# ALPES Mid-Term Review

Andrea Castrichini

ALPES ESR 1

# My background

- Bachelor Degree in Aerospace Engineering from the University of Rome La Sapienza (2007-2010).

- Master Degree in Aeronautical Engineering from the University of Rome La Sapienza (2010-2013).

- 10 months internship at MSC Software Toulouse (2012-2013): research activities focused on Aeroelasticity and Fluid-Structure interaction problems.

- Marie Curie ESR in Aircraft Aeroelasticity and Loads (2013 – ongoing)

  - Siemens PLM (Oct 2013 – Mar 2015)

  - University of Bristol (Apr 2015 – ongoing).

# Training experiences in ALPES

- Scientific Courses:
  - Practical Modal Analysis (3 days)
  - Numerical simulation of multi-body systems (3 days)
  - Introduction to Aircraft Aeroelasticity and Loads (5 days)
  - Ground Vibration Testing (GVT) Master Class (4 days)
  - Experimental NVH (2 days)
  - Course on Detection, Modeling and Identification of Nonlinearities in Engineering Structures (2 days)

- Transferable skills training:
  - Presentation skills (2 days)
  - Project Management (1 day)
  - Intermediate French Course - B2 (1 semester)

- Conferences:
  - LMS Aerospace Conference 2013
  - DIPART 2013
  - ISMA-ISAAC International Conference on Noise and Vibration Engineering
  - 4th Aircraft Structural Design Conference – Belfast, October 2014 (Presented: Preliminary Investigation of Use of Flexible Folding Wing-Tips for Static and Dynamic Loads Alleviation)
  - Scitech Conference - Orlando, January 2015 (Presented : Nonlinear Folding Wing-Tips for Gust Loads Alleviation. )
  - DIPART 2014 (Presented)
  - LMS Aerospace Conference 2015
  - NAFEMS - San Diego, June 2015 (Will presented : Unsteady aerodynamics in multibody simulations for aircraft loads prediction )
  - Scitech Conference – San Diego, January 2016 (Abstract: Nonlinear Negative Stiffness Folding Wing-Tip Device for Gust Loads Alleviation)

# Main objectives of my research project

- To improve the modelling of landing, manoeuvres and gust loads for combined high load events:
  - Investigate effects of different loads sources on aircraft structural model:
    - Ground loads during landing and taxing manoeuvres.
    - Aerodynamic loads coming from in-flight and ground manoeuvres, gusts and high lift devices.
  - UDF Implementation to couple a non-linear multi-body dynamic analysis coupled with an external aerodynamic code.

- Design and numerical modeling of novel structural configurations  such as aircraft with folding wing-tips:
  - Allow more efficient aircraft by increasing the wing aspect ratio.
  - Minimize structural weight increment by using folding tip device for loads alleviation.

# Multibody Aeroelastic Simulations

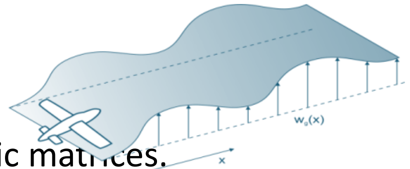
- Floating Reference of Frame formulation for flexible bodies:
  - Reference coordinates $R^i$(X,Y,Z), $\theta^i$ ($\theta_0, \theta_1, \theta_2, \theta_3$) → large displacements, finite rotations (rigid body) → $r^i = R^i + A^i(u_0^i + u_f^i)$
  - Elastic modal coordinates $q_f^i$ → small linear deformations with respect the body ref → $u_f^i = \sum_n^{N_{Modes}} \Phi_n^i(x)\, q_n^i(t)$

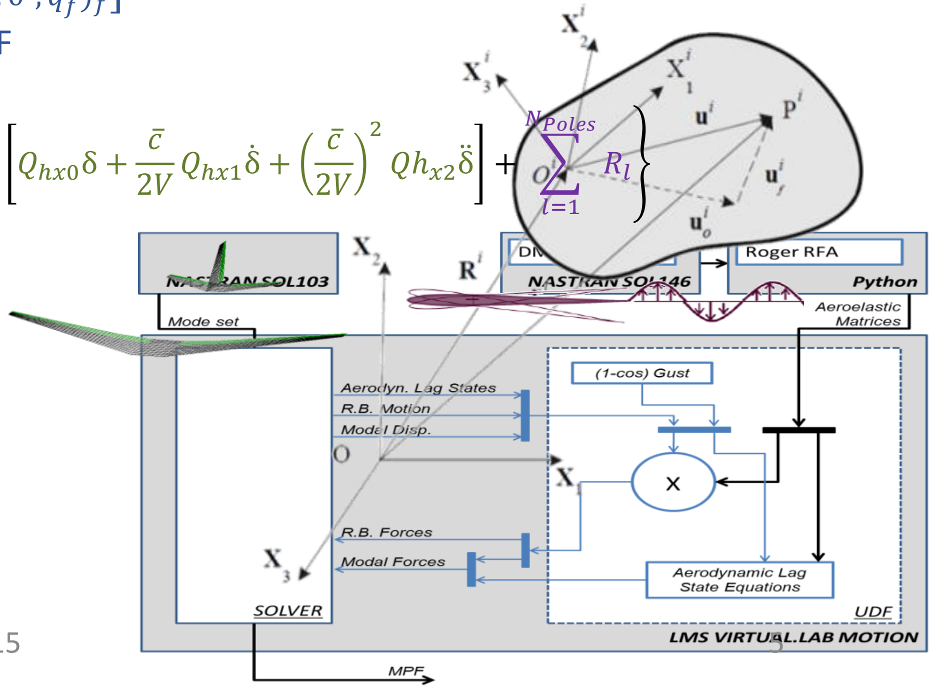
$$\begin{bmatrix} m_{RR}^i & m_{R\theta}^i & m_{Rf}^i \\ m_{\theta R}^i & m_{\theta\theta}^i & m_{\theta f}^i \\ m_{fR}^i & m_{f\theta}^i & m_{ff}^i \end{bmatrix} \begin{Bmatrix} \ddot{R}^i \\ \ddot{\theta}^i \\ \ddot{q}_f^i \end{Bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & D_{ff}^i \end{bmatrix} \begin{Bmatrix} \dot{R}^i \\ \dot{\theta}^i \\ \dot{q}_f^i \end{Bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & K_{ff}^i \end{bmatrix} \begin{Bmatrix} R^i \\ \theta^i \\ q_f^i \end{Bmatrix} + \begin{Bmatrix} C_{R^i}^T \\ C_{\theta^i}^T \\ C_{q_f^i}^T \end{Bmatrix} \lambda = \begin{Bmatrix} Q_{e\,R}^i \\ Q_{e\,\theta}^i \\ Q_{e\,f}^i \end{Bmatrix} + \begin{Bmatrix} Q_{v\,R}^i \\ Q_{v\,\theta}^i \\ Q_{v\,f}^i \end{Bmatrix} + \begin{bmatrix} Q_{Aero}^i(R^i, \theta^i, q_f^i)_R \\ Q_{Aero}^i(R^i, \theta^i, q_f^i)_\theta \\ Q_{Aero}^i(R^i, \theta^i, q_f^i)_f \end{bmatrix}$$

UDF

- Aerodynamic Forces Formulation:

$$F_{Aero} = q_{dyn}\left\{\left[Q_{hh0}\xi + \frac{\bar{c}}{2V} Qhh_1\dot{\xi} + \left(\frac{\bar{c}}{2V}\right)^2 Q_{hh2}\ddot{\xi}\right] + \left[Q_{hj0}w + \frac{\bar{c}}{2V} Q_{hj1}\dot{w} + \left(\frac{\bar{c}}{2V}\right)^2 Q_{hj2}\ddot{w}\right] + \left[Q_{hx0}\delta + \frac{\bar{c}}{2V} Q_{hx1}\dot{\delta} + \left(\frac{\bar{c}}{2V}\right)^2 Qh_{x2}\ddot{\delta}\right] + \sum_{l=1}^{N_{Poles}} R_l\right\}$$

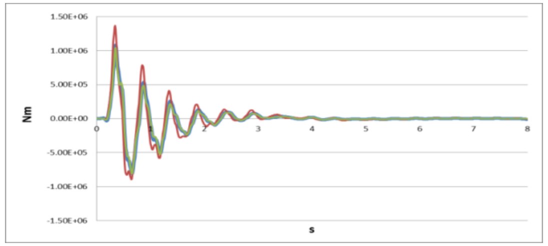


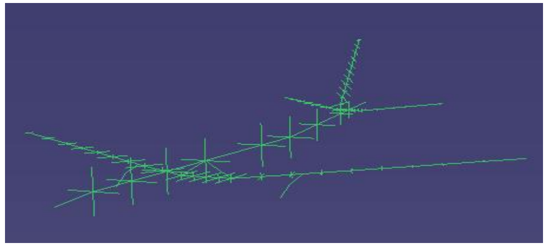




- The User Defined Force Element:
  - A DMAP code used to extract the Doublet Latticeaeroelastic matrices.
  - The matrices are read by the UDF at the very beginning of the analysis.
  - At each step these aeroelastic matrices, combined with the rigid body motions ($R^i, \theta^i$) and local deformations ($q_f^i$ ), provide the related aerodynamic forces.
  - The generalized aerodynamic forces then applied on the related generalized coordinates of the body of interest.

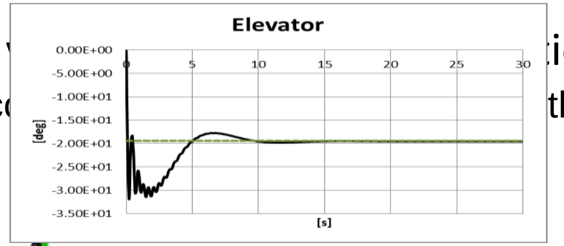
# Numerical Results

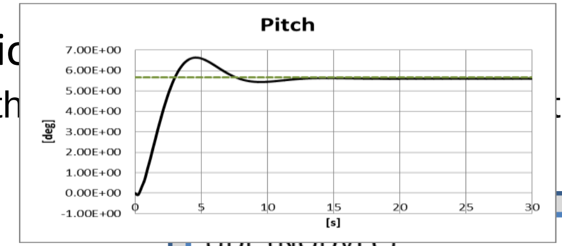
- Dynamic Gust Response

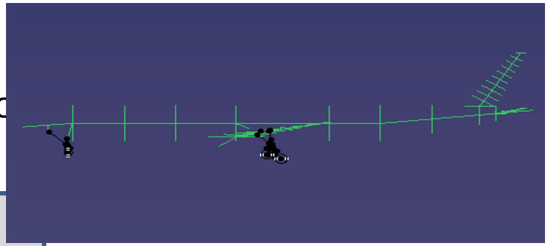


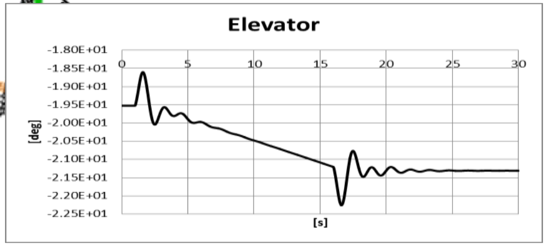
- Aeroservoelastic Analyses performed w
  - Possibility to manoeuver the aircraft acc
- Trim Analysis

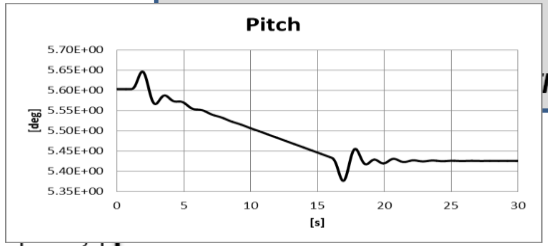


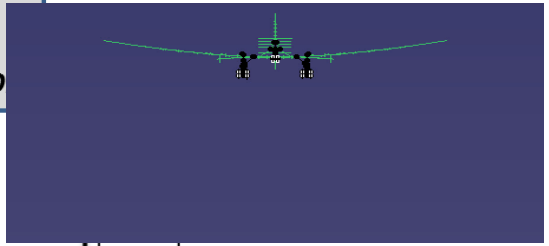



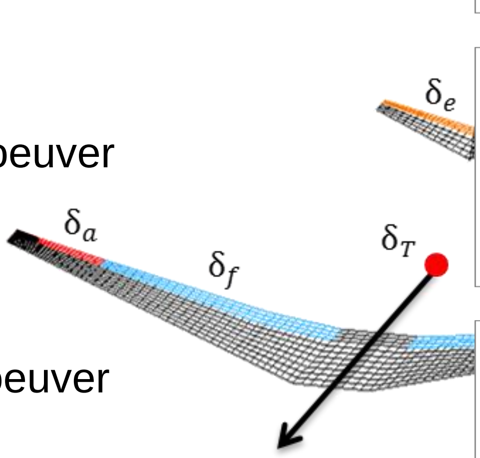
- Descent manoeuver

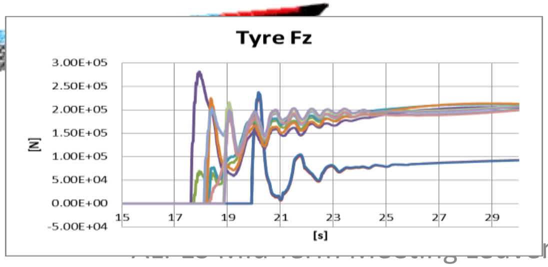


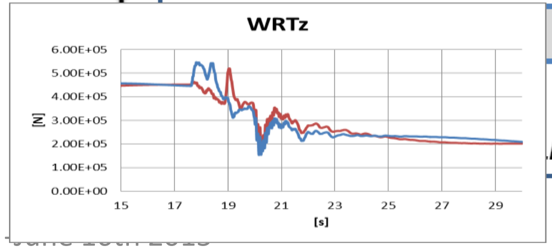



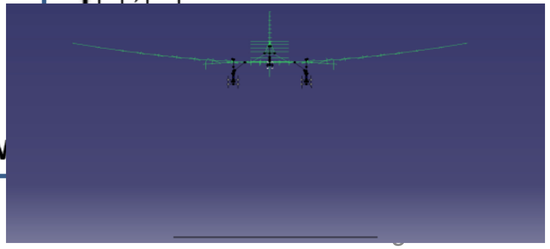



- Landing manoeuver



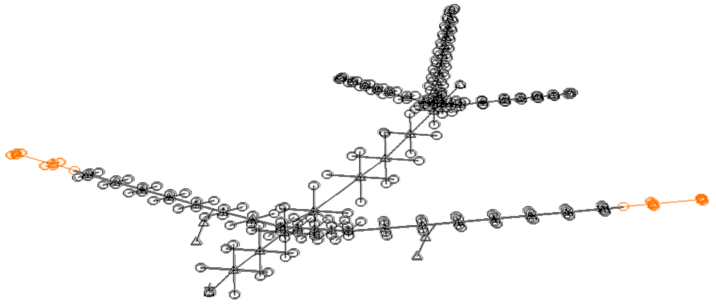



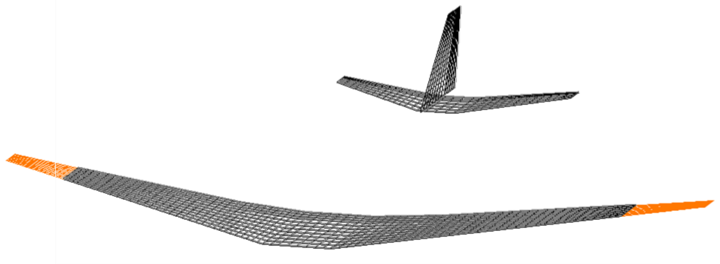



# Linear Folding Wing-Tip For Loads Alleviation

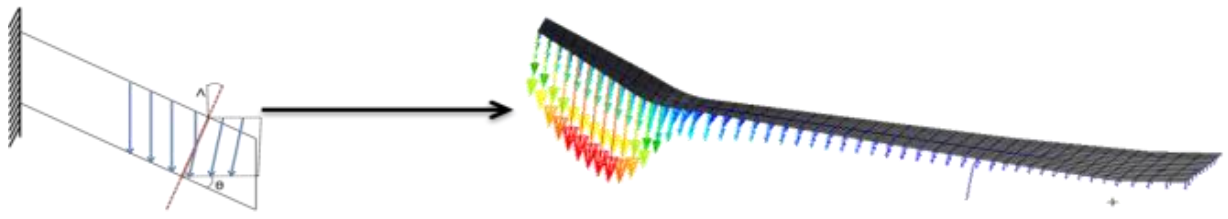
- Investigate the possibility to attach folding wing-tips to a baseline model to increase the wing span.
- Wing-tip connected to the main airframe through a linear elastic hinge.
- Several configurations:
  - $\Lambda$=0°-25°.
  - wing-tip weight = 100 Kg - 943Kg.
  - K=$10^{0}$-$10^{10}$ Nm/rad.





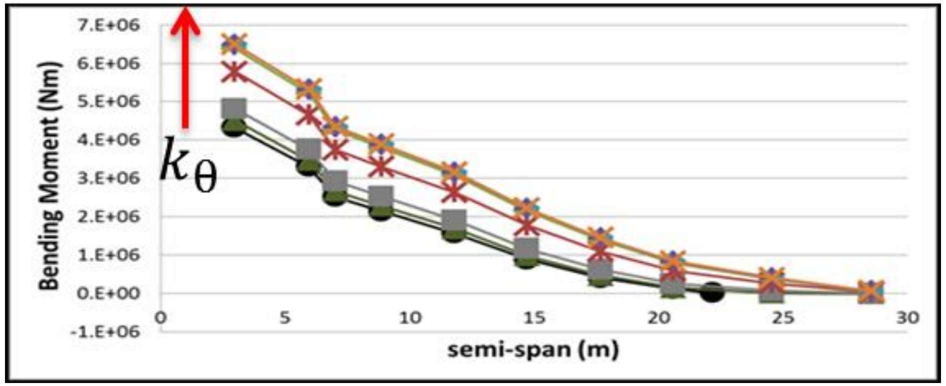
- <u>25% increment of the span</u>

- Allow significant local $\Delta\alpha$ at the wing-tip to generate forces that reduce the global wing root bending moment.

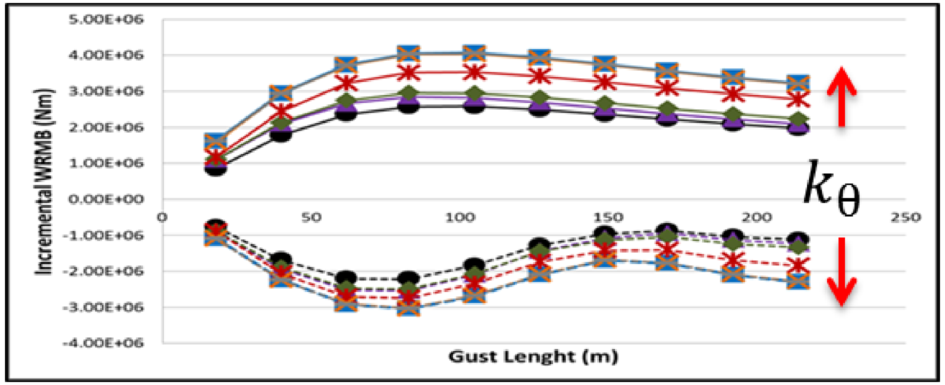


# Numerical Results

- 25° hinge, m=100 Kg model



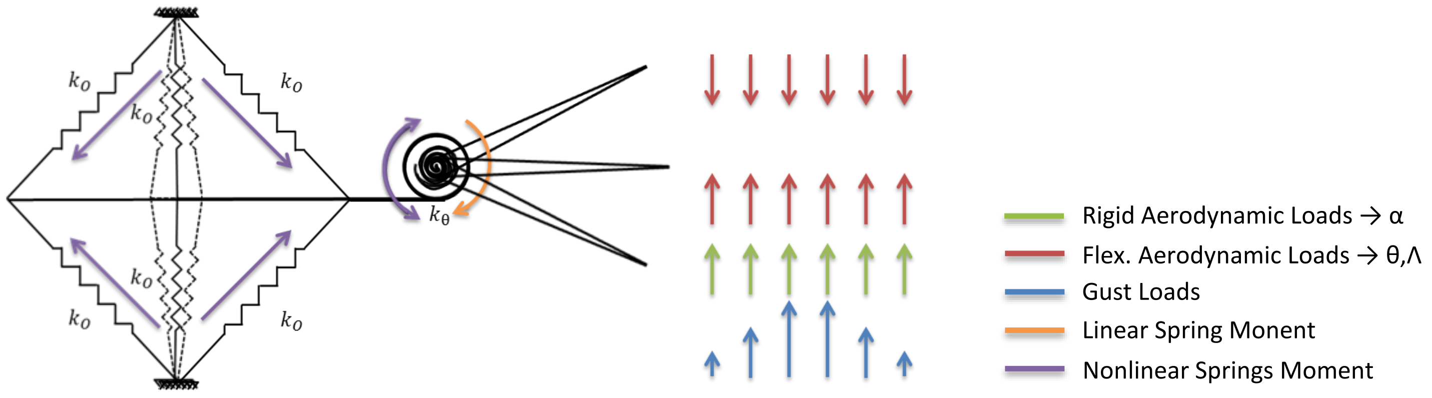

- Static trim analysis
  - The lower $k_\theta$ the higher is the wing-tip rotation the lower are the loads




- Unsteady gust response
  - The lower $k_\theta$ the higher and the faster is the wing-tip rotation the lower are the loads

# Ongoing / Future work

- Folding wing-tip:
  - Understanding of the dynamics of a nonlinear SDOF FWT model.
  - Validation of the loads alleviation using a civil aircraft model in VLM.




- Aeroelastic Landing Simulation:
  - Improvement of the landing gear model (stiffness and damping parameters tuning).
  - Structural loads evaluation for different landing scenarios:
    - Gust intensity and direction.
    - Aircraft longitudinal and vertical speed.

# Expectations on My Future Career

- I would like to continue to have a technical career as researcher or application engineer.

- I believe that the experiences matured during this 3 years industrial PhD will allow me to be a suitable candidate for a relevant and exciting position within the European aeronautical industrial/academic community.

# ALPES Mid-Term Review

Adrien PONCET-MONTANGES

ALPES ESR #2

# My background

- 25 years old, from Eastern France
- Engineer in fluids dynamics  from INP Toulouse

  Specialization in aerodynamics in TU Berlin

- Last experiences in industry/research :
  - 3 months internship, Airbus, Bremen : development of validation tools
  - Gap year, Airbus, Toulouse : aerodynamic data for performance
  - Master thesis at DLR, Braunschweig : efficient calculation of aerodynamic uncertainties for a missile configuration

# Training experiences in ALPES

## Trainings

- Two weeks placement at Airbus
- GVT Masterclass organized by Siemens in Leuven
- Introduction to Aircraft Aerolasticity and Loads
- Manage your PhD

## Conferences

- DiPART, November 2014
- Paper submitted for IFASD, June 2015
- Abstract submitted for AiAA SciTech, January 2016

## Transferable skills

- Lab demonstrating
- Two semesters of teaching in labs

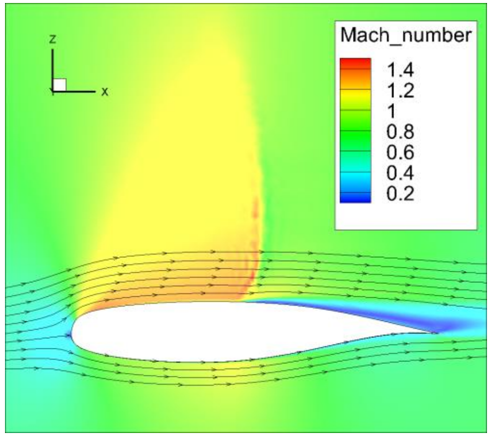
# Main objectives of my research project

## Prediction the aerodynamic coefficients for unsteady motions

- Creation of a numerical model able to provide relevant inputs

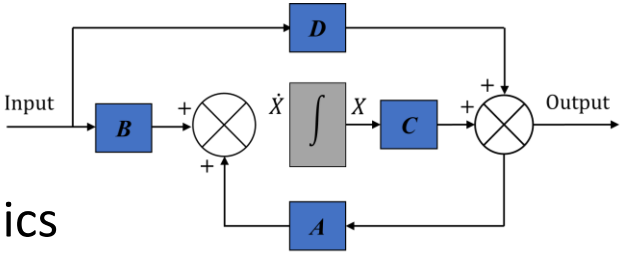
## Investigation of nonlinearities in the transonic domain

- Shock wave and separation




## Construction of fast and efficient reduced order models (ROMs)

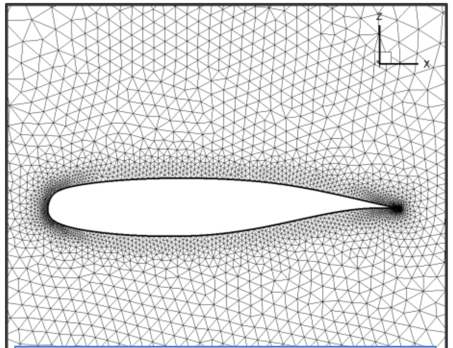
- Solving unsteady phenomena is expensive
- Models : set of inputs and outputs
- Reduce the size of the model by only capturing the dominant system dynamics



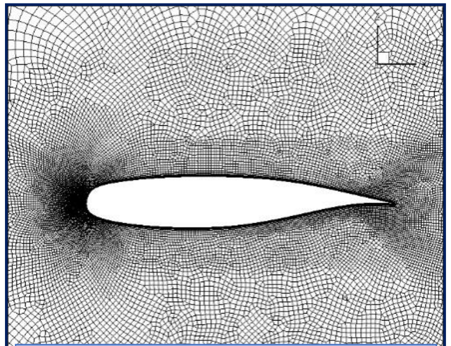
# CFD used to provide aerodynamic data

## CFD : code + mesh

- Solver used : TAU
- Building of unstructured meshes for viscous and inviscid calculations
- Airfoil chosen : NLR7301, supercritical



Inviscid mesh



Viscous mesh

## Methods of calculation

- Viscous calculations : RANS.

  *Higher cost but solves the boundary layer*

- Inviscid calculations : Euler

  *Faster, does not take viscosity into account*

- Linearized frequency domain (LFD)

  *Linearization around the steady state, applied to periodic motions of small amplitude.*

$$u(t) = \bar{u} + \tilde{u}(t)$$
$$x(t) = \bar{x} + \tilde{x}(t)$$

# Validation of the numerical model

## Comparison with wind tunnel results (McCroskey et. al & AGARD 702 )

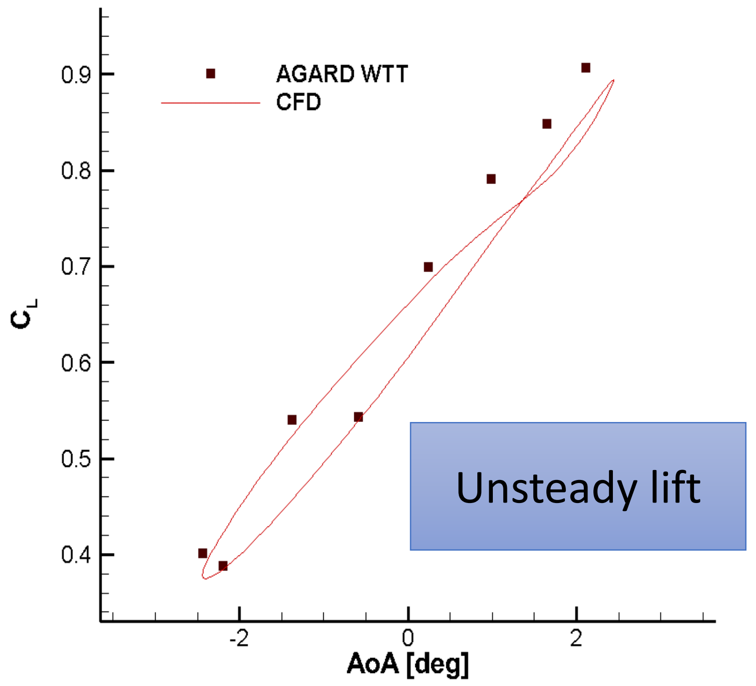
- Unsteady validation :

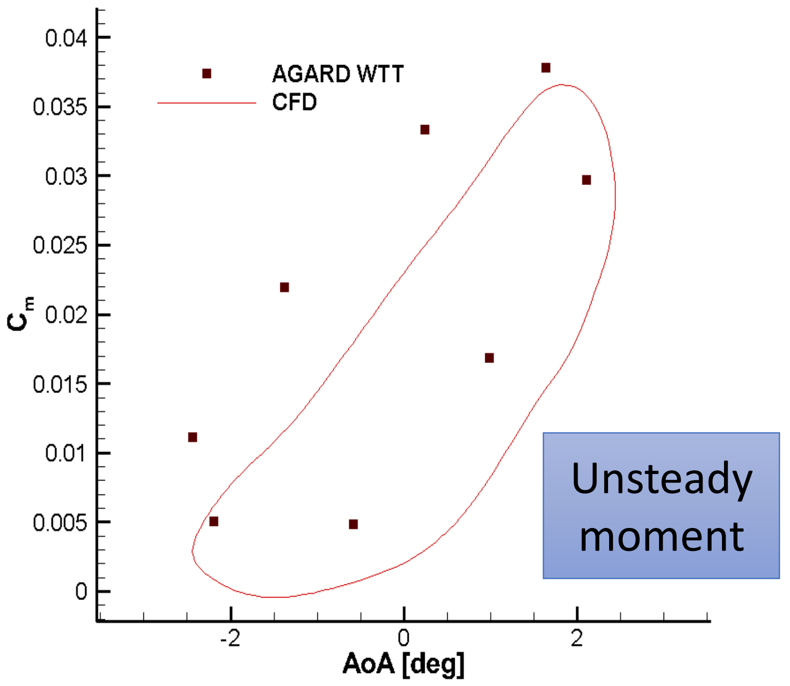
Pitching airfoil

*Ma = 0 .6, around $\alpha$ = 4.86°*

*Amplitude = 4.88 °*

*Strong non linearities well captured*



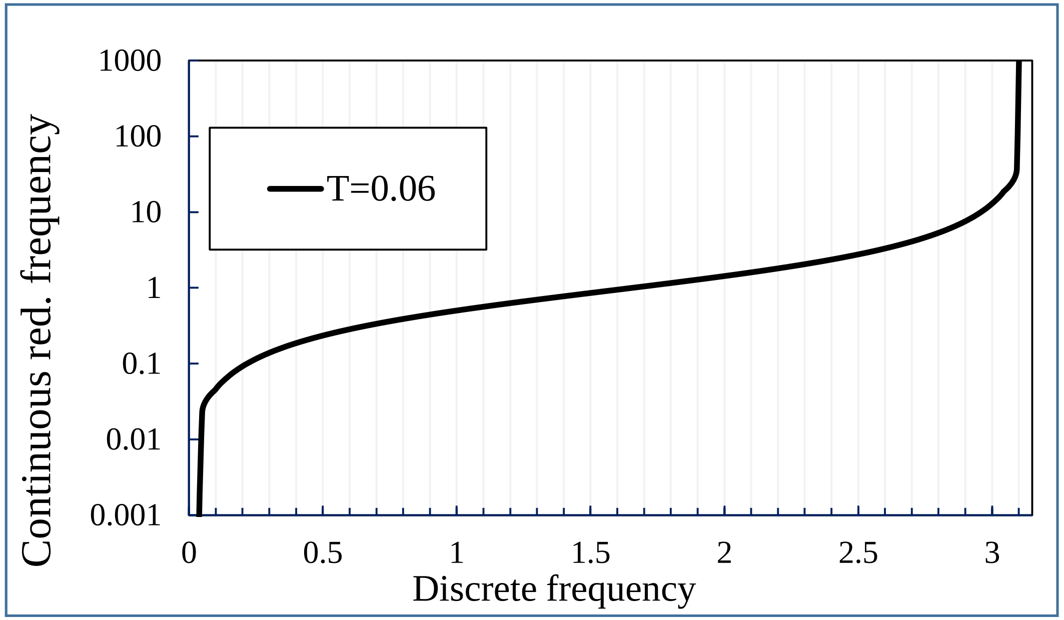



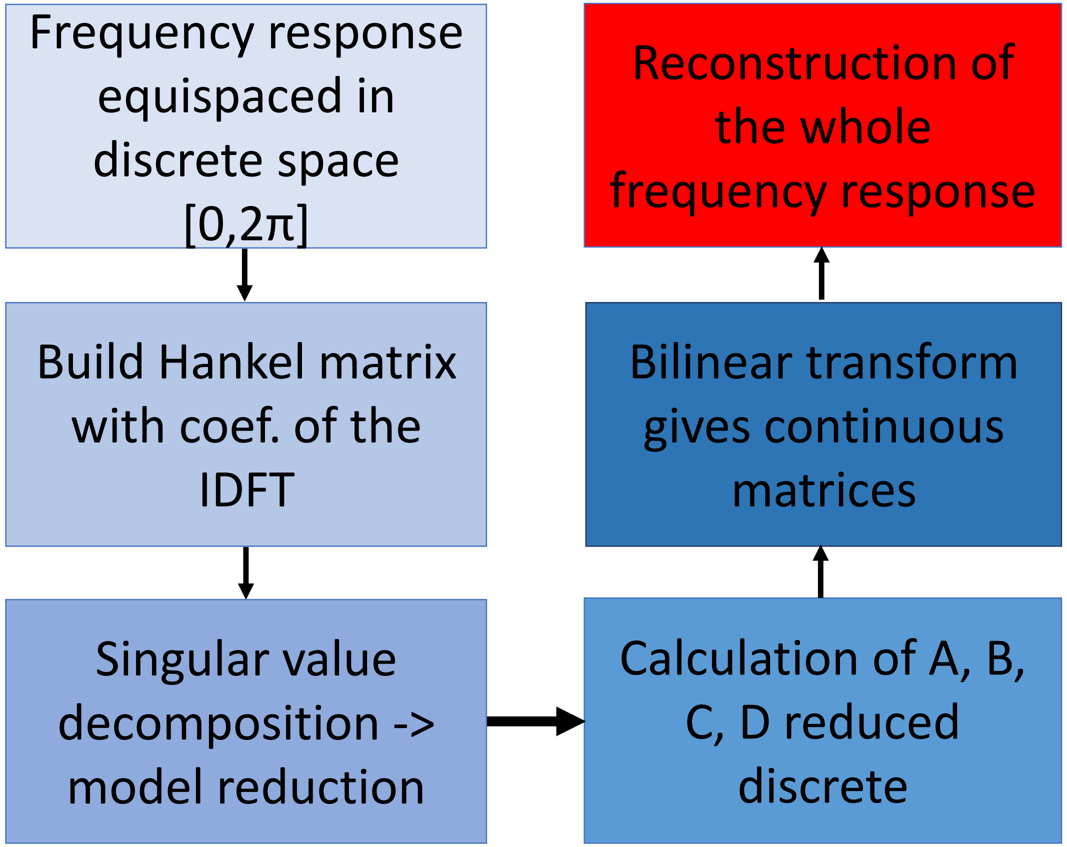
# Frequency domain model reduction

## Bilinear transform

- A link between continuous and discrete time

$$\omega_c = \frac{2}{T} \tan \frac{\omega_d}{2}$$




Applied to model the aero. coefficients of a pitching airfoil

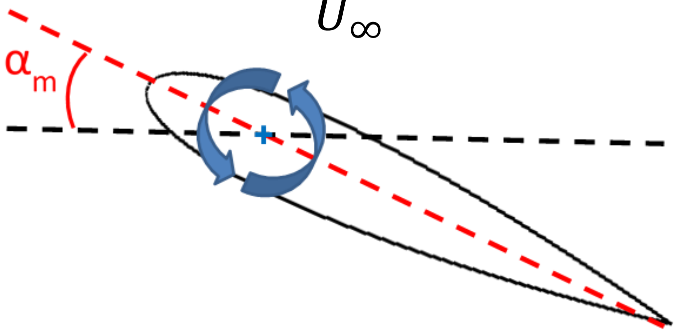
# ROM : validation and results (1/2)

## Case : pitching of an airfoil

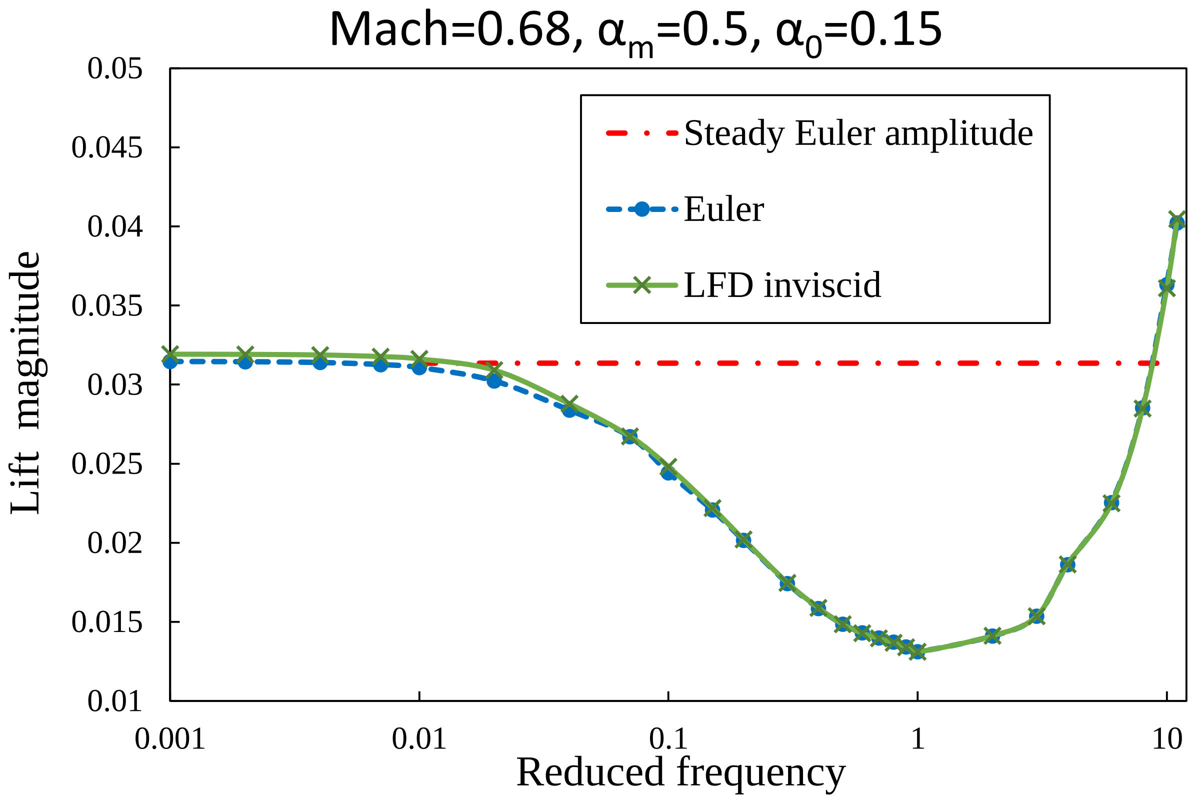
- Input : LFD
- Small amplitude of motion
- Harmonic motion about the pitch axis

$$\alpha = \alpha_m + \alpha_0 \sin\ (\omega t)$$

$$k = \frac{\omega \cdot c}{U_\infty}$$



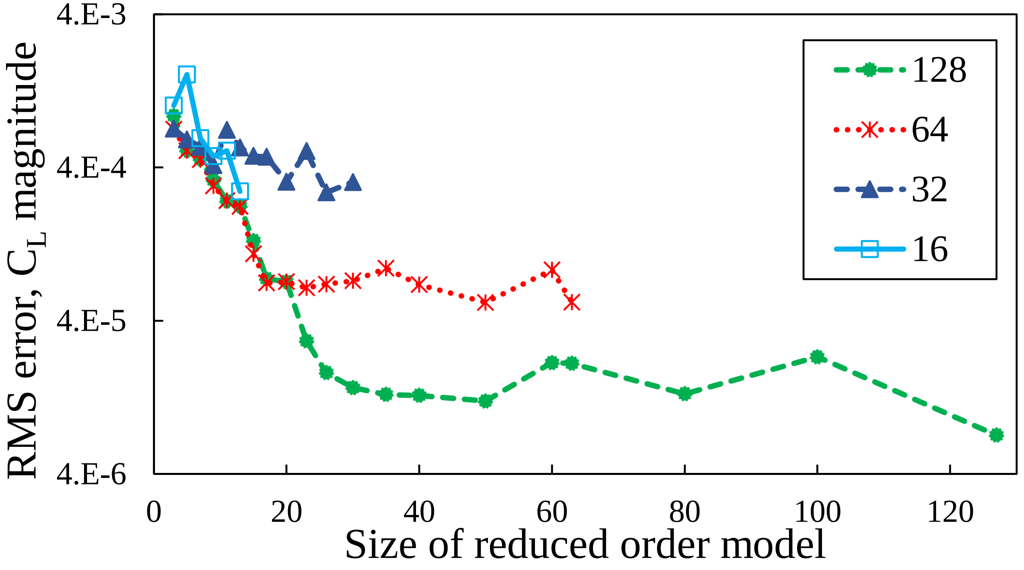

## The LFD solver is accurate



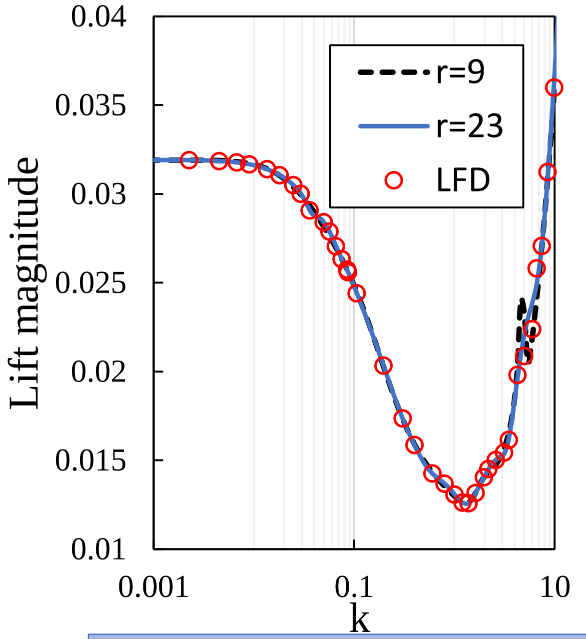
# ROM : validation and results (2/2)

## Cross validation

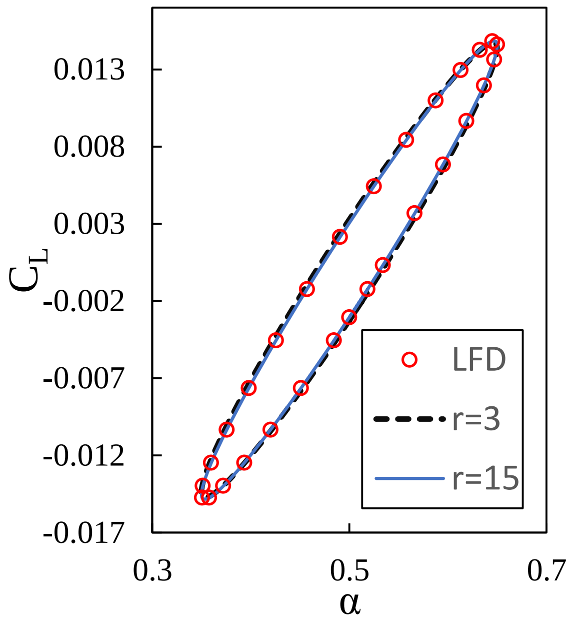
- 256 LFD calculations
- ROM built using 16, 32, 64, 128 samples
- RMS error for $C_L$ and $C_M$ magnitude & phase




## Strong ability to reconstruct the frequency response (32 samples)




Ma = 0.68, frequency response




Lift over a period, k=0.5

# Ongoing / Future work

- Working on the linear model to make it more robust :
  - Finding the best sampling for the bilinear transform
  - Enabling the model to have non equispaced input data

- Nonlinear model
  - Use the data on the shock position so that the model can handle nonlinearities
  - Investigate more on the separation

- Provide the ALPES model fast and accurate aerodynamic input

# Expectations on My Future Career

## Skills

- Gain experience in aerodynamics, CFD and reduced order modelling
- Develop transferable and management skills

## I would like to work …

- In - or in close relationship with - the industry, in a stimulating environment
- On joint research projects in aeronautics

# ALPES Mid-Term Review

Carmine Valente

ALPES ESR 3

# My background

- Bachelor Degree in Aerospace Engineering from the University of Rome “La Sapienza”
- Master Degree in Aeronautical Engineering from the University of Rome “La Sapienza”
- Stress and Structural Dynamics Engineer at SAFRAN Engineering Services, contractor for Airbus France (Toulouse)
- Structural Dynamics Engineer at LABINAL GMBH, contractor for Airbus Germany (Bremen)
- Marie Curie Early Stage Researcher Fellow in Aircraft Loads, Department of Aerospace Engineering, University of Bristol

# Training experiences in ALPES

- Scientific Courses:
  - Numerical simulation of multi-body systems
  - Introduction to Aircraft Aeroelasticity and Loads
  - Ground Vibration Testing (GVT) Master Class
  - Workshop on Nonlinear Aeroelasticity of very flexible Aircraft
  - Introduction Workshops to Python, C, C++, HPC, Parallel Programming
- Transferable skills training:
  - Managing your PhD
  - Presenting your research at meetings, seminars and conferences in internationally diverse contexts
  - STT PGRs Lab Demonstrating
  - Quality Papers: Getting your paper published in your target journal
- Conferences:
  - DIPART 2014
  - IFASD 2015 – Saint Petersburg, 28th June – 2nd July

# Main objectives of my research project

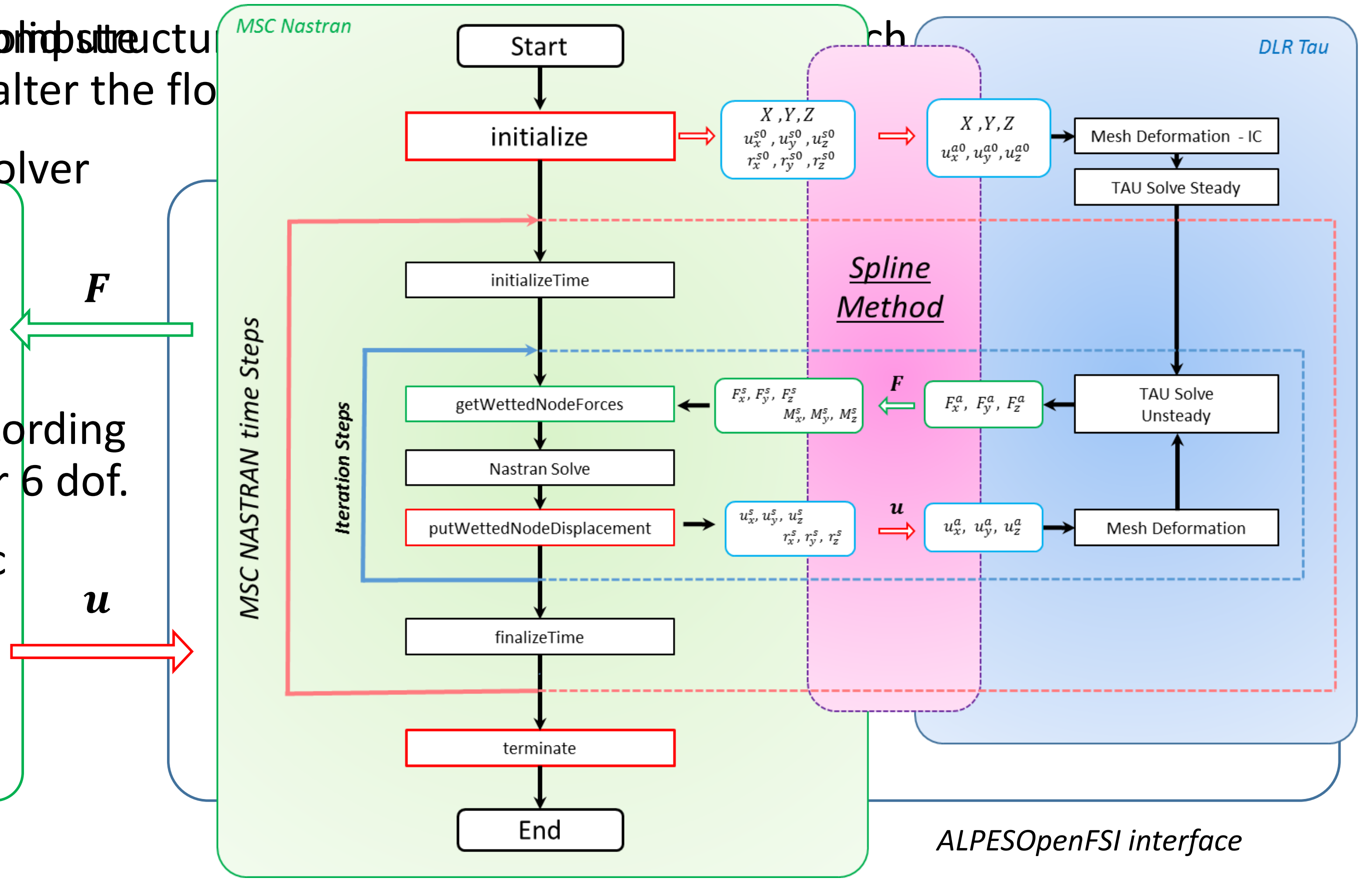
- To produce an efficient and accurate gust loads modelling scheme:
  - A novel methodology will be developed to correct the aero loads currently evaluated with linear unsteady aerodynamics in the industrial standard loads process.
  - The main objective is to use CFD data to update the results obtained with the Doublet Lattice panel Method (DLM), to achieve gust load predictions that are both fast and accurate.
  - The final goals will be to define a correction technique capable of minimising the number of unsteady CFD analysis necessary to update the DLM results.

- To evaluate the reference accurate gust loads:
  - A new computational environment able to perform strongly coupled FEM/CFD steady and unsteady analysis has been developed.

# Accurate Gust Loads Analysis

- **Fluid structure interaction:** a fluid interacting with a solid structure ... displacement of the structure, and as a consequence alter the flo...
- The **ALPESOpenFSI** interface allows to couple the FE solver MSC Nastran and the CFD code DLR Tau.
- The interface has been developed using the Software Development Kit (SDK) by MSC software.
- Different type of splining matrix have been tested, according to the need and characteristics of the models: 3 dof or 6 dof.
- Capability to perform **steady** and **unsteady** aeroelastic computations.

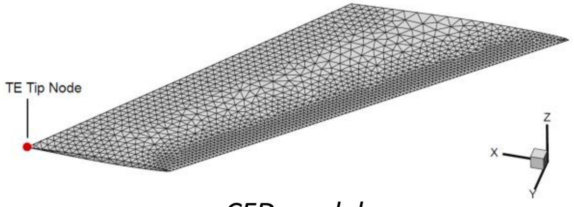
*Structure – FE model*



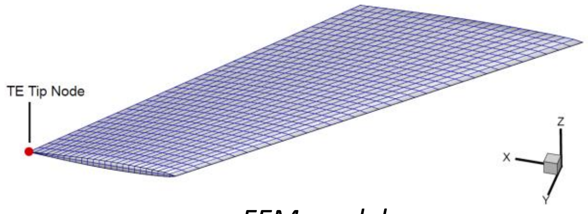

*ALPESOpenFSI interface*

# AGARD 445.6 Test Case

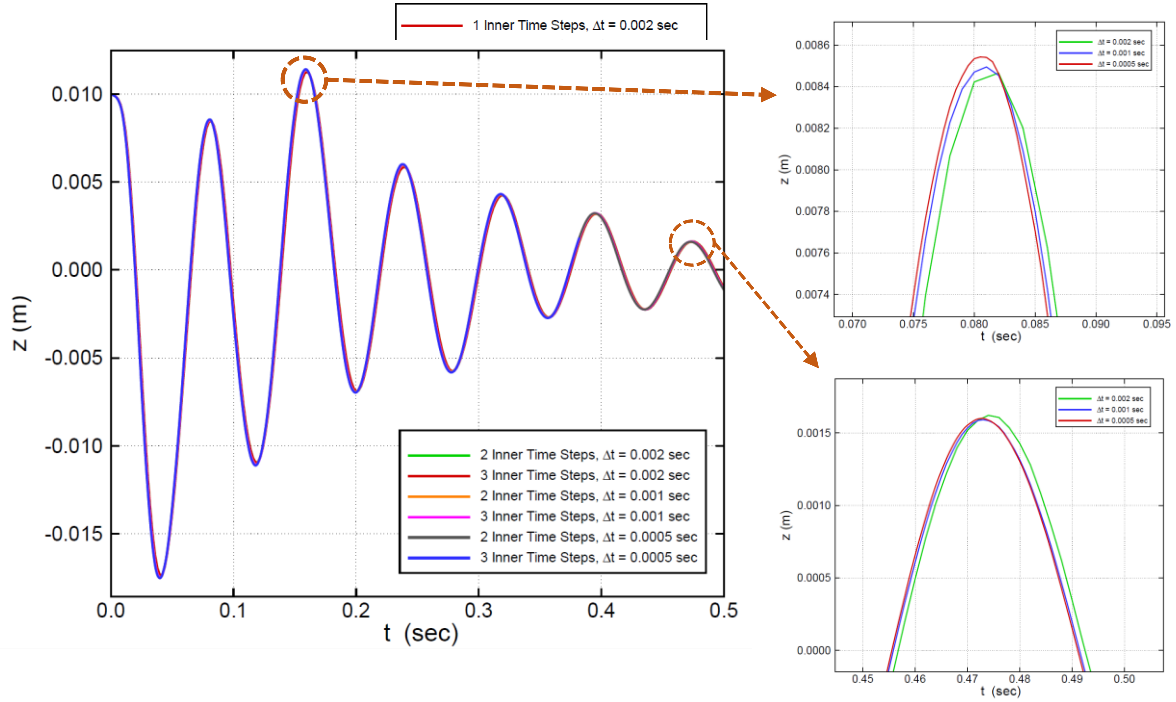
- The AGARD 445.6 wing model has been chosen as the first aeroelastic test for the ALPESOpenFSI interface.
- This model has been analysed in the subsonic regime:
  - Ma=0.901, Δt= 0.0005 sec
  - The dynamic response of the structure following an initial deflection, proportional to the 1st bending mode, with a maximum displacement at tip TE of 1 cm, has been studied.
- The benefit of a strongly coupled analysis have shown how there is a little time step influence on the dynamic response:
  - Bigger time step
  - Reduce the number of computations to complete the analysis
- For this specific case, two inner iterations where sufficient to achieve convergence between the FEM and CFD solver.




*CFD model*




*FEM model*

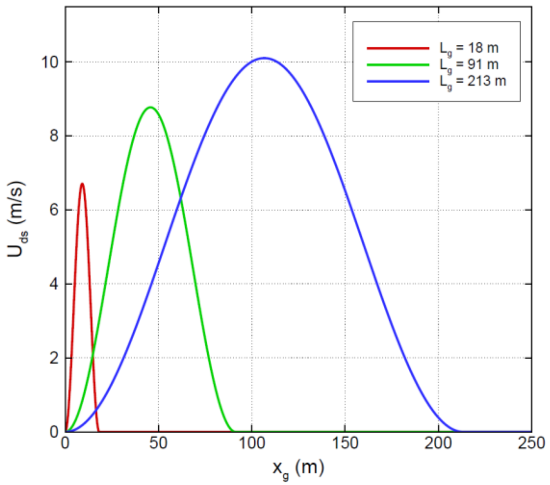


# FFAST Right Wing Aeroelastic Analysis - Trim

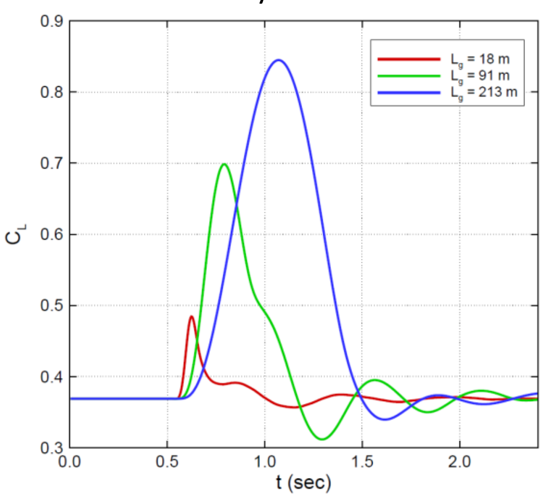
- To demonstrate the capability of the methodology to be applied in a gust load analysis, the ALPESOpenFSI interface has been first used to identify the trim aeroelastic steady deformation of a more representative geometry: the FFAST wing.
- From the trim configuration an unsteady load analysis has been computed to study the interaction of the wing with an "one minus cosine" gust shape.

Aerodynamic Effects

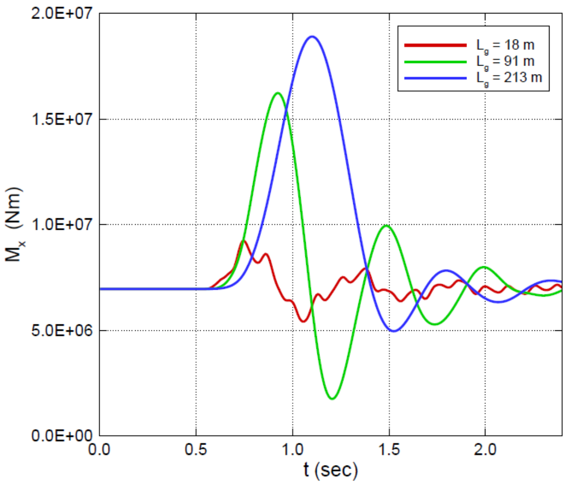
Structural Effects




Gust shapes analysed

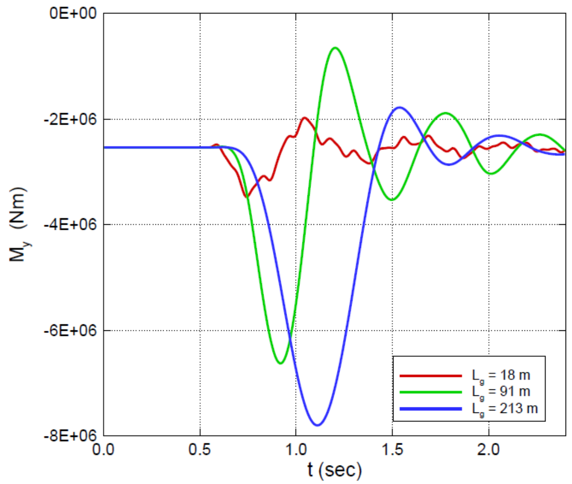



Wing total lift coefficient




Aeroelastic convergence of trim calculation

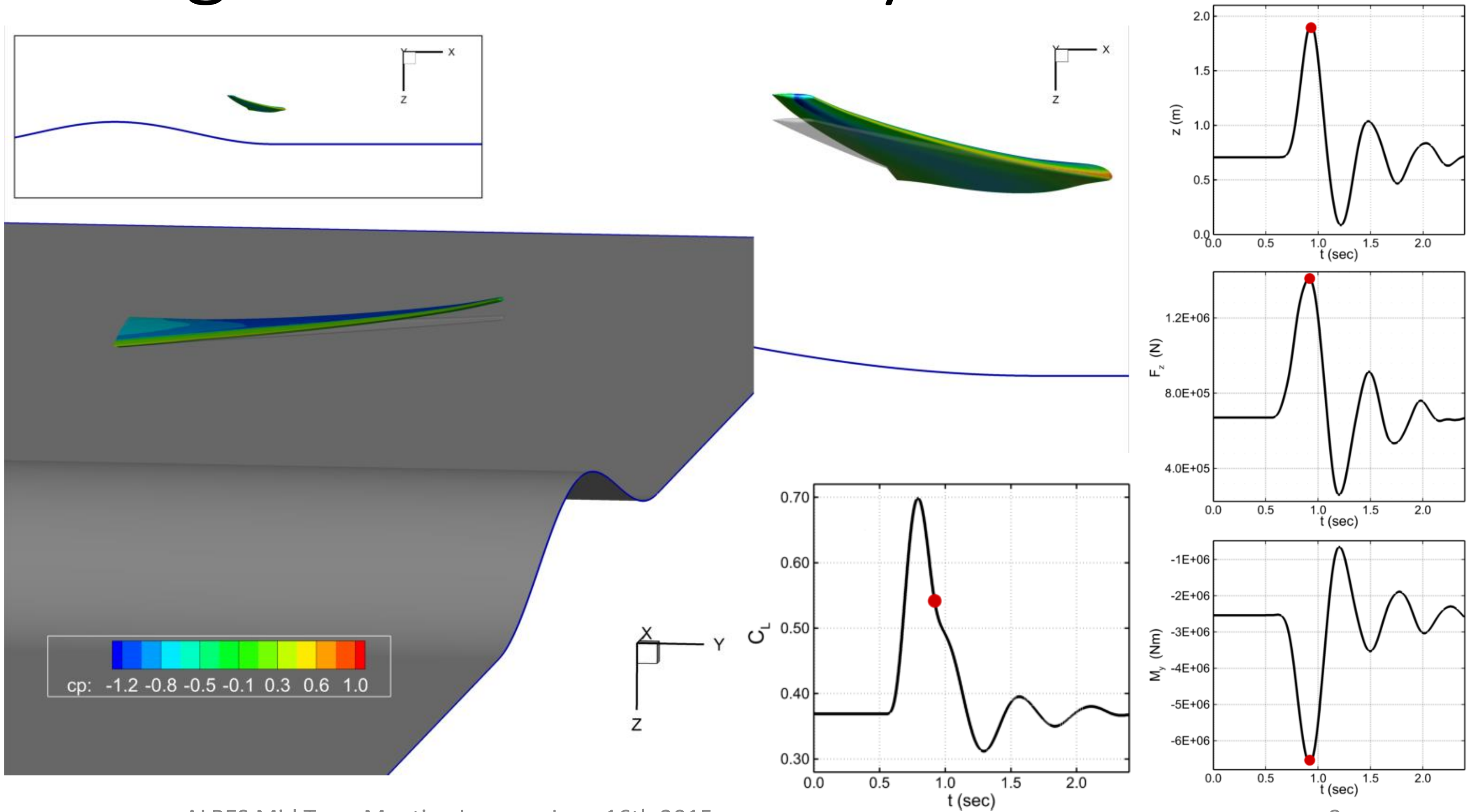
FEM – Mx moment at root




FEM – My moment at root

# FFAST Right Wing Aeroelastic Analysis - Gust

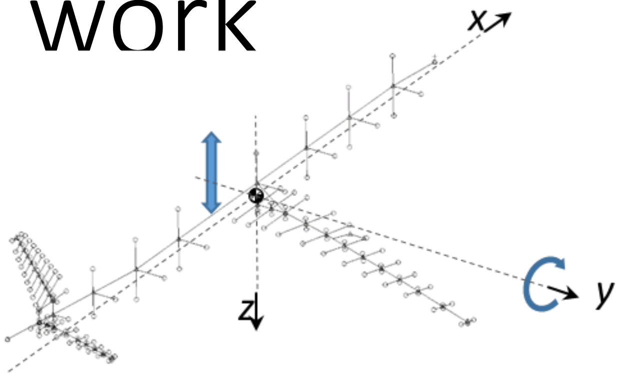
- Gust still far away (in front of the wing) having no influence with the model.
- The effect of a vertical gust is the same as to increase the AoA: the effect is an enlargement of the lift. The wing is bending upwards relative to the flight shape. The maximum effect is achieved when the centre of the gust is close to the aerodynamic centre of the wing.
- The maximum effect in terms of structural displacement is achieved with a delay compared with the maximum aerodynamic forces.



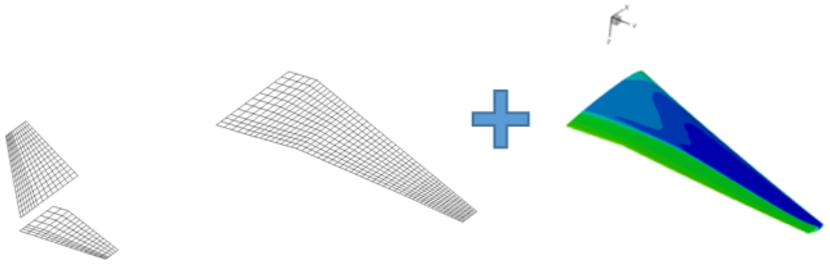
# Ongoing / Future work

NEXT STAGE

- Enable the ALPESOpenFSI interface to include the rigid body mode of **pitch** and **heave** in the aeroelastic computations.

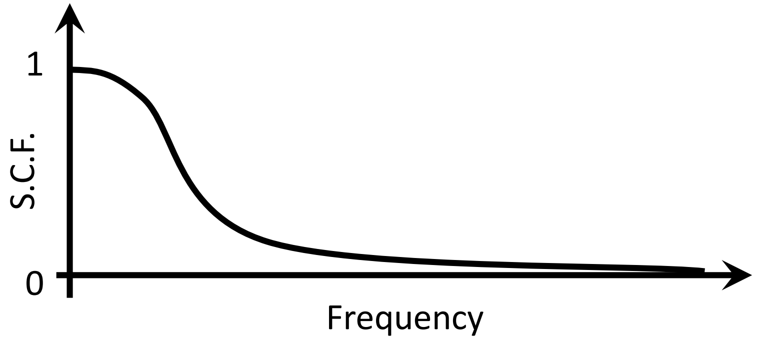



*FFAST FEM - half model*



*FFAST Doublet-Lattice panel model and CFD Model*

- Make use of the linearised frequency domain solver to correct the air loads computed with the doublet-lattice method:
  - In its simplest form the LFD could be used to scale static corrections
  - Investigate generating of scaling with Mach, AoA, mass case.
  - Investigate other methods of including LFD.
  - Moving from doublett-lattice to vortex lattice method.




*Static Correction Factor vs Frequency*

FINAL STAGE

- How do we choose conditions to give the correction for the most accurate worst case gust loads.

# Expectations on My Future Career

- I hope that the experience collected during this project, as Marie Curie Research Fellow, could give me the opportunity to have a future career in the European aeronautic industries and research institutes.

- I would like to continue to work as an engineer, solving technical problems and giving a contribution to the development of the next generation of aircrafts.

# ALPES Mid-Term Review

Michele Castellani

ALPES ESR 4

# My background

- Jul-2011: M.Sc. in Aeronautical Engineering at Politecnico di Milano
- Sep-2011/Apr-2014: Loads Engineer at Pilatus Aircraft Ltd. (CH) in the development and certification programme of business jet PC-24
- May-2014/Apr 2017: ESR in EID ALPES
    I. SISW from May 2014 to October 2015
    II. University of Bristol from November 2015 to April 2017

# Training experiences in ALPES

| Main Training Events | Project Year | Date | Lead Institution |
|---|---|---|---|
| **Technical Skills** | | | |
| LMS Virtual.Lab Motion Basic Training | 1 | 7-9 May-14 | SISW |
| Introduction to Aircraft Aeroelasticity and Loads | 1 | 14-18 Jul-14 | UoB |
| Detection, Modeling and Identification of Nonlinearities in Engineering Structures | 1 | 18-19 Sep-14 | SISW |
| GVT Master Class | 1 | 22-25 Sep-14 | SISW |
| Nonlinear Aeroelasticity of Very Flexible Aircraft | 1 | 13-14 Nov-14 | UoB |
| **Transferable Skills** | | | |
| Presentation Skills | 1 | 8-9 Sep-14 | SISW |
| **Industrial Placement** | | | |
| Secondment at Airbus UK - Loads & Aeroelastics (two weeks) | 1 | Aug-14 | Airbus |

| Conferences and Workshops | Project Year | Date | Lead Institution | Presenter |
|---|---|---|---|---|
| ALPES Kick-Off Meeting | 1 | Jun-14 | UoB/SISW | ✓ |
| ISMA-ISAAC International Conference on Noise and Vibration Engineering | 1 | Sep-14 | SISW | |
| 4th EASN International Workshop on Flight Physics and Aircraft Design | 1 | Oct-14 | SISW | |
| Dipart 2014 | 1 | Nov-14 | UoB | ✓ |
| Siemens Aerospace User Conference 2015 | 1 | Mar-15 | SISW | |

# Main objectives of my research project

- Development and testing of methodologies to speed-up aircraft loads prediction
- Development and testing of methodologies to model structural nonlinearities in aeroelastic analyses
- Evaluation of the impact of structural nonlinearities on flight dynamics, loads and aeroelastic stability of novel aircraft concepts

# Methodologies and Results (1)

*Aircraft Loads Prediction Loop*

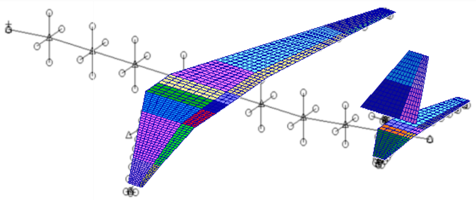
**Aircraft aeroelastic model**

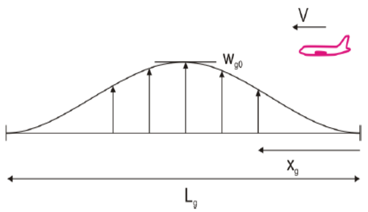
+

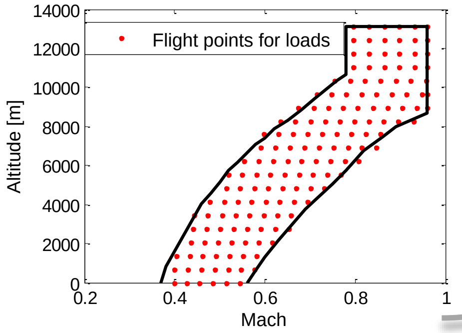
**Gust, manoeuvre and landing load cases**

+

**Flight envelope sweep**






*~100’000 load cases*

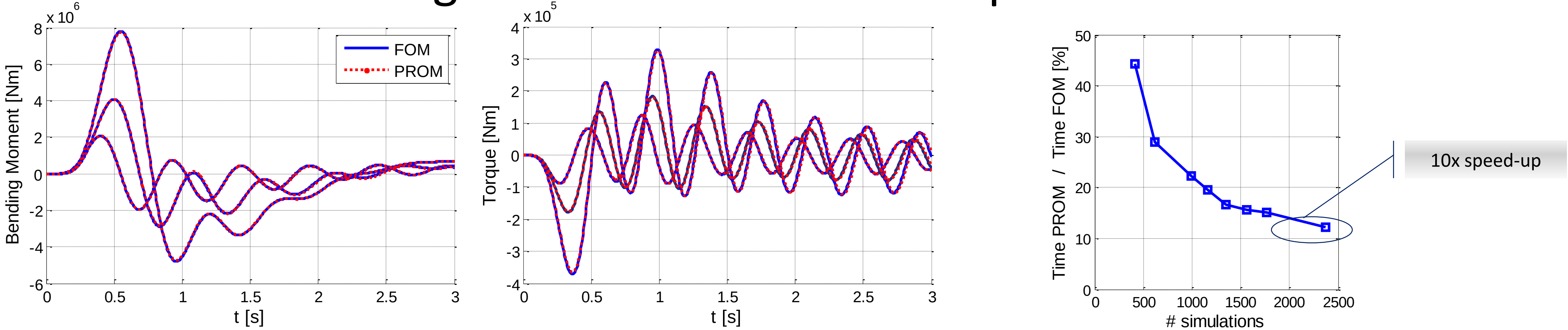
*High turnaround time*

**Parametric Model Order Reduction**

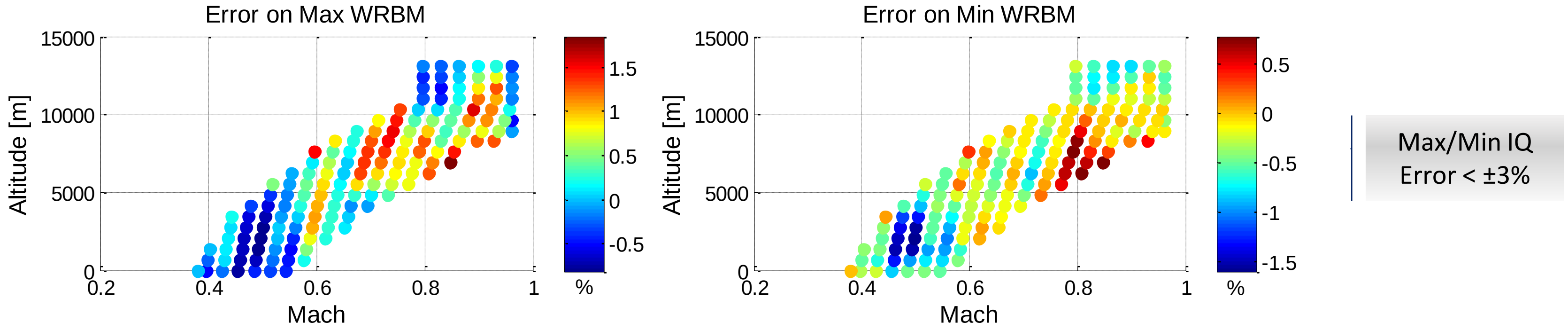
- Reduce size of the model
- Retain accuracy
- Fast generation for all flight conditions
- Speed-up loads computation

# Methodologies and Results (2)

- Faster simulation of gust and manoeuvre compared to full order model

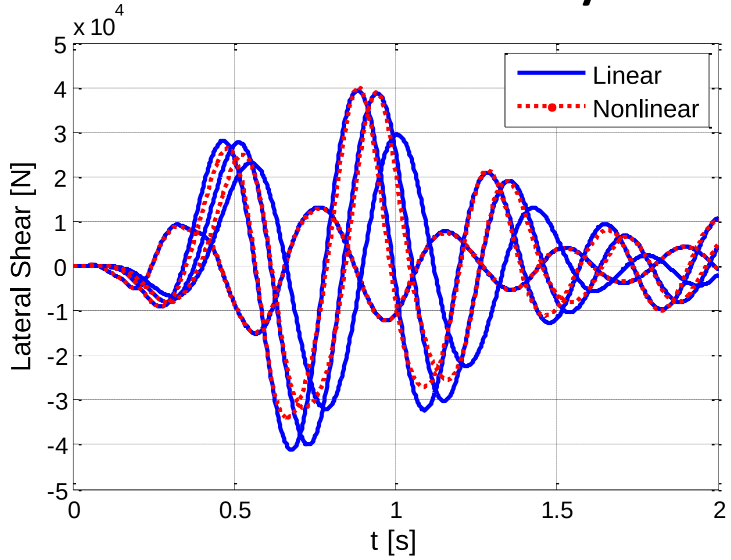


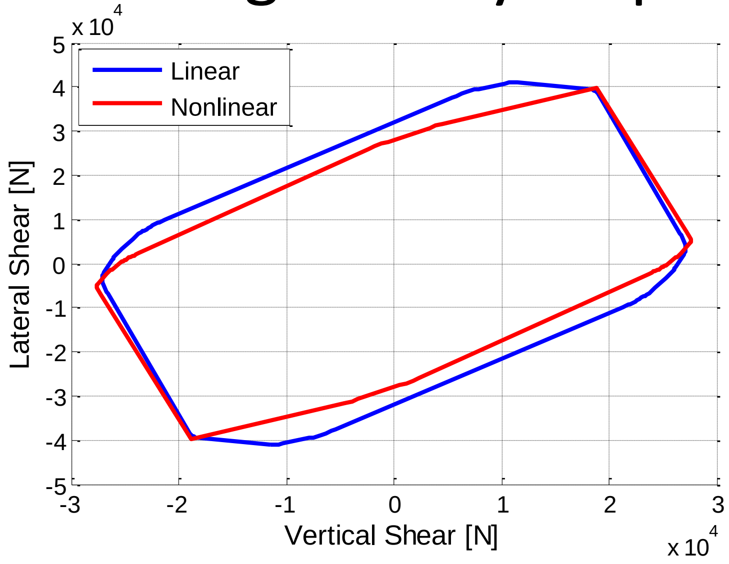

- Accurate prediction of loads in the flight envelope



# Methodologies and Results (3)

- Method extended to model nonlinear stiffness in engine-pylon connection
- Formulation based on standard industrial linear models and tools
- Piecewise linear simulation
- Effect of nonlinearity on loads cannot generally be predicted a-priori



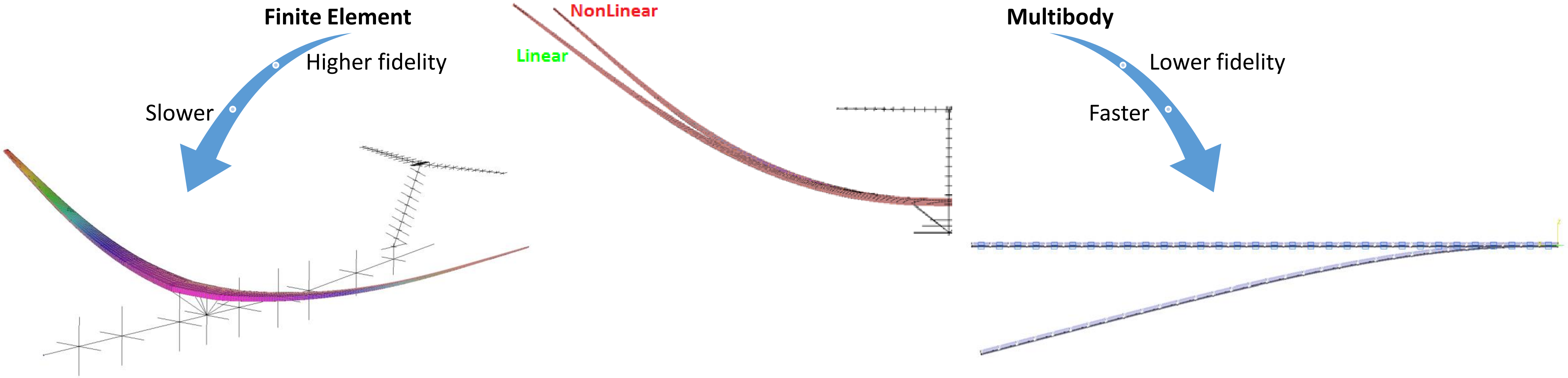



# Publications

| Authors | Title | Journal/Conference | Date | Status |
|---|---|---|---|---|
| | **Journal Papers** | | | |
| **Castellani M.**, Lemmens Y. and Cooper J.E. | Parametric Reduced Order Model Approach for Rapid Dynamic Loads Prediction | Aerospace Science & Technology | Mar-15 | Submitted, under review |
| **Castellani M.**, Lemmens Y. and Cooper J.E. | Parametric Reduced Order Model Approach for Simulation and Optimization of Aeroelastic Systems with Structural Nonlinearities | Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering | May-15 | Submitted, under review |
| | **Conference Papers** | | | |
| **Castellani M.**, Lemmens Y. and Cooper J.E. | Parametric Reduced Order Model for Rapid Prediction of Dynamic Loads and Aeroelastic Response with Structural Nonlinearities | International Forum on Aeroelasticity and Structural Dynamics 2015 (St. Petersburg, Russia) | Jun-15 | Accepted for presentation |
| **Castellani M.**, Lemmens Y. and Cooper J.E. | Reduced Order Model Approach for Efficient Aircraft Loads Prediction | SAE Aerotech 2015 (Seattle, USA) | Sep-15 | Accepted for presentation |
| **Castellani M.**, Lemmens Y. and Cooper J.E. | Multi-Fidelity Nonlinear Structural Dynamics and Static Aeroelasticity of Very Flexible Aircraft | AIAA Scitech 2016 (San Diego, USA) | Jan-16 | Abstract submitted, under review |

# Ongoing / Future work

- Nonlinear aeroelastic response of high aspect ratio wing aircraft
- Large deflections under loads introduce structural nonlinear effects
- Multi-fidelity approach for structural modelling



# Expectations on My Future Career

- Develop state-of-the-art industrially focused competencies in aeroelasticity and aircraft loads
- Complement technical education with soft skills training
- Move into the European aerospace industry
- Become a technical specialist in loads & aeroelastics

# ALPES Mid-Term Review

Irene Tartaruga

ALPES ESR #5

# My background

**Qualifications**

- *Graduated* cum laude in *Aerospace Engineering* (July 2011) and in *Aeronautical Engineering* (January 2014) at *Sapienza - Università di Roma* (Italy).
- My student career at '*La Sapienza*' has been recognised as "excellent"

**Interest**

- Strong passion for the *aeronautical/aerospace science*, in particular for *vehicle/aircraft structure, dynamics and control fields* and this is reflected by my student carrier as undergraduate and my current position.
- I am fascinated by *mathematics science* since I was a child and I always tried to approach physical problem by an engineering point of view exploiting mathematical means.
- The problem of *uncertainty* has captured my attention since the last period of my degree in *Aeronautical Engineering*, which I concluded with a thesis focused on the development of *robust trajectory control for a quadrotor*.

# Training experiences in ALPES

- **Scientific Courses**
  - *Introduction to Aircraft Aeroelasticity and Loads* and *Workshop on Nonlinear Aeroelasticity of Very Flexible Aircraft*
  - Accepted for the *Cabot Institute Summer school on risk and uncertainty in natural hazards 2015*
- **Industrial experience**

Thanks to this project I am having the possibility in being aware of what is of industrial interest and of the industrial process in loads analysis.

  - *Placement in Airbus* of two weeks. Frequent contact with *Simon Coggon*, ground loads modelling expert in Airbus
  - Application of my methodologies in Airbus next month
  - Half of the period of the project in Siemens, Leuven, Belgium
- **Presentation of my work**

Have presented my methodologies and results at international conferences and submitted journal papers.

  - *Conferences and Meetings*: 4th Aircraft Structural Design Conference in Belfast, SCITECH in Orlando, DIPART in Bristol, UNCECOMP 2015 in Crete, Dynamic and Control Group Seminar in Bristol
  - *Journals*: submitted two papers, to CEAS Aeronautical Journal and SIAM/ASA J. UNCERTAINTY QUANTIFICATION

# Main objectives of my research project

- Efficient surrogate modelling and uncertainty quantification of **correlated quantities**.
  - **Novel SVD/HOSVD based methodology**: an alternative to Monte Carlo Simulations
  - Application: ***correlated aircraft loads*** and ***locus of Hopf bifurcation points*** for a landing gear

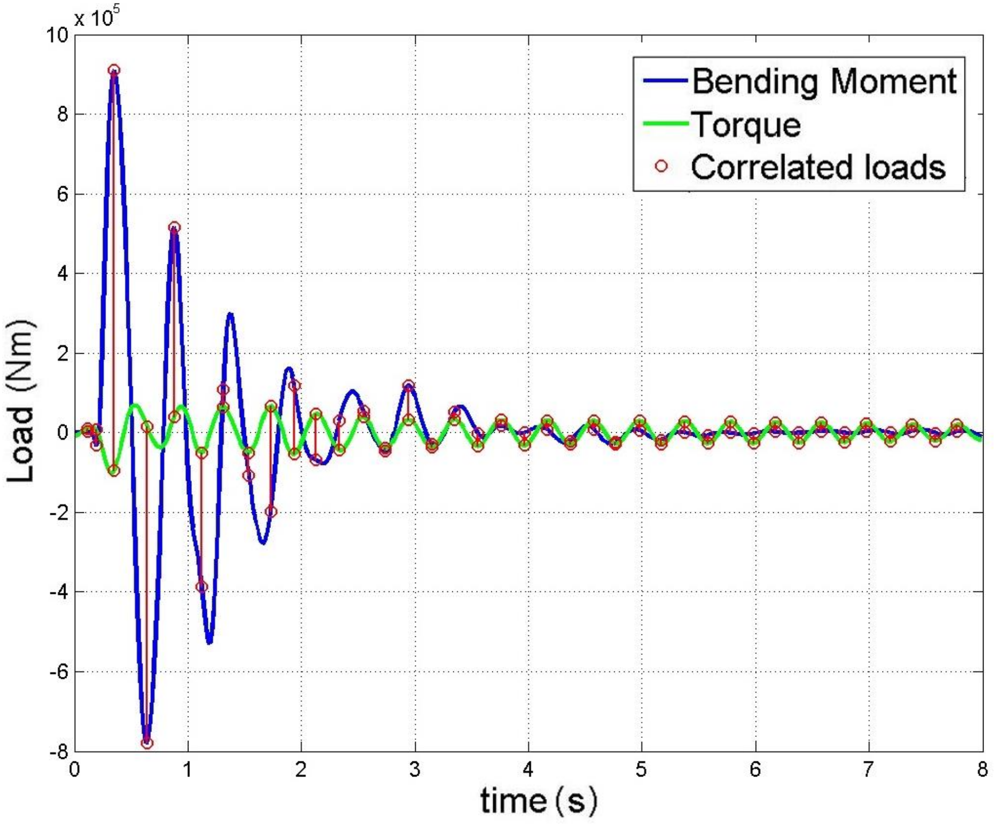
- Improvement of **design process** for a landing gear system, including **robust optimization** steps that takes into account *shimmy* occurrence and the *uncertainty* in the system.

Since the interdisciplinary of this topic, the integration and development of different methodologies is required, namely:

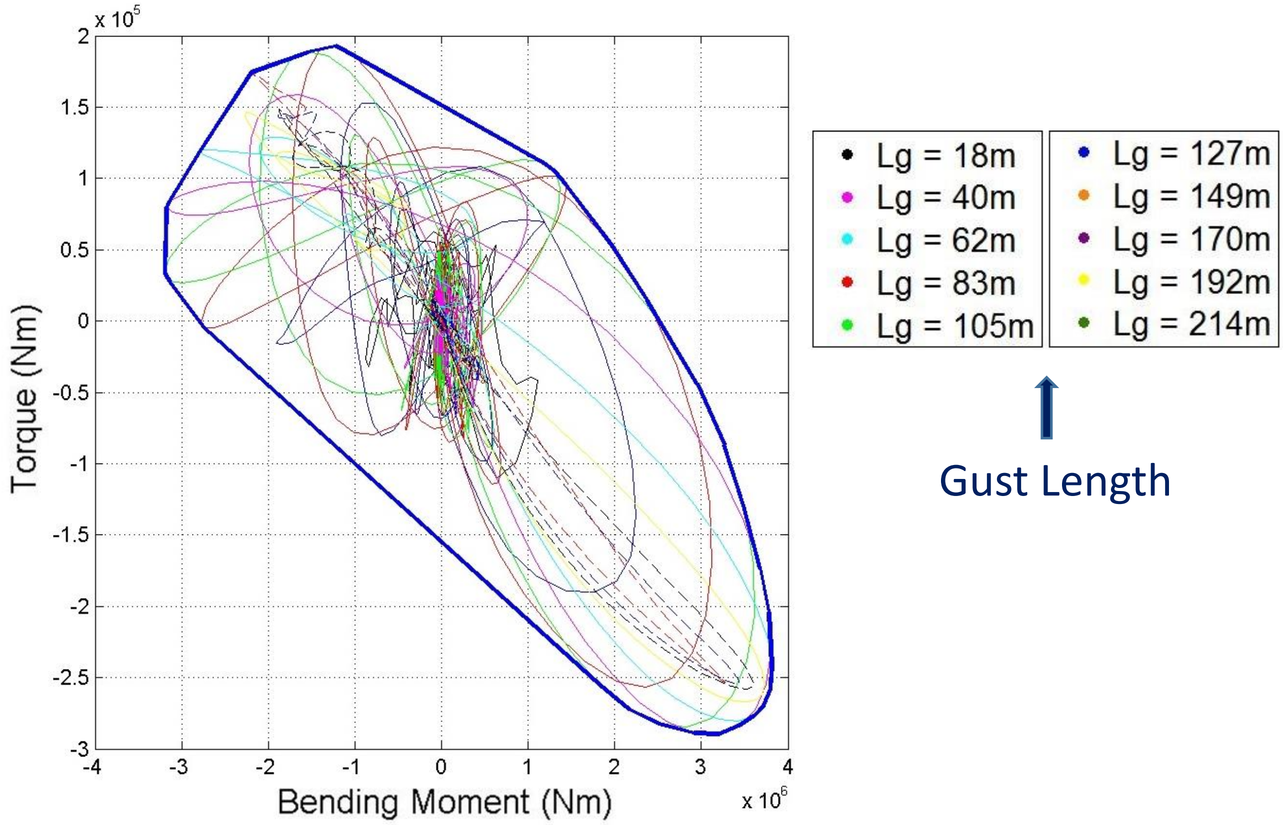
- to *perform uncertainty and sensitivity analysis in complex scenario*
- to *couple the adopted multi-body software* (LMS Virtual.Lab Motion) with the selected continuation software
- to suitably describe the *tyre/ground interaction*, including effects due to both lateral and longitudinal slips
- to develop a *multidisciplinary optimization method* to cope with requirements possibly of different discipline
- to identify the parameters and values that change the *shimmy* phenomenon (modal participation, stability of limit cycle)

# Methodologies and Results: ***Correlated Quantities*** (1)

## Correlated Aircraft Loads




Convex Hull in 2D

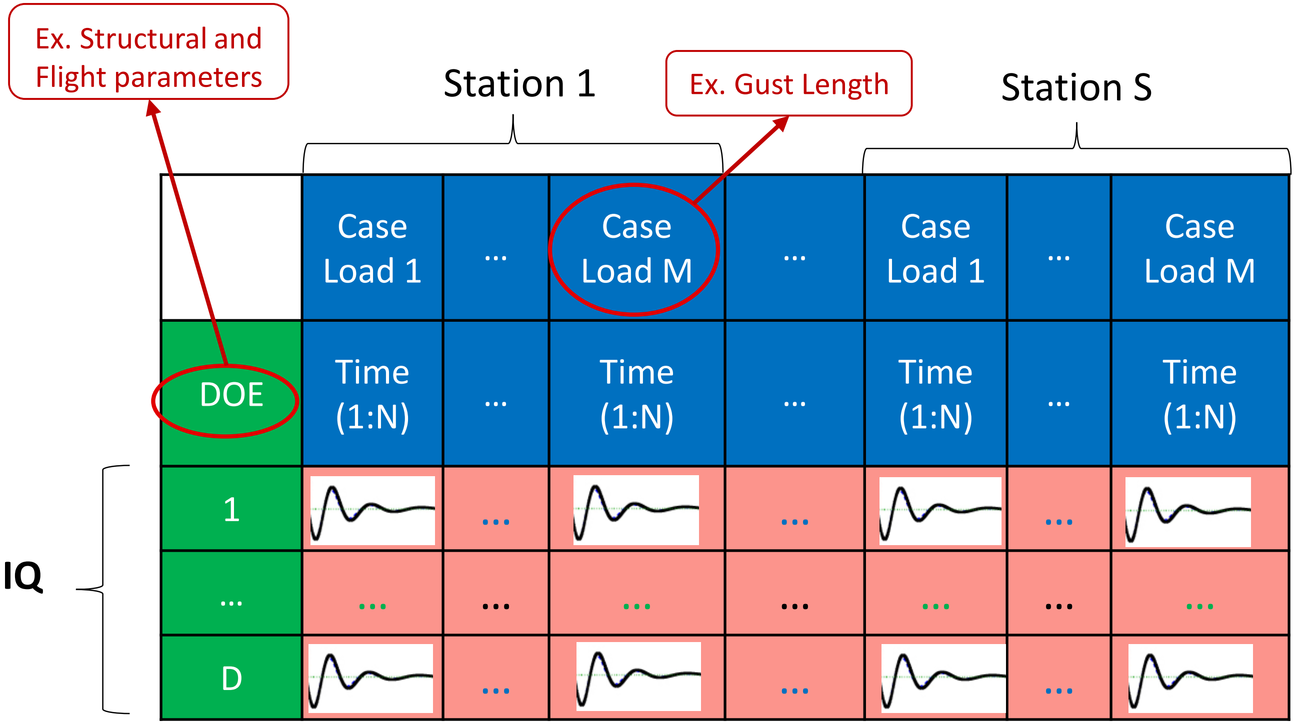



Gust Length

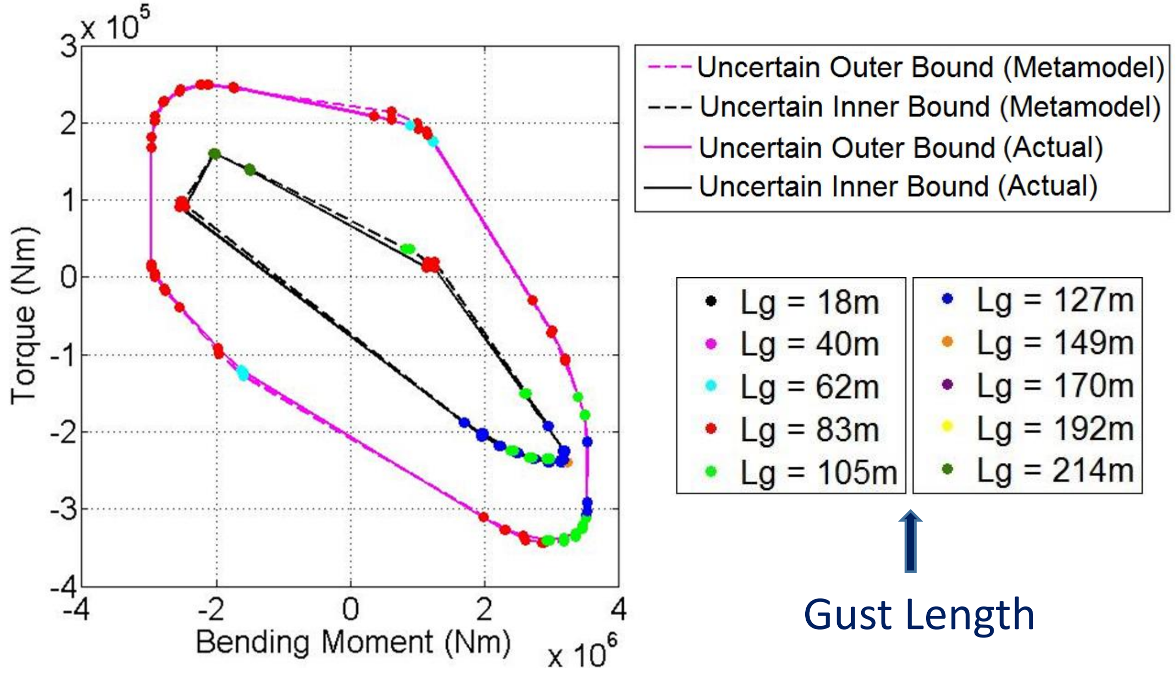
# Methodologies and Results: *Correlated Quantities* (2)

## Correlated Aircraft Loads

– Singular Value Decomposition (SVD) + Blind Kriging Metamodel ➡ same accuracy and less computation than MCS (time reduction of 95%)



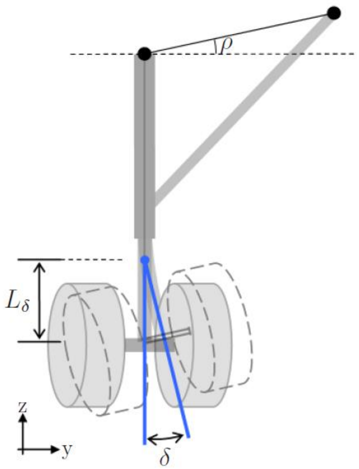

Confidence Bounds for Convex Hull in 2D

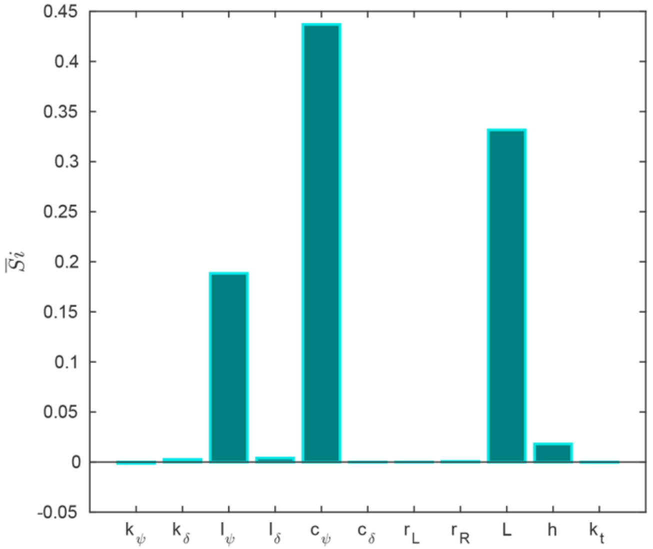


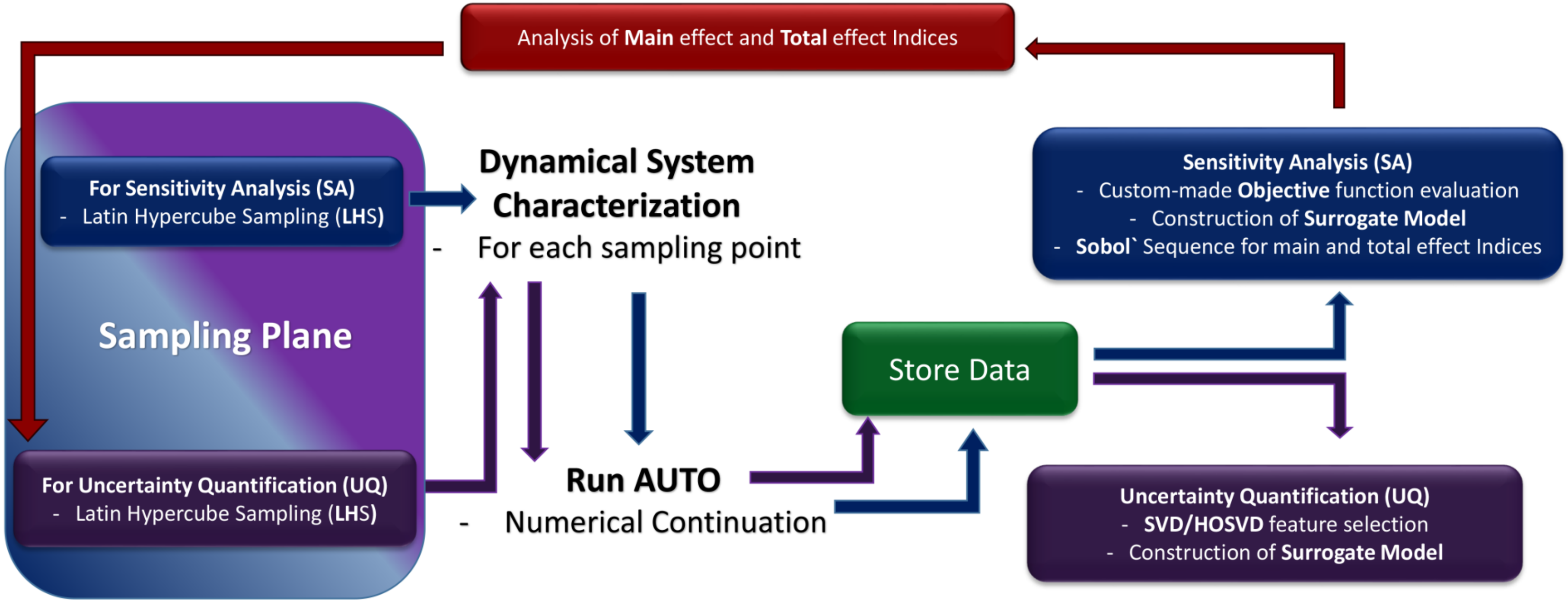
# Methodologies and Results: *Correlated Quantities* (3)

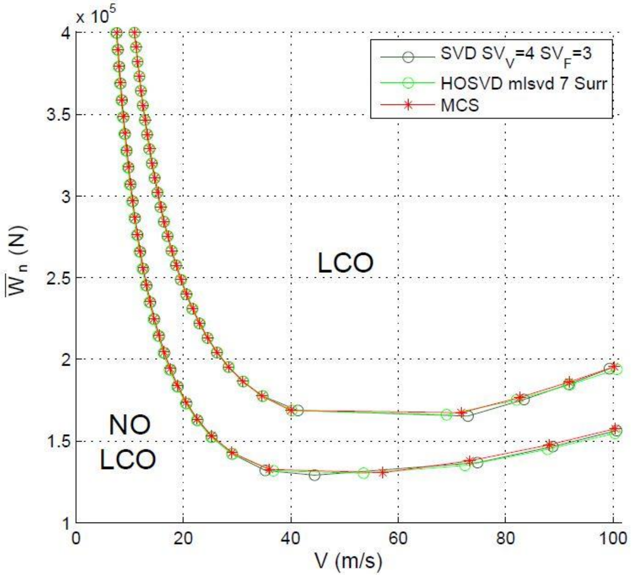
## Locus of Hopf Bifurcation Points

- Global analysis: main and total effect indices
- SVD/HOSVD + Blind Kriging Metamodel



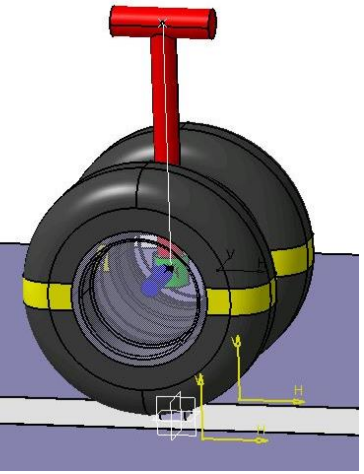



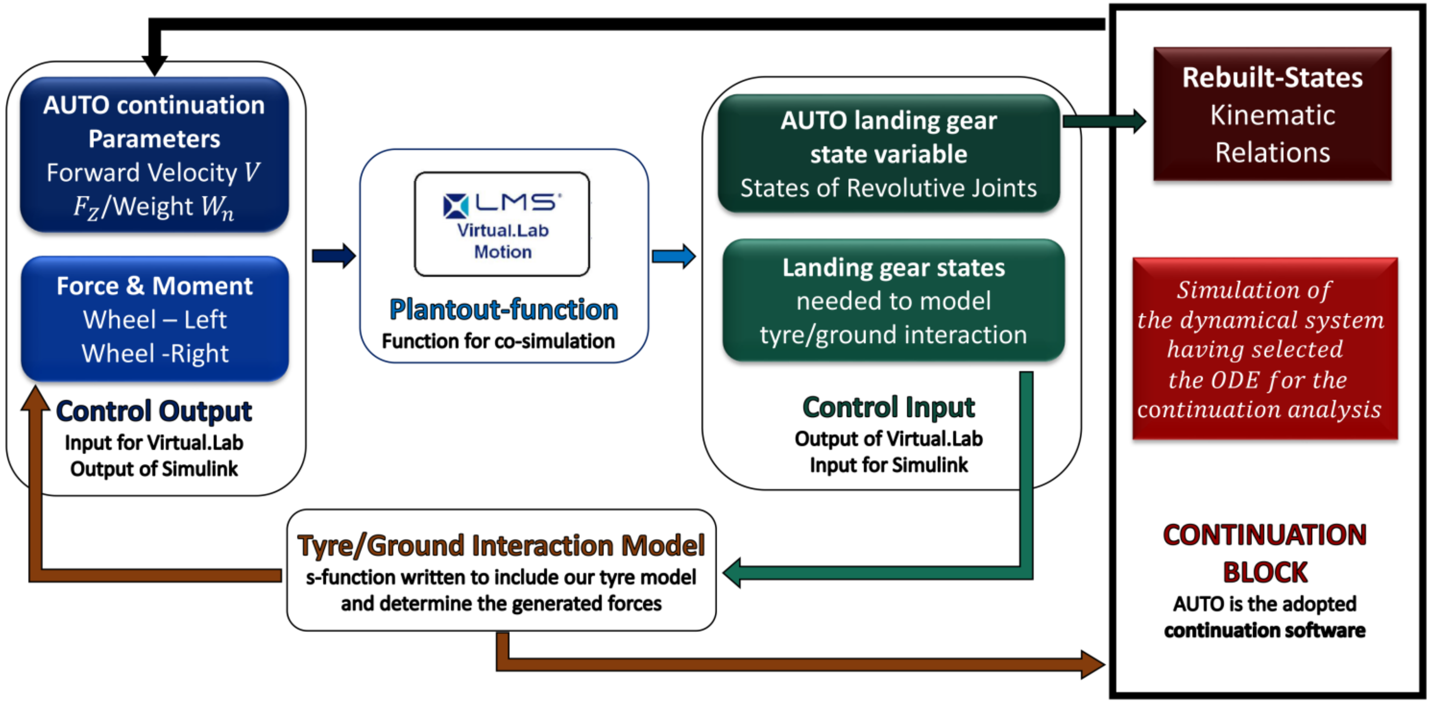



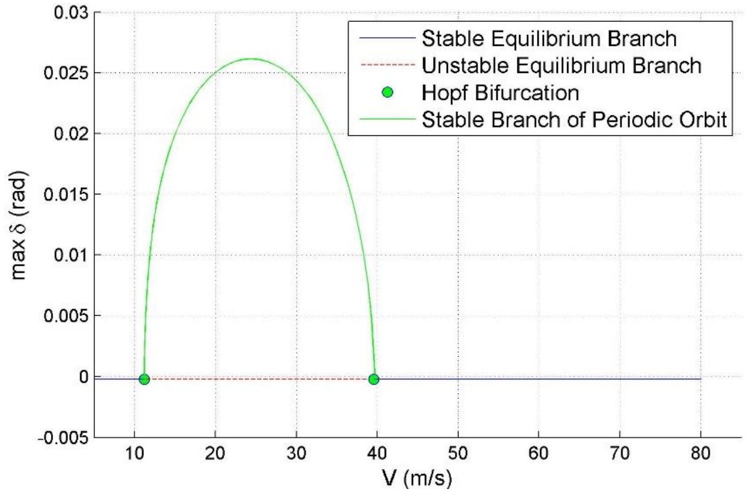
# Methodologies and Results: *AUTO with VLM*

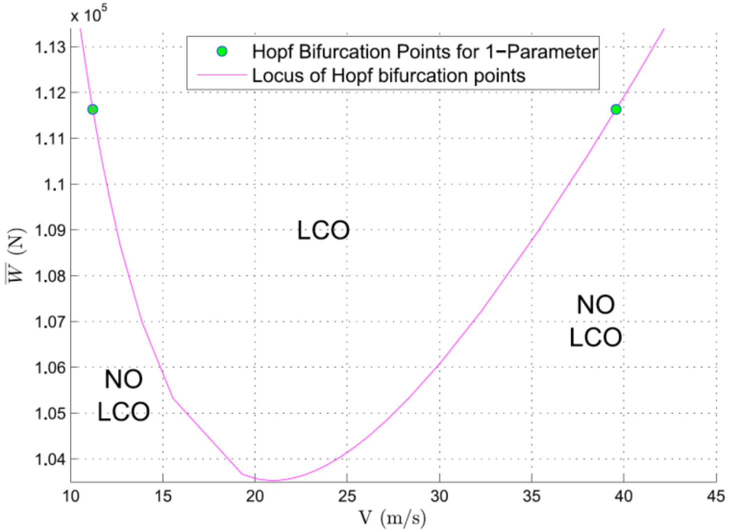
**Strategy to couple a continuation software (AUTO) with a multi-body software (LMS Virtual.Lab Motion).**

- Matlab/Simulink environment
- Tyre/Ground modeling





# Ongoing / Future work

1. **Landing Gear**

*Robust design approach looking at instability/loads*

- Improving of the code written to couple VLM Virtual.Lab to AUTO using more complete Tyre Model.
- Developing a complete Tyre Model for the multi-body landing gear model (VLM Virtual.Lab) and look at instability as well as loads issues (touch-down, spin up, braking … ) considering longitudinal and lateral slip
- Performing comprehensive bifurcation analyses of a multi-body landing gear, taking into account lateral and longitudinal slip.

Sensitivity analysis and uncertainty quantification need to be taken in to account

2. **Correlated Aircraft Loads**

- Period in Airbus to apply the already developed methodology to identify the worst case scenario in terms of correlated loads
- Improvement and extension of the methodology

# Expectations on My Future Career

Since I started the project, I have spent my time at the *University* and sometimes in Airbus. In the second half period I will be based in Leuven at Siemens.

For what I have experienced so far, I really like the *research* if it is directed towards topics of interest for the society.

After the three years project I would like to continue working on topics related to ***bifurcation analysis*** since it is a science in which my love for the interdisciplinary context can be corresponded, and possibly ***landing gear related***.

I would like to go on in facing problems that requires an integration of knowledge of my interest, namely *vehicle/aircraft structure, dynamics and control fields, mathematics, uncertainty and sensitivity analysis*, as I am doing for the present project.