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in aeronautics

AEROSPACE TECHNOLOGY CONGRESS 2016

Swedish Aerospace Technology in a Globalised World

Subscale Ground and Flight Testing Methodologies for Advanced Aircraft Design

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ITA - Brazil

OCTOBER 11-12
Quality Hotel Friends, Solna, Stockholm

INTRODUCTION

- Laboratory of New Concepts in Aeronautics, from the Aerospace Engineering Division - ITA (www.lnca.ita.br).
  - Currently LNCA is formed by a multidisciplinary team of professors, researchers, undergraduate and graduate students from ITA.
- As a companion research project “Methods for sub-scaled demonstrator and control law testing MSDEMO" is an ongoing initiative from LiU, funded by the Swedish research and development fostering agency Vinnova " and takes part of the cooperation activities between ITA and LiU.

Team

- Prof. Roberto Gil Annes da Silva
- Prof. Dr**. Peter Krus** is participating in the project as a mentor and senior advisor from **University of Linköping** and also holder of the SAAB Chair at ITA.
- Prof. **David Lundström** from **University of Linköping**
- Dr. **Christopher Jouannet** from **SAAB** as mentor of innovation and technological applications
- Prof. Luiz Carlos Sandoval Goes
- Prof. Jose Manoel Balthazar
- Prof.Flávio José Silvestre
- Prof. Maurício Morales

Motivation

- Dynamically Scaled models are aircraft on a reduced scale, with the same geometries of the actual model and the scale factor properly applied to its mass and inertia characteristics. This model should perform a free flight or radio controlled so that it is possible to identify the model stability derivatives from the measurements.
- The instrumentation of this type of testing system was very robust, heavy and expensive. However, with the advent of electronics and control systems, the in-flight dynamic testing technique of sub scaled model becomes a technological, safe and economical solution for unconventional aircraft development and design

Objective of the project

- The Generic Future Fighter (GFF) - University of Linköping is an example on the development of methods for subscale demonstrators through testing of new aircraft design concepts, and development of potential methodologies for validation of flight control laws besides aerodynamically challenging configurations

Historical review - Modeling Flight

- Trends of today: **MODELING FLIGHT** : The Role of Dynamically Scaled Free-Flight Models in Support of NASA’s Aerospace Programs : Joseph R. Chambers, **NASA SP 2009-575**

Subscaling methodology

- The application of the similarity criteria can be widely used in reduced scale wind tunnel model tests. From these tests, one can construct a database of aerodynamic parameters, from static or dynamic nature, depending on the measuring device employed
- The wind tunnel static test is conventional, while the dynamic is usually more complex and restrictive. The use of remotely piloted aircraft, on the other hand enable the identification of parameters via a properly defined flight test instrumentation.

Scaling factors for Incompressible flow

Source: Chambers, 2010 – Modeling flight; NASA SP 2009-575,
www.nasa.gov/pdf/483000main_ModelingFlight.pdf

SCALE FACTOR	
Linear dimension	n
Relative density ($m/\rho l^3$)	1
Froude number (V^2/lg)	1
Angle of attack	1
Linear acceleration	1
Weight, mass	n^3/σ
Moment of inertia	n^5/σ
Linear velocity	$n^{1/2}$
Angular velocity	$1/ n^{1/2}$
Time	$n^{1/2}$
Reynolds number (Vl/ν)	$n^{1.5}\nu/\nu_0$

Scale factors for rigid dynamic models tested at sea level. Multiply full-scale values by the indicated scale factors to determine model values, where n is the ratio of model-to-full-scale dimensions, σ is the ratio of air density to that at sea level (ρ/ρ_0), and ν is the value of kinematic viscosity.

Present approach

- The objective of this project is to develop a ground and flight test methodology for geometric and dynamically scaled aircraft, respectively.
- The ground tests are specifically the wind tunnel tests. The linear and nonlinear aerodynamic models will be validated and identified, respectively, by specifying a test matrix including high angles of attack
- From the high angle of attack conditions the nonlinear aerodynamic model should be identified providing data for a nonlinear flight mechanics model upgrade.
- At the end the in-flight measured dynamics behavior and the numerical models shall be confronted in this first project phase.

Tasks

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- 1) Aerodynamic modeling of the RPVs using potential based panel methods to estimate the same longitudinal static derivatives of the vehicles;
- 2) Validation of linear aerodynamic models through wind tunnel testing for the full scale RPVs
  - lift and moment coefficients derivatives as a function of aircraft angles of attack.
- 3) Development of longitudinal linear dynamic model of the RPVs for aircraft flight quality performance quantification.
- 4) Static lift and moment coefficients as a function of the angle of attack in non-linear longitudinal flight regime - high angles of attack by wind-tunnel testing.
- 5) Dynamic model update by introducing nonlinearities in high angle of attack as lift and moment corrected global aerodynamic coefficients
- 6) Preparation of test campaign and risk management plan based on results of linear and nonlinear flight dynamics simulations;
- 7) Instrumentation of the RPVs for flight testing to identify the same derivatives as a function of angle of attack in linear and nonlinear flight conditions.
- 8) Flight quality testing and identification of the longitudinal stability derivatives for the RPVs;
- 9) Filtering and dynamic data reduction collected during the flight test campaign;
- 10) Theoretical and experimental comparison with flight dynamics simulated linear model the RPVs;
- 11) Experimental theoretical comparison with nonlinear flight dynamics simulated model of the RPVs.

Tasks

- 1) Aerodynamic modeling of the RPVs using potential based panel methods to estimate the same longitudinal static derivatives of the vehicles;
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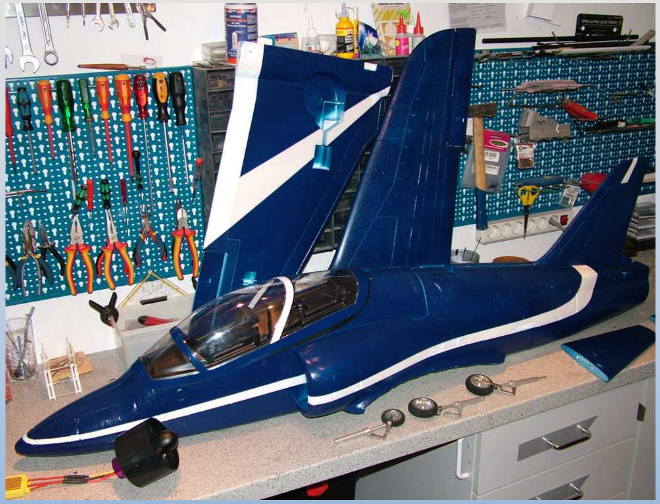
ONLY ACOMPLISHED TO ITA - BWB

Selected Models

- BAe Hawk – RPV
- Liu - GFF - RPV
- ITA - BWB - RPV



BAe Hawk – of the shelf Airmodel

Pattinson et al. 2013

- Known by its flat spin recovery capability
- Available data in the literature for full scale to subscale a/c;

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Investigation of Poststall Pitch Oscillations of an Aircraft Wind-Tunnel Model

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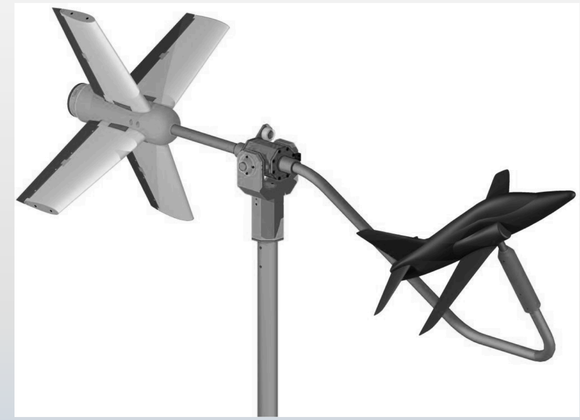
M. G. Goman‡
De Montfort University, Leicester, LE1 9BH England, United Kingdom

DOI: 10.2514/1.C032184



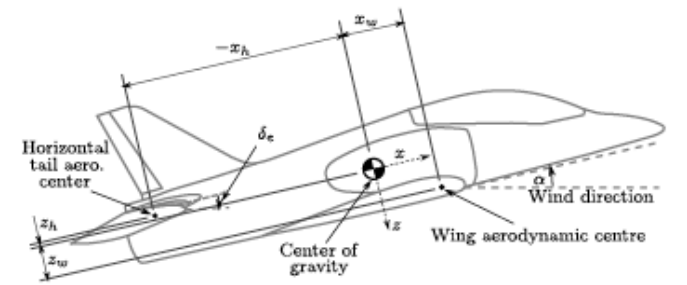
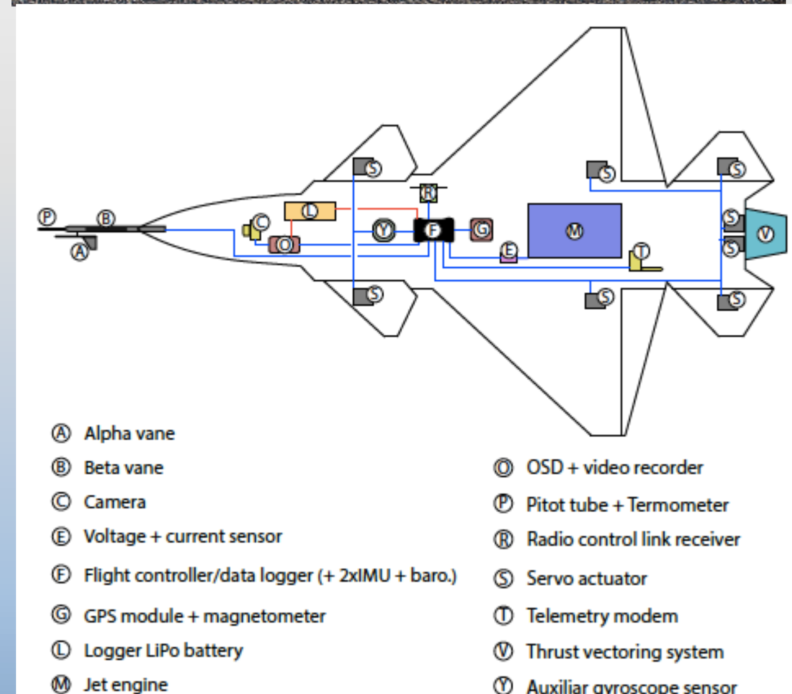


Fig. 6 Location of Hawk model wing and tailplane aerodynamic centers relative to center of gravity.

- Open questions: airmodel geometry not scaled based on the full scale BAe Hawk;
- Low cost test bench for data acquisition system validation.

LiU GFF-RPV

- MSDEMO project: investigates methods for subscale flight testing and demonstration,
- It is a subset of a larger initiative regarding Future Aircraft Design and Demonstration (FADEMO)
- project as a whole is focusing on the following topics:
  - Possibilities and limitations of subscale demonstrators in aircraft development,
  - Dynamic scaling for development of control laws for unconventional configurations,
  - Scaling methods depending on the issues to be addressed and the associated cost,
  - Flight testing methods, repeatability and uncertainty issues,
  - Implementations of an efficient avionic system for flight control and data logging.
  - Components such as miniature gas turbine engines, powerful and precise actuators, robust and redundant data links, telemetry systems, and other advanced equipment are available **of the shelf** at low cost.



ICAS 2016

SUBSCALE FLIGHT TESTING OF A GENERIC FIGHTER AIRCRAFT

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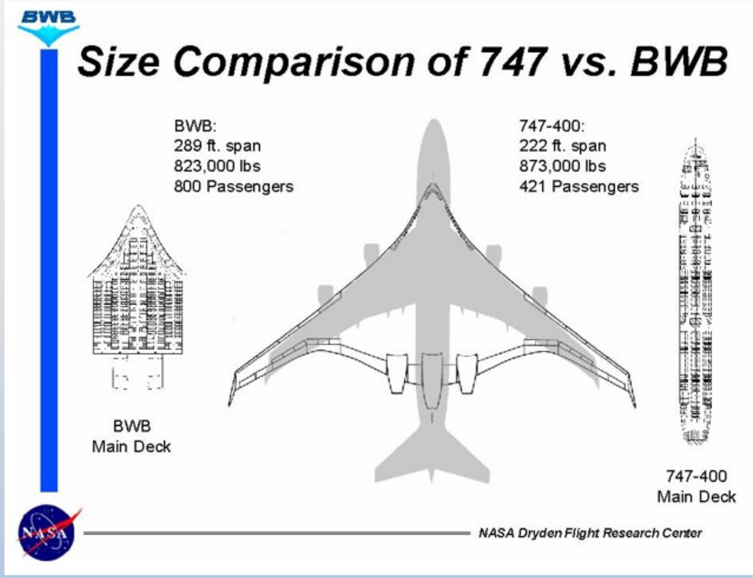
**Saab AB, Sweden
***Instituto Tecnológico de Aeronáutica, São José dos Campos, Brazil

Keywords: *subscale, free flight test, demonstrator, data acquisition*

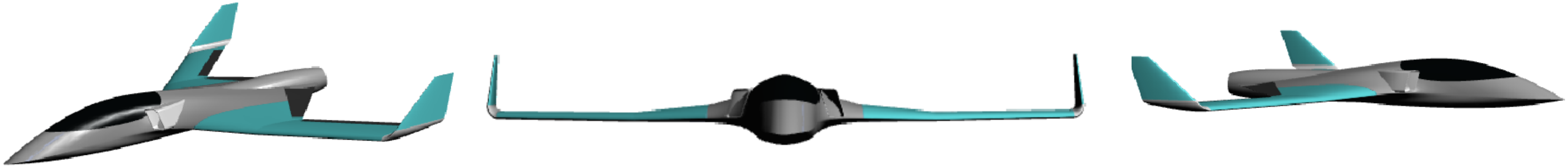
ITA-BWB research vehicle

- Inspired in a different sort of vehicles;



http://www.twitt.org/Slide5a.jpg http://www.wingco.com/bwb_jeb_profiles.htm

- Master thesis under development at ITA (Monteiro, D. M.);



ISR manned / unhumanned sensorcraft requirements

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BWB concept

Nasa BWB - from static WT tests to subscale flight

http://www.nasa.gov/centers/langley/news/factsheets/FS-2003-11-81-LaRC.html

http://www.nasa.gov/centers/langley/news/researchernews/rn_bwbsmithsonian.html

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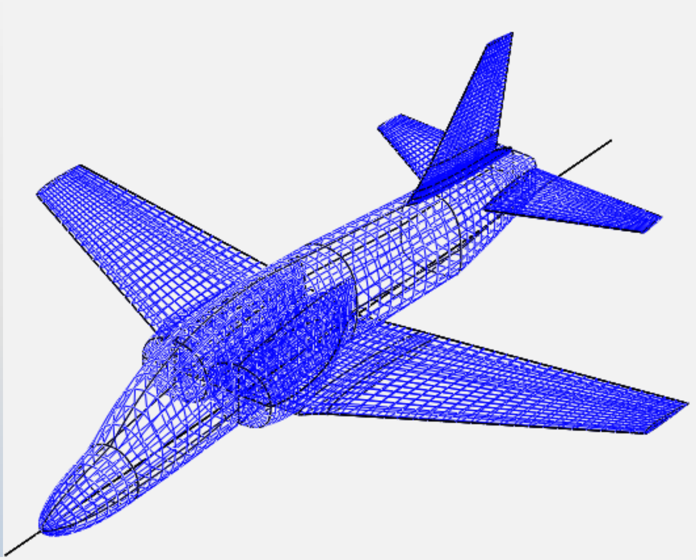
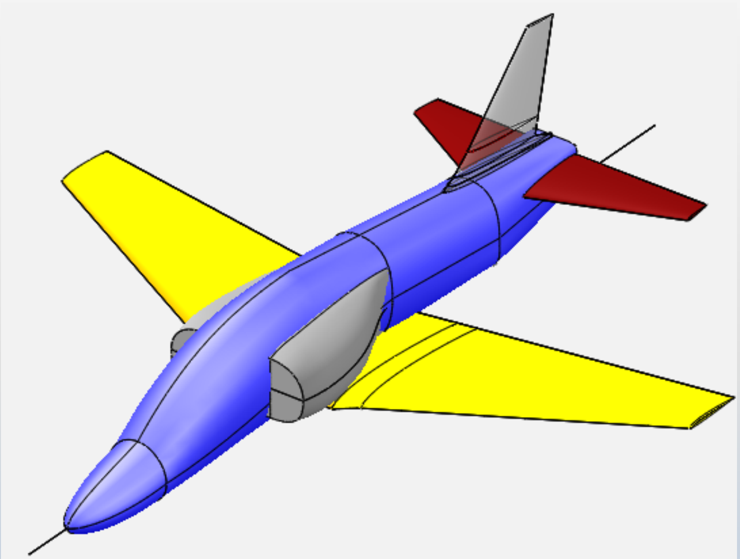
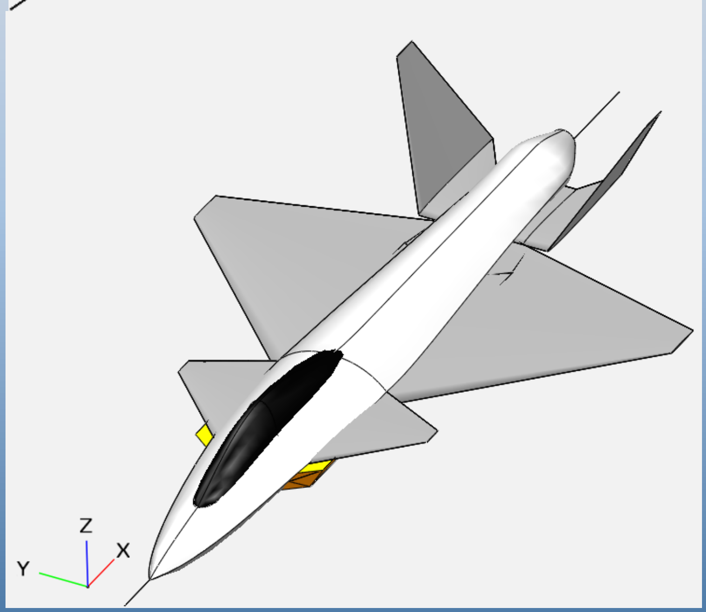
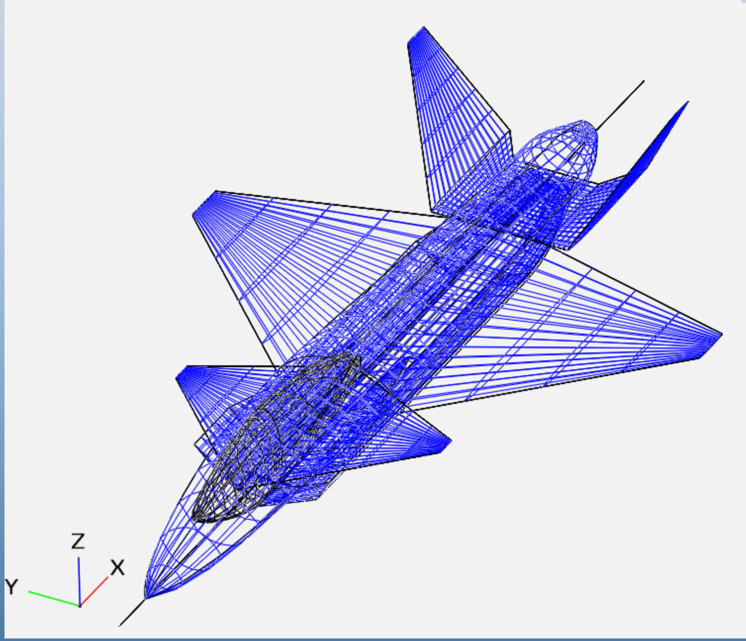
Numerical modeling



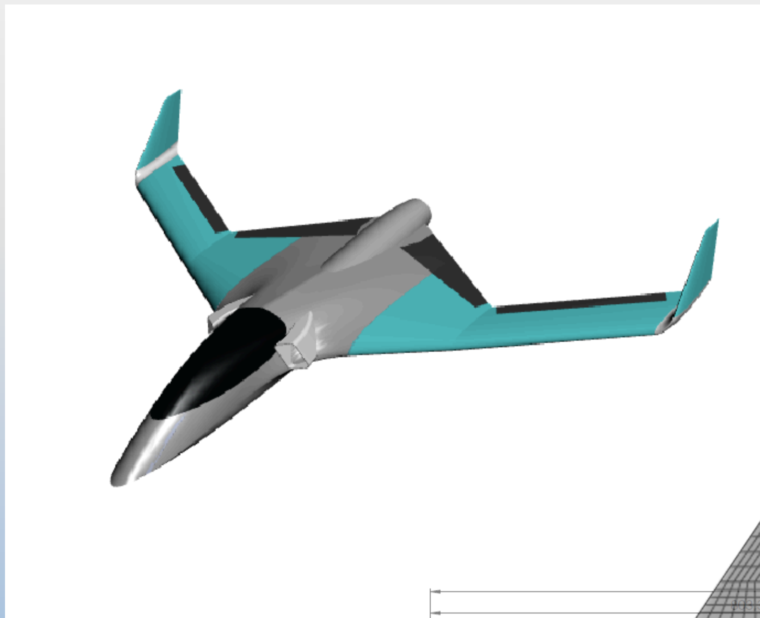


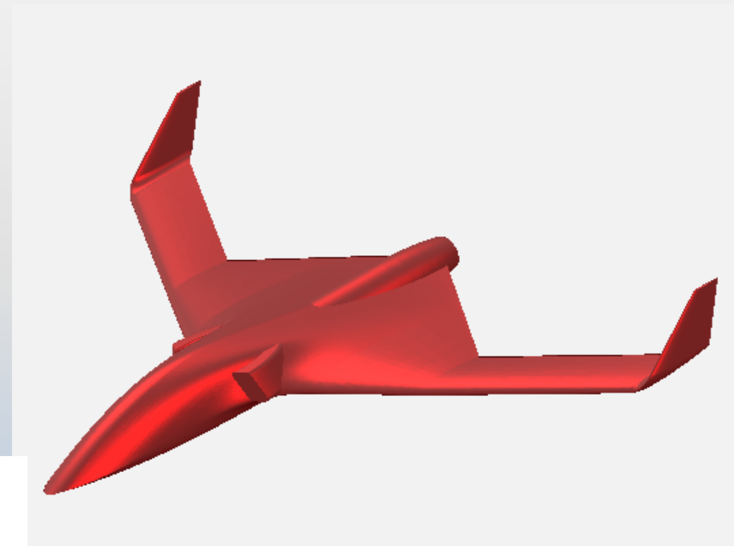


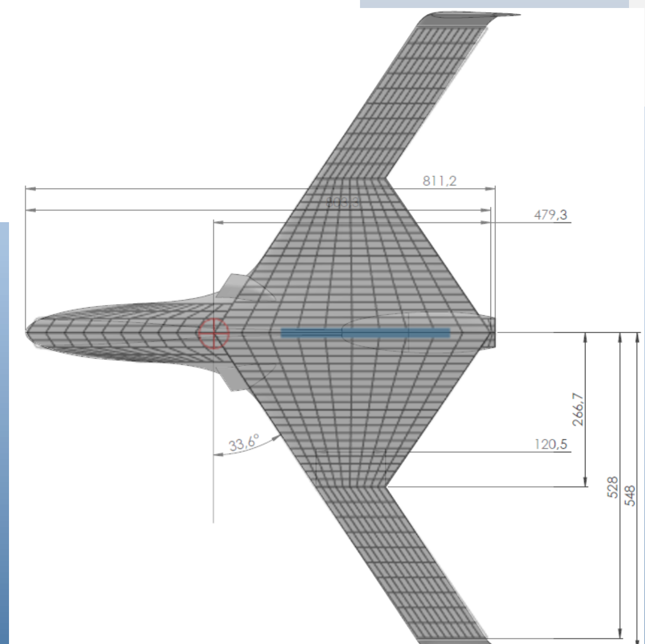


Numerical modeling

Concept ITA - BWB vehicle



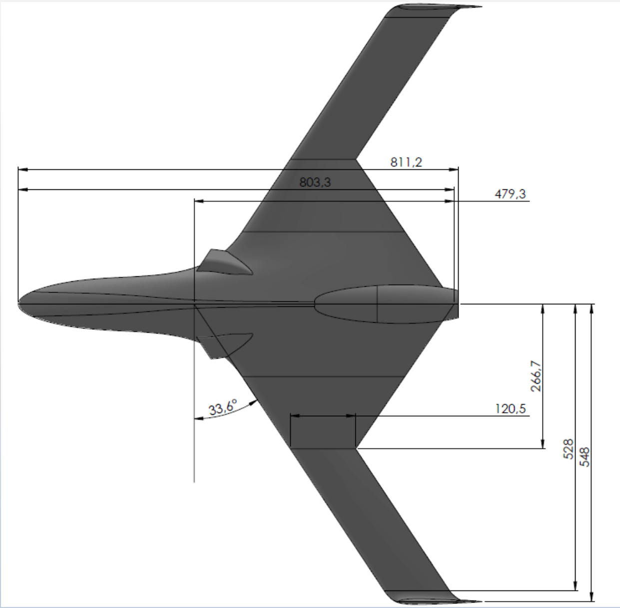


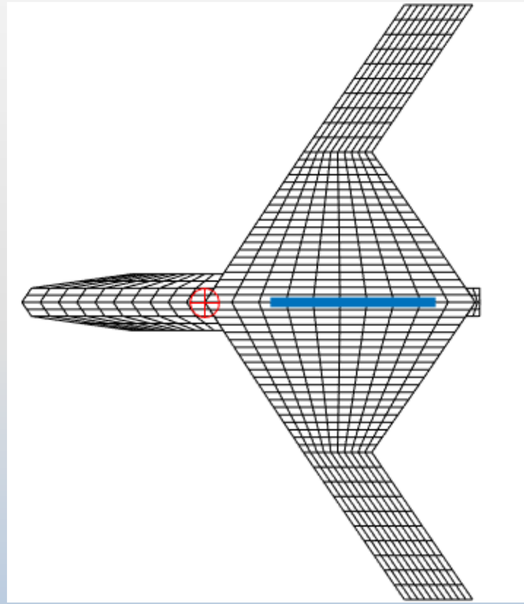


Preliminary Subscale model

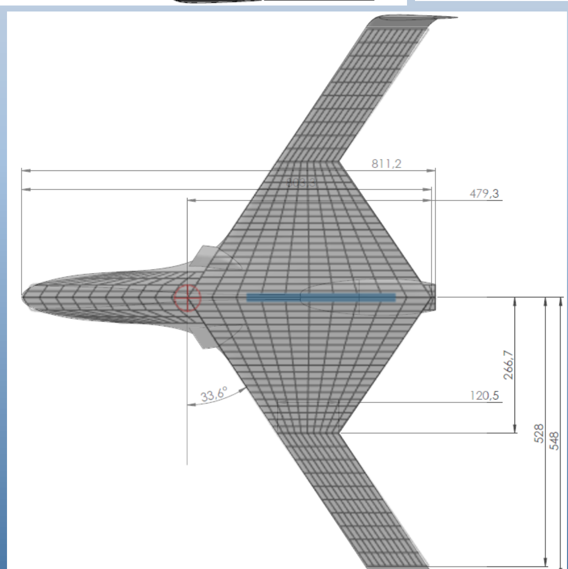
- Qualitative flight handling test – prop-pusher “foamy” model
  - CNC machined P3 foam model;
  - Electric brushless motor;
  - Open loop remote control system;
  - Handling and static stability;
  - Same size / different mass of the composite material EDF driven model:

Numerical Aerodynamic model

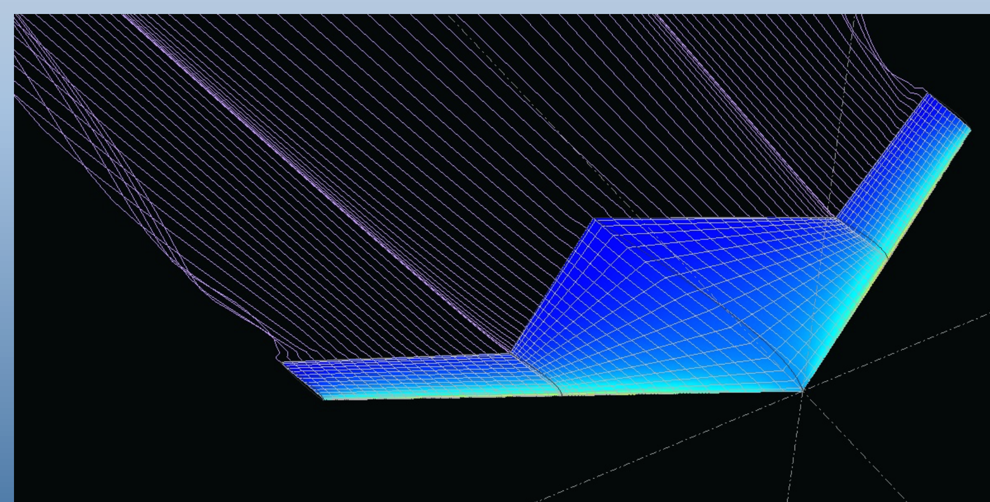




Tornado VLM



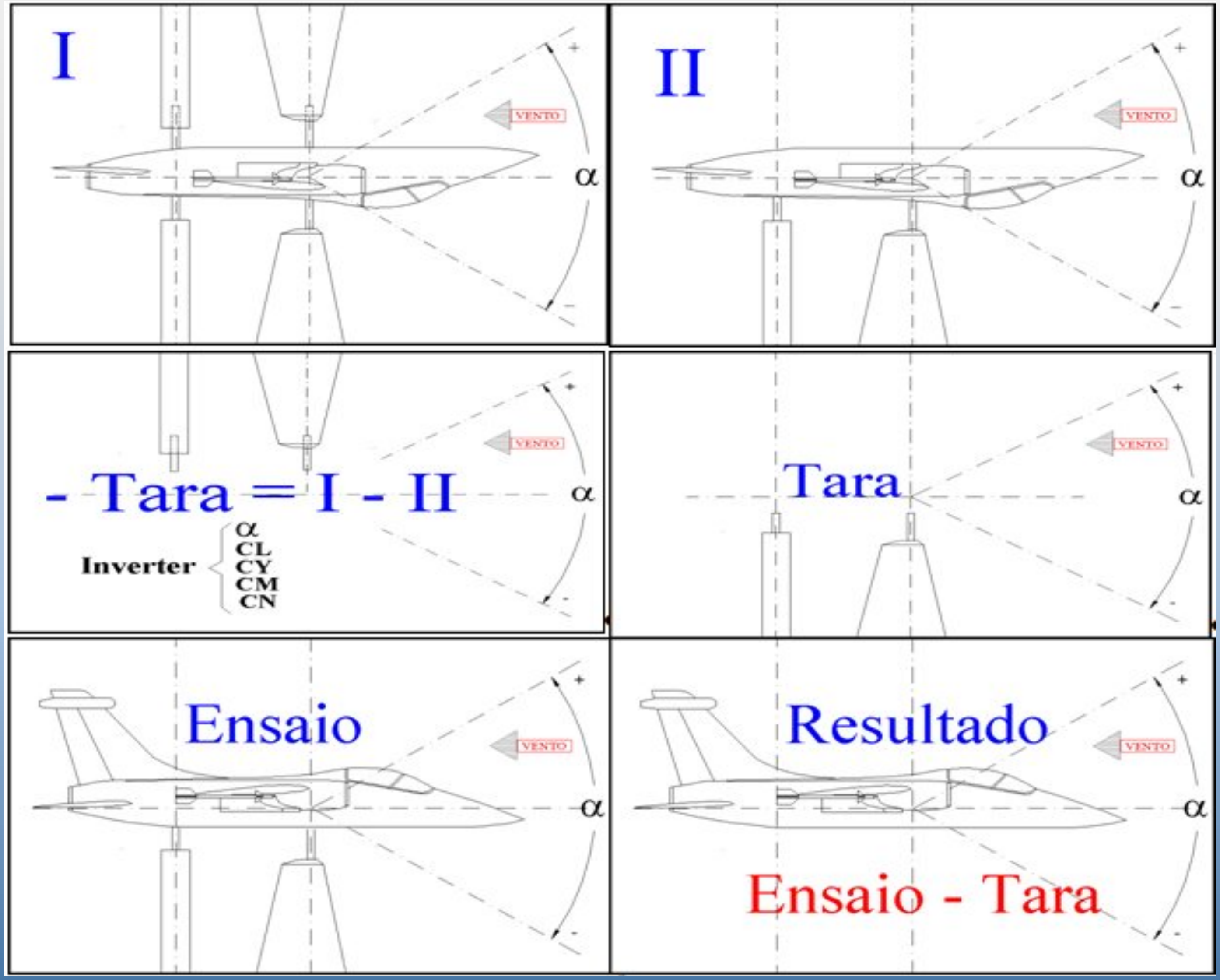
XFRL5 “wing only"



Ground testing wind tunnel – TA2 - IAE

- Subsonic wind tunnel
- 10X7 ft (3 X 2,1 m)
- Measurement range:
- Speed: 5,0 a 127,0 m/s.
- Aerodynamic forces: 8.000 a 16.000 N.
- Aerodynamic moment: ± 1.650 Nm
- Uncertainty:
- Speed: ± 0,2%.
- Aerodynamic forces: ± 0,2%.
- Aerodynamic moment: ± 0,3%

Aerodynamic Tare - Concept



Aerodynamic Tare - BWB

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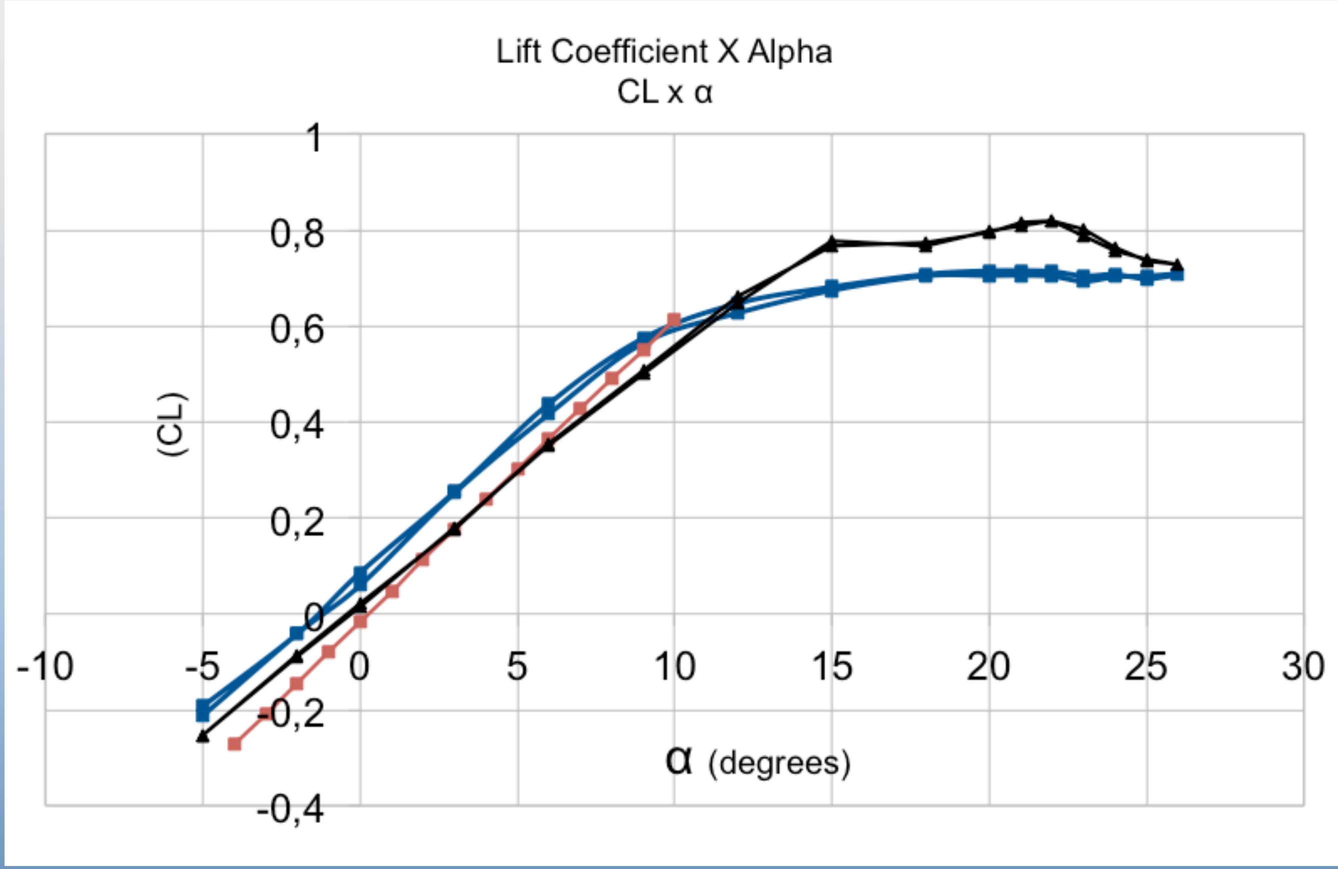
Preliminary results

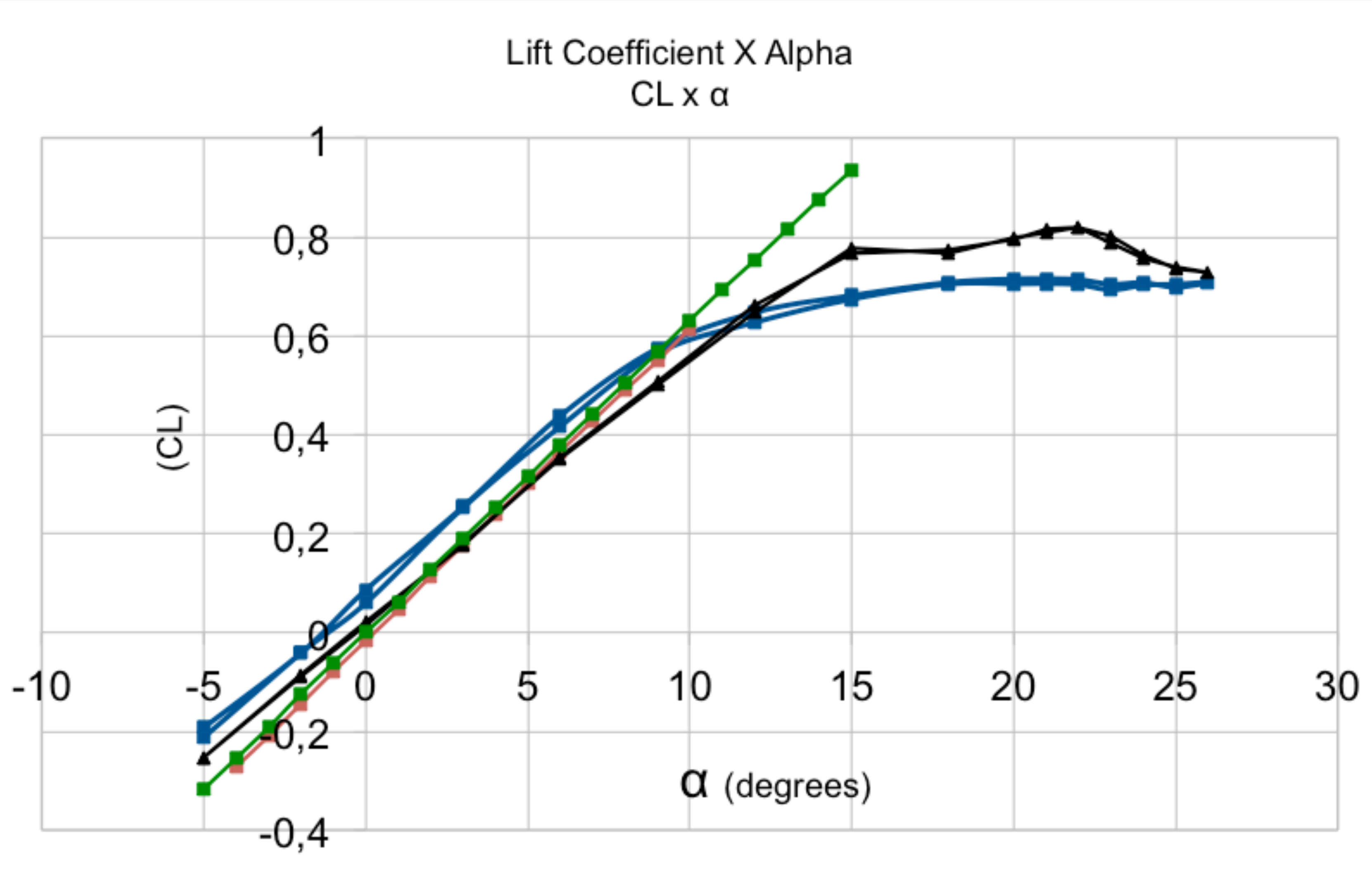
- Lift Coefficient– without tare correction



- Red – VLM, blue 20m/s , black 40 m/s

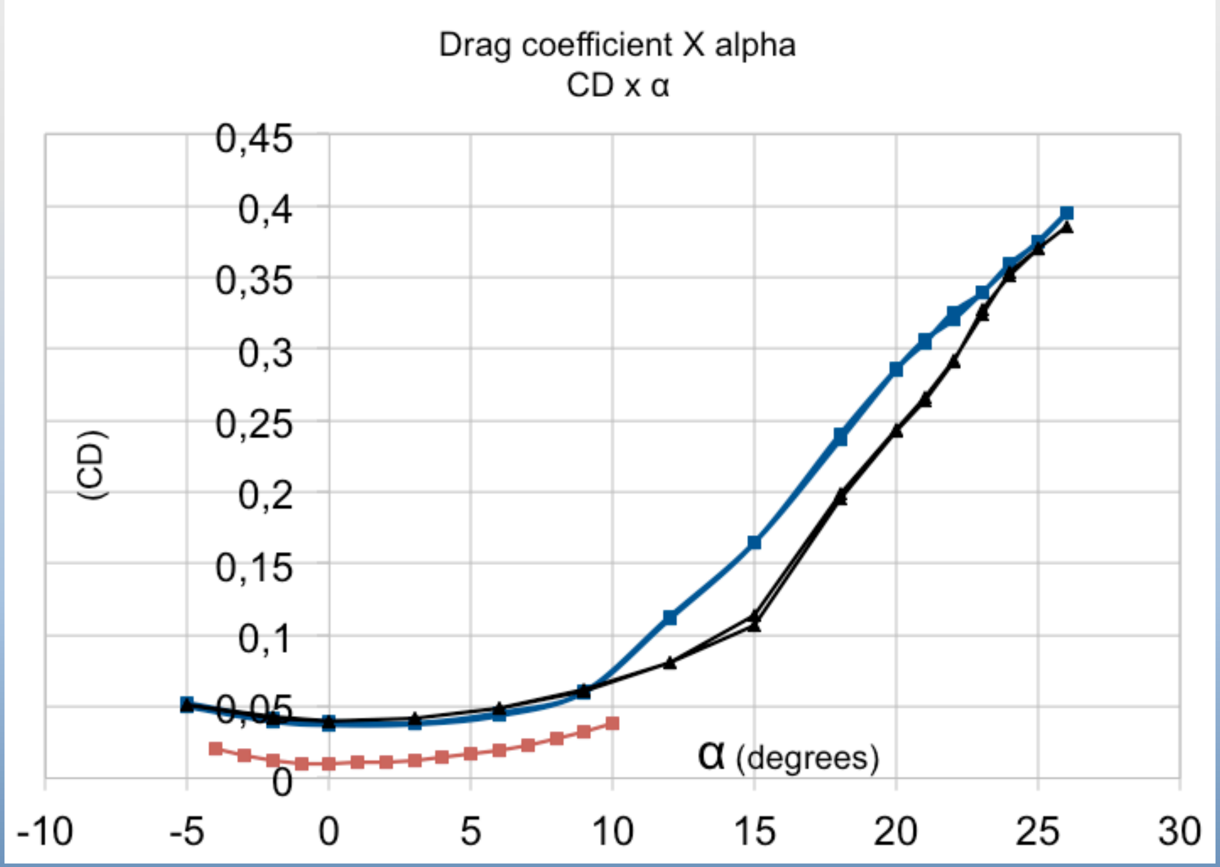
VLM – Tornado and XFRL5

Red – TORNADO-VLM, blue 20m/s , black 40 m/s, green XFRL5-VLM



Preliminary results

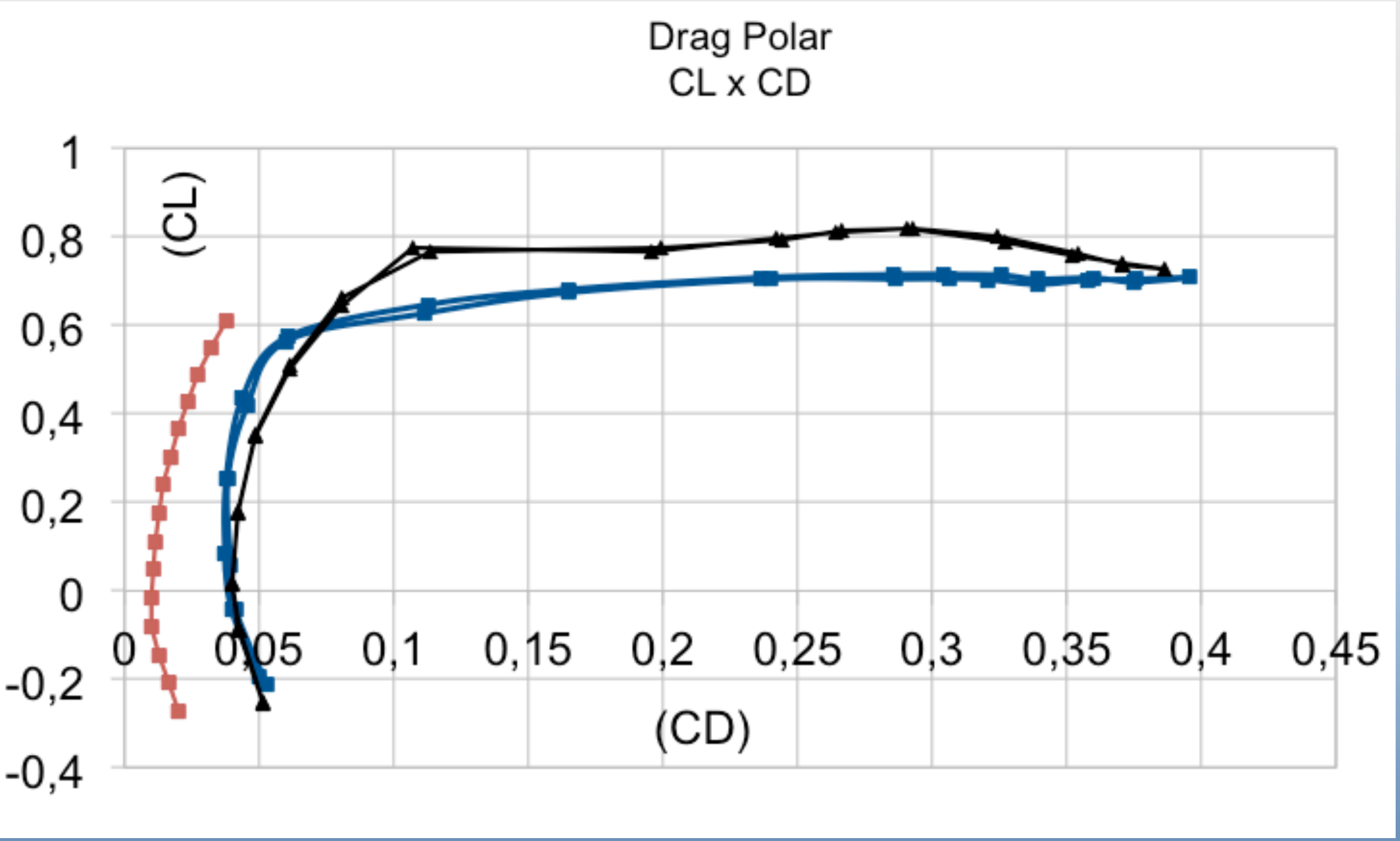
- Drag – without tare correction



- Red – VLM, blue 20m/s , black 40 m/s

Preliminary results

- Drag Polar – without tare correction

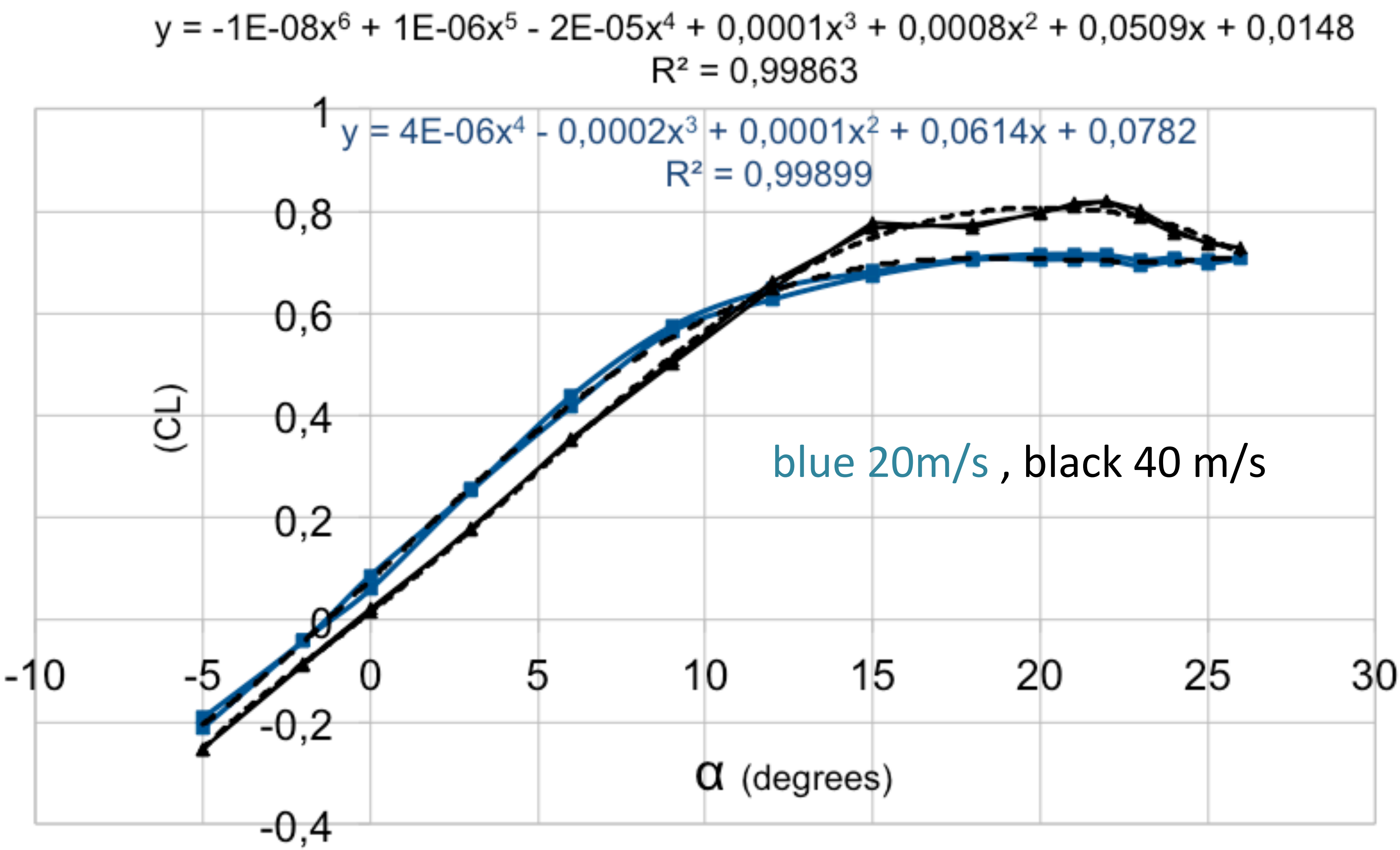


- Red – VLM, blue 20m/s , black 40 m/s

Comments

- Aerodynamic tare possible cause to CL an CD shift
- Trend curves behave in good agreement in terms of trend lines;
- Hi AoA discarded in numerical analysis;
- Numerical model improvement to take into account vortex lift
- Moment coefficient require special care on data reduction since it is more sensitive to interference effects
- Mechanical restrictions / structural limits avoid evolving to higher AoA
- Flow speed instead of Reynolds number – MAC Based?

Global aerodynamic model - C_L



Comments – nonlinear aerodynamics

- Nonlinear global aerodynamic model for higher speed is of six order and does not capture well the primary vortex lift mechanism;
- Is it necessary a higher order polynomial – flight dynamic (FD) updated model against flight test data shall answer this question;
- Global nonlinear aerodynamic models are often used in FD;

$$C_z = c_1 + c_2\alpha + c_3\alpha^2 + c_4\delta_s + c_5\alpha^3 + c_6\alpha\delta_s + c_7\alpha^2\delta_s$$
$$+c_8M + (c_9 + c_{10}\alpha + c_{11}\alpha^2 + c_{12}\alpha^3 + c_{13}\alpha^4 + c_{14}M$$
$$+c_{15}\alpha M + c_{16}\alpha^2 M)(q\bar{c}/2V) + (c_{17} + c_{18}\alpha)\delta_n$$
$$+(c_{19} + c_{20}\alpha + c_{21}M + c_{22}\alpha^2)\delta_f$$

Morales, Mauricio Andrés Varela
Equações de movimento para o estudo de manobras ótimas com modelos aerodinâmicos globais e método indireto / Mauricio Andrés Varela Morales.
São José dos Campos, 2016.

- Still necessary to find out the best cost benefit for nonlinear FD and control system design:

JOURNAL OF GUIDANCE, CONTROL, AND DYNAMICS
Vol. 24, No. 1, January–February 2001

Analysis of Longitudinal Flight Dynamics: A Bifurcation-Theoretic Approach

Der-Cherng Liaw* and Chau-Chung Song†
National Chiao Tung University, Hsinchu 30010, Taiwan, Republic of China

Aircraft model

- Rigid body aircraft, 6 DOF nonlinear equations of motion

- We are interested in flights at high angles of attack: modern high-performance aircrafts are usually required to have improved maneuver capabilities.

- We work with a nonlinear model to represent the aircraft:

$$X = f(X, U, W)$$

States (X)

Control (U)

Disturbances (W)

- Nonlinear aerodynamics is also considered to fully represent the aircraft flight at high angles of attack.

- Nonlinear phenomena, such as bifurcations, may exist.

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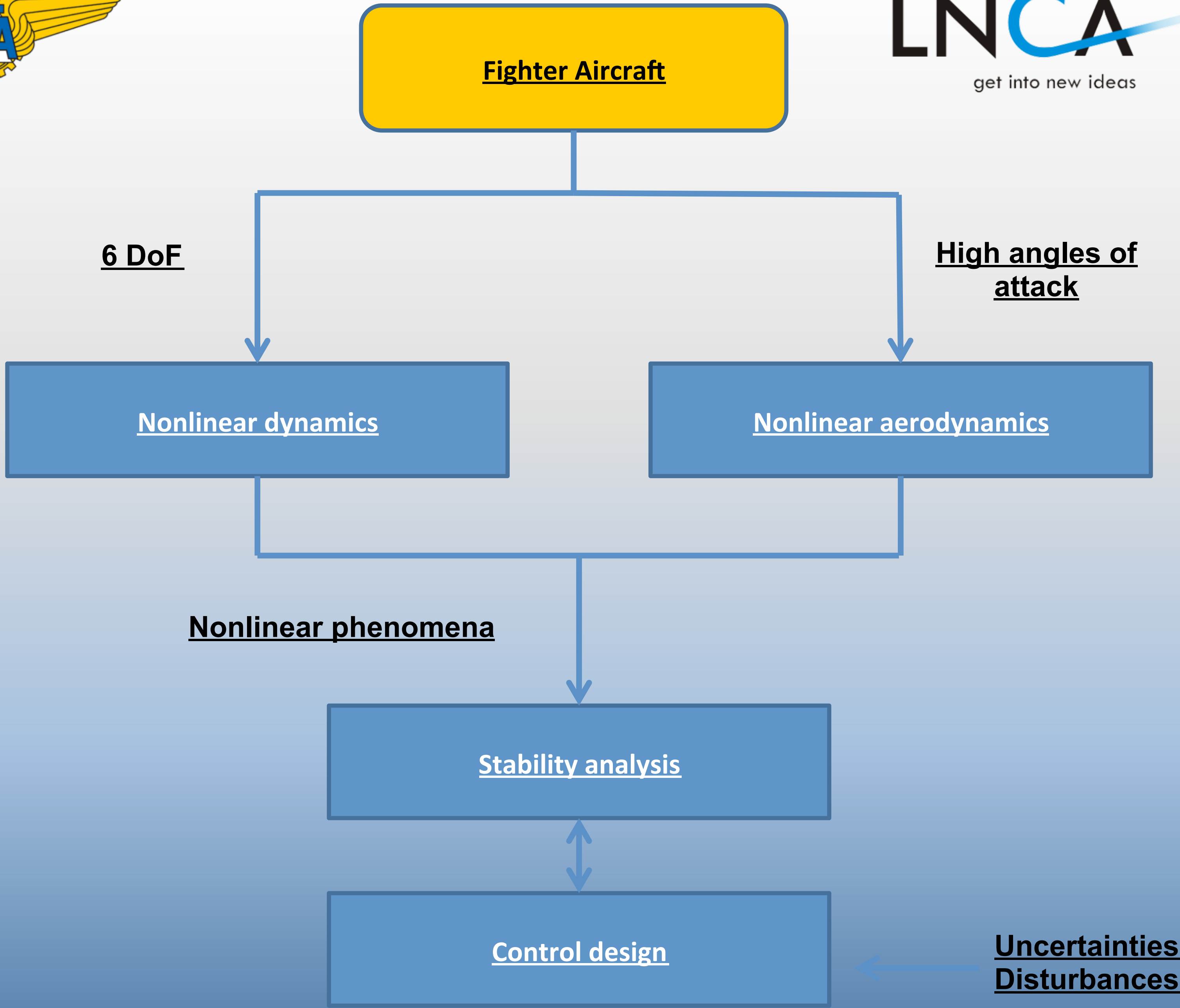


Aircraft model

- States

Linear velocities

Attitude

$$X = [u \; v \; w \; p \; q \; r \; \phi \; \theta \; \psi \; x_N \; x_E \; x_D \; \mu \; \lambda]^T$$

Angular velocities

Position

- Observations

Angle of attack

Acceleration

$$Y = [V_T \; \alpha \; \beta \; \gamma \; p \; q \; r \; \phi \; \theta \; \psi \; a_x \; a_y \; a_z \; h \; \mu \; \lambda]^T$$

Velocity

Climb angle

Altitude

- Control inputs

Throttle

$$U = [\delta_{tc} \; \delta_e \; \delta_a \; \delta_r]^T$$

Elevator

Aircraft model – ITA-BWB

- In flights at high angles of attack, the lift coefficient cannot be represented as a linear function of angle of attack and therefore nonlinear aerodynamic terms should be taken into consideration.
- Cubic approximations are found in the literature.

Control design

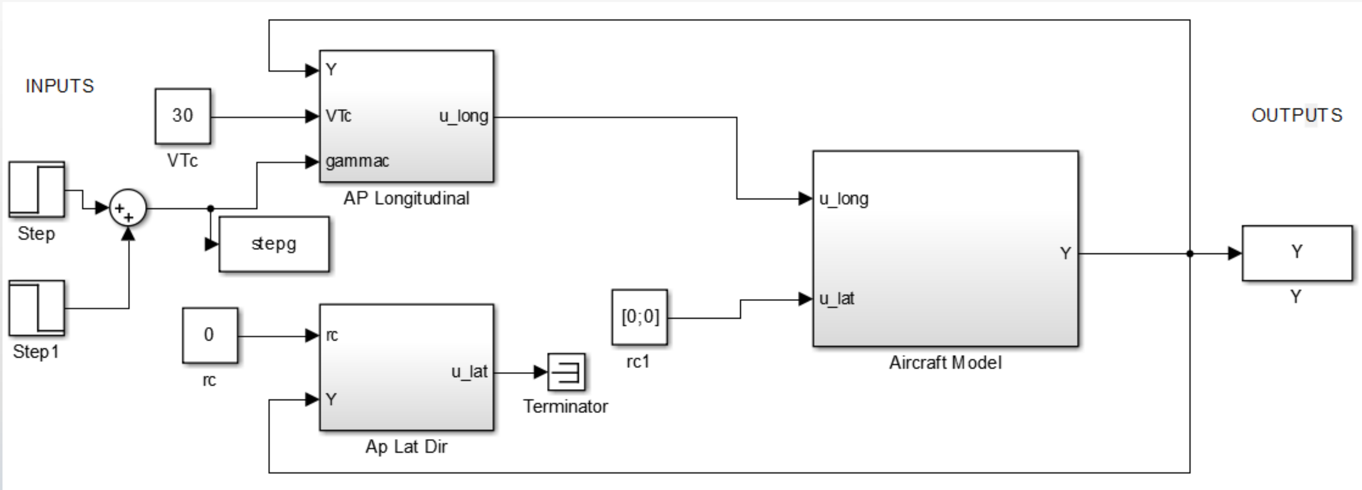
- Loop shaping: robust control method

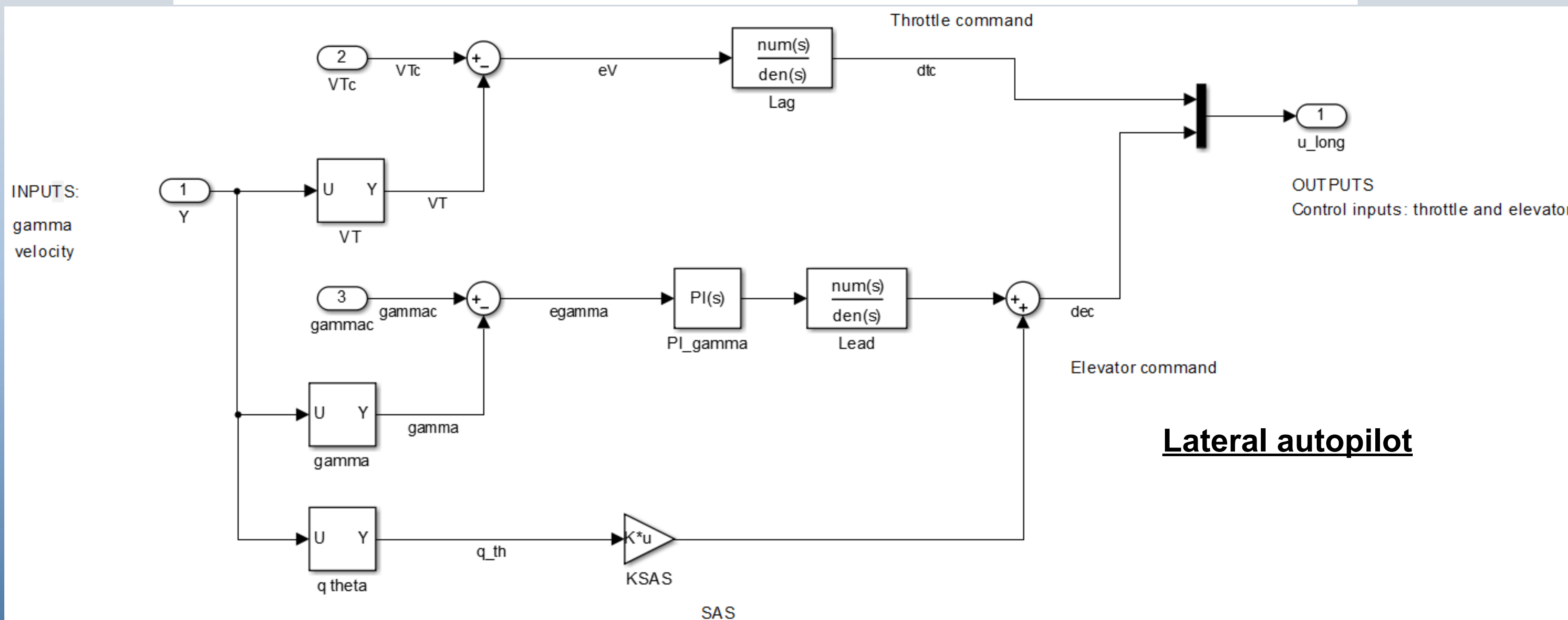
- The goal is to shape the closed-loop transfer function so as to minimize a H_∞ index according to the design requirements

- Frequency domain specifications are selected for disturbance attenuation.

- Longitudinal autopilot design tracks velocity (lag compensator) and climb angle (proportional-integral controller + lead compensator). SAS is a proportional controller wrt q and θ.

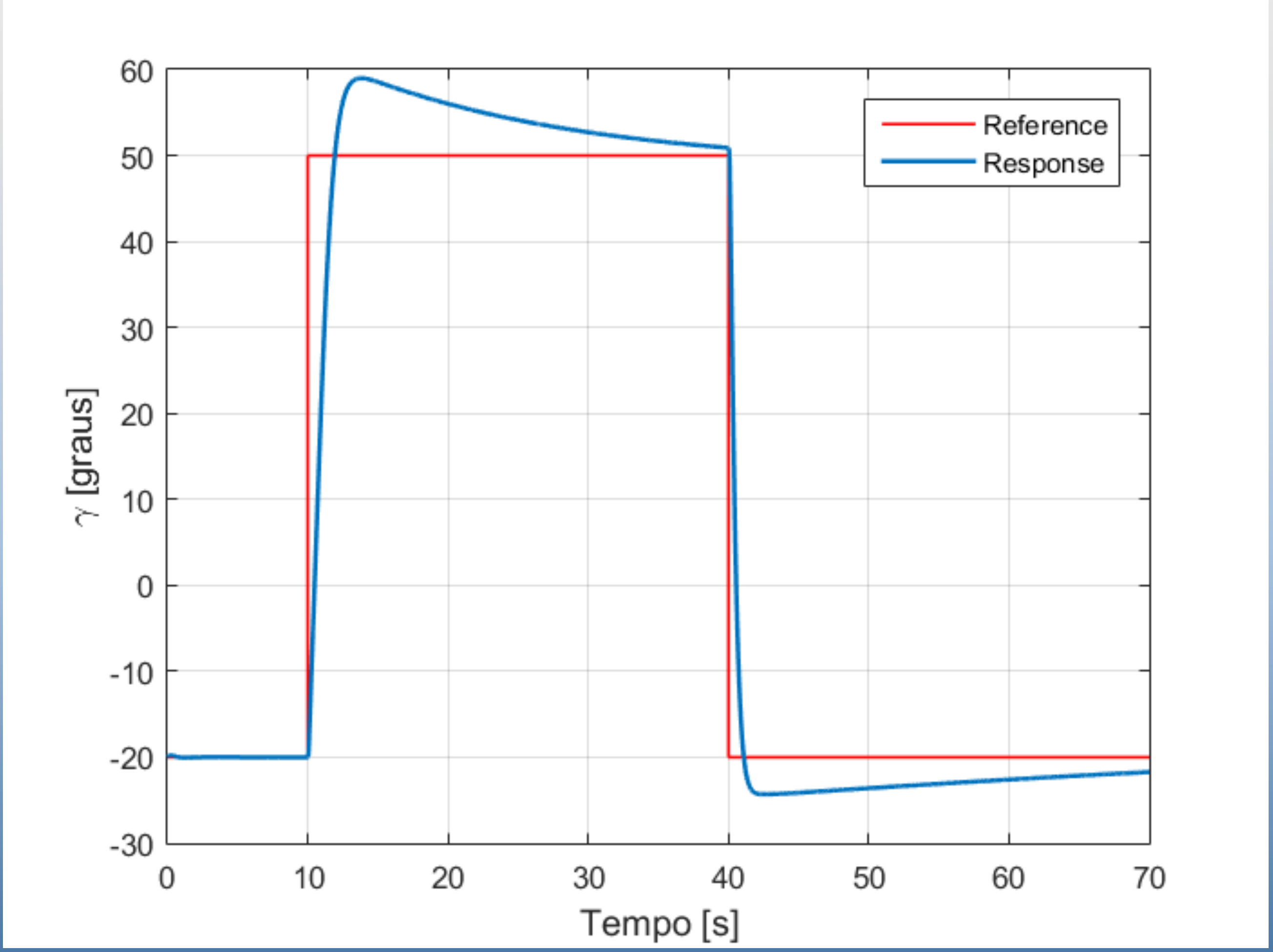
Simulink model





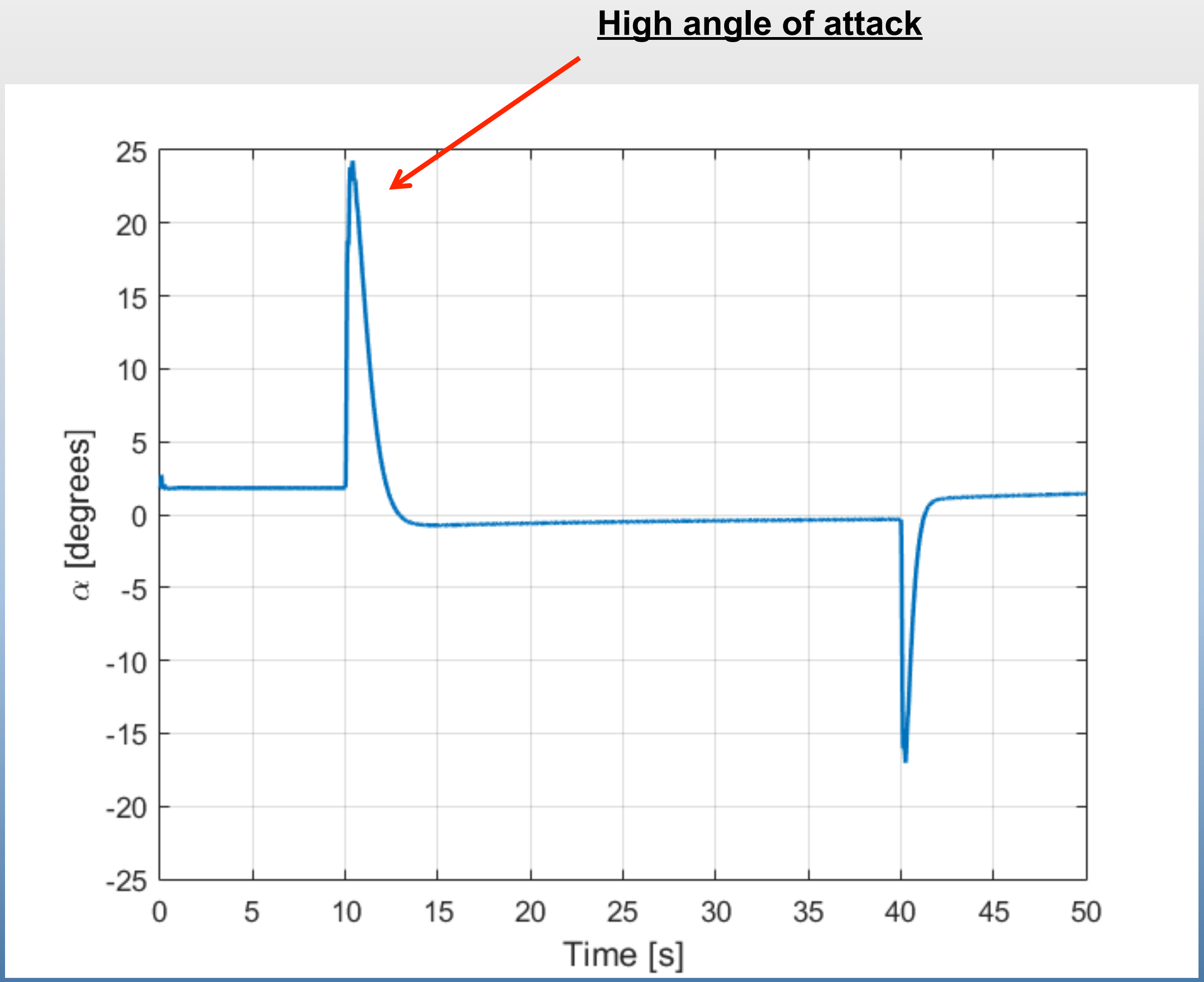
Simulation

- High angle of attack maneuver: steep ramp to reach a reference altitude
- Input: Climb angle γ



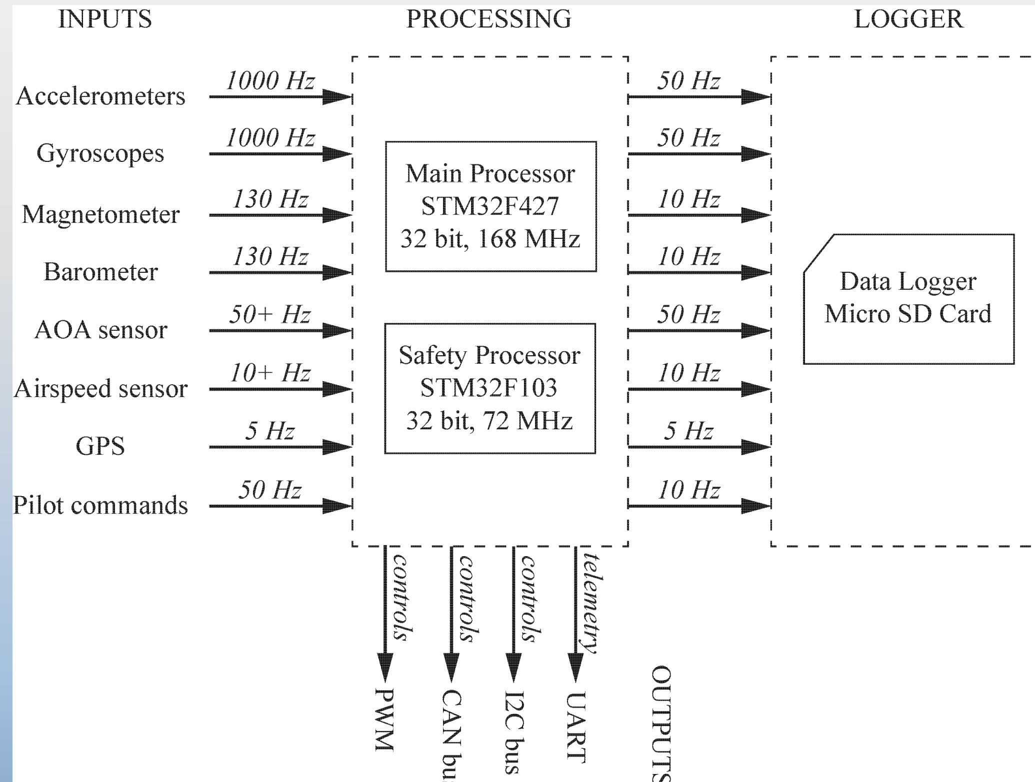
Simulation results

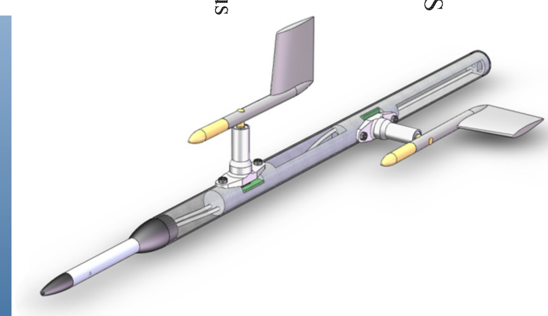
- The aircraft is recovered from high angles of attack



Next Steps – BWB final assembly and instrumentation

- BWB propulsion system installation - 70mm EDF 5S LiPO battery
- Inflight instrumentation
  – Pitot tube
  – AoA measurement probe
  – Pixhawk® →
- PREDICTED FLIGHTS 12/16





Final comments

- Preliminary developments aiming the application to LiU GFF subcale ground and flight testing activities
  - Wind tunnel testing at IAE-TA2 wind tunnel;
  - Fight test in Brazil;
  - Interlaboratorial experimention;
  - Different control systems design approch;
  - Sys id techniques.
- Other subscale models?
- Finep/Vinnova Funding:
  - Brazilian GFF airframe construction, systems and instrumentation acquisition
  - Wind tunnel testing full scal GFF means the flying subscale model
  - Support for joint activity between LiU / ITA and EESC-USP
- Partnership with Brazilian and Swedish companies
- Students / researchers exchange

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Acknowledgements

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PESQUISA E INOVAÇÃO
SUECO-BRASILEIRO

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Simulation results

- The reference altitude was successfully reached.