Matlab/Simulink Tools for Teaching Flight Control Conceptual Design:

An Integrated Approach

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Hanyo Vera Anders
Tomas Melin
Arthur Rizzi
The Royal Institute of Technology, Sweden.

Presentation Outline

- Computer Tools for Preliminary Aircraft Design
- QCARD Conceptual Design Tool
- Tornado Vortex Lattice Method
- CIFCAD Flight Simulator
- Case study: Student Project for Conceptual Design.
- Questions-Comments

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Problems on Preliminary Aircraft Design

- The simplified methods used in the early phases of design do not give sufficient fidelity, which may result in **mistakes** which are costly to correct later in the design cycle.

- Some examples pertaining to the Flight Control System are:

  DC-9: unexpected pitch-up and deep stall of T-tail lead to costly redesign

  DC-9-50 & MD-80: inadequate directional stiffness at high angles of attack in sideslip; adoption of low-set nose strakes

  SAAB2000: larger than expected wheel forces caused delay in certification; costly redesign of control system

  Boeing 777: missed horizontal tail effectiveness led to larger than needed horizontal tail

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Computer Tools for Preliminary Aircraft Design

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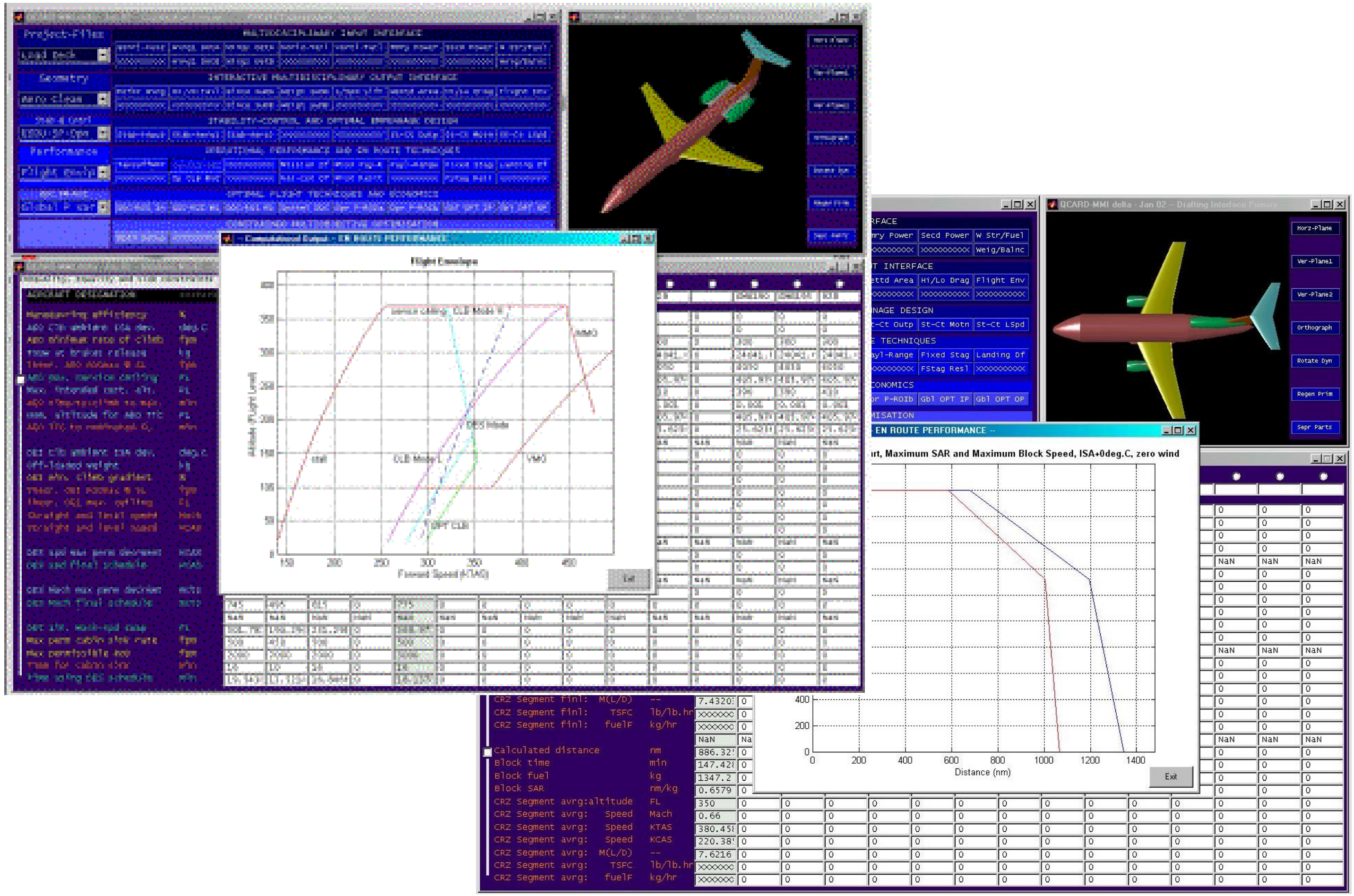
- There is work going on into the development of Computer Tools to facilitate the preliminary aircraft design process:
  - QCARD
  - Tornado
  - SIFCAD Flight Simulator

QCARD:
Quick Conceptual Aircraft Research & Development



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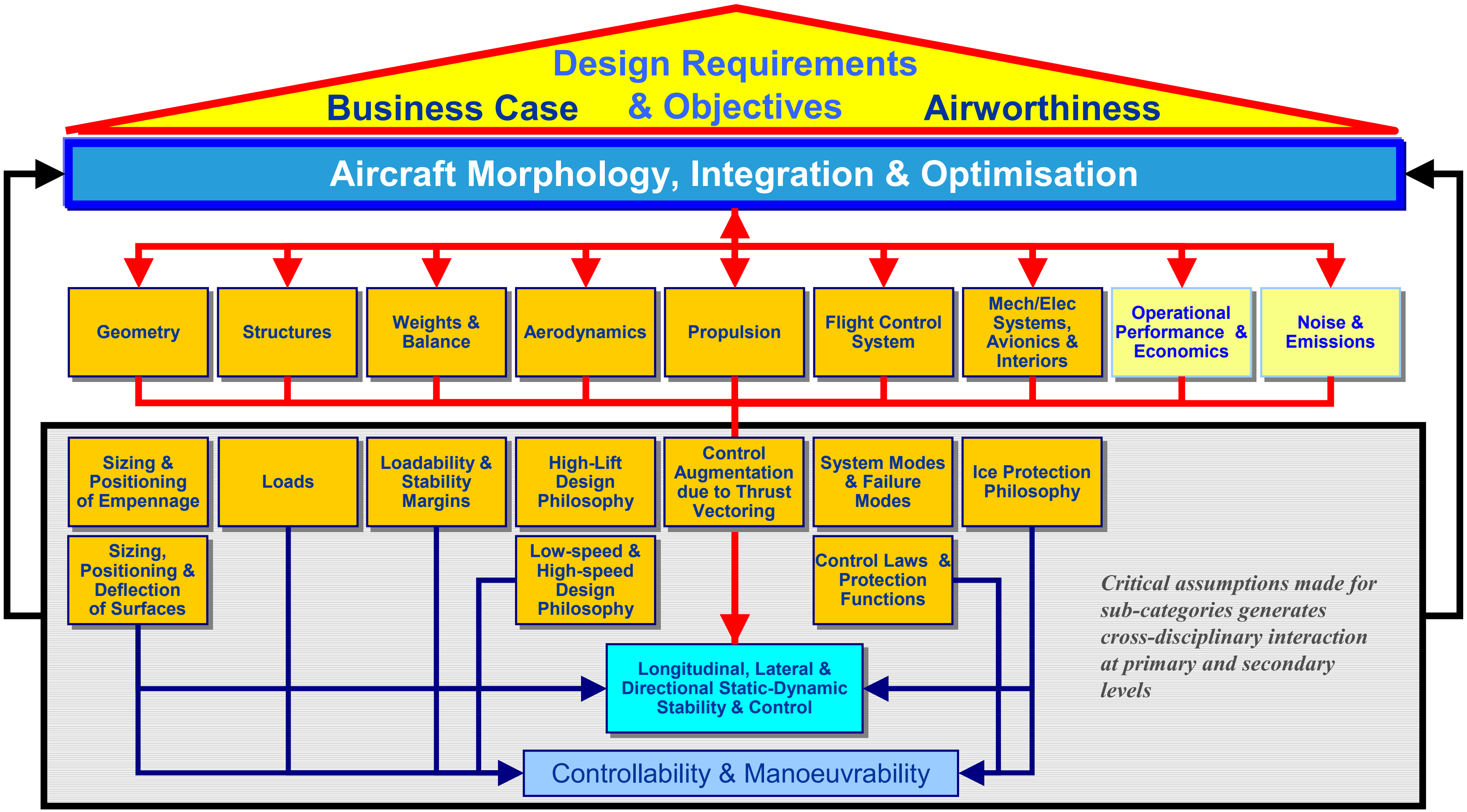
QCARD in the Conceptual Design Process



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Core Simulation Modules

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Iteration loop/feedback on design

CAD geometry data

Mesh generation

Flight state:
•Motion and altitude
•Trajectory
Control surface state:
•Position and motion

Each partners' **CFD solver** with moving mesh capabilities

QCARD core:
Comp Static/Dyn Derivativ, limited Aeroelast, buffet effects

QCARD analyzer
•Stability margin
•Empennage/ con sur. sizing
•S&C modes, damping modes

Controllability-Maneuverability
• Control surface effectiveness
• Handling qualities
• Pilot work load
• etc

QCARD Environment Modules

KTH working on two topics **today**:

- Tornado (Dynamic Derivatives)
- SIFCAD

Conceptual Prediction Methods: Stability & Control

- This discipline has lacked any form of sophistication & depth at the conceptual level
  - fundamental issues: controllability & manoeuvrability
  - tail volume method was adequate in the past; today, critical scenarios need to be identified & addressed early on
- Introduction of the Mitchell Code during sizing
  - original ICL FORTRAN code now converted to MATLAB
  - estimates: aero derivatives, moments of inertia, eigenvalues of motion equations, forced response and limiting speeds
- Assessing the suitability of design candidates
  - avoidance of esoteric figures of merit for uninitiated
  - extensive use of Cooper-Harper scale correlated with merit function plots, i.e. ESDU, MIL-Spec, ICAO, SAE, etc.

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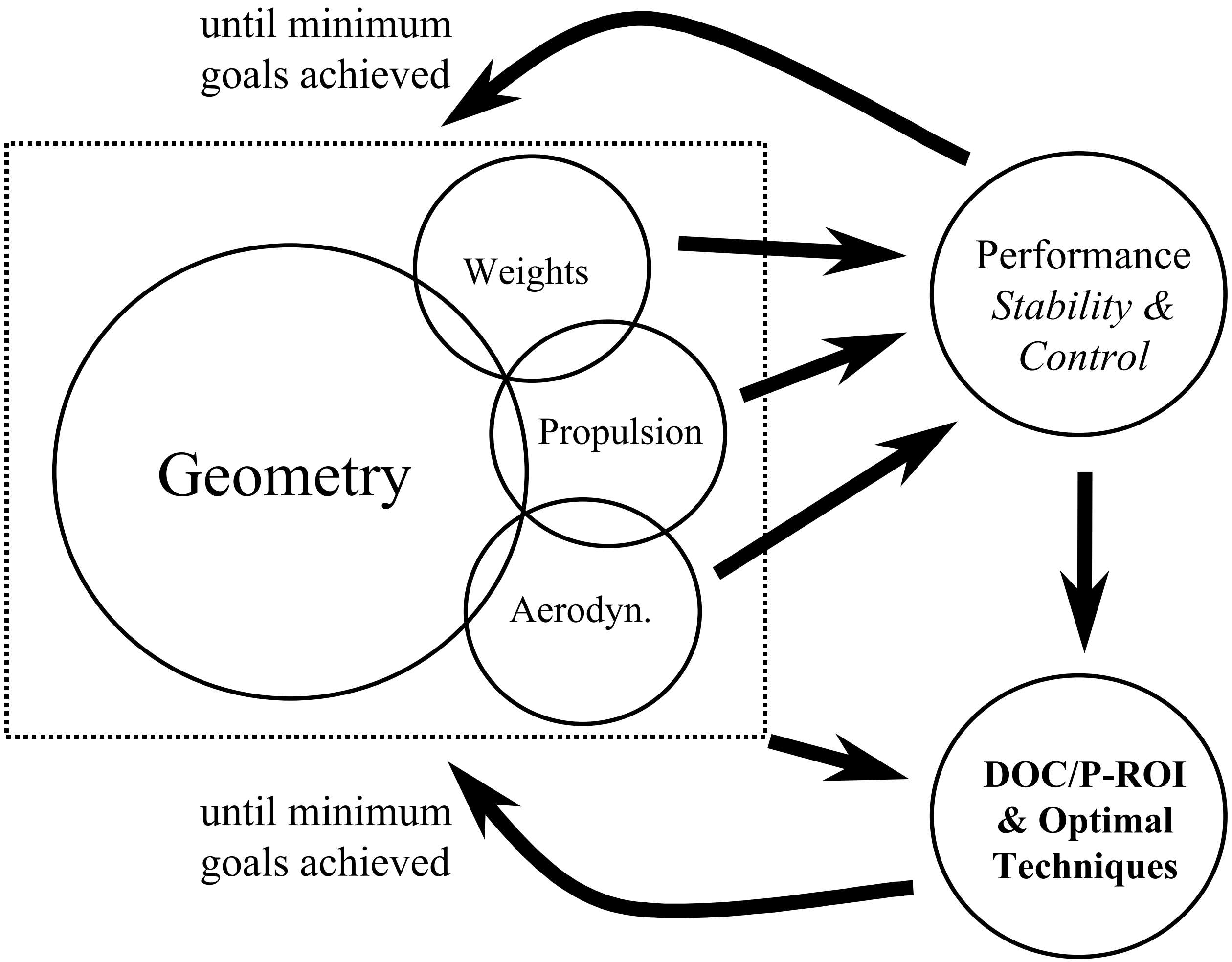
Sub-space Coupling & Process Logic



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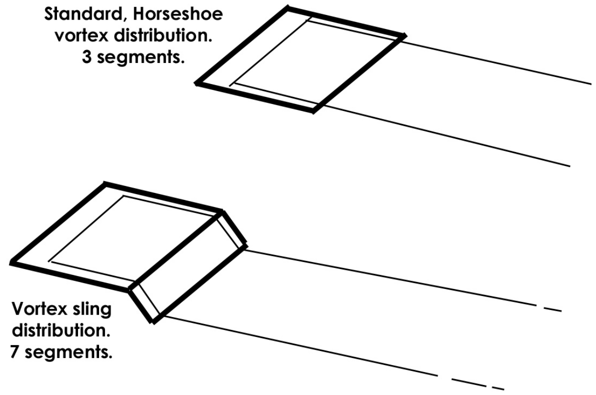
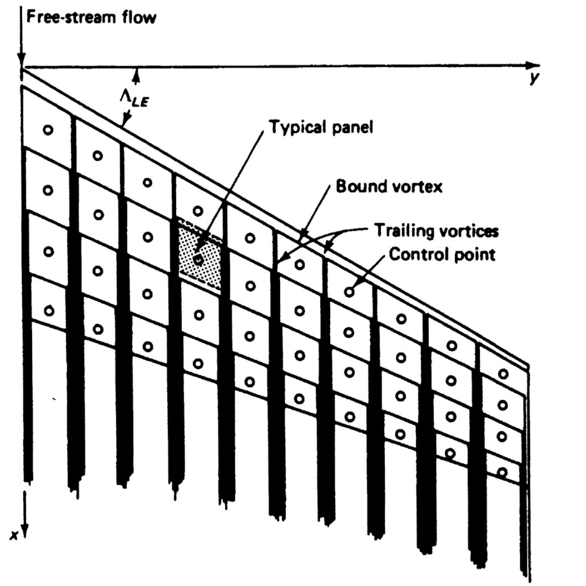
Aerodynamic Coefficients: **TORNADO**

- Developed by Tomas Melin, KTH.
- Vortex-Lattice Method.
- Implemented in Matlab
- Allows the analysis of complex geometry wings (swept, tapper, dihedral, tails,...)
- Different Flying Condition (Angles of Attack and Sideslip Angles, Roll, Tip and Yaw velocities)
- For wing-configuration, good results with projection of body along x-z and x-y planes.





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TORNADO:
Basic Assumption-Potential Flow

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- Inviscous
- Incompressible
- Irrotational
- Existence of Velocity potential

$$\nabla \times \nabla \phi = 0$$

$$\nabla^2 \phi = 0$$

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Tornado Implementation

- Sample Output

Tornado Computation Results

JID:	ilona$_3$	Downwash matrix condition:	870034.5925		
Reference area:	74.6078				
Reference chord:	2.8041	Reference point pos:	2.8583	0	0.58619
Reference span:	30.16				

Net Wind Forces: (N)		Net Body Forces: (N)		Net Body Moments: (Nm)	
Drag:	3859.3759	X:	-9538.6779	Roll:	371527.6714
Side:	35533.5133	Y:	35533.5133	Pitch:	-244497.527
Lift:	291384.6908	Z:	291284.6705	Yaw:	516493.7084

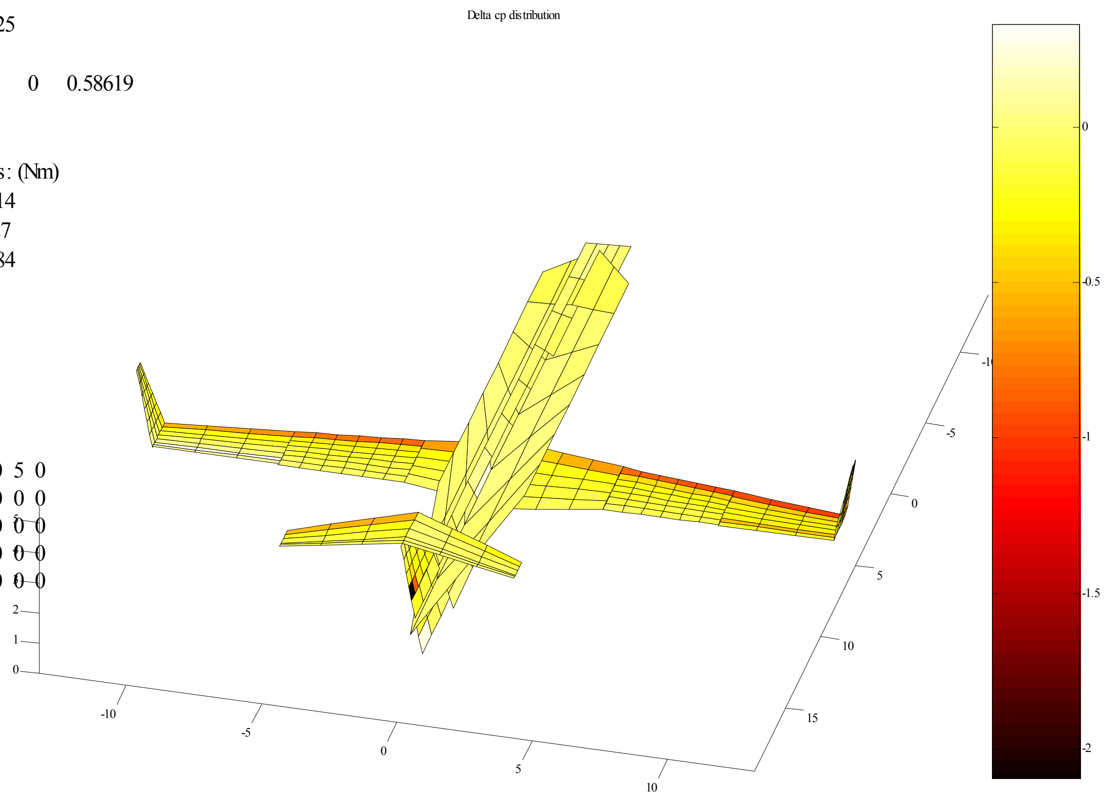
CL	0.2834	CZ	0.2833	Cm	-0.084803
CD	0.0037536	CX	-0.0092772	Cn	0.016656
CY	0.034559	CC	0.034559	Cl	0.011981

STATE:

alpha:	3	P:	0
beta:	0	Q:	0
Airspeed:	150	R:	0
Density:	1.225		

Rudder setting [deg]:

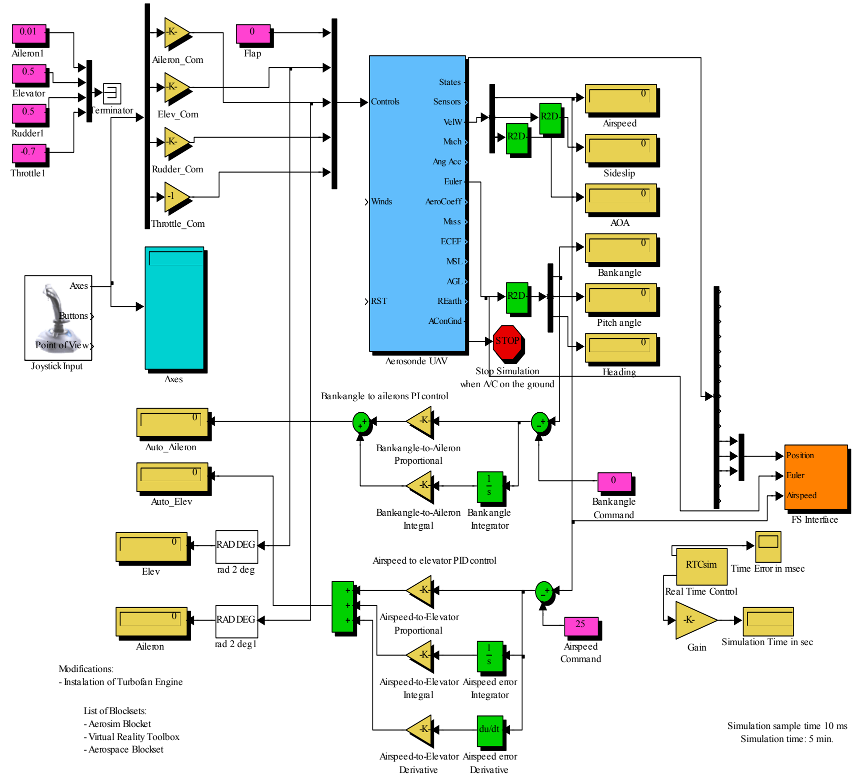
0	0	5	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0



SIFCAD Flight Simulator

- OBJECTIVES:

- Flight Control System Design.
- Analysis of Handling Qualities.
- Assessment of Mission Profile.



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SIFCAD: Characteristics

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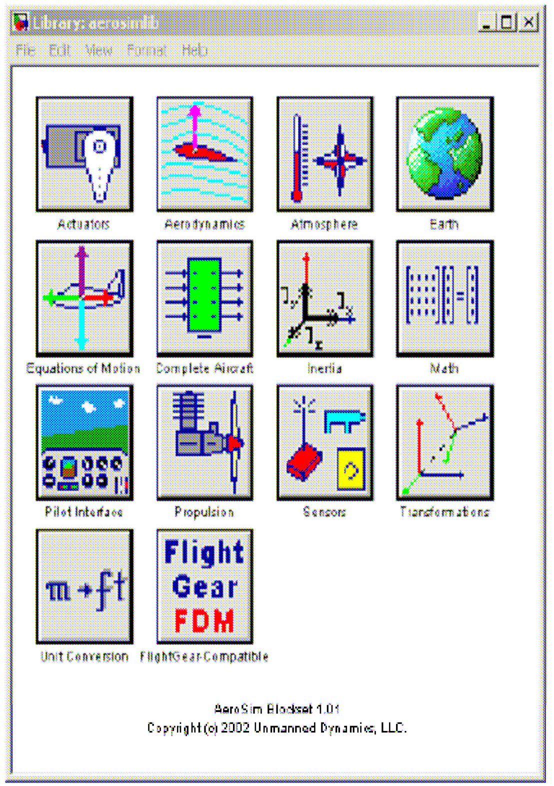
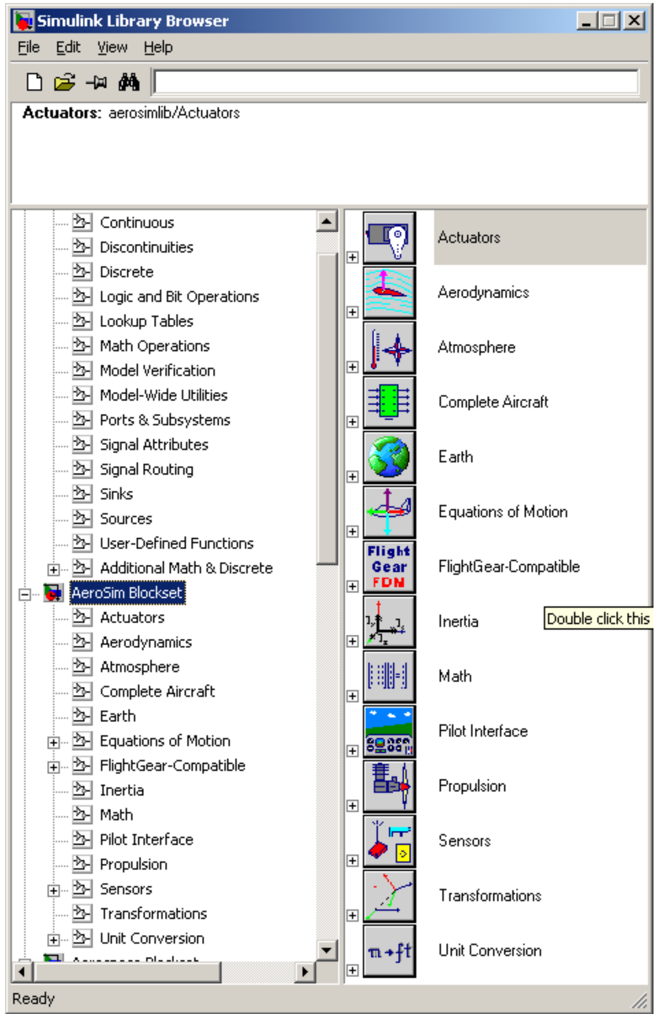
- Flight Simulator in Simulink Environment
- Based on commercially available Simulink Toolboxes
- Graphics provided by Microsoft Flight Simulator
- Highly Flexible and easily customable (Simulink format)
- Options: Fast-time or Real-time.

The MathWorks
Accelerating the pace of engineering and science



Simulink Toolboxes:

- Aerospace Blockset - Mathworks
  - Aerodynamic
  - Engine,
  - Earth and Atmosphere models.
- Virtual Reality Toolbox - Mathworks
  - Man-Machine interface i.e. Joysticks)
- AeroSim Blockset – Unmanned Dynamics
  - Aerodynamic,
  - Engine,
  - Earth and Atmosphere models



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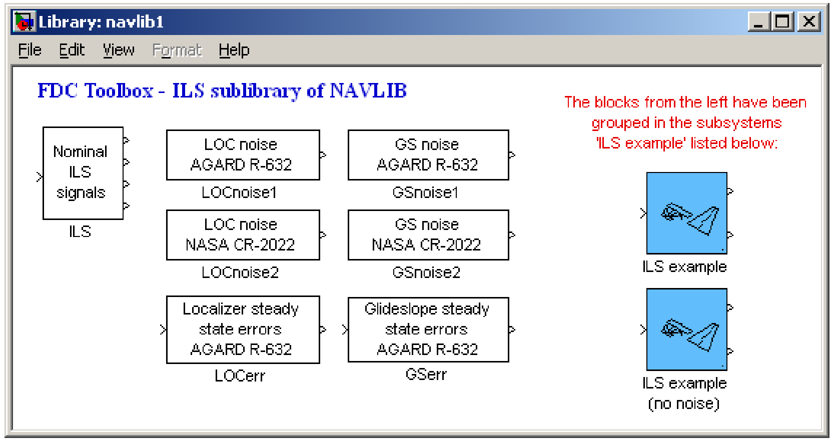
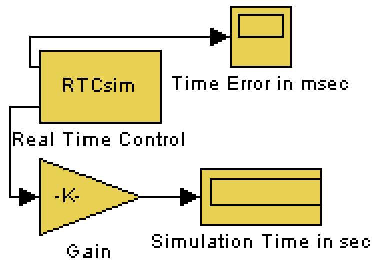
Simulink Toolboxes:

- Flight Dynamic and Control Blocket
  - M.O. Rauw, Netherlands.
  - Aerodynamic,
  - Engine,
  - Earth and Atmosphere models
  - Avionics.
- Port and Memory IO for Matlab and Simulink – Werner Zimmermann, FHT Esslingen
  - Real time execution in Matlab Environment.





Interface with Microsoft Flight Simulator

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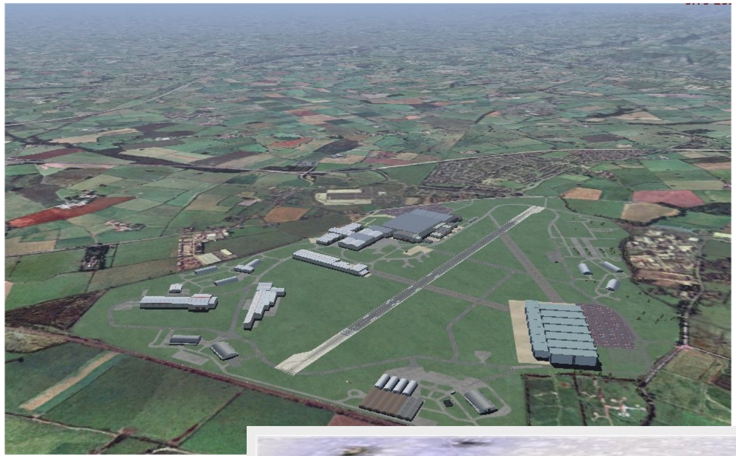
- Use of interface provided by AeroSim Blockset
- Possibility to send information to a Second Computer Running Microsoft Flight Simulator
- Information sent involves position, attitude and gauges information.
- The result is high quality graphic interface without the need of extensive programming.



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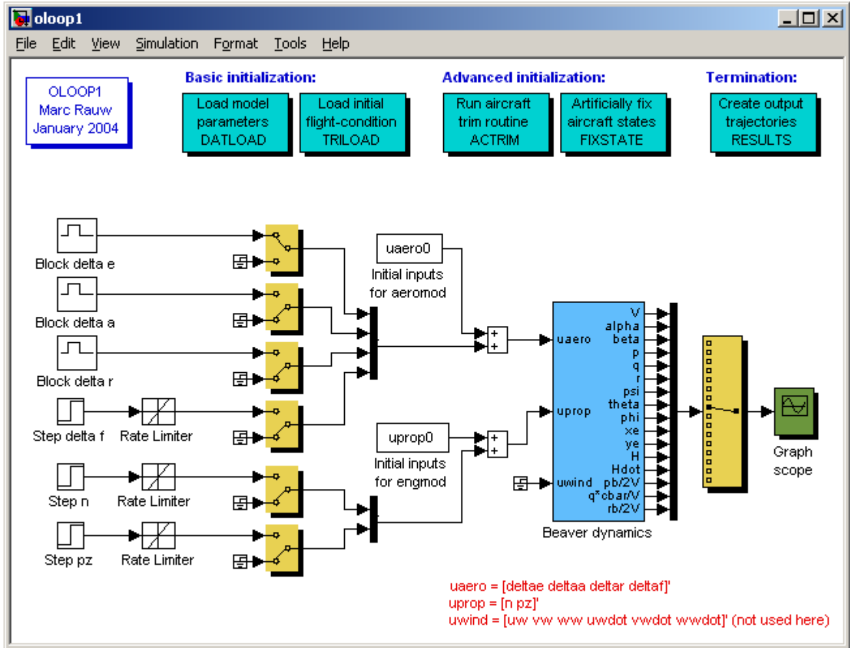
Use of Simulator

- Simulator Running at Fast-Time:
  - Airplane Model development
  - FCS development and testing
  - Autpilot testing
  - Mission profile Assesment
- Real Time Simulation:
  - Handling Qualities Assesment
  - Pilot-in-the-loop analysis
  - Research in Aircraft Operational Factors
  - Research in Human Factors.



Case Study: Horizon Project

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- Conceptual Design Student Project in The Royal Institute of Technology in collaboration with Ecole Polytechnique of Montréal

- Objective:
  - Analysis of 70 PAX regional airliner
  - Unducted Fan
  - Able to achieve speeds close to Turbofan

Case Study: Horizon Project

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- Procedure: Use of QCARD in the conceptual design process:
  - Estimation of Low Speed Aerodynamic Properties
  - Estimation of High Speed Aerodynamic Properties
  - Stability and Control Analysis

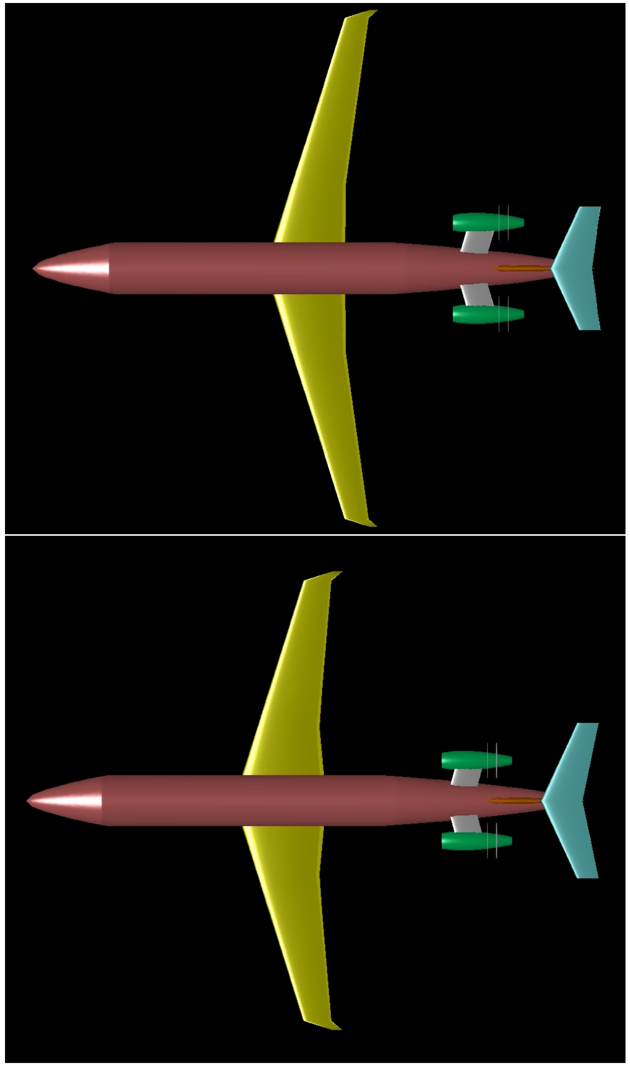
- Conclusion: The initial design has poor stability qualities. Need to improve the design to reach reasonable stability characteristics.

Geometric Modifications

- Wing:
  - Moved Forward
  - Increased Area
  - Reduced Aspect Ratio

- Horizontal Tail:
  - Lowered
  - Increased Area
  - Increaed Aspect Ratio

- Vertical Tail:
  - Reduced Area.



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Results of the Modifications

Type of motion	Name	Period (s)		Time-to-half (s)		Cycles-to-half	
		Initial	Improved	Initial	Improved	Initial	Improved
Longitudinal	Phugoid	$1.76e^5$	$1.81e^6$	94.98	95.9	$5.4e^{-4}$	$5.3e^{-4}$
	Short-period	4.35	2.92	0.82	0.58	0.19	0.20
Lateral	Dutch roll	5.11	5.40	12.94	6.84	2.52	1.26
	Spiral	128.4	117.5				
	Rolling convergence	0.86	0.89				

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Stability and Control Analysis

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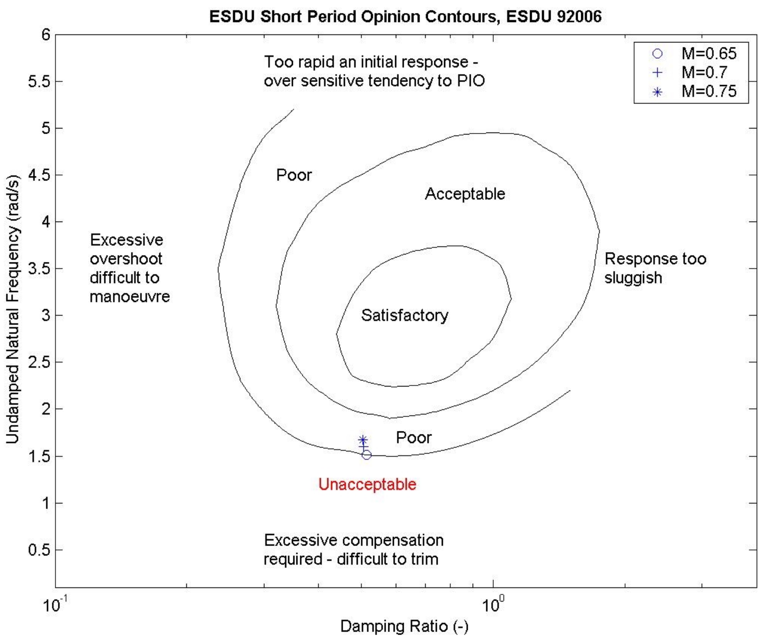

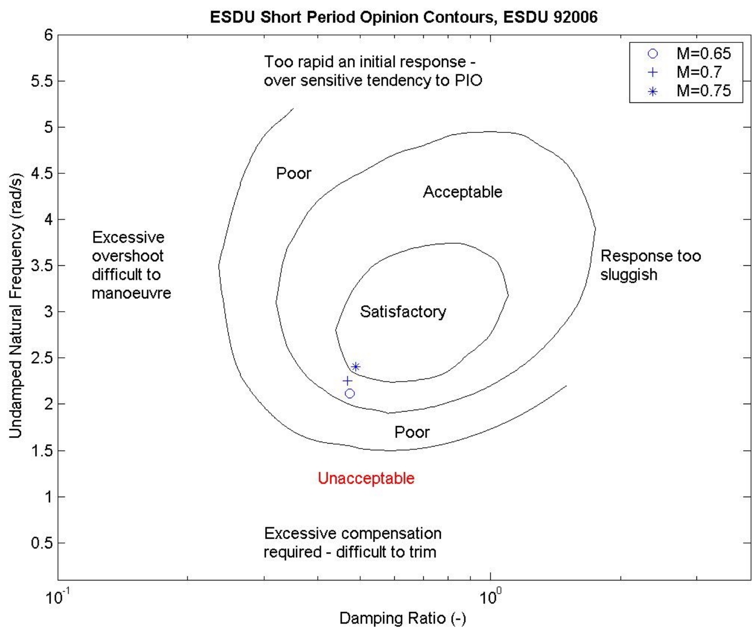

Stability and Control Analysis

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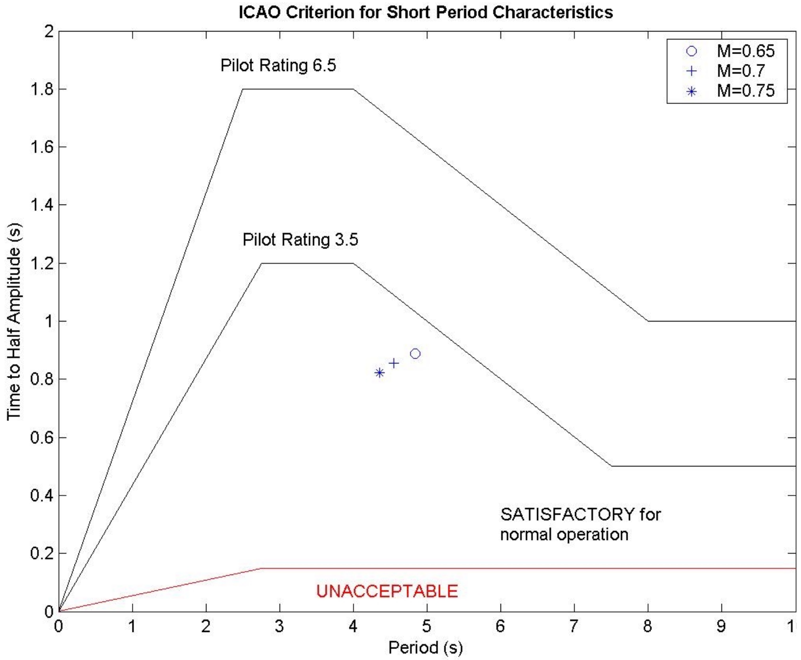
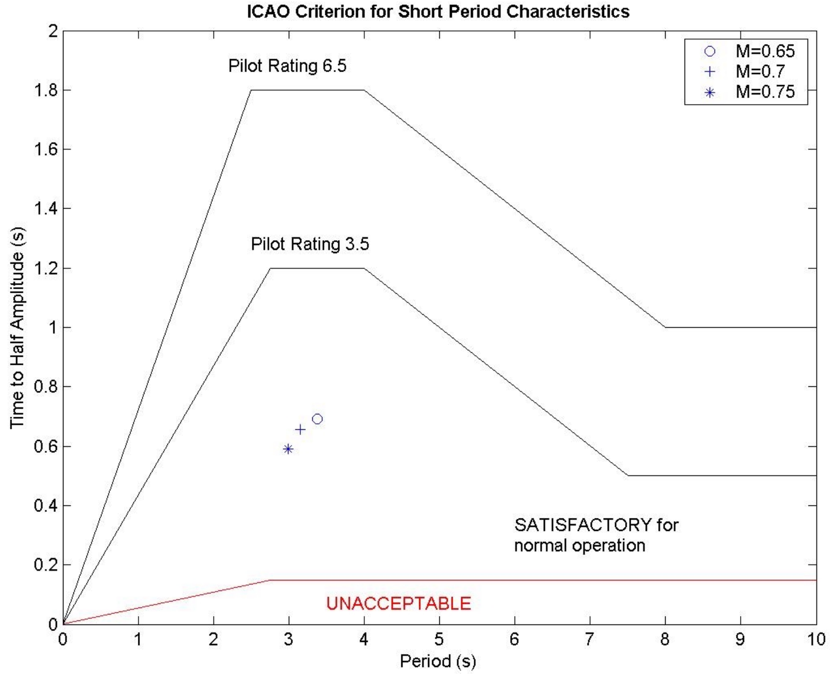
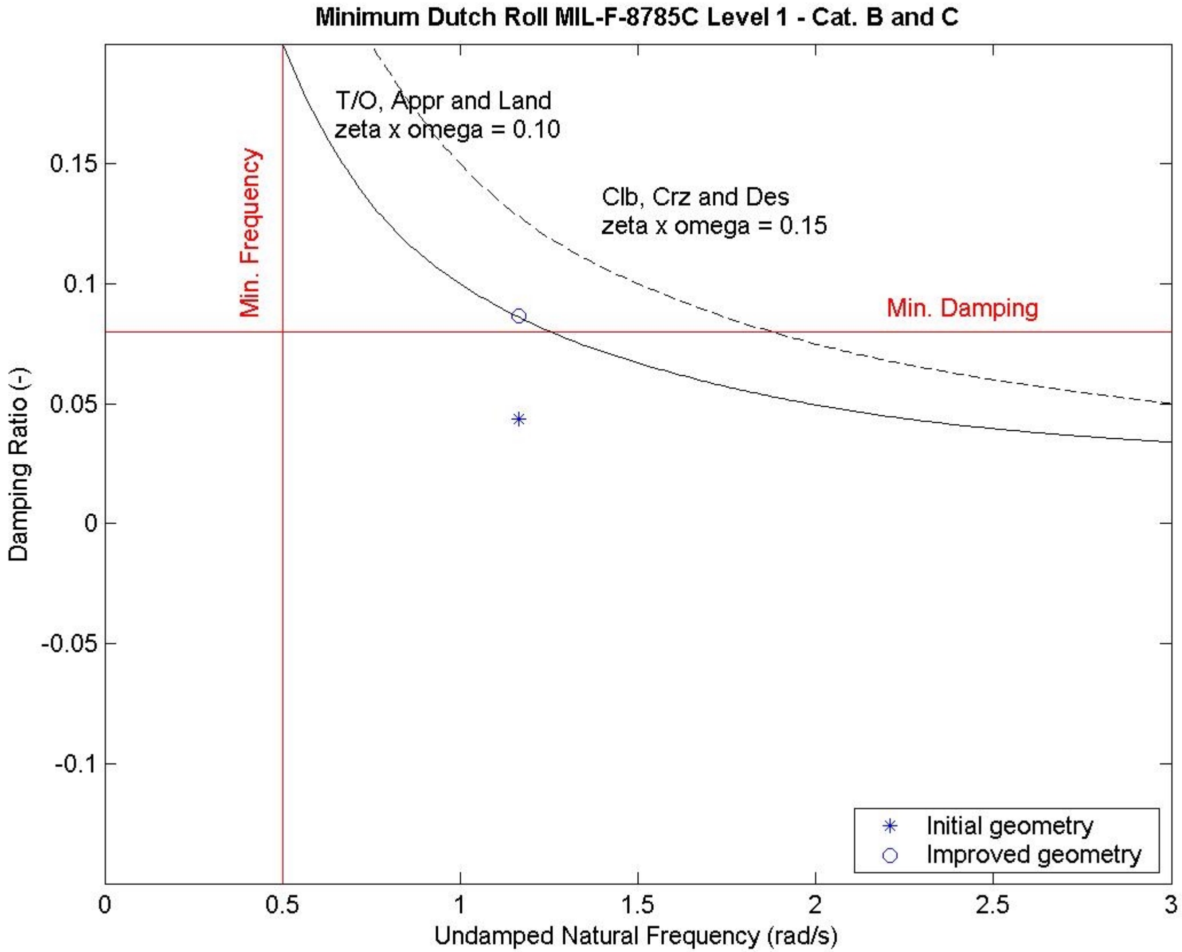




Stability and Control Analysis



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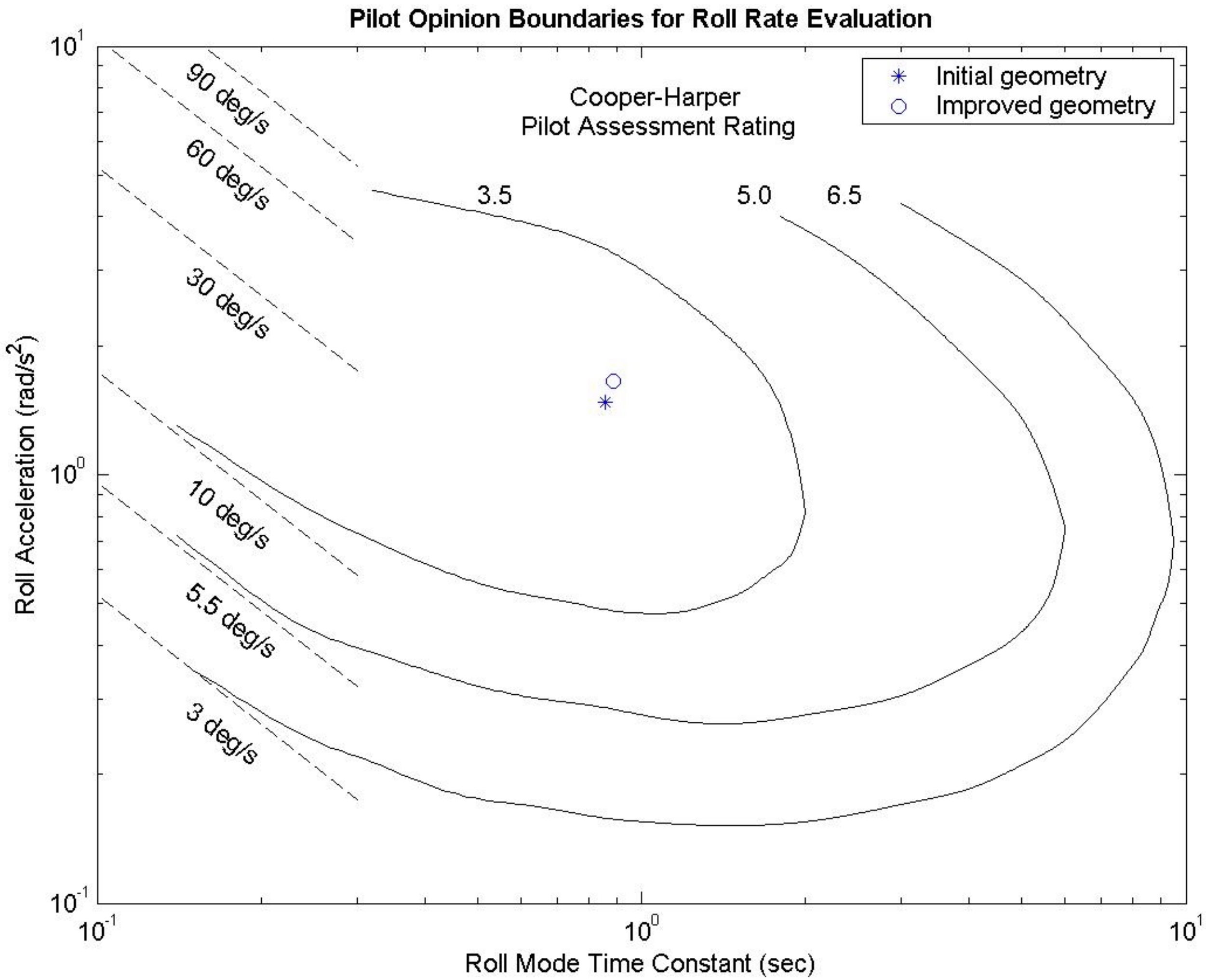
Stability and Control Analysis



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Possibilities of using SIFCAD in Horizon Project

- Higher understanding of criteria for stability.
- Analysis of airplane handling with Pilot-in-the-loop.
- Possibilities of considering relaxed stability in design.
- Design of Flight Control Systems.
- Mission Profile Analysis.
- Response to medium and heavy weather phenomen (i.e. Gusts, windshear, etc.)
- Explore operational profile (take-off, approach, landing)

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SIFCAD Demo: Horizon Model

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SIFCAD: Future Goals

- SIFCAD in Aeronautic Education
  - Teach to student effects of changes in Aerodynamic Coefficients in Airplane Handling
  - Effects of Center of Gravity in Aerodynamic Stability.
  - Suitable for teaching Concepts on Flight Control System Design
  - Suitable for practical examples in Avionics use and Limitations.

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SIFCAD: Future Goals

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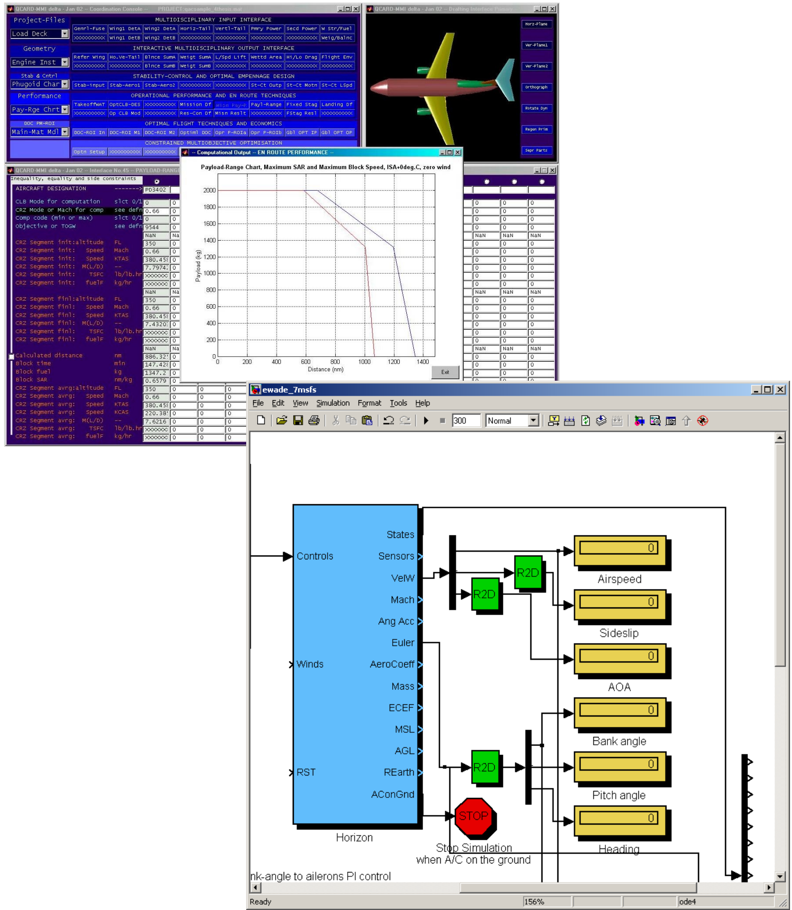
- Full Integration with QCARD software:
  - Automatic Load of Aerodynamic, engine and mass properties onto the Simulator Model.
  - Requisite for integration on the Conceptual Design package.
- Use in research:
  - Airplane Design
  - Operations
  - Human Factor
  - Etc.



SIFCAD: Ongoing and Future Work.

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- Improve the Aerodynamic Model
    - Possibility to manage non-linear aerodynamic phenomena.

- Develop a stable simulation platform with ”best of commercial packages” plus native development.

- Improve Human-Machine interface:
    - Projectors
    - Glass-Cockpit
    - Improved Joysticks
    - Pedals

Questions – Comments?

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