EWADE 2011

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Development of a Software for Aircraft Preliminary Design and Analysis (ADAS)

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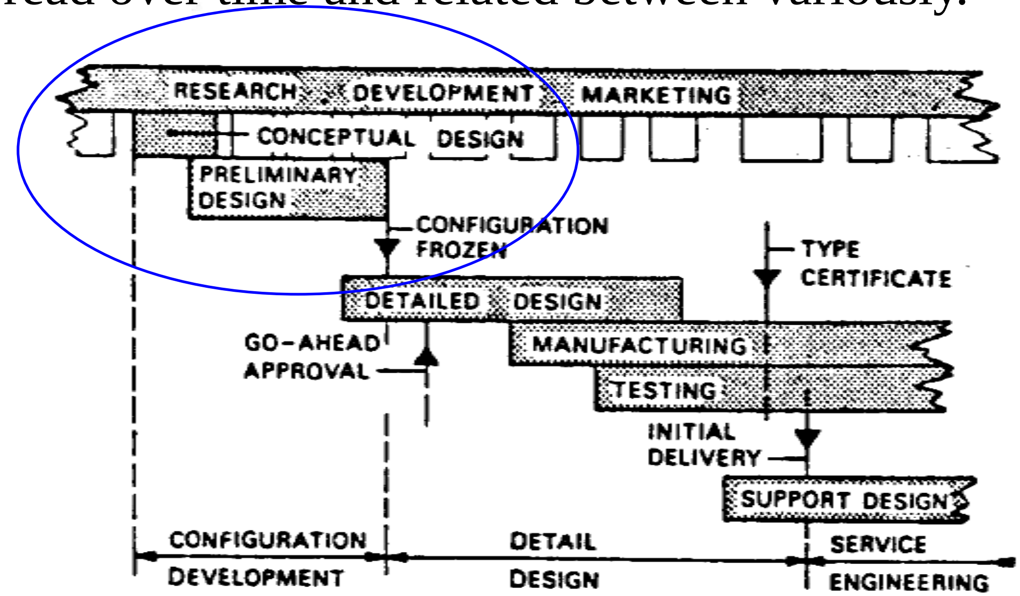
Aircraft Design

Aircraft Design is a complex process, articulated in many different stages spread over time and related between variously.



The preliminary/conceptual design is intended as an objective determination of the main geometric parameters, aerodynamic, structural, propulsion, stability and control characteristics useful to the initial definition of the new project, starting from the knowledge of the mission specifics.

ADAS 1.0

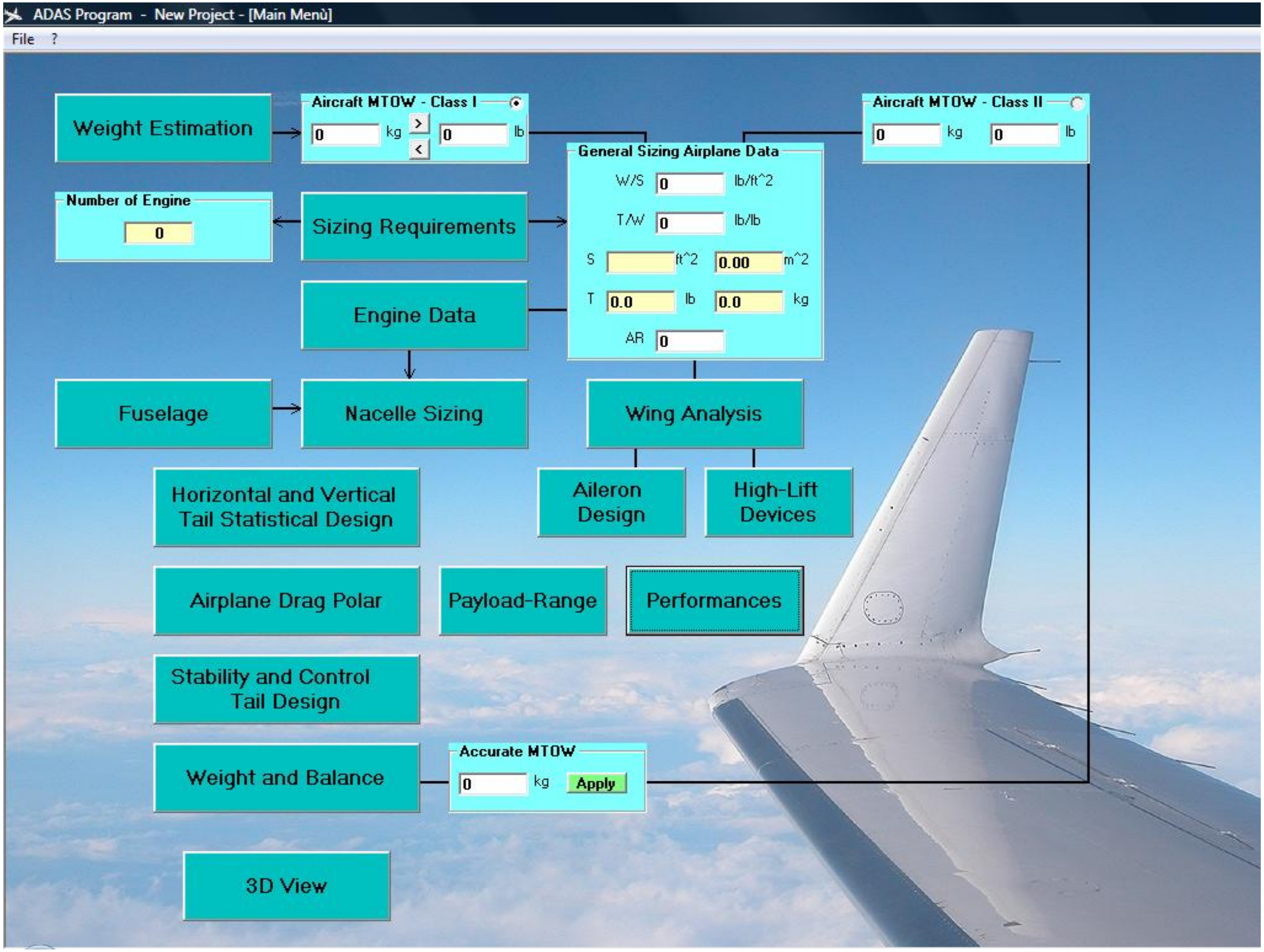
Aircraft Design and Analysis Software

ADAS 1.0

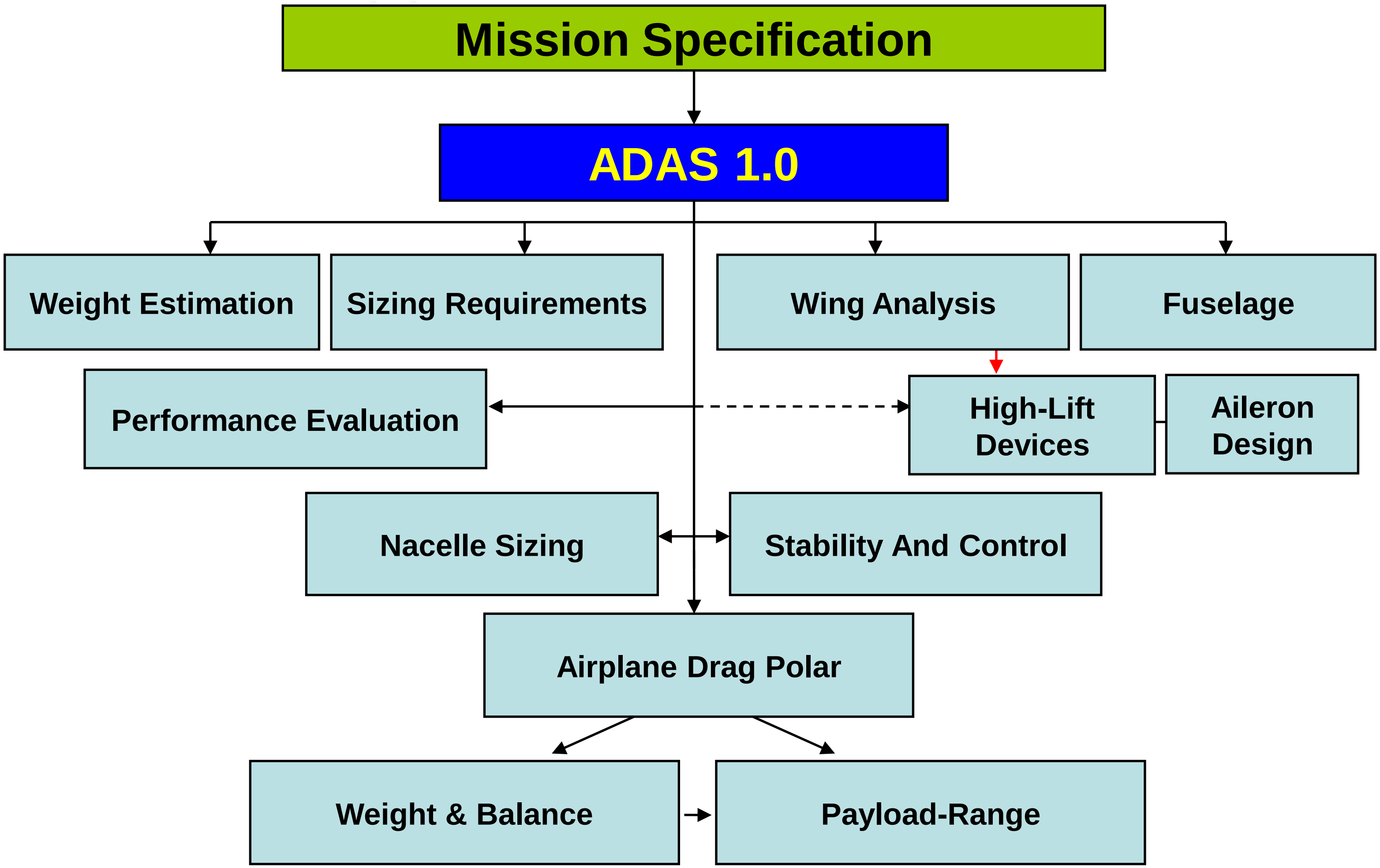
Aircraft Design and Analysis Software

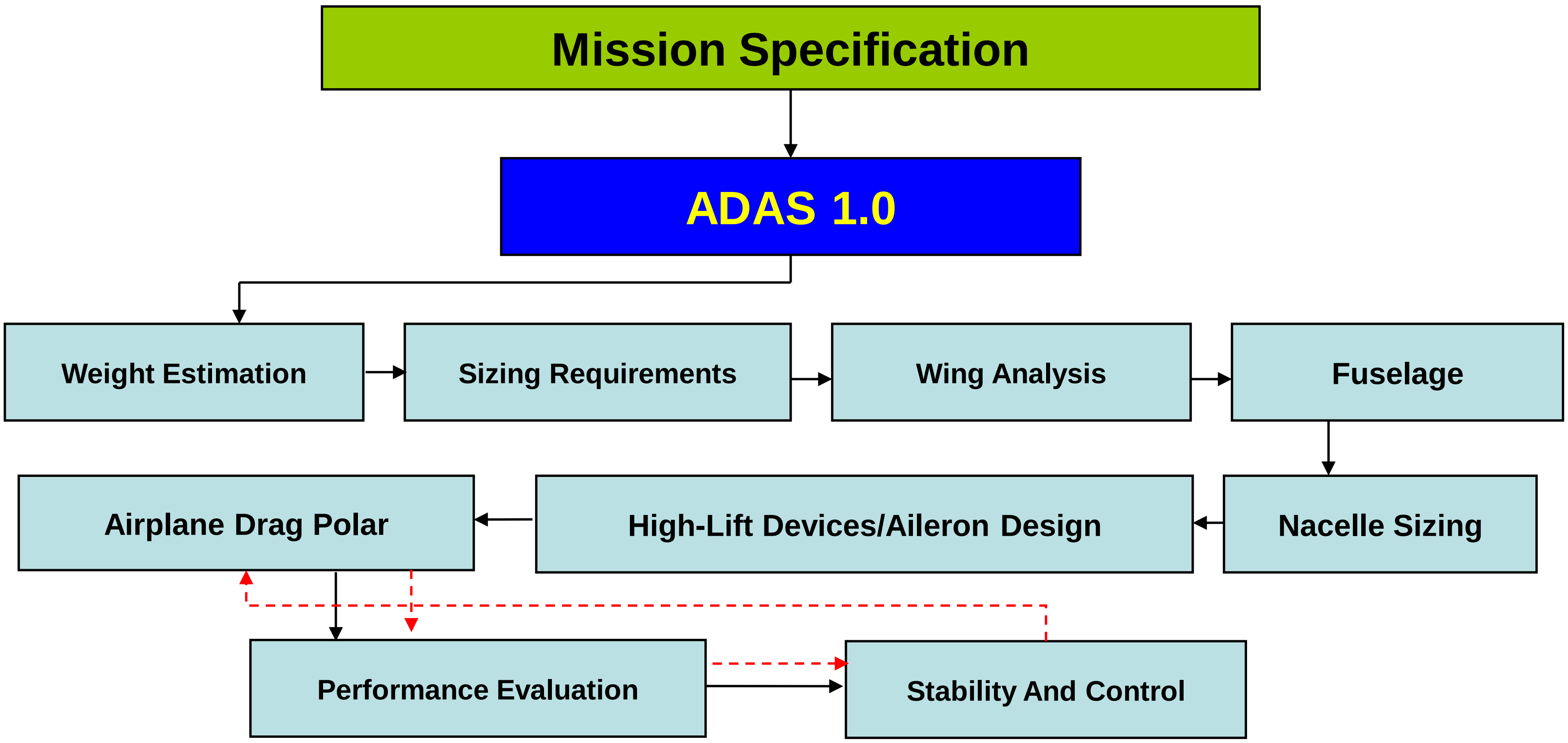
A Software for the conceptual/preliminary design of transport aircraft (Transport Jet, regional TBP, business jet) and light aircraft

- Written in *VISUAL BASIC (80 form x 1000 Average code lines)*
- *User Friendly GUI* and useble on any *Microsoft Windows Platform*
- Indipendent calculation modules
- .txt Output Files
- Valid for Teaching and Professional applications
- Development started 2005


ADAS Program - New Project - [Main Menù]
File ?
Weight Estimation
Aircraft MTOW - Class I
0 kg
0 lb
Aircraft MTOW - Class II
0 kg
0 lb
General Sizing Airplane Data
W/S 0 lb/ft^2
T/W 0 lb/lb
S ft^2 0.00 m^2
T 0.0 lb 0.0 kg
AR 0
Number of Engine
0
Sizing Requirements
Engine Data
Fuselage
Nacelle Sizing
Wing Analysis
Horizontal and Vertical Tail Statistical Design
Aileron Design
High-Lift Devices
Airplane Drag Polar
Payload-Range
Performances
Stability and Control Tail Design
Weight and Balance
Accurate MTOW
0 kg
Apply
3D View

ADAS Flow Chart

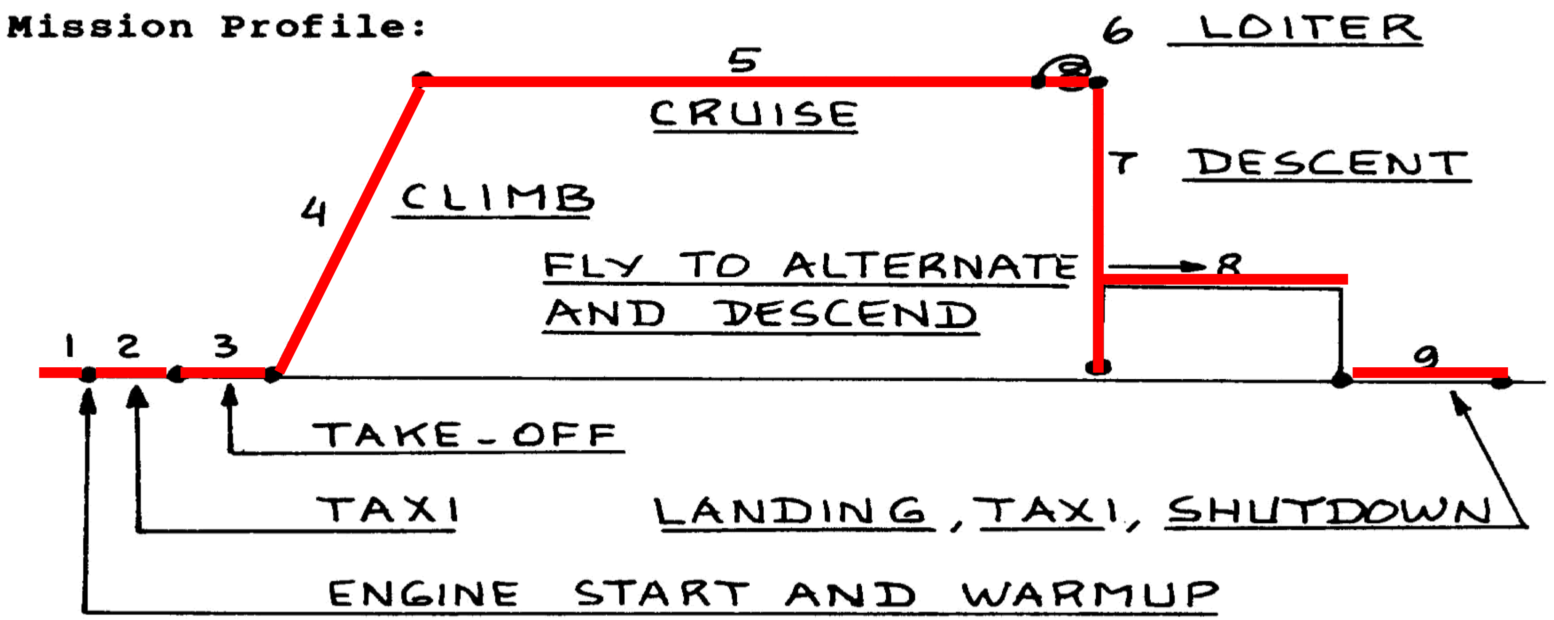



Mission Specification
ADAS 1.0
Weight Estimation
Sizing Requirements
Wing Analysis
Fuselage
Nacelle Sizing
High-Lift Devices/Aileron Design
Airplane Drag Polar
Performance Evaluation
Stability And Control

ADAS Modules

- ***Weight Estimation:***

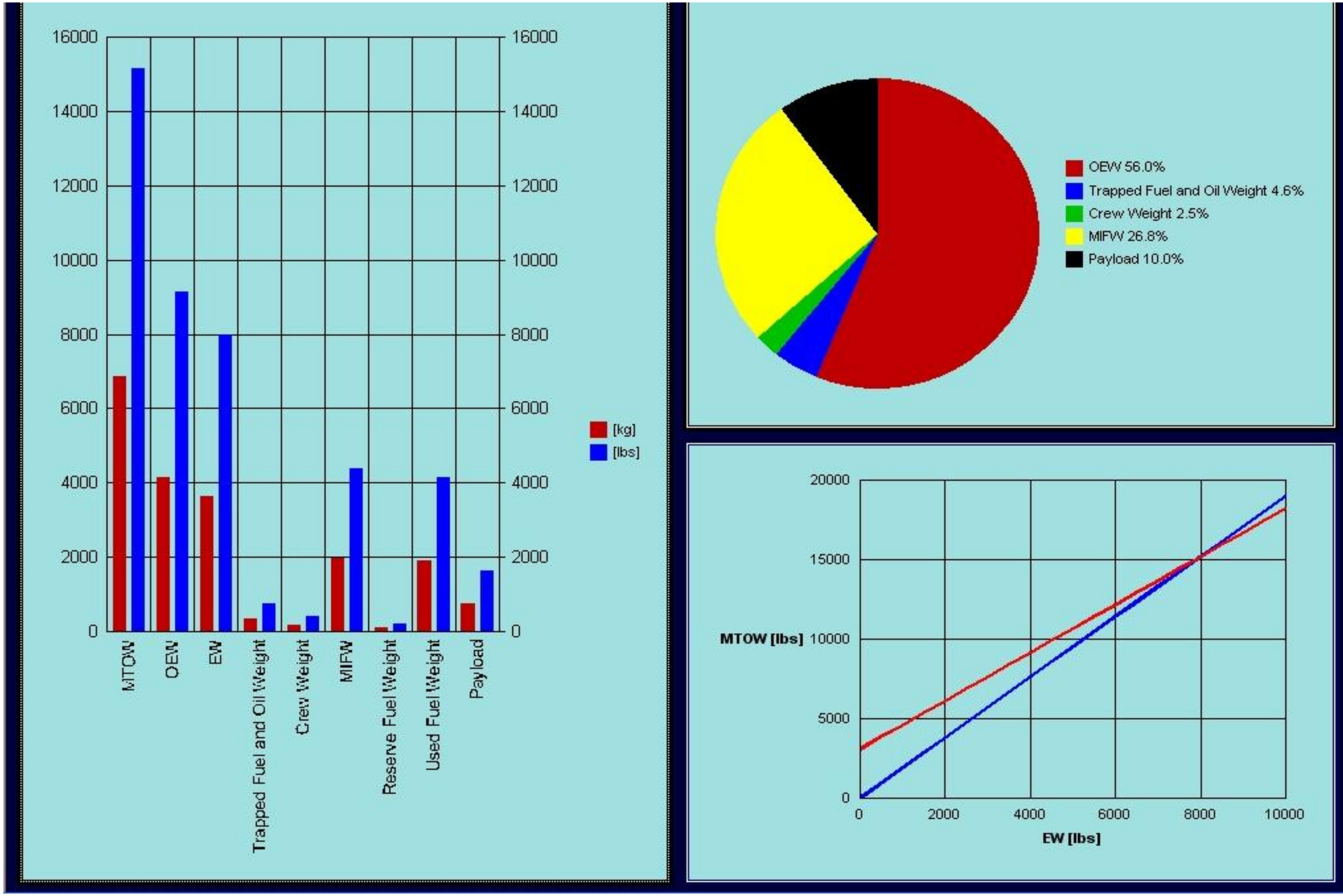
FUEL FRACTION METHOD



For any phase is possible to evaluate the fuel fraction: $\dfrac{W_{end}}{W_{start}}$

ADAS Modules

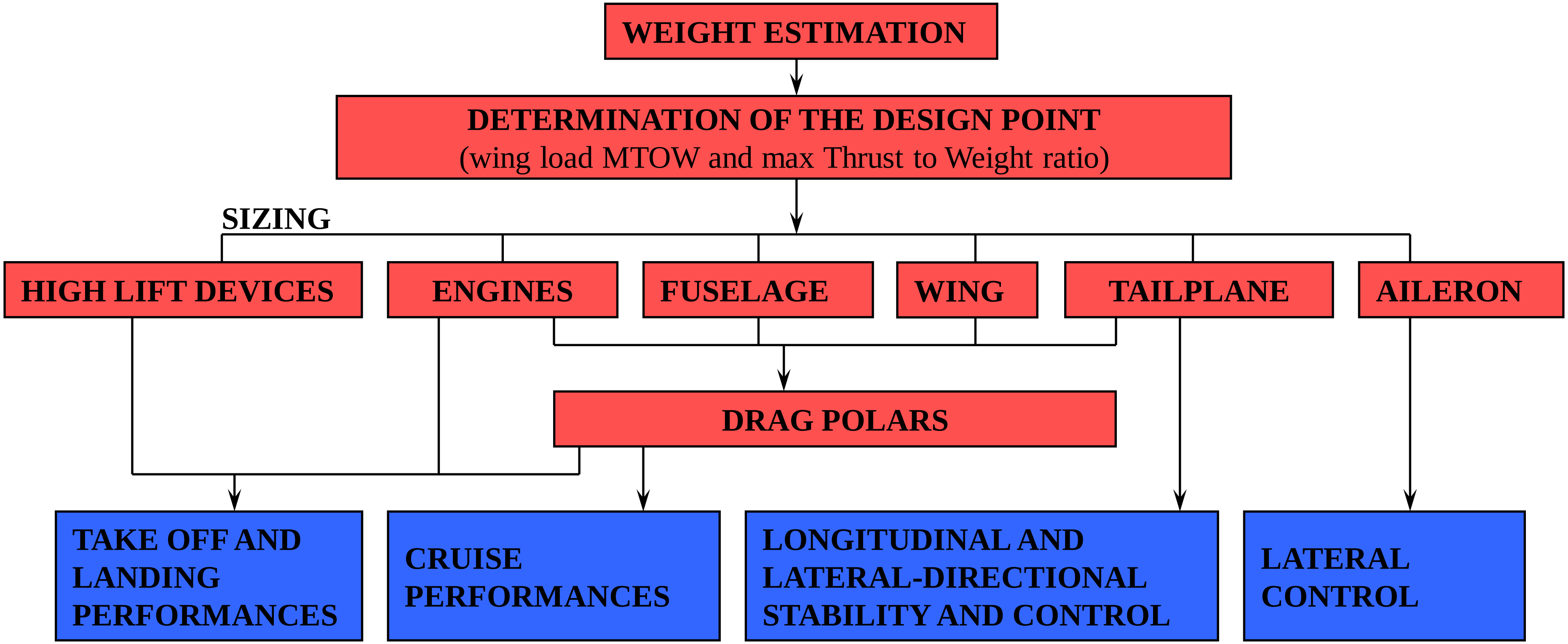
Example of results:



ADAS Modules

- *Sizing Requirements:*

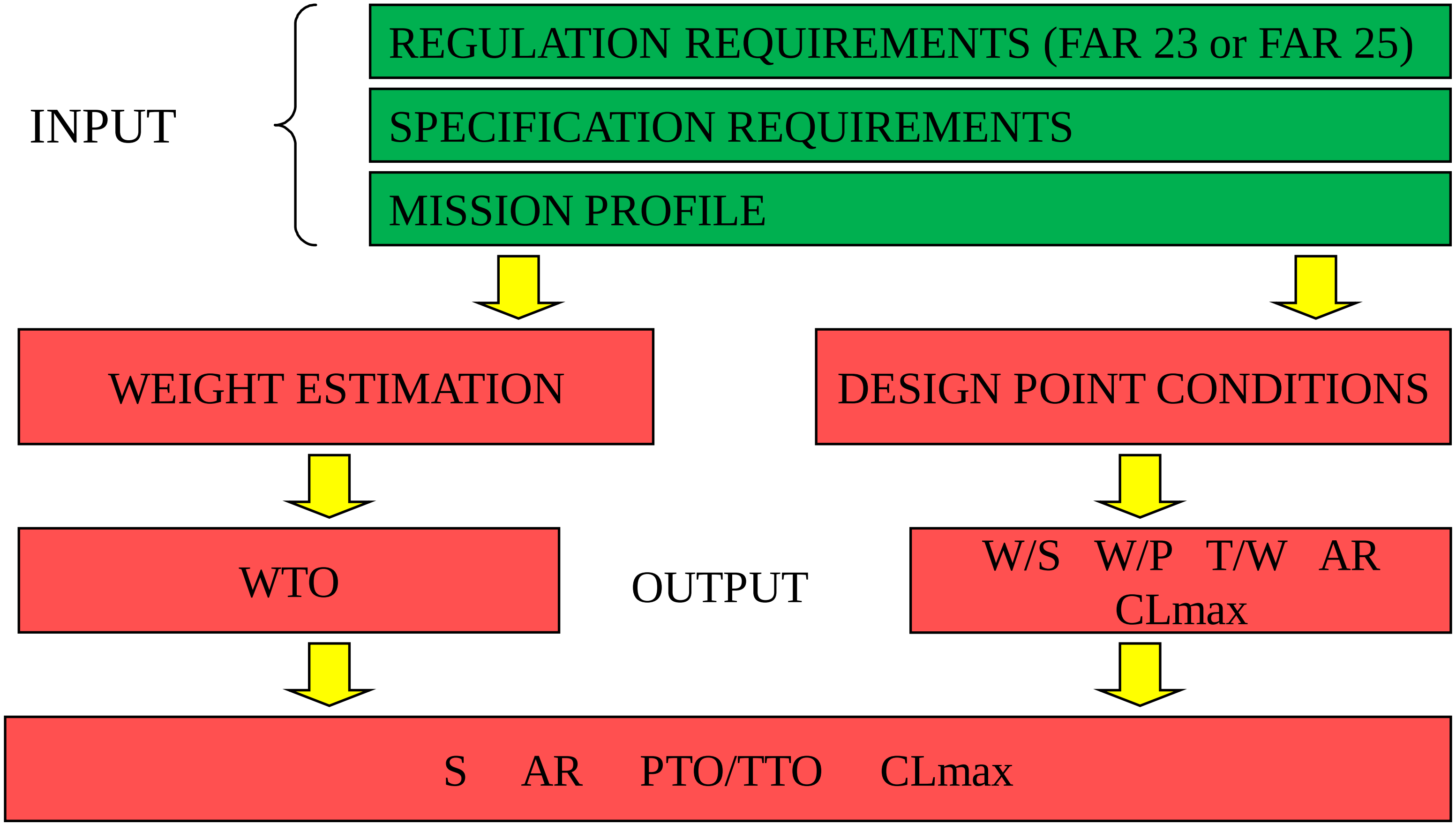
In this module will be estabilished the Design Point. That is very Important for the next Modules as here shown:



ADAS Modules

- ***Sizing Requirements:***

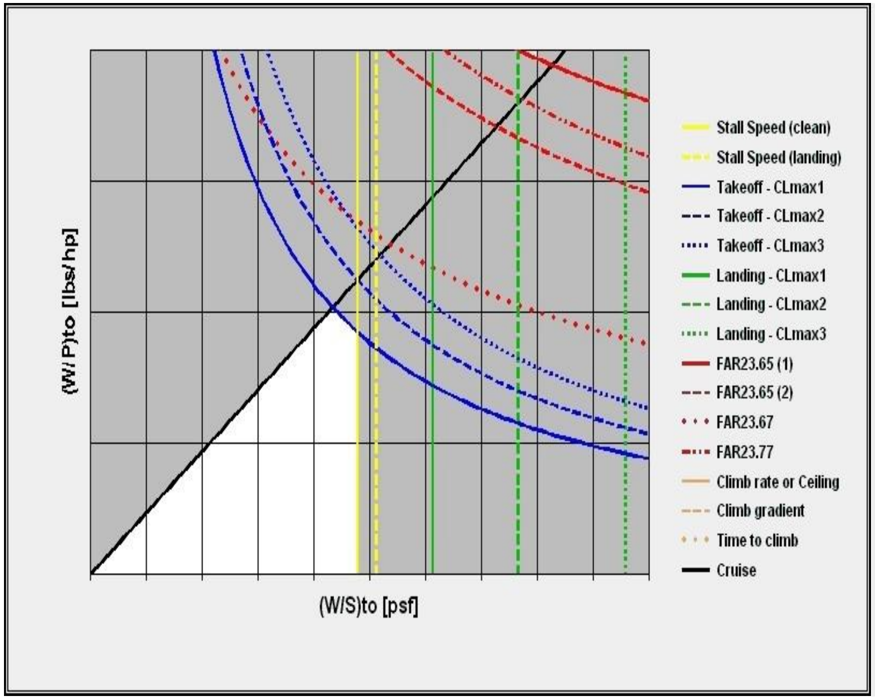
The method choosed for this module is the classical use of the FAR 23 and FAR 25, as shown by Roskam:



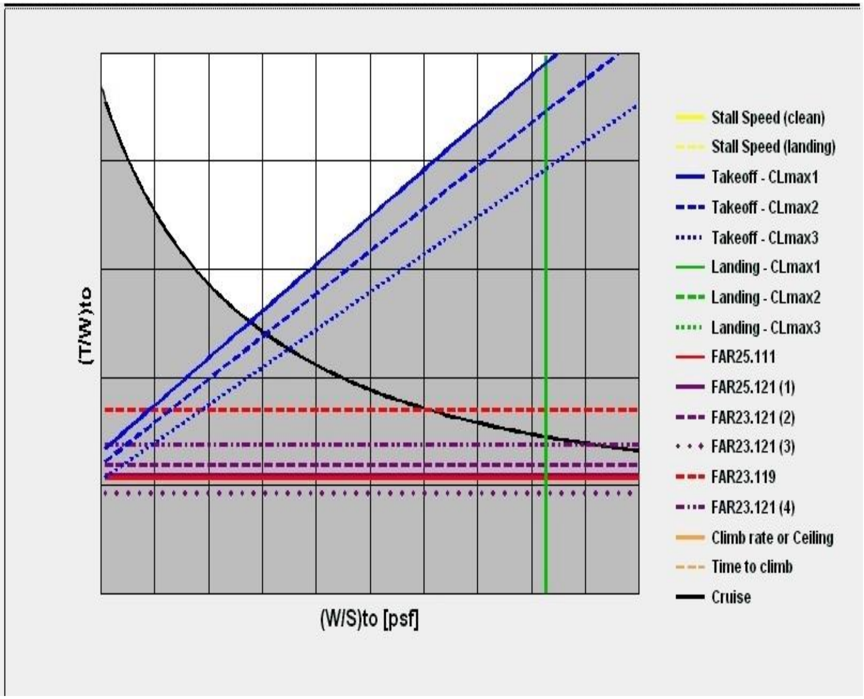
ADAS Modules

- ***Sizing Requirements:***

The Restrictions for the two type of FAR are summarized below:



Propeller Aircraft

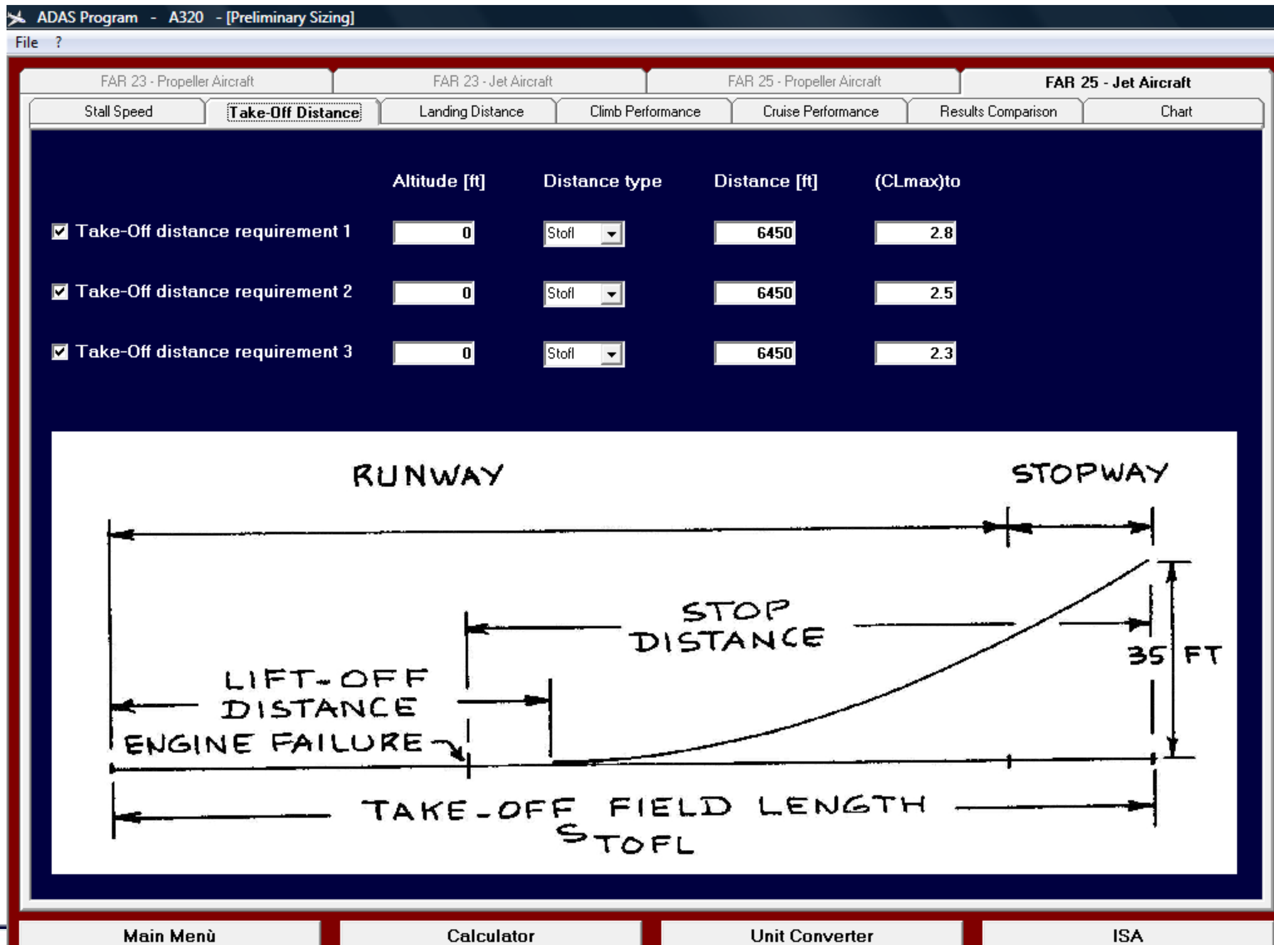


Jet Aircraft

ADAS Modules

- *Sizing Requirements:*

In ADAS all Data must be insert in Tabs. First choise is the FAR then there is one Tab for each Flight Condition, here FAR 25 JET is shown:



ADAS Modules

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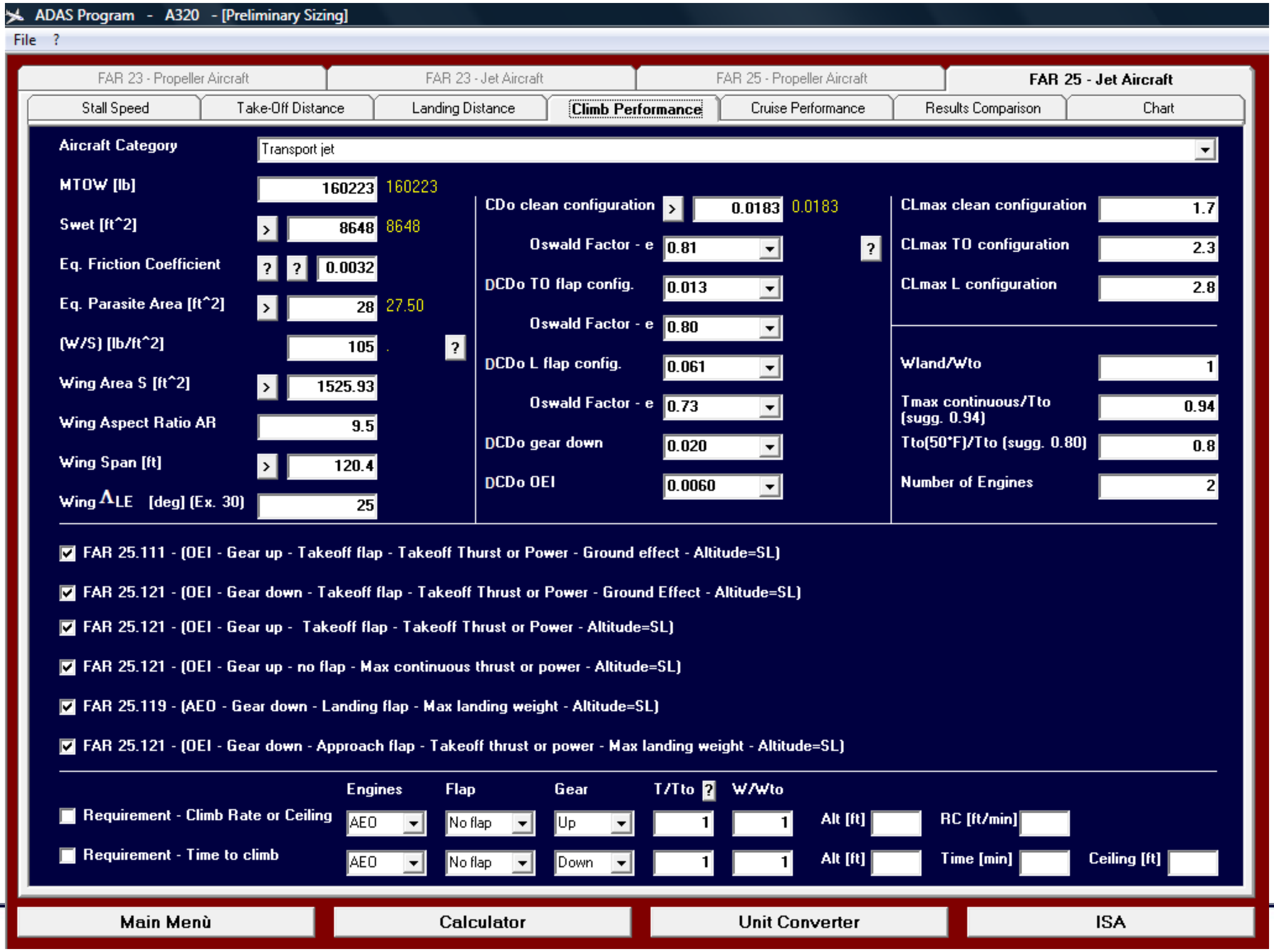
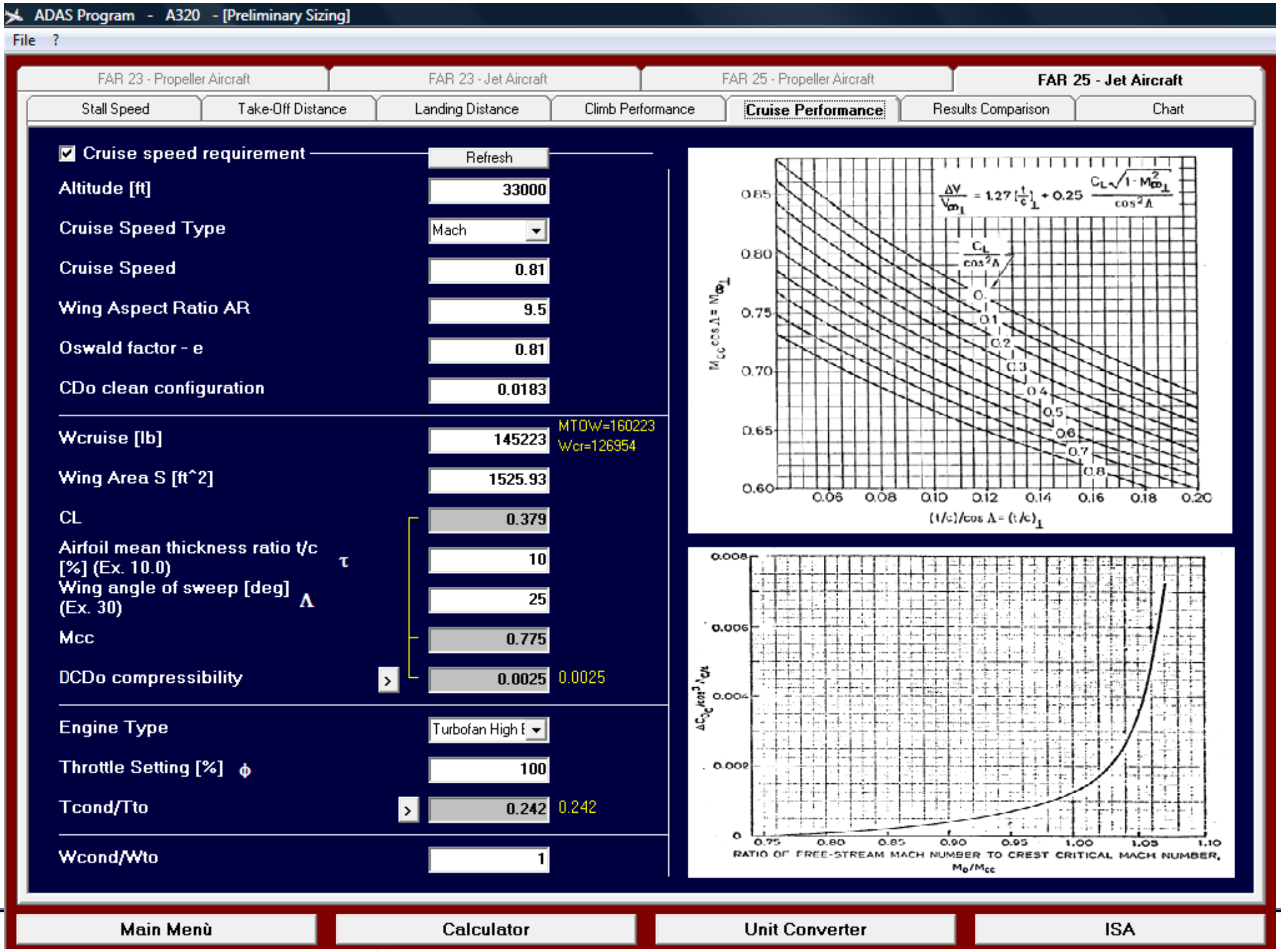


ADAS Modules

- *Sizing Requirements:*

In ADAS all Data must be insert in Tabs. First choise is the FAR then there is one Tab for each Flight Condition, here FAR 25 JET is shown:

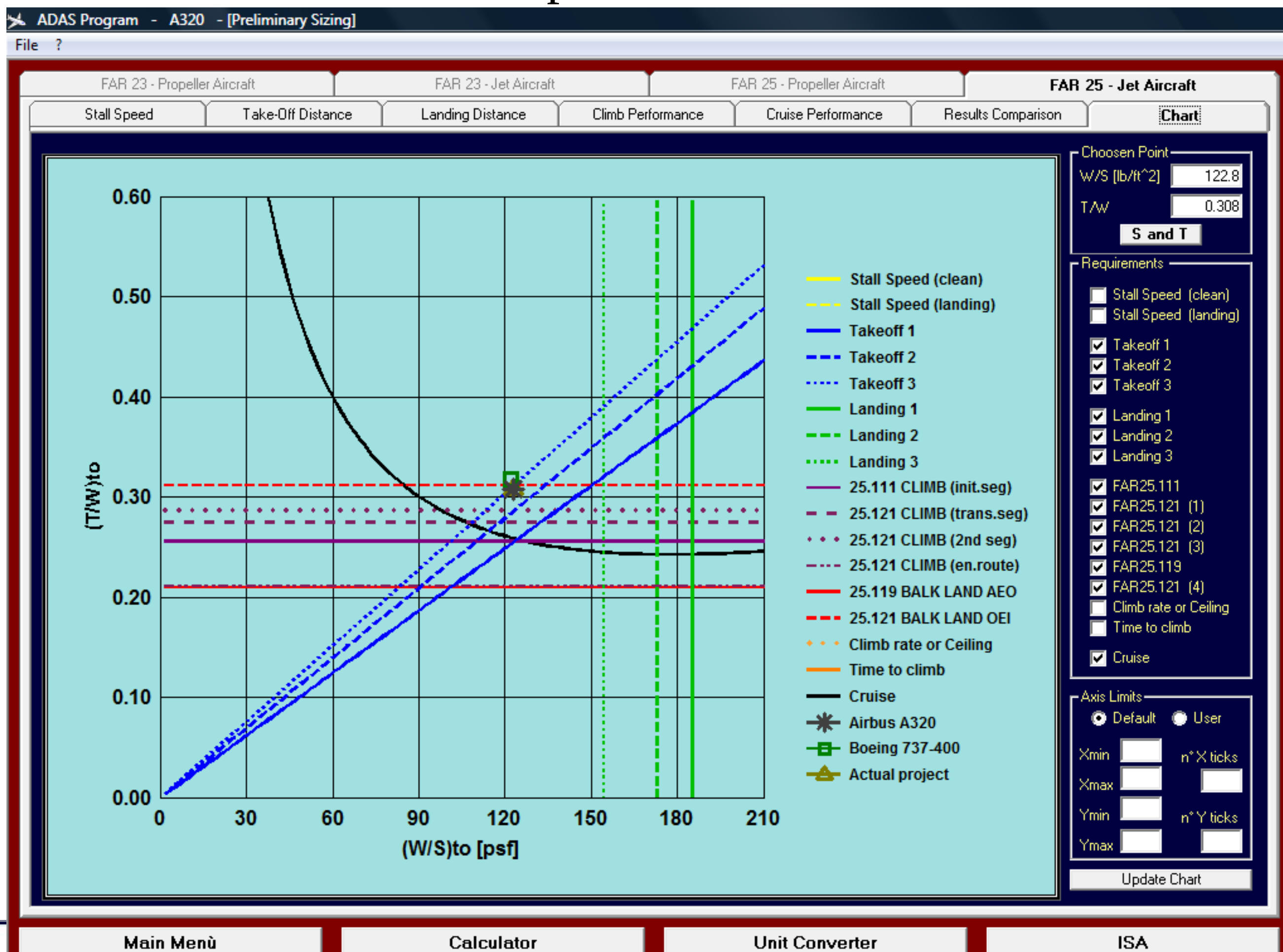


ADAS Modules

- *Sizing Requirements:*

When all required data has been entered it will be displayed:

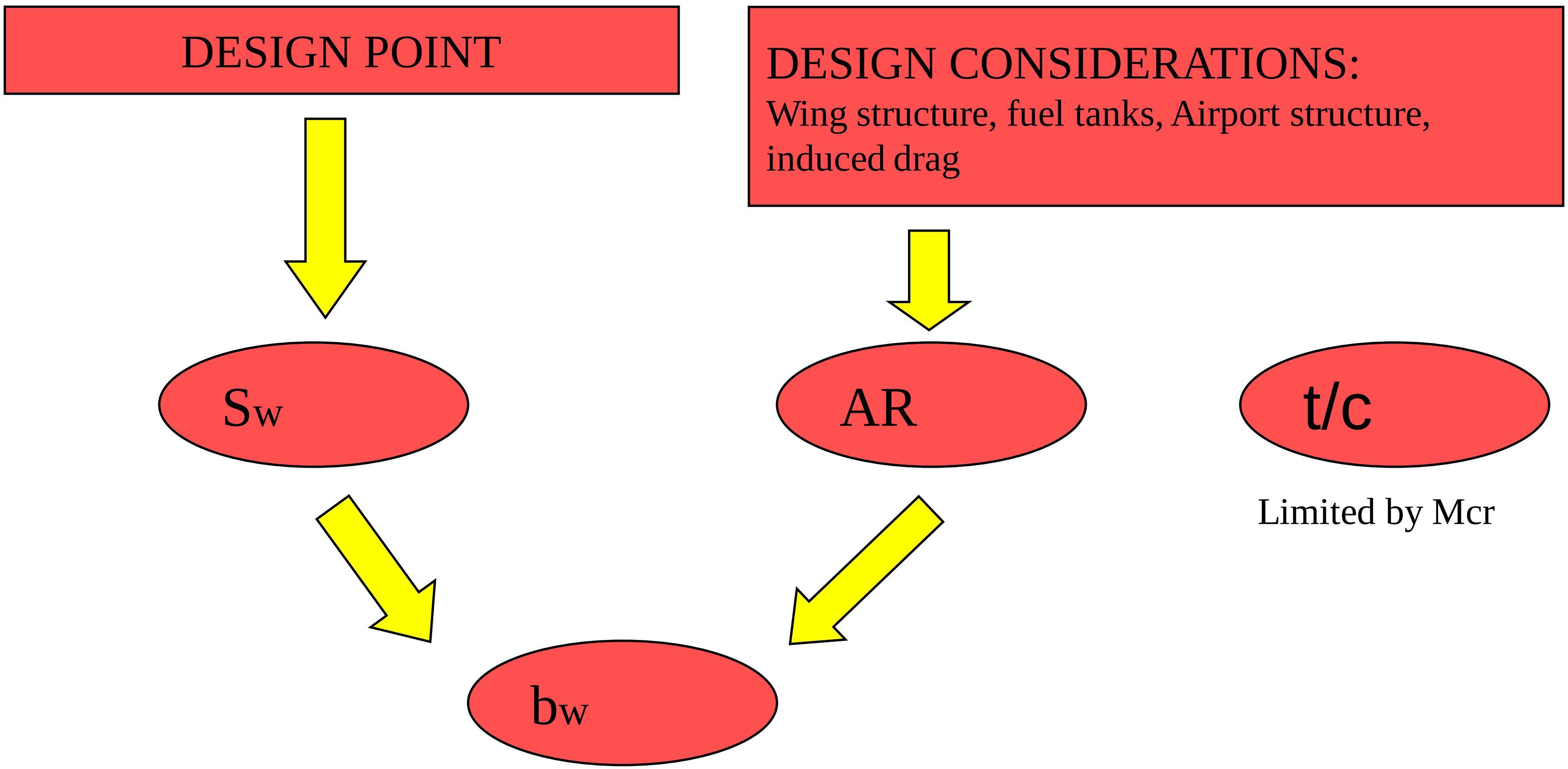
Then updating chart the requirements can be compared some similar aircraft from a Database to compare:



ADAS Modules

- ***Wing Analysis:***

This module allow to design and analyze any type of wings.
The first step is to decide the **Wing Planform**:



ADAS Modules

- ***Wing Analysis:***

Next step is to decide the aerodynamic and geometrical characteristics for the representative sections of the wing :

Section	y/(b/2)	Chord [m]	X l.e. [m]	Epsilon [°]	Alpha zl [°]	Xac/c	Cm ac	Clalpha[1/°]	Clmax	t/c	dy/c [%]	Cl*
1	0	2.7	0	0	-2	0.25	-0.02	0.11	1.5	0.12	2.6	1.1
2	0.3	2.7	0	-1	-2	0.25	-0.04	0.11	1.5	0.09	2.6	1.1
3	1	1.59	0.7	-2	-3	0.25	-0.06	0.11	1.5	0.09	2.6	1.1

Reynolds	Cd min. turb.	Cl0	Lam. Bucket	Cd0 Bucket	k factor	Cm 0.25c(Cl=0)	dCm 0.25c/dCl	Cl(Cm 0.25c n.l.)	Cm 0.25c(Clmax
2,000,000	0.006	0.5	0.2	0.006	0.01	-0.02	0	1	-0.048

This step can be done also automatically, by the command "Wing Planform Easy Creator" that help the user to create:

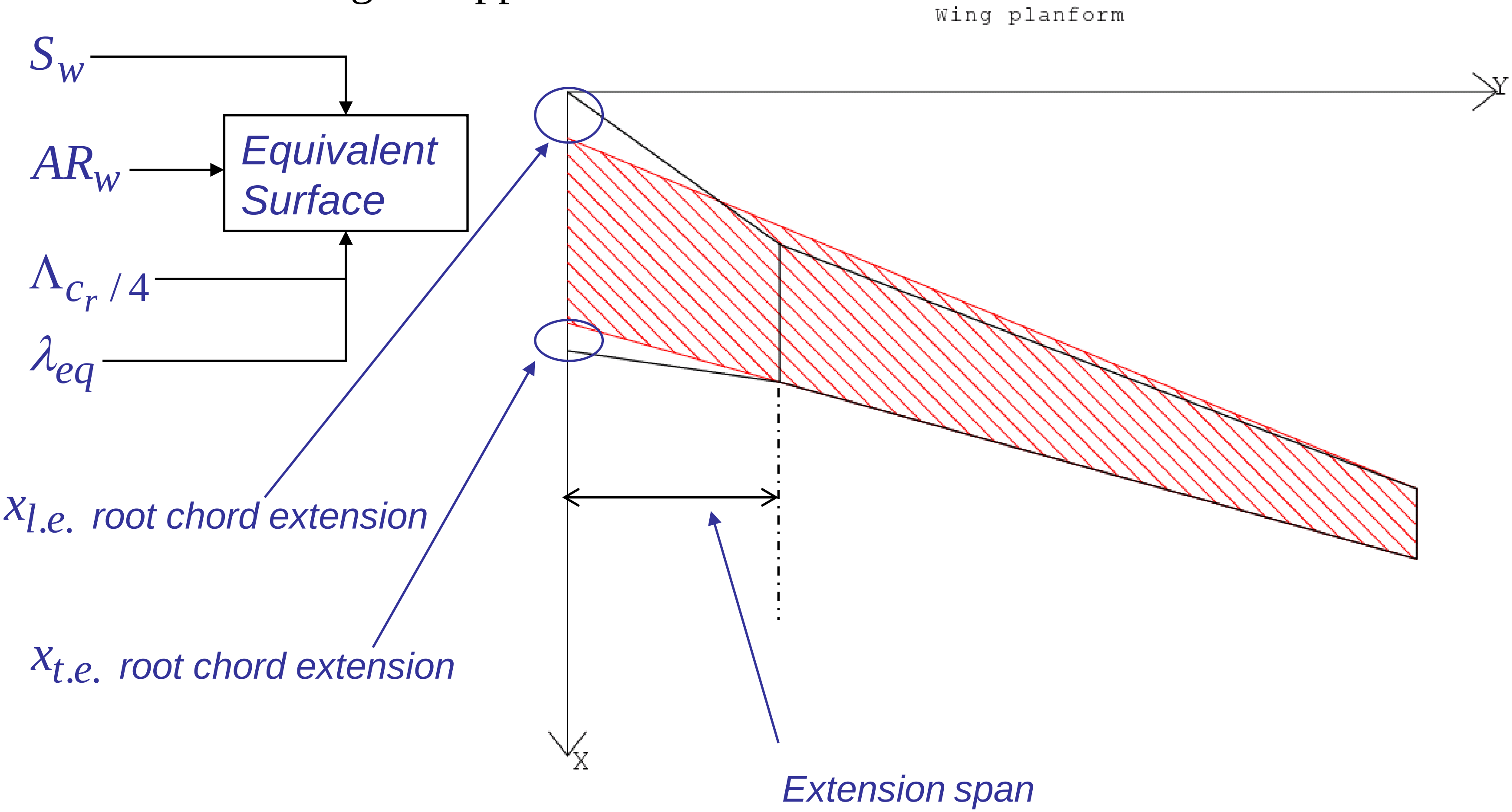
- STRAIGHT TAPERED WING

- CRANKED WING

ADAS Modules

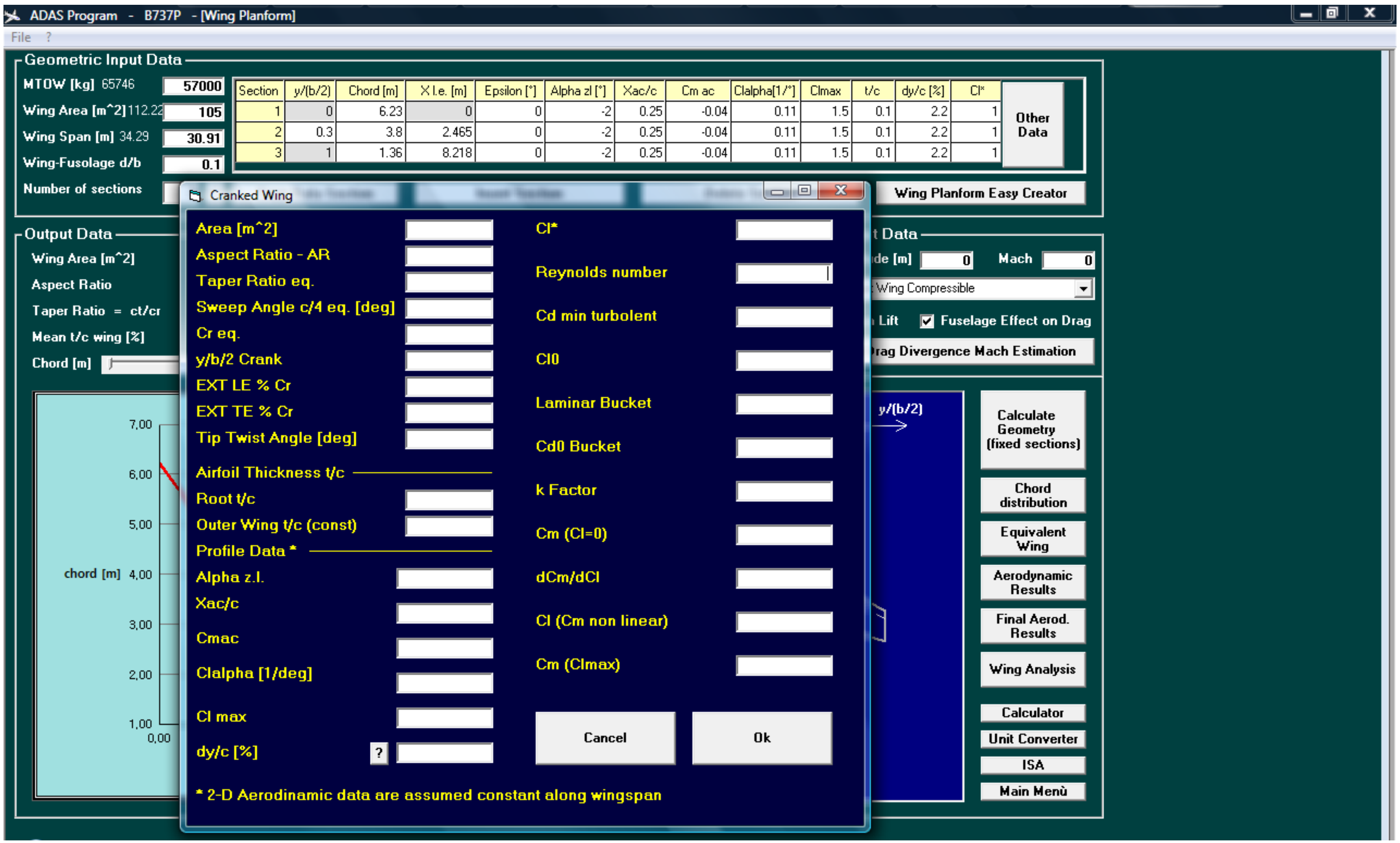
-***Wing Analysis:***

For Cranked wing the approach is sketched below:



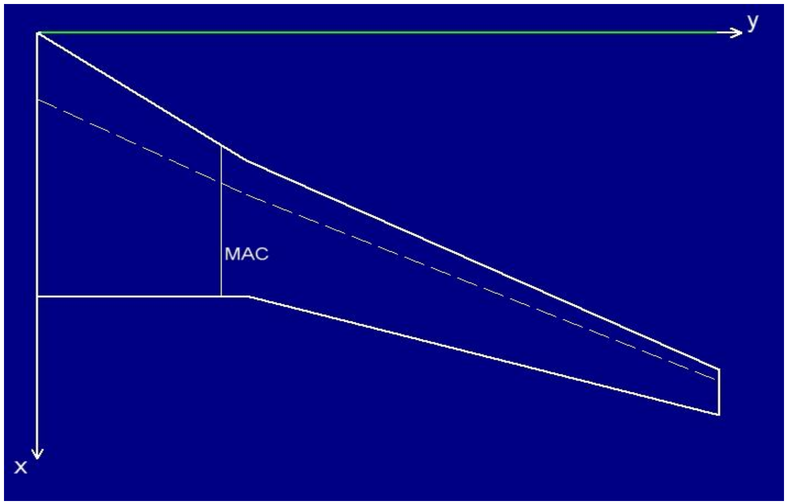
ADAS Modules

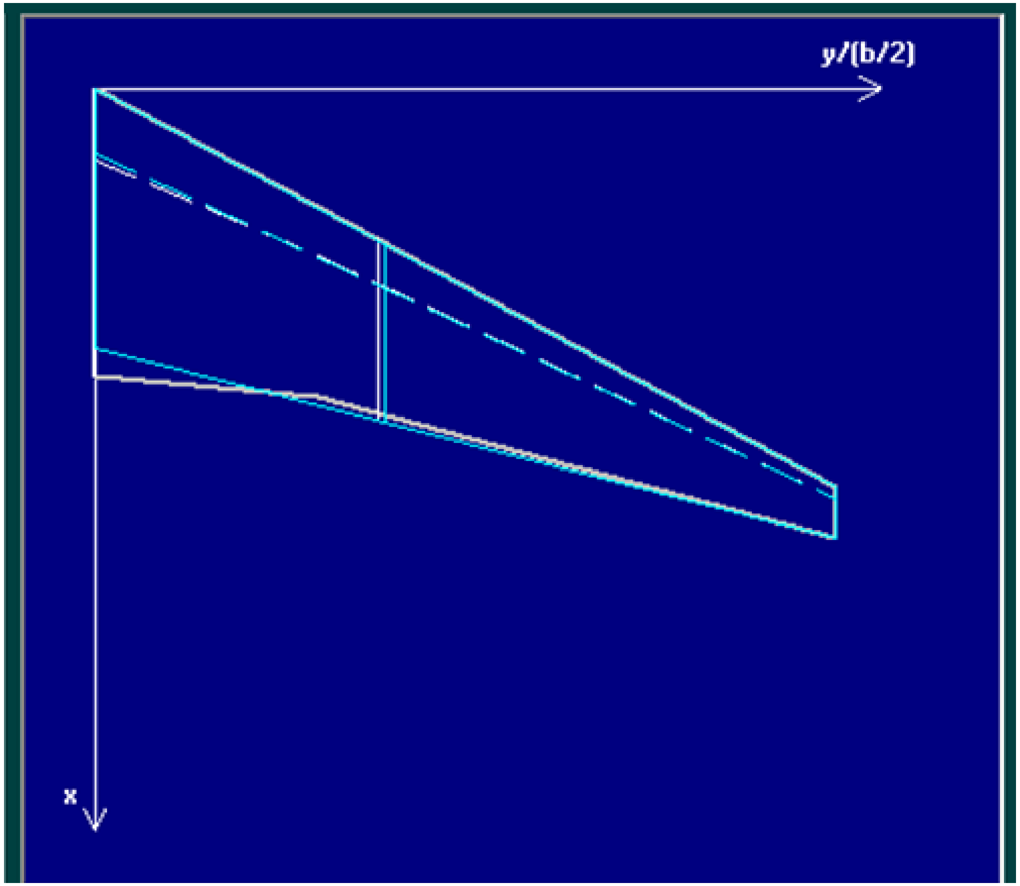
-*Wing Analysis:*



ADAS Modules

- *Wing Analysis:*



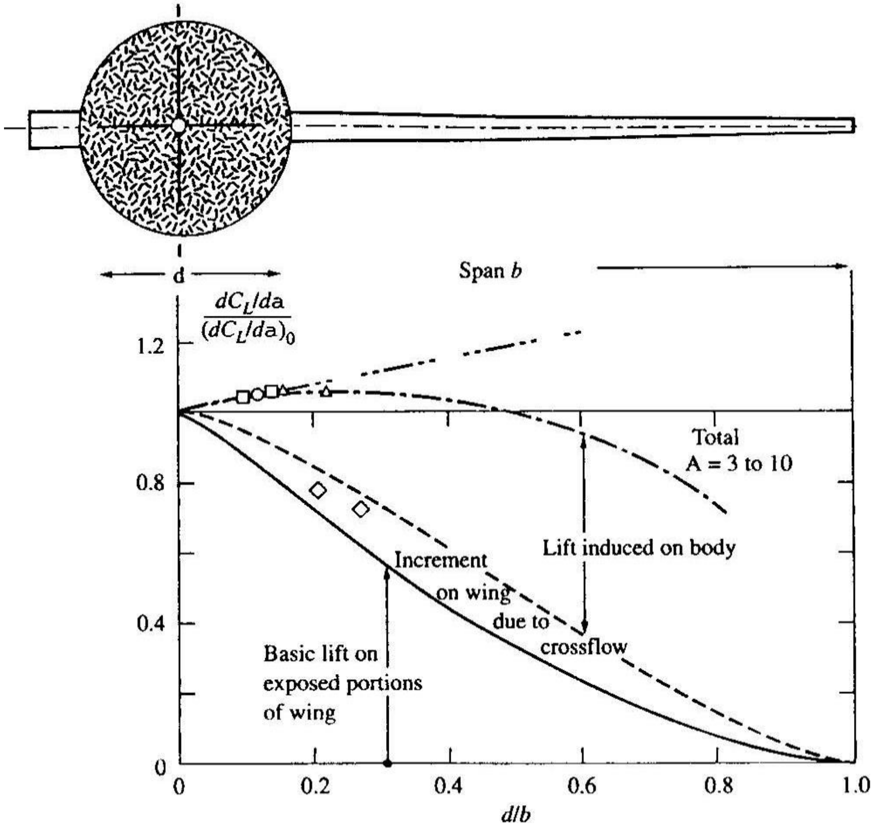


ADAS Modules

- *Wing Analysis:*

If required the correction for the presence of the fuselage is estimated

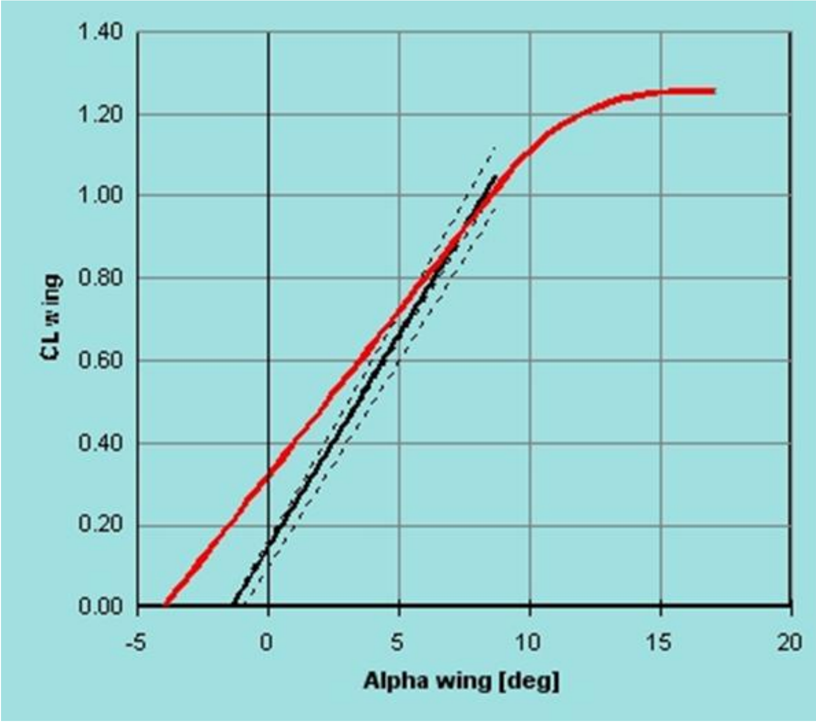
$$C_{L\alpha} = \frac{2 \cdot \pi \cdot AR}{2 + \sqrt{\frac{4 \cdot \pi^2 \cdot AR^2 \cdot \left(1 - M^2\right)^2}{\overline{C}_{l\alpha}^2 \cdot \left(1 - M^2\right)^2} \cdot \left(1 + \frac{\tan^2 \Lambda_{\frac{c}{2}}}{\left(1 - M^2\right)^2}\right) + 4}}$$

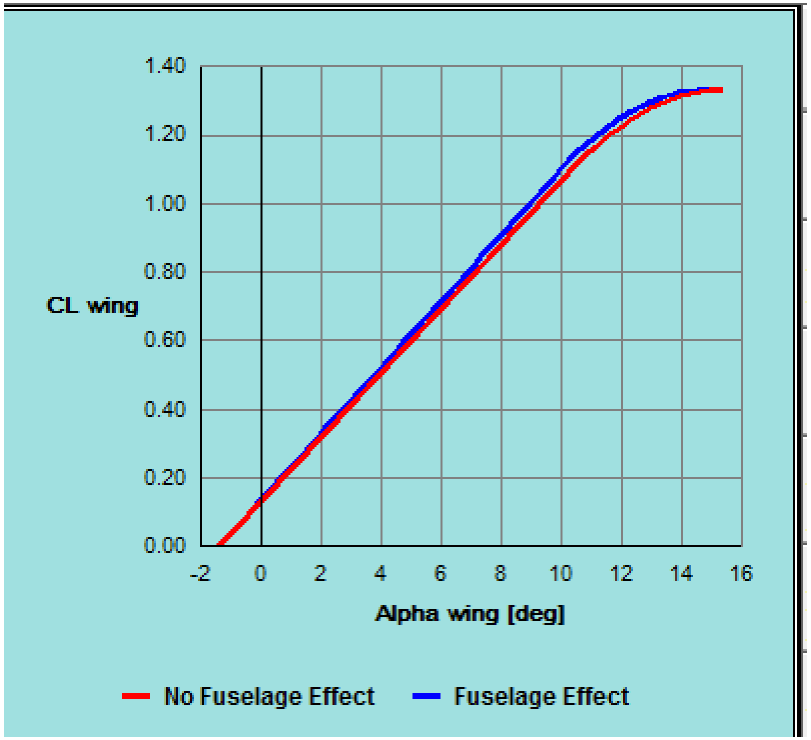


ADAS Modules

- ***Wing Analysis:***

Here some skecth of results:

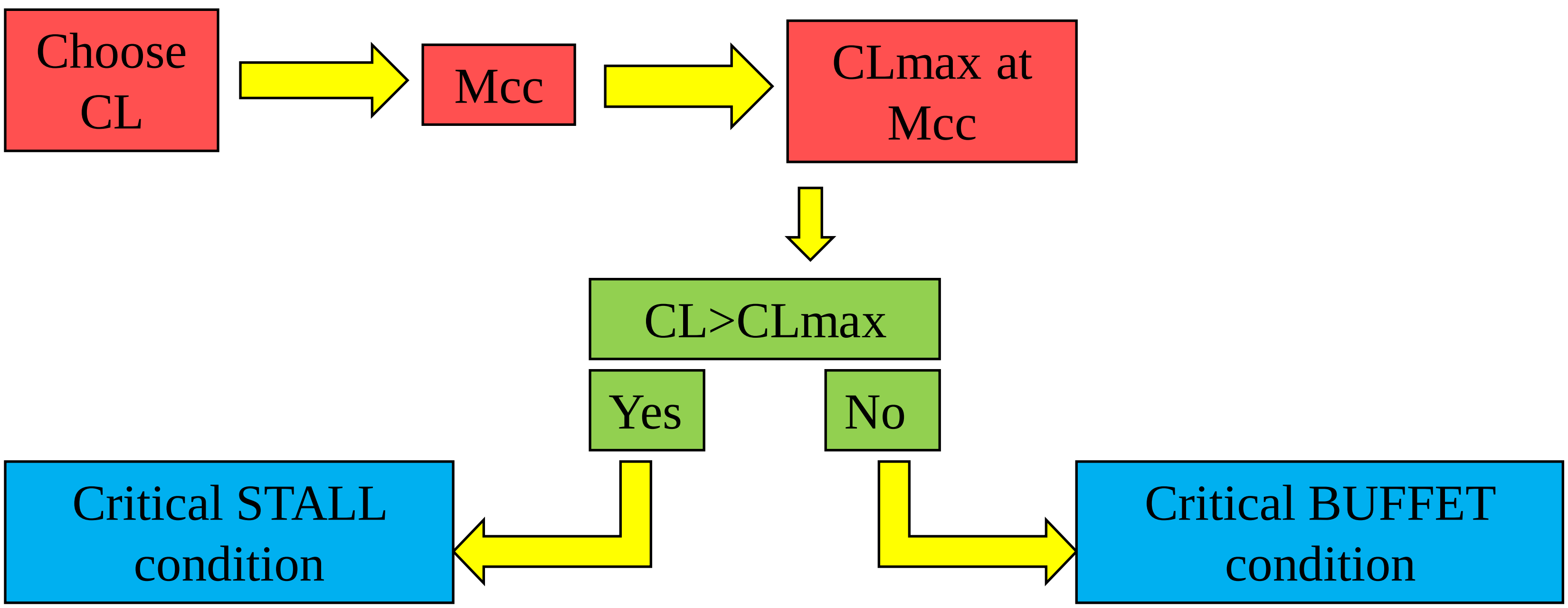




ADAS Modules

- ***Wing Analysis:***

A great help for the choise of CLmax is given by the secondary module called *Crest Critical and Drag Divergence Mach Estimation*:



ADAS Modules

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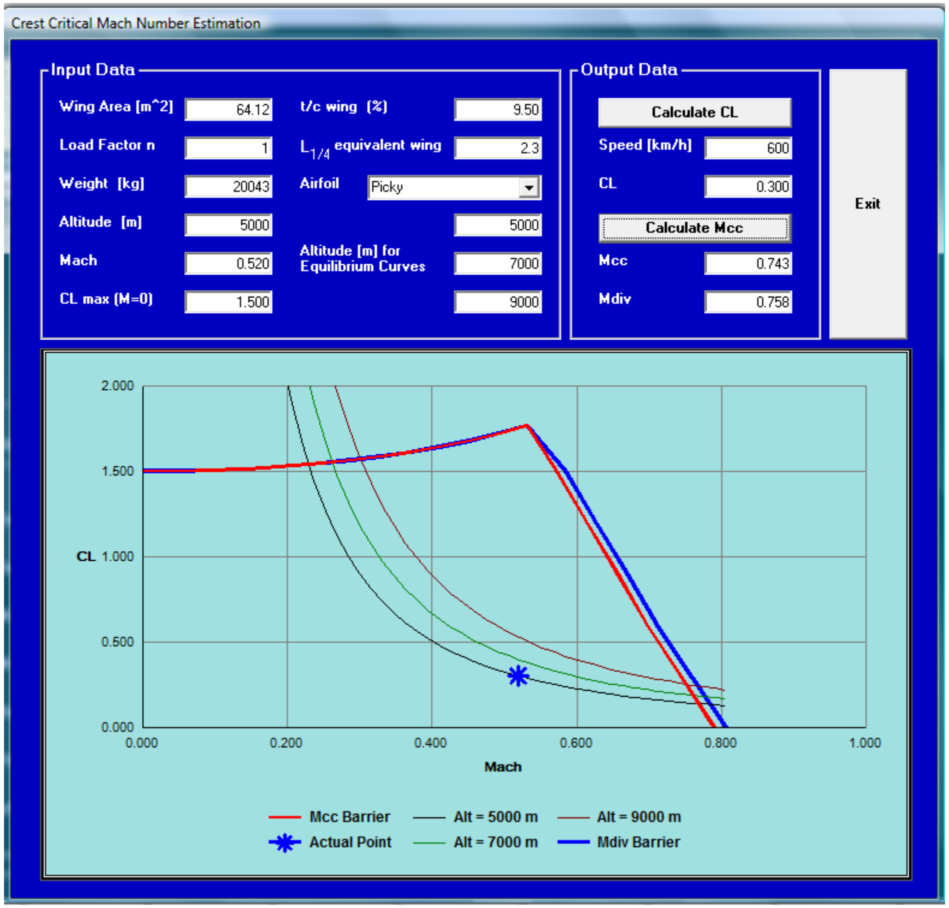
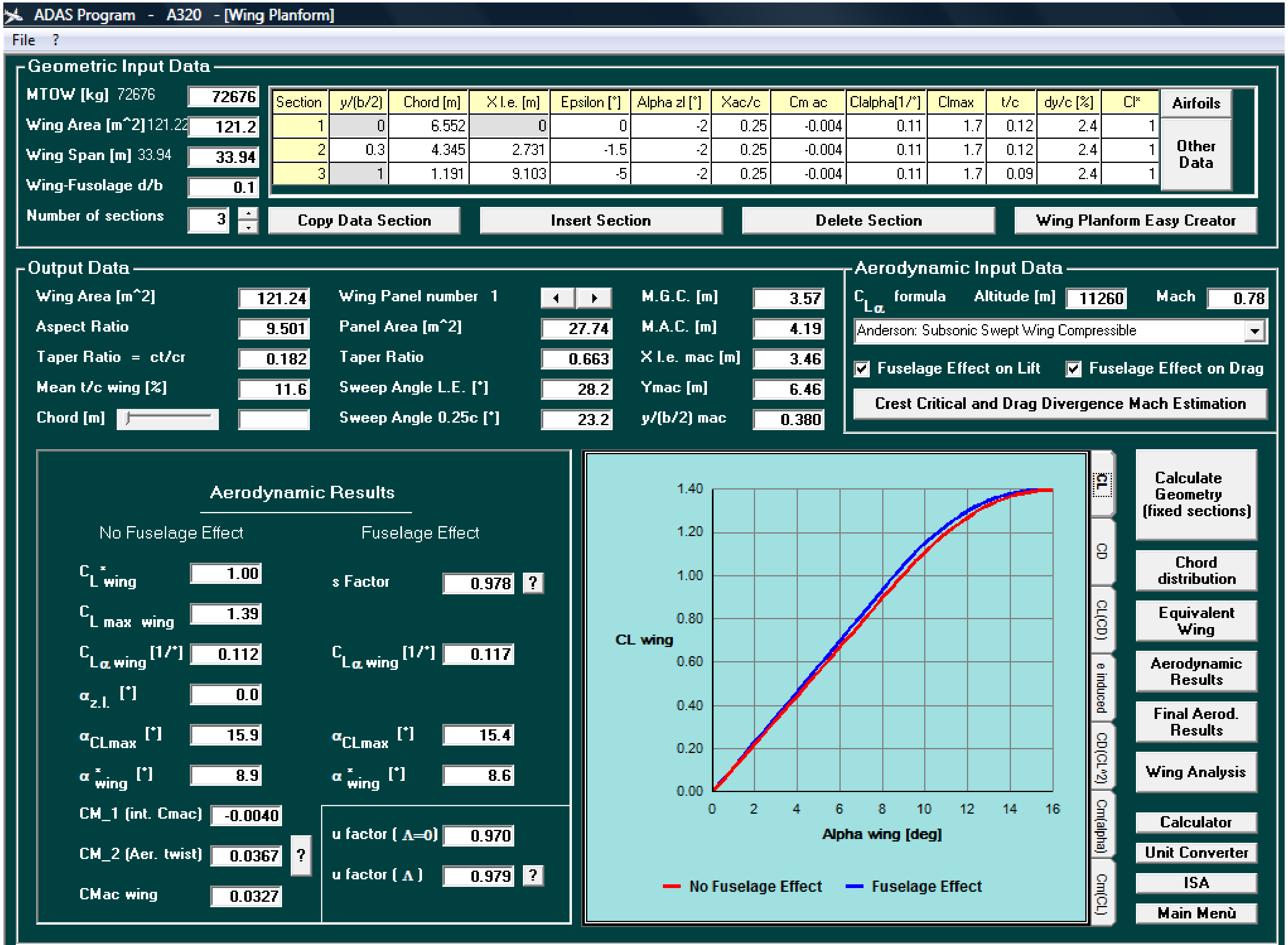


ADAS Modules - *Wing Analysis:*



ADAS Modules

- ***Wing Analysis:***

A more detailed analysis is possible after the Semiempirical calculation with panels methods:

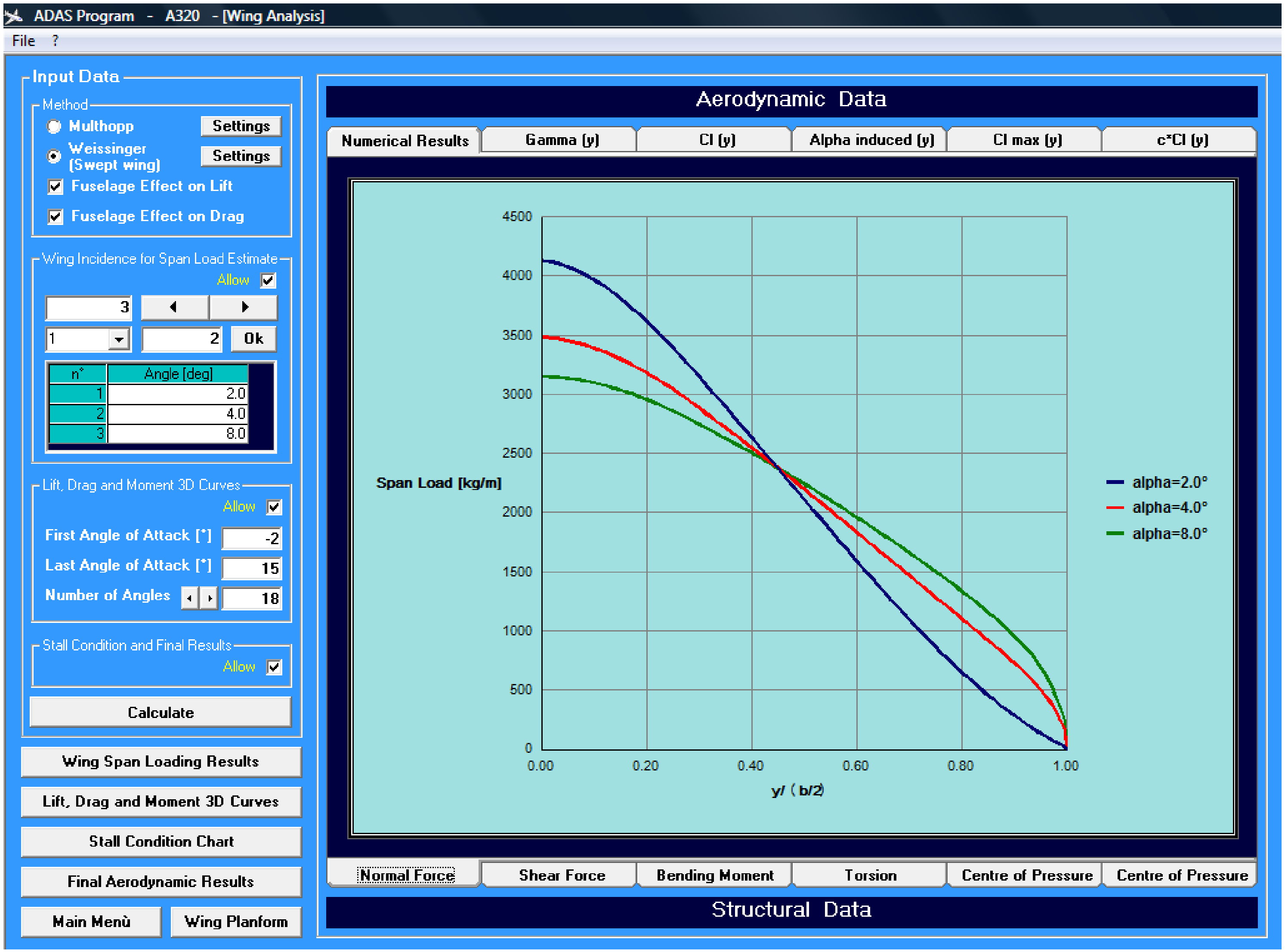
- Multhopp (for straight wing)

- Vortex Lattice (useful for Swept wing)

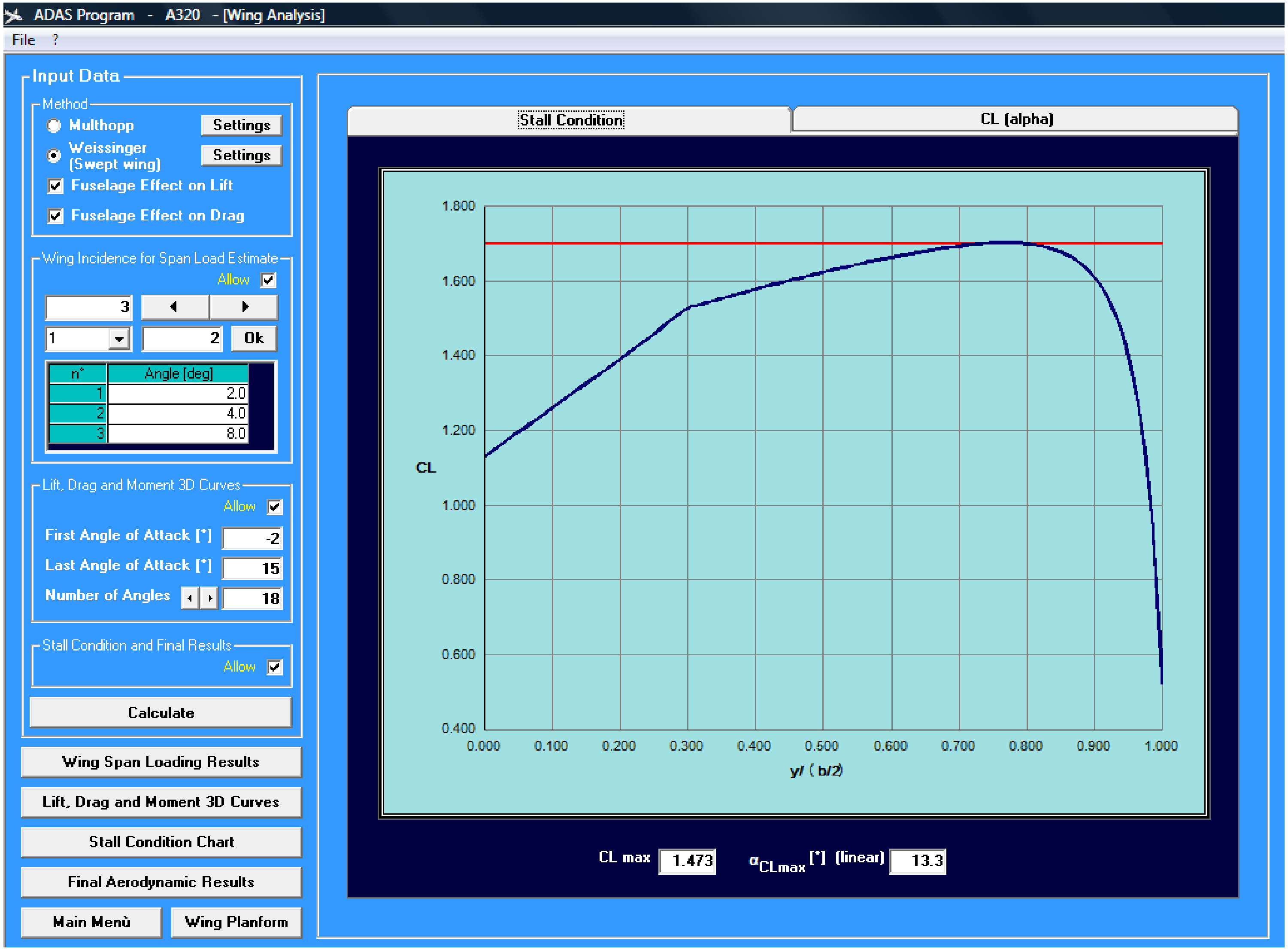
This methods allow us to calculate with a good approximation:

- Position of the Aerodynamic Centre
- CLmax with Stall Condition
- Structural Effect as Normal Force, Shear, Bending Moment and Torsion

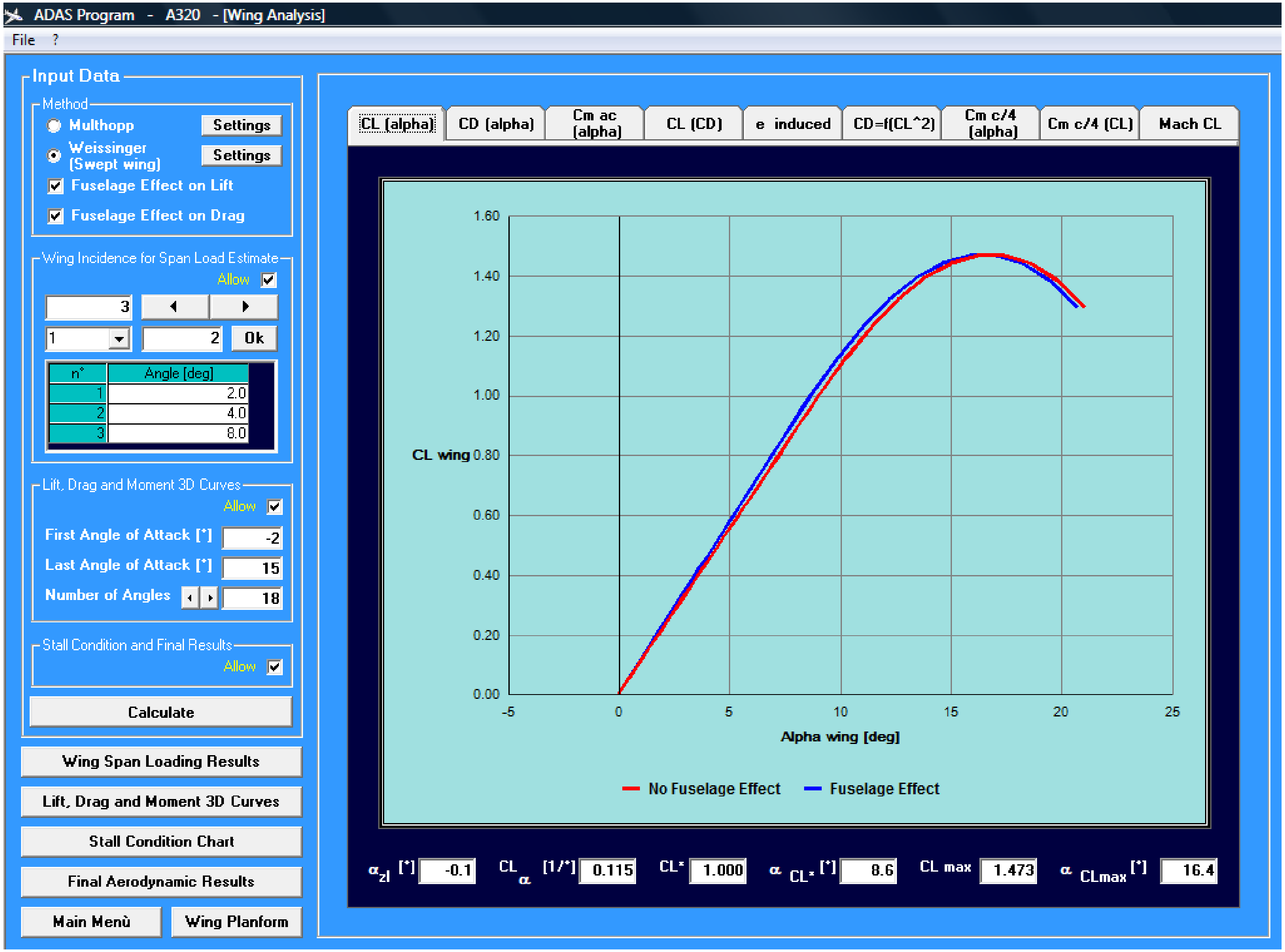
ADAS Modules - *Wing Analysis:*



ADAS Modules - *Wing Analysis:*



ADAS Modules - *Wing Analysis:*

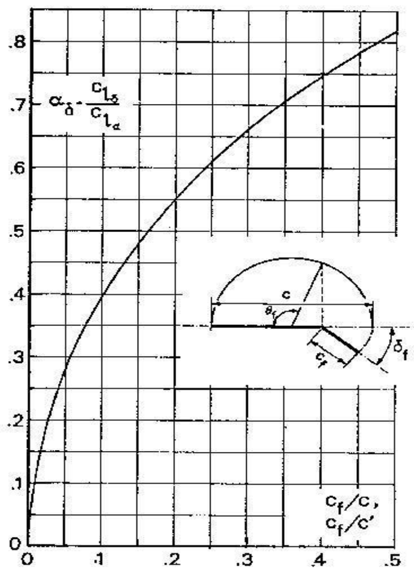


ADAS Modules

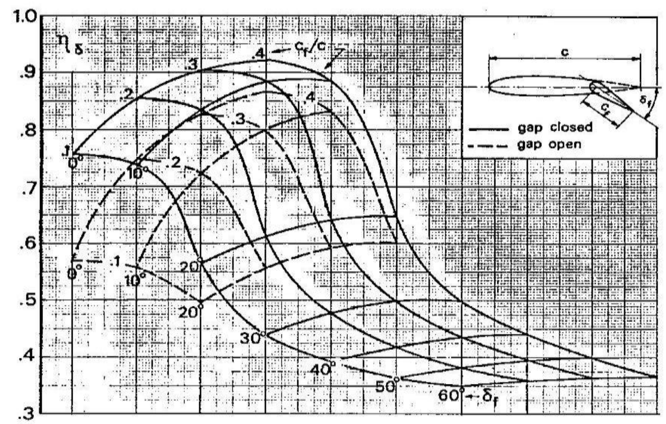
- *High Lift Devices:*

For this module it’s used Semi-empirical approach combined by Torenbeek and Roskam methods.

$\Delta Cl_{0:}$



$$\Delta Cl_0 = \alpha_\delta \eta_\delta Cl_\alpha \delta_f$$



Clmax:

$$Cl_{max} = \left(Cl_{max}\right)_{\delta=0} + \frac{2}{3}\Delta_f Cl_0$$

$$c_{\ell_{max}}' = .533\ \Delta y \left(\frac{R_c}{3\times10^6}\right)^{.08} + \frac{1}{2}\left(c_{\ell_o} + \Delta_f c_{\ell_o}'\right)$$

ADAS Modules

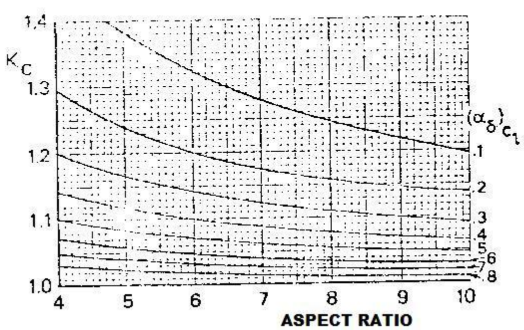
- *High Lift Devices:*

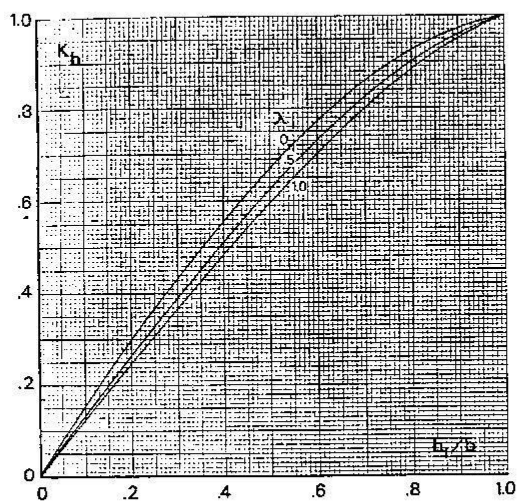
For this module it’s used Semi-empirical approach combined by Torenbeek and Roskam methods.

- From 2D calculation to 3D

ΔCL_0:

$$\Delta_f C_{L_0} = \Delta_f C_{l_0} \left(\frac{C_{L\alpha}}{C_{l\alpha}} \right) \left[\frac{(\alpha_\delta) C_L}{(\alpha_\delta) C_l} \right] K_b$$





$\Delta CLmax$:

$$\Delta_f C_{L\max} = 0.92 \Delta_f Cl_{\max} \frac{S_{wf}}{S} \cos \Lambda_{c/4}$$

ADAS Modules

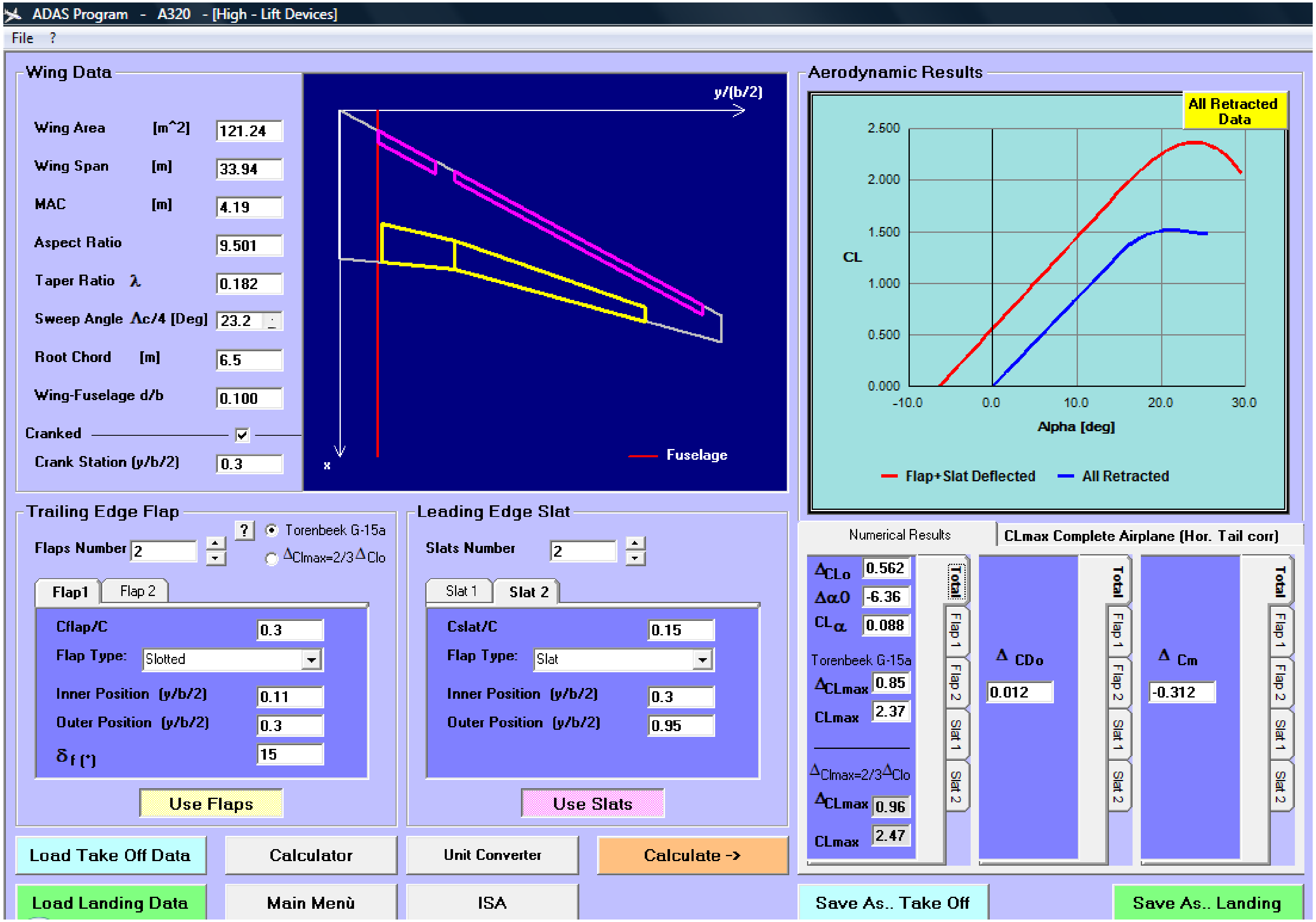
- *High Lift Devices:*

For this module it's used Semi-empirical approach combined by Torenbeek and Roskam methods.

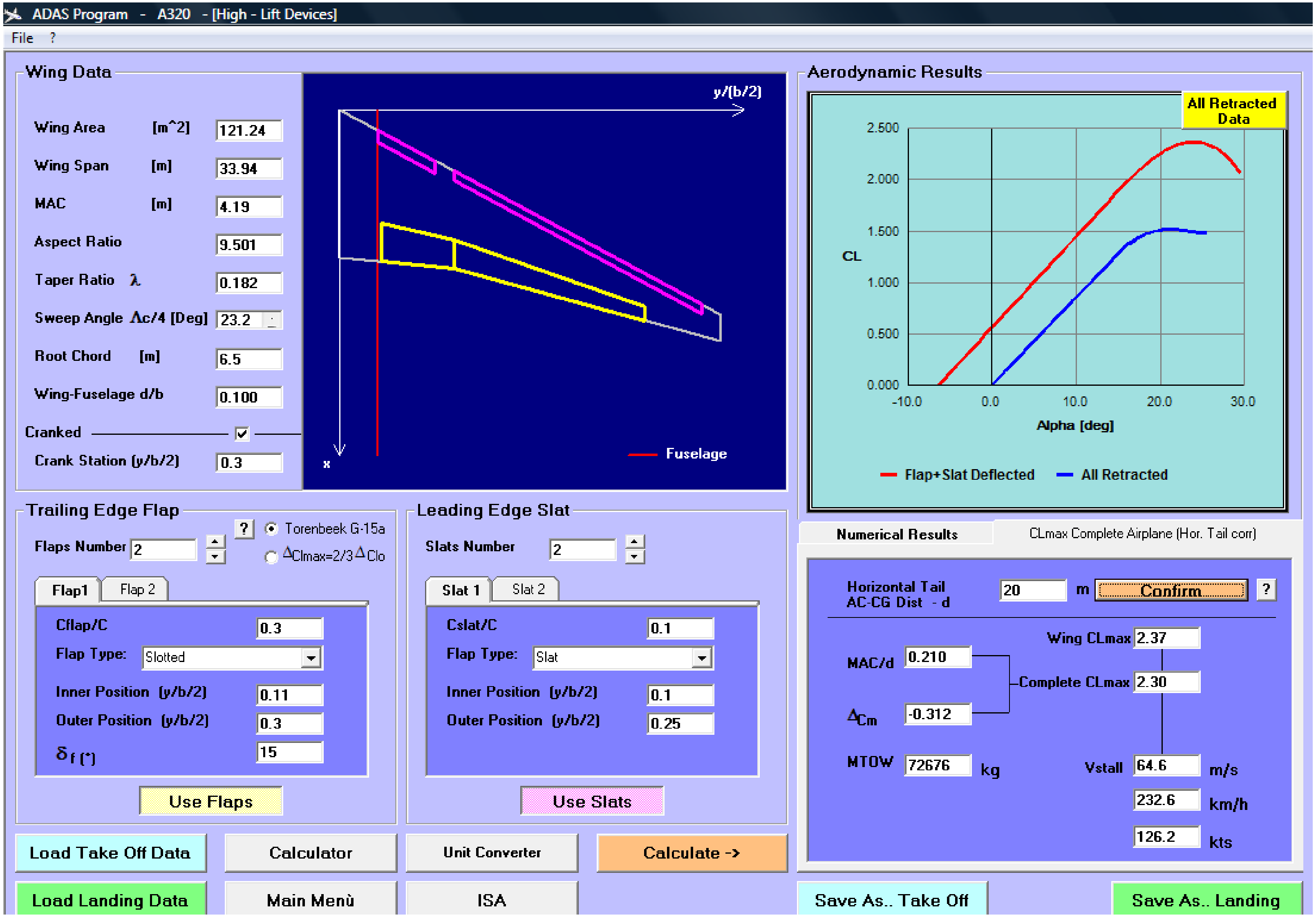
- From 2D calculation to 3D

- Flap Type used:
  - Plain
  - Single Slot
  - Fowler
  - Double Slot
- Slat Type:
  - Leading-Edge Plain Flap
  - Slat
  - Krouger Flap
- Take Off and Landing are individually saved

ADAS Modules - *High Lift Devices:*

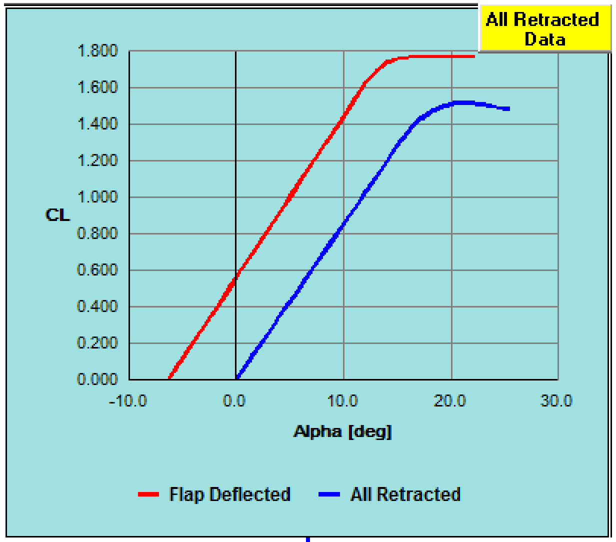


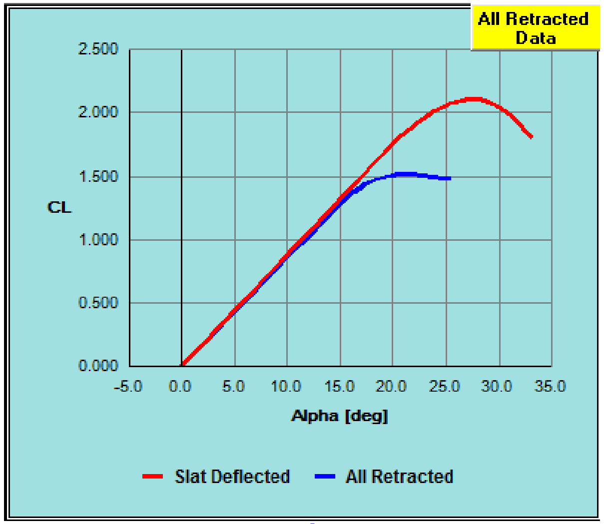
ADAS Modules - *High Lift Devices:*

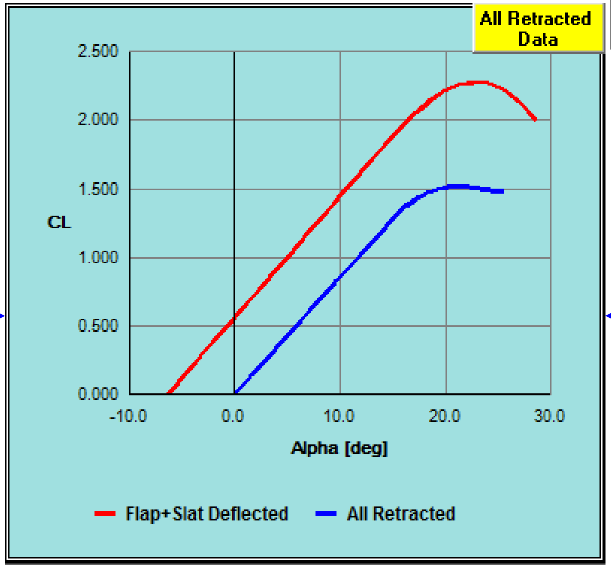


ADAS Modules

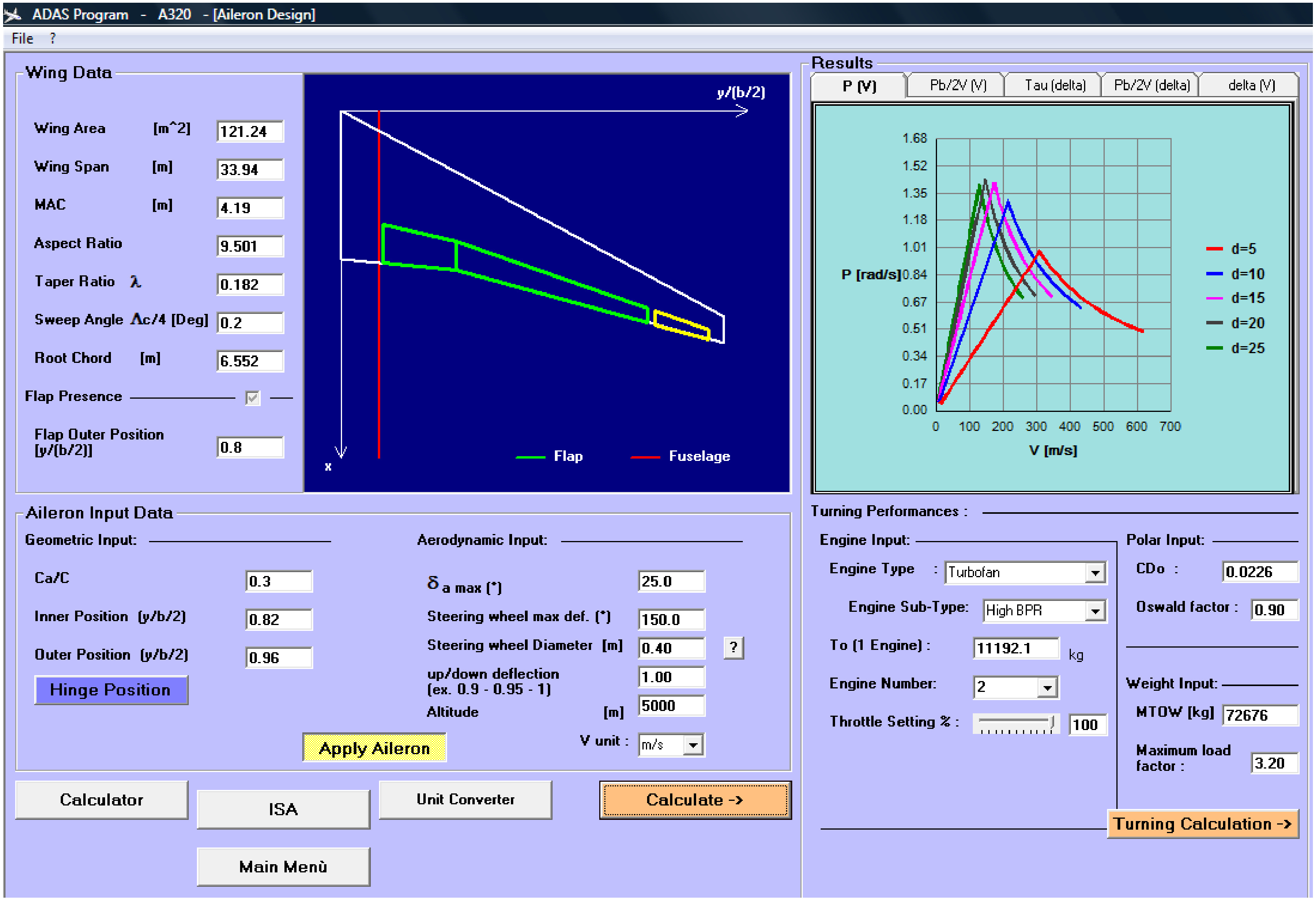
- *High Lift Devices:*



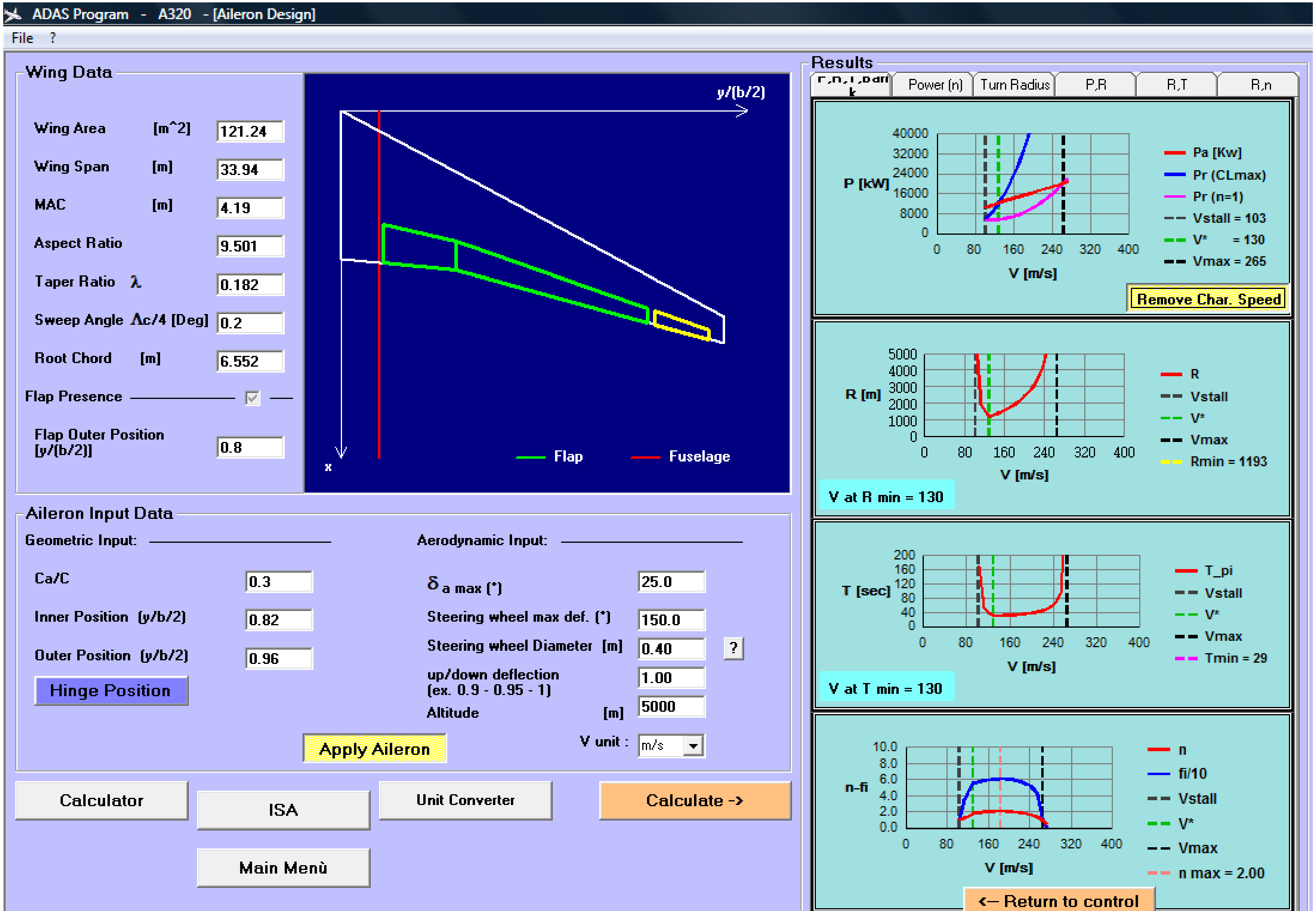




ADAS Modules - *Ailerons:*



ADAS Modules - *Ailerons:*



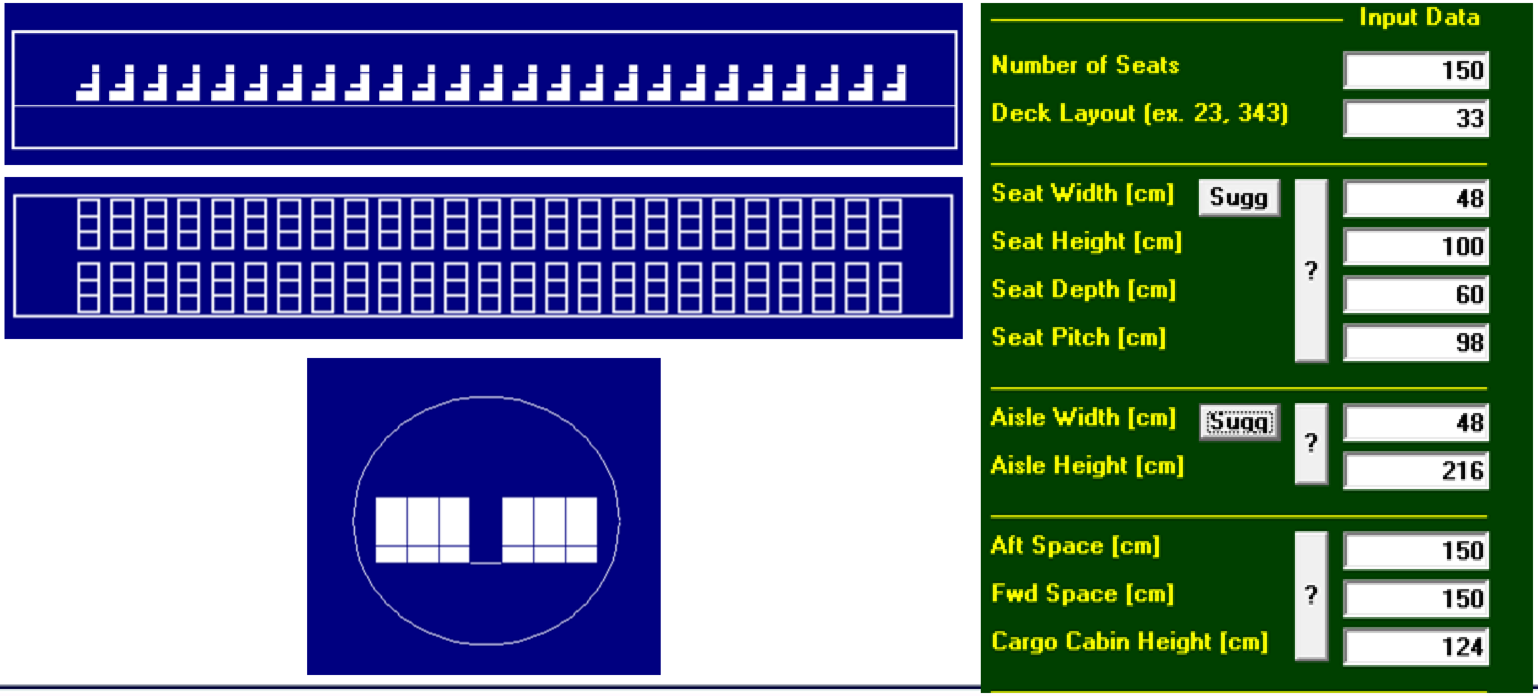
ADAS Modules

- ***Fuselage:***

This module help the user to design a Fuselage for transport aircraft, contains also a sub-module that allow to approximate very well any type of fuselage shape.

- *Basic Passengers Cabin Layout*

The first step of Fuselage Design is to choose the Deck Layout:

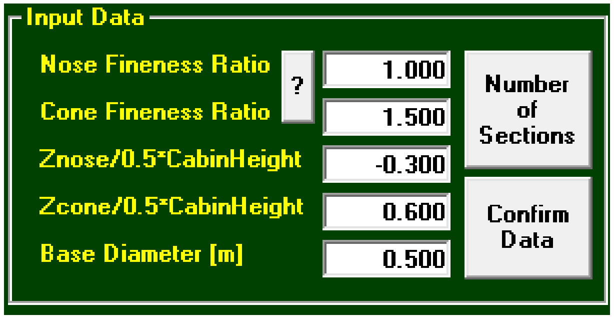


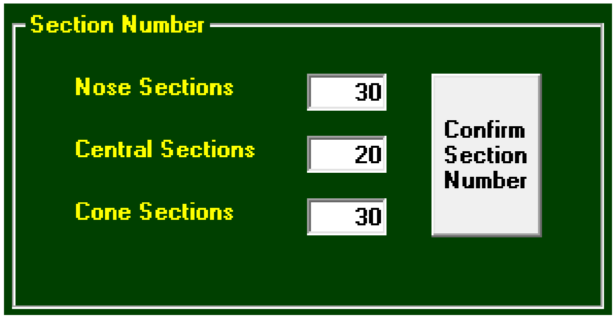
ADAS Modules - *Fuselage:*

- *Standard Fuselage Layout for Transport Aircraft*

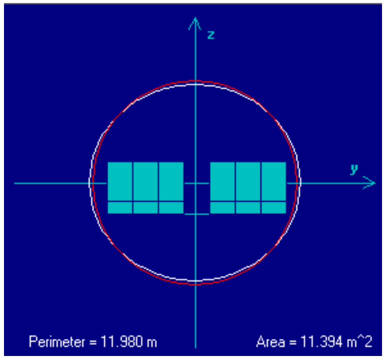
The second step is to design the fuselage Shape. It can be done with Standard approach, typical for Transport Aircraft, or Advanced.

For Standard Approach the program need:

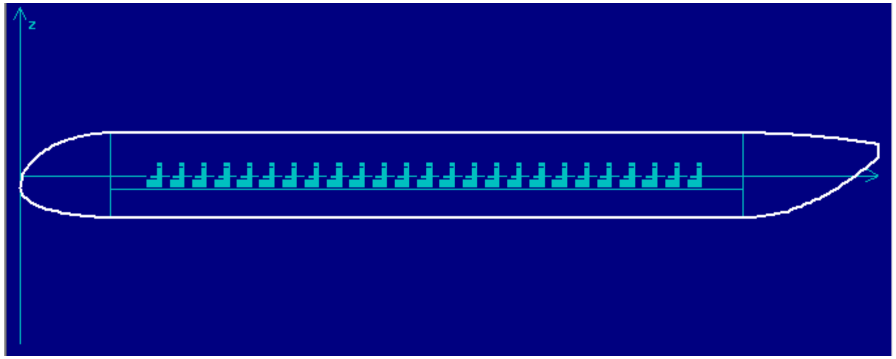




With the use of 4 classical polinomial is described the fuselage shape



Only elliptical section shape.



ADAS Modules

- ***Fuselage:*** - *Draw Advanced Fuselage Layout*

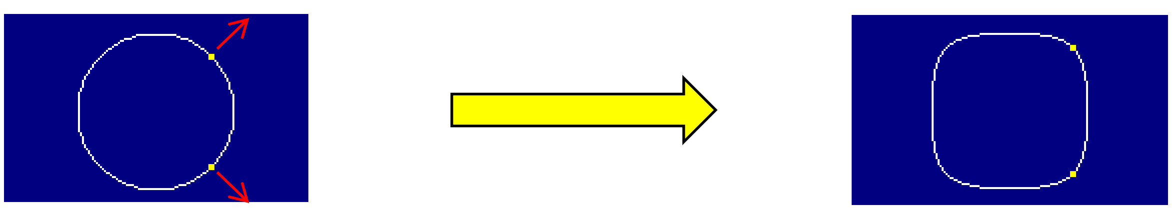
The alternative method to design a more detailed fuselage layout is to use the Advanced Fuselage Layout toolbox included in ADAS.
This sub-module allow to:

- Modify standard fuselage as desired.

- Custom a new fuselage by clicking each point on the picture.

Lateral and plant view are constucted by a Spline through all choosed point.

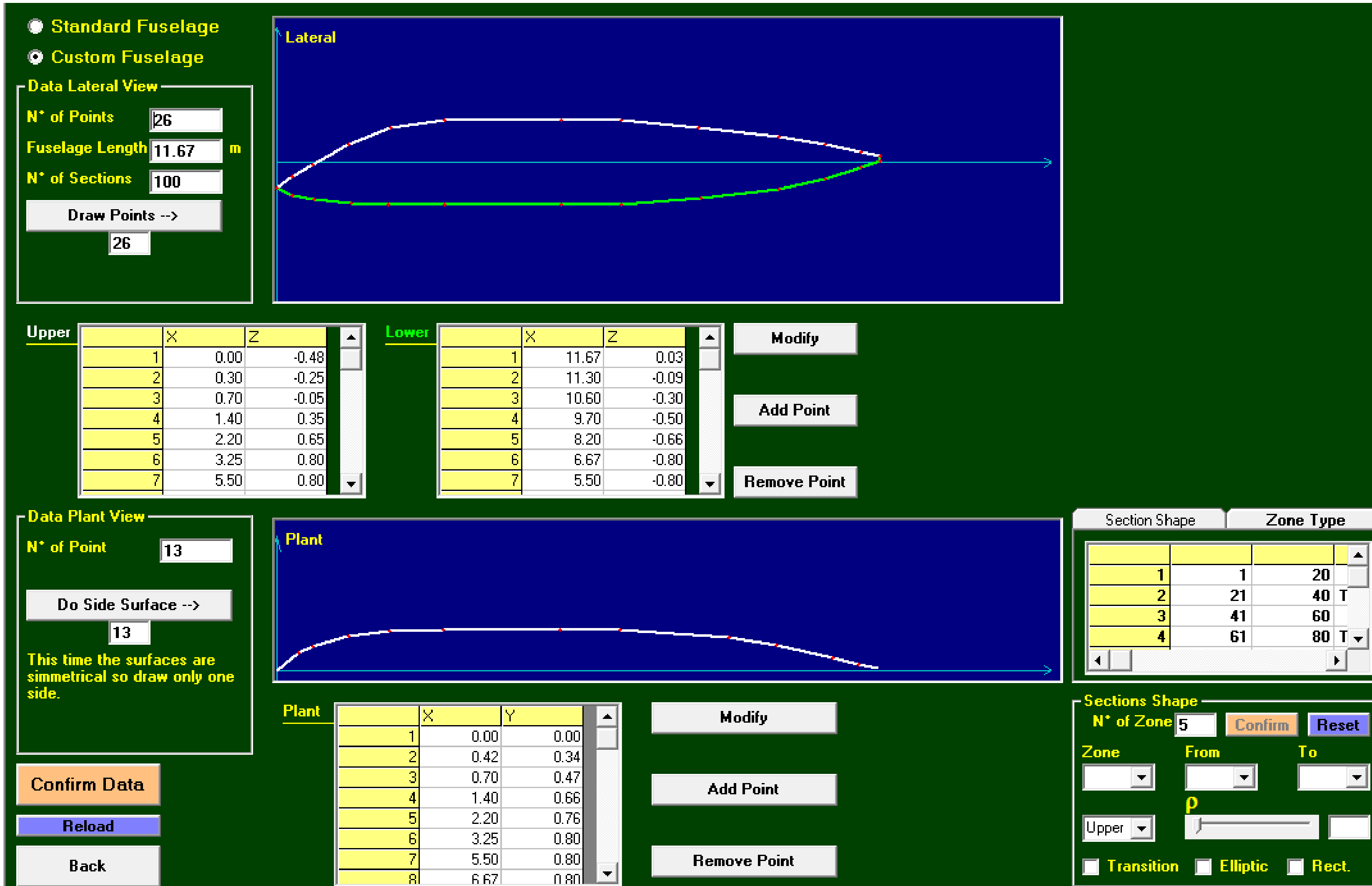
The sections shapes are default elliptical in all part. But they can be changed by modification of two ***control point***, and placed in any part of the fuselage.



Zone with different type of section may be linked by a *transition zone.*

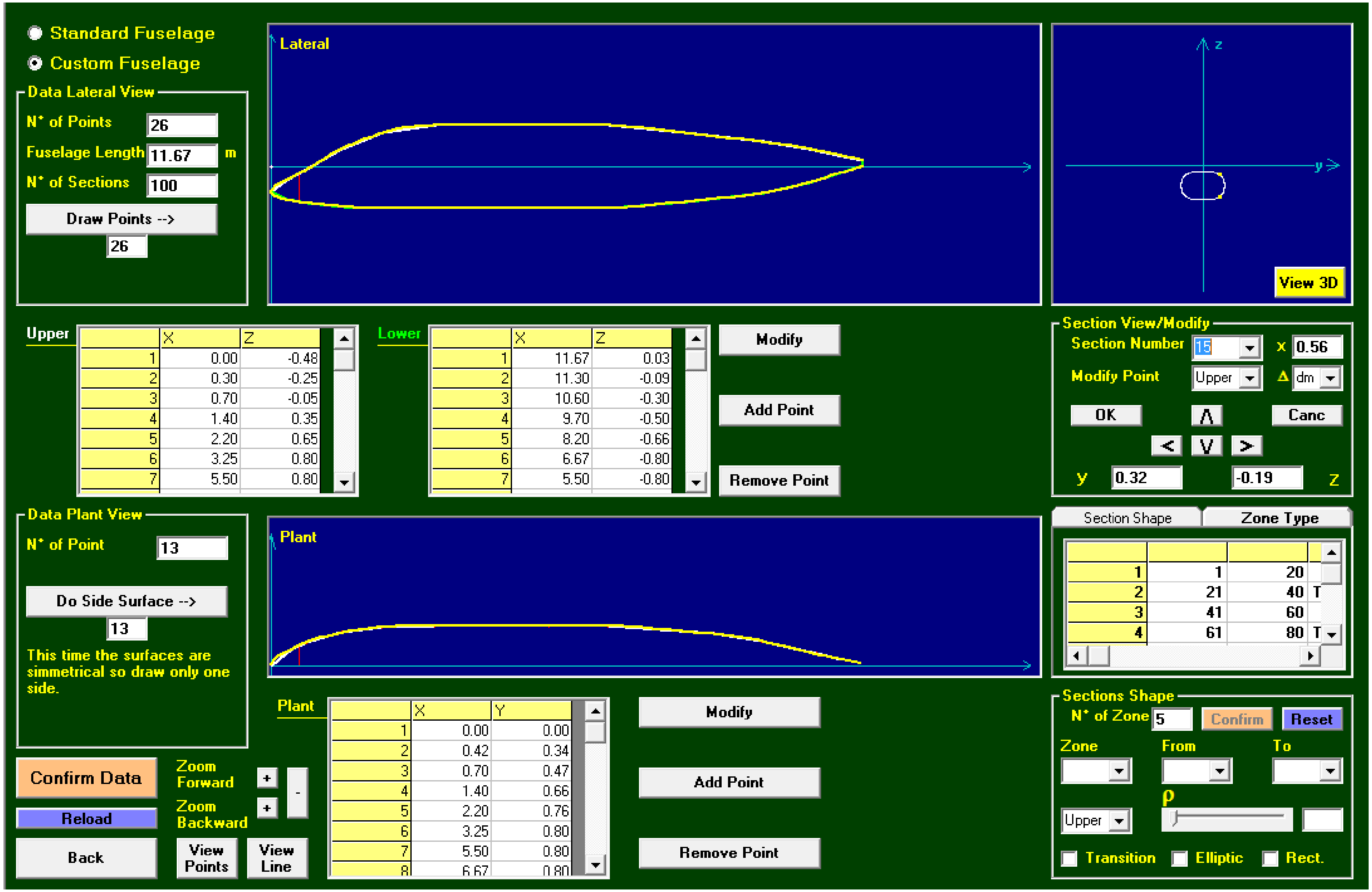
ADAS Modules

- *Fuselage:* - *Draw Advanced Fuselage Layout*



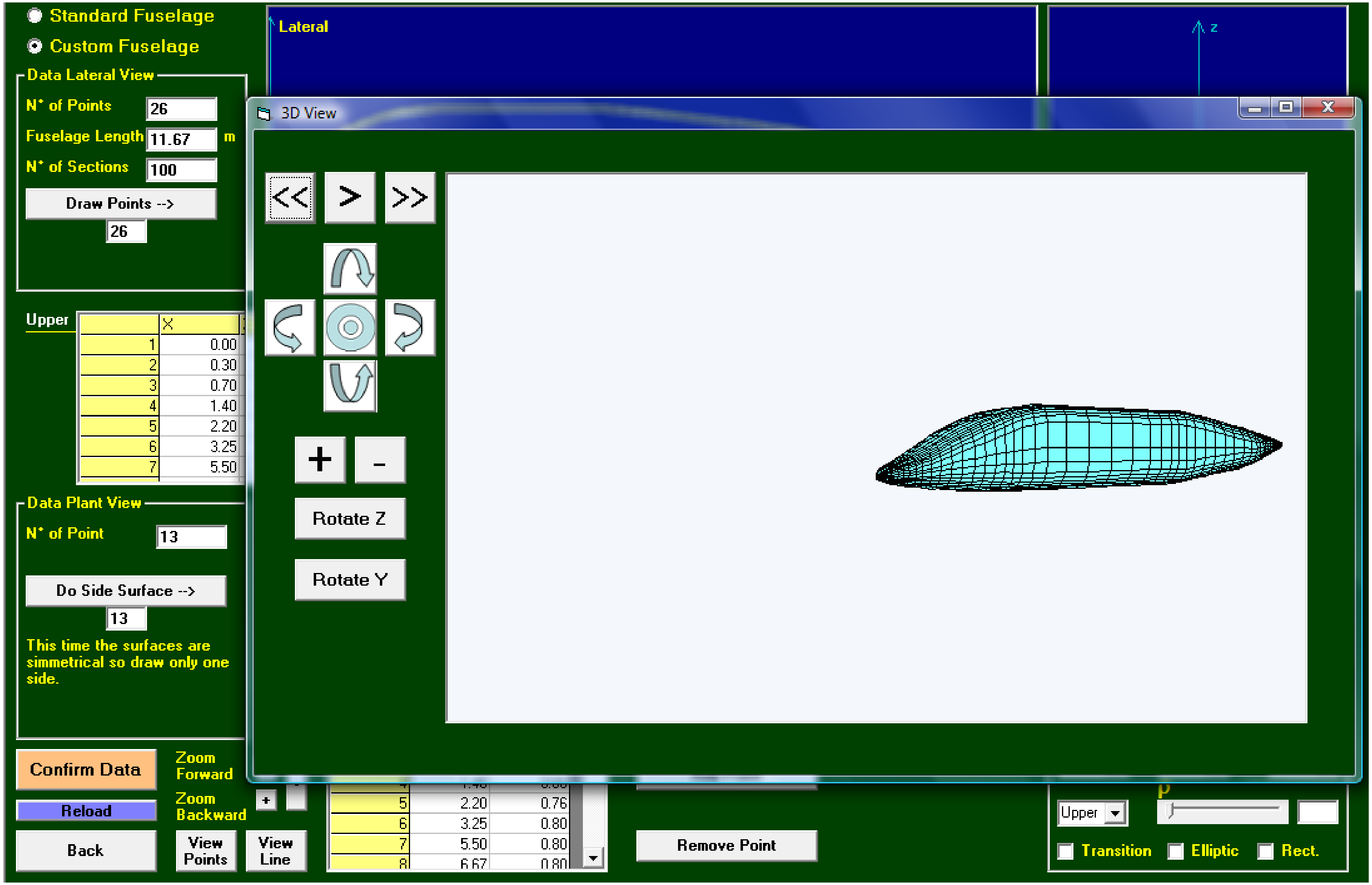
ADAS Modules

- *Fuselage:* - *Draw Advanced Fuselage Layout*



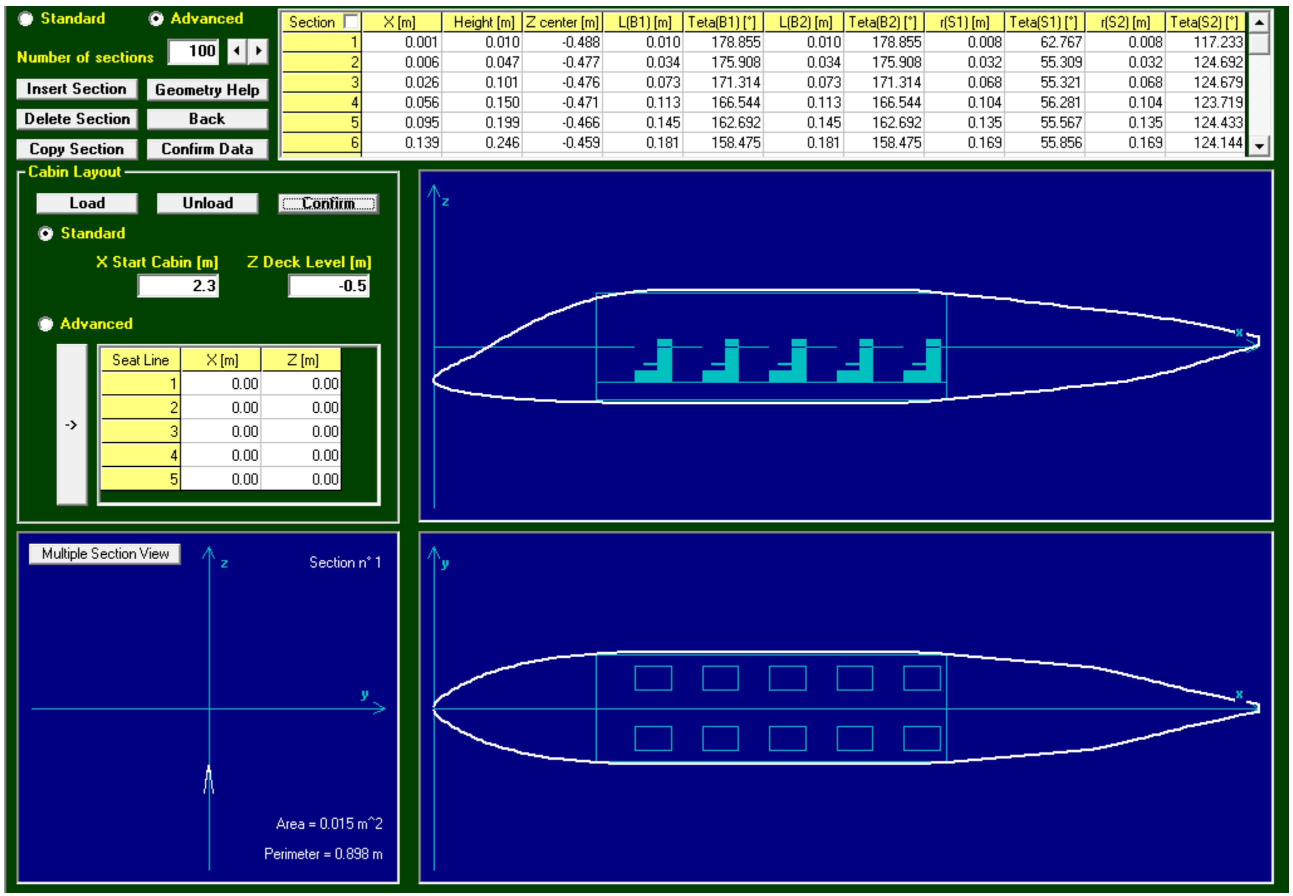
ADAS Modules

- *Fuselage:* - *Draw Advanced Fuselage Layout*



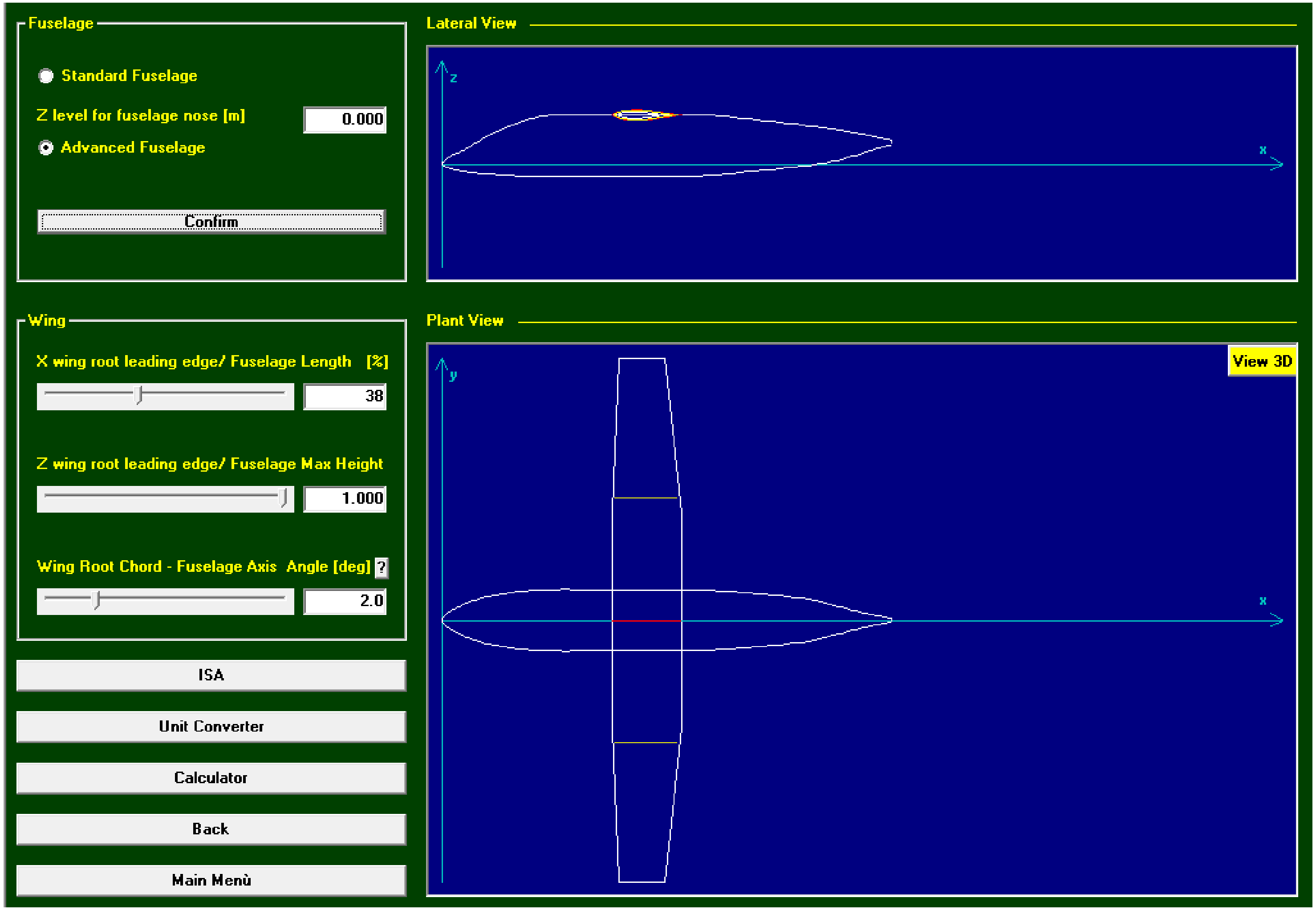
ADAS Modules - *Fuselage:* - *Advanced Fuselage Layout*

Another way to particolarize the fuselage shape is to modify section per section all part, it’s also possible here to choose the X position of the passenger’s cabin.



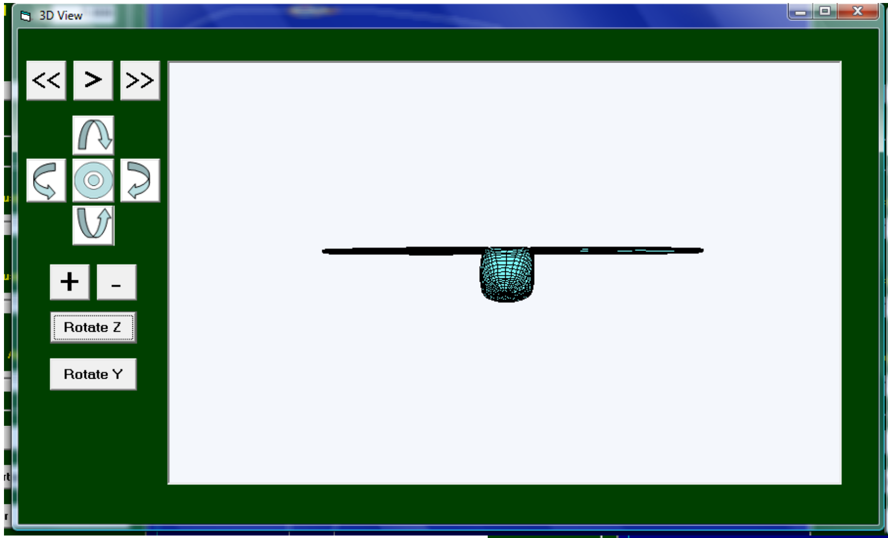
ADAS Modules - *Fuselage:* - *Wing-Fuselage Layout*

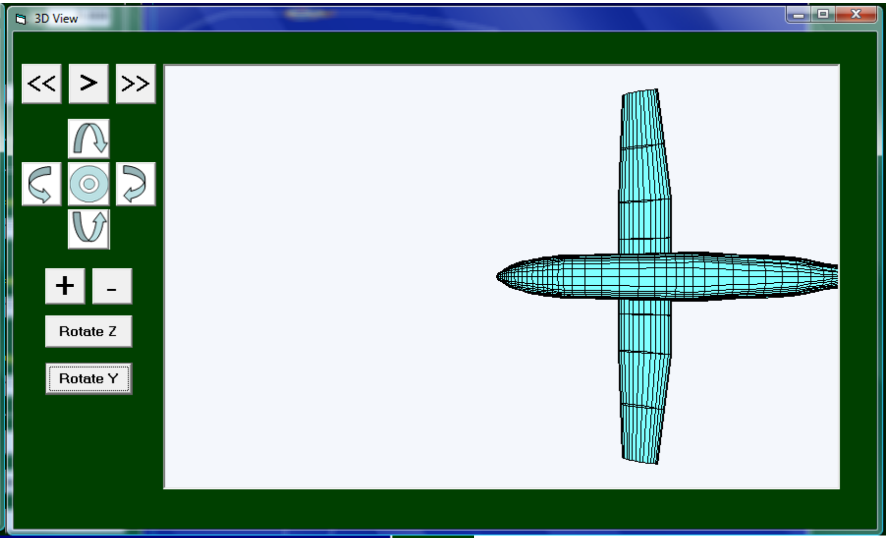
The Third Step is to choose the position of Wing.

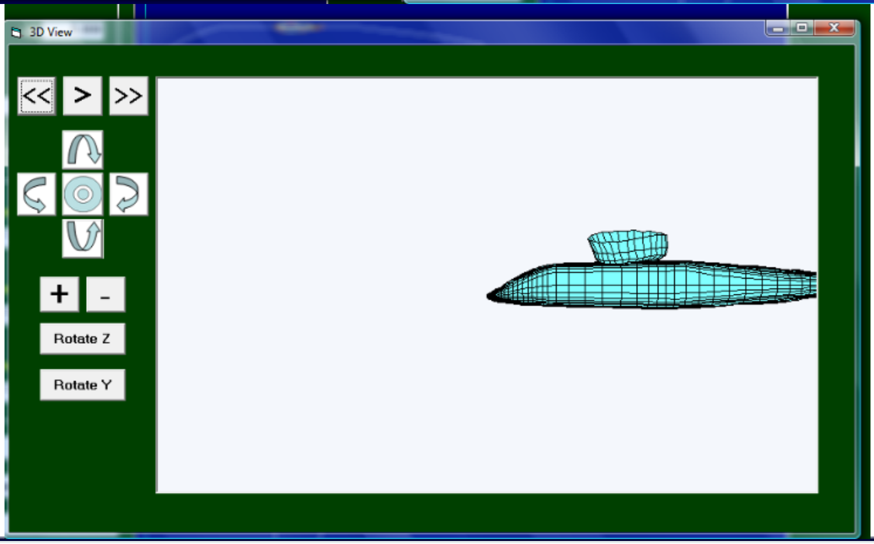


ADAS Modules - ***Fuselage:*** - *Wing-Fuselage Layout*

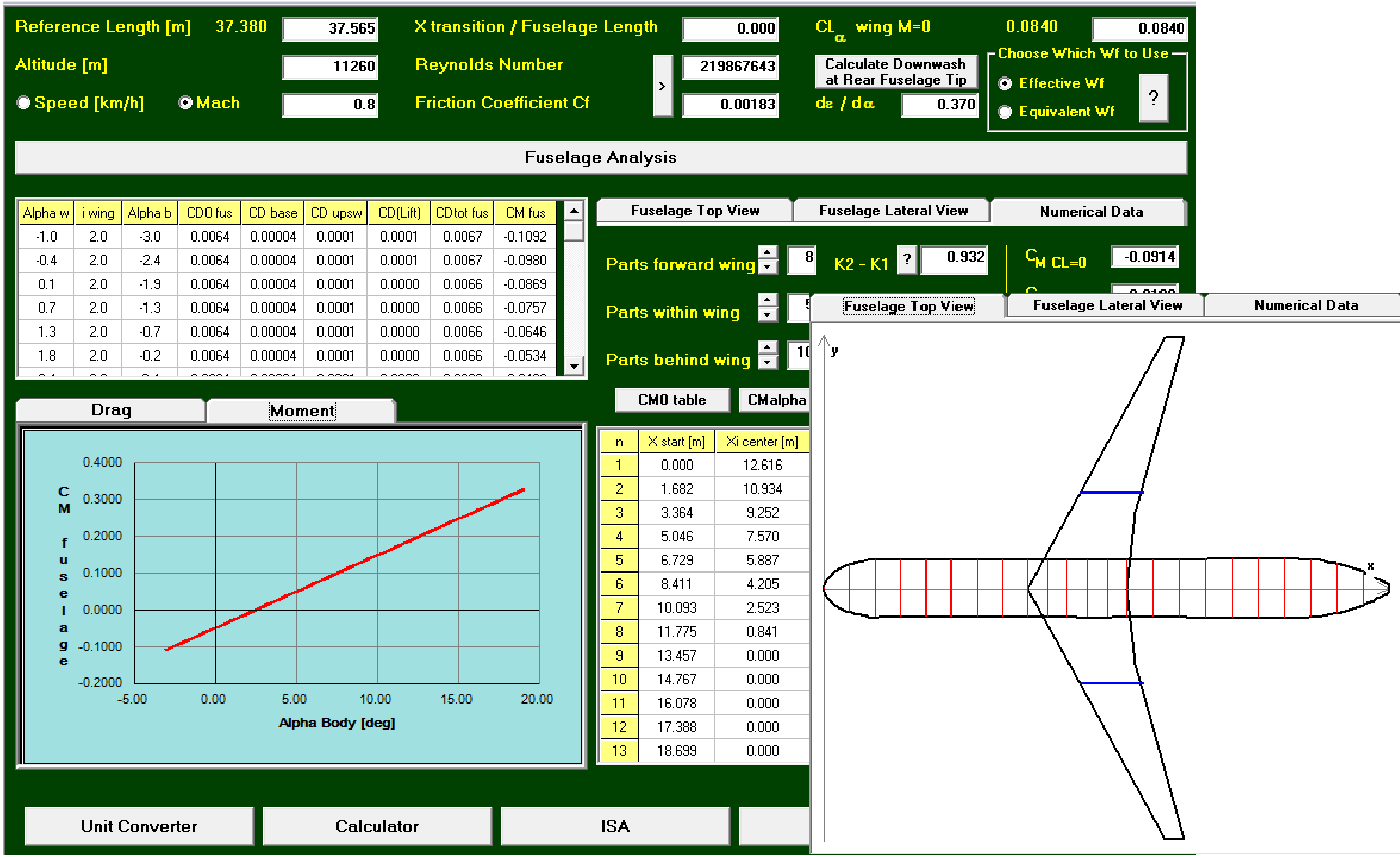
The Third Step is to choose the position of Wing.





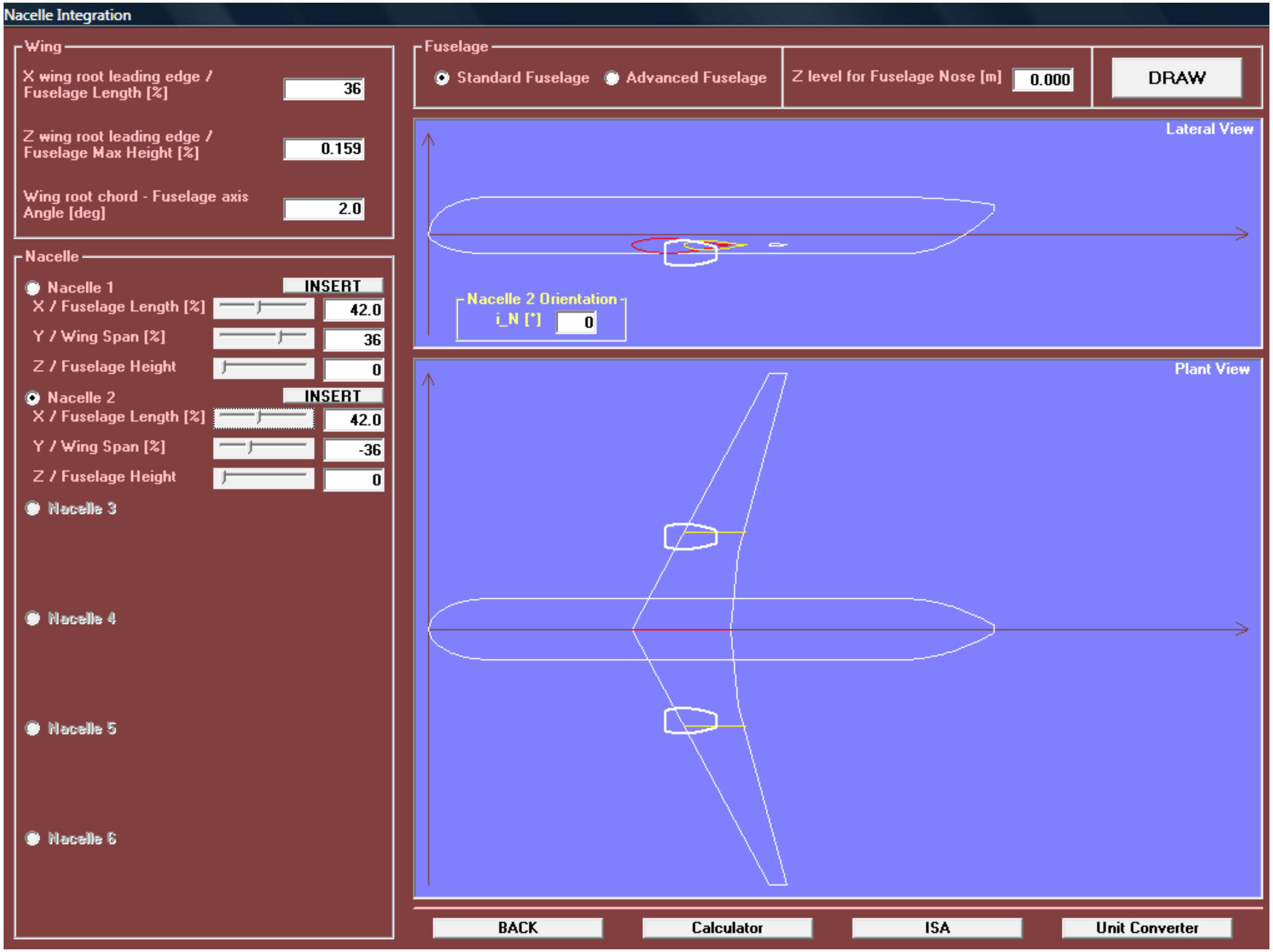


ADAS Modules - *Fuselage:* - *Analysis*

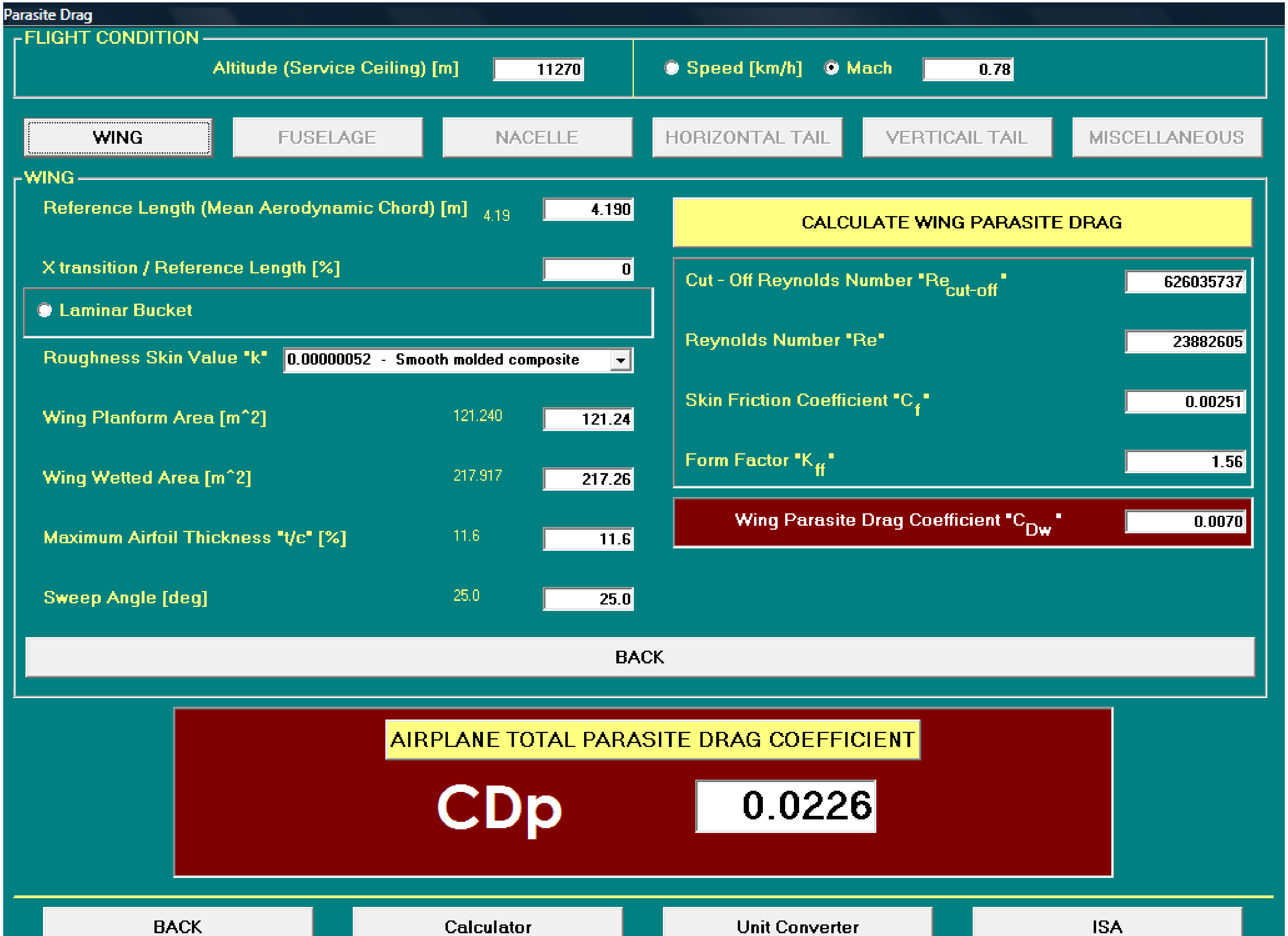


ADAS Modules - *Nacelle:*

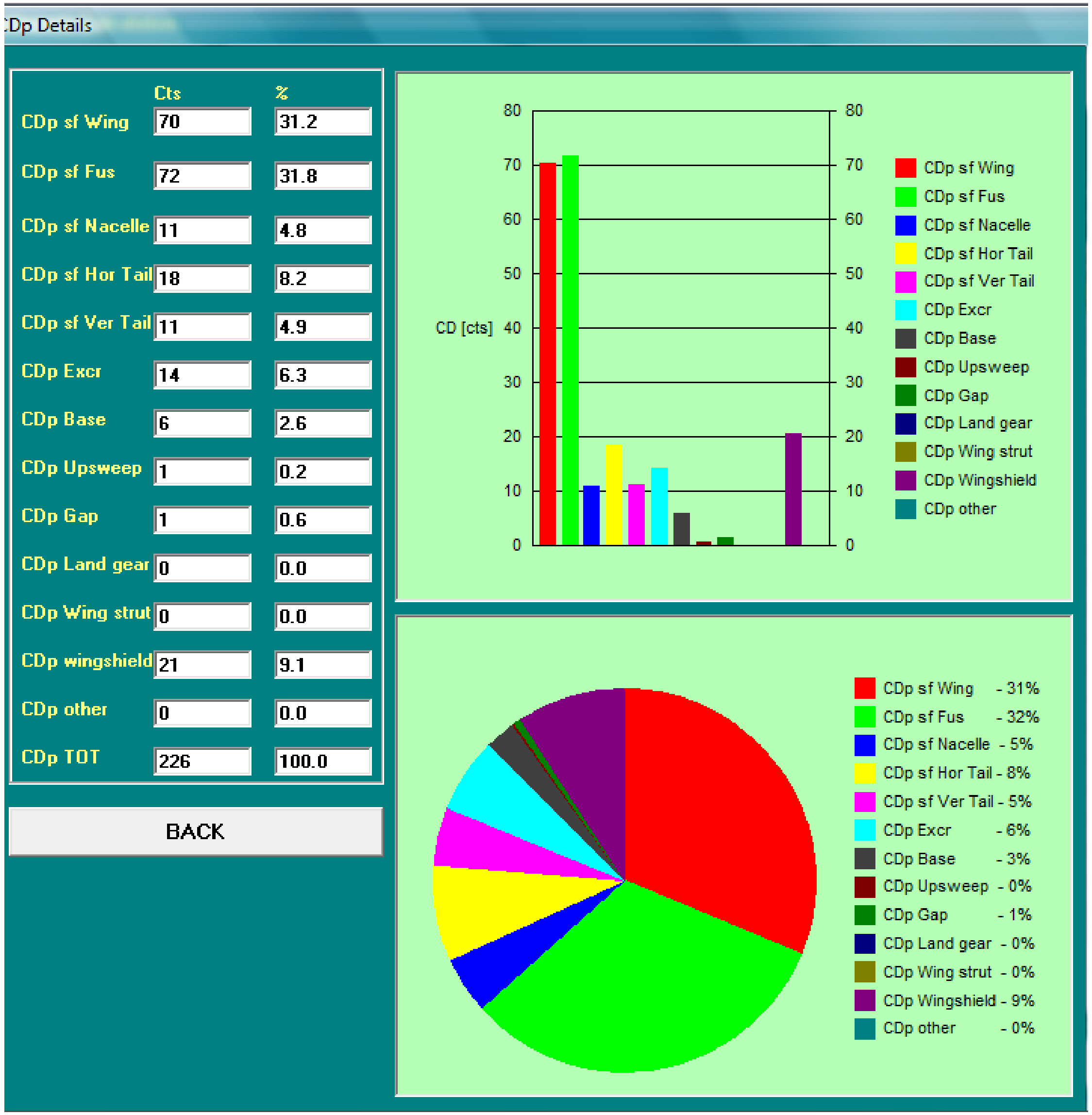
Another possibility of ADAS is to design the Nacelles:



ADAS Modules



ADAS Modules



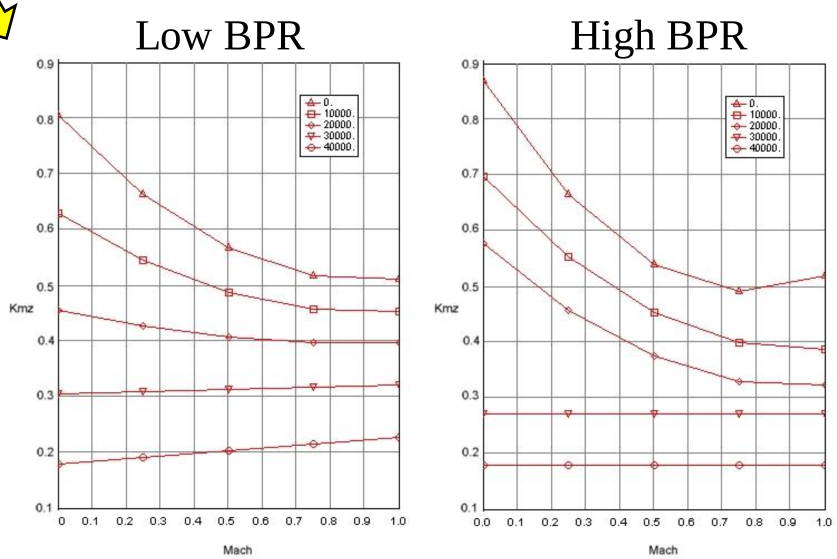
ADAS Modules - *Performances:*

➢ Turbofan model:

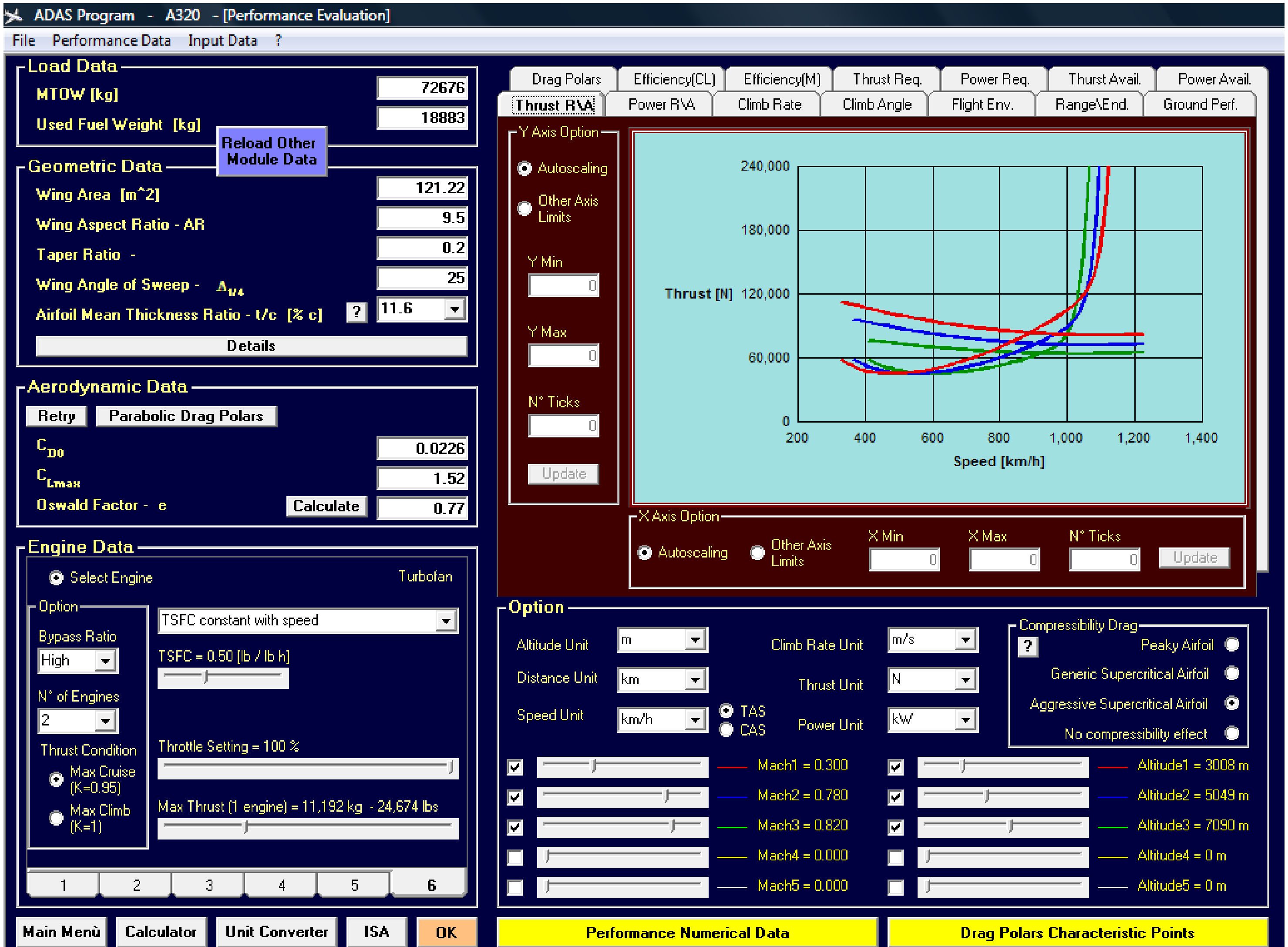
The model used for Low Bypass ratio is the *Pratt & Whitney* JT8-D
For High Bypass ratio is the *Pratt & Whitney* PW-2037

$$k_{mz} = \frac{T}{T_{\text{maxcruise}}} = f(z, M) \quad \Rightarrow \quad f(z,M) = a_1(z) + a_2(z)\cdot M + a_3(z)\cdot M^2$$

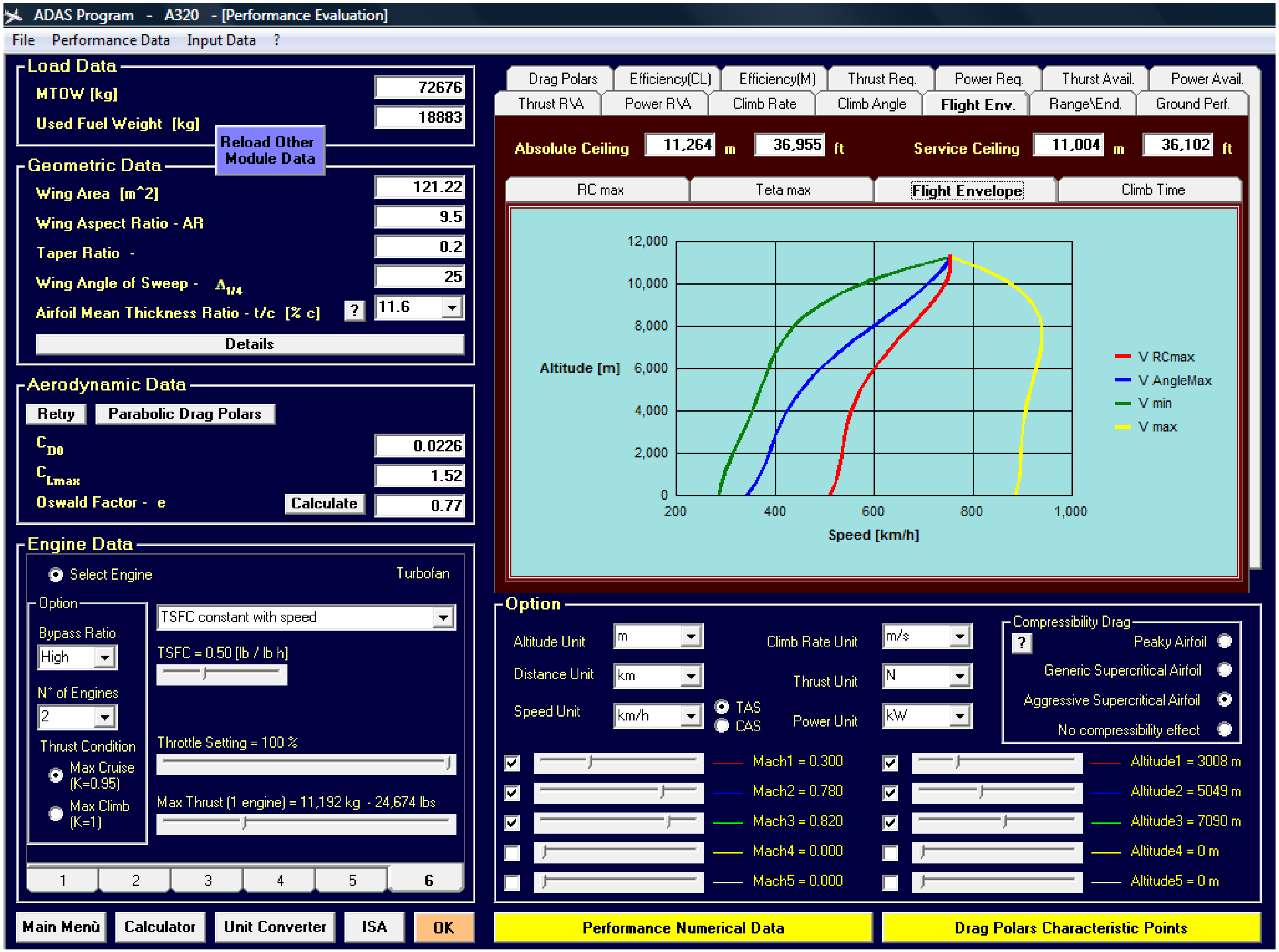
$$\begin{cases} T = T_0 \cdot N_{engines} \cdot \varphi \cdot k_{mz} \\ P = T \cdot V \end{cases}$$



ADAS Modules - *Performance:*

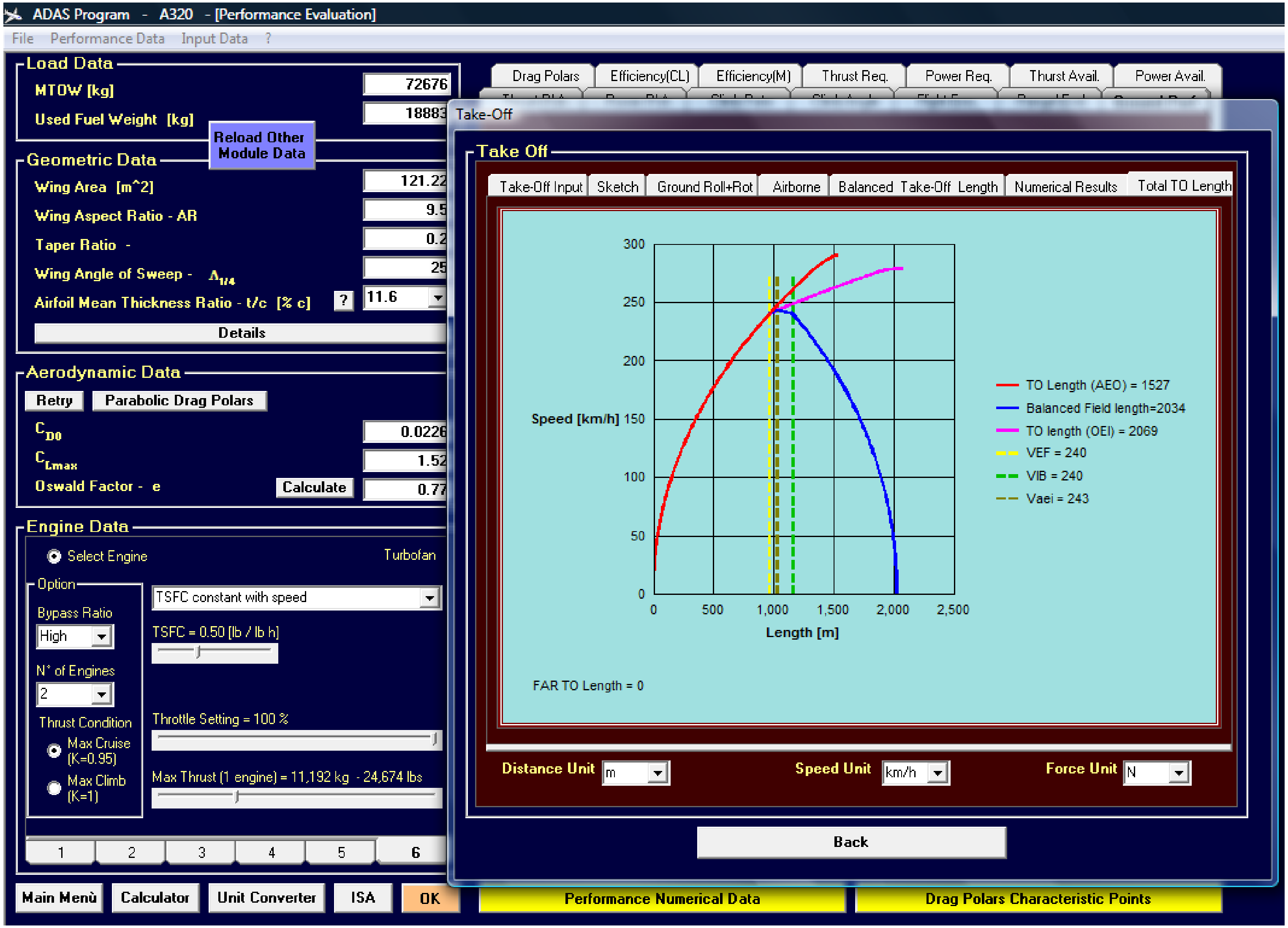


ADAS Modules - *Performance:*



ADAS Modules - *Performance:*

- Take Off:



ADAS Modules

- *Stability and Control:*

The analysis of stability and control is divided in two part:

- Horizontal Tail Design – Longitudinal Stability and Control
- Vertical Tail Design – Directional Stability

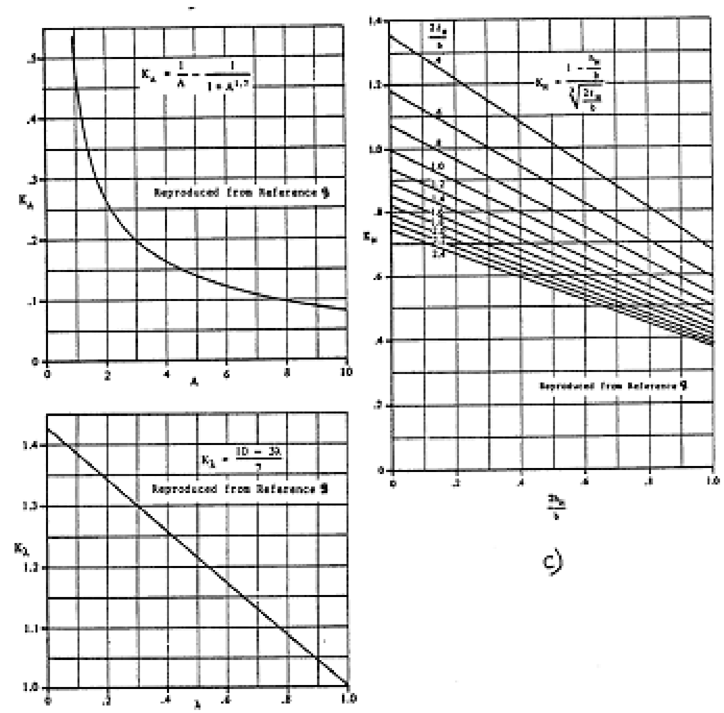
ADAS Modules

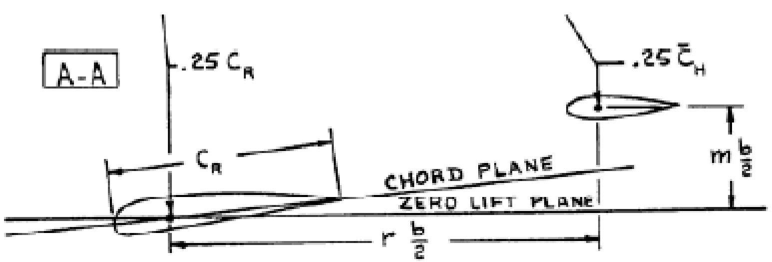
- ***Stability and Control:***

The methodologies used for this module:

- Wing Downwash:
  Roskam approach

$$\frac{\partial \varepsilon}{\partial \alpha} = 4.44\left[\left(K_A K_\lambda K_h \left(cos\Lambda_{c/4}\right)^{1/2}\right)^{1.19}\right]\frac{CL_\alpha}{CL_{\alpha\ M=0}}$$

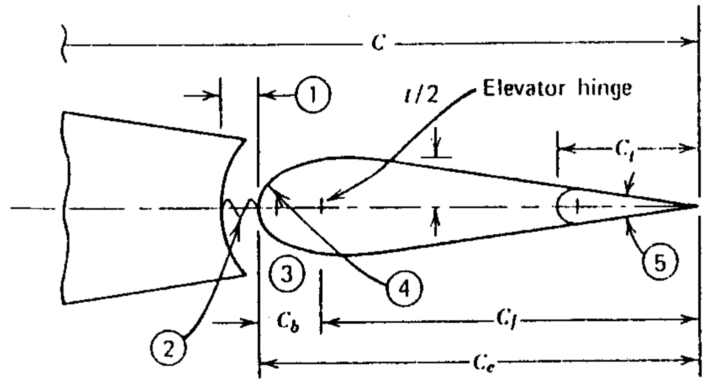




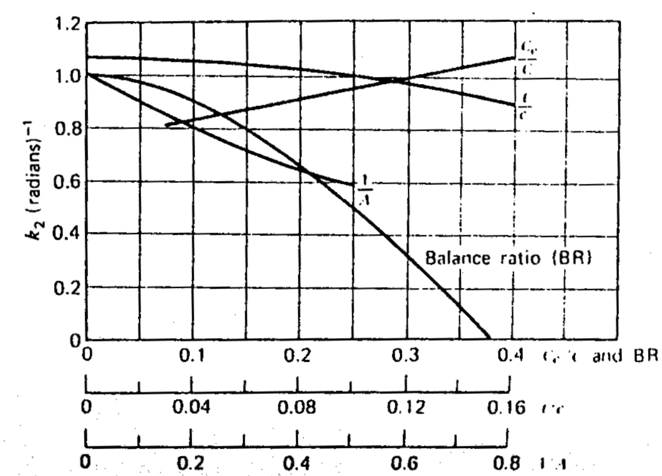
ADAS Modules

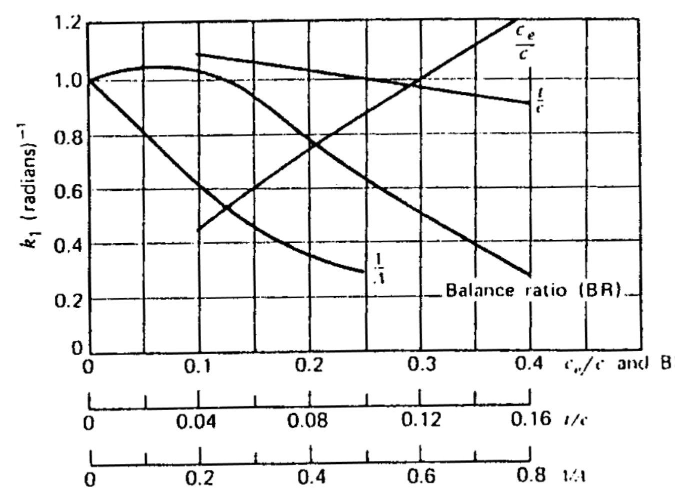
- ***Stability and Control:***

The methodologies used for this module:



- $C_{h\alpha}$ and $C_{h\delta}$:
  McCormick approach

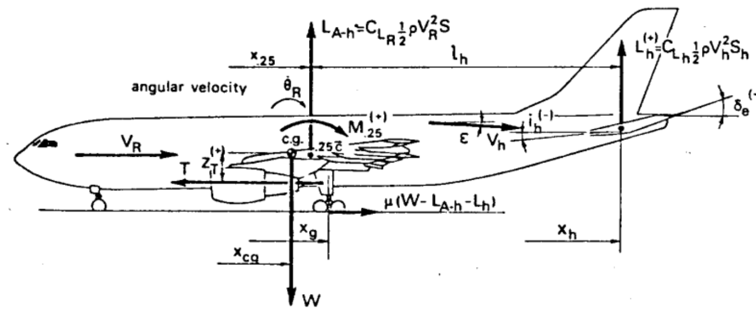




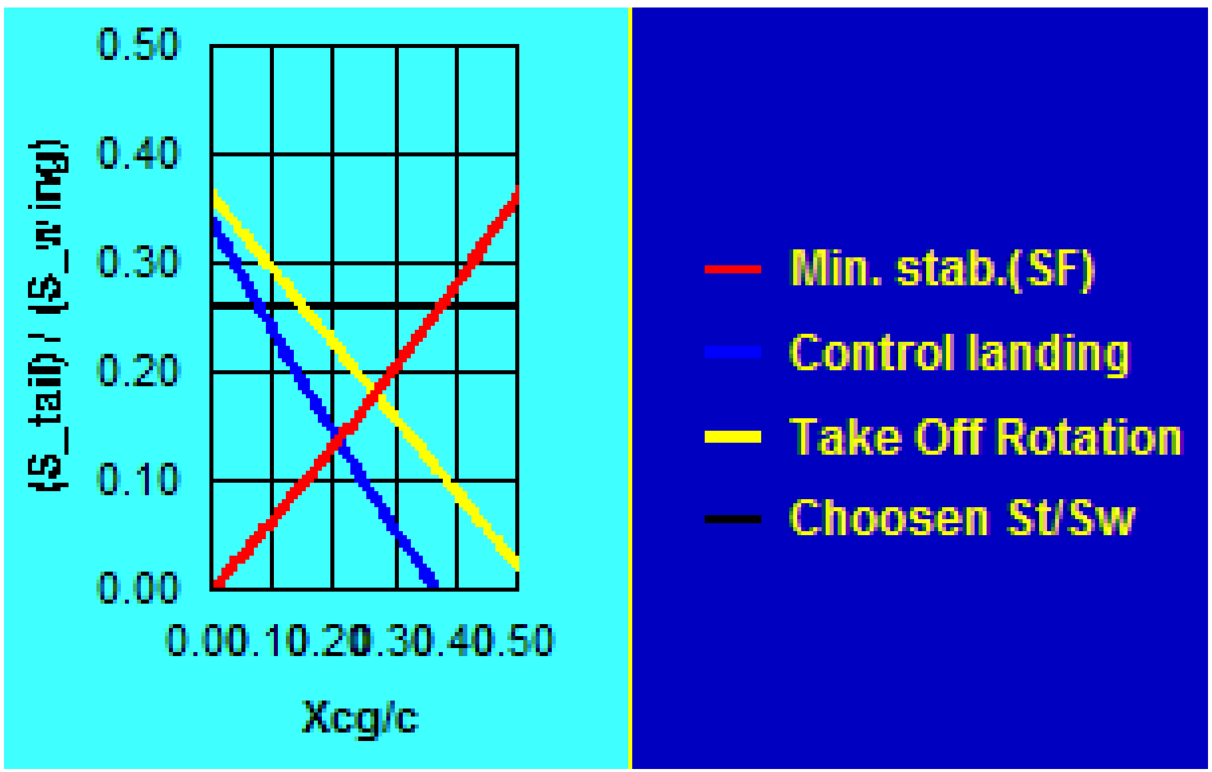
ADAS Modules

- ***Stability and Control:***

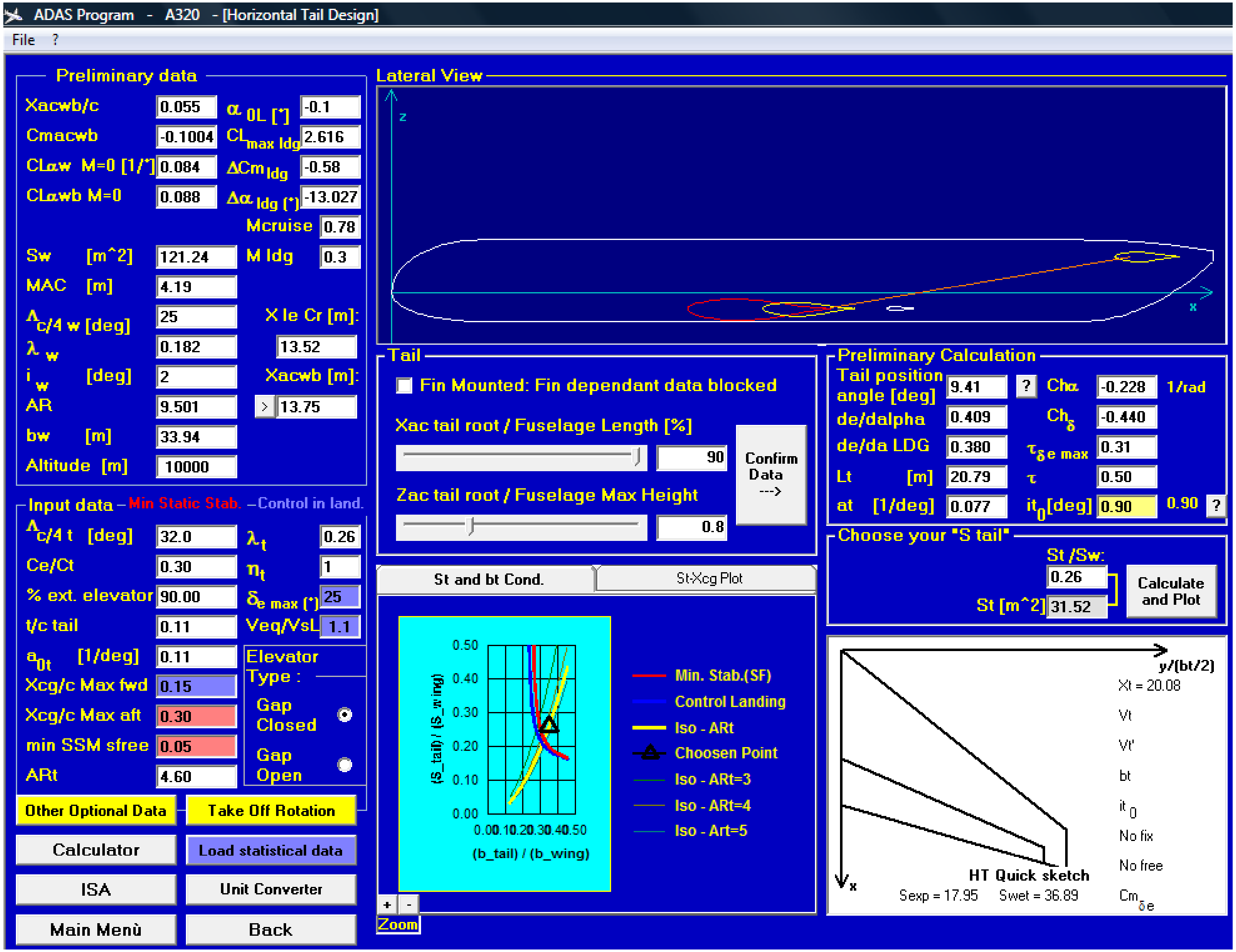
For Horizontal Tail Design CG constraints due to minimum stability (stick free), Control deflection in landing and take off rotation have been considered



Take off Rotation forces



ADAS Modules - *Stability and Control:*



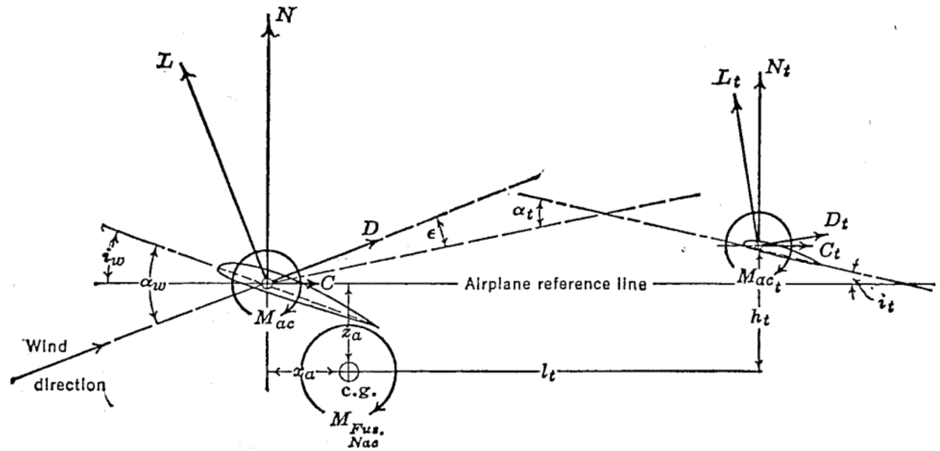
ADAS Modules

- ***Stability and Control:***

➢ <u>*Longitudinal Stability and Control*</u>:

The equations used for the study of longitudinal stability are taken by classic methodology:

$$C_{m_{cg}} = C_N \frac{x_a}{c} + C_c \frac{z_a}{c} + C_{m_{ac}} + C_{m_{\substack{Fus\\Nac}}} + C_{m_{act}} \frac{S_t}{S_w} \frac{c_t}{c} \eta_t + C_{c_t} \frac{S_t}{S_w} \frac{h_t}{c} \eta_t - C_{N_t} \frac{S_t}{S_w} \frac{l_t}{c} \eta_t$$



The slope of pitching moment with CL is given by:

$$\frac{dC_m}{dC_L} = \underbrace{\frac{dC_N}{dC_L}\frac{x_a}{c} + \frac{dC_c}{dC_L}\frac{z_a}{c} + \frac{dC_{mac}}{dC_L}}_{\text{Contr. of wing}} + \underbrace{\left(\frac{dC_m}{dC_L}\right)_{\substack{Fus\\Nac}}}_{\substack{\text{Contr. of}\\\text{fuselage and}\\\text{nacelles}}} - \underbrace{\frac{dC_{N_t}}{dC_L}\frac{S_t}{S_w}\frac{l_t}{c}}_{\substack{\text{Contr. of}\\\text{horizontal tail}}}\eta_t$$

PENDULAR Stability

ADAS Modules

- *Stability and Control:*

➢ *Longitudinal Stability and Control*:

The equation used for the calculation of neutral point is:

$$N_0 = x_{cg(dC_m/dC_L=0)} = x_{ac} - \left(\frac{dC_m}{dC_L}\right)_{\substack{Fus\\Nac}} + \frac{a_t}{a_w}\bar{V}\eta_t\left(1 - \frac{d\epsilon}{d\alpha}\right)$$

So the Stability Static Margin can be calculated:

$$\frac{dC_m}{dC_L} = x_{cg} - N_0$$

The effect of Thrust on these equations is an additive term calculated by:

- For Propeller: $$\left(\frac{dC_m}{dC_L}\right)_{N_{pTc=0}} = \frac{(dC_N/d\alpha)_{pT=0}(1 + d\epsilon/d\alpha)l_p S_p\, N}{S_w c a_w}$$

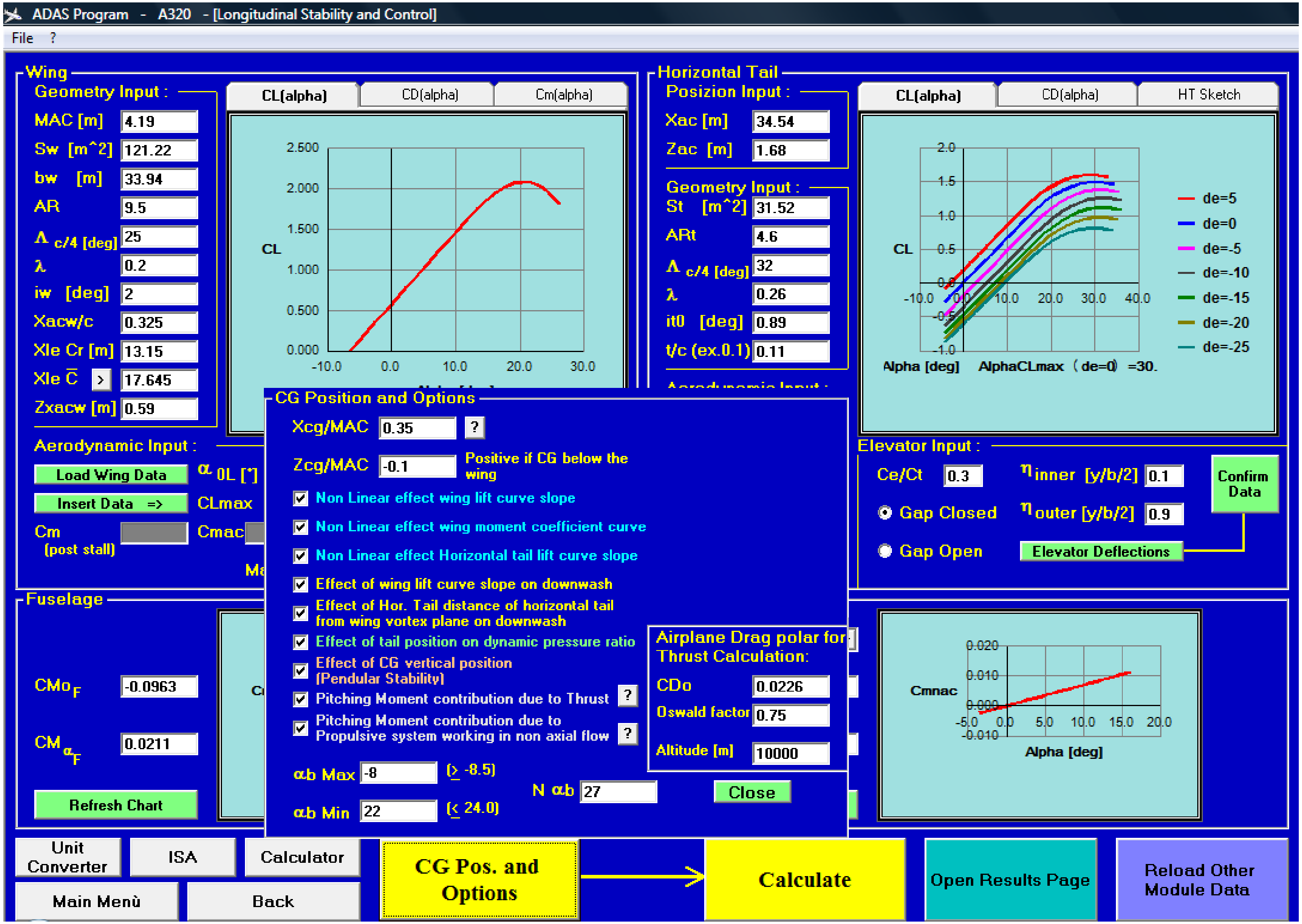
$(dC_N/d\alpha)_{pT=0}$*	
.0024	Two-bladed propellers
.0032	Three-bladed propellers
.004	Four-bladed propellers
.0065	Six-bladed counter-rotating propellers

- For Jet:

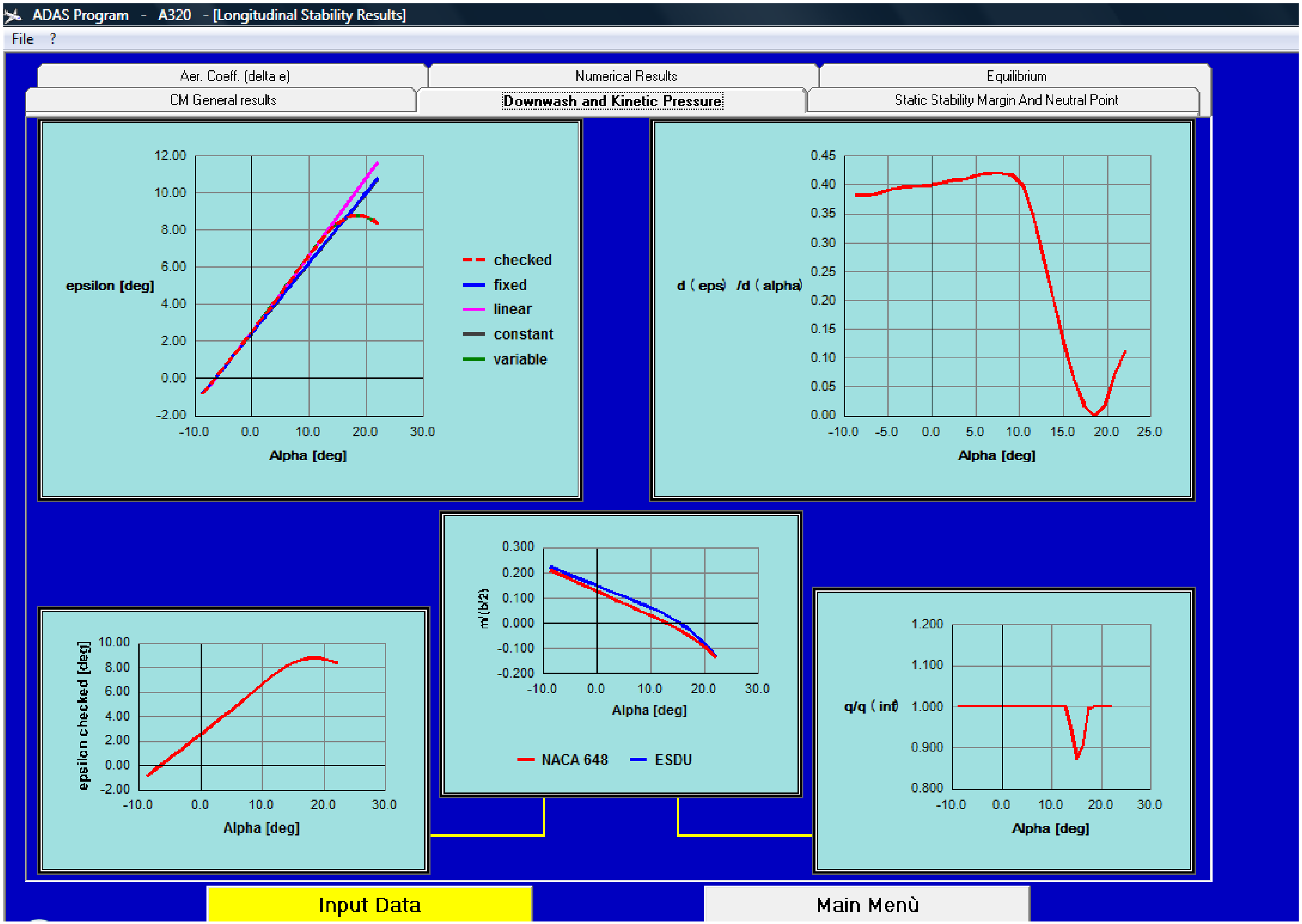
$$\frac{dC_M}{dC_L} = 0.035\frac{\dot{m}}{\rho\sqrt{2q/\rho}}\frac{l_T N}{S_w c a_w}$$

$$\dot{m} = 0.032 \cdot T/N$$

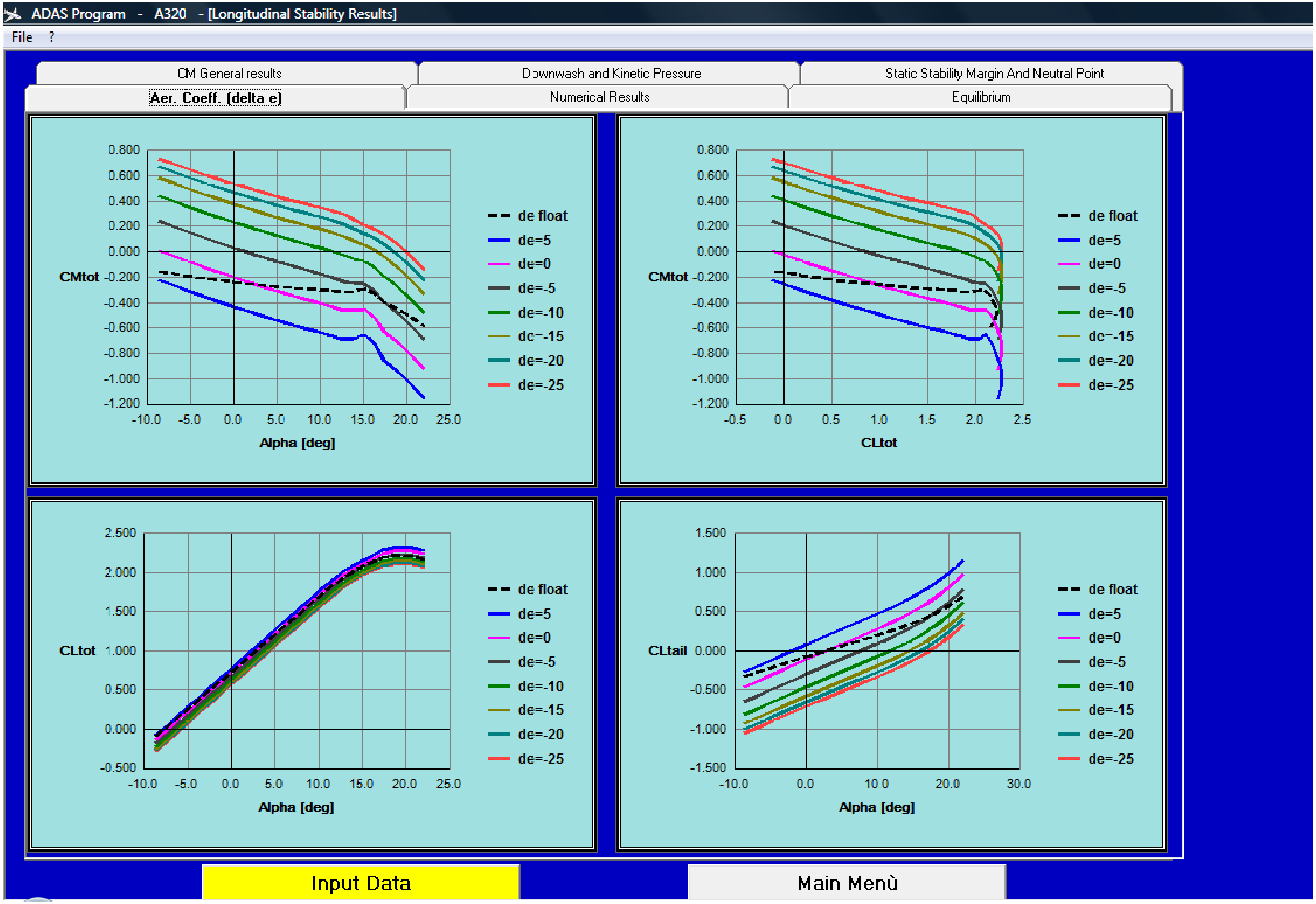
ADAS Modules - *Stability and Control:*



ADAS Modules - *Stability and Control:*

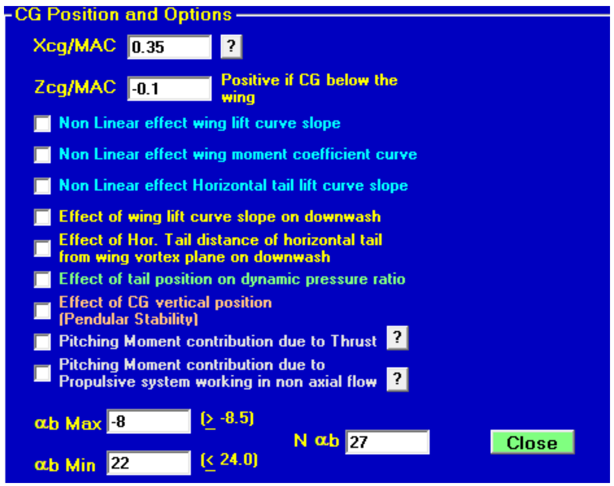


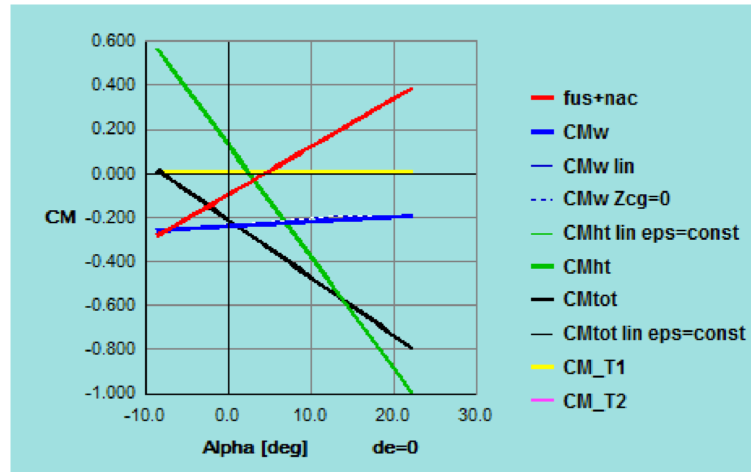
ADAS Modules - *Stability and Control:*

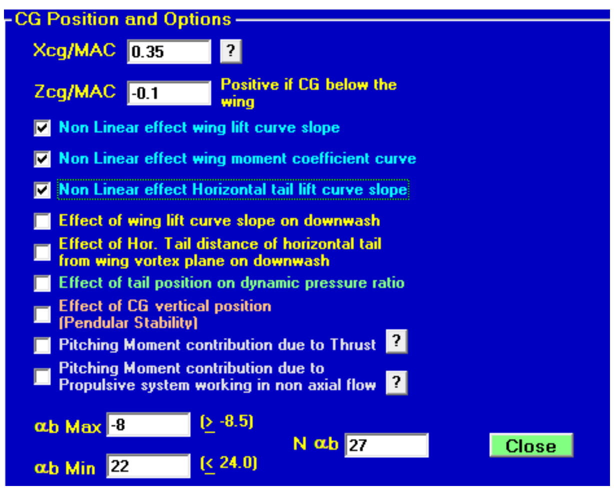


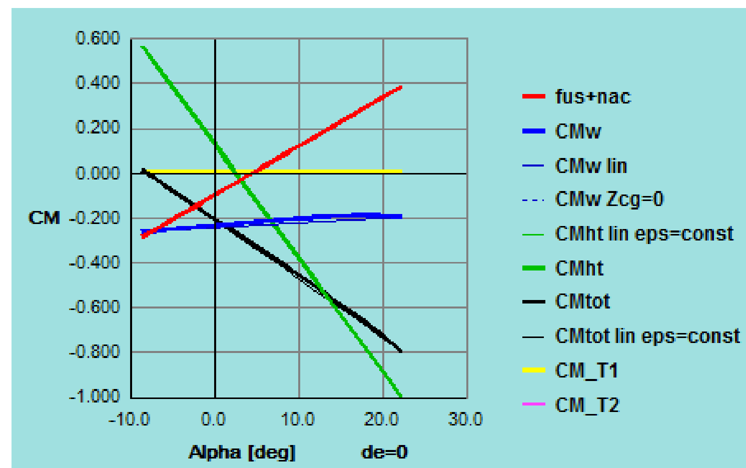
ADAS Modules

- Stability and Control:



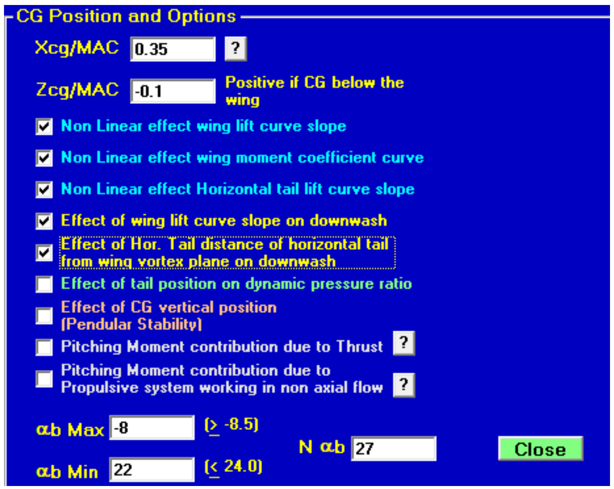


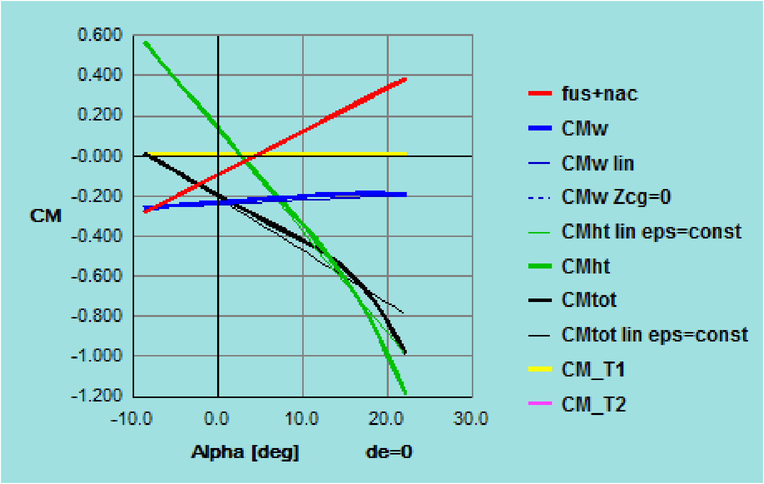


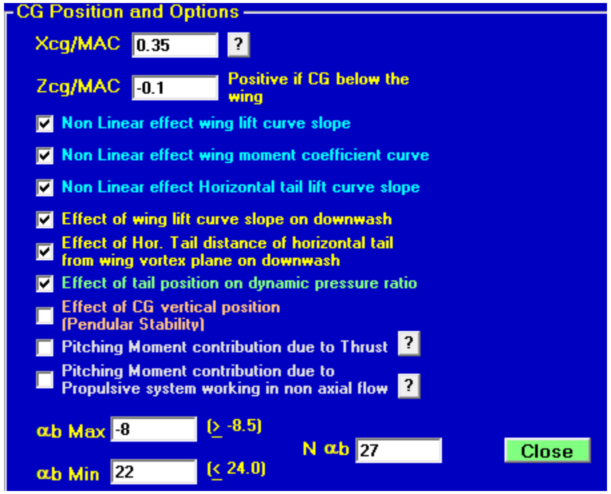


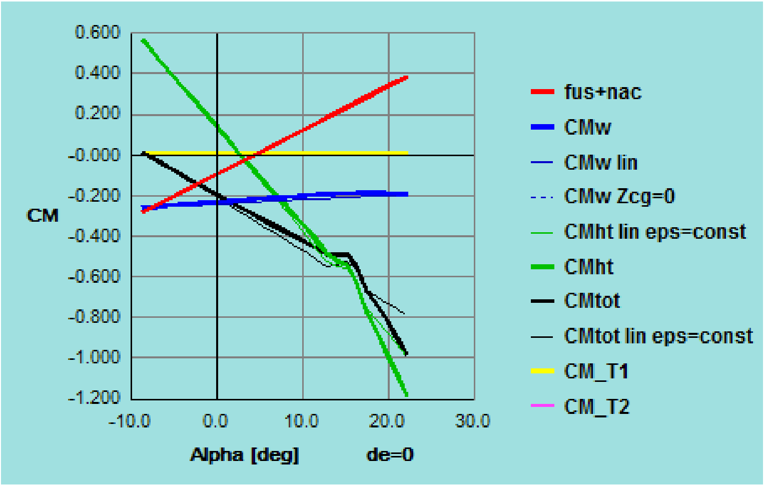
ADAS Modules

- Stability and Control:



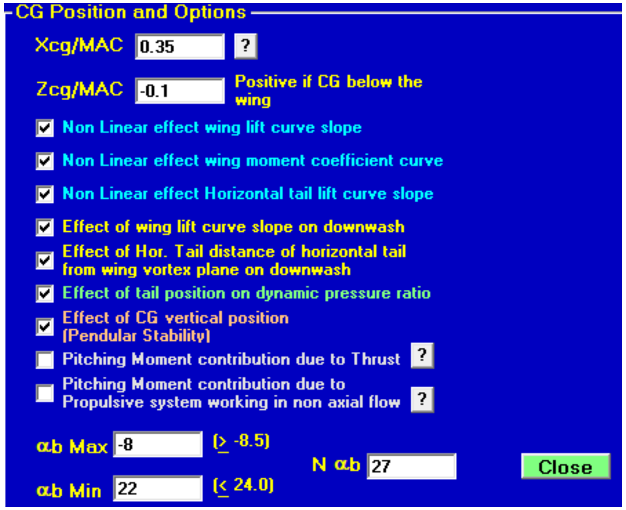


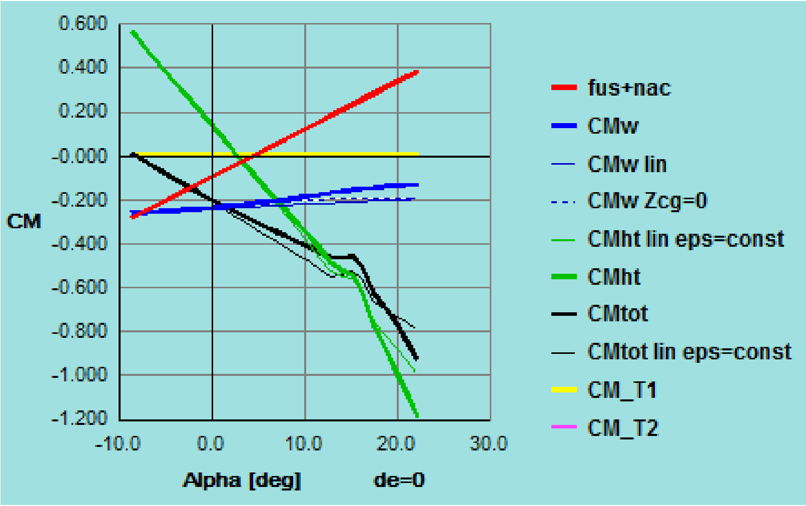


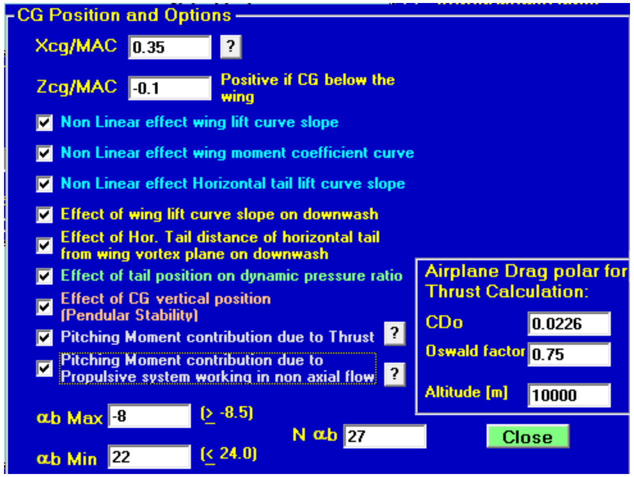


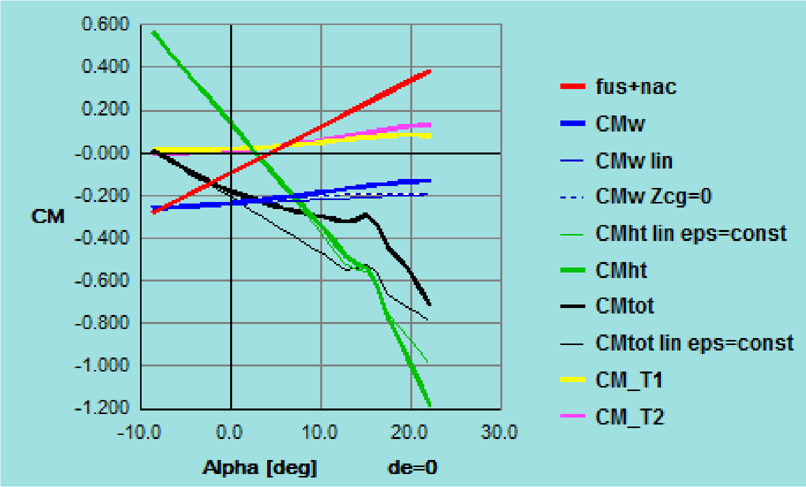
ADAS Modules

- *Stability and Control:*





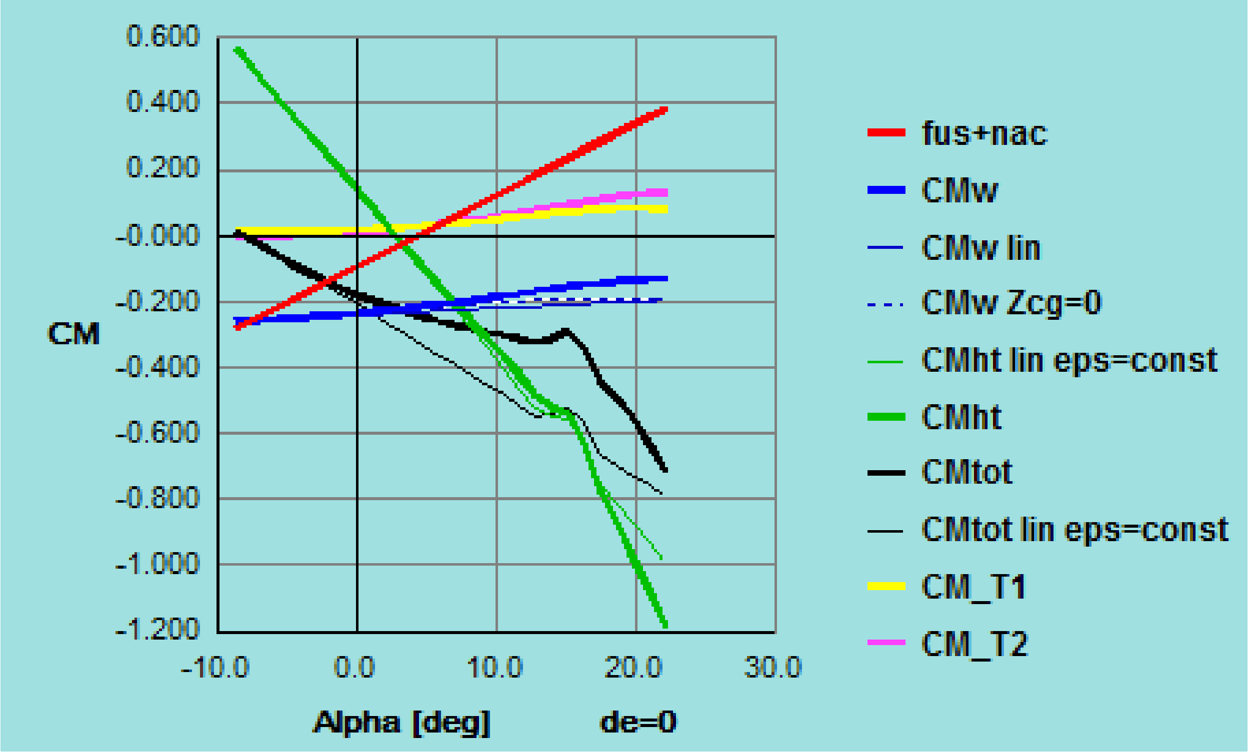




ADAS Modules

- *Stability and Control:*

+ *Non linear effects*
+ *Downwash on wing and Tail effects*
+ *Effect of Tail position on pressure ratio*
+ *Pendular Stability*
+ *Effect of Thrust*

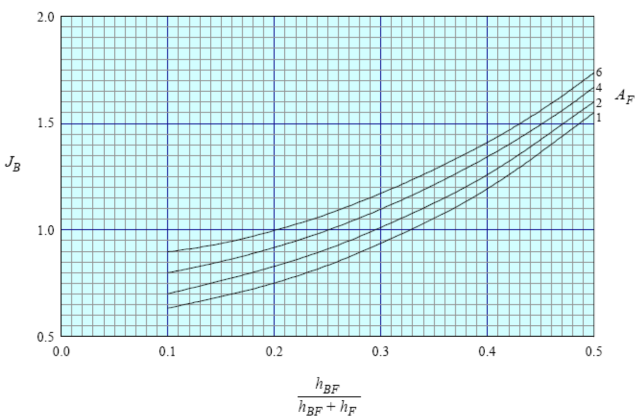


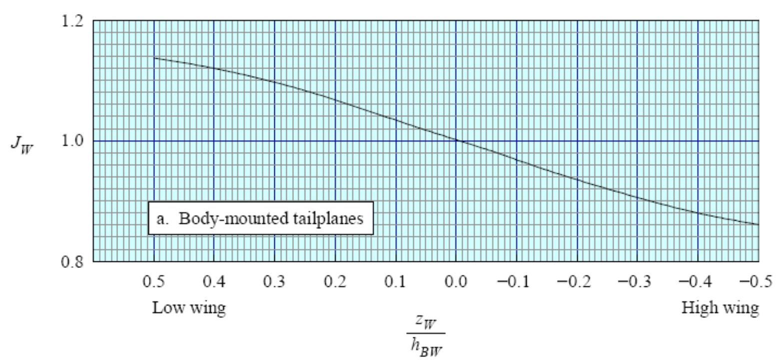
ADAS Modules - *Directional Stability and Control:*

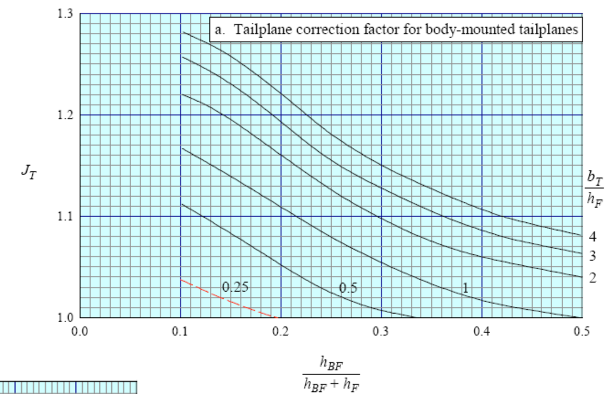
The methodologies used for the Vertical Tail contribution on the Yaw Derivative coefficient due to β are from ESDU and Roskam:

- ESDU Approach:

$$Cy_v = \boxed{J_B} \cdot \boxed{J_W} \cdot \boxed{J_T} \cdot (C_{L\alpha})_V \cdot \frac{S_V}{S_W}$$





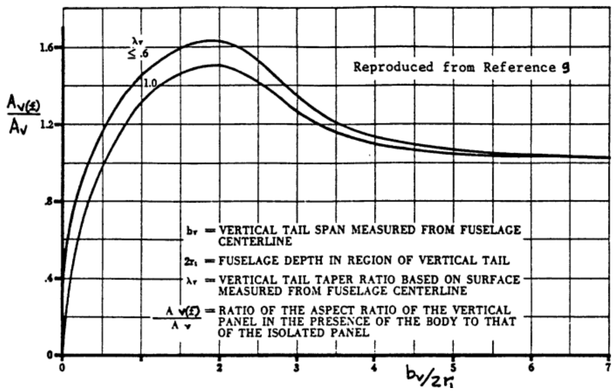


ADAS Modules

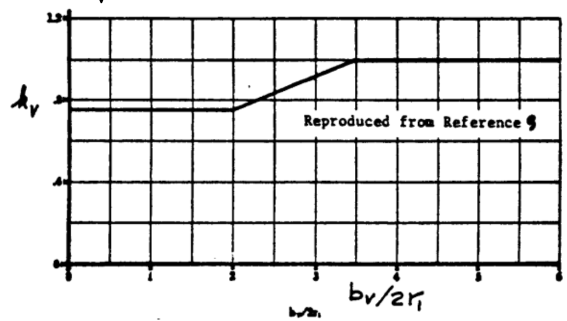
- ***Stability and Control:***

- Roskam Approach need the estimation of the follow contributions:

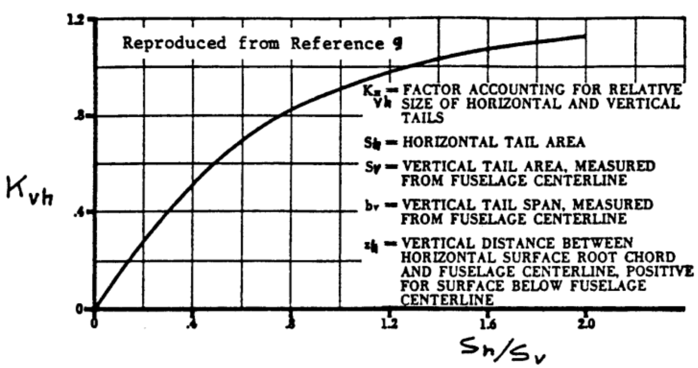
J_B - Vertical Tail/Fuselage



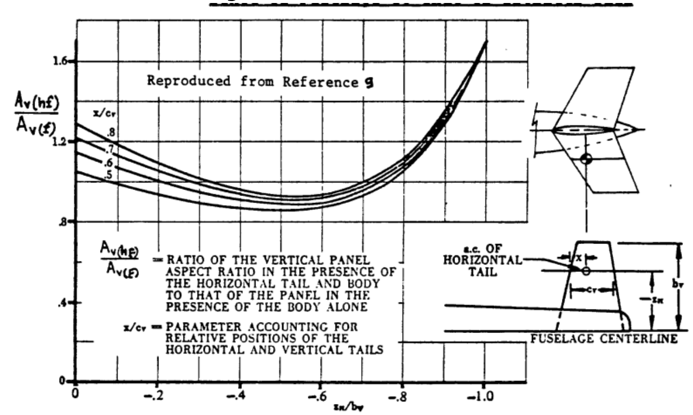
k_v - Isolated Vertical Tail



k_{VH} - Vertical Tail/Horizontal Tail



J_T - Horizontal and Vertical Tail Layout



ADAS Modules

- ***Stability and Control:***

So the the Yaw Derivative coefficient due to β of vertical tail:

$$Cn_{\beta_V} = -k_V CL_{\alpha_V}\left(1+\frac{\partial\sigma}{\partial\beta}\right)\eta_V \frac{S_V}{S}\frac{l_V}{b}$$

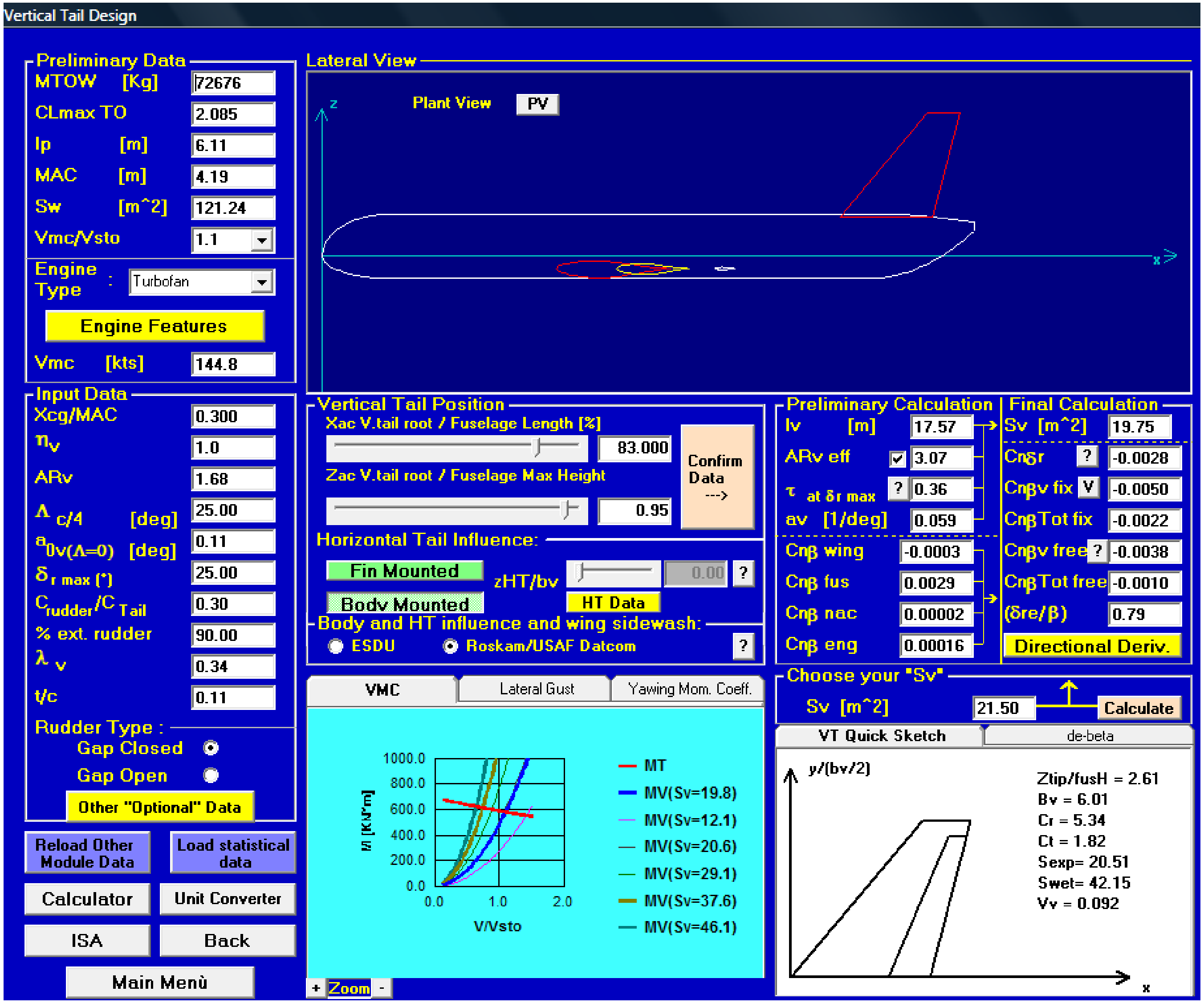
Where $CL\alpha_V$ is calculated with effective AR_V:

$$AR_{Veff} = J_B[1 + K_{VH}(J_T - 1)]$$

For free stick condition, the hinge moments are estimated with the same methodology used in the Horizontal Tail design (McCormick approach).

$$Cn_{\beta_{Vfree}} = -k_V CL_{\alpha_V}\left(1+\frac{\partial\sigma}{\partial\beta}\right)\left(1-\frac{C_{h\beta}}{C_{h\delta}}\tau\right)\eta_V \frac{S_V}{S}\frac{l_V}{b}$$

ADAS Modules - *Stability and Control:*



ADAS Modules

- *Stability and Control:*

➢ *<u>Lateral Stability (Dihedral effect)</u>* :

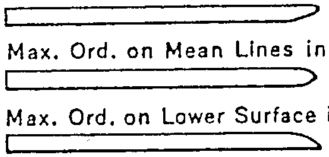
For the analysis of lateral stability it required after the design of all tailplane also the wing and horizontal tail dihedral angle.
The lateral derivative coefficient due to β is founded by:

$$C_{\ell_\beta} = \left(C_{\ell_\beta}\right)_w + \left(C_{\ell_\beta}\right)_{\Gamma w} + \left(C_{\ell_\beta}\right)_{\varepsilon w} + \left(C_{\ell_\beta}\right)_{HT} + \left(C_{\ell_\beta}\right)_{\Gamma HT} + \left(C_{\ell_\beta}\right)_{\varepsilon HT} + \left(C_{\ell_\beta}\right)_{v.tail}$$

$$+\Delta C_{\ell_\beta posw} + \Delta C_{\ell_\beta posHT} + \Delta C_{\ell_\beta tipW} + \Delta C_{\ell_\beta tipHT}$$

Where:

- $\left(C_{\ell_\beta}\right)_w = -\dfrac{1+2\lambda}{3(1+\lambda)} \cdot C_L \cdot \tan\Lambda_{c/4}$
- $\left(C_{\ell_\beta}\right)_{v.tail} = -a_v \cdot \eta_v \cdot \dfrac{S_v}{S_w} \cdot \dfrac{z_v}{b_w}$
- $\left(C_{l_\beta}\right)_{posW} = -1.2\sqrt{AR}\,\dfrac{Z_w}{b}\,2\,\dfrac{d_{fus}}{b}$
- $\left(C_{l_\beta}\right)_{\varepsilon W} = -\varepsilon \cdot tan\left(\Lambda_{c/4}\right)K_{\lambda AR}$



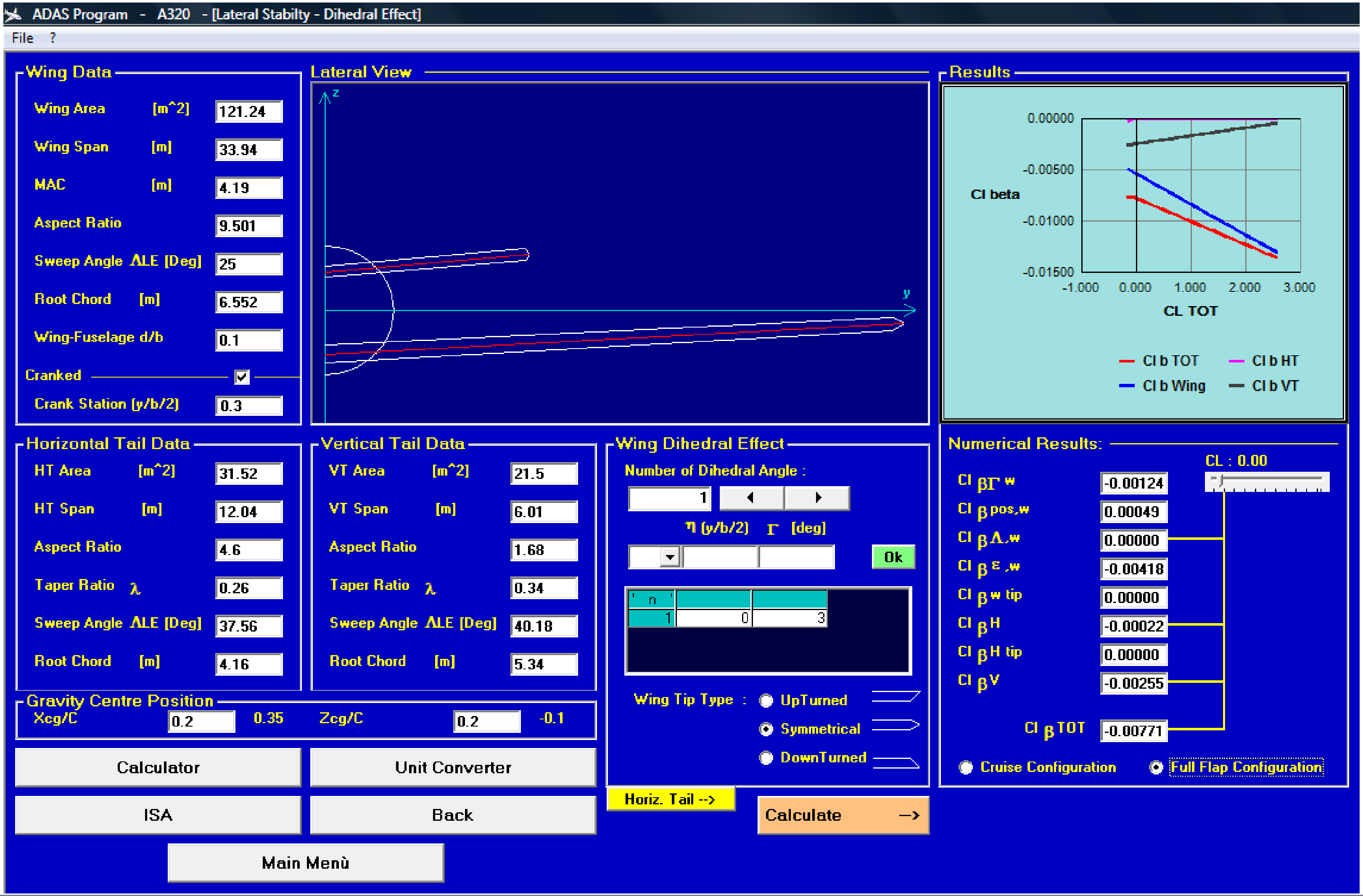
(a) Max. Ord. on Upper Surface in Plane $\Delta C_{l_\psi} = .0002$

(b) Max. Ord. on Mean Lines in Plane $\Delta C_{l_\psi} = 0$

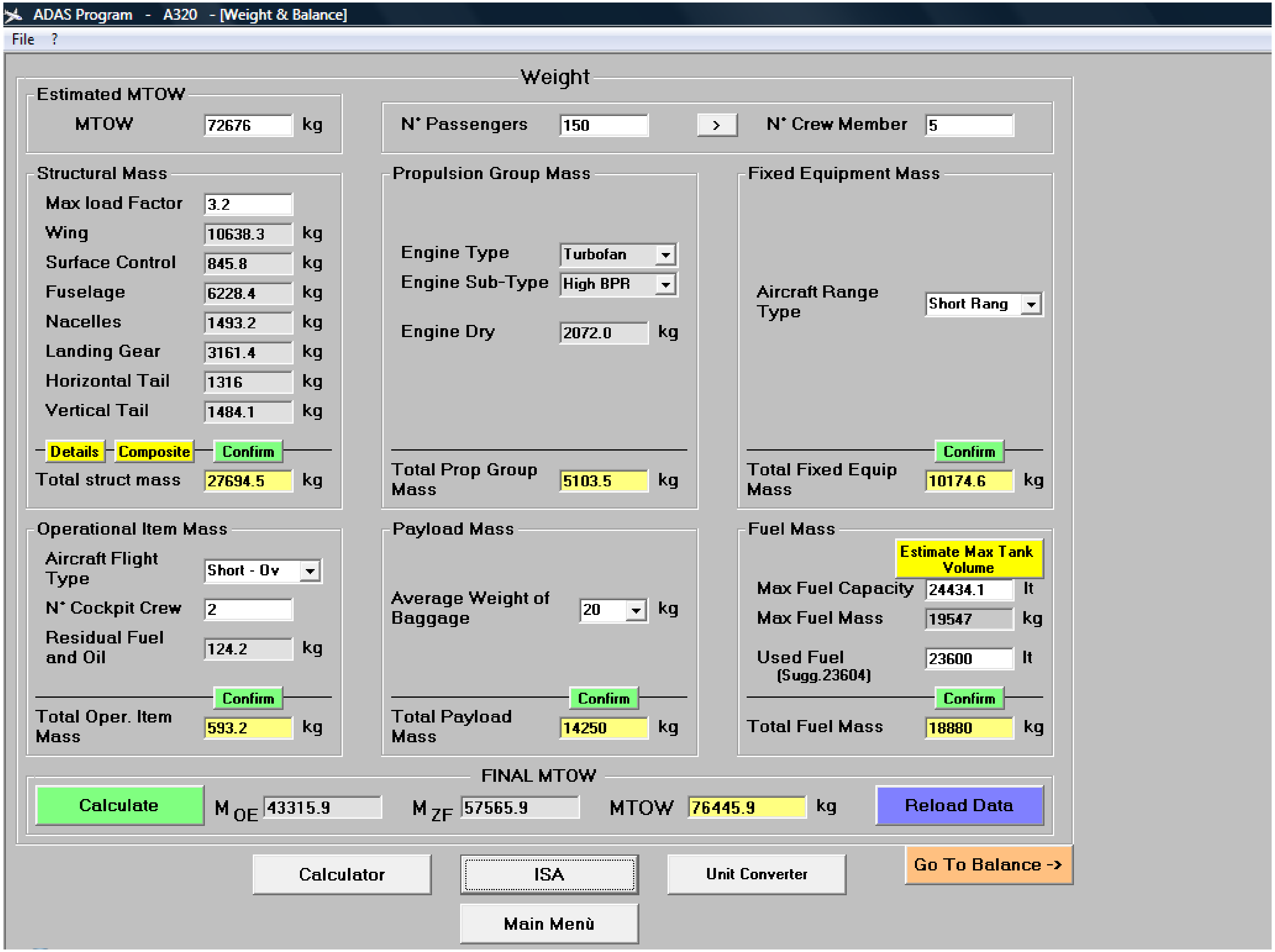
(c) Max. Ord. on Lower Surface in Plane $\Delta C_{l_\psi} = -.0002$

ADAS Modules

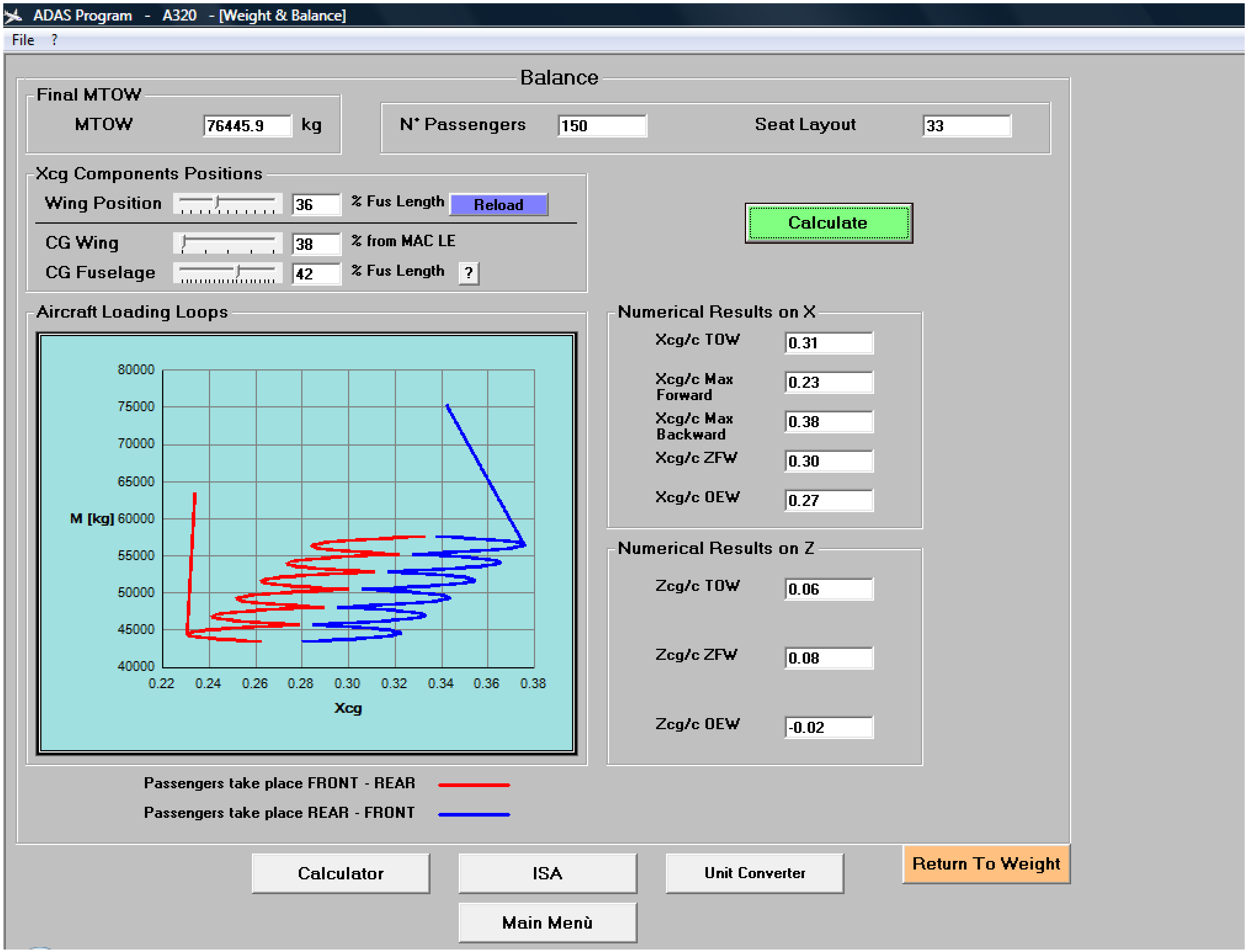
- *Stability and Control:*



ADAS Modules - *Weight and Balance:*

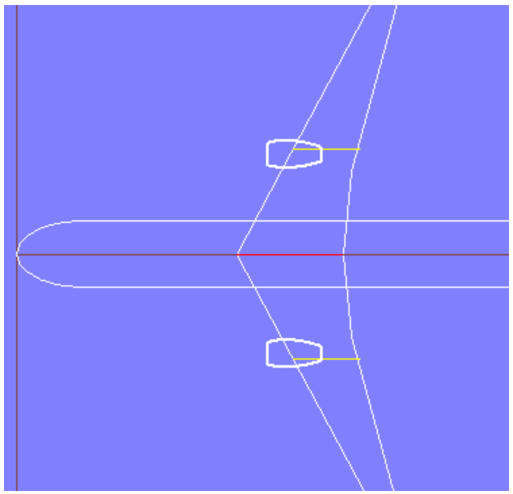


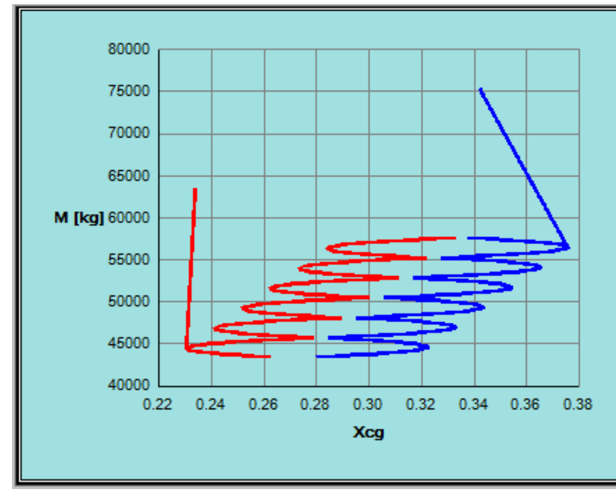
ADAS Modules - *Weight and Balance:*

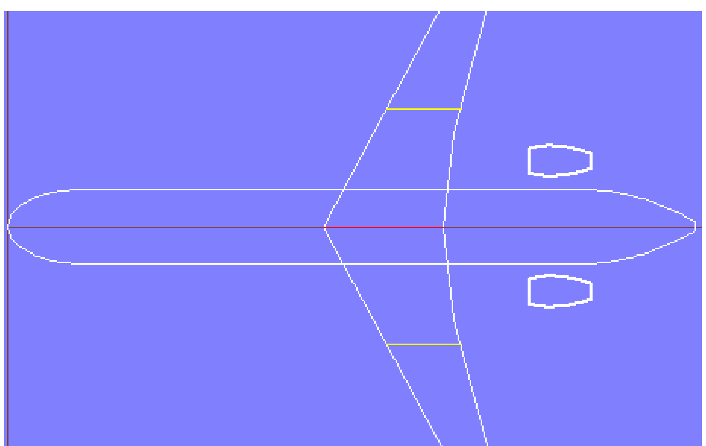


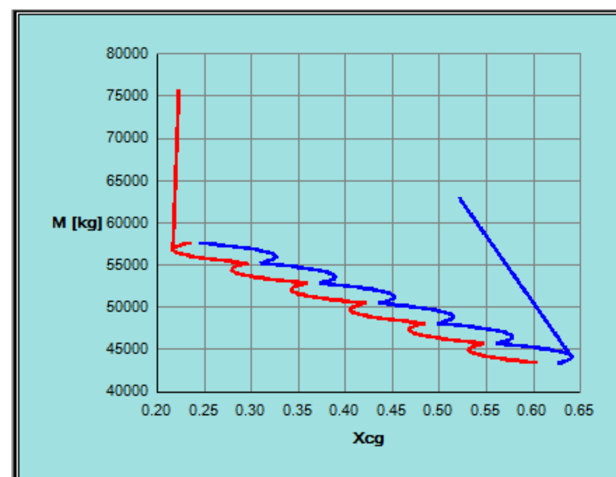
ADAS Modules

- *Weight and Balance:*



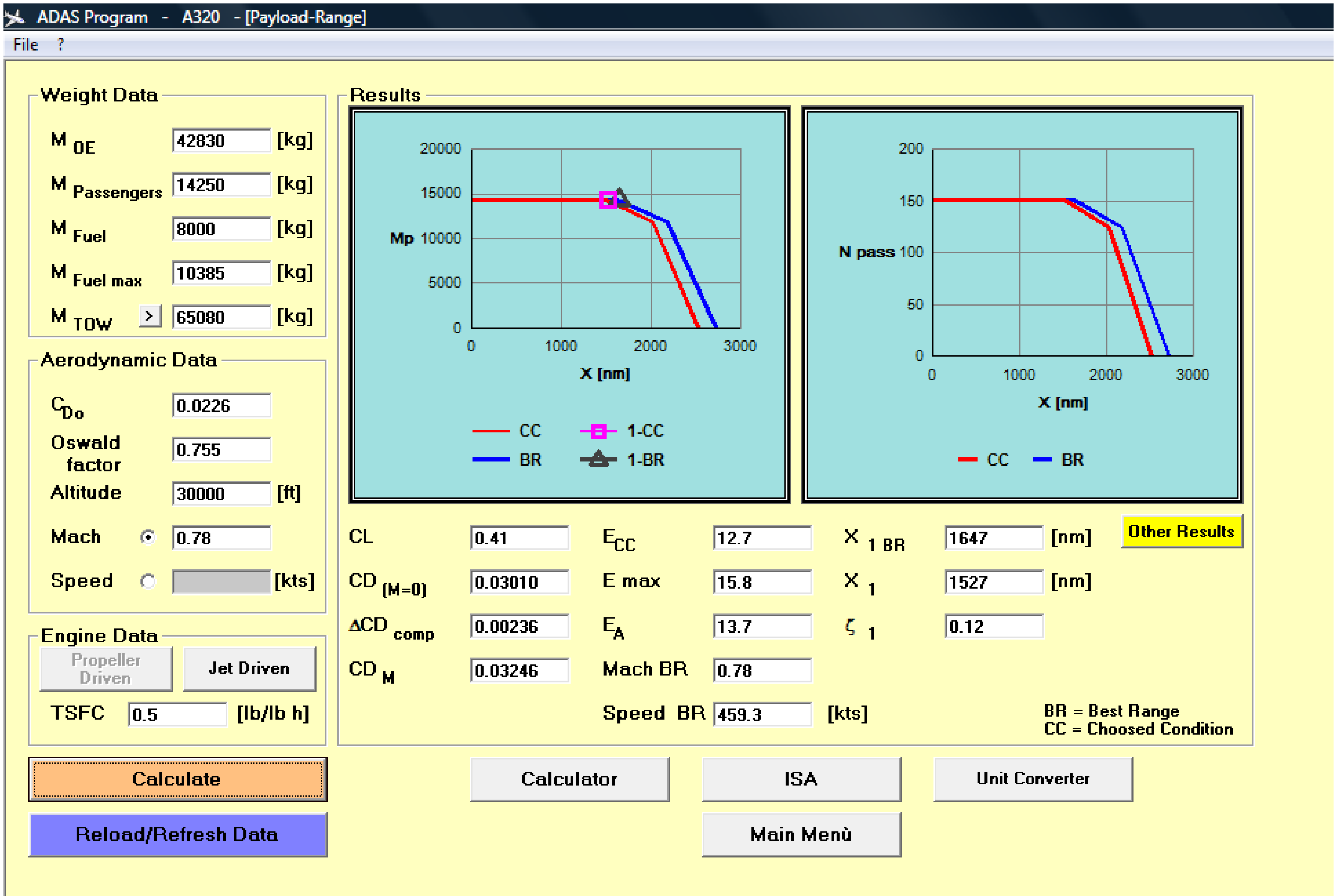






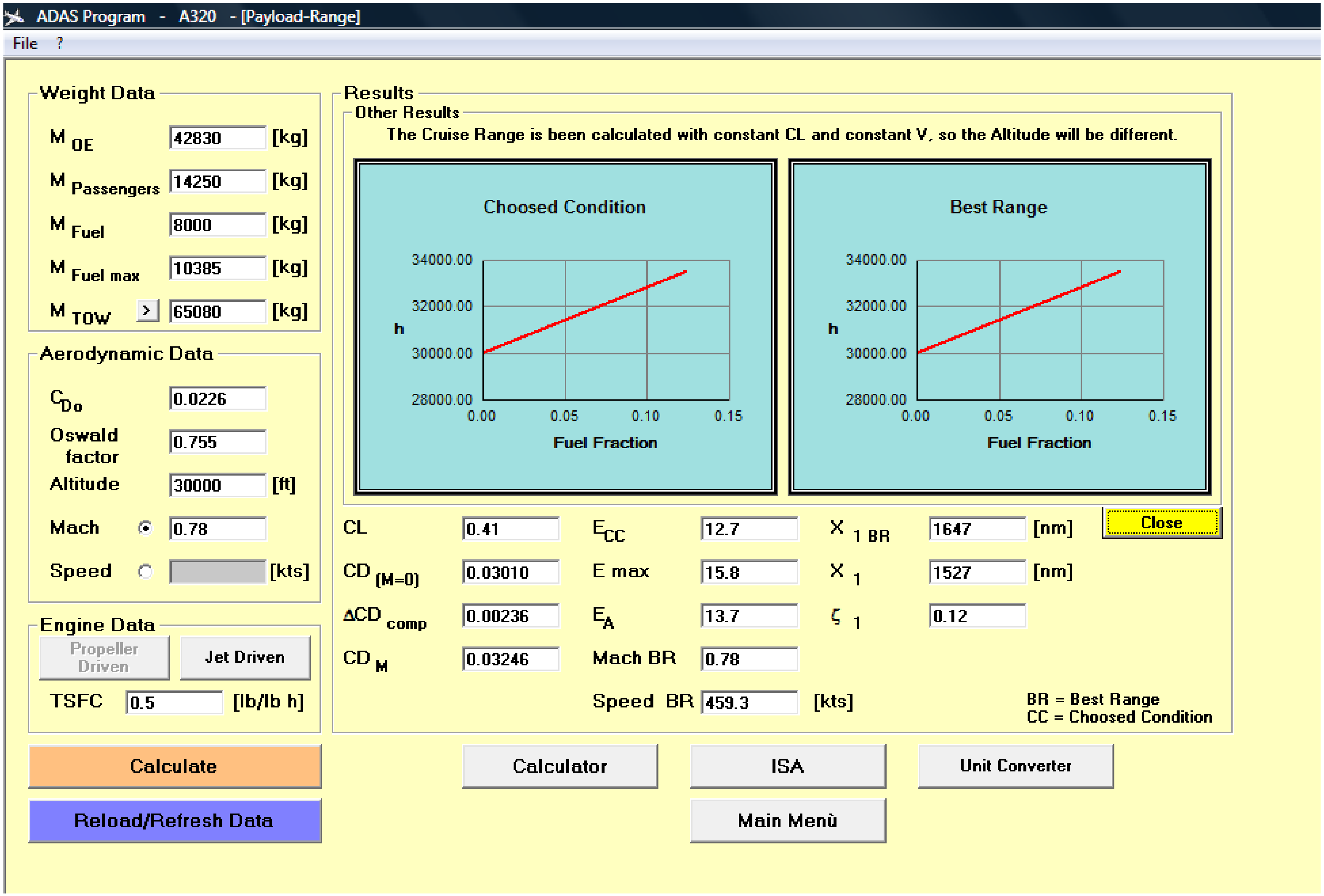
ADAS Modules

- *Payload Range:*



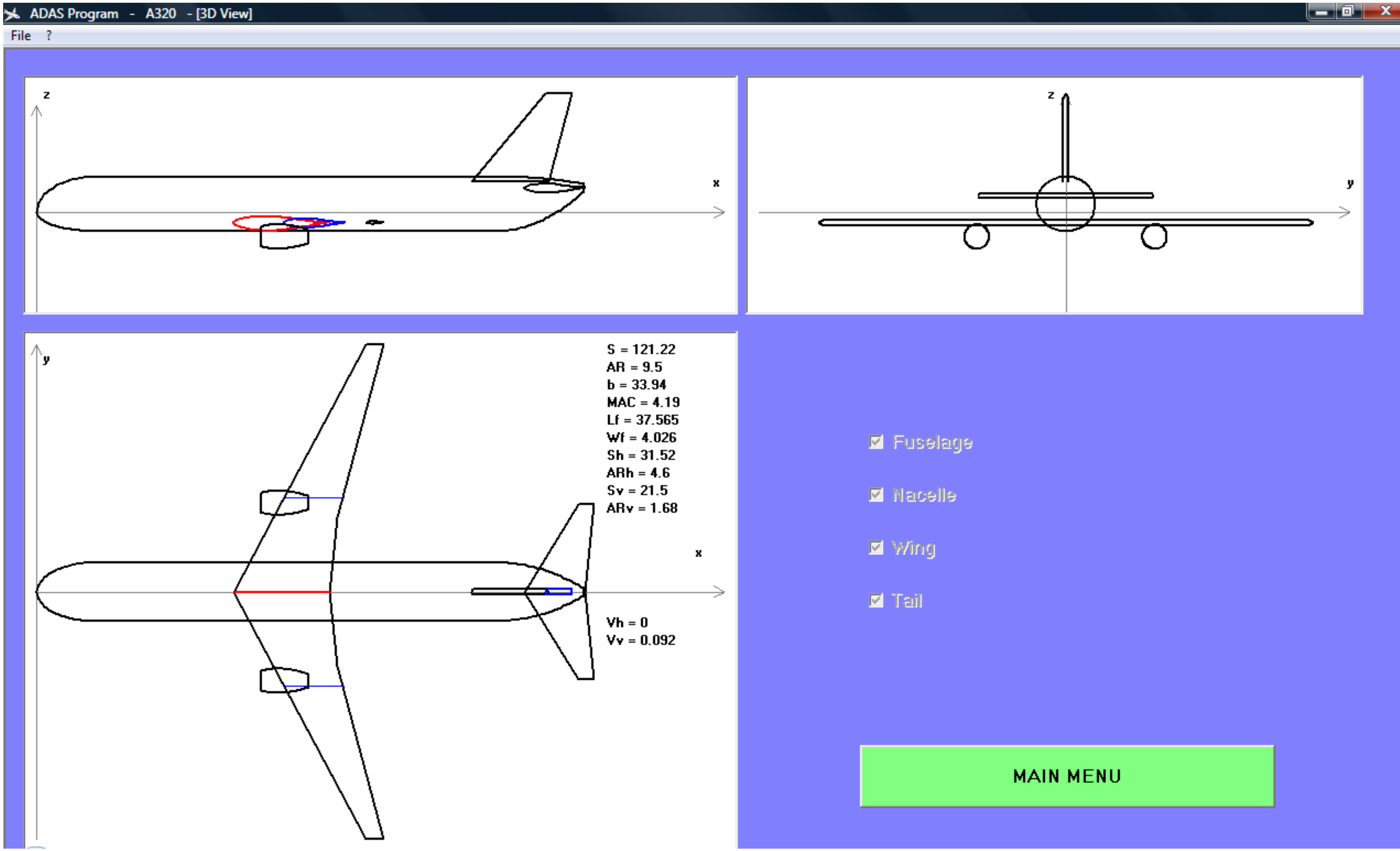
ADAS Modules

- *Payload Range:*



ADAS Modules

- *3D view:*



CONCLUSIONS:

- The software allows the conceptual design and a preliminary analysis of the aircraft in less than 1 hour
- The software is USER FRIENDLY with many helps (but also to be improved)
- Many graphs helps user (students) with the comprehension of theory which is behind and to get the feeling of the obtained results
- Some non-linear effects are included (pendular stability, downwash, etc.)
- Students can “play” with the software learning all the links between separate performances and characteristics of the airplane
- The software can be also useful for researchers and people from industry

FUTURE DEVELOPMENTS:

- **The software will be commercialized next year (hopefully)**
- **Optimization should be included**
- **Obtaining new semi-empirical laws to be implemented to enhance the software accuracy (both through wind-tunnel tests or through 3D and 2D aerodynamic analysis (panel methods) or CFD (NS) calculations.**

THANKS for the ATTENTION