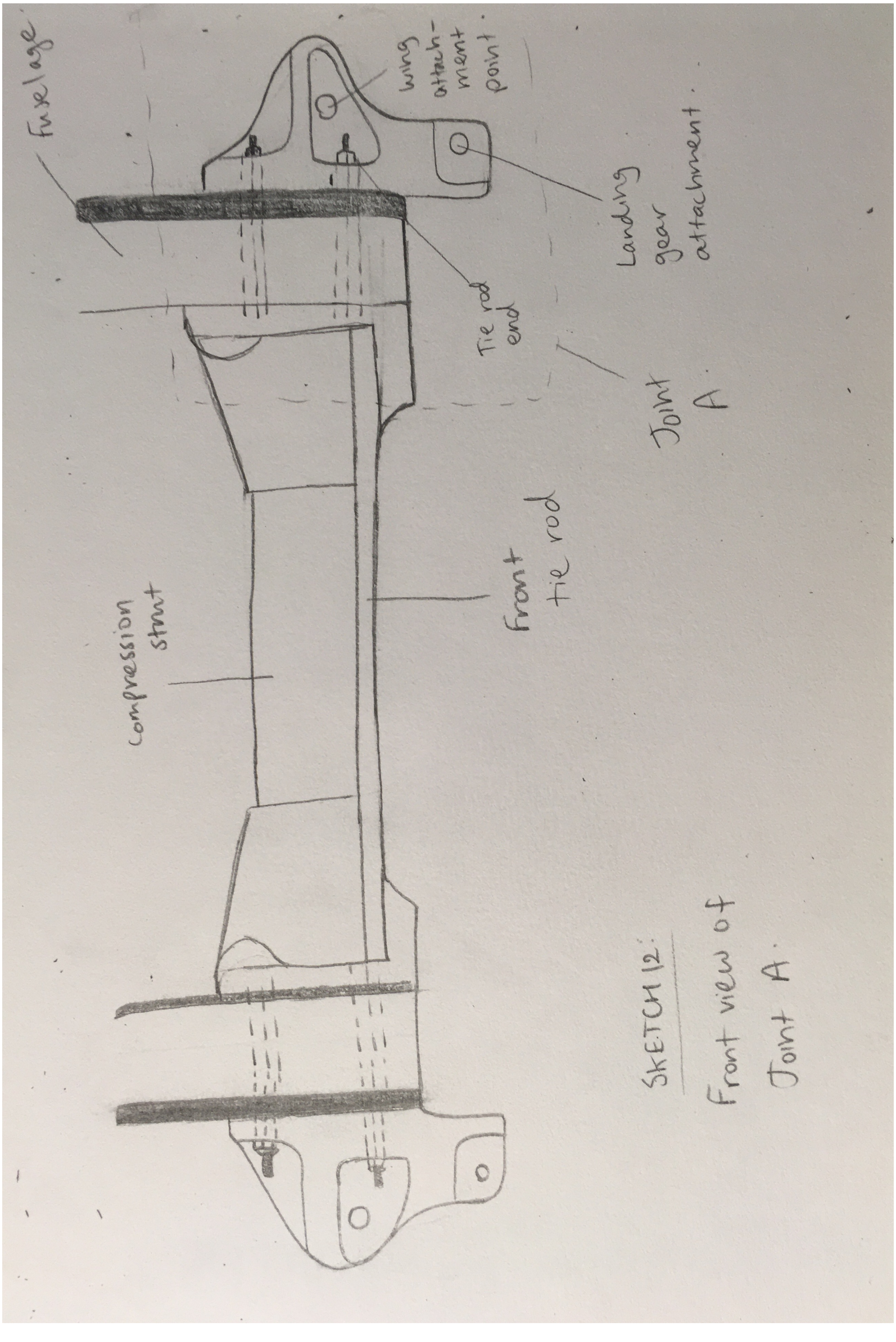

Figure 12: Tiger Moth front view of Joint A.