Progettazione di veicoli aerospaziali (AA-LZ)

E2. Conceptual Design of hybrid-electric aircraft

14. Weights update, TLARs & AVL

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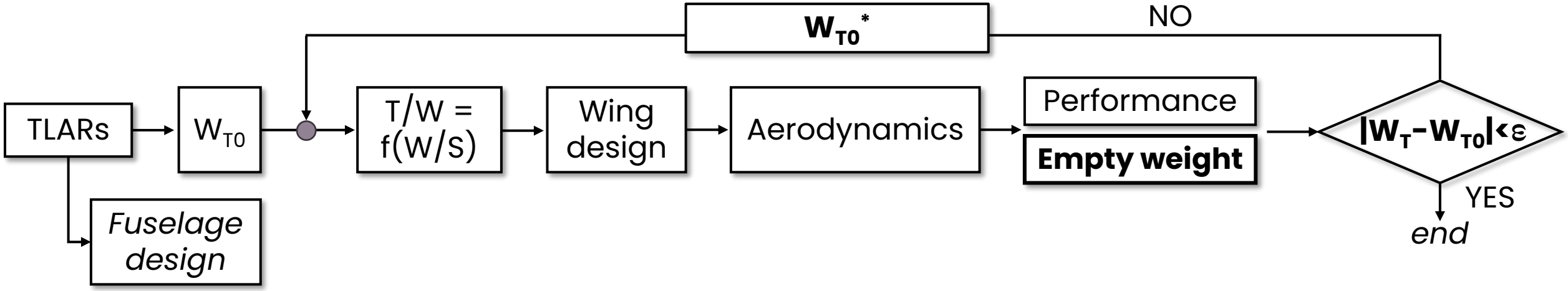
Part I: Weights update

Operating empty weight



The **operating empty weight** is the weight of the airplane in a condition **ready to fly**, but with **no fuel or payload** yet taken on board.

Operating empty weight

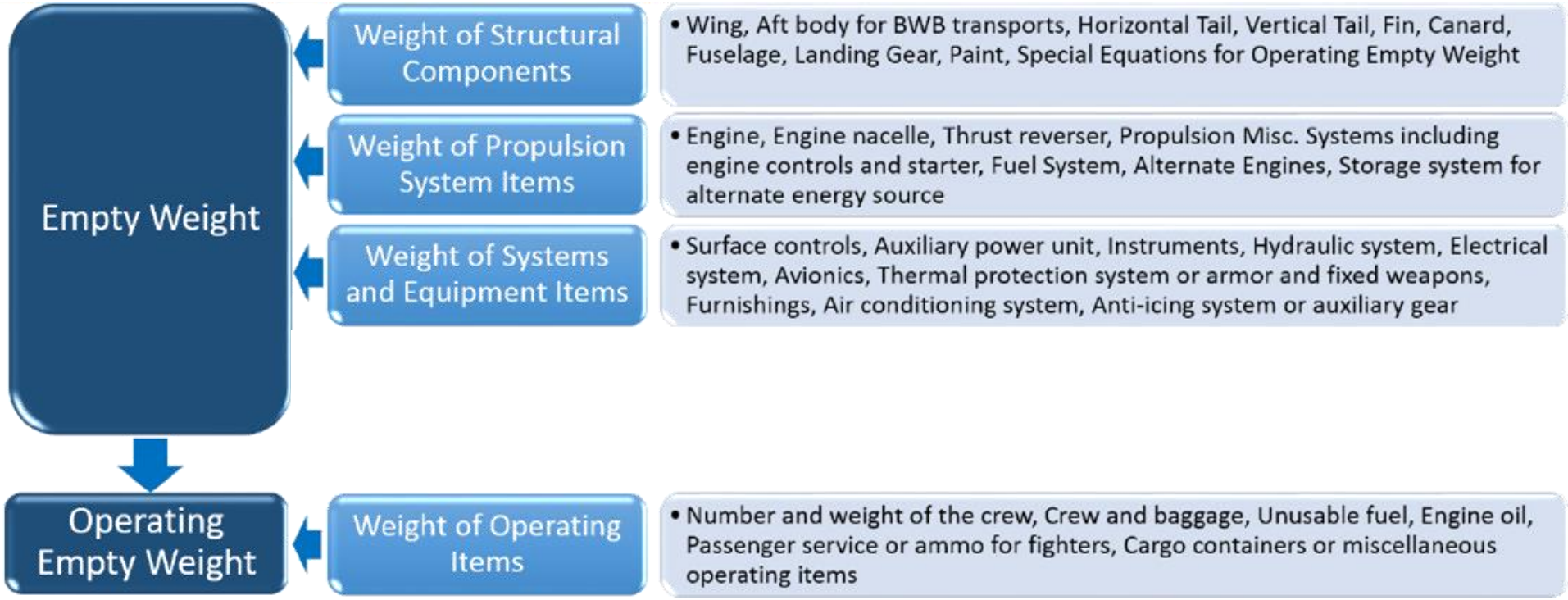
Aircraft operating empty weight

Structural mass
Wing
Tail
Fuselage
Landing gear

Propulsion
Engine and Nacelle

Systems
Fuel, Hydraulic, Electric, Pneumatic, Anti-icing, Instruments, Avionics, Engine

Operating
Furnishing, Services
Crew and attendants



Operating empty weight - Powertrain

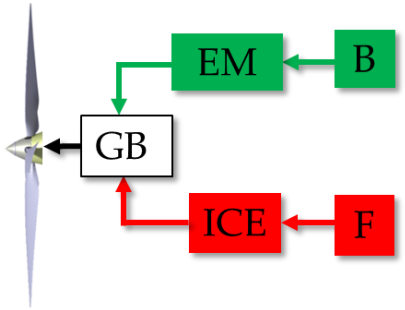
Aircraft operating empty weight

Structural mass
Wing
Tail
Fuselage
Landing gear

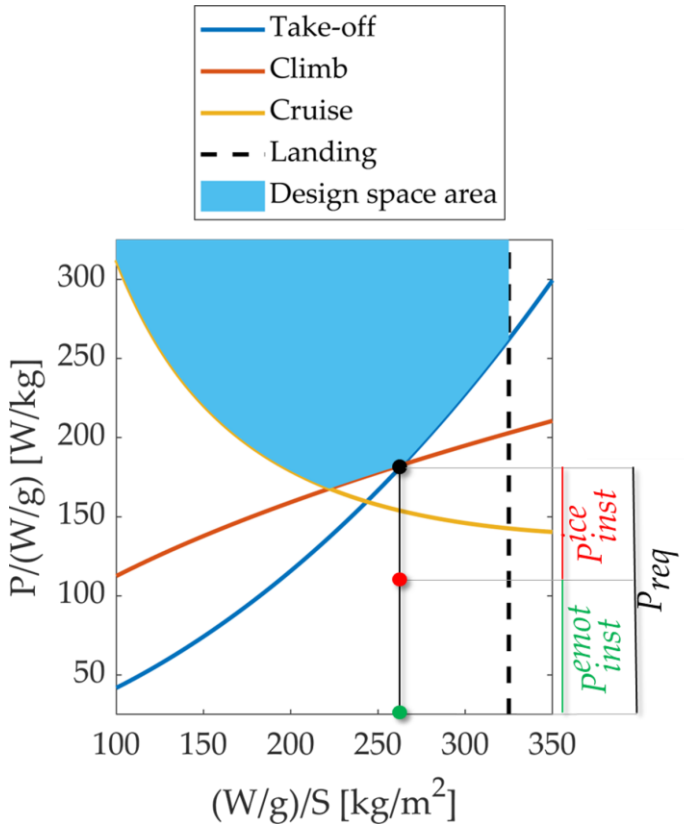
Propulsion
Engine, Nacelle and Prop.

Systems
Fuel, Hydraulic, Electric, Pneumatic, Anti-icing, Instruments, Avionics, Engine

Operating
Furnishing, Services
Crew and attendants



$$H_P = \frac{P_{inst}^{emot}}{P_{inst}^{ice} + P_{inst}^{emot}}$$



Operating empty weight - Powertrain

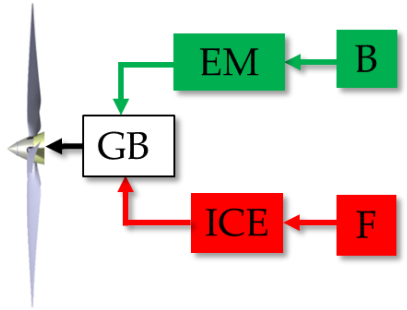
Aircraft operating empty weight

Structural mass
Wing
Tail
Fuselage
Landing gear

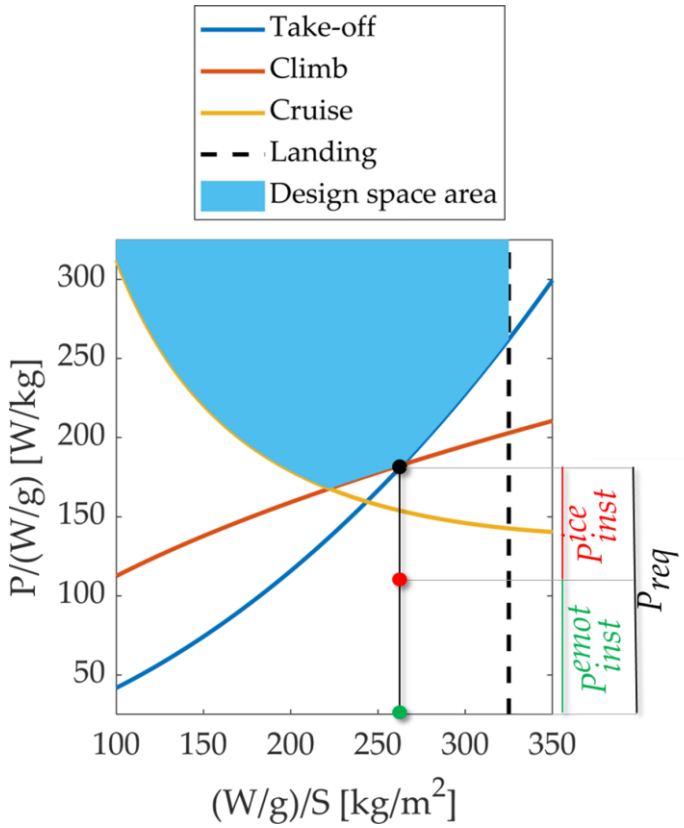
Propulsion
Engine, Nacelle and Prop.

Systems
Fuel, Hydraulic, Electric, Pneumatic, Anti-icing, Instruments, Avionics, Engine

Operating
Furnishing, Services
Crew and attendants



$$H_P = \frac{P_{inst}^{emot}}{P_{inst}^{ice} + P_{inst}^{emot}}$$



Thermal Engine Update

$$W_{ice} = N_{prop} \frac{\frac{P_{inst}^{ice}}{N_{prop}} - 12970}{3878}$$

$W_{ice} = mass\ of\ thermal\ engines\ [kg]$

$P_{inst}^{ice} = installed\ power\ of\ t.es.\ [W]$

Operating empty weight - Engine

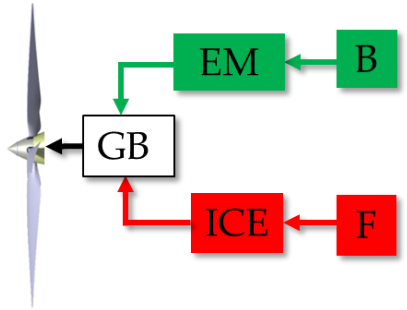
Aircraft operating empty weight

Structural mass
Wing
Tail
Fuselage
Landing gear

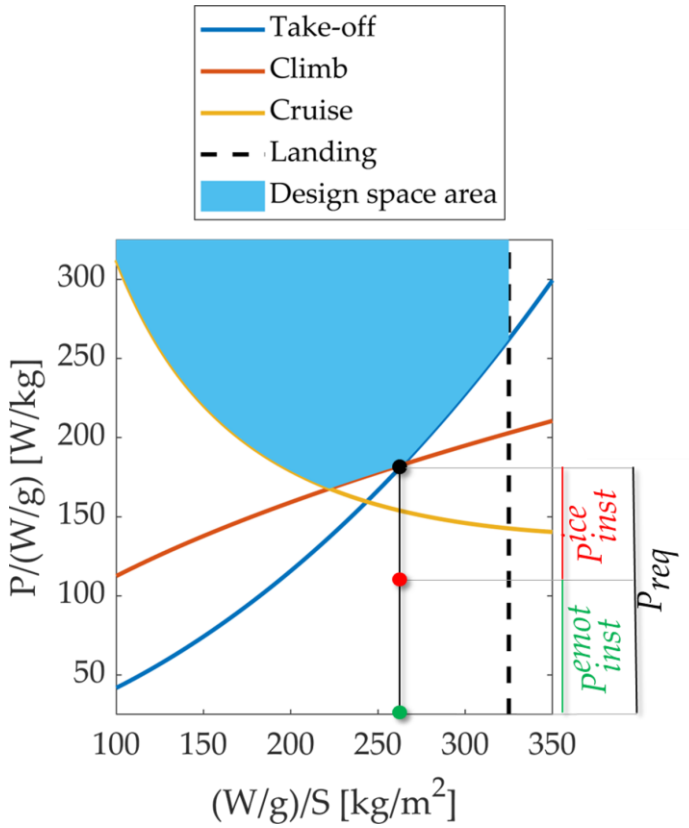
Propulsion
Engine, Nacelle and Prop.

Systems
Fuel, Hydraulic, Electric, Pneumatic, Anti-icing, Instruments, Avionics, Engine

Operating
Furnishing, Services
Crew and attendants



$$H_P = \frac{P_{inst}^{emot}}{P_{inst}^{ice} + P_{inst}^{emot}}$$



Electric Motor (NEW!!)

$$W_{emot} = \frac{P_{inst}^{emot}}{EMPD}$$

$W_{emot} = mass\ of\ electric\ motors\ [kg]$
$P_{inst}^{emot} = installed\ power\ of\ e.ms.\ [W]$
$EMPD = electric\ motor\ power\ density\ [W/kg]$

EMPD =16 kW/kg

Operating empty weight - Nacelle

Aircraft operating empty weight

Structural mass
Wing
Tail
Fuselage
Landing gear

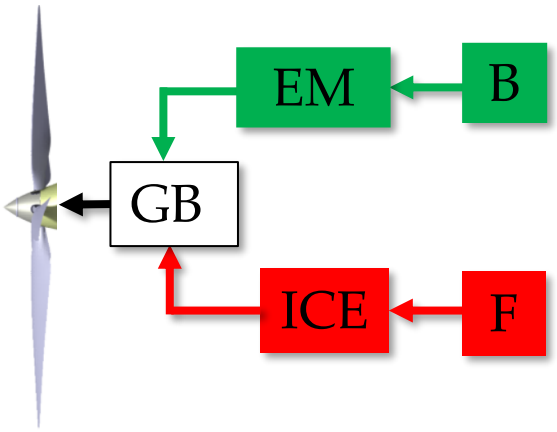
Propulsion
Engine, Nacelle and Prop.

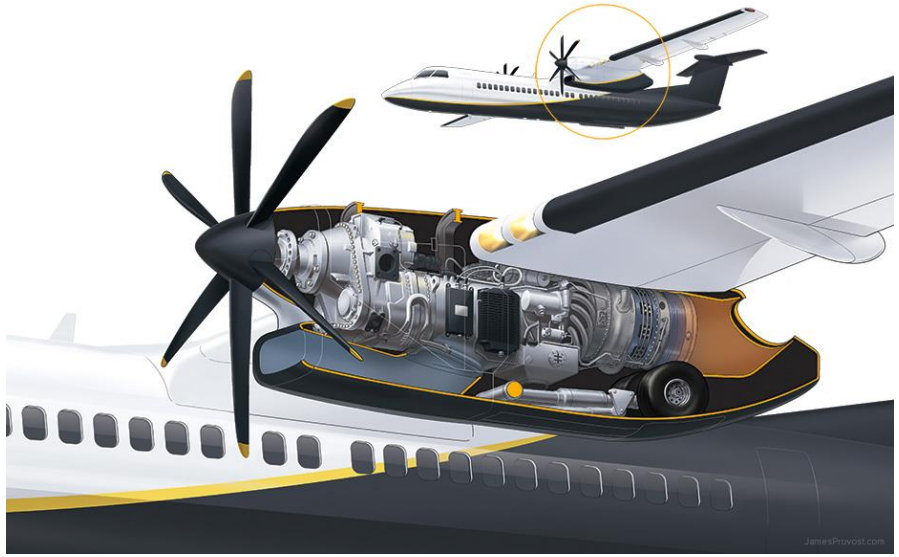
Systems
Fuel, Hydraulic, Electric, Pneumatic, Anti-icing, Instruments, Avionics, Engine

Operating
Furnishing, Services
Crew and attendants

$$W_{nac} = K \times (P_{inst}^{ice} + P_{inst}^{emot})$$

$$K = 0.14 \frac{lb}{hp}$$





Operating empty weight - Propeller

Aircraft operating empty weight

Structural mass
Wing
Tail
Fuselage
Landing gear

Propulsion
Engine, Nacelle and Prop.

Systems
Fuel, Hydraulic, Electric, Pneumatic, Anti-icing, Instruments, Avionics, Engine

Operating
Furnishing, Services
Crew and attendants

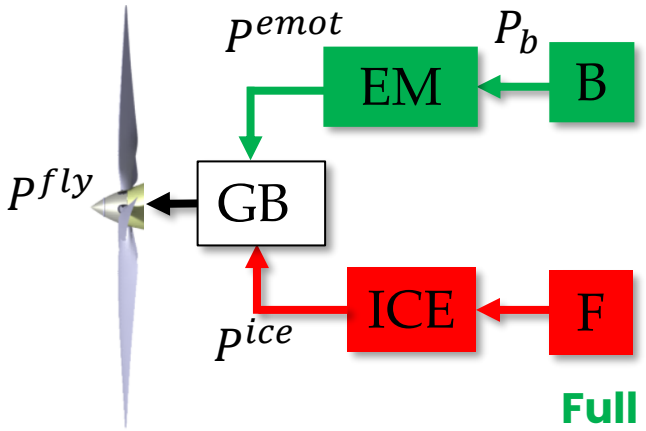
$$W_{prop} = 0.1256 N_{prop} \left(12.0546 \frac{P_{inst}^{ice} + P_{inst}^{emot}}{N_{prop}} \right)^{0.782}$$

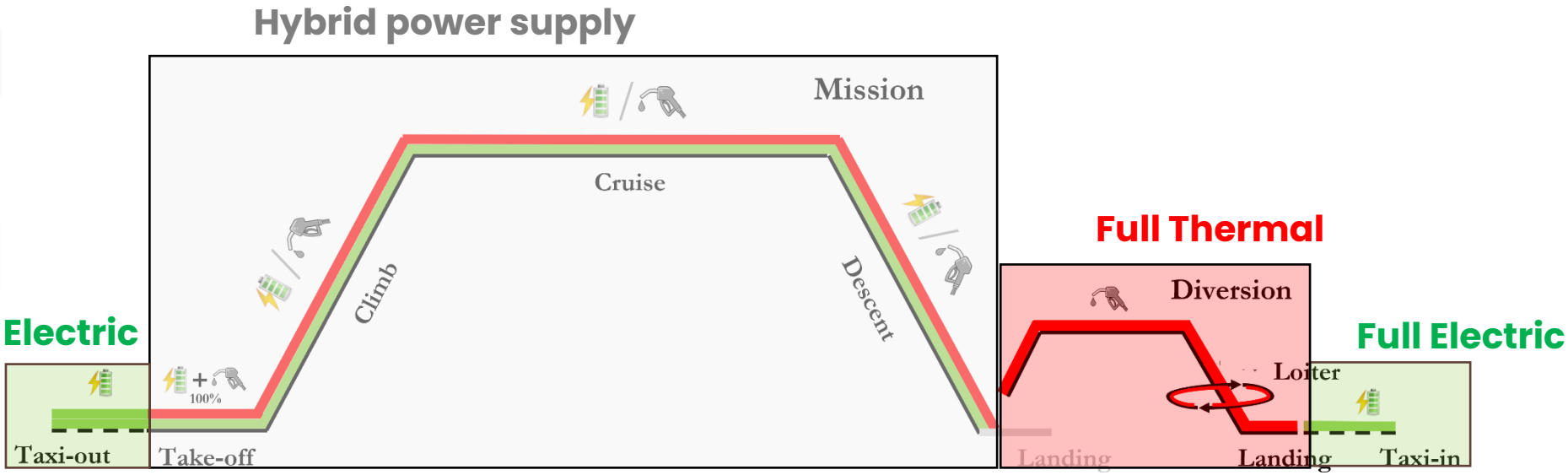
$P_{inst}^{ice} = installed\ power\ of\ thermal\ engines [hp]$

$P_{inst}^{emot} = installed\ power\ of\ electric\ motors [hp]$

$W_{prop} = weight\ of\ propellers\ [lb]$

Battery mass





$$\dot{W}(t_k) = -k_c\, P^{ice}(t_k)$$

$$P^{ice} = f(\Phi^{ice})$$

$$P_b = P^{emot}/(\eta_{em})$$

$$\dot{E}_b(t_k) = P_b(t_k)$$

$$W_b = \frac{\int_0^t P_b\, dt}{(SOC_{in} - SOC_{fin})BED}$$

Battery mass [kg]

100 %

20 %

Battery energy density [J/kg]

Part II: TLARs and DVs update

TLARs

Group A TLARs

- **Number of seats:** 30
- **Mission range:** 500 nm
- **BFL:** 1100 m
- **Cruise Mach:** 0.40
- **Cruise altitude:** 20000 ft
- **Maximum wingspan:** 36 m
- **BED:** 500 Wh/kg (~2035)

Group B TLARs

- **Number of seats:** 25
- **Mission range:** 550 nm
- **BFL:** 1100 m
- **Cruise Mach:** 0.40
- **Cruise altitude:** 20000 ft
- **Maximum wingspan:** 36 m
- **BED:** 500 Wh/kg (~2035)

Group C TLARs

- **Number of seats:** 40
- **Mission range:** 600 nm
- **BFL:** 1100 m
- **Cruise Mach:** 0.40
- **Cruise altitude:** 20000 ft
- **Maximum wingspan:** 36 m
- **BED:** 650 Wh/kg (~2045)

Group D TLARs

- **Number of seats:** 50
- **Mission range:** 450 nm
- **BFL:** 1100 m
- **Cruise Mach:** 0.40
- **Cruise altitude:** 20000 ft
- **Maximum wingspan:** 36 m
- **BED:** 650 Wh/kg (~2045)

Other data

Group A other data

- **Cruise range:** 356 nm
- **fuel fraction:** a*MTOW+b
- **Climb RoC:** 900 ft/min
- **Climb IAS:** 170 kt
- **Descent RoD:** -1110 ft/min
- **Descent IAS:** 220 kt

Group B other data

- **Cruise range:** 406 nm
- **fuel fraction :** a*MTOW+b
- **Climb RoC:** 900 ft/min
- **Climb IAS:** 170 kt
- **Descent RoD:** -1110 ft/min
- **Descent IAS:** 220 kt

Group C other data

- **Cruise range:** 456 nm
- **fuel fraction :** a*MTOW+b
- **Climb RoC:** 900 ft/min
- **Climb IAS:** 170 kt
- **Descent RoD:** -1110 ft/min
- **Descent IAS:** 220 kt

Group D other data

- **Cruise range:** 306 nm
- **fuel fraction :** a*MTOW+b
- **Climb RoC:** 900 ft/min
- **Climb IAS:** 170 kt
- **Descent RoD:** -1110 ft/min
- **Descent IAS:** 220 kt

Other data

Group A other data

- **Cruise range:** 356 nm
- **fuel fraction :** a*MTOW+b
- **Climb RoC:** 900 ft/min
- **Climb IAS:** 170 kt
- **Descent RoD:** -1110 ft/min
- **Descent IAS:** 220 kt

Group B other data

- **Cruise range:** 406 nm
- **fuel fraction :** a*MTOW+b
- **Climb RoC:** 900 ft/min
- **Climb IAS:** 170 kt
- **Descent RoD:** -1110 ft/min
- **Descent IAS:** 220 kt

fuel fraction = m_{fd}/MTOW
a = 0.0122 1/t
b = 15.6357
20 t < MTOW < 55 t

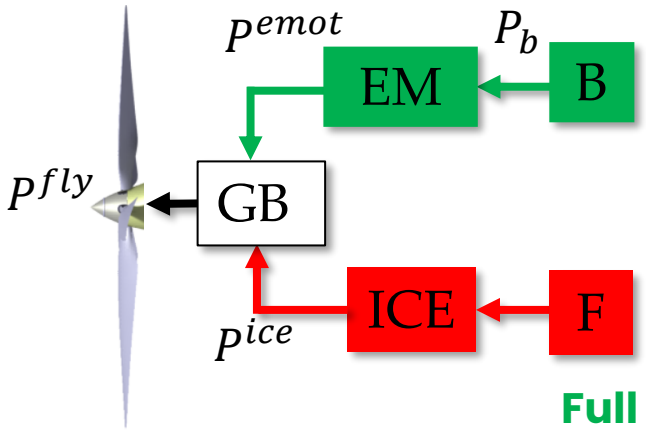
Group C other data

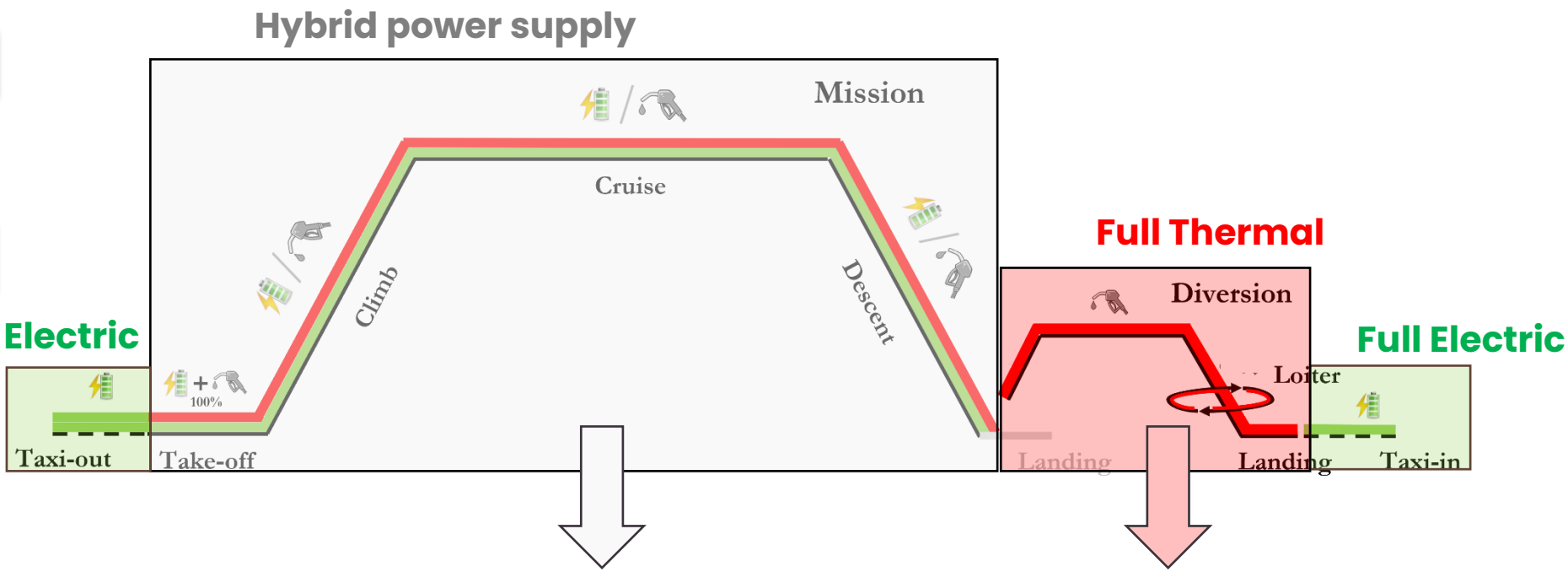
- **Cruise range:** 456 nm
- **fuel fraction :** a*MTOW+b
- **Climb RoC:** 900 ft/min
- **Climb IAS:** 170 kt
- **Descent RoD:** -1110 ft/min
- **Descent IAS:** 220 kt

Group D other data

- **Cruise range:** 306 nm
- **fuel fraction :** a*MTOW+b
- **Climb RoC:** 900 ft/min
- **Climb IAS:** 170 kt
- **Descent RoD:** -1110 ft/min
- **Descent IAS:** 220 kt

Other data

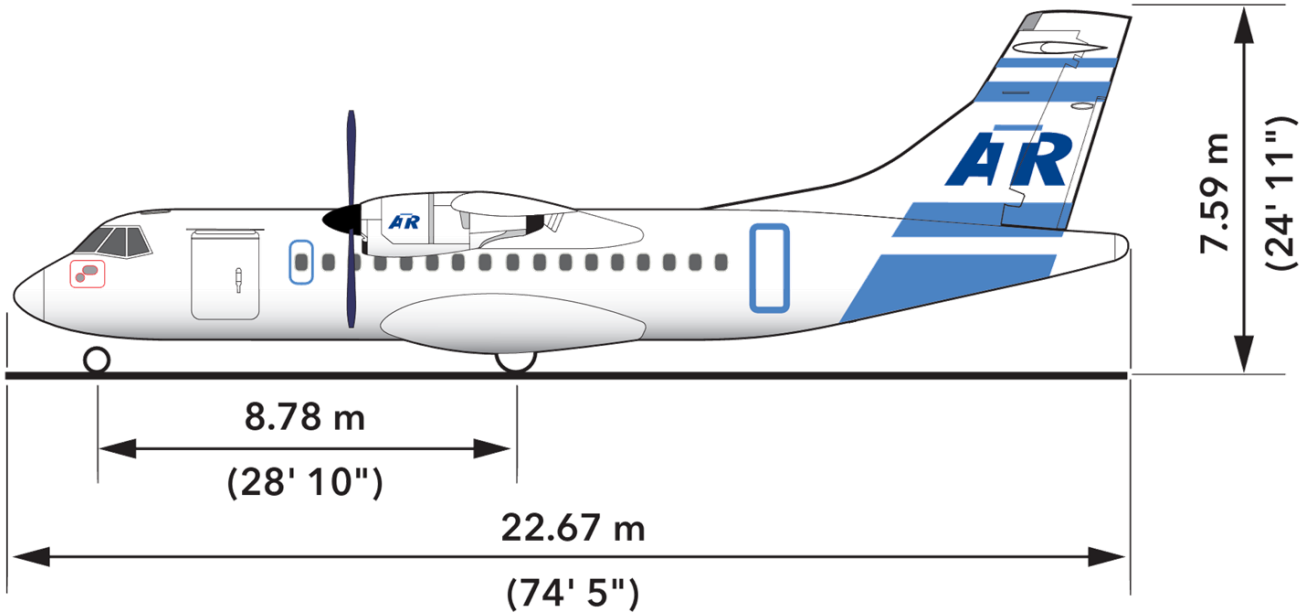


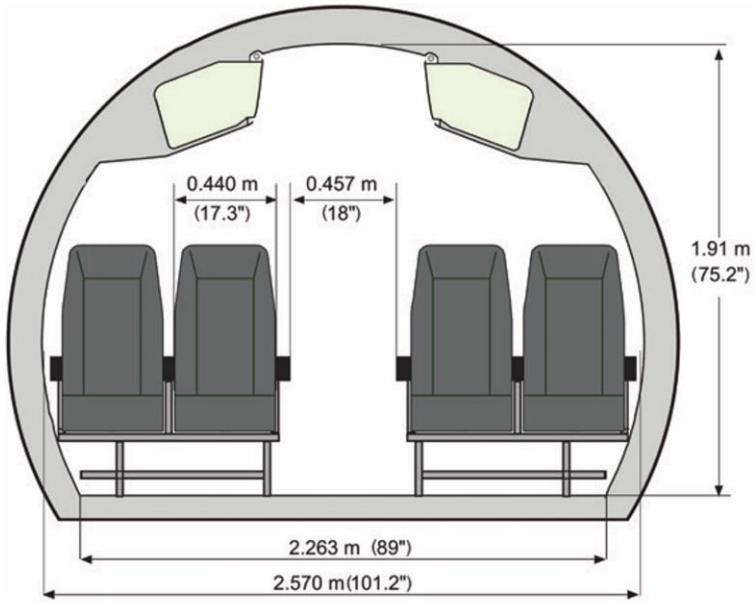


Block fuel = f(H_p,W/S,Φ^{ice}) → Diversion fuel = f(MTOW)

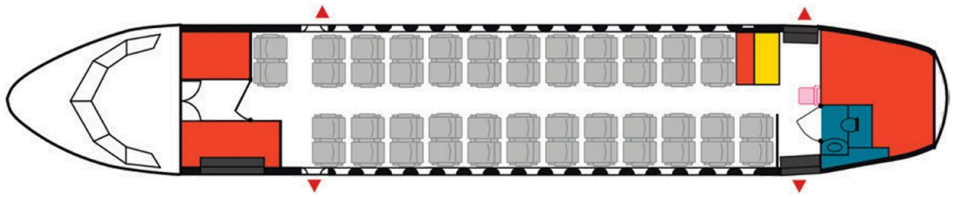
m_{fd}/MTOW = a*MTOW+b
a = 0.0122 1/t
b = 15.6357
20 t < MTOW < 55 t

TLARs: fuselage update





48 pax at 30″ pitch



Attendant seat Galley Toilet Baggage Emergency Exits

Parametric HE design

Design Variables Medium-Range Conventional Aircraft:

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

$\mathbf{M_{vect}}$ = [0.76 … … 0.82]

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

$\mathbf{AR_{vect}}$ = [7 … … 11]

$\boldsymbol{\lambda_{vect}}$ = [0.25 … … 0.35]

$\boldsymbol{\Lambda_{vect}}$ = [20 … … 35] deg

Parametric HE design

Design Variables Regional Hybrid-Electric Aircraft:

$(W/S)_{vect}$ = [500 … … 700] kg/m²

M_{vect} = [0.76 … … 0.82]

$(t/c)_{vect}$ [0 … … 0.14]

AR_{vect} [… … 11]

λ_{vect} = [0.25 … … 0.35]

Λ_{vect} = [20 … … 35] deg

X

New set of DVs!

Parametric HE design

Design Variables Regional Hybrid-Electric Aircraft:

$\mathbf{(w/s)_{vect}}$ = [250 300 350] kg/m^2

$\mathbf{H_{P\ vect}}$ = [0.1 0.2 0.3 0.4]

$\mathbf{\Phi^{ice}_{cl\ vect}}$ = [0.10 0.30 0.50]

$\mathbf{\Phi^{ice}_{cr\ vect}}$ = [0.10 0.20 0.30 0.40 0.50]

$\mathbf{\Phi^{ice}_{de\ vect}}$ = [0.10 0.30]

New set of DVs!

Parametric HE design

Design Variables Regional Hybrid-Electric Aircraft:

$(w/s)_{vect}$ = [250 300 350] kg/m²

$H_{P\ vect}$ = [0.1 0.2 0.3 0.4]

$\Phi^{ice}_{cl\ vect}$ = [0.10 0.30 0.50]

$\Phi^{ice}_{cr\ vect}$ = [0.10 0.20 0.30 0.40 0.50]

$\Phi^{ice}_{de\ vect}$ = [0.10 0.30]

New set of DVs!

Parametric HE design

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
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]	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	[illegible]	[illegible]	[illegible]	x.xx	x.xx	x.xx	x.xx	x.xx	x.xx
…	…	…	…	…	…	…	…	…	…	…	…	…	…	[illegible]	[illegible]	[illegible]	[illegible]	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	…	…	…	…	…	…	…	…	…	…
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]	[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	[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]	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
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..?

Part III: AVL (live demo)

Upgrade aerodynamic evaluations

A focus on potential aerodynamic solvers

Live demo: An example of utilization of Vortex Lattice Method AVL

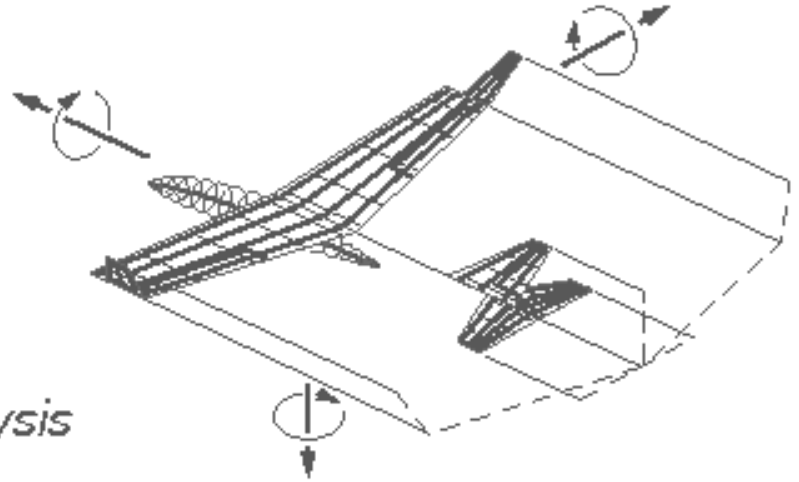
AVL

Aerodynamic Analysis

Trim Calculation

Dynamic Stability Analysis

Aircraft Configuration Development



https://web.mit.edu/drela/Public/web/avl/

Input file

General parameters and settings

```
!*************************************
!AVL dataset for NOME FILE
!*************************************
velivolo.avl      ! Titolo
!-------------------------------------------------------------
!-------------------------------------------------------------
0                 ! Mach   {n° di mach del flusso imperturbato}
!-------------------------------------------------------------
!-------------------------------------------------------------
0 0 0             ! IYsym   IZsym   Zsym  {simmetria}
!-------------------------------------------------------------
!-------------------------------------------------------------
7.20e+01 3.50e+00 2.80e+01    ! Sref    Cref    Bref
#
11.50  0 2.35 ! Xref    Yref    Zref  {Polo momenti}
!-------------------------------------------------------------
!-------------------------------------------------------------
```

Input file

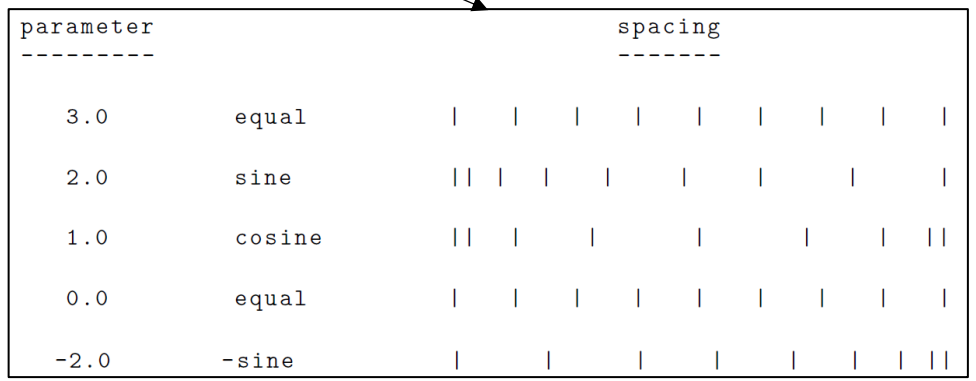
General lifting surface definition

```
#*****************************************
#*****************************************
#      DEFINIZIONE ALA [1]
#*****************************************
#*****************************************
SURFACE       ! comando di creazione nuova superficie
ala           ! nome univoco della surface
8 2           ! n° pannelli in corda    tipo di distribuzione
YDUPLICATE    ! comando 'specchio' rispetto ad y
0             ! coordinata y per YDUPLICATE
#
ANGLE        ! comando angolo di calettamento SURFACE
0             ! valore del calettamento
```

Input file

General lifting surface definition

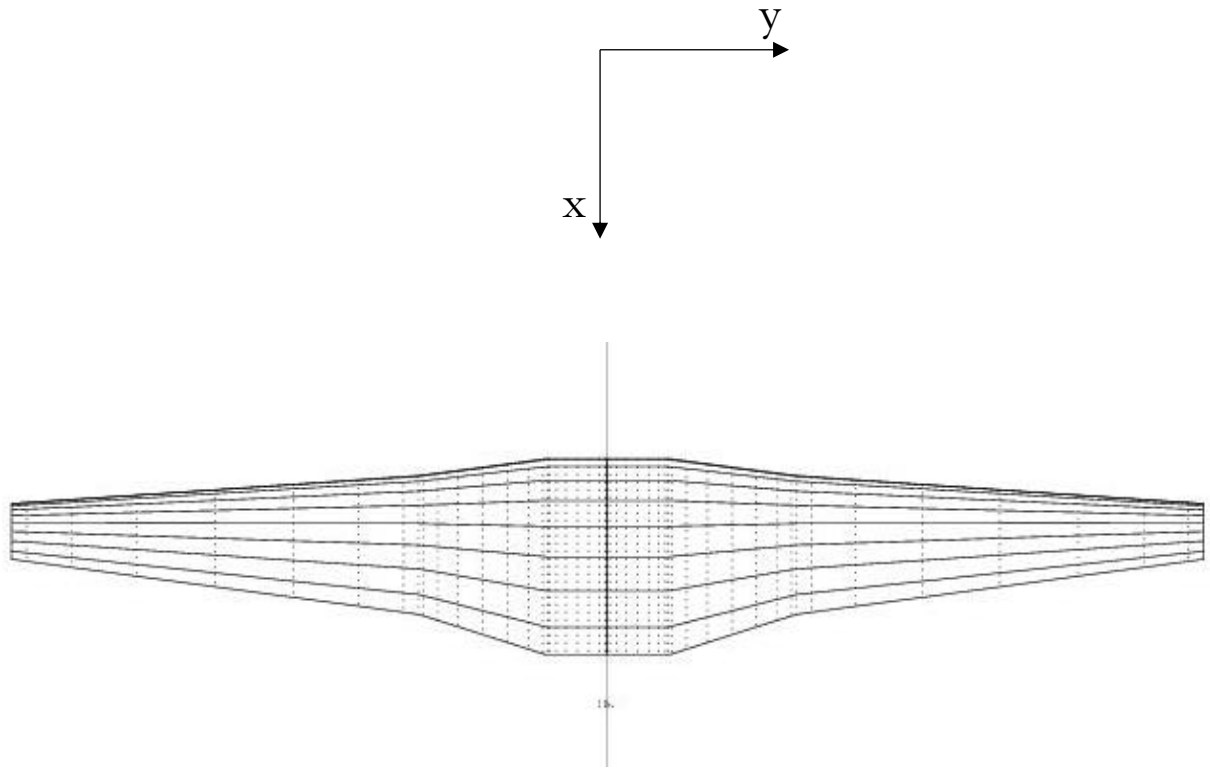
```
#****************************************
#****************************************
#      DEFINIZIONE ALA [1]
#****************************************
#****************************************
SURFACE       ! comando di creazione nuova superficie
ala           ! nome univoco della surface
8 2           ! n° pannelli in corda    tipo di distribuzione
YDUPLICATE    ! comando 'specchio' rispetto ad y
0             ! coordinata y per YDUPLICATE
#
ANGLE        ! comando angolo di calettamento SURFACE
0             ! valore del calettamento
```



Input file

Definition of the sections of the lifting surfaces

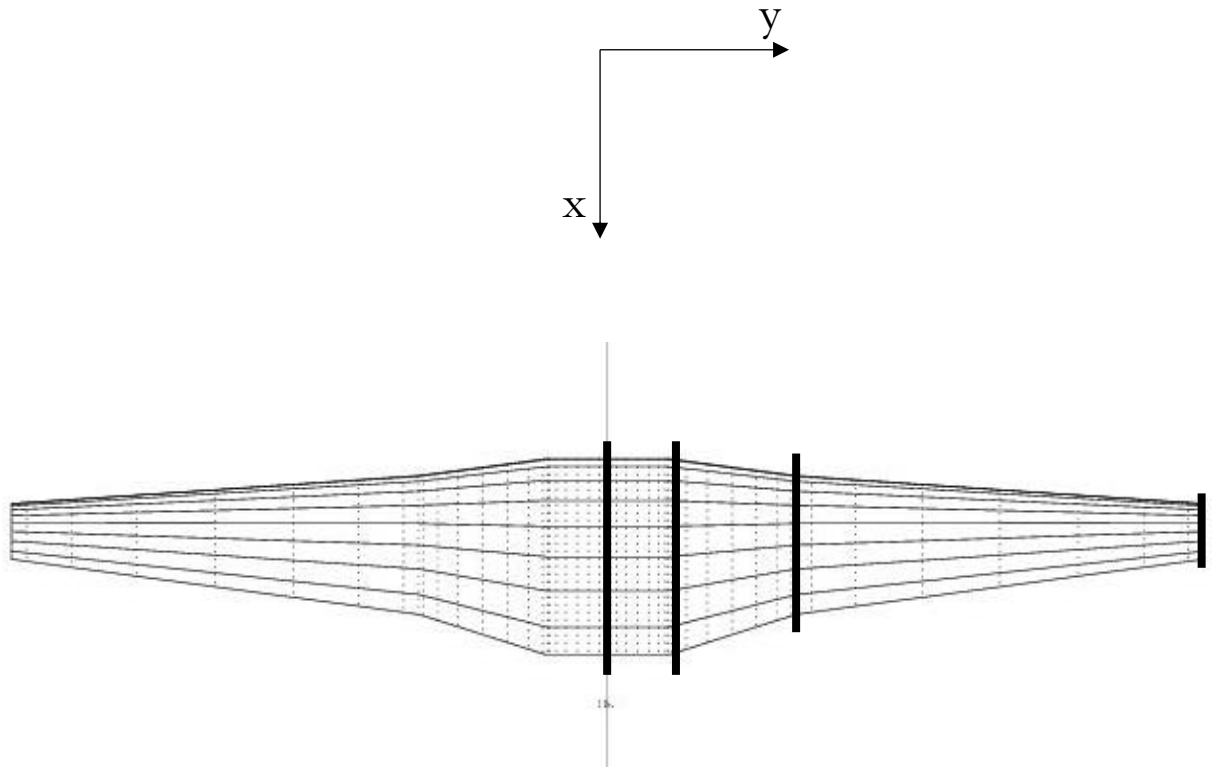
```
!-------------------------------------------------------------
SECTION      ! comando di creazione nuova sezione
# Xle      Yle     Zle       Chord    Ainc Nspanwise Space
9.12e+00    0     3.125    4.71e+00     0      8       1
AFILE        ! comando di assegnazione coordinate profilo
43018.dat    ! nome file dat coordinate profilo
!-------------------------------------------------------------
!-------------------------------------------------------------
SECTION
# Xle      Yle     Zle       Chord    Ainc Nspanwise Space
9.12e+00 1.44e+00 3.125e+00 4.71e+00  3.90     8       1
AFILE
43018.dat
!-------------------------------------------------------------
!-------------------------------------------------------------
SECTION
# Xle      Yle     Zle       Chord    Ainc Nspanwise Space
9.53e+00 4.53e+00 3.125e+00 3.32e+00   3.9     8       1
AFILE
43018.dat
!-------------------------------------------------------------
!-------------------------------------------------------------
SECTION
# Xle      Yle     Zle       Chord    Ainc Nspanwise Space
1.02e+01 1.43e+01 3.125e+00 1.33e+00  9e-01    8       1
AFILE
43018.dat
!-------------------------------------------------------------
```



Input file

Definition of the sections of the lifting surfaces

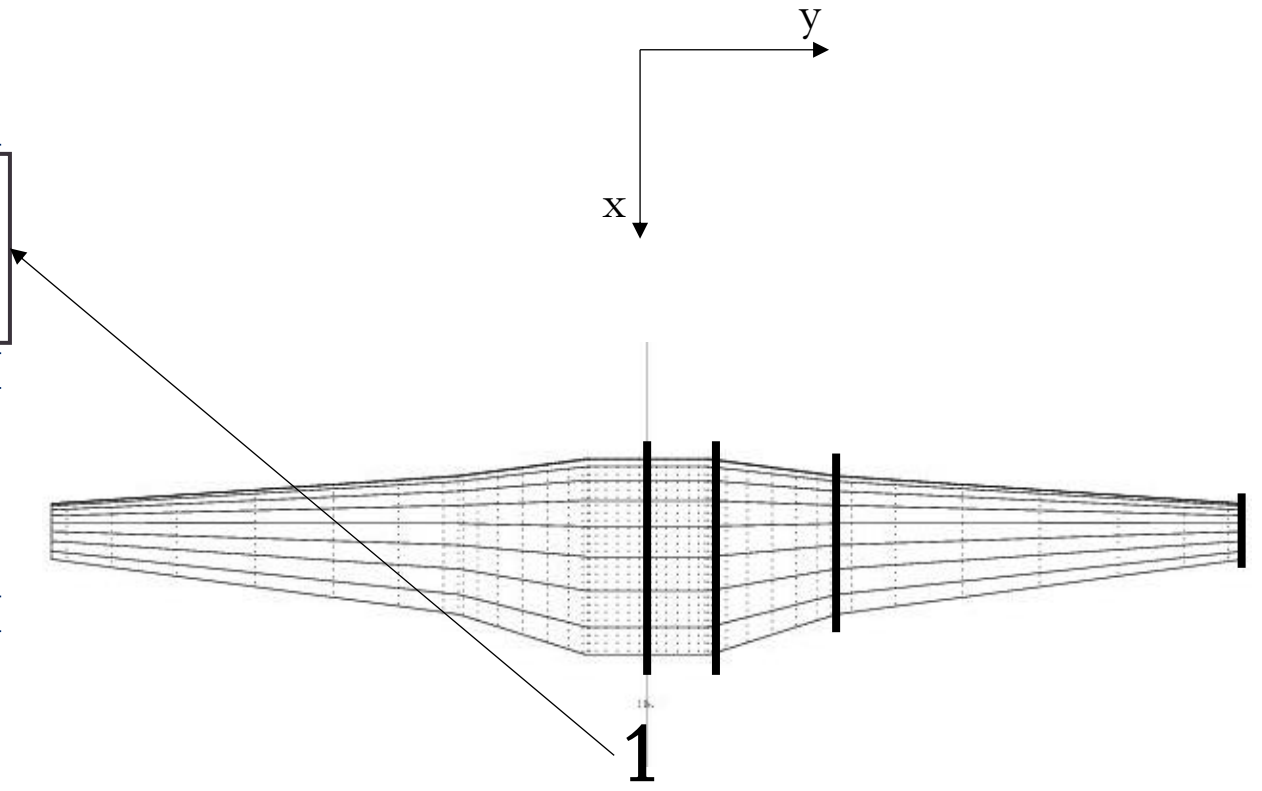
```
!---------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
9.12e+00     0      3.125     4.71e+00      0       8        1
AFILE
43018.dat
!---------------------------------------------------------
!---------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
9.12e+00 1.44e+00 3.125e+00 4.71e+00   3.90      8        1
AFILE
43018.dat
!---------------------------------------------------------
!---------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
9.53e+00 4.53e+00 3.125e+00 3.32e+00    3.9      8        1
AFILE
43018.dat
!---------------------------------------------------------
!---------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
1.02e+01 1.43e+01 3.125e+00 1.33e+00   9e-01     8        1
AFILE
43018.dat
!---------------------------------------------------------
```



Input file

Definition of the sections of the lifting surfaces

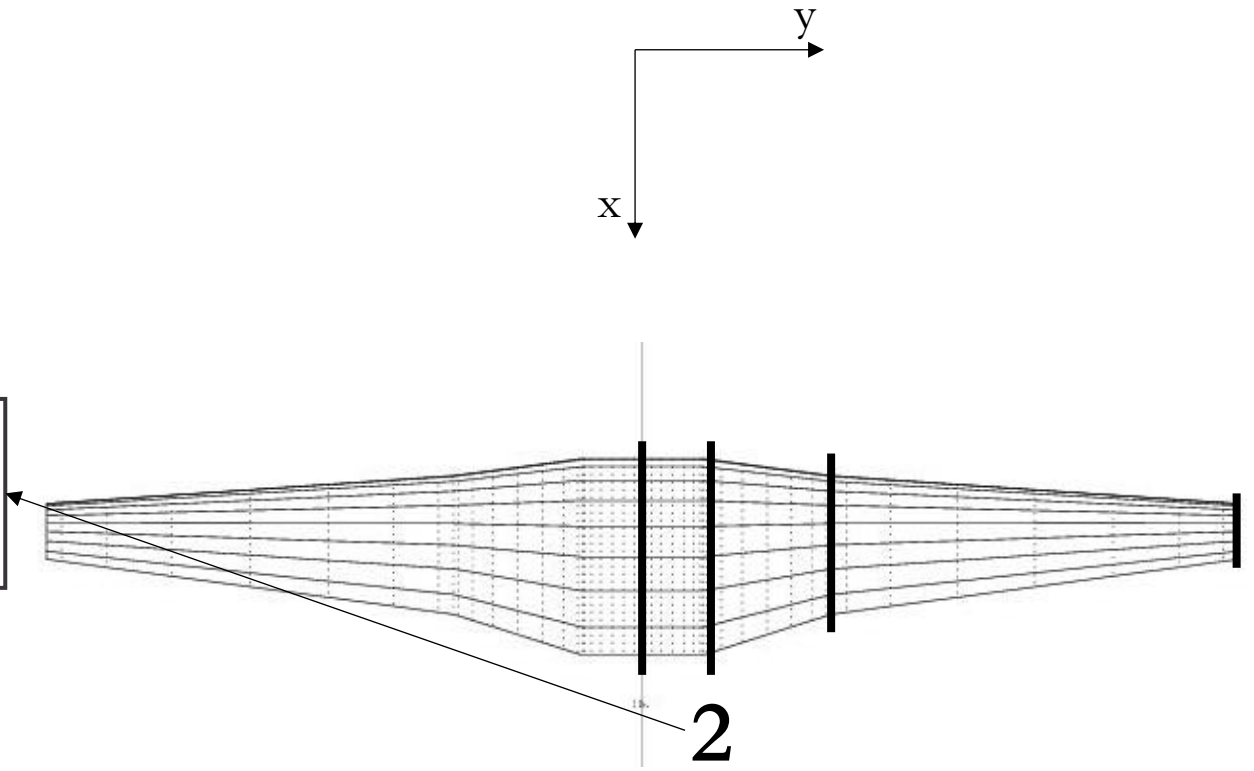
```
!-------------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
9.12e+00     0      3.125     4.71e+00      0       8        1
AFILE
43018.dat
!-------------------------------------------------------------
!-------------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
9.12e+00 1.44e+00 3.125e+00 4.71e+00   3.90      8        1
AFILE
43018.dat
!-------------------------------------------------------------
!-------------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
9.53e+00 4.53e+00 3.125e+00 3.32e+00    3.9      8        1
AFILE
43018.dat
!-------------------------------------------------------------
!-------------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
1.02e+01 1.43e+01 3.125e+00 1.33e+00   9e-01     8        1
AFILE
43018.dat
!-------------------------------------------------------------
```



Input file

Definition of the sections of the lifting surfaces

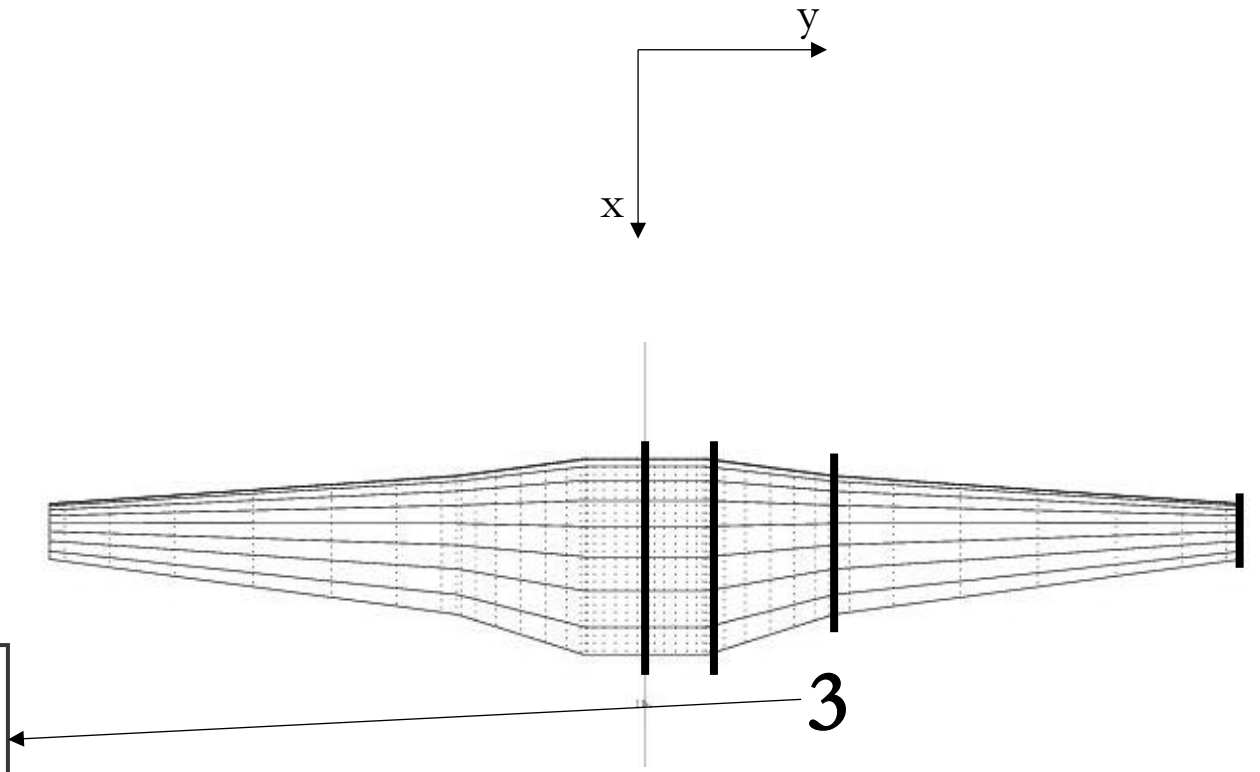
```
!-------------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
9.12e+00     0      3.125     4.71e+00      0       8        1
AFILE
43018.dat
!-------------------------------------------------------------
!-------------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
9.12e+00 1.44e+00 3.125e+00 4.71e+00   3.90      8        1
AFILE
43018.dat
!-------------------------------------------------------------
!-------------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
9.53e+00 4.53e+00 3.125e+00 3.32e+00    3.9      8        1
AFILE
43018.dat
!-------------------------------------------------------------
!-------------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
1.02e+01 1.43e+01 3.125e+00 1.33e+00   9e-01     8        1
AFILE
43018.dat
!-------------------------------------------------------------
```



Input file

Definition of the sections of the lifting surfaces

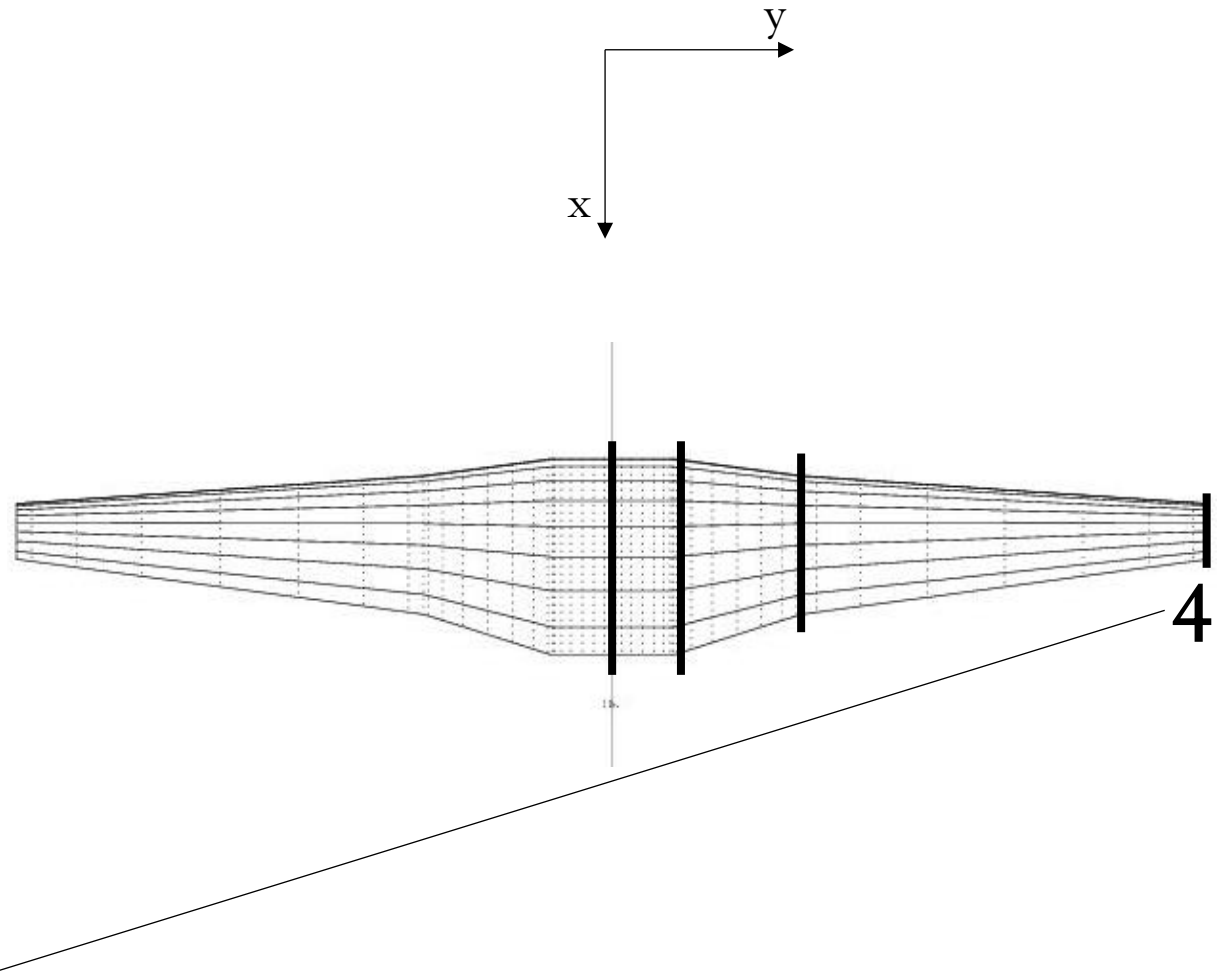
```
!------------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
9.12e+00     0      3.125     4.71e+00      0       8        1
AFILE
43018.dat
!------------------------------------------------------------
!------------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
9.12e+00 1.44e+00 3.125e+00 4.71e+00   3.90      8        1
AFILE
43018.dat
!------------------------------------------------------------
!------------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
9.53e+00 4.53e+00 3.125e+00 3.32e+00    3.9      8        1
AFILE
43018.dat
!------------------------------------------------------------
!------------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
1.02e+01 1.43e+01 3.125e+00 1.33e+00   9e-01     8        1
AFILE
43018.dat
!------------------------------------------------------------
```



Input file

Definition of the sections of the lifting surfaces

```
!---------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
9.12e+00     0      3.125     4.71e+00      0       8        1
AFILE
43018.dat
!---------------------------------------------------------
!---------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
9.12e+00 1.44e+00 3.125e+00 4.71e+00   3.90      8        1
AFILE
43018.dat
!---------------------------------------------------------
!---------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
9.53e+00 4.53e+00 3.125e+00 3.32e+00    3.9      8        1
AFILE
43018.dat
!---------------------------------------------------------
!---------------------------------------------------------
SECTION
# Xle       Yle      Zle        Chord     Ainc Nspanwise Space
1.02e+01 1.43e+01 3.125e+00 1.33e+00   9e-01     8        1
AFILE
43018.dat
!---------------------------------------------------------
```



Basic controls

Load: loads input file

Oper: set operating case

G: plot geometry

A: set alpha

D_n: set n-deflection

X: execute operating case

post-processing

O: options

ST: stability derivatives

T: plot Trefftz plane

End