Imperial College London

Department of AERONAUTICS

Conceptual Design for a Regional Jet Aircraft

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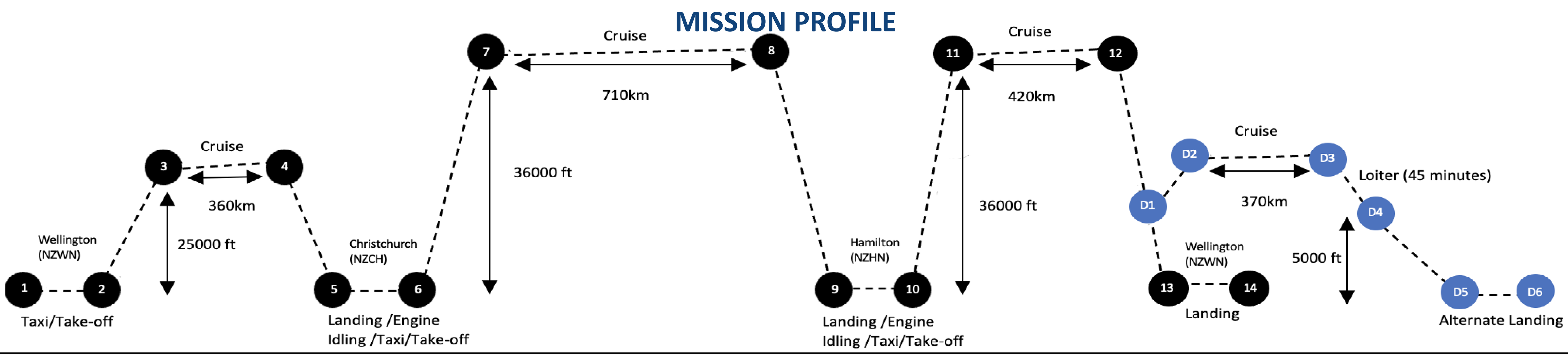
DESIGN SPECIFICATION

MISSION PROFILE



DESIGN CONSTRAINTS

- 90 passengers and baggage.
- 2 pilots and 3 cabin crew.
- 30 minute turnaround at each location with powerplant idling: no refuelling.
- Diversion and 45 minute loiter at 5000 ft
- Absolute ceiling: 40,000 ft
- Maximum speed of Mach 0.75
- Compliant with FAR-25 regulations.

BASELINE CONFIGURATION

LOW WING

- Easy cabin access.
- Shortened take-off distance due to enhanced ground effect and softer touchdown.
- Reduced impact of downwash from wings on horizontal stabiliser.

UNDERWING ENGINES

- High bypass turbofan engines.
- Minimise interference drag.
- Easy to service: minimal extra equipment required and faster turnaround.

TRICYCLE UNDERCARRIAGE

- Front wheel enables steering and prevents tipping in the event of harsh braking.
- Stored underwing for better aerodynamics.

CONVENTIONAL TAIL

- Lightweight: no additional reinforcement needed.
- Good indication when stall is near: violently vibrates when approaching stall.

HIGH LIFT DEVICES

Fowler flaps:

- Increase $C_{L_{max}}$
- Easily maintained
- Reliable activation mechanism

Slats:

- Increase $C_{L_{max}}$

INITIAL SIZING

Table 1: Weight Fraction Estimations

Journey Segments	Weight Fractions
S1: Wellington – Christchurch	0.918
S2: Christchurch – Hamilton	0.834
S3: Hamilton – Wellington	0.767
D: Hamilton – Wellington (including diversion)	0.734

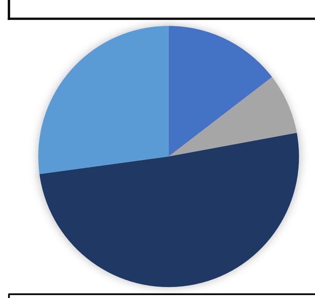


Figure 1: Weight Fractions

Description	S1 Weight Fractions	S2 Weight Fractions	S3 Weight Fractions
Taxi + Take-off	0.970	0.970	0.970
Climb + Accelerate	0.985	0.985	0.985
Cruise	0.986	0.975	0.985
Descent	0.980	0.980	0.980
Landing + Taxi	0.995	0.995	0.995

Description (Diversion)	Weight Fractions
Missed Approach	0.985
Cruise	0.987
Loiter	0.985
Descent	0.980
Landing + Taxi	0.995

- Initial guesses of $AR = 8$, $S_{wet}/S_{ref} = 5.5$ and $e = 0.8$ were made.
- $\left(\frac{L}{D}\right)_{max}$ and C_{D_o} calculated using $\left(\frac{L}{D}\right)_{max} = \frac{1}{2}\sqrt{\frac{\pi ARe}{C_{D_o}}} = K_{LD}\sqrt{\frac{AR}{\frac{S_{wet}}{S_{ref}}}}$. [4]
- Weight fractions for specific flight segments make use of [4]:
  - Specific Fuel Consumption: $c_{cruise} = 1.38 * 10^{-4}\ s^{-1}$, $c_{loiter} = 1.11 * 10^{-4}\ s^{-1}$.
  - Range constraints: $\frac{W_i}{W_{i-1}} = e^{\frac{-RC}{V\left(\frac{L}{D}\right)_{cruise}}}$.
  - Endurance constraints: $\frac{W_i}{W_{i-1}} = e^{\frac{-EC}{\left(\frac{L}{D}\right)_{max}}}$.
- Fuel weight fraction: $\frac{W_f}{W_0} = 1.01\left(1 - \frac{W_n}{W_0}\right)$, where $\frac{W_n}{W_0} = \frac{W_i}{W_{i-1}} * \dots \frac{W_1}{W_0}$.
- Empty weight fraction: $\frac{W_e}{W_0} = AW_0^C$, where A = 0.97 and C = -0.06. [1]
- Iterative equation based on initial W_0 guess : $W_0 = \frac{W_{crew}+W_{payload}}{1-\left(\frac{W_f}{W_0}\right)-\left(\frac{W_e}{W_0}\right)}$.

SIZING TO CONSTRAINT

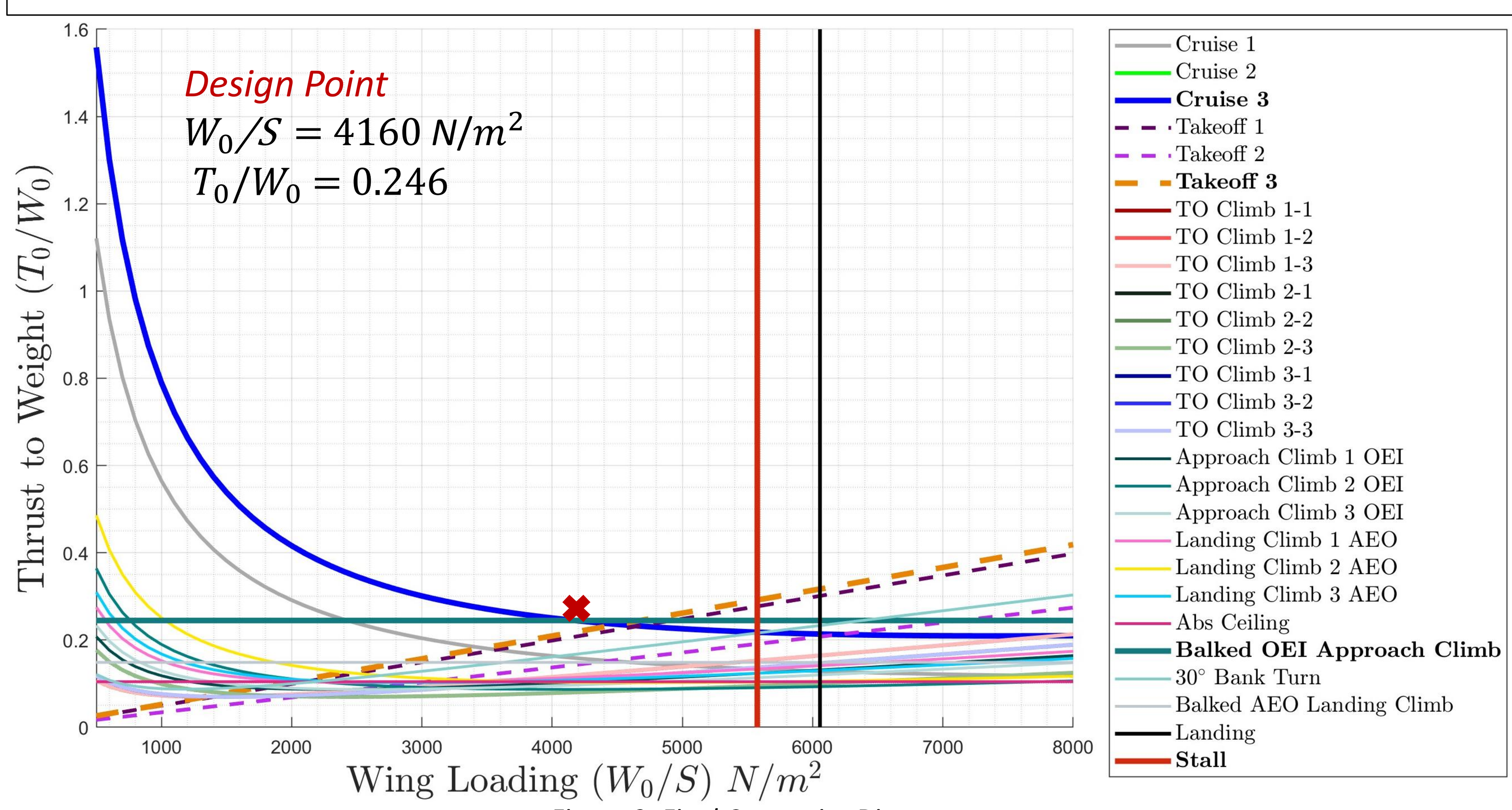


Figure 2: Final Constraint Diagram

POINT PERFORMANCE: Using the Specific Excess Power [3] equation at ISA conditions, all point performances were determined except for absolute ceiling.

$$\left(\frac{T}{W}\right)_0 = \frac{\alpha}{\beta}\left(\frac{1}{V_\infty}\frac{dh}{dt} + \frac{1}{g}\frac{dV_\infty}{dt} + \frac{\frac{1}{2}\rho V_\infty^2 C_{D_0}}{\alpha\frac{W_0}{S_{ref}}} + \frac{\alpha n^2\frac{W_0}{S_{ref}}}{\frac{1}{2}\rho V_\infty^2 \pi ARe}\right) [3]$$

Table 3:Design Process for Point Performance

Mission Segment	Reasoning and Parameters	Assumptions
Take-off and Landing Climb	Take-off climb for twin-engines consists of 3 stages, subjected to minimum climb gradients, dh/dt, of 0%, 2.4% and 1.2% respectively.[5] Similarly, landing climb (AEO) and approach climb (OEI) require dh/dt of 3.2% and 2.1% respectively.[5]	• Instantaneous climb assumed such that the aircraft only operates at minimum climb gradient. • Negligible ground effects.
Cruise	Cruise 1 performed at 25,000 ft as per requirements. Cruise 2 and 3 performed at 36,000 ft from typical values of similar aircraft. $C_{L_{max}}$(clean configuration) = 1.9	• Steady level flight. • Cruise 1 performed at Mach 0.69. • Cruise 2 & 3 performed at maximum speed of Mach 0.75 (to present the most constraining situation).
Absolute Ceiling	Absolute ceiling is at 40,000 ft. Since $T = D_{min}$ at steady level flight, using: $\frac{T_0}{W} = \frac{T}{D_{min}}\frac{1}{1.439\sigma\left(\frac{L}{D}\right)_{max}}$, $\left(\frac{T}{W}\right)_0$ for maximum ceiling is calculated.	• Max ceiling is reached during Cruise 2 and 3. • $\left(\frac{L}{D}\right)_{max_{cruise}} = 0.866\left(\frac{L}{D}\right)_{max}$ • Clean configuration for aircraft assumed.

FIELD PERFORMANCE: Empirical formulae shown below are used to calculate T/O & landing distances.

Table 2:Design Process for Field Performance

Segment	Formula used [3]	Constraints	$C_{L_{max}}$ and V [2]
Take-off	$TOP = \frac{W/S}{(T/W)\sigma C_{L_{max_{TO}}}}$	$TOP_1 = 9576\ N/m^2$ $TOP_2 = 13885\ N/m^2$ $TOP_3 = 9097\ N/m^2$	$C_{L_{max_{TO}}} = 2.1$ $V_{TO} = 1.1V_S$
Landing / Approach	$ALD = \frac{0.51W/S}{\sigma C_{L_{max_L}}}K_R + S_a$	$ALD = \frac{3}{5} * LDA$	$C_{L_{max_L}} = 3.3$ $\Delta C_{L_{max_{HLD}}} = 1.7$ $V_A = 1.3V_S$

FINAL RESULTS AT CHOSEN DESIGN POINT

Table 4: Final results at chosen design point

W_0/S_{ref}	S_{ref}	T_0/W_0	W_0	AR	e	S_{wet}/S_{ref}	C_{D_0}	W_e/W_0	W_f/W_0	$\left(\frac{L}{D}\right)_{max}$	K_{LD}	MAX Range	MAX Endurance
$4160\ N/m^2$	$113.87\ m^2$	0.246	$48288\ kg$	8	0.8	5.007	0.0262	0.508	0.269	19.6	15.5	$7570\ km$	$9.06\ hrs$

[1] Daniel P. Raymer. *Aircraft Design: A Conceptual Approach*. American Institute of Aeronautics and Astronautics. 1992.
[2] Dr. Jan Roskam. *Airplane Design Part I: Preliminary sizing of airplanes*. Roskam Aviation and Engineering Corporation. 1985.
[3] Dr. Errikos Levis. *Sizing to Constraints Lecture Notes*. Department of Aeronautics, Imperial College London. 2022.
[4] Dr. Robert Hewson. *Initial Sizing Lecture Notes*. Department of Aeronautics, Imperial College London. 2022.
[5] Part 25 Airworthiness Standards: Transport Category Airplanes, Code of Federal Regulations. 2022