Mission analysis

Wednesday, August 30, 2017 14:12

For the glory of God

Introduction

- Let's say you are expected to design a new aircraft. What shall you do?
  - Requirement analysis : Go over customer's needs and specify the problem.
  - Sizing : Calculate all weight and volumetric parameters for the given requirements.
  - Synthesis : Bring different disciplines together

It is consisted of mission analysis and constraint analysis

Mission analysis

- We are looking for our very first size of aircraft. What is the first thing that we have to do?
  - Answer : Estimate Takeoff gross weight

This is actually available fuel.

$$W_{TO} = W_{crew} + W_{payload} + W_{empty} + W_{fuel}$$

$$= W_{crew} + W_{payload} + \frac{W_{empty}}{W_{TO}} W_{TO} + \frac{W_{fuel}}{W_{TO}} W_{TO}$$

$$\Leftrightarrow W_{TO} - W_{TO}\frac{W_f}{W_{TO}} - W_{TO}\frac{W_E}{W_{TO}} = W_c + W_p$$

$$\Leftrightarrow W_{TO}\left(1 - \frac{W_f}{W_{TO}} - \frac{W_E}{W_{TO}}\right) = W_c + W_p$$

$$\therefore W_{TO} = \frac{W_c + W_p}{1 - \frac{W_f}{W_{TO}} - \frac{W_E}{W_{TO}}}$$; where $W_{Empty} = W_{wing} + W_{fuel} + \cdots$ (Lots of component)

Here,

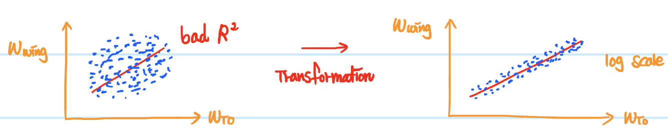
W_{crew} : It will be determined by requirements

$W_{payload}$: It is a sort of carrying something which is also determined by requirements

W_E / W_{TO} : It is typically given from historical data

↳ Then how? Actually, there had been strong empirical correlations between W_E and W_{TO}

e.g.



In doing so, $W_{wing} = b + m W_{TO}$

{ Even if the data doesn't exist, now we can guess it.

$W_{Empty} = \sum W_{components}$

See FWD binder for derivation ↓

$W_{wing} = \alpha W_{TO}^{\beta}$ ($W_{wing} \rightarrow W_E$)

What if there is no historical data at all?

: We may need to estimate a weight for each component and guess W_{TO} and W_E.

→ And then, we can start mission analysis.

W_f / W_{TO} : It is estimated by Mission analysis

1. Determine W_{crew} and $W_{payload}$ from the requirements
2. Estimate W_{empty} from the historical data (If the data doesn't exist, use the RSM)
3. Fuel balance analysis

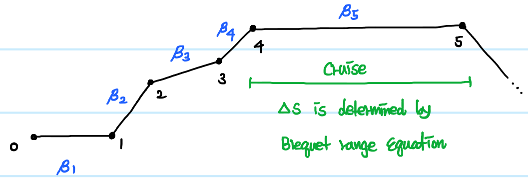
Hence, $W_{TO} = W_{crew} + W_{payload} + W_{empty} + W_{fuel}$

3. Fuel balance analysis

Hence, $W_{TO} = W_{crew} + W_{payload} + W_{empty} + W_{fuel}$

($W_{crew} + W_{payload}$: known) (W_{empty}: known) (W_{fuel}: It will be investigated (Fuel balance analysis))

In terms of 3. Fuel balance analysis,



This is a sort of **mission profile** → It is a description of what aircraft should be able to do in the mission.

; where $\beta_1 = \frac{W_1}{W_{TO}}$ (weight fraction)

- First of all, we will estimate W_{TO} based on the historical data of aircraft that has same mission.
  - W_f / W_{TO} → known
- And then, at every point, we would stop and ask ourselves " How much fuel have I burned ? "
  - we need to know what velocity, altitude, and drag information at every points.
  - we also need to know a set of information with respect to Engine at specific condition.
  - we may need to use an equilibrium state such as Drag = $T_{required}$
  - Finally, we will get ; $\int_0^1 \frac{d}{dt}(W_f) = \Delta W_{fuel}$ (from 0 to 1)

$$\vdots$$

$$\sum_{n=0}^{n} \Delta W_{fuel} = \Delta W_{fuel}(0\to1) + \cdots = W_{fuel,\ required}$$

↑ Total Fuel Required

Repeat it until LHS = RHS ($W_{TO} = W_c + \cdots$) ↑ if we don't know ?

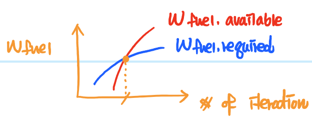
- Let's say we already knew about $W_{fuel,\ available}$ from an analysis. (we need to see volume layout though)
  - However, keep in mind that { For civil aircraft, it usually doesn't care about it because of lots of volumes. / For military aircraft, it will take it carefully because they don't have enough space.
  - Anyhow, we know the value at this point.
- Check Fuel balance { if $W_{fuel,\ available} > W_{fuel,\ required}$: W_f / W_{TO} (W_f → known; W_{TO} → we already estimated it at the first step) → Now, we'll be able to estimate W_{TO}

$$W_{TO} = \frac{W_c + W_p}{1 - \frac{W_p}{W_{TO}} - \frac{W_E}{W_{TO}}}$$

  if $W_{fuel,\ available} < W_{fuel,\ required}$

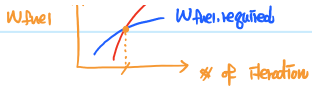
For this case,

1. Take the $W_{fuel,\ required}$ and substitute it into W_f
   $W_{TO} = W_C + W_P + W_E + W_f$
2. Re-estimate W_{TO} ; at this point, we may need to re-think about relationship b/w W_{TO} and W_E
3. Iterate the process to find W_f with new W_{TO}
4. Repeat it until $W_{fuel,\ available} > W_{fuel,\ required}$



; Here, the reason why fuel available isn't constant ?

→ we are still in sizing ! (wing area could be changed)



; Here, the reason why fuel available isn't constant?

→ we are still in sizing! (wing area could be changed)

↳ So that volume can be also changed.

5. Now, we will be able to obtain W_{TO}

Constraint analysis

- Mission analysis will give us β and W_{TO} information so that we can complete the constraint analysis.
- And then, a sized configuration will be determined after synthesis process.

Known values

Takeoff : $\beta_1 = \frac{W_1}{W_{TO}}$; where $\Delta W_{fuel}(0 \to 1) = W_{TO} - W_1$

Climb : $\beta_2 = \frac{W_2}{W_{TO}} \Leftrightarrow \beta_2 = \frac{W_1}{W_{TO}} \frac{W_2}{W_1}$; where $\Delta W_{fuel}(1 \to 2) = W_1 - W_2$

∴ β can be calculated

↳ for example, we might know ΔW_{fuel} at every stage by asking how much fuel did I burn. Also, W_{TO} would be given from the beginning

Breguet range Equation

- Ranges are particularly important to the mission analysis.
  - Sometimes we are required to know the range information.
- Since the dominant section of the civil transport is a cruise, Breguet range Equation could be an envelope of the mission analysis for civil aircraft. (Traditional way)

only valid for cruise section

- However, keep in mind that this is no longer valid in alternative propulsion systems. (such as zero emission aircraft)

weight isn't change because of fuel

- The basic idea is that ; for steady-level flight

The rate of change of the gross weight of aircraft is equal to the fuel weight flow.

- It's the best idea if I can start with TSFC or SFC definition.

$$TSFC \equiv \frac{\text{weight of fuel consumed}}{(\text{unit thrust})(\text{unit time})} = \frac{-\dot{w}}{\text{Thrust}}$$

$$SFC \equiv \frac{\text{weight of fuel consumed}}{(\text{unit power})(\text{unit time})} = \frac{-\dot{w}}{\text{power}}$$

Note that we usually consider ;

- For Jet aircraft, TSFC = const. / SFC = variable
- For Propeller aircraft, SFC = const. / TSFC = variable

It stands for Thrust Specific Fuel Consumption

- Low TSFC = High efficiency
- High TSFC = Low efficiency

e.g. CFM Engine TSFC = 0.55

- Let's derive the Breguet Range Equation from the TSFC definition.

$$TSFC = \frac{-\dot{w}}{T}$$

$$\Leftrightarrow \frac{dw}{dt} = -TSFC \times T$$

Here, for steady-level flight. $T = D = \frac{W}{L/D}$

$$\frac{dw}{dt} = -TSFC \times \frac{W}{L/D}$$

$$\Leftrightarrow \frac{dw}{\frac{ds}{u}} = -TSFC \times \frac{W}{L/D} \quad ; \text{ where } u = \frac{ds}{dt}$$

$$\Leftrightarrow ds = \frac{u\,dw}{-TSFC \times \frac{W}{L/D}}$$

L/D

$$= -\frac{1}{TSFC}\frac{1}{W} u\, L/D\, dW$$

By integrating, we have

$$S_2 - S_1 = -\frac{u \cdot L/D}{TSFC} \ln \frac{W_2}{W_1}$$

$$\Leftrightarrow \Delta S = \frac{u \cdot L/D}{TSFC} \ln \left(\frac{W_{initial}}{W_{final}}\right)$$

⇒ In order for long range flight, TSFC ↓ / L/D ↑ / u ↑

(Good Engine)