INITIAL DESIGN FOR A REGIONAL JET AIRCRAFT

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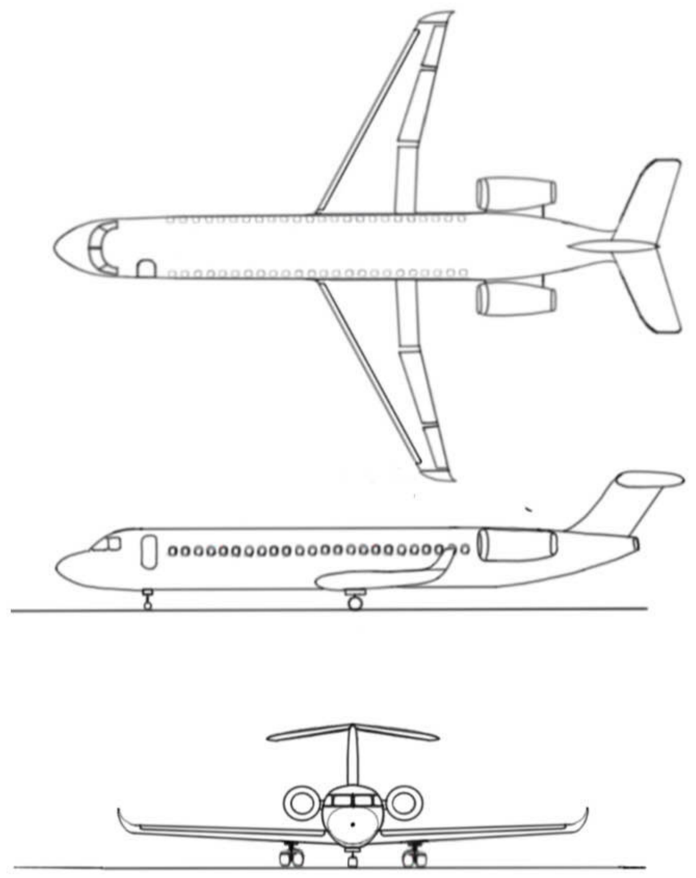
Baseline Configuration

Low mounted wings

+ Easy maintenance and refueling
+ Accomodates wing Undercarriage mounting
+ Wing doesn't pass through cabin.
+ Safer in crash as low mounted wing absorbs more energy compared to high Wing.
+ In event of water landing, fuselage is kept above water

− Worse ground clearance.
− Low wing is worse for ground affects



T-Tail

+ Allows rear mounted engine configuration
+ High mounted elevator reduces effects of the wings downwash
+ Reduces effects of vorticies from the rudder
+ Better control during spin[1]

− More suseptible to deep Stall [2]
− Heavier than conventional tail [3]
− Harder to install and maintain [4]

Two fuselage-mounted engines

+ Avoids ground clearance issues
+ Lower risk of foreign object damage
+ Lower friction drag [5]
+ Better cross wind landing capability [6] (NZ is one of the windiest countries in the world)
+ For OEI, engines are closer to center line therefore less asymmetric thrust.

− Engine location makes Maintenance more difficult, expensive and time consuming.
− Engine stall and surge at high angles of attack. [2]
− Produce more noise inside the cabin
− Engines are located further from and above fuel in wings therefore need more piping and more powerful fuel pump which is heavier.

Trycicle undercarriage

+ Better visibility during takeoff , landing and taxi.
+ Makes loading and unloading easier as fuselage is horizontal when landed.
+ Better cross wind landing capability. [7]
+ Better ground handeling (no ground loop)

− Heavier than other configurations
− Front gear is prone to breaking when landing on poor surfaces risks damage to front gear.
− Susceptible to tail strikes

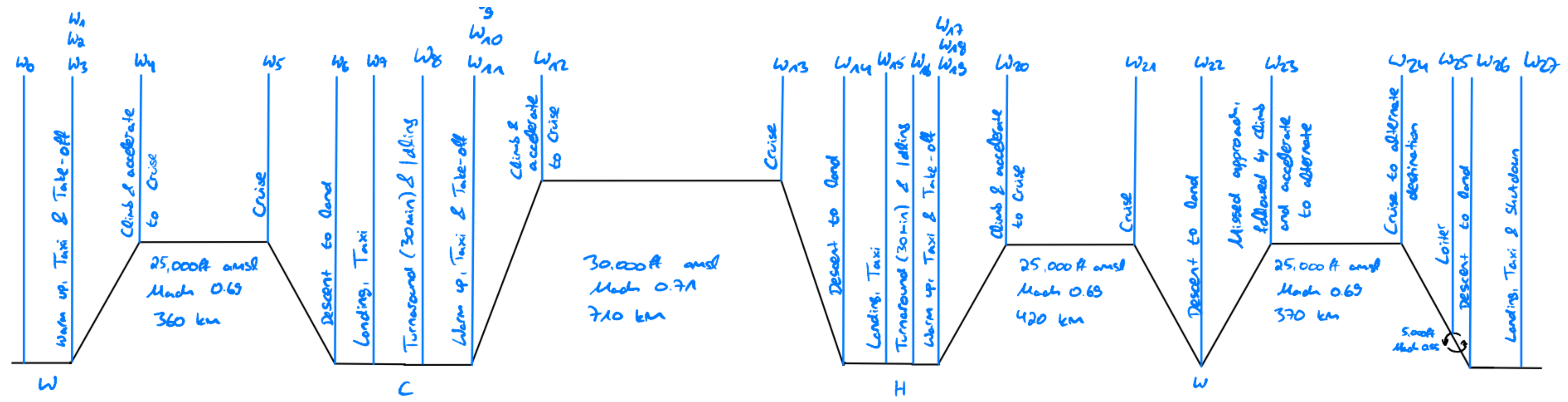
Mission profile

Introduction

From the design brief [12] for the aircraft, a mission profile was made encompassing all the phases across the three legs of the route from Wellington - Christchurch - Hamilton - Wellington. This includes the taxi and takeoff phase where the plane leaves the gate, taxis to the runway and takes off, the warm up phase was added in front of this to account for engine start up to begin the mission. Climb and accelerate as the aircraft climbs from the airport to the cruising altitude. Cruise for the given leg, descent, and landing and taxi phases which were specified in the brief as well as the idling and turnaround phase between each legs. In addition to these, the legs for a missed approach and climb, cruise to alternate, loiter, descent and landing and taxi were added at the end of the mission as given in the mission. These were added to the last leg, Hamilton - Wellington, to account for a missed approach at the lowest fuel scenario.

Target Design Specifications

- Accomodate **90 passengers + baggage + 2 pilots + 3 cabin crew**
- First cruise segment at an altitude of **25,000 ft and Mach 0.69**
- A fourth mission leg **(Diversion)** following a **missed approach**
- Cruise to alternate destination **370 km** away
- Loiter at **5,000 ft for 45 minutes**
- Capable of reaching **Mach 0.75** at cruise altitude
- Absolute ceiling of **40,000 ft** amsl at **Vx**
- Comply with all **FAR-25** regulations



Initial Weight Sizing

Crew and payload weight

Average weight appropriate for passengers on a plane with capacity of 80-99: **75kg**. [8]
7kg of cabin baggage per person [8] aswell as an average holduggage allotment of **17kg**. [9]
So **Wcrew+payload = 5*(75+7)+90*(75+7+17) = 9287 kg**

Empty weight

To calculate the ratio of the empty weight and the take off weight equation E.2 was used with values of **A = 0.97** and **C = -0.06** appropriote for a jet transport. [10]

Fuel fraction estimate

Weight fraction for cruise is determined by the Braguet range E.3 and endurance E.4 equations.

The specific fuel consumption was chosen to be equal to **C = 0.5 lbs/lbs/hr** as a high bypass ratio turbofan is most appropriote for the brief due to its high efficiency. [11]
In accordance with the desired performance of our aircraft, the lift to drag ratio was chosen to be equal to **L/D = 14**. [11]

The weight fractions for the warm-up, taxi, take-off, climb, descent and landing have been found in the litterature. [11]

The tournaround time with the engines idling was taken into account. The fuel consumption during this time is **15%** of the fuel consumption during the cruise. Weight fraction was found with E.4 .

We can therefore calculate the overall fuel fraction thanks to the equation E.5 which includes a **1%** factor to account unusable fuel.

Key equations

E.1 $$Wo = \frac{Wcrew + Wpayload}{1 - \frac{We}{Wo} - \frac{Wfuel}{Wo}}$$

E.2 $$\frac{We}{Wo} = AWo^C$$

E.3 $$\frac{W_i}{W_{i-1}} = e^{\frac{-RC}{V(L/D)}}$$

E.4 $$\frac{W_i}{W_{i-1}} = e^{\frac{-EC}{(L/D)}}$$

E.5 $$\frac{W_f}{W_0} = 1.01\left(1 - \frac{W_n}{W_0}\right)$$

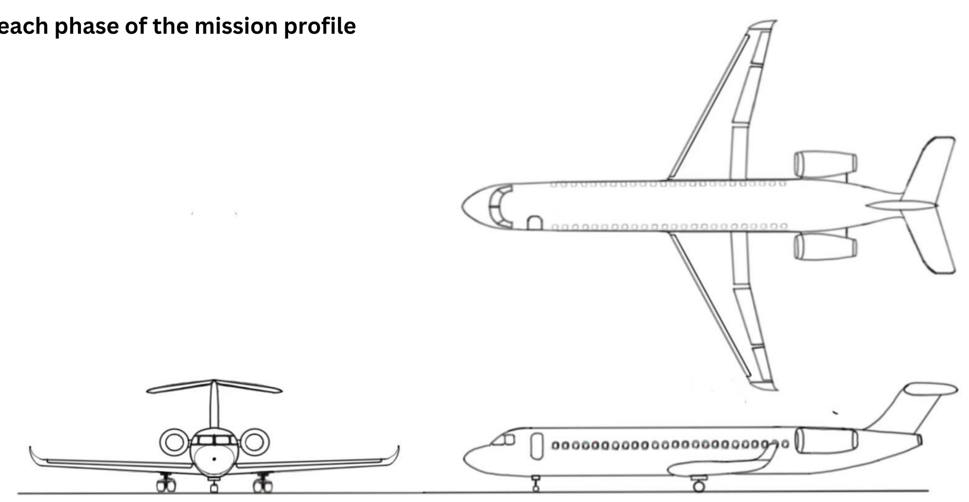
	Weelington - Christchurch							Idling	Christchurch - Hamilton							Idling	Hamilton - Welington							Diversion				
Legs	Warm up	Taxi	Take off	Climb	Cruise	Descent	Landing & Taxi	Idling	Warm up	Taxi	Take off	Climb	Cruise	Descent	Landing, Taxi	Idling	Warm up	Taxi	Take off	Climb	Cruise	Descent	Landing & Taxi	Missed approach & climb	Cruise	Loiter	Descent	Landing, taxi & shutdown
Wi/Wi-1	0.990	0.990	0.995	0.980	0.981	0.990	0.992	0.997	0.990	0.990	0.995	0.980	0.963	0.990	0.992	0.997	0.990	0.995	0.995	0.980	0.978	0.990	0.992	0.980	0.980	0.979	0.990	0.992
Cumulative weight fraction	0.990	0.980	0.975	0.956	0.937	0.928	0.921	0.918	0.909	0.900	0.895	0.877	0.845	0.836	0.830	0.828	0.819	0.815	0.811	0.795	0.777	0.769	0.763	0.748	0.733	0.718	0.711	0.705

Fig. 1: Detail of fuel fraction for each phase of the mission profile

Results

By using equations E.1 E.2 and E.5 we can determine all weight values.

Weight sizing final values	
Wo	47290 kg
We	24047 kg
We/Wo	0.51
Wf	14096 kg
Wf/Wo	0.30



Initial Wing and Thrust sizing

Key parameters

- Aspect ratio was chosen to be equal to **AR = 7.5** according to similar aircraft [10]
- Oswald efficiency number is equal to **e = 0.75** according to literature [13]
- Using the equation $C_{D_0} = \frac{\pi.AR.e}{(2L/D)^2}$ the drag coefficient $\mathbf{C_{D_0} = 0.225}$ was calculated
- **Sweep** was determined to be **23 deg** using the relation between maximum mach number and leading-edge sweep. [14]
- A mix of historical data and compromise between efficiency and complexity lead to the choice of a maximum lift coefficient of: $\mathbf{C_{L_{maxL}} = 2.5}$

Cruise parameters

W-C	Mach	0.69
	Altitude	25,000 ft
	α (W/Wo)	0.956
	β (T/To)	0.27
C-H	Mach	0.71
	Altitude	30,000 ft
	α (W/Wo)	0.880
	β (T/To)	0.23
H-W	Mach	0.69
	Altitude	25,000 ft
	α (W/Wo)	0.799
	β (T/To)	0.27
Loiter	Mach	0.61
	Altitude	5,000 ft
	α (W/Wo)	0.961
	β (T/To)	0.35
Cruise Missed approach	Mach	0.69
	Altitude	25,000 ft
	α (W/Wo)	0.980
	β (T/To)	0.27

Values required by the **target design specifications**

Range cruise is doubled compared to W-C cruise so it should be worthy to climb higher in order to **consume less fuel during the cruise**. Adding a little more speed to travel faster

Range is close to the W-C cruise one so we assumed Mach and altitude should be the same

Altitude is given by the **target design specifications** while the Mach number is calculated by dividing the cruise velocity by 1.14 [15]

For each leg, **α** is calculated using **Fig. 1** and **β** is determined thanks to **empirical law**. [14]

Stall speed constraint

The reference stall speed was found by first emperically finding the approach speed from the landing field length [11]. A correction divisor of 1.3 was applied to calculate the stall speed according to FAR-25 regulations giving the value of $\mathbf{V_{stall,max} = 55.8\ m/s}$. This value was also checked to be consistent with other similar aircraft.

By using the equation $\left(\frac{W_0}{S}\right)_{max} = \frac{1}{2}\rho V^2_{stall,max}$ the maximum stall speed constraint can be calculated.

$$\left(\frac{\mathbf{W_0}}{\mathbf{S}}\right)_{\mathbf{max}} = \mathbf{4760\ N/m^2}$$

Landing distance constraint

The landing distance constraint is given by this empirical law:

$$ALD = 0.51\frac{W/S}{\sigma C_{L_{maxL}}}K_R + S_a$$

- The ALD contains a security factor of 1.667 defined in FAR 25 regulations.
- Considering our aircraft type $\mathbf{S_a = 305\ m}$ was chosen. [14]
- By looking at many similar aircraft, most of them use a thrust reverser so it was decided to incorporate one in our aircraft to make the constraint way less limiting. Therefore a correction factor of $\mathbf{K_R = 0.66}$ was used yielding the following constraint.

$$\left(\frac{\mathbf{W_0}}{\mathbf{S}}\right)_{\mathbf{max}} = \mathbf{5807\ N/m^2}$$

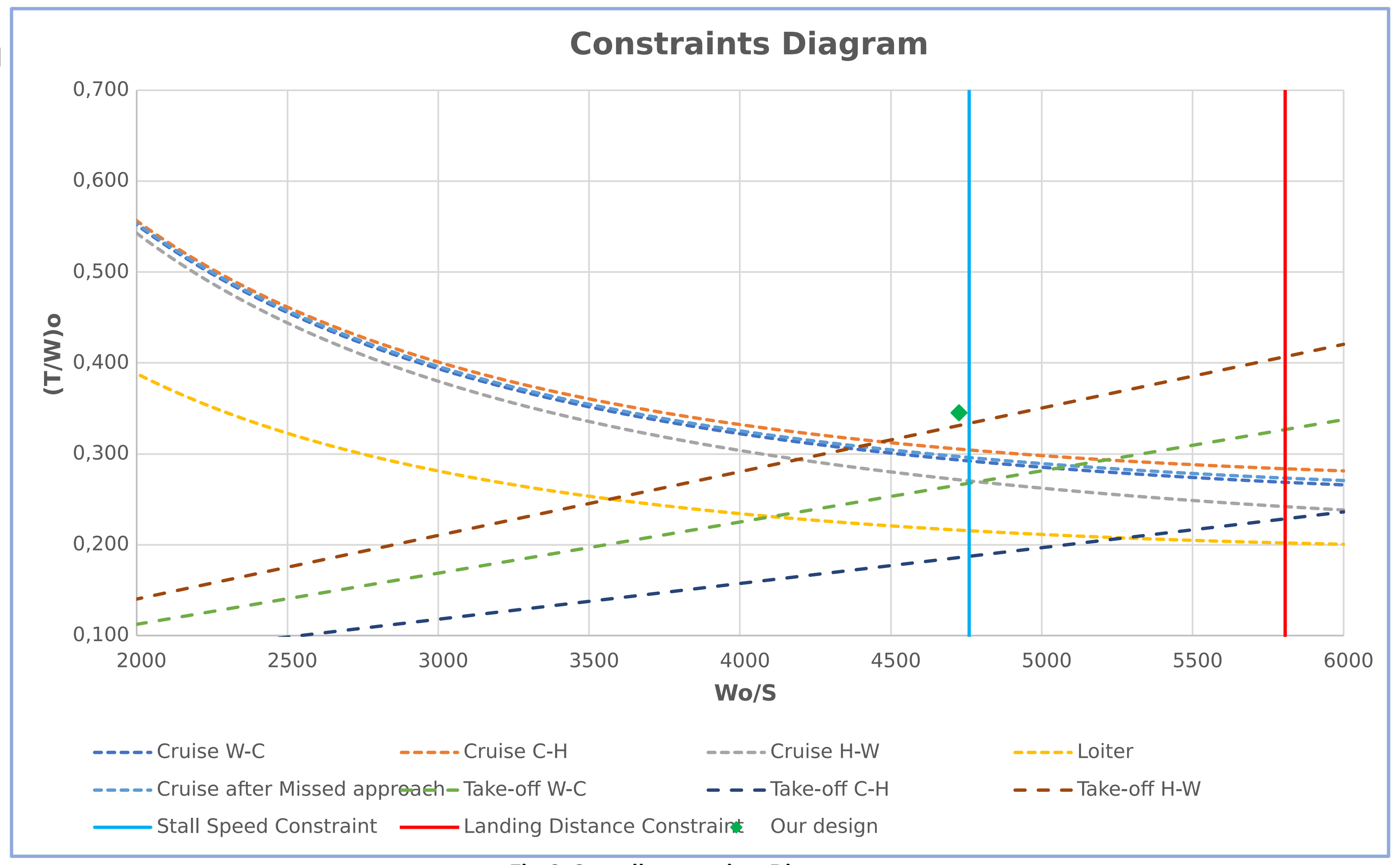


Fig. 2: Overall constraints Diagram

Results

To choose the optimal design it was aimed to minimize Thrust/Weight ratio and maximise the Wing Loading. The lines in the constraints diagram **Fig. 2** force a choice between these two goals. It was chosen to favour the maximisation of the wing loading in order to not reach the limit of the engine during cruise. Thus the chosen design point was:

	Our design
(T/W)o	0.345
Wo/S	4725

With the calculated MTOW value the required thrust of the engine and the area of the wings could be calculated:

$$\mathbf{T_0 = 160.05\ kN} \qquad \mathbf{S_{wing} = 98.18\ m^2}$$

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