Progettazione di veicoli aerospaziali (AA-LZ)

E1. Conceptual Design of subsonic commercial aircraft

7. Design objectives

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Introduction

A brief recap…

The Aircraft Design Process

Multi-Stage

Requirements
Initial Sizing

Conceptual Design

Preliminary Design

Detailed Design

Production

Testing

..Fly!

Multi-Disciplinary

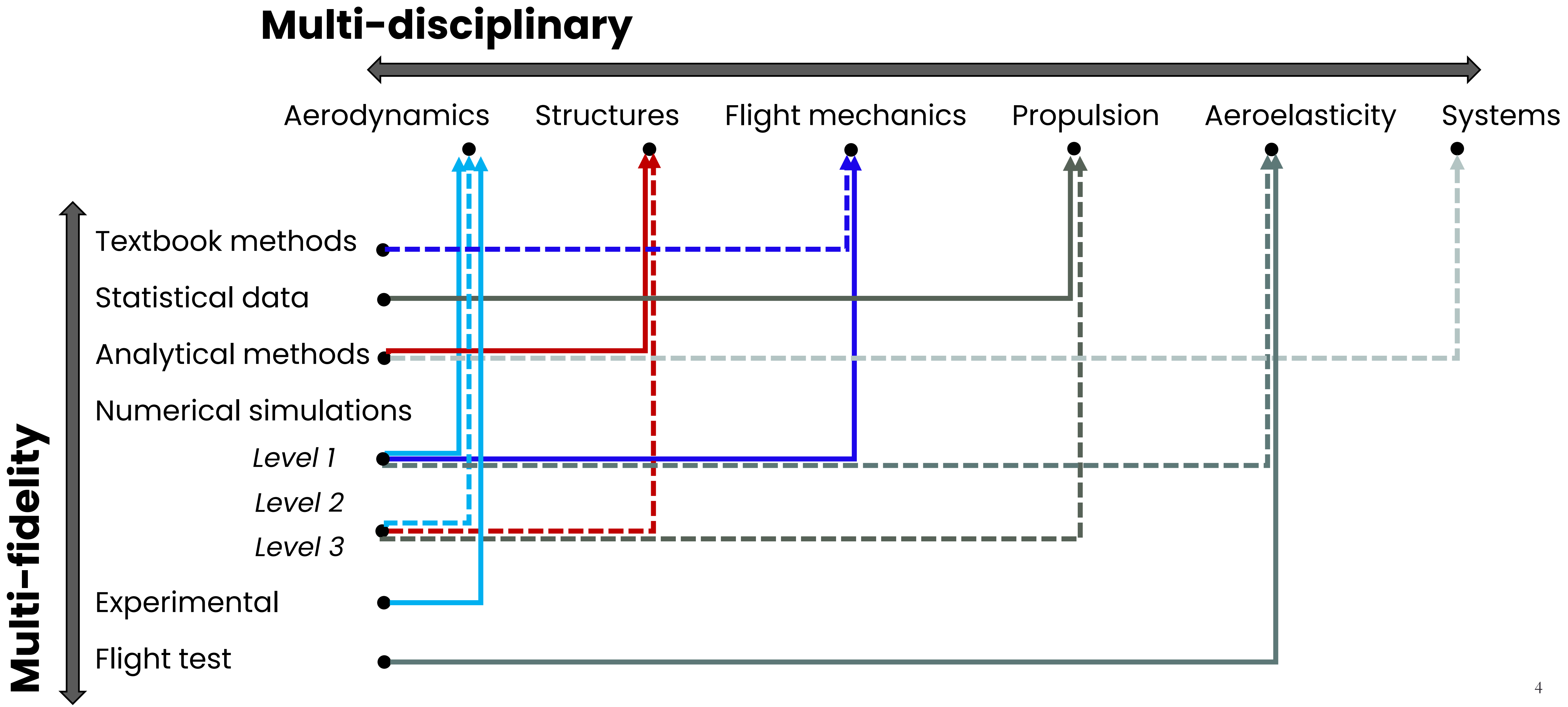
- Aerodynamics
- Structures
- Flight mechanics
- Propulsion
- On-board systems
- Weights optimization
- Payload
- Performance
- Control systems

?

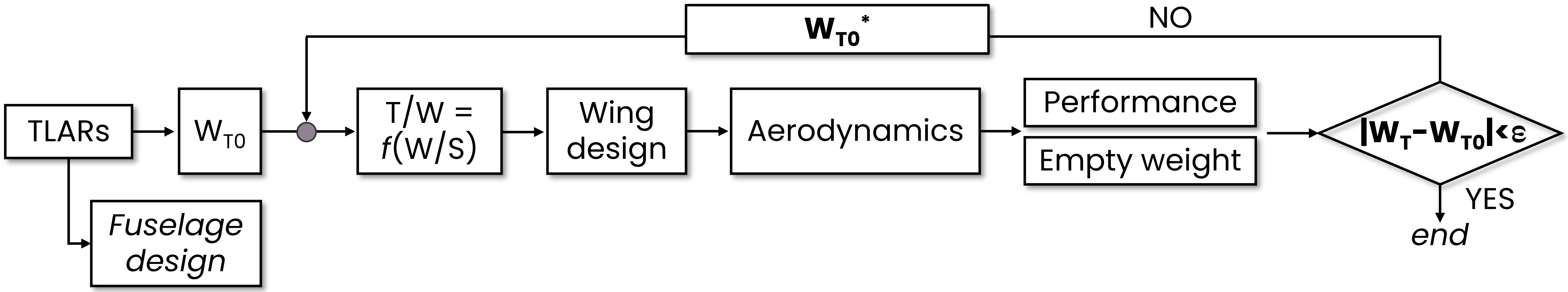
Multi-Fidelity

- Textbook methods
- Statistics/empirical data
- Analytical methods
- Numerical simulations
  - Level 1
  - Level 2
  - Level 3
- Experimental
- Flight test

The Aircraft Design Process



The Aircraft Design Process



Configurations Matrix

Summary of the set of configurations designed

Main configuration features should be inserted in the configuration matrix, e.g.:

Geo: S_{ref}, b, c_r, c_t, Λ, λ, AR, t/c, W/S, $S_{wet\ wing}$, Vol_{tank}, *and others*

Perfo: E_{cruise}, M, m_{fuel}, C_{D0}, C_{Dw}, C_{Di}, C_{dtot}, e, C_{Ltrim}, C_{Lmax}, T/W, T_{max}, *and others*

Weights: MTOW, W_{eo}, W_{wing}, *and others*

Geometry						Weights						Performance						FoMs					
x_1	x_2	x_3	…	…	x_n	w_1	w_2	w_3	…	…	w_n	y_1	y_2	y_3	…	…	y_n	f_1	f_2	f_3	…	…	f_n
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Introduction

Analysing the design results

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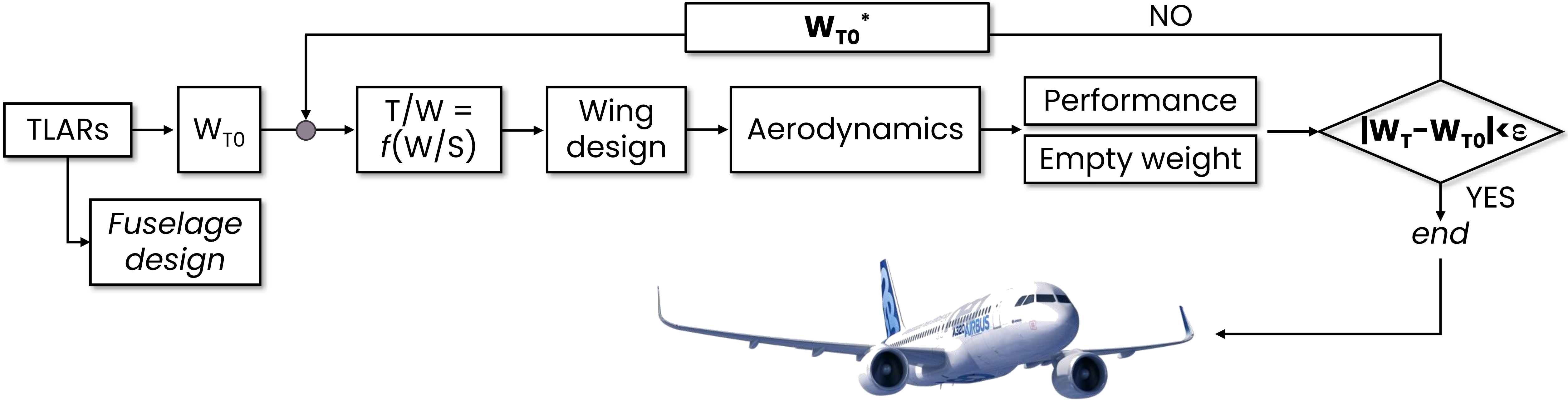
The Aircraft Design Process



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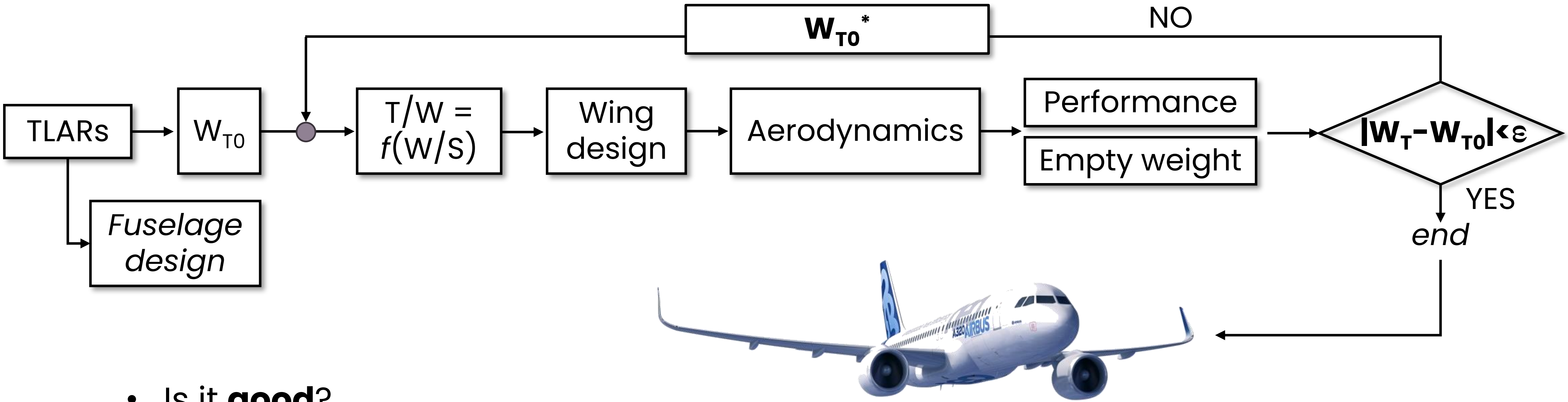
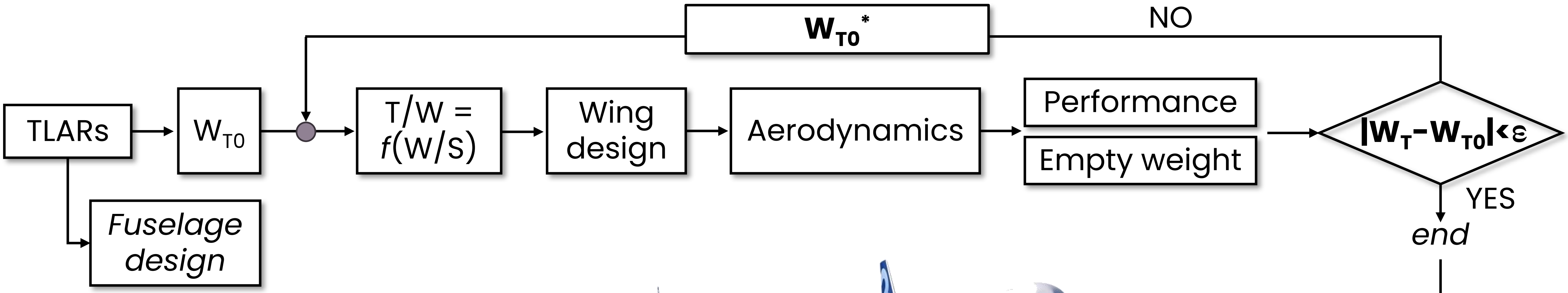
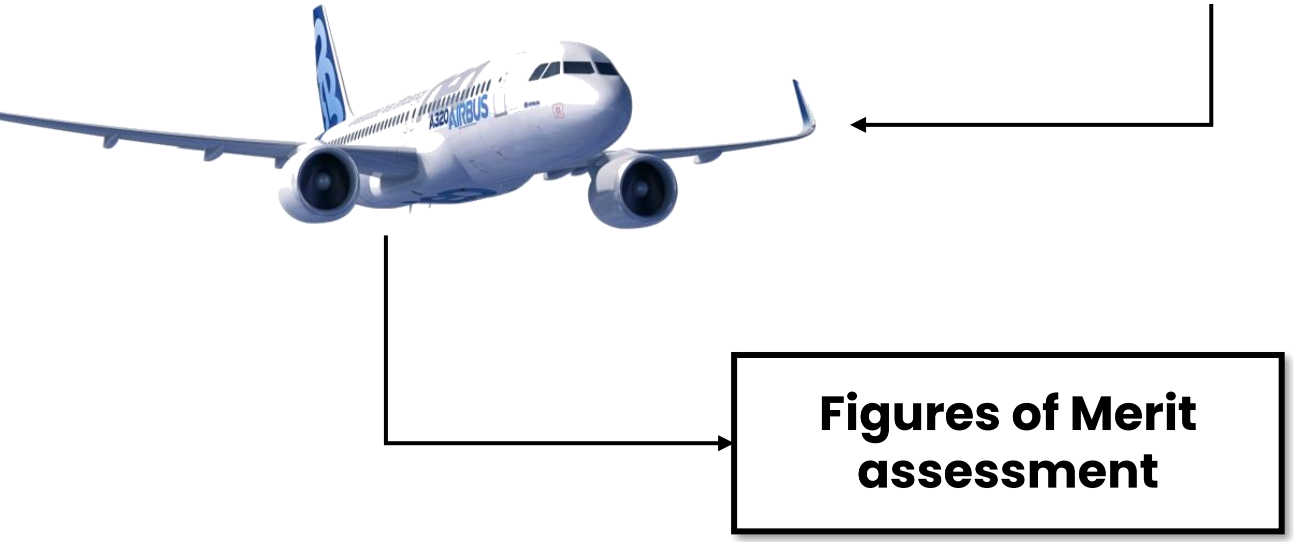


- Is it **good**?
- What does '**good**' means?
- How can I **measure** this 'good'?
- Is my design the **best** one (*'optimum'*)?

Figures of Merit





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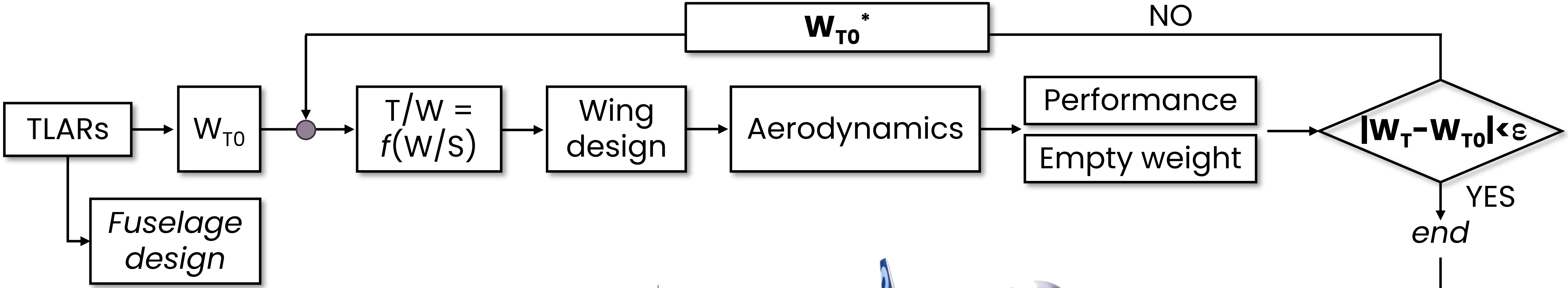

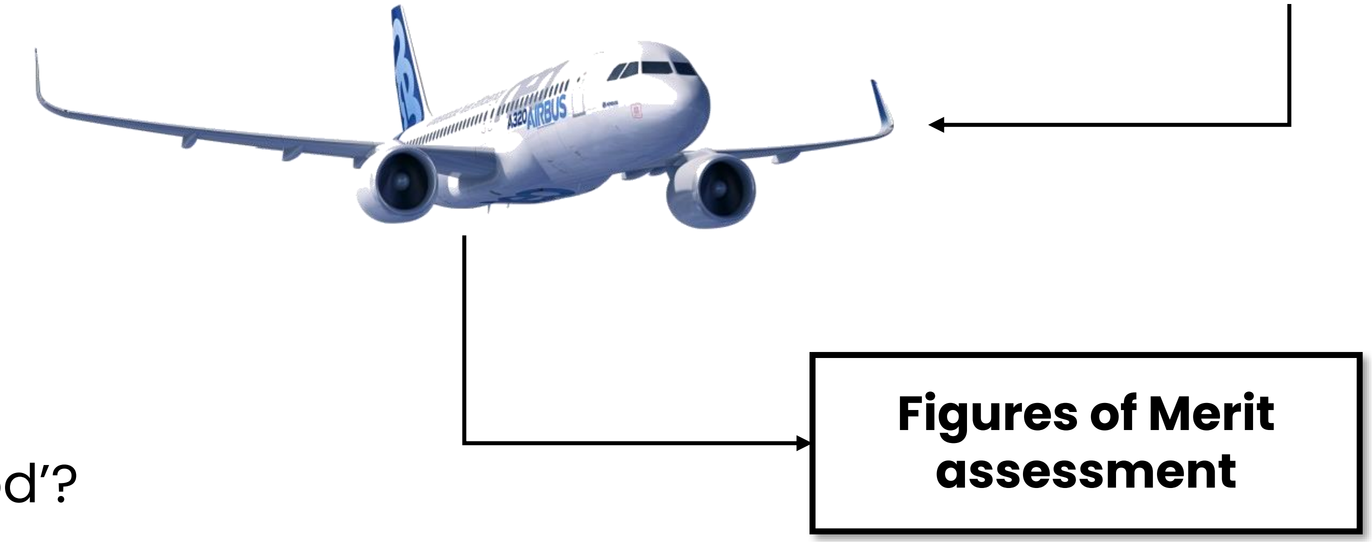

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What are these '***Figures of Merit***'?

Figures of Merit

Let's take a brief digression regarding the concept of 'requirements'.

Top Level Aircraft Requirements: the main objectives that this complex product **must** achieve

Figures of Merit

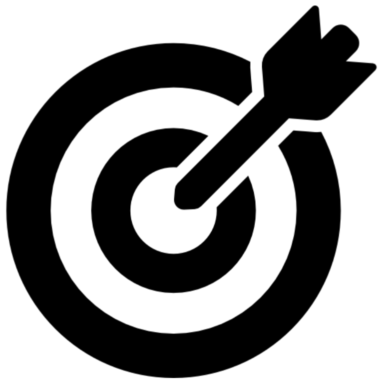
Let's take a brief digression regarding the concept of 'requirements'.

Top Level Aircraft Requirements:

- Payload
- Range
- Cruise Mach
- Wingspan
- Balanced field length
- Landing distance
- *...and others*

the main objectives that this complex product **must** achieve

mandatory targets that aeronautical designers must meet with their final product, i.e., the transport aircraft



Figures of Merit

Let's take a brief digression regarding the concept of 'requirements'.

Figures of merit (FoMs), on the other hand, are particular functions/requirements that must be **maximised (or minimised)** by specifically acting on the different available design levers (i.e., the design variables) to achieve a specific performance.

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FoMs are quantitative metrics that evaluate **how well an aircraft performs** in relation to assigned design goals

Steer and guide design development

Provide a systematic way for quantitative comparison among several diverse design alternatives

Figures of Merit

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FoMs are quantitative metrics that evaluate **how well an aircraft performs** in relation to assigned design goals

- FoMs can include a variety of aspects, such as fuel efficiency, operating capability, economic assessment, environmental impact, social acceptance, etc.

- FoMs support the development and the optimization of concepts by quantifying performance trade-offs

Figures of Merit

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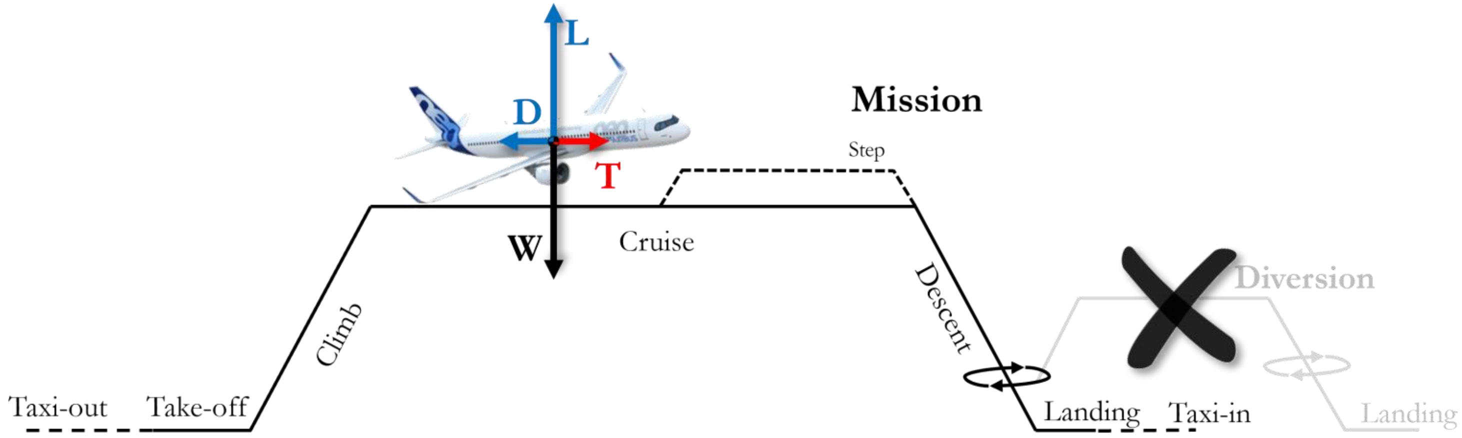
Figures of Merit

FoMs can include a variety of aspects, such as **fuel efficiency**, operating capability, economic assessment, environmental impact, social acceptance, etc.

In this regard, the main FoM is the **block fuel consumption m_{bf}**

The definition **'block fuel'** refers to the total amount of fuel actually consumed during a standard mission, from the start of taxiing until the complete stop at the destination gate. Block fuel includes the fuel used for:

- ***Taxi-out***
- ***Take-off***
- ***Climb***
- ***Cruise***
- ***Descent***
- ***Landing***
- ***Taxi-in***



It does not include reserve fuel, which is carried for contingencies such as diversions or adverse weather conditions.

Block fuel is a key metric for determining the **overall efficiency** of the aircraft, together with its **environmental impact** and the **costs** associated with a specific mission.

Figures of Merit

FoMs can include a variety of aspects, such as **fuel efficiency**, operating capability, economic assessment, environmental impact, social acceptance, etc.

Can we consider **L/D** as a driver FoM?

L/D $\triangleq$ **E** is directly related to fuel consumption:

$$\frac{W_{i+1}}{W_i} = e^{-\frac{c \cdot \Delta x_i}{V \cdot E}}$$

However, it is not fully-representative of the overall fuel consumption, that depends also on other aircraft parameters (e.g. MTOW, engine performance).

In general L/D could be used as FoM steering the aircraft design, but the designer should be aware of the limitations and the risks hidden behind this choice!

Figures of Merit

FoMs can include a variety of aspects, such as **fuel efficiency**, **operating capability**, **economic assessment**, environmental impact, social acceptance, etc.

Can we consider **MTOW** as a driver FoM?

MTOW is traditionally directly related to **aircraft economic performance**. It has also a relevant impact on aircraft mission performance, e.g. fuel consumption.

Conventionally, minimizing the MTOW of the aircraft is a good practice to identify best trade-off solutions, **BUT** the designer knowledge must directly act on the decisional process. Indeed, generally, an aircraft optimized for weight is not leading to minimum fuel consumption.

An improved interpretation could be: “in the case of conventional aircraft, MTOW is a general figure of merit, which if minimized could lead to performance benefits in terms of fuel consumption. In fact, <u>once the aerodynamic is optimized</u>, weight reduction leads to fuel saving.”

In general, MTOW could be used as FoM steering the aircraft design, but the designer should be aware of the limitations and the risks hidden behind this choice!

Figures of Merit

FoMs can include a variety of aspects, such as fuel efficiency, **operating capability**, economic assessment, environmental impact, social acceptance, etc.

In this regard, the main FoM is the **Payload-Range Efficiency PREE**

PREE is a metric that indicates the aircraft productivity, defined as the product of flight distance and payload weight, per unit of energy spent.

$$PREE = \frac{W_{pay} R}{E_{bf}}$$

fuel energy density FED= 12000 [Wh/kg] $(E_{bf} = FED * m_{bf})$

Interpretation: this nondimensional parameter represents the amount of useful work, taken as the work required to transport a unit of payload weight over a unit of distance, extracted per joule of energy consumed.

This metric is traditionally considered as general and overarching of an aircraft performance, especially during the conceptual design phase.

Figures of Merit

FoMs can include a variety of aspects, such as fuel efficiency, operating capability, **economic assessment**, environmental impact, social acceptance, etc.

In this regard, the main FoM is **Direct Operating Costs DOC**

- During the conceptual design phase, **an estimate is performed for all cost components**, and at the end of the analysis, a document known as the Cost Estimating Relationship (CER) is produced.

- The factors influencing the cost of an aircraft are of various natures, such as maximum speed, the level of sophistication of the systems, and the number of aircraft produced; however**, weight remains the most important benchmark** within the same category.

- The following discussion considers **costs from the perspective of airlines**, for which the purchase of the aircraft must generate sufficient revenue to justify the total investment.

Focus on DOC

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In this regard, the main FoM is **Direct Operating Costs DOC**

The operating costs incurred by airlines (**TOC: Total Operating Cost**) are generally divided into two main components:

$$\mathrm{TOC} = \mathrm{IOC} + \mathrm{DOC}$$

IOC: Indirect Operating Costs, associated with the management of the airline and depend on factors unrelated to the aircraft's design and performance characteristics, such as administration costs, office expenses, ticketing costs, etc.

DOC: Direct Operating Costs, that can reasonably **be considered an expression of the effectiveness of the engineering outcomes** achieved and can be used for the selection of the optimal configuration among the possible options.

Focus on DOC

The **DOC** represent how much it costs (in dollars) to transport a passenger per kilometre of route travelled and are defined as:

$$DOC = \frac{TC}{N_{pass} \cdot V_B}$$

TC : costi totali per ora di volo

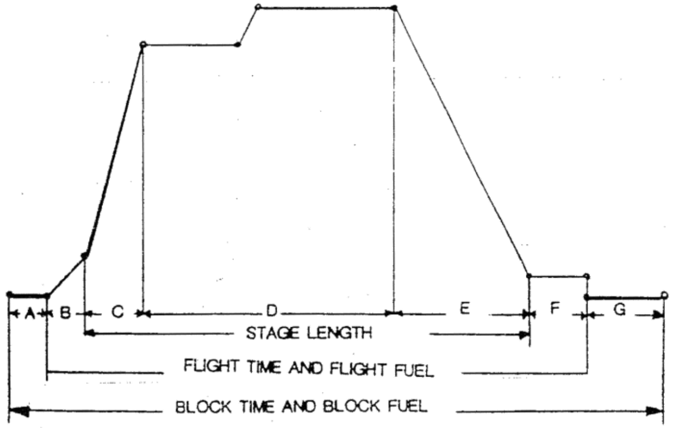
N_{pass} : numero dei passeggeri

$\boxed{V_B}$: velocità commerciale

$$V_B = \frac{R}{Bt}$$

R : lunghezza della tratta (*Range*)

B_t : tempo totale di svolgimento della missione (*Block Time*)



A. Start-up and taxi-out (20 min)
B. Take-off and initial climb to 1,500 ft.
C. Climb from 1,500 ft to initial cruise altitude.
D. Cruise at selected speed and altitude including any stepped climb required (min 4000 ft).
E. Descent to 1,500 ft.
F. 8 min. hold at 1,500 ft including APP and landing.
G. Taxi-in 5 min.

The dependence on **block speed**, rather than on cruise speed, highlights how the DOC are a function of route length. For short routes productivity decreases, increasing the impact of the time spent on ground on the total flight time.

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$$V_B = \frac{R}{Bt}$$

Time → *hrs*

R : lunghezza della tratta (*Range*)

B_t : tempo totale di svolgimento della missione (*Block Time*)

Block time is the total mission time, defined as the time elapsed from when the aircraft "releases the brakes" at the departure airport until it comes to a complete stop at the parking stand at the destination airport.

This is the sum of two components: one dependent on the flight mission FLT_t (Flight Time) and the other a constant, accounting for ground manoeuvres (start-up, taxi-in, and taxi-out). This depends on the length of the route flown by the aircraft.

Short-Medium Range : $B_t = FLT_t + 0.25$

Long Range : $B_t = FLT_t + 0.42$

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From the analysis of the formula, it is noted that to reduce the DOC one can:

- Decrease total costs;
- Increase the number of passengers;
- Increase cruise speed.

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Leads to an increase in weight, resulting in a general rise in costs.

Focus on DOC

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Increases weights, design and manufacturing costs to achieve higher Mach numbers.

Focus on DOC

The **DOC** represent how much it costs (in dollars) to transport a passenger per kilometre of route travelled and are defined as (recap):

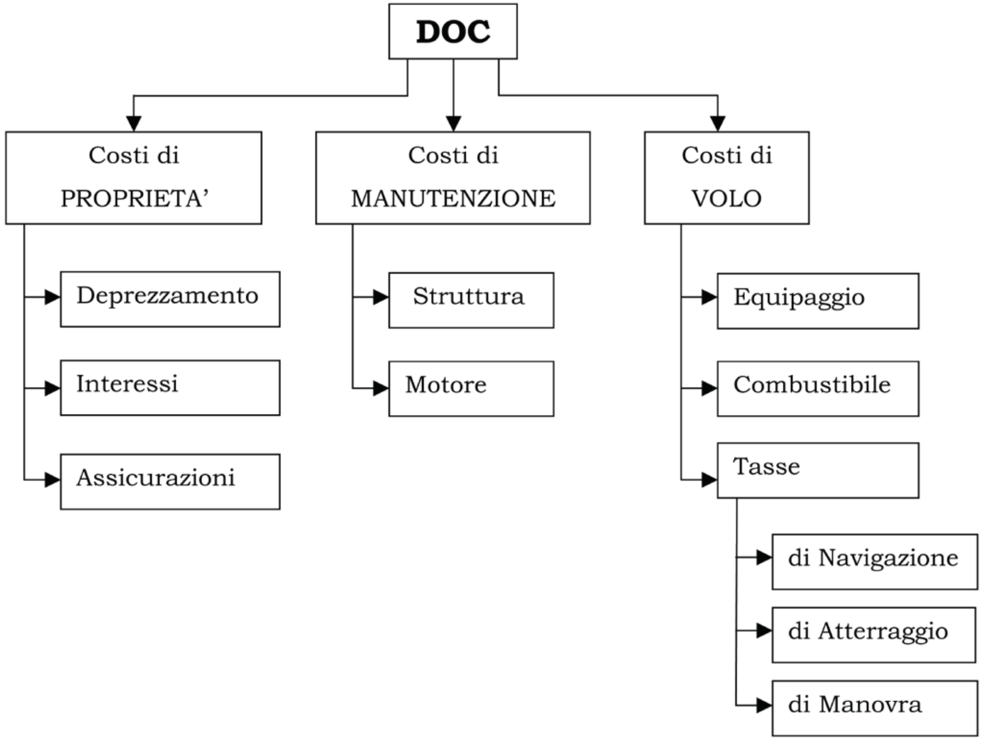
$$DOC = \frac{Costi\ Totali\ per\ ora\ di\ volo}{Numero\ passeggeri \cdot Velocità\ commerciale} \quad \left[\frac{\$}{km \cdot seat}\right]$$

$$DOC = \frac{Flight_{cost} + Ownership_{cost} + Maintenance_{cost}}{Productivity}$$

Focus on DOC

TC breakdown: Total Costs include all expenses associated with the **operation of the aircraft**, divided into ***Ownership (Annual) Costs***, ***Maintenance Costs***, and ***Flight Costs***.

$$TC = CF + CM + CA$$



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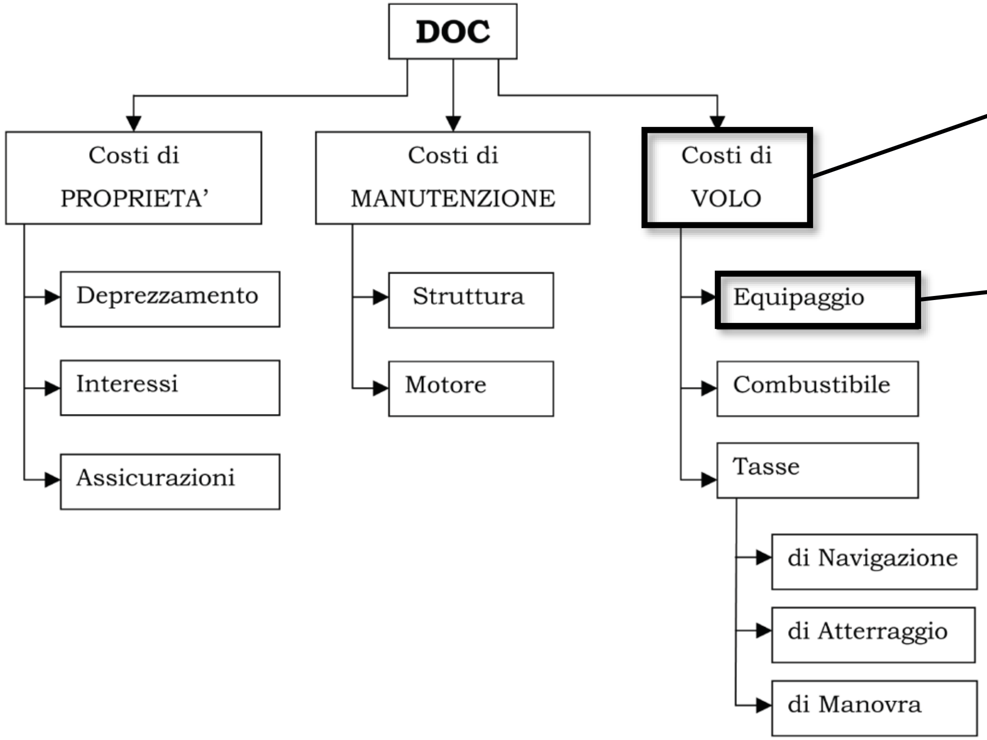


$$CF = CREW\cos t + FUEL\cos t + TAX\cos t$$

$$CREW\cos t = Npil \cdot Cpil + Nass \cdot Cass$$

Cpil : Costo per ogni pilota (315 US$/flt hrs $\boxed{\text{al 1986}}$)

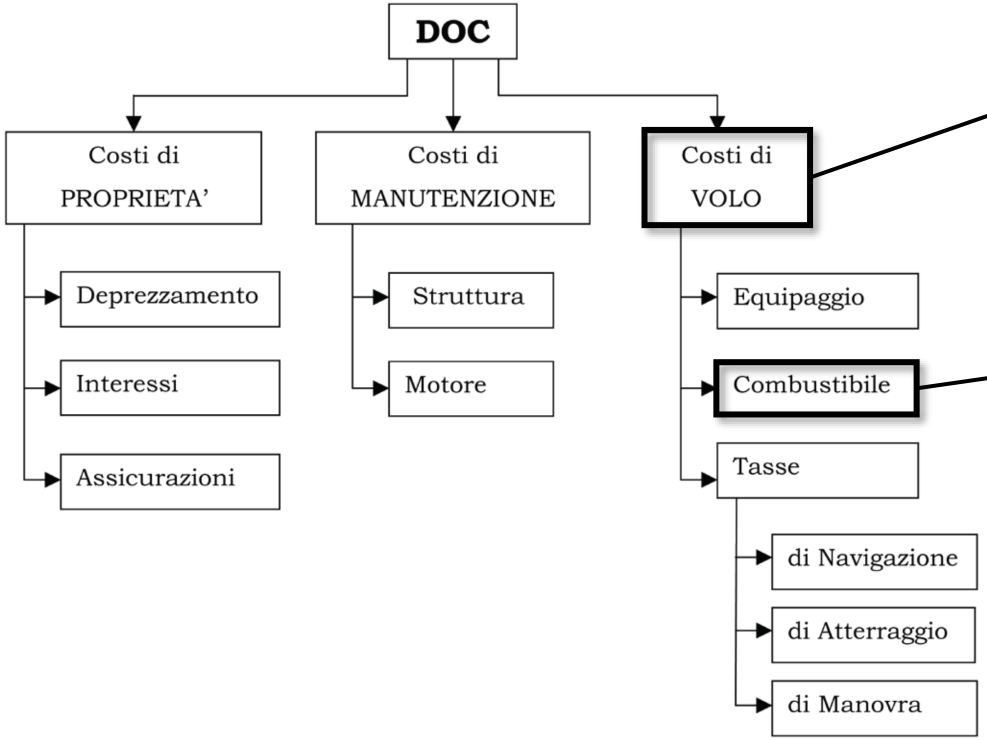
Cass : Costo per ogni assistente di volo (77 US$/flt hrs $\boxed{\text{al 1986}}$)

Conversione al valore odierno: x1,64

Focus on DOC

TC breakdown: Total Costs include all expenses associated with the **operation of the aircraft**, divided into ***Ownership (Annual) Costs***, ***Maintenance Costs***, and ***Flight Costs***.

$$TC = CF + CM + CA$$



$$CF = CREW\cos t + FUEL\cos t + TAX\cos t$$

$$FUEL\cos t = \frac{FP \cdot W_{fuel}}{Bt}$$

FP : Costo del combustibile (0.25 US$/Kg al 2006)

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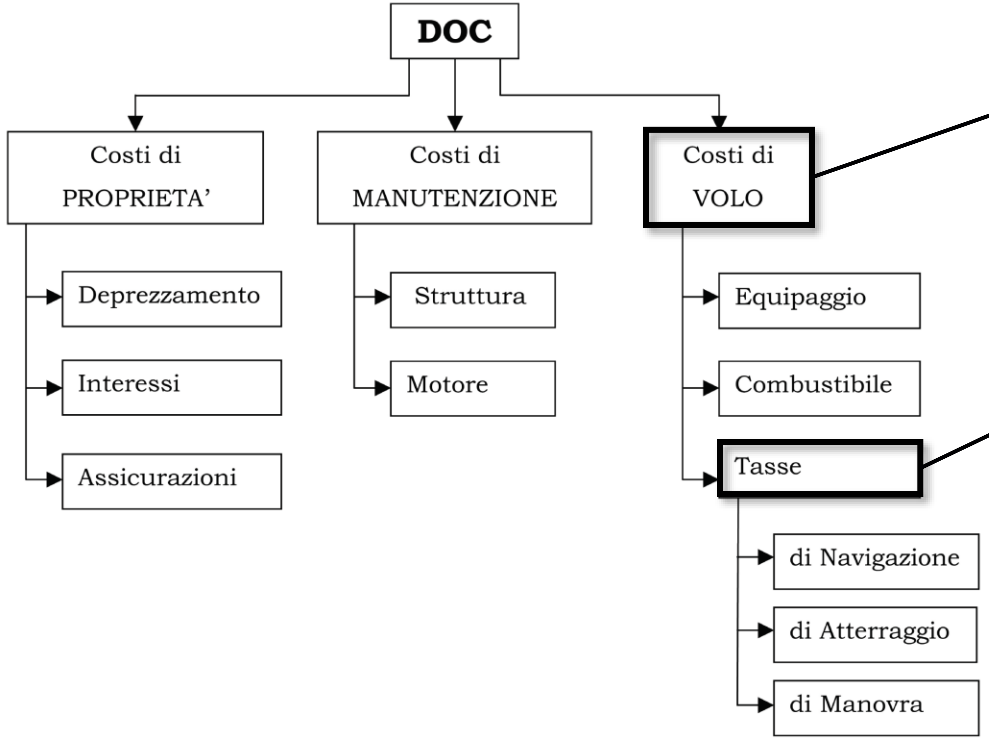

$$CF = CREW\cos t + FUEL\cos t + TAX\cos t$$

$$TAX\cos t = LF + NC + GHC$$

Tasse d'atterraggio : $LF = \dfrac{K_L \cdot W_{TO}}{Bt}$

Tasse di navigazione: $NC = \dfrac{K_N \cdot R}{Bt} \cdot \sqrt{\dfrac{W_{TO}}{50}}$

Tasse di manovra a terra: $GHC = \dfrac{K_{GHC} \cdot W_{payload}}{Bt}$

Weights in [tons]
Range in [km]
Block time [hr]

Tipo di tratta	K_L	K_N	K_{GHC}
Short-Medium Range	7	0.4	93
Long Range	6	0.17	103

Conversione al valore odierno: x1,64

Focus on DOC

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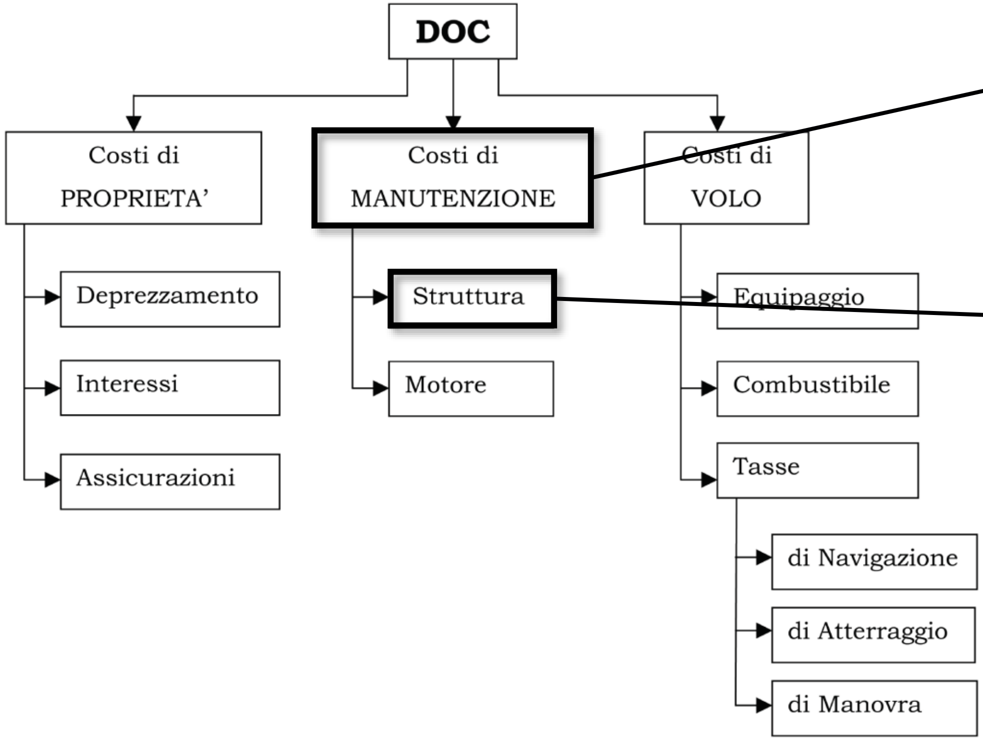
$$TC=CF+CM+CA$$

Weights in [tons]
Thrust in [tons]



$$CM = A_{LABOUR}+A_{MATERIAL}+N_{ENG}\cdot(E_{LABOUR}+E_{MATERIAL})\cdot\left(\frac{FLTt+1.3}{Bt}\right)$$

A=Airframe *E=Engine*

Conversione al valore odierno: x1,64

C_{rma} : Costo orario medio per uomo (55 US$/ flt hr al 1986)

- Costo della manodopera per la manutenzione della cellula (US$/ flt hrs)

$$A_{LABOUR}=\left(0.09\,\boxed{W_{af}}+6.7-\frac{350}{W_{af}+75}\right)\cdot\left(\frac{0.8+0.68\cdot FLTt}{Bt}\right)\cdot\boxed{CRma}$$

- Costo del materiale di ricambio per la cellula

$$A_{MATERIAL}=\frac{(4.2+2.2\cdot FLTt)\cdot(\boxed{ADP}-Neng\cdot\boxed{BEP})}{Bt}$$

W_{af} : Peso della struttura dell'aereo in tonnellate, ovvero il peso a vuoto meno il peso dei motori

$$W_{af}=W_{eo}-N_{Eng}\cdot W_{Eng}$$

BEP : Costo del singolo motore (Bare Engine Unit Price) (MUS$)

ADP : Prezzo di consegna (*Aircraft Delivery Price*)

Focus on DOC

TC breakdown: Total Costs include all expenses associated with the **operation of the aircraft**, divided into ***Ownership (Annual) Costs***, ***Maintenance Costs***, and ***Flight Costs***.

$$TC = CF + CM + CA$$

Weights in [tons]
Thrust in [tons]

- **DOC**
  - Costi di PROPRIETA'
    - Deprezzamento
    - Interessi
    - Assicurazioni
  - Costi di MANUTENZIONE
    - Struttura
    - Motore
  - Costi di VOLO
    - Equipaggio
    - Combustibile
    - Tasse
      - di Navigazione
      - di Atterraggio
      - di Manovra

$$CM = A_{LABOUR} + A_{MATERIAL} + N_{ENG} \cdot (E_{LABOUR} + E_{MATERIAL}) \cdot \left(\frac{FLTt + 1.3}{Bt}\right)$$

A=Airframe *E=Engine*

C_{rma} : Costo orario medio per uomo (55 US$/ flt hr al 1986)

T_{max} : Spinta a punto fisso (SL)

- Costo della manodopera per la manutenzione dei motori (US$/ flt hrs)

$$E_{LABOUR} = 0.21 \cdot \boxed{CRma} \cdot C1 \cdot C3 \cdot (1 + \boxed{T\max})^{0.4}$$

- Costo annuale del materiale di ricambio dei motori (US$/ flt hrs)

$$E_{MATERIAL} = 2.56 \cdot (1 + T\max)^{0.8} \cdot \boxed{C1 \cdot (C2 + C3)}$$

$$\boxed{\begin{aligned} C1 &= 1.27 - 0.2 \cdot BPR^{0.2} \\ C2 &= 0.4 \cdot \left(\frac{OPR}{20}\right)^{1.3} + 0.4 \\ C3 &= 0.032 \cdot Ncomp + K \end{aligned}}$$

$Ncomp$: Numero degli stadi di compressione
K : Funzione del N_{shaft}
BPR : *By-Pass Ratio*
OPR : *Overall Pressare Ratio*

N_{shaft}	1	2	3
K	0.50	0.57	0.64

$N_{comp}=12$
$N_{shaft}=2$
$OPR=32$

Conversione al valore odierno: x1,64

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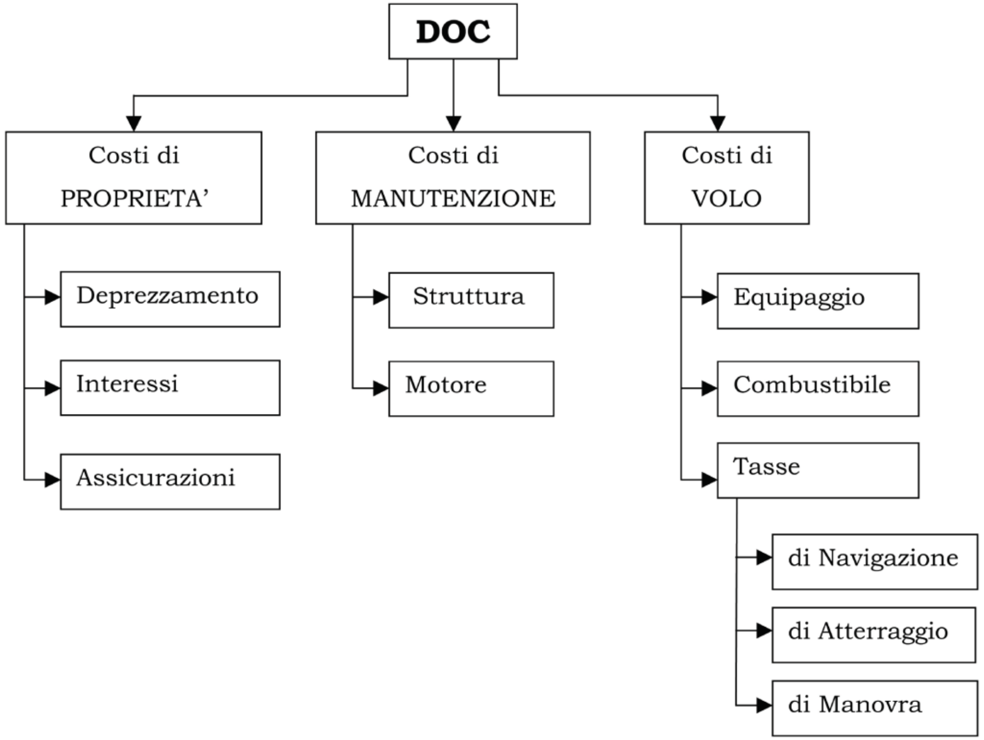

Given data:

ADP : Prezzo di consegna (*Aircraft Delivery Price*)

BEP : Costo del singolo motore (Bare Engine Unit Price) (MUS$)

Figures of Merit

FoMs can include a variety of aspects, such as fuel efficiency, operating capability, economic assessment, **environmental impact**, social acceptance, etc.

In this regard, the main FoM is the **....????....**

Transport aviation provides a **relevant contribution** to the global pollution problems. The environmental impact of the transport aviation is twofold: **degradation of local air quality** and **climate change**.

Environmental impact of transport aviation

Local Air Quality

- Problem confined to the airport areas/regions
- Dominated by Landing and Take-Off cycle (LTO)
- Aircraft ground operations cause air quality degradation
- Direct damage to health (observed increases in cardiovascular/respiratory diseases and consequent increases in premature deaths)

Climate Change

- Worldwide general problem
- Depends on the whole operating mission
- Aviation share ~4% of global greenhouse gas emissions (expected to grow significantly)
- Large-scale effects with catastrophic implications (severe meteorological events, increase food/water shortages, disruption of ecosystems, worsening of the quality of life, rising sea levels, large-scale damage to agriculture, desertification, etc.)

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Figures of Merit

FoMs can include a variety of aspects, such as fuel efficiency, operating capability, economic assessment, **environmental impact**, social acceptance, etc.

In this regard, the main FoM is the:

- **CO_2 emissions:** impact on climate change

$$E_{CO_2} = EI_{CO_{2f}} \, m_{fb}$$

Emission index: 3,16 kg/kg

Block fuel

- **non-CO_2 emissions:** impact on climate change and local air quality

  (i.e. NO_x, HC, SO_2, CO, PM)

Difficult to quantify. Difficult to assess the climate impact. Quite clear the effects on local air quality

Configurations Matrix

Summary of the set of configurations designed

Geometry						Weights						Performance						FoMs					
x_1	x_2	x_3	…	…	x_n	w_1	w_2	w_3	…	…	w_n	y_1	y_2	y_3	…	…	y_n	f_1	f_2	f_3	…	…	f_n
x.xx	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*	*x.xx*
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Configurations Matrix

Summary of the set of configurations designed

Geometry						Weights						Performance						FoMs					
x_1	x_2	x_3	…	…	x_n	w_1	w_2	w_3	…	…	w_n	y_1	y_2	y_3	…	…	y_n	f_1	f_2	f_3	…	…	f_n
x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx
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Parametric Wing Design

Design Variables:

- Reference Surface $\boldsymbol{S_{ref}}$ $\longrightarrow$ $\mathbf{(W/S)_{vect}} = [(W/S)_1\ (W/S)_2 \ldots (W/S)_k]$
- Cruise Mach $\boldsymbol{M}$ $\longrightarrow$ $\mathbf{M_{vect}} = [M_1\ M_2 \ldots M_k]$
- Thickness-chord ratio $\boldsymbol{t/c}$ $\longrightarrow$ $\mathbf{(t/c)_{vect}} = [(t/c)_1\ (t/c)_2 \ldots (t/c)_k]$
- Aspect Ratio $\boldsymbol{AR}$ $\longrightarrow$ $\mathbf{AR_{vect}} = [AR_1\ AR_2 \ldots AR_k]$
- Taper Ratio $\boldsymbol{\lambda}$ $\longrightarrow$ $\boldsymbol{\lambda_{vect}} = [\lambda_1\ \lambda_2 \ldots \lambda_k]$
- Sweep Angle $\boldsymbol{\Lambda}$ $\longrightarrow$ $\boldsymbol{\Lambda_{vect}} = [\Lambda_1\ \Lambda_2 \ldots \Lambda_k]$

Parametric Wing Design

Design Variables - Example 1:

$\mathbf{(W/S)_{vect}}$ = [500 550 600 650 700] kg/m^2

$\mathbf{M_{vect}}$ = [0.76 0.78 0.80 0.82]

$\mathbf{(t/c)_{vect}}$ = [0.10 0.14]

$\mathbf{AR_{vect}}$ = [7 8 9 10 11]

$\boldsymbol{\lambda}_{\mathbf{vect}}$ = [0.25 0.35]

$\boldsymbol{\Lambda}_{\mathbf{vect}}$ = [20 25 30 35] deg

Parametric Wing Design

Design Variables - Example 1:

$\mathbf{(W/S)_{vect}}$ = [500 550 600 650 700] kg/m²

$\mathbf{M_{vect}}$ = [0.76 0.78 0.80 0.82]

$\mathbf{(t/c)_{vect}}$ = [0.10 0.14]

$\mathbf{AR_{vect}}$ = [7 8 9 10 11]

$\boldsymbol{\lambda}_{\mathbf{vect}}$ = [0.25 0.35]

$\boldsymbol{\Lambda}_{\mathbf{vect}}$ = [20 25 30 35] deg

1600 confs!

Parametric Wing Design

Design Variables - Example 2:

$\mathbf{(W/S)_{vect}}$ = [$\cancel{500}$ 550 600 650 700] kg/m^2

$\mathbf{M_{vect}}$ = [$\cancel{0.76}$ 0.78 0.80 0.82]

$\mathbf{(t/c)_{vect}}$ = [0.10 0.14]

$\mathbf{AR_{vect}}$ = [$\cancel{7}$ 8 9 10 11]

$\boldsymbol{\lambda}_{\mathbf{vect}}$ = [$\cancel{0.25}$ 0.35]

$\boldsymbol{\Lambda}_{\mathbf{vect}}$ = [$\cancel{20}$ 25 30 35] deg

Parametric Wing Design

Design Variables - Example 2:

$(\mathbf{W/S})_{\mathbf{vect}} = [\cancel{500}\ 550\ 600\ 650\ 700]\ \mathrm{kg/m^2}$

$\mathbf{M}_{\mathbf{vect}} = [\cancel{0.76}\ 0.78\ 0.80\ 0.82]$

$(\mathbf{t/c})_{\mathbf{vect}} = [0.10\ 0.14]$

$\mathbf{AR}_{\mathbf{vect}} = [\cancel{7}\ 8\ 9\ 10\ 11]$

$\lambda_{\mathbf{vect}} = [\cancel{0.25}\ 0.35]$ ✘ Lost sensitivity to this parameter

$\Lambda_{\mathbf{vect}} = [\cancel{20}\ 25\ 30\ 35]\ \mathrm{deg}$

✓ Reduced number of desings

✘ Reduced information quality

Parametric Wing Design

Design Variables - Example 3: User-specified set

$$\mathbf{Input}_{\mathbf{matrix}} = \begin{bmatrix} 550 & 550 & 650 & 700 & 700 \\ 0.76 & 0.80 & 0.78 & 0.80 & 0.82 \\ 0.14 & 0.12 & 0.13 & 0.14 & 0.14 \\ 9 & 10 & 11 & 10 & 9 \\ 0.25 & 0.30 & 0.30 & 0.30 & 0.25 \\ 20 & 30 & 27 & 30 & 35 \end{bmatrix} \begin{array}{ll} \mathrm{kg/m^2} & W/S \\ & M \\ & t/c \\ & AR \\ & \lambda \\ \mathrm{deg} & \Lambda \end{array}$$

Configurations Matrix

Summary of the set of configurations designed

Geometry						Weights						Performance						FoMs					
x_1	x_2	x_3	…	…	x_n	w_1	w_2	w_3	…	…	w_n	y_1	y_2	y_3	…	…	y_n	f_1	f_2	f_3	…	…	f_n
x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx
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x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx
x.xx	x.xx	x.xx	x.xx	x.xx	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx
x.xx	x.xx	x.xx	x.xx	x.xx	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx
x.xx	x.xx	x.xx	x.xx	x.xx	[illegible]	[illegible]	[illegible]	[illegible]	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx
…	…	…	…	…	[illegible]	[illegible]	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	[illegible]	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
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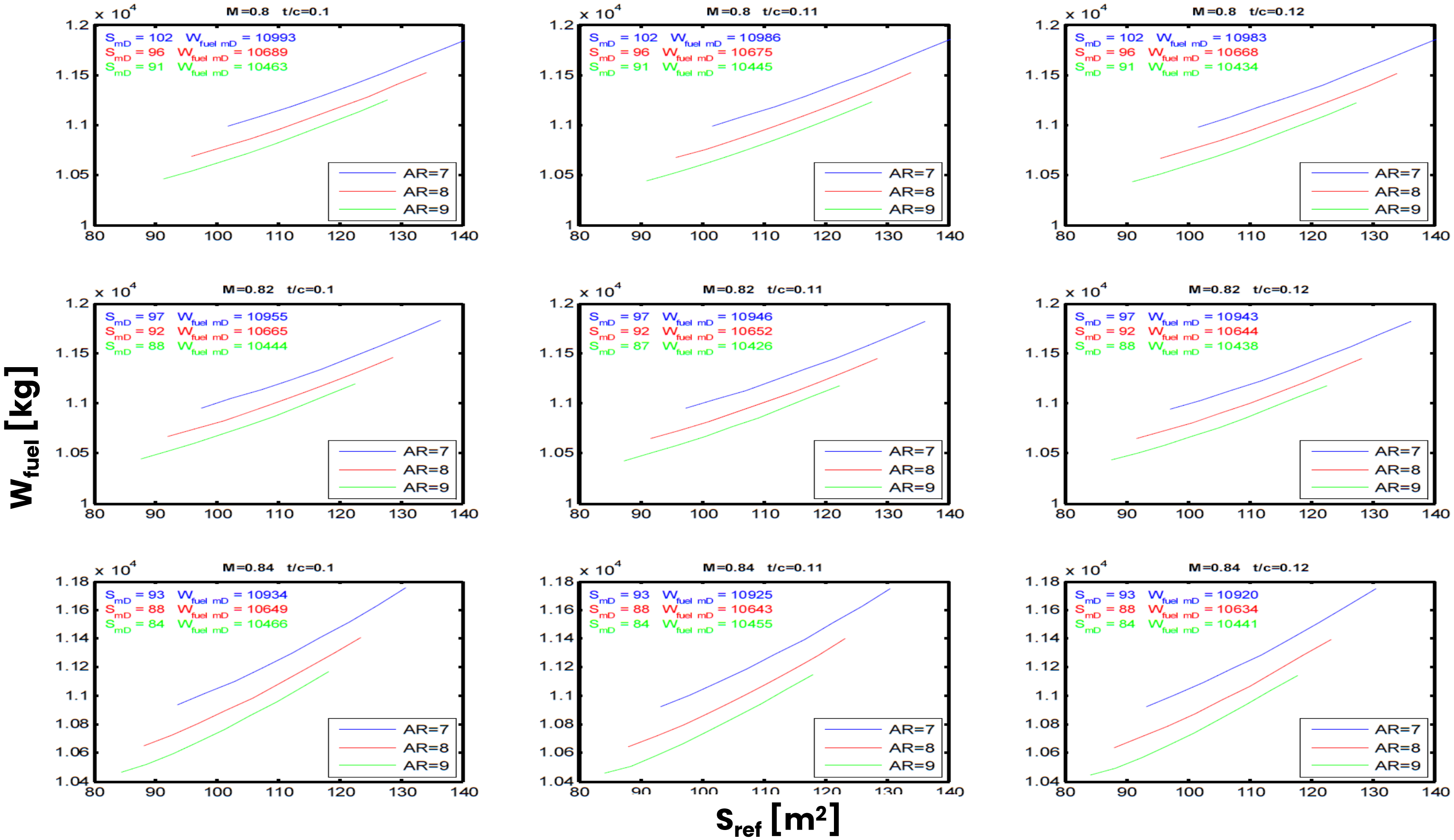
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx

Configuration selected!!
How to read results..?

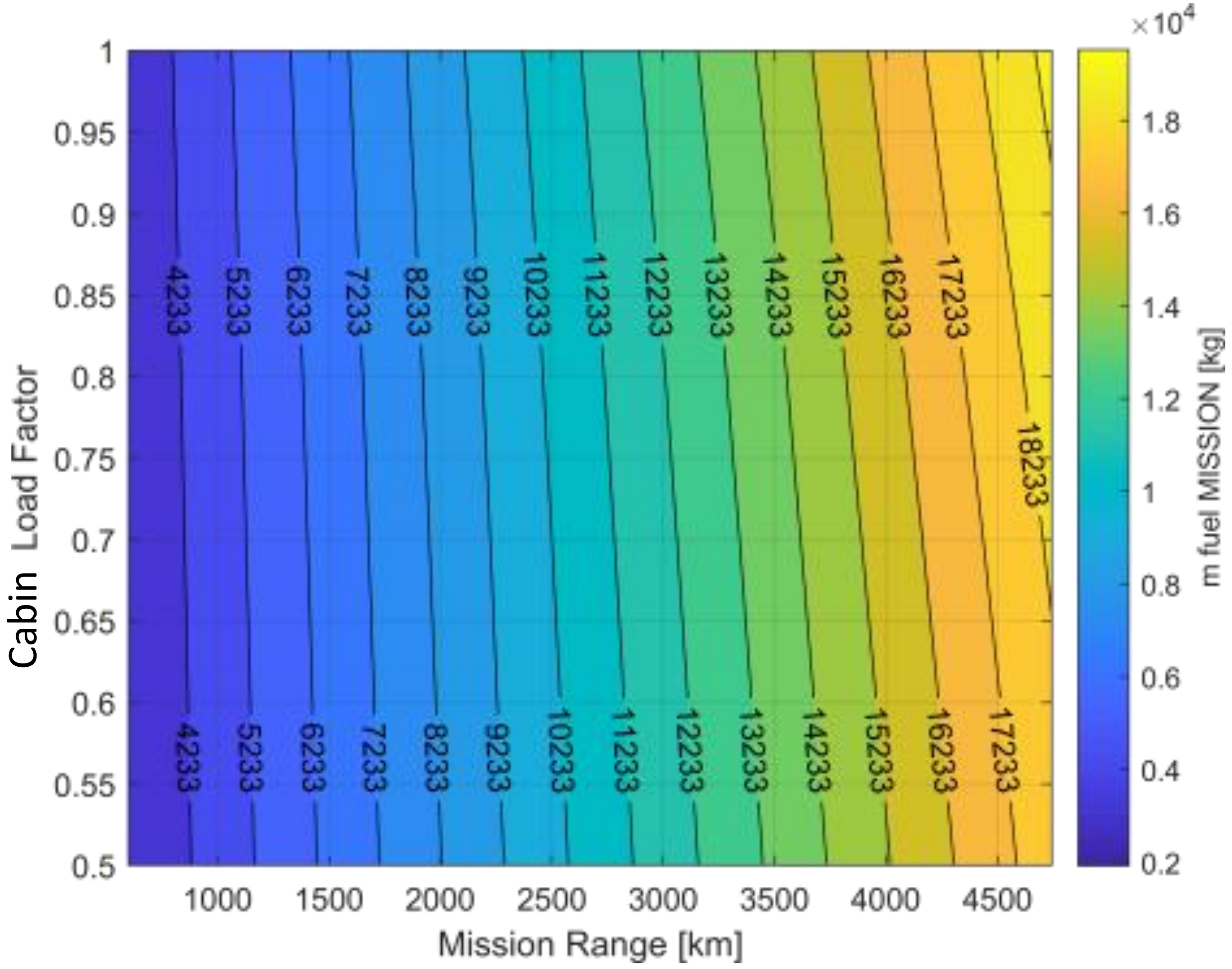
Results representation and analysis

Plain graphs: 1-vs-1 trends (be careful!!)



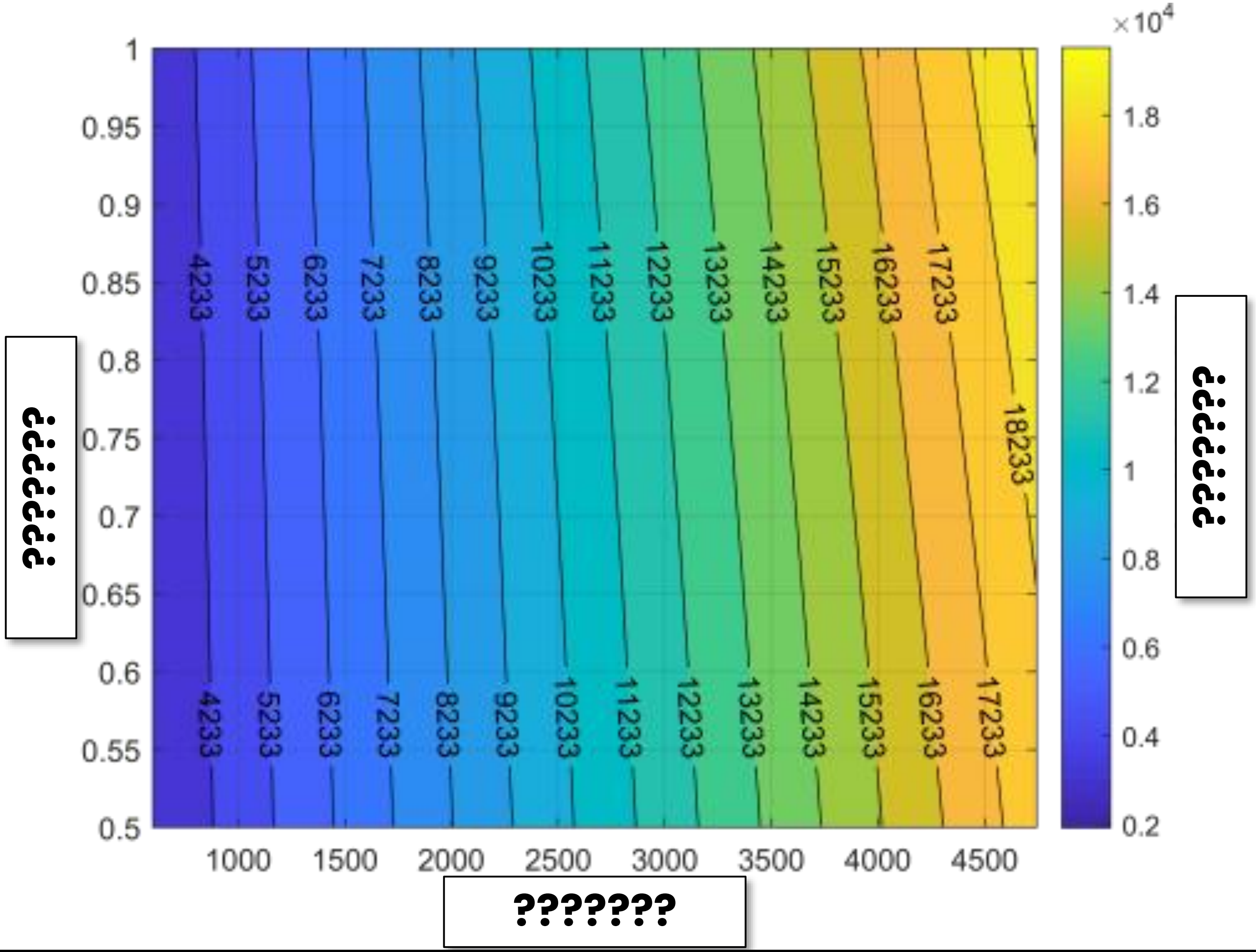
Results representation and analysis

Contour maps: 2-vs-1 trends (be careful!!)



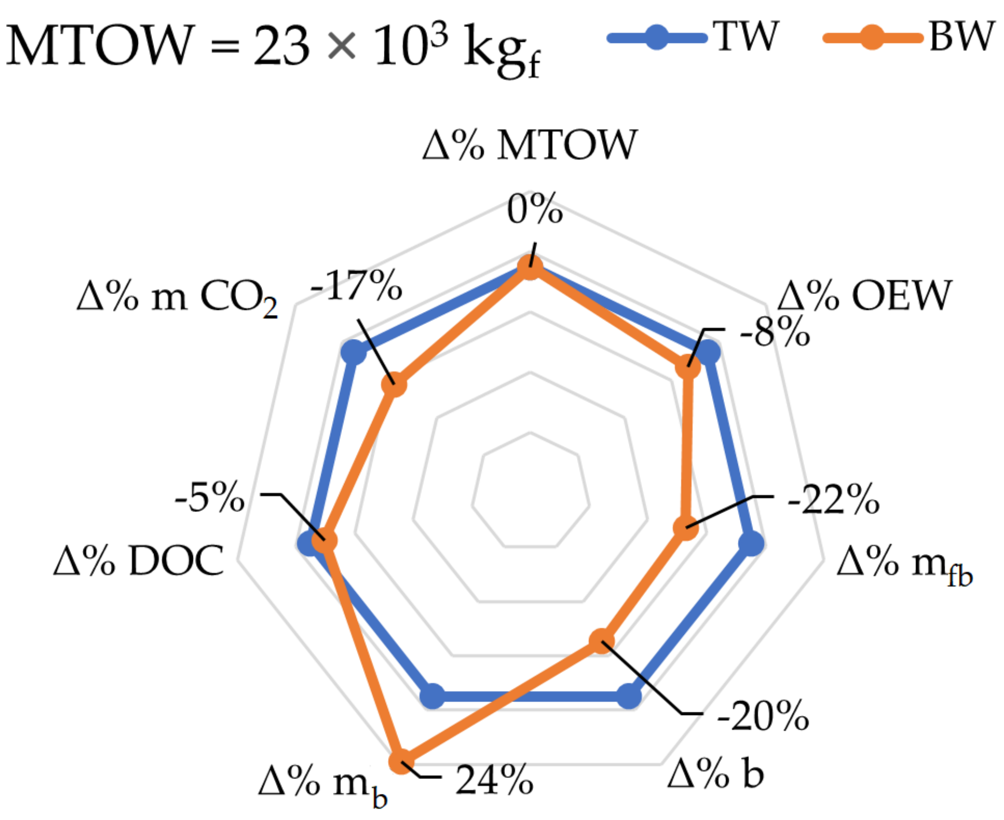
Results representation and analysis

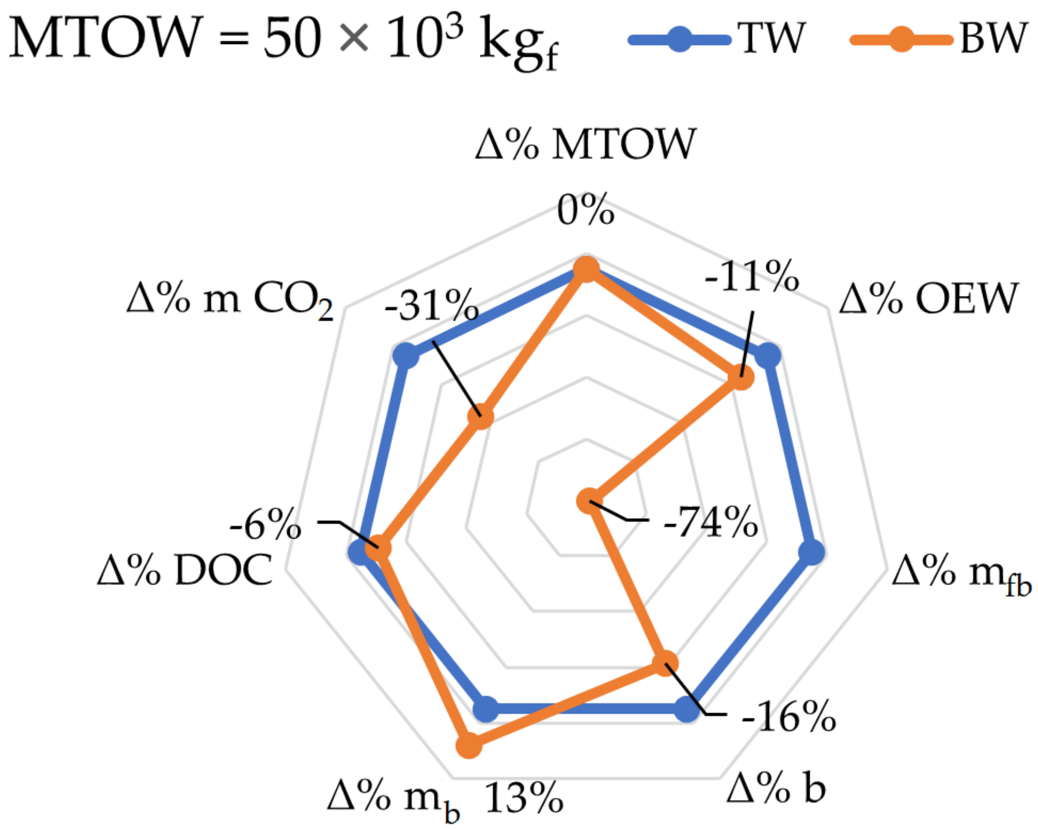
Contour maps: 2-vs-1 trends (be careful!!)



Results representation and analysis

Radar charts





Introduction to Optimization

Aircraft design is a strong intertwined multidisciplinary process, hence it is not easy to find direct correlations between performance and design variables.

Indeed, varying some design variables in different combinations may introduce effects not detectable if we vary the same variables ‘one-by-one’

The aircraft designer needs as much aids as possible to assess trends between inputs and outputs, to strengthen his choices and discard unsuitable solutions

→ **Numerical Optimization!**

Numerical Optimization

$$
\begin{cases}
min\,\boxed{f(x)} \\
\boxed{\begin{array}{l} h(x) = 0 \\ g(x) \geq 0 \end{array}} \\
lb \leq \boxed{x} \leq ub
\end{cases}
$$

- Objective function (Figure of Merit, *FoM*)
- Constraints (geometry, aerodynamics, flight mechanics, etc.)
- Design space (vector of the Design Variables, *DVs* + upper and lower boundaries, *ub* & *lb*)

Numerical Optimization

$$\begin{cases} min\,\boxed{f(x)} \\ h(x) = 0 \\ g(x) \geq 0 \\ lb \leq \boxed{x} \leq ub \end{cases}$$

- Objective function (Figure of Merit, *FoM*)
- Constraints (geometry, aerodynamics, flight mechanics, etc.)
- Design space (vector of the Design Variables, *DVs* + upper and lower boundaries, *ub* & *lb*)

- L/D
- Block fuel
- MTOW
- DOC
- CO_2 emissions
- non-CO_2 emissions
- Climate impact
- PREE
- ..and others

Numerical Optimization

$$
\begin{cases}
min f(x) \\
\boxed{\begin{array}{l} h(x) = 0 \\ g(x) \geq 0 \end{array}} \\
lb \leq x \leq ub
\end{cases}
$$

- Objective function (Figure of Merit, *FoM*)
- Constraints (geometry, aerodynamics, flight mechanics, etc.)
- Design space (vector of the Design Variables, *DVs* + upper and lower boundaries, *ub* & *lb*)

- Trim
- Stability
- Max local C_L
- Kink position
- TE sweep
- ..and others

Numerical Optimization

$$\begin{cases} min f(x) \\ h(x) = 0 \\ g(x) \geq 0 \\ lb \leq \boxed{x} \leq ub \end{cases}$$

- Objective function (Figure of Merit, *FoM*)
- Constraints (geometry, aerodynamics, flight mechanics, etc.)
- Design space (vector of the Design Variables, *DVs* + upper and lower boundaries, *ub* & *lb*)

- Reference Surface $\boldsymbol{S_{ref}}$
- Cruise Mach ***M***
- Thickness-chord ratio ***t/c***
- Aspect Ratio ***AR***
- Taper Ratio $\boldsymbol{\lambda}$
- Sweep Angle $\boldsymbol{\Lambda}$

$(\mathbf{W/S})_{\mathbf{vect}} = [(W/S)_1\ (W/S)_2 \dots (W/S)_k]$

$\mathbf{M}_{\mathbf{vect}} = [M_1\ M_2 \dots M_k]$

$(\mathbf{t/c})_{\mathbf{vect}} = [(t/c)_1\ (t/c)_2 \dots (t/c)_k]$

$\mathbf{AR}_{\mathbf{vect}} = [AR_1\ AR_2 \dots AR_k]$

$\boldsymbol{\lambda}_{\mathbf{vect}} = [\lambda_1\ \lambda_2 \dots \lambda_k]$

$\boldsymbol{\Lambda}_{\mathbf{vect}} = [\Lambda_1\ \Lambda_2 \dots \Lambda_k]$

Numerical Optimization

$$\begin{cases} min f(x) \\ h(x) = 0 \\ g(x) \geq 0 \\ lb \leq \boxed{x} \leq ub \end{cases}$$

- Objective function (Figure of Merit, *FoM*)

- Constraints (geometry, aerodynamics, flight mechanics, etc.)

- Design space (vector of the Design Variables, *DVs* + upper and lower boundaries, *ub* & *lb*)

[5]	'XLEala_ant'	[10]
[1.1000]	'C1 ala_ant'	[3]
[-2]	'Theta1 ala_ant'	[2]
[0.9000]	'C2 ala_ant'	[3]
[-2]	'Theta2 ala_ant'	[2]
[0.7000]	'C3 ala_ant'	[3]
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[1]	'b1 ala_ant'	[3]
[0]	'Dihed1 ala_ant'	[6]
[0]	'SW1 ala_ant'	[40]
[0]	'Dihed2 ala_ant'	[6]
[0]	'SW2 ala_ant'	[40]
[-5]	'Angleala_ant'	[5]
[10]	'XLEala_post'	[13]
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[-2]	'Theta1 ala_post'	[2]
[0.7000]	'C2 ala_post'	[3]
[-2]	'Theta2 ala_post'	[2]
[2]	'b1 ala_post'	[20]
[-6]	'Dihed1 ala_post'	[0]
[-40]	'SW1 ala_post'	[0]
[-5]	'Angleala_post'	[5]

Task

Task:

Build the matrix of configurations
Select your 'best' design
Draw the wing planform
Comment and discuss the overall results

Extra content

Back-up content for class open discussion

Title