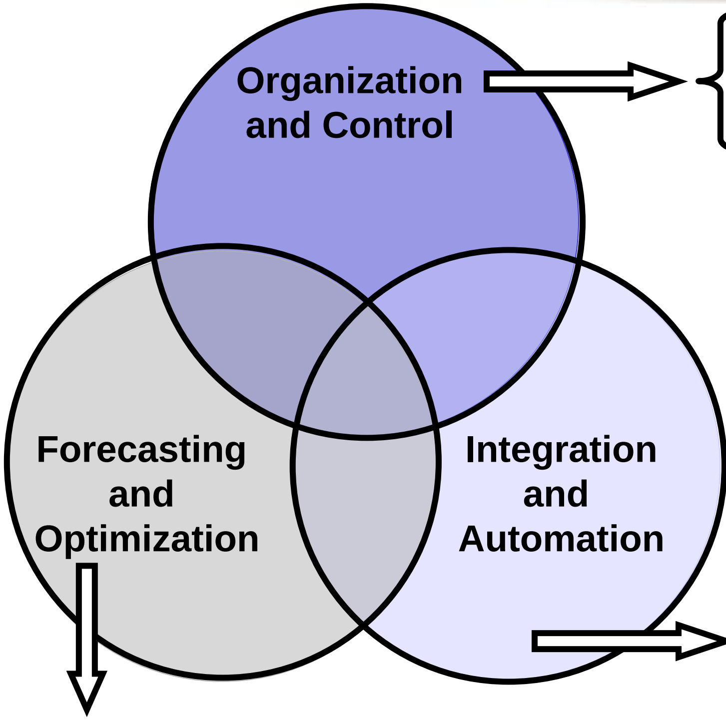
The MDO experience at Embraer with modeFrontier

Juliano Machado Tenório Cavalcanti
September – 2006
Trieste - Italy

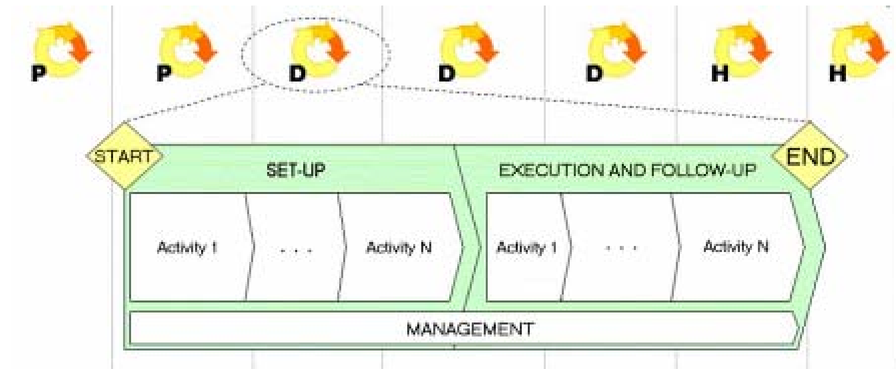
Outline

- The Embraer Engineering Proccess Environment
- Case Study – Level 1
  - Problem Statement
  - Disciplinary Models
  - Resulting mF Workflow
  - Results
  - Concluding Remarks
- Case Study – Level 2
  - Integration Framework
- Concluding remarks and prospective future work

Engineering Process Environment

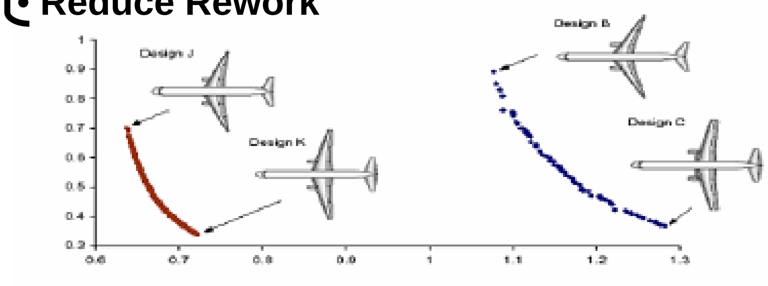


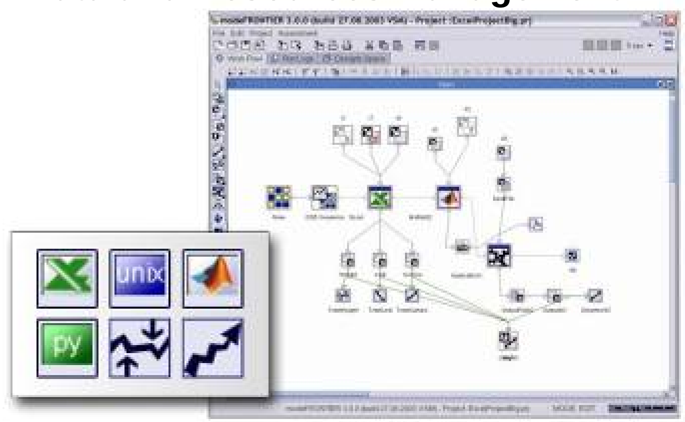
- Engineering Data Management
- Engineering Configuration Control
- Extensive Use/Interfacing of PLM Solutions



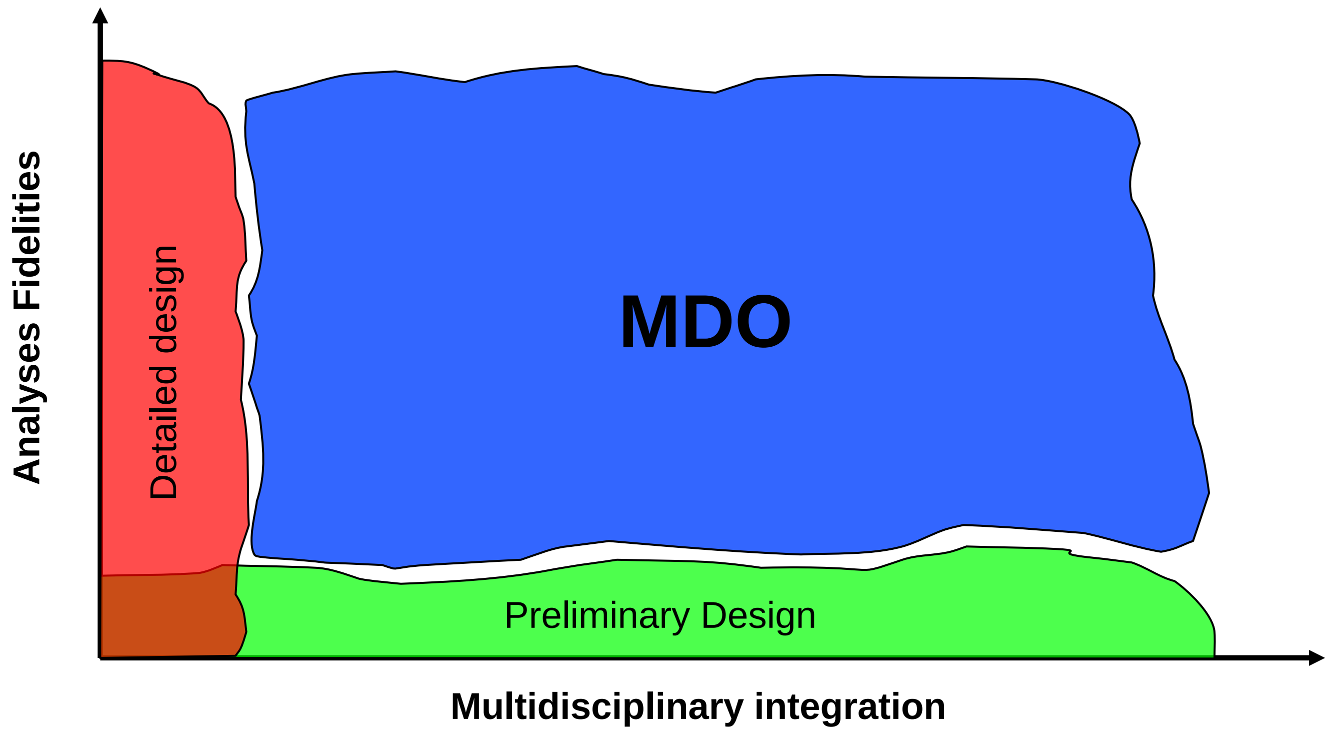
- Flow Engines
- Visual Process Definition
- Network Data and Resources Management

- Reuse Engineering Information
- Translate Better Process into Better Product
- Reduce Rework





Why MDO?



Analyses Fidelities
Detailed design
MDO
Preliminary Design
Multidisciplinary integration

Case Study 1 – Problem Statement

- A simplified aircraft optimization was proposed in order to better identify the problem:
  - The aircraft fuselage will not change
  - The wing load factor will be assumed as 2.5 g´s
    - Used in semi-empirical weight prediction methodology
  - The aircraft engine will be assumed as fixed.
  - Aeroelastic stability was not considered
  - Structural analysis was not considered
  - Latero-directional stability and control analysis was not considered

Case Study 1 – Problem Statement

Candidate objectives / constraints:

- Fuel tank capacity.
- TOFL – Take off field length.
- Flight quality parameters
  - Static margin
  - Short-period damping and undumped natural frequency (with and without the stability augmentation system)
  - Trim capability
- Block fuel
- Block time
- Weights
  - Maximum take-off weight
  - Basic weight

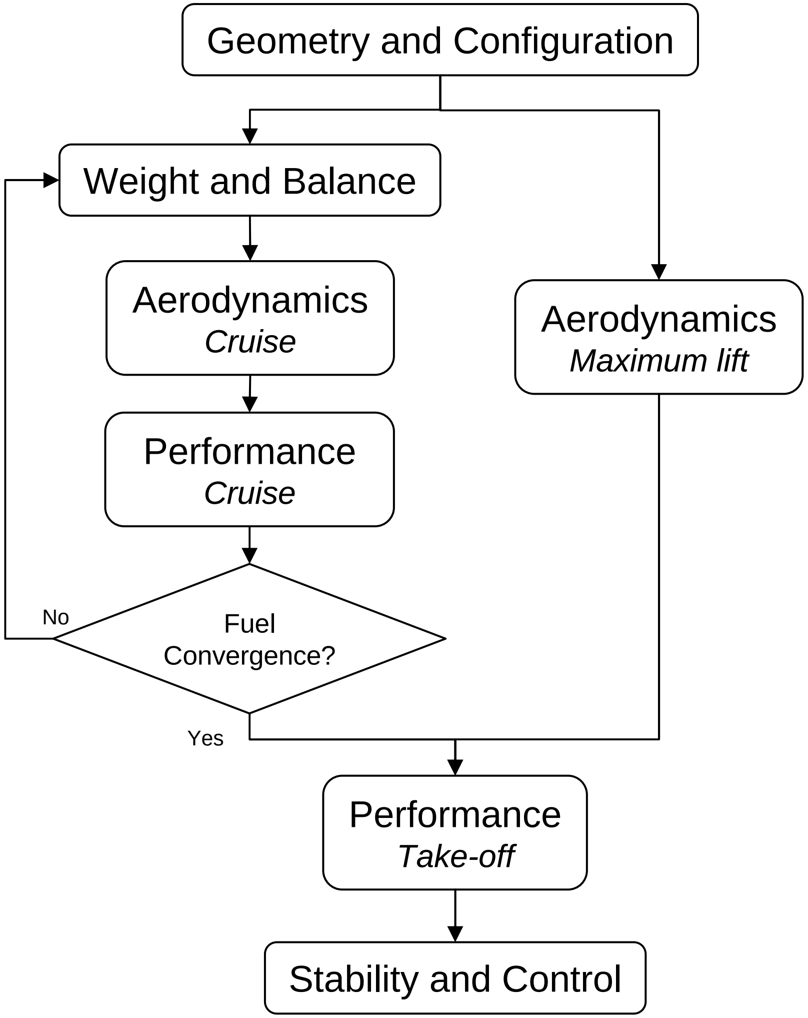
Candidate design variables:

- Aspect ratio
- Kink position
- Wing area
- Inner wing leading edge sweep
- Outer wing leading edge sweep
- Inner wing taper ratio
- Outer wing taper ratio
- Wing torsion (root, kink and tip)
- Airfoil variables (10 variables each)
  - Thickness
  - Maximum camber
  - …
- Horizontal and vertical tail volume
- Wing position

Case Study 1 – Disciplinary Models

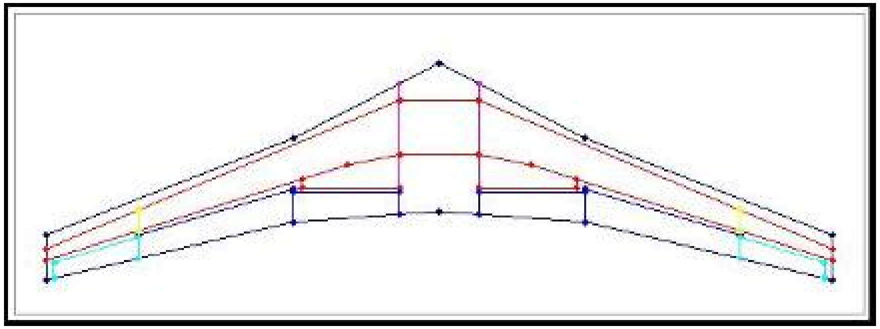
Processes description:

- Geometry and Configuration:
  - Generates wing planform and airfoils to be analyzed
- Weight and Balance:
  - Predicts the wing and horizontal tail weight and computes the aircraft CG variation
- Aerodynamics (cruise condition):
  - Trims and computes the aircraft lift to drag ratio at a typical cruise condition
- Performance (cruise condition):
  - Calculates the block fuel and time for a specified mission
- Aerodynamics (maximum lift):
  - Predicts the flapped aircraft maximum lift and drag
- Performance (take off):
  - Computes the so called balanced field length (BFL)
- Stability and Control:
  - Calculates all the parameters relative to the aircraft longitudinal stability and controllability, and implements a simple stability augmentation system (SAS) at the aircraft dynamics.

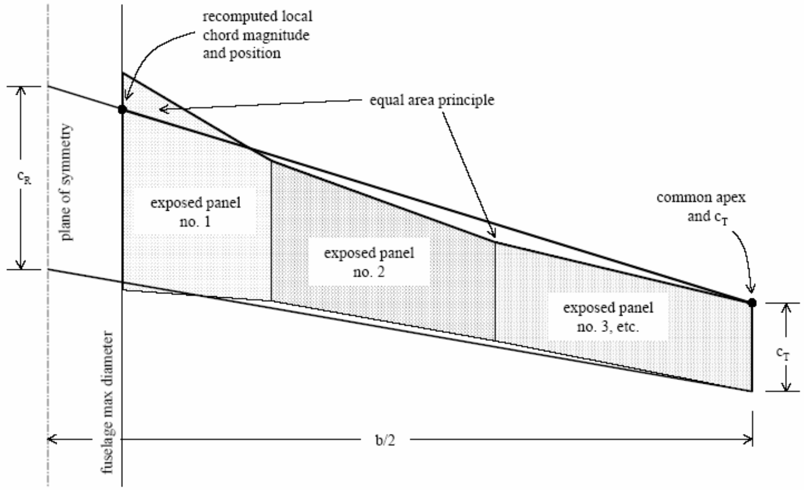


Case Study 1 – Disciplinary Models

Geometry and Configuration:



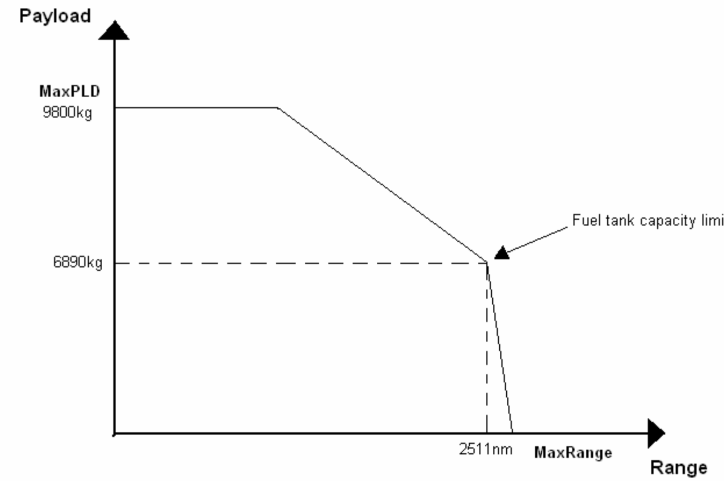
- Excel based
- Computes all geometry data for additional analyses:
  - Span, chords,…
  - Flaps geometry
  - …
- Computes the so called equivalent wing using the ESDU method
  - Used in weight prediction
- Computes the maximum fuel tank capacity

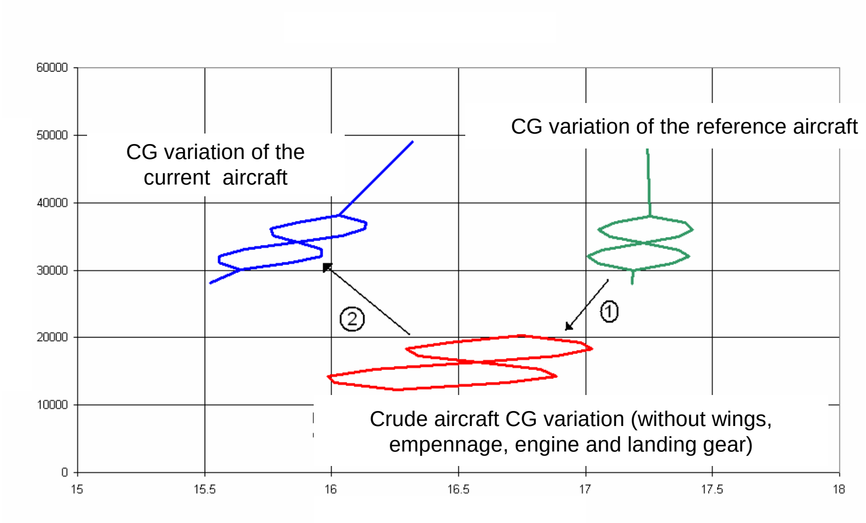


Case Study 1 – Disciplinary Models

Weight and Balance:

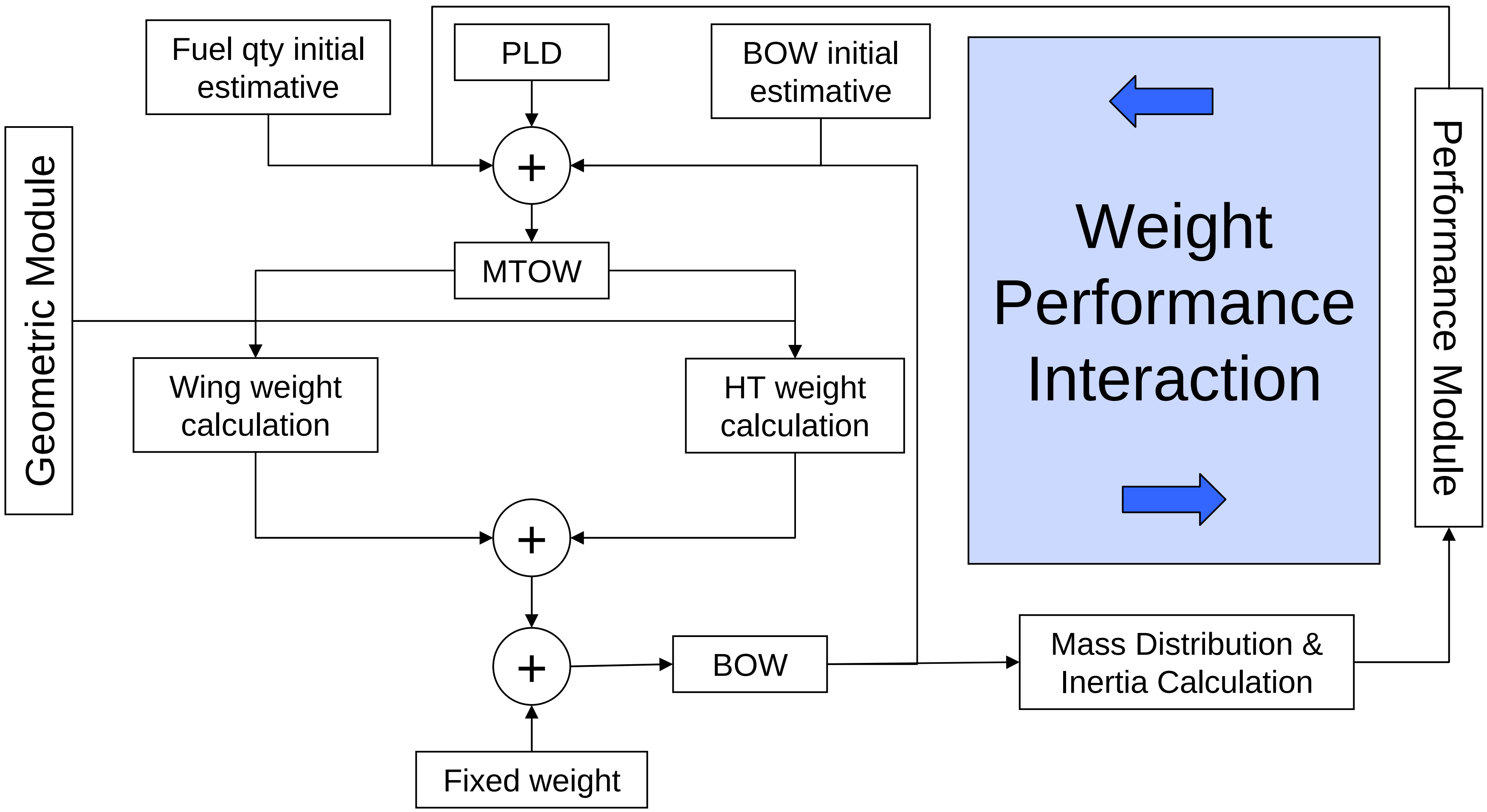
- Raymer and Torenbeek methodology
  - Inputs: MTOW, b, AR, sweep, t/c,...
- Iterative process
  - Fixed weight based on a reference aircraft
  - Fuel based on a 2511nm@6890kg mission
- Calculates de cruise medium weight
  - For the aircraft medium lift coefficient prediction
- CG variation:
  - Based at the fuselage variation of the reference aircraft computes the disturbance due to new components
  - Computes the aft and forward CG position for stability and control calculation, and the mean CG position on cruise for trimming.





Case Study 1 – Disciplinary Models

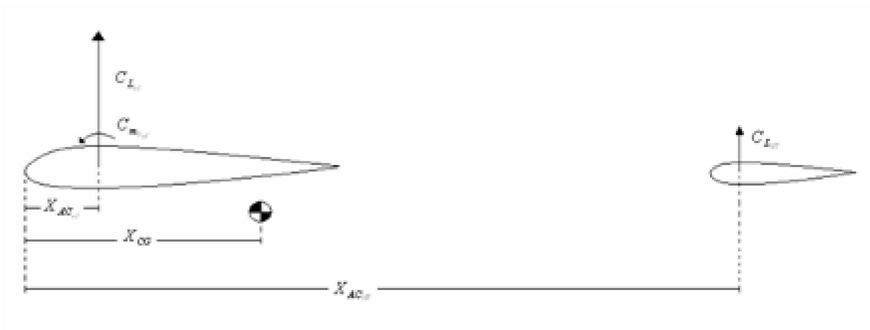
- Iterative MTOW solution

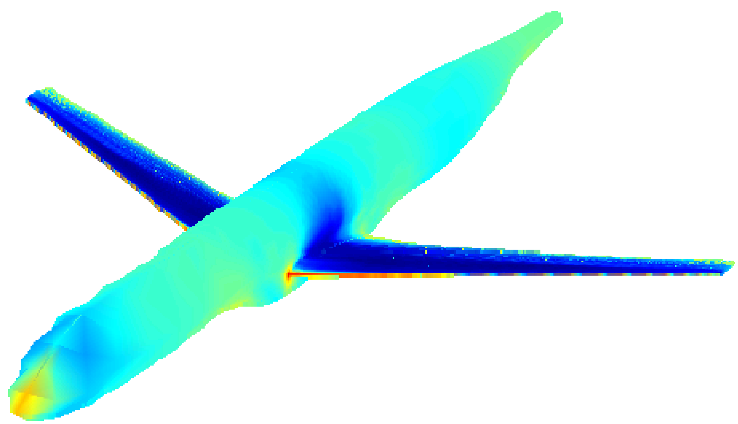


Case Study 1 – Disciplinary Models

Aerodynamics (cruise):

- Computes the wing-fuselage aerodynamic center and the zero-lift moment coefficient based on a CFD analysis
- Trim the aircraft for a mean cruise condition
    - Engine thrust is not being considered on the trimming analysis
- Computes the aircraft drag
    - The horizontal tail drag is computed using a vortex lattice code with Gutterd correction
    - The wing drag is computed with a full potential code with boundary layer correction
    - All other aircraft components drag is considered constant

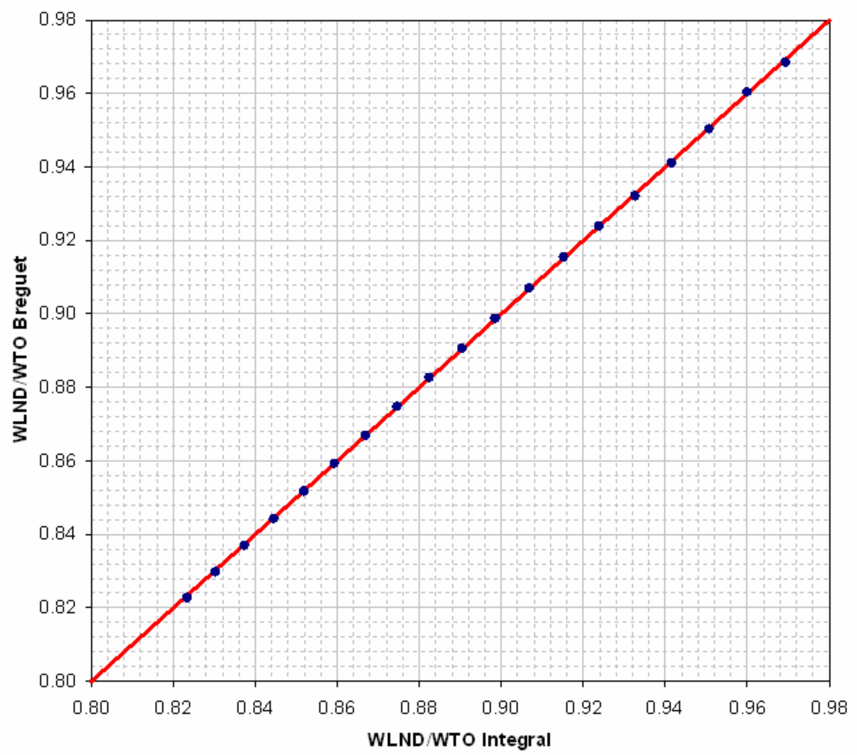




Case Study 1 – Disciplinary Models

Performance (cruise):

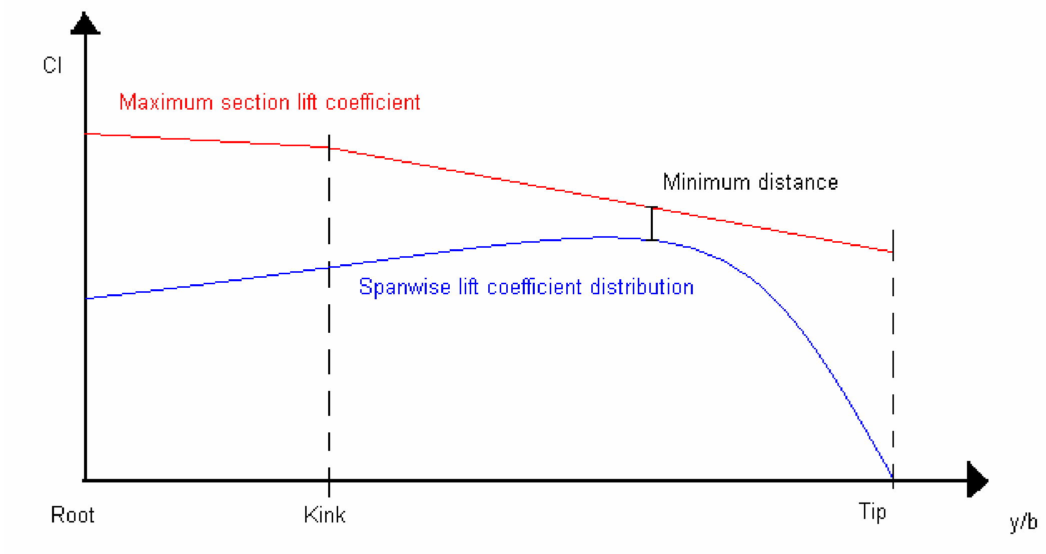
- Uses the calibrated Breguet formulation
  - The benefit of the Breguet formulation is the need of a single point at the aerodynamics calculation, drastically reducing the computational cost.
- Main statements:
  - Range: 2511nm
  - Payload: 6890kg
  - Reserve fuel remains constant.
- Breguet formulation seems suitable for long range mission analysis.

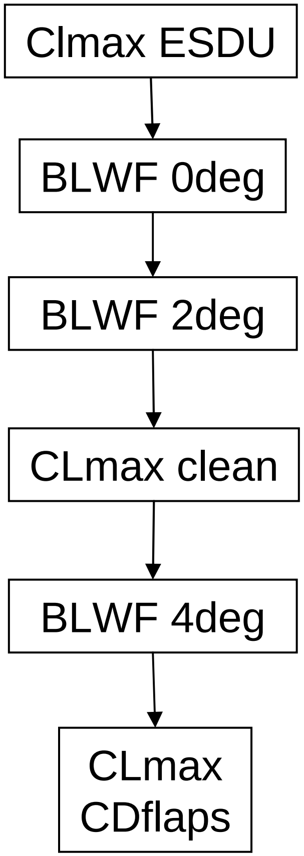


Case Study 1 – Disciplinary Models

Aerodynamics (maximum lift):

- Calculates the clean wing (no flaps) maximum lift using the so called critical section method
  - Wing stations maximum lift computed with the ESDU method
  - Wing lift distribution computed with a full-potential CFD code
- Lift and drag increments due to flaps computed with semi-empirical methods

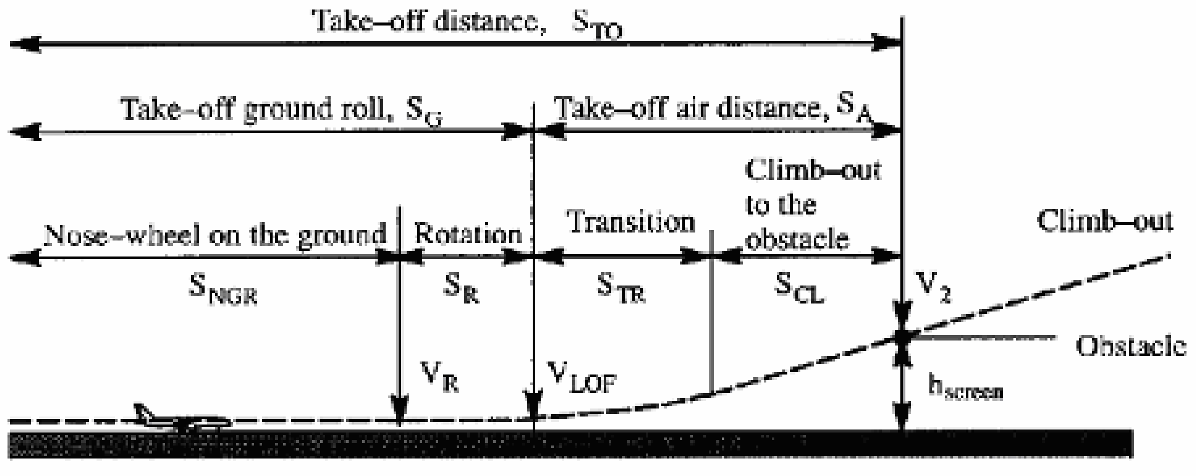




Case Study 1 – Disciplinary Models

Performance (take off):

- Computes the balanced field length (BFL) using the ESDU method
  - Similar to the so called semi-empirical method TOP25
  - 2º segment gradient correction (lift to drag ratio impacts the final result)
  - Flap deflection at take off is set to 20º.

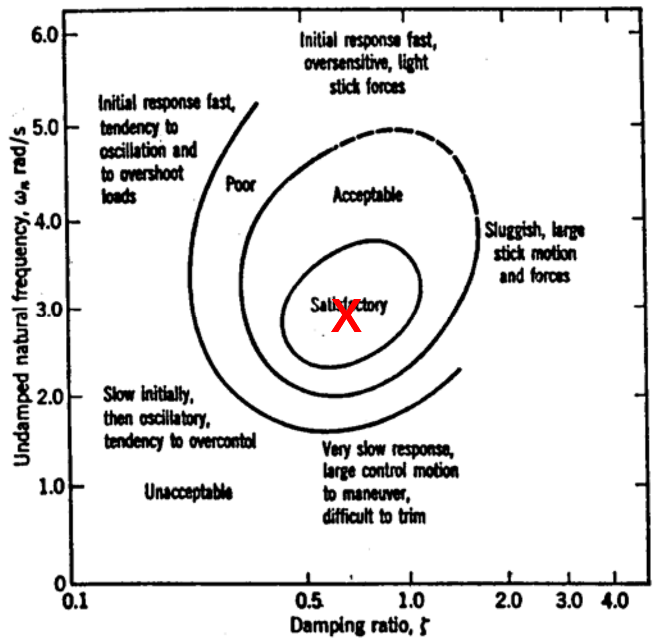


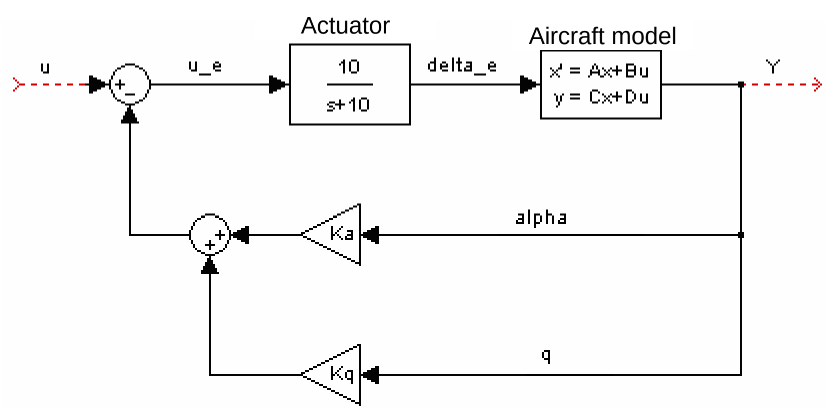
Case Study 1 – Disciplinary Models

Stability and Control:

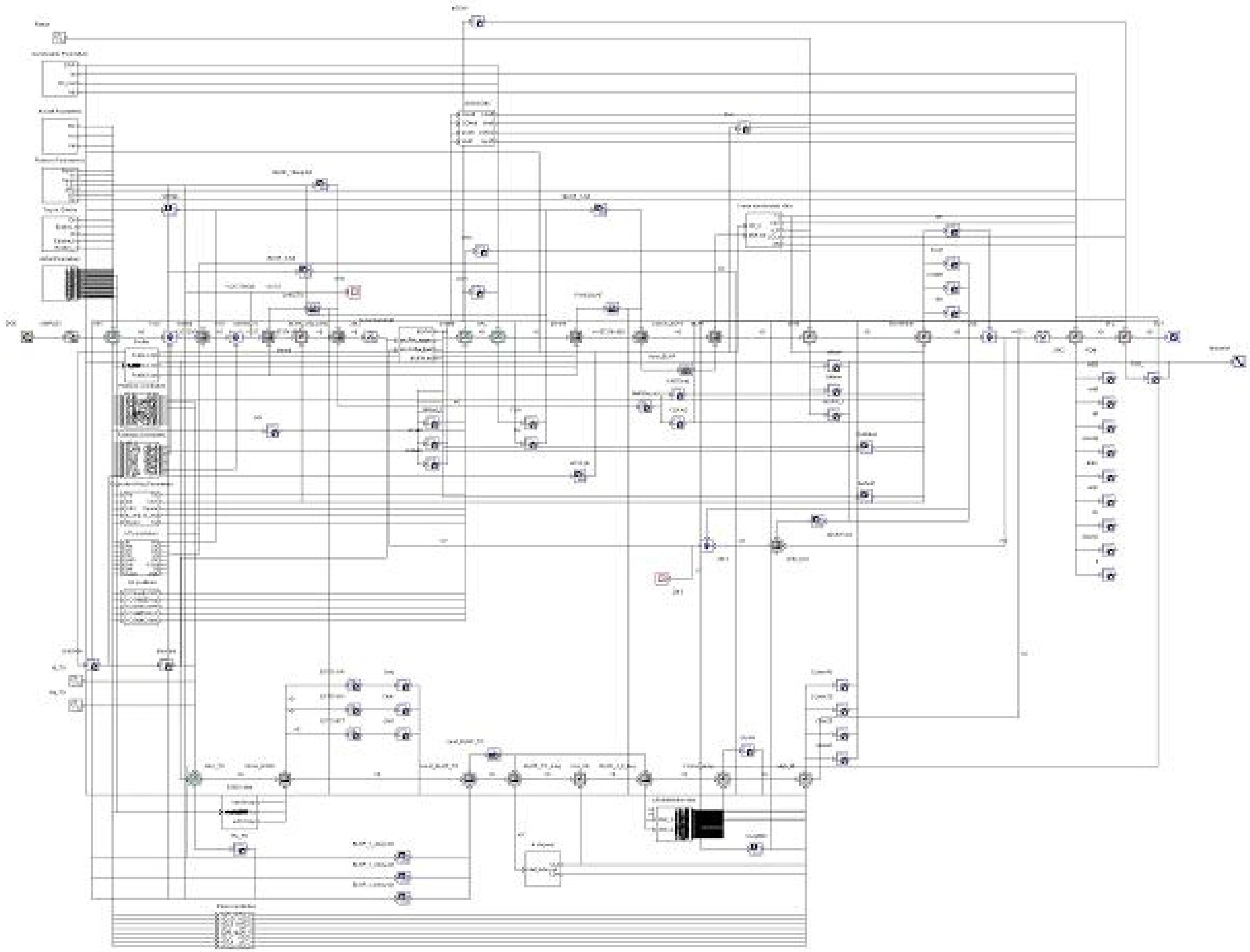
- Computes de aircraft flight quality based on the short-period analysis

- Calculates the controller feedback gains for angle of attack and pitch rate, K_α and $K_{q,}$ based on the system poles positioning criteria.
  - Wn = 3 rad /s
  - Csi = 0,75





Case Study 1 – Resulting mF Workflow



Case Study 1 – Results

Existing Scenarios:

Run Case	Optimization Type	Optimization Algorithm	Design Variables	Constraints	Objectives
01	Mono	Simplex	•Leading edge sweep •Taper (Inner & Outer) •Kink Position •Wing area •Aspect ratio	-	•Block fuel
02	Mono	GA	•Leading edge sweep •Taper (Inner & Outer) •Kink Position •Wing area •Aspect ratio	-	•Block fuel
03	Mono	SQP	•Leading edge sweep •Taper (Inner & Outer) •Kink Position •Wing area •Aspect ratio	-	•Block fuel
04	Mono	Simplex	•Leading edge sweep (Inner & Outer) •Taper (Inner & Outer) •Kink Position •Wing area •Aspect ratio	-	•Block fuel

Case Study 1 – Results

Existing Scenarios:

Run Case	Optimization Type	Optimization Algorithm	Design Variables	Constraints	Objectives
05	Mono	Simplex	•Leading edge sweep (Inner & Outer) •Taper (Inner & Outer) •Kink Position •Wing area •Aspect ratio	•Maximum fuel tank capacity	•Block fuel
06	Mono	Simplex	•Leading edge sweep •Taper (Inner & Outer) •Kink Position •Wing area •Aspect ratio •Horizontal tail volume •Wing position	-	•Block fuel
07	Mono	Simplex	•Leading edge sweep •Taper (Inner & Outer) •Kink Position •Wing area •Aspect ratio •Horizontal tail volume •Wing position	•Maximum fuel tank capacity •Flight quality •TOFL •HT deflection for trimming	•Block fuel

Case Study 1 – Results

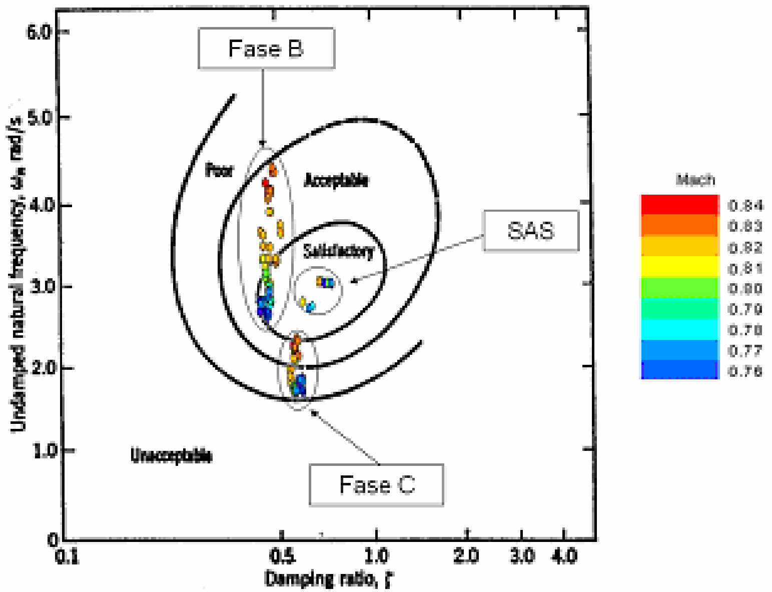
Existing Scenarios:

Run Case	Optimization Type	Optimization Algorithm	Design Variables	Constraints	Objectives
08	Multi	GA	•Leading edge sweep (Inner & Outer) •Taper (Inner & Outer) •Kink Position •Wing area •Aspect ratio •Horizontal tail volume •Wing position	-	•Block fuel •Block time
09	Multi	GA	•Leading edge sweep (Inner & Outer) •Taper (Inner & Outer) •Kink Position •Wing area •Aspect ratio •Horizontal tail volume •Wing position	•Maximum fuel tank capacity •Flight quality •TOFL •HT deflection for trimming	•Block fuel •Block time
10	Compromisse programming	Simplex	•Leading edge sweep (Inner & Outer) •Taper (Inner & Outer) •Kink Position •Wing area •Aspect ratio	-	•Block fuel •Cruise Mach number •TOFL

Case Study 1 – Results

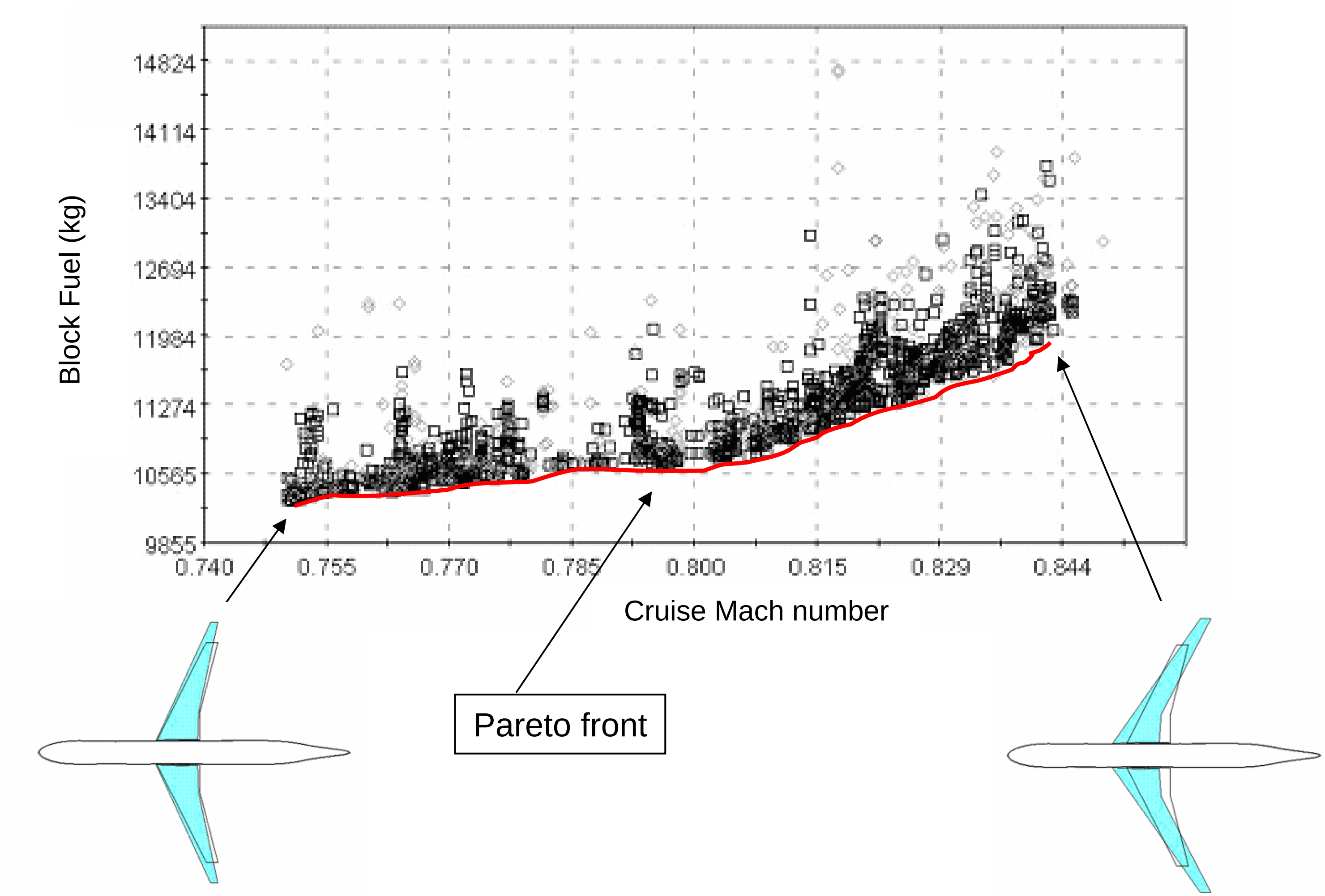
Selected Scenario: Run case 09 - Constrained multi-objective optimization using G.A.

Optimization performance parameters	
Population size:	50
Number of experiments:	3000
Total time:	208 hs



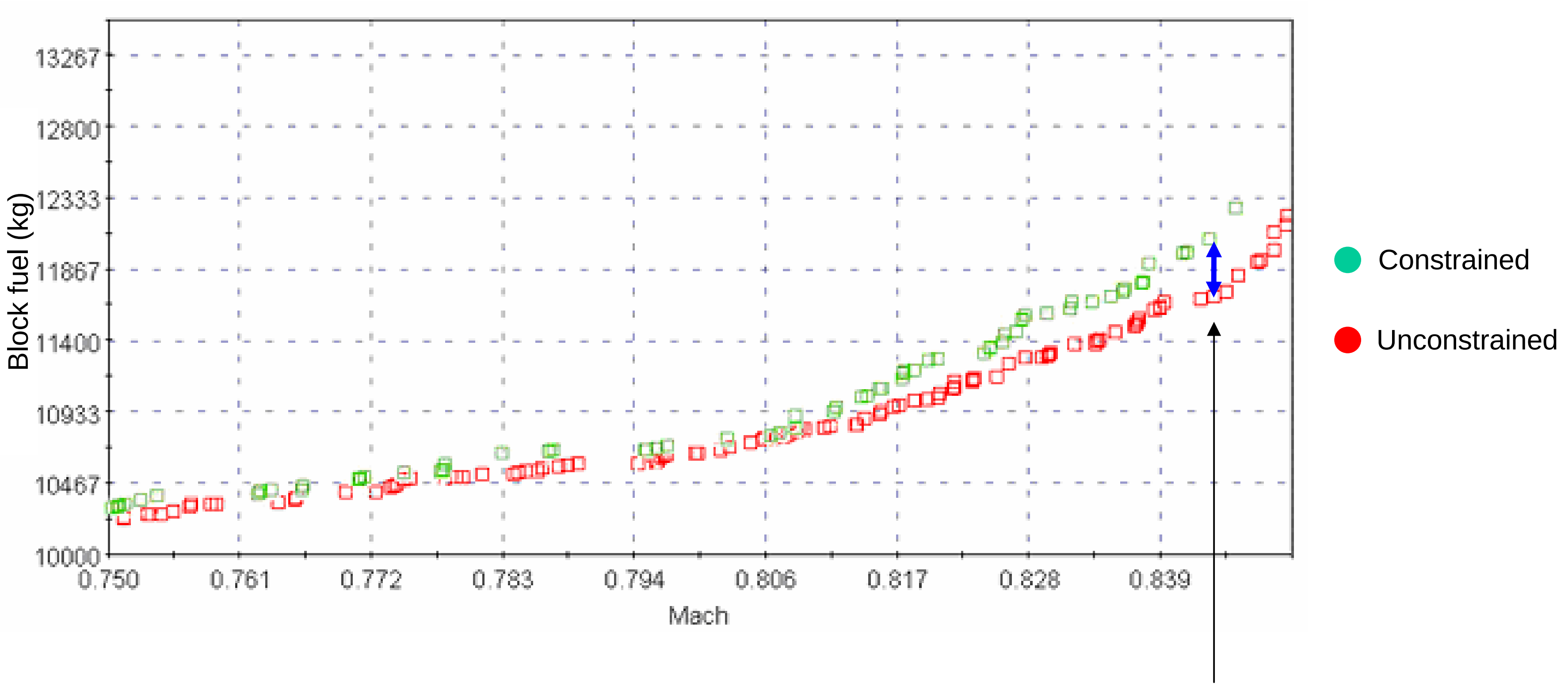
Case Study 1 – Results

Selected Scenario: Run case 09 - Solutions



Case Study 1 – Results

Selected Scenario: Run case 09 – Comparisson with run case 08 (unconstrained)

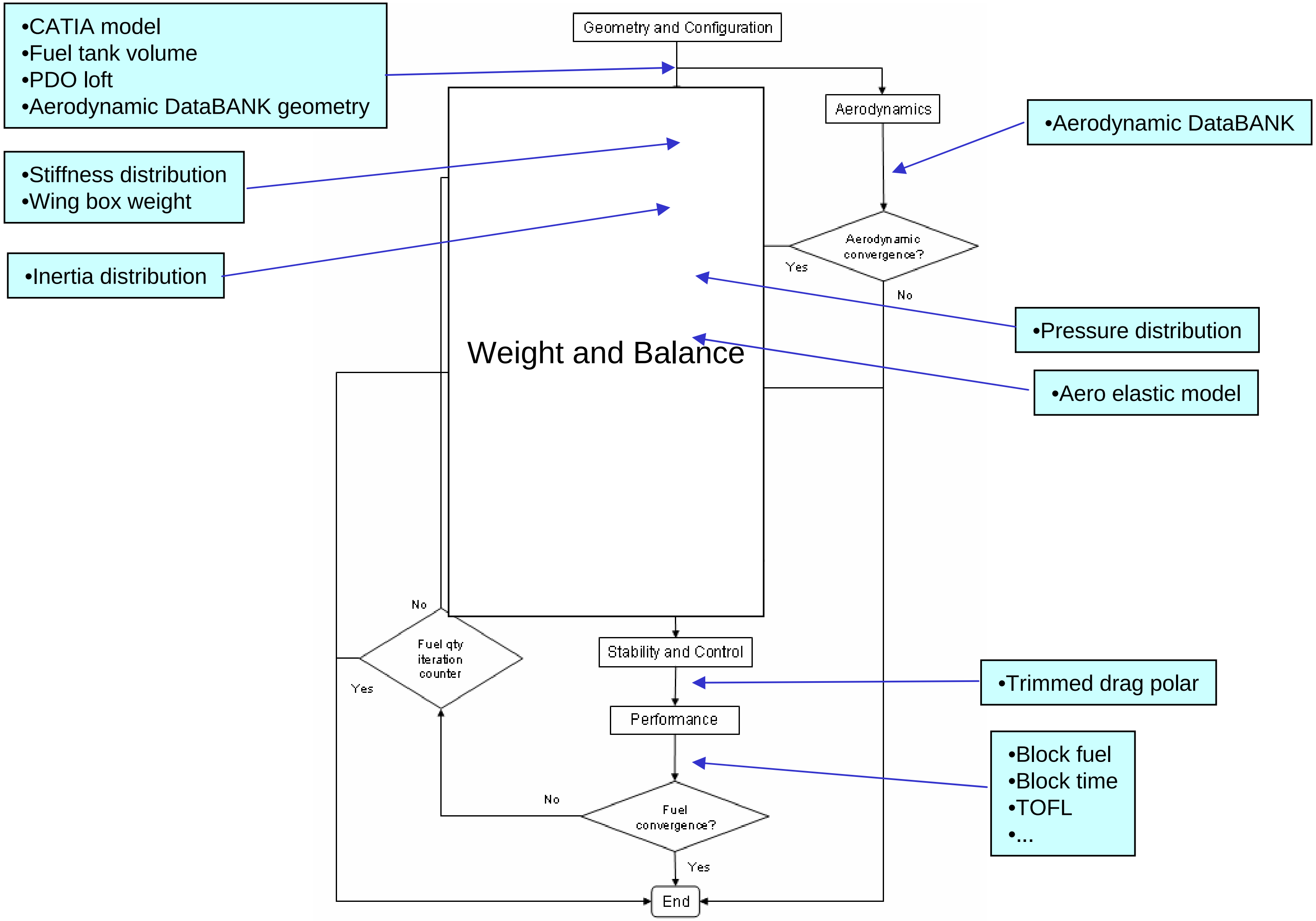


Lost of performance due to constraints
(up to 2.5% increase in block fuel)

Case Study 1 – Concluding Remarks

- Fuel consumption reduction of up to 5% were achieved
- Further studies must include flutter and cost analyses as well as the capability of analyzing more then one mission.
- Results shows that the wing aspect ratio reached the upper limit of its envelope. Some explanations for this behavior are:
  - The result is ok and there is nothing wrong with great aspect ratio wings.
  - The semi-empirical methodology used for weight estimation is unable to predict the wing weight with good accuracy for high aspect ratio wings.
  - Since the aircraft MTOW increases, and the aircraft direct operational cost (DOC) is directly proportional to its weight, maybe the best block fuel solution does not imply on the best DOC solution.
  - Aeroelastic stability analysis was not considered, and there is a strong possibility that the resulting wings will have flutter problems.

Case Study 2 – Problem Statement and Comparison with Level 1



Prospective Future Work

- Include airfoil design variables
- More sophisticated statistical analysis
  - Check design variables variance
  - Generate meta-models
- Include more complexes engine models
- Include more system models at the analysis
  - Landing gear
  - Anti-icing
  - ...

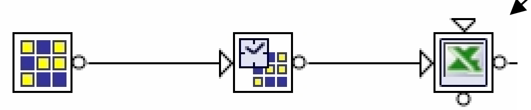
Thank you!

Back-up Slides

Processes Workflow

DOE:
Set the design of experiments

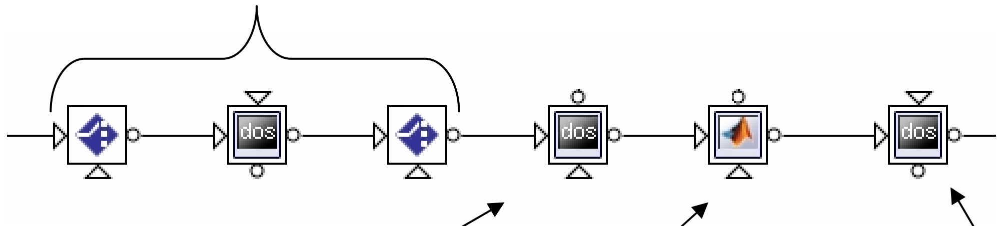
AGDE (*Aircraft Geometric Design Environment*):
Set the aircraft geometry



Scheduler:
Set the analysis / optimization criteria

Processes Workflow

Check the fairing forward and aft position



Geoset:
Set the BLWF (CFD code) input files

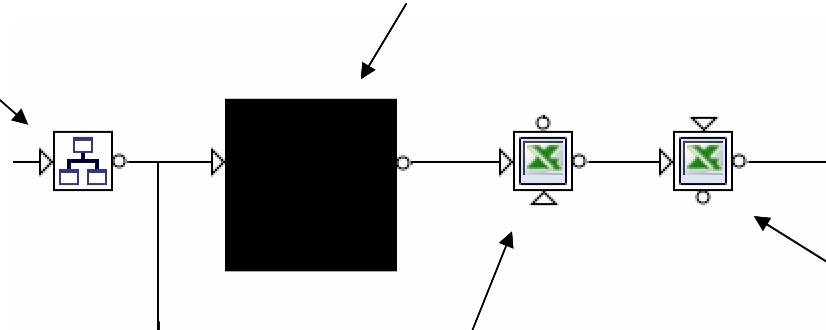
Atmosf:
Set the atmospheric conditions for the CFD code

BLWFtrans_0deg:
Run the transonic CFD code for 0º of AOA

Processes Workflow

Processes division

Fuel and aerodynamic coefficients initial estimative



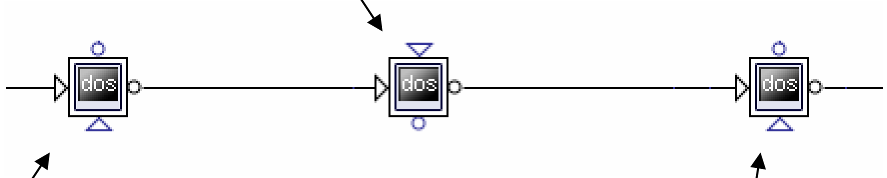
EWBM (*Empirical Weight and Balance Module*): Estimates the wing and HT weight as well as the aircraft inertia distribution.

BAC (*Basic Aerodynamic Calculator*): Trim the aircraft and calculate the HT drag, as well as the aerodynamic inputs for the CFD code.

Maximum lift processes

Processes Workflow

Concat BLWF:
Concatenate the CFD code input files



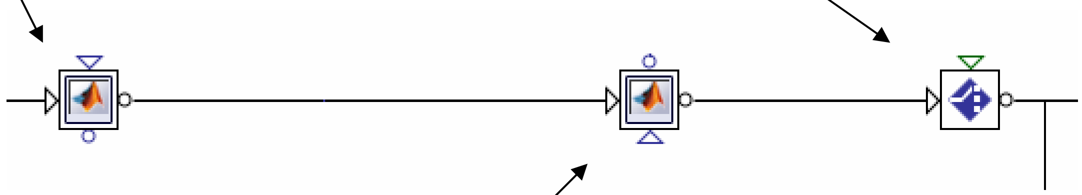
geoset:
Set the BLWF (CFD code) input files

BLWF:
Transonic CFD analysis

Processes Workflow

BPM *(Basic Performance Module)* :
Calculate the block fuel

Checks the fuel convergence criteria

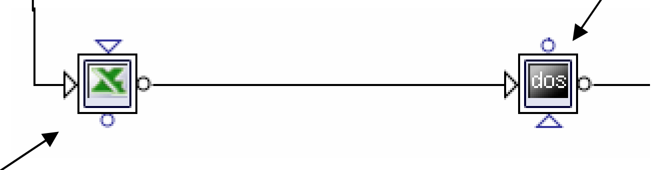


momentum :
Calculates the aircraft aerodynamic center and lift slope

Processes Workflow

Cruise processes

Clmax_ESDU:
Computes the airfoils maximum lift (root, kink and tip)

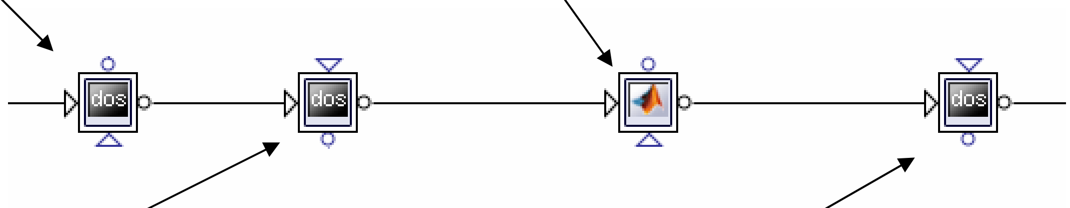


BAC_TO (*Basic Aerodynamic Calculator*):
Calculates the CFD code input parameters for the take off condition

Processes Workflow

Concat BLWF_TO:
Concatenates the CFD code input files for the subsonic condition

CL4_chk:
Checks the CFD code convergence

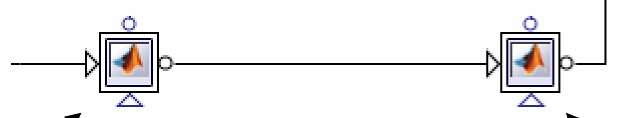


BLWF_TO_4deg:
Runs the CFD code for 4º of AOA at a subsonic condition

BLWF_TO_2_0_deg:
Runs the CFD code for 0º and 2º of AOA at a subsonic condition

Processes Workflow

Cruise processes



CLmax_clean:
Computes the clean wing maximum lift (no flaps and slats)

High_lift:
Computes the lift and drag increments due to hiper-lift devices

Processes Workflow