REGIONAL TURBOPROP AIRCRAFT MODEL AS A BENCHMARK FOR FUTURE CONCEPT STUDIES

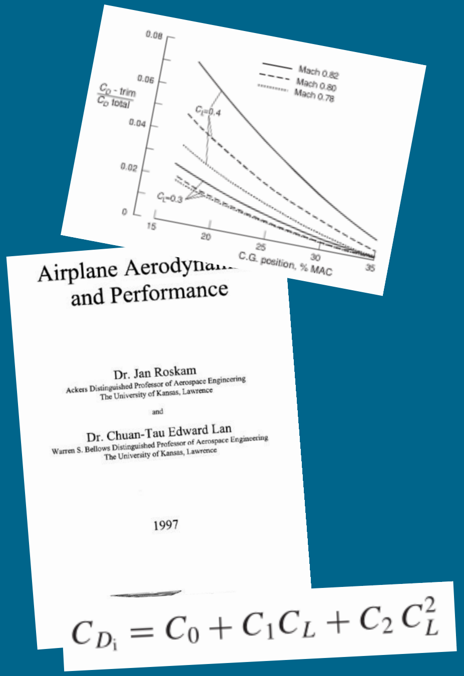
Felix Fritzsche, Simon Müller, G. Atanasov, D. Silberhorn, N. Schneiders, T. Zill

DLR-SL, 20.09.2023, DLRK 2023

DLR

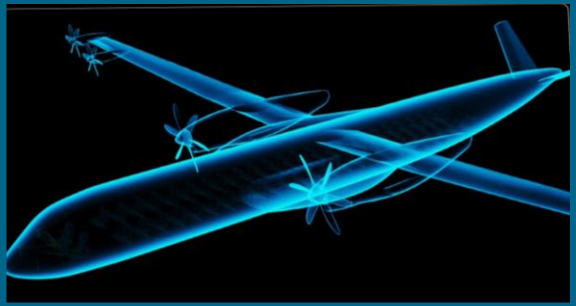
Motivation

Aircraft Design Workflow



Aircraft Design Methods

Existing Reference Aircraft



New Aircraft Design

Flight Crew Operating Manual - FCOM

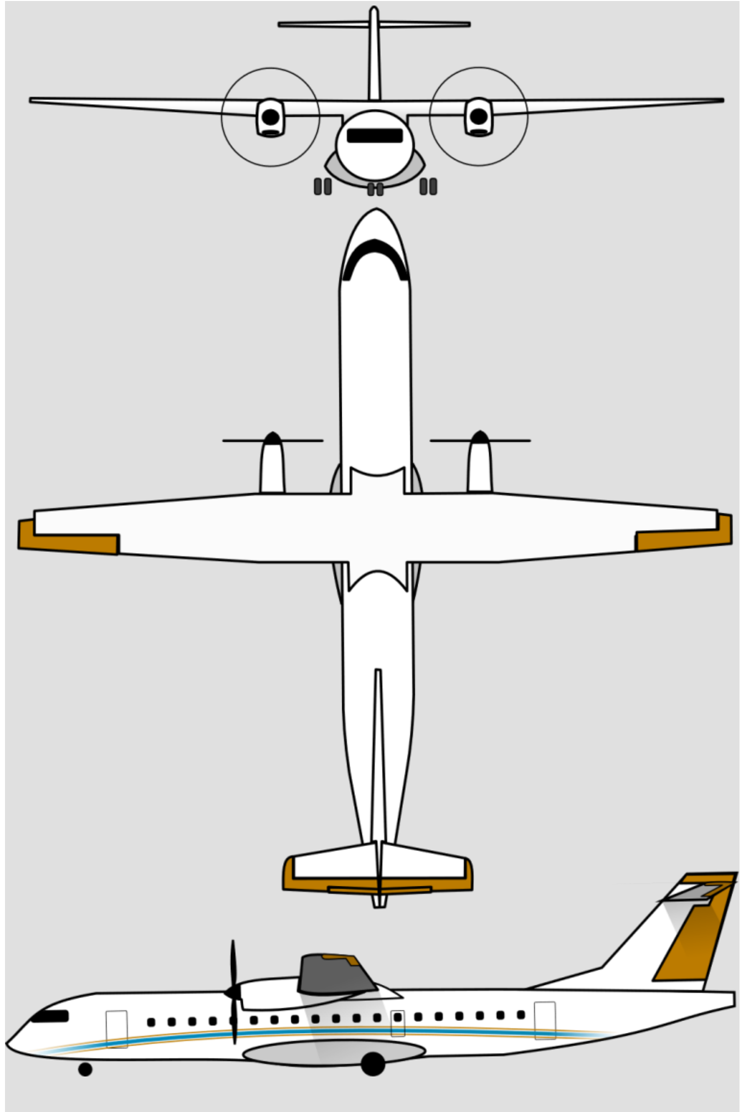
FCOM
Flight Crew Operating Manual

- Issued by manufacturer
- Guideline for safe and efficient use of the aircraft
- Contains In-Flight Performance Data
- FCOMs were used in scientific works
- FCOMs sometimes obtainable on the secondary market

https://www.kleinanzeigen.de/s-anzeige/boeing-737-300-flight-crew-operations-manual-fcom-vol-i-und-ii/2488902637-75-4501

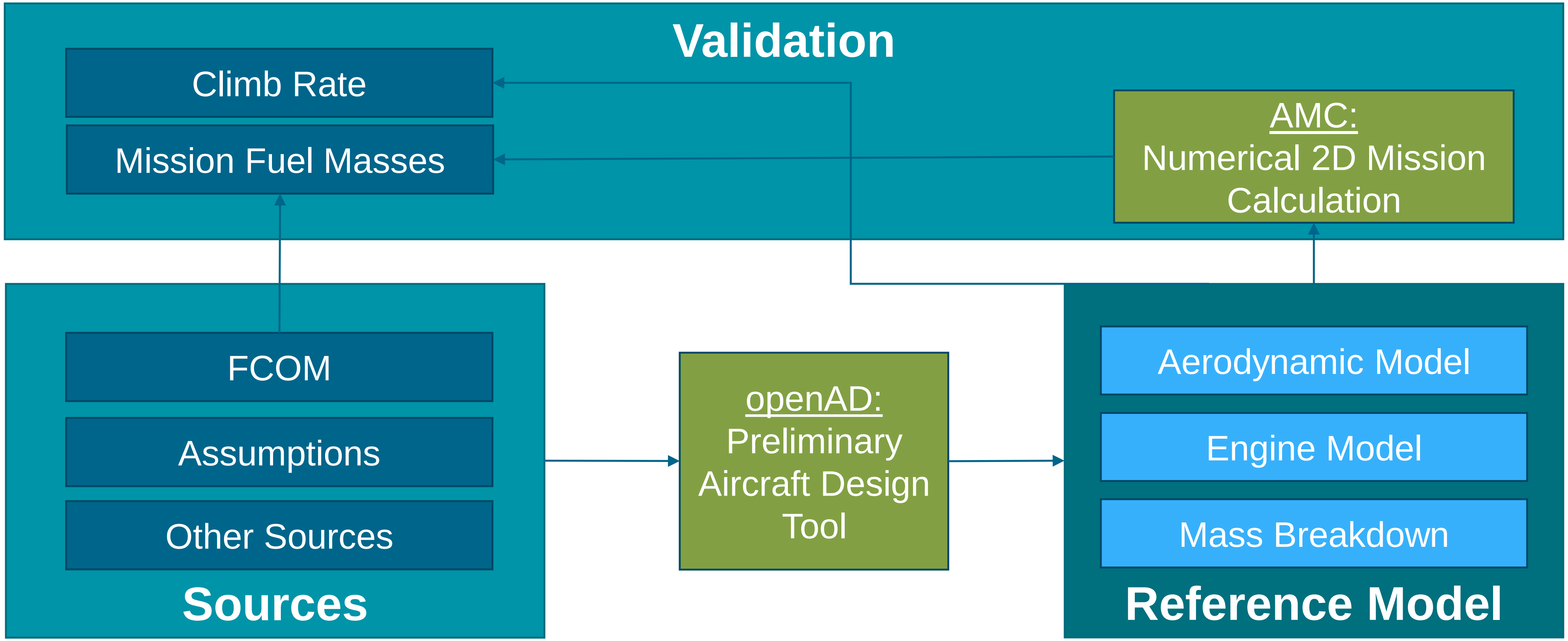
Reference Aircraft

Model	Data
MTOM	~20000 kg
Wing Area	~60 m^2
Wing Span	< 30 m
Design Range	715 NM
Fuselage Diameter	~2.9 m
Passengers	~70
Control Surfaces	Manual, Aero-Balanced
Engines	2x PW100 Family

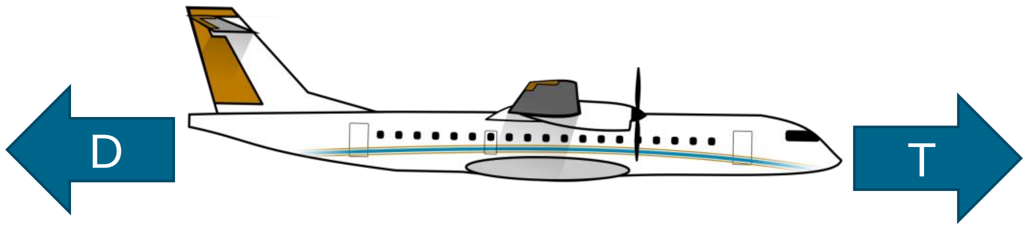


Methods
Overview

Workflow Schematics



Aerodynamic Model Estimation
FCOM Cruise Chart



$$T = D$$

$$P_{Shaft} = (TQ[\%] \cdot TQ_{ref}) \cdot (NP[\%] \cdot NP_{ref})$$

$$T_{Prop} = \frac{P_{Shaft}}{V_{TAS}} \eta_{Prop}$$

Aircraft Weight, 18 T		
	Delta ISA	ISA -10
Flight Level	VIAS/TAS FF, TQ, NP	
60		170/190 kts 200 kg/h/Eng 76.5%, 85 %

From Cruise Charts, drag is determined via calculating engine thrust

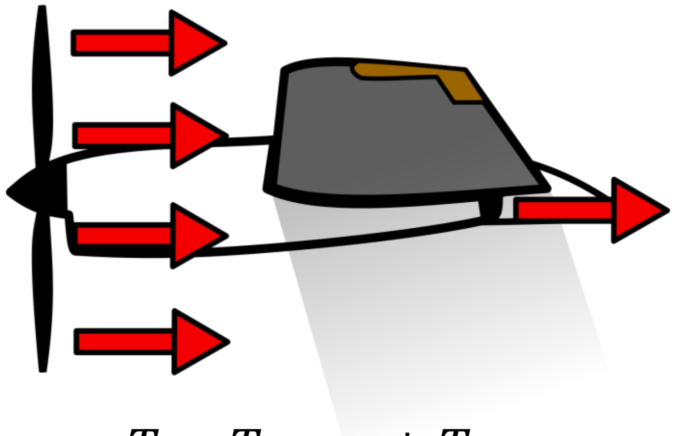
Aerodynamic Model Estimation
Thrust Propeller Model

- Propeller Thrust T_{prop}:
  Tuckenbrodt Model
  - No shock formation at high Mach Number considered
  - No friction: Instead constant loss parameter ζ – 0.8 to 0.9
- Residual Thrust T_{res}:
  2%-10% of Total Thrust T

Two parameters of the thrust model are assumed. These are iterated to find the best combination for model validation.

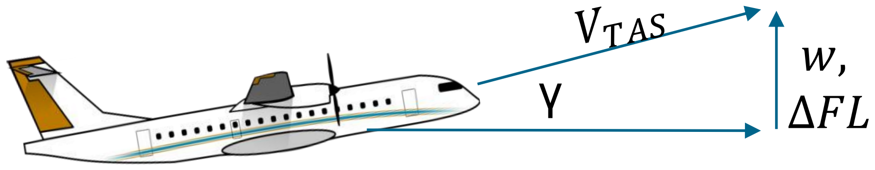
$$\eta_{Prop} = \zeta \frac{2[1 - J^2 \log\left(1 + \frac{1}{J^2}\right)]}{1 + \sqrt{1 + c_s} - 2J^2 \log(1 + \frac{1}{J^2})}$$

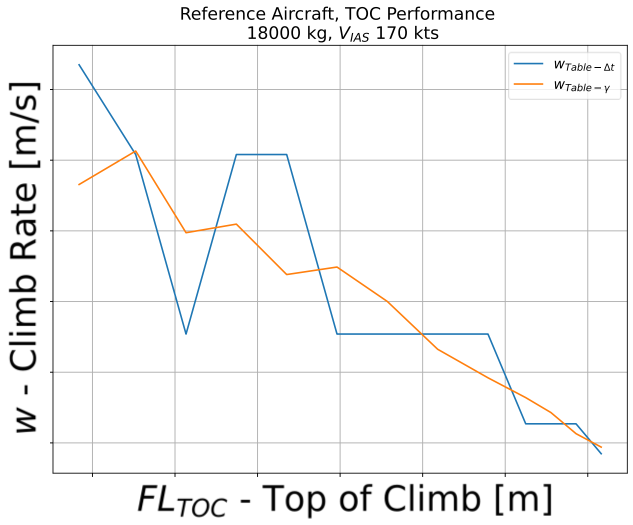
J – *Propeller Advance Ratio*
c_s – *Propeller Disk Loading*



$$T = Tprop + Tres$$

Validation & Engine Model Estimation
Climb Chart





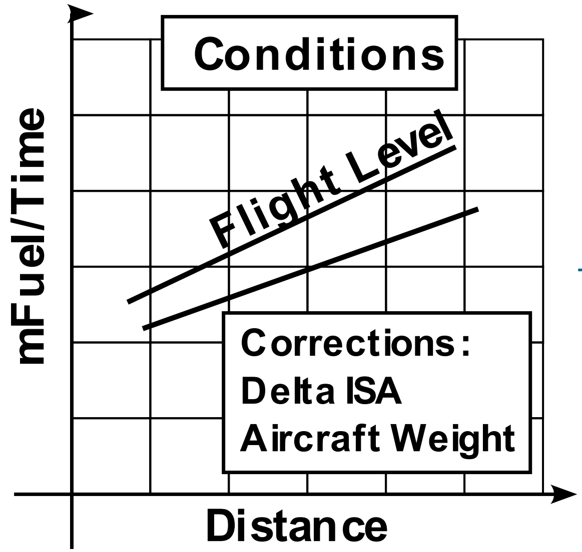
$$w_{table-\Delta t} = \frac{\Delta FL}{\Delta t} \qquad w = \frac{T - D}{G} V_{TAS}$$

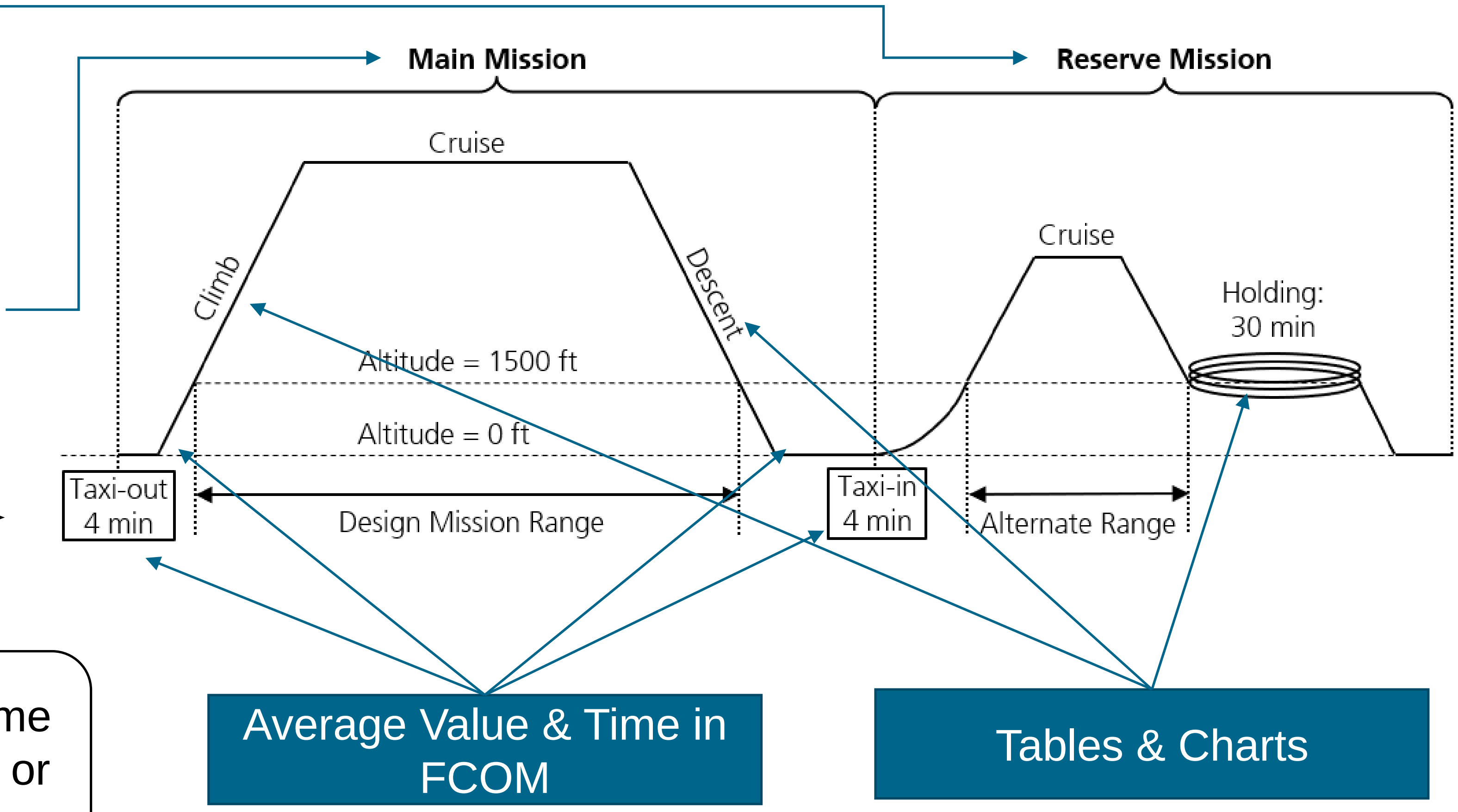
$$w_{table-\gamma} = \sin(\gamma) V_{TAS} = \sin(\tan^{-1}(\frac{\Delta FL}{\Delta d}))$$

Airspeed		
	Aircraft Weight at BOC	17 T
Flight Level 15	tsc, dsc, mFsc, VTAS	5 min, 15 NM, 80 kg, 180 kts
		0 min, 0 NM, 0 kg, 0 kts

Climb Rate is calculated from Climb Chart. Used for thrust calculation and drag validation

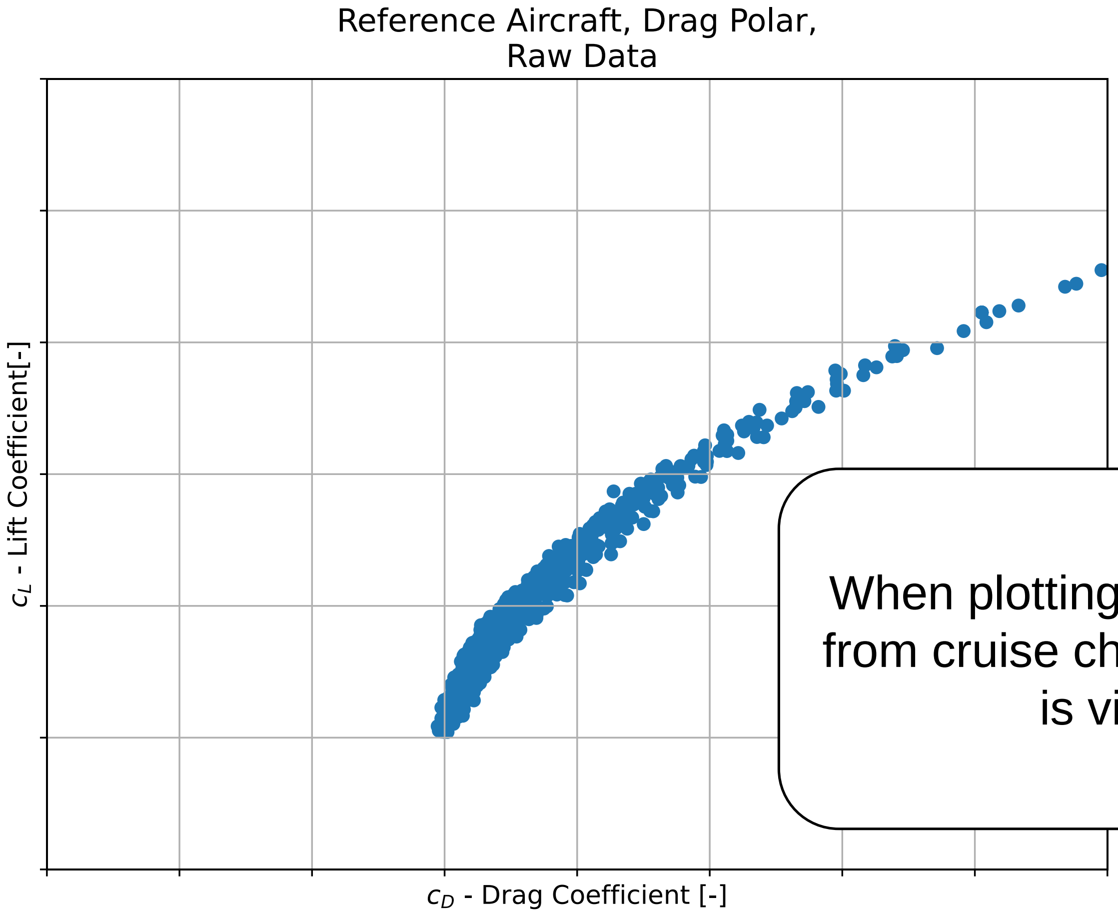
Validation
Mission Fuel Masses





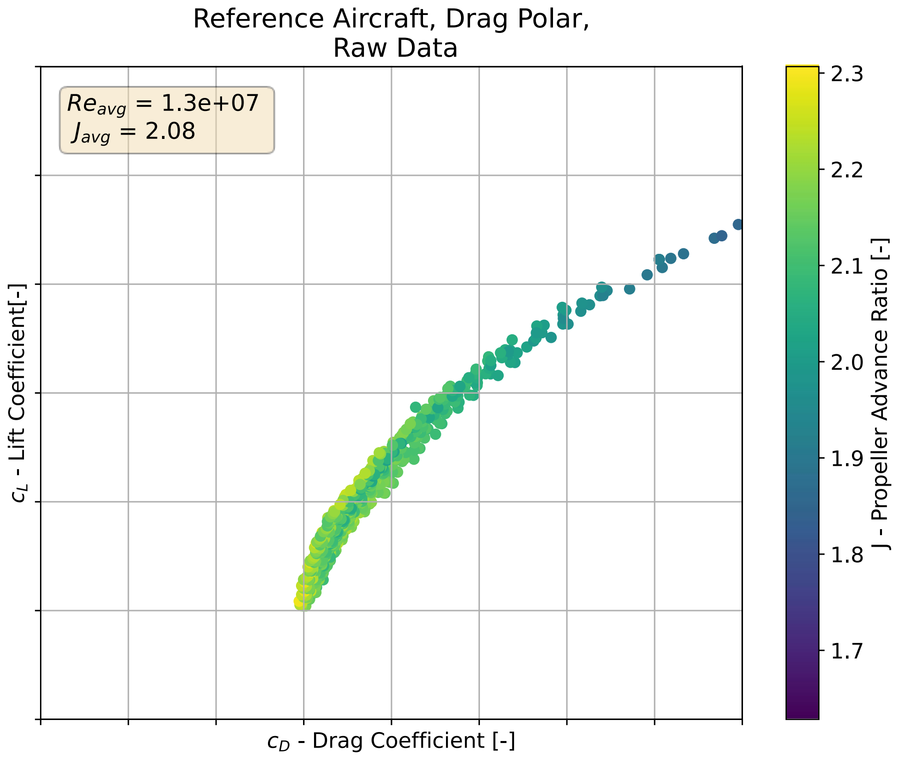
For each mission segment, time and fuel mass can be directly or indirectly calculated.

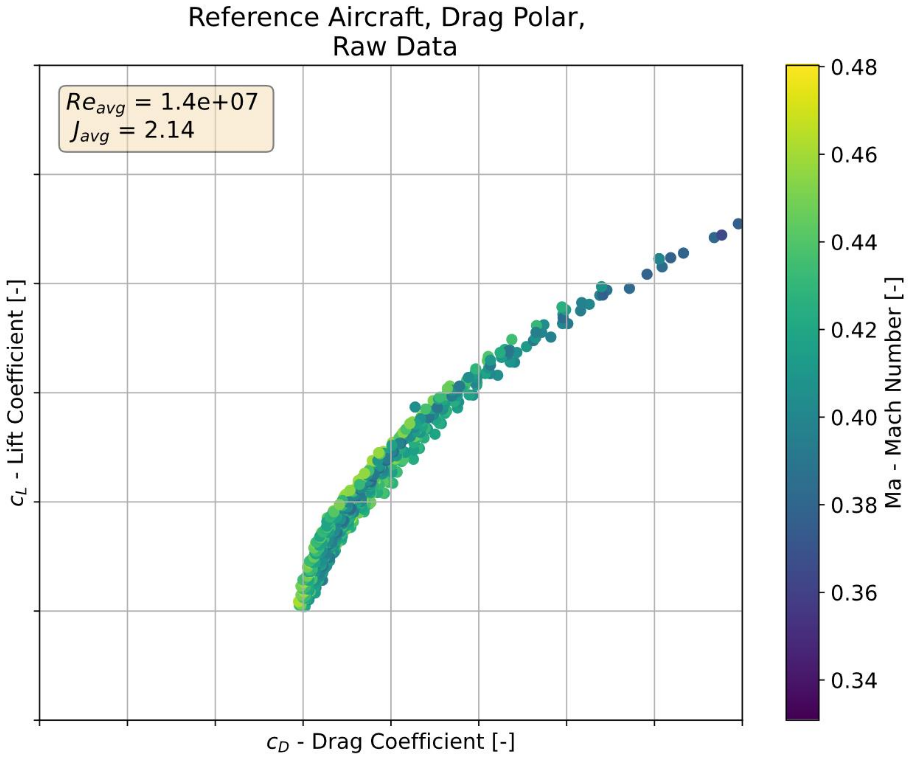
Aerodynamic Model
Raw Data



When plotting the drag polar from cruise charts, scattering is visible

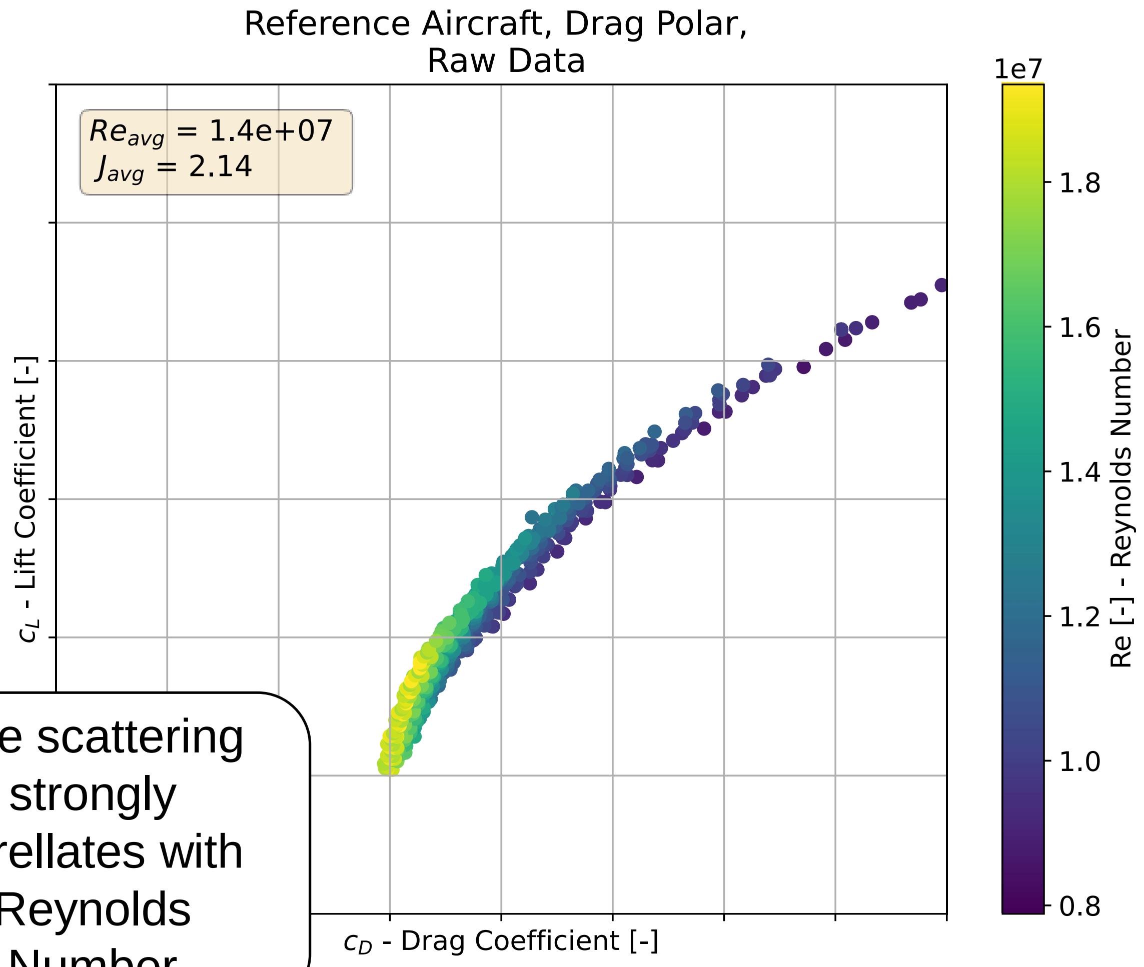
Aerodynamic Model
Data Cleaning



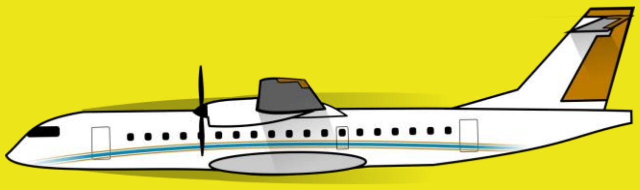


The scattering does not correlate with Mach Number or Propeller Advance Ratio.

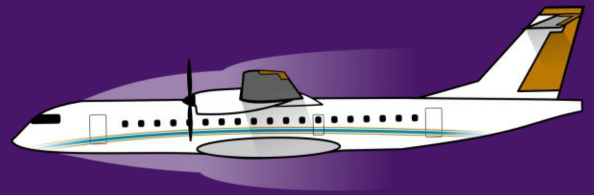
Aerodynamic Model
Reynolds Effect



The scattering strongly corellates with Reynolds Number



High Reynolds Number
Low Displacement Thickness
Low Pressure Drag



Low Reynolds Number
High Displacement Thickness
High Pressure Drag

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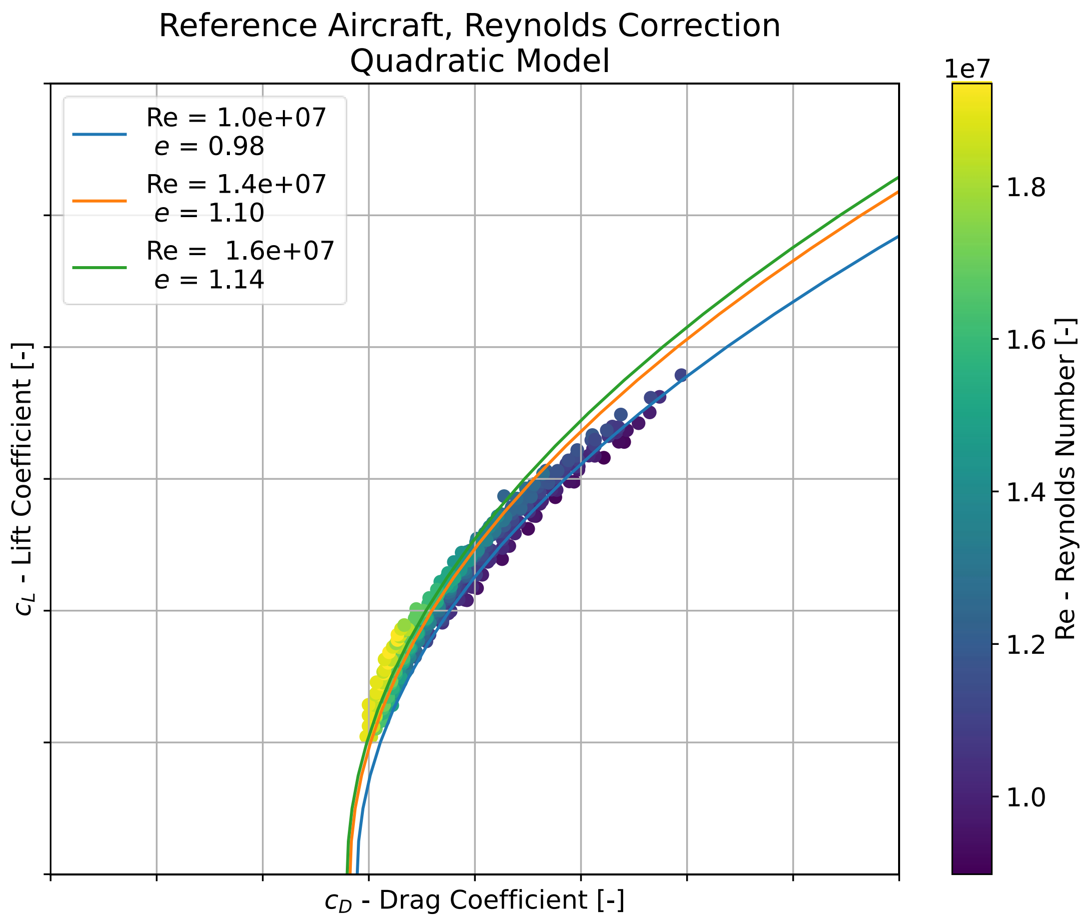
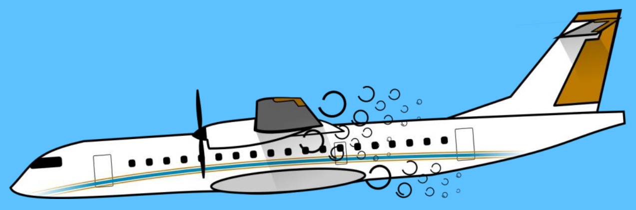
Aerodynamic Model
Quadratic Drag Polar





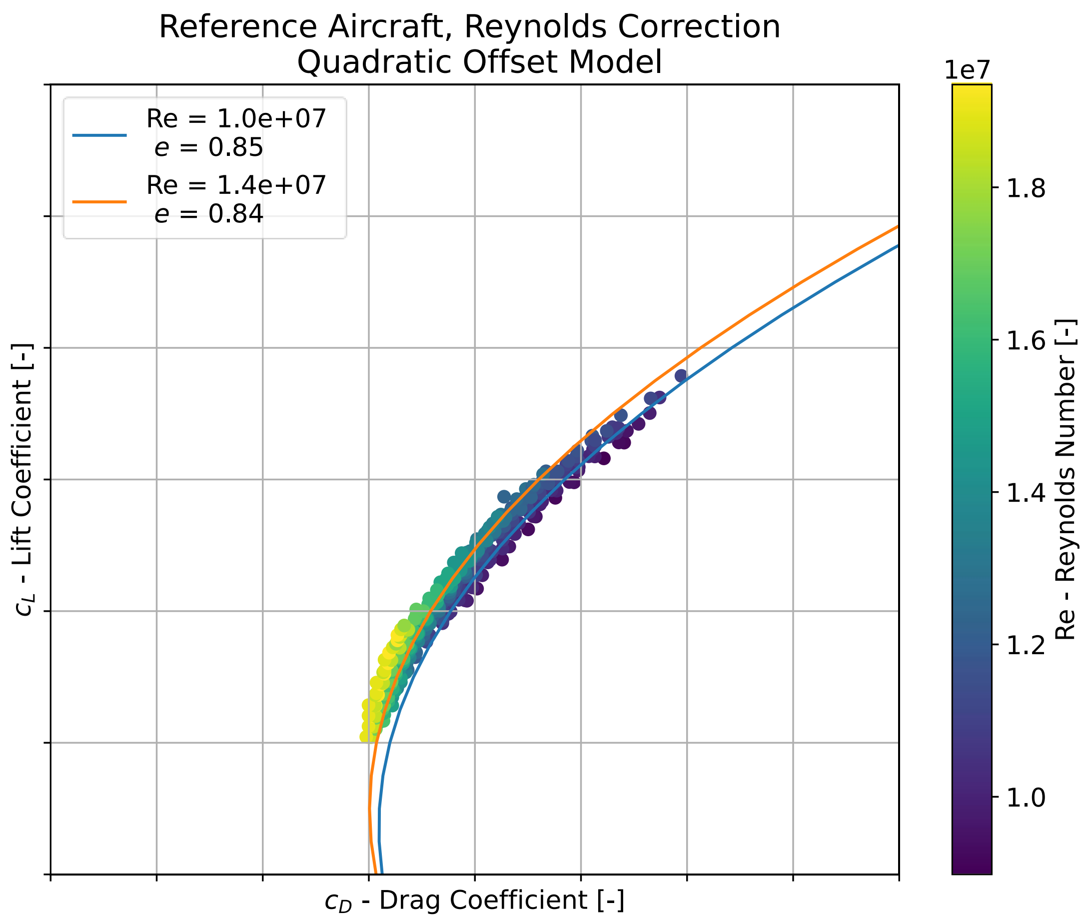
Aircraft unfavourably aligned with airflow at $c_L = 0$

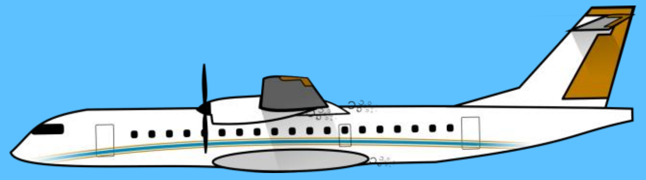
$$c_D = c_{D0} + k c_L^2$$

$$k = \frac{1}{\pi \Lambda e}$$

Fitting a Quadratic Drag Polar to similar Reynolds Numbers leads to unrealistic Oswald values

Aerodynamic Model
Quadratic Offset Drag Polar





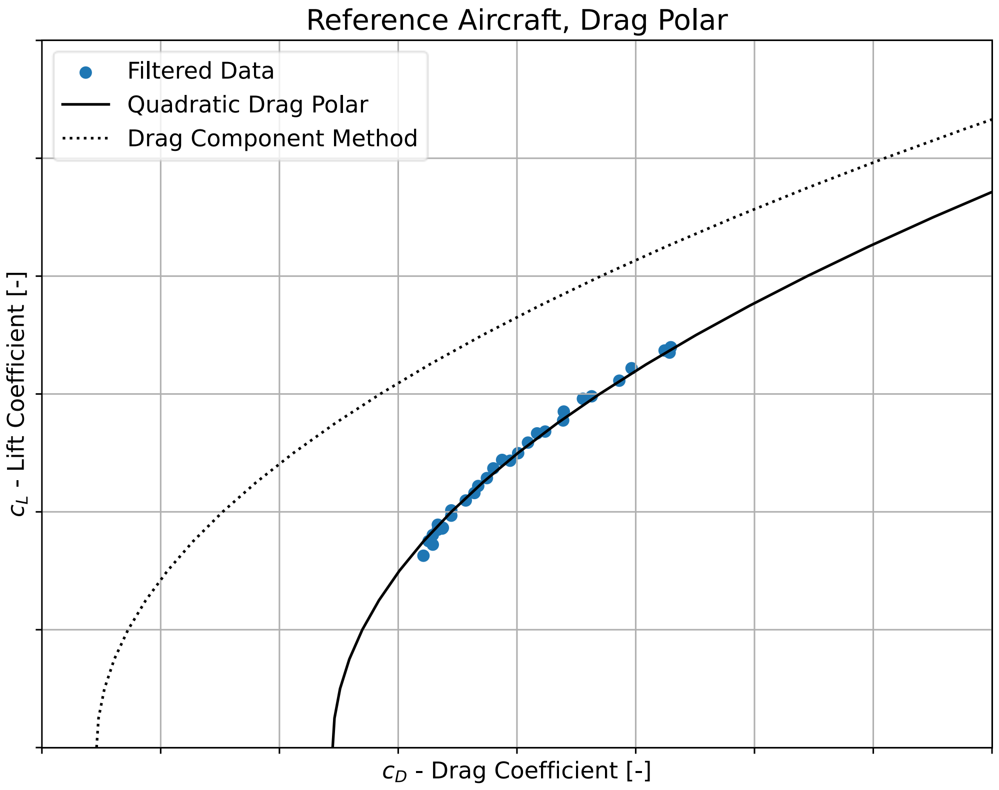
Aircraft better aligned with airflow at $c_L = c_{L,Dmin}$

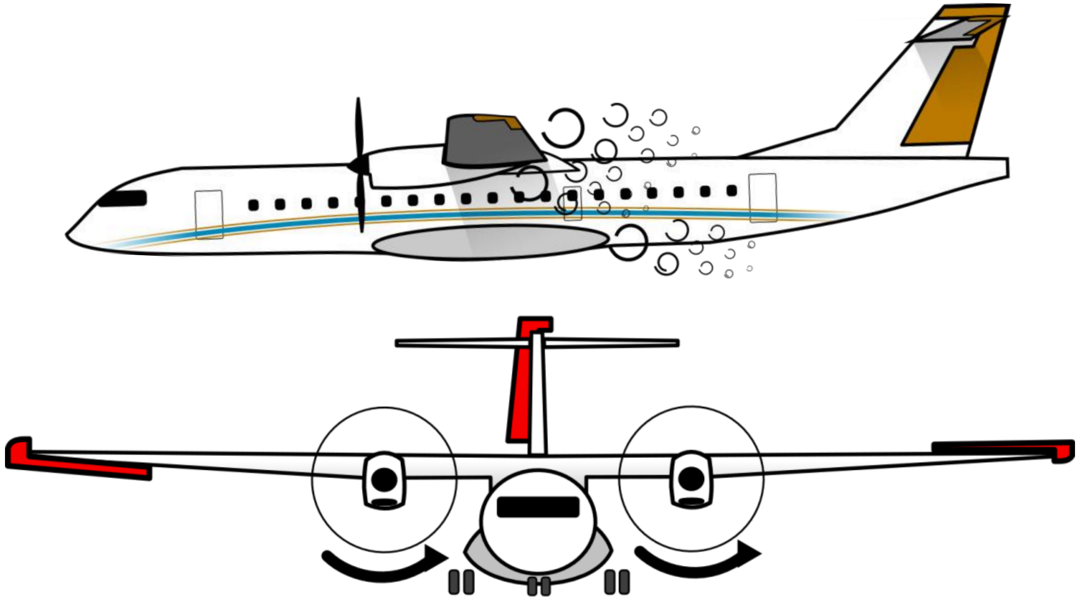
$$c_D = c_{Dmin} + k(c_L^2 - c_{L,Dmin})$$

$$k = \frac{1}{\pi \Lambda e}$$

A Quadratic Offset Model fits better to the data.

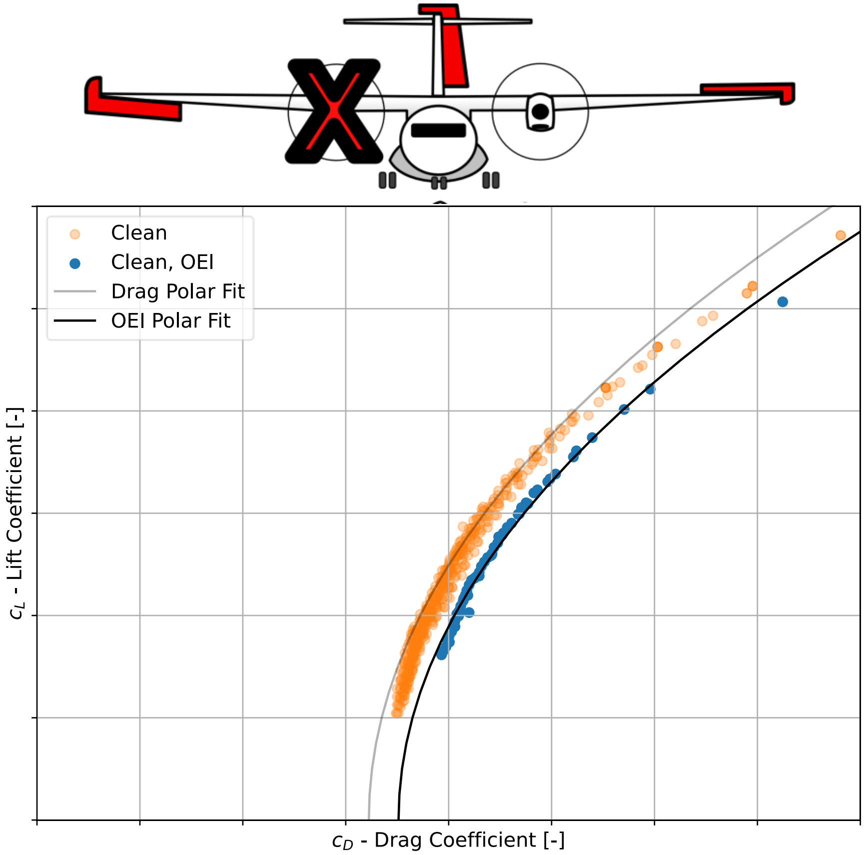
Aerodynamic Model
Final Quadratic Polar

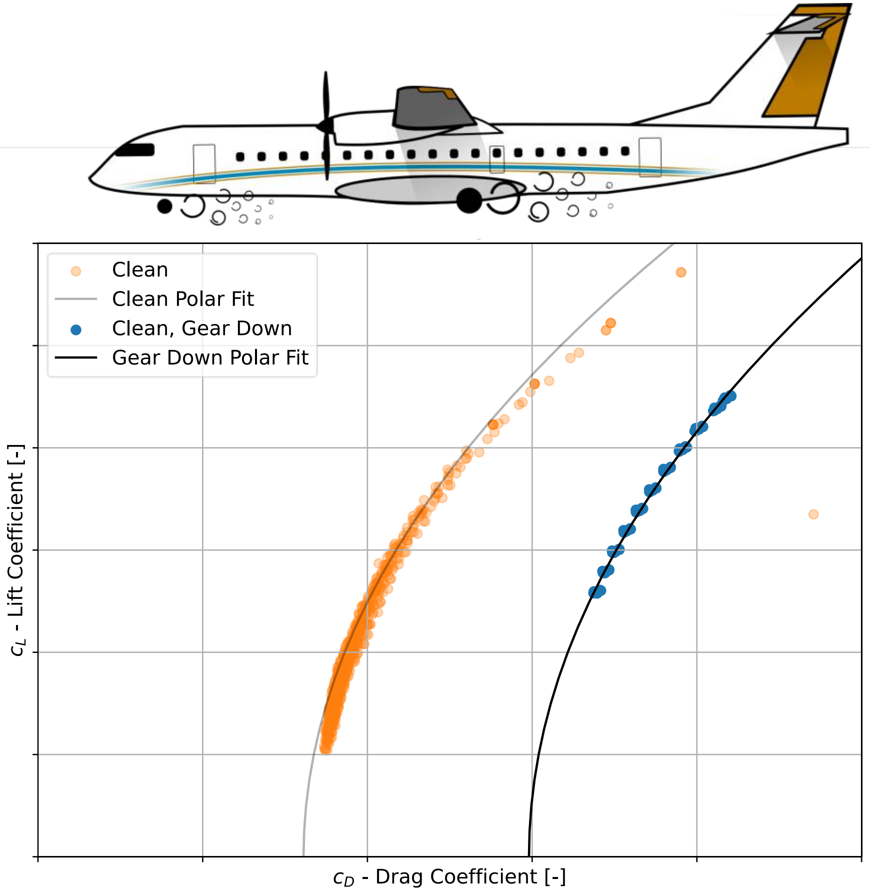




Preliminary Aircraft Design Method underestimates aircraft drag. Probably due to pressure and interference drag from fairings and controls.

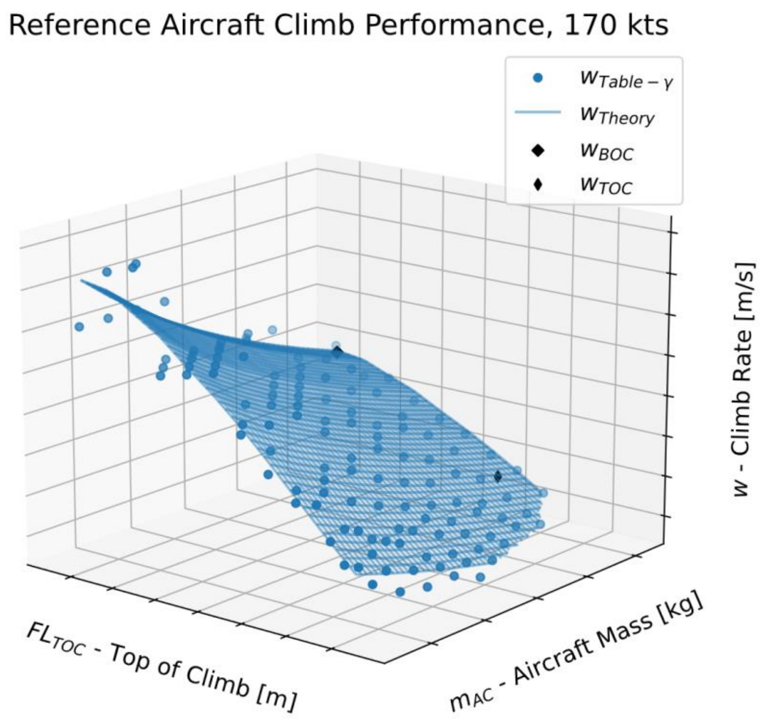
Aerodynamic Model
Special Conditions

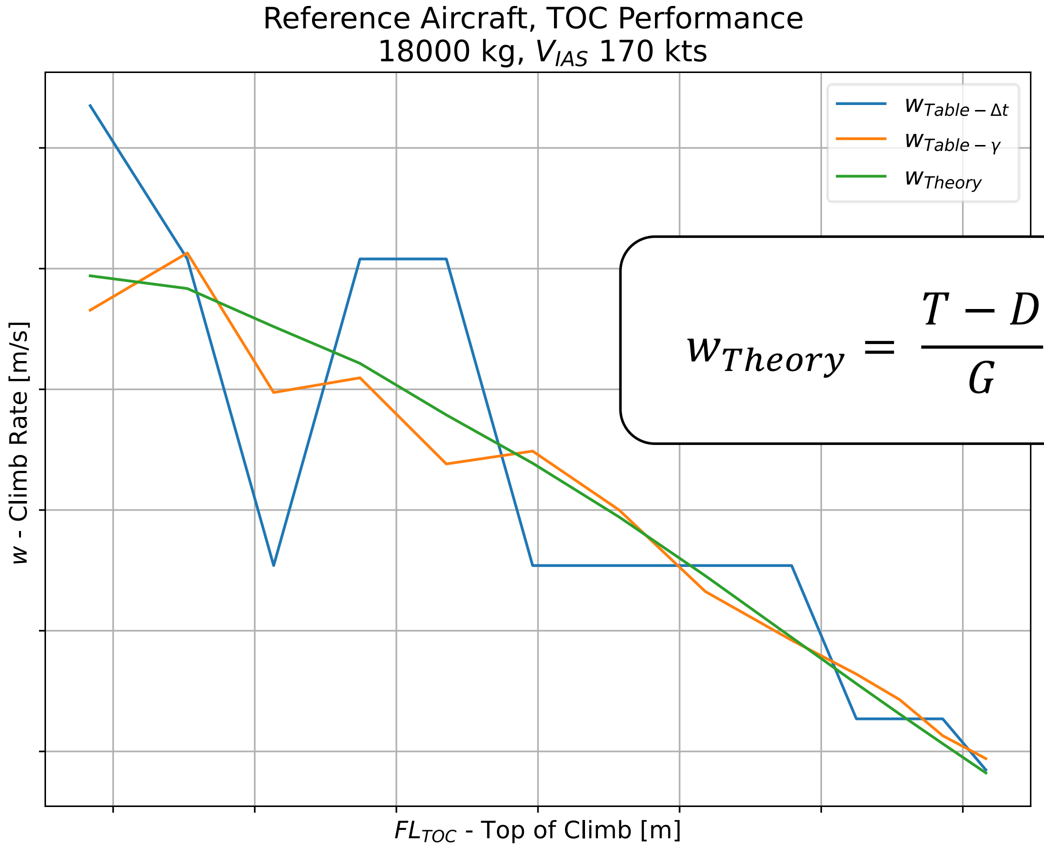




For One Engine Inoperative and Gear Down, drag is increased as expected.

Aerodynamic Model Validation





$$w_{Theory} = \frac{T - D}{G} V_{TAS}$$

The Climb Rate data from the FCOM can be replicated using the generated models.

Summary

- FCOM is a good data source for reference model generation
- A minimum set of assumptions regarding propeller efficiency yields rich aerodynamic and engine data for analysis
- Validation with Climb Rate reconstruction indicates a consistent Aerodynamic and Engine Model
- However: Drag/Mass Breakdown needs to be done „by hand“.

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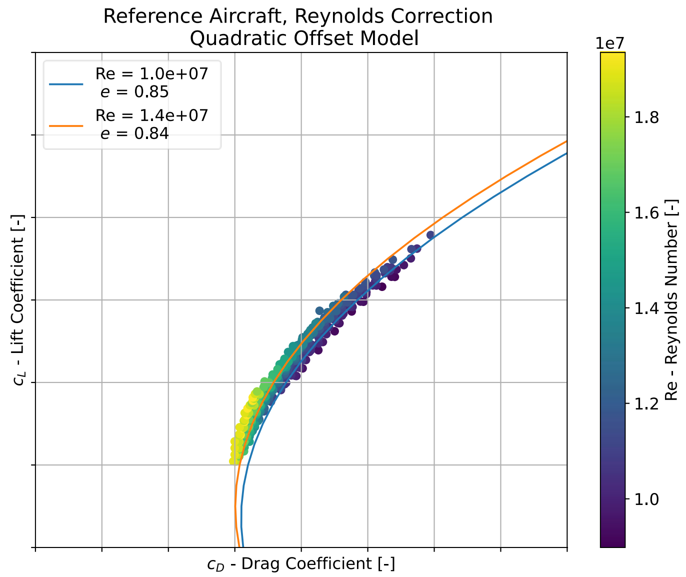

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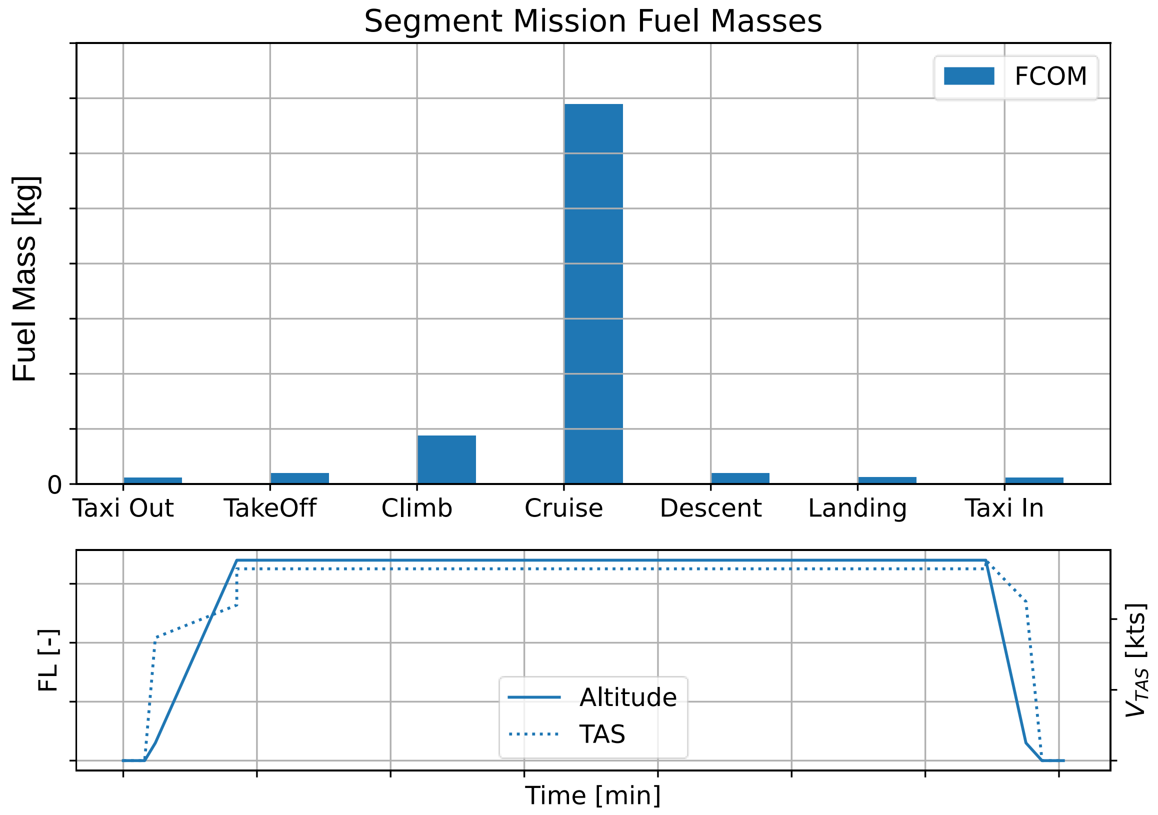
Outlook

- Mission Segment Fuel Mass Validation
- Apply method to other members of an aircraft family
- Use Reference Model for sensitivity analysis



Imprint

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Author:	Felix Fritzsche
Institute:	DLR-SL
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