



Green Regional Aircraft ITD
“Low-Noise Configuration” Domain

Call 11 - GRA-02-019

**Advanced, high aspect ratio Transonic
Laminar Wing for Regional Aircraft with
Load Control & Alleviation devices**

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GRA-02-019

Advanced, high aspect ratio Transonic Laminar Wing for Regional Aircraft with Load Control & Alleviation devices

Technological Optimization and Validation through an Innovative WT Model matching the full-size wing flexibility

1.1.1 Background

Taking into account **several A/C configurations** and different power plant architectures to contribute to drastically reduce the environmental impact of regional air transport.

On this scenario, **rear-fuselage engine A/C configuration:**

- i) Natural Laminar Flow wing to reduce fuel consumption and pollution at cruising flight condition;
- ii) Load control to enhance **wing aerodynamic efficiency** in **all flight phases**, so as to **reduce fuel consumption and gaseous emissions** over the A/C whole mission profile, also allowing for steeper, **noise-abatement take-off/ initial climbing trajectories;**
- iii) **Load alleviation** to avoid any possible loads exceeding over structural design point so as to optimise the wing structural design for weight savings.

Short description

⇒ On the basis of a Natural Laminar Flow (NLF) wing aerodynamic design, aero-elastic model and Load Control & Alleviation (LC&A) concepts provided

⇐ **Optimization and development of wing control devices aimed at** achieving optimal **loads distributions**, in order to enhance aerodynamic efficiency in climb and other off-design conditions and also **alleviate wing bending moment**.

Design and manufacturing of a flexible WT wing model representative of the full-size awing aerodynamic performance and structural response in cruise and off-design conditions, as predicted by computational analyses.

WT tests at transonic speed and high Reynolds number, in order to validate in a representative environment at cruise, climb and over-speed off-design conditions:
a) **NLF wing design** (namely laminar flow extent) considering the nominal aerodynamic shape and also

simulating the presence of surface irregularities (steps/gaps and distributed roughness);

b) **wing control devices** effectiveness in getting reduced aerodynamic static loads and/or drag in both cruise and off-design conditions.

1.3 Type of work

Wing aerodynamic (CFD) analysis, structural (FEM) modelling, structural/aero-mechanics analysis (aerodynamic and loads), static aero-elasticity analyses, mechanical design, wind tunnel testing and experimental data acquisition.

GRA ITD – Collaborative Project

TOPIC

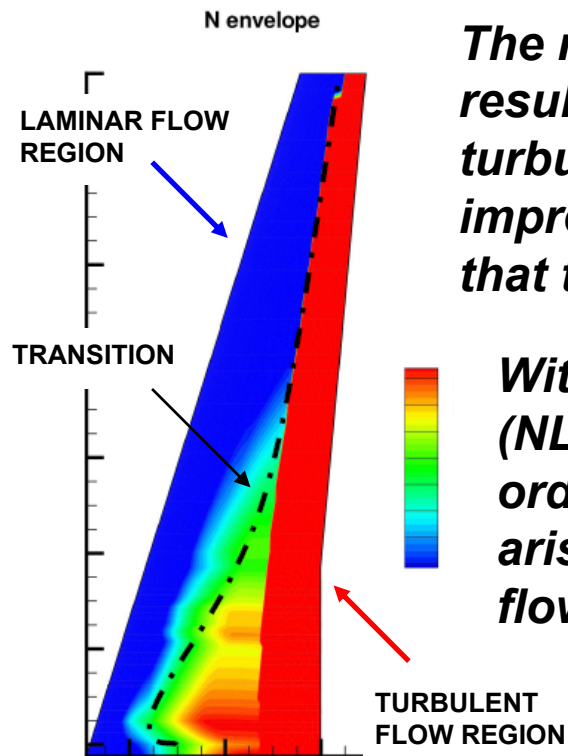
***Advanced, high aspect ratio Transonic Laminar Wing for Regional Aircraft with Load Control & Alleviation devices –
Technological Optimisation and Experimental Validation through
an Innovative WT Model matching the full-size wing flexibility***

In the framework of the GRA ITD – LNC Project a NLF wing aerodynamic / aero-elastic design integrated with Load Control & Alleviation devices is under development aiming at:

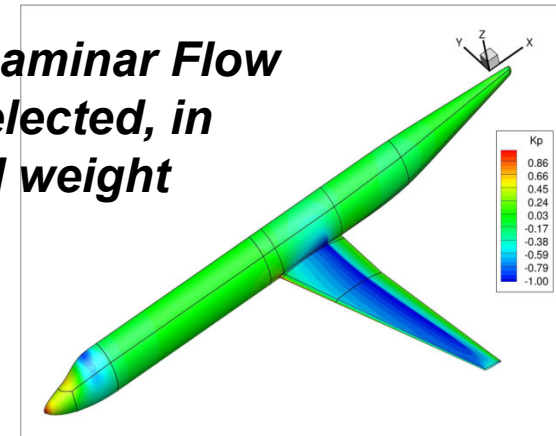
- ❑ Optimising aerodynamic efficiency in cruise condition***
- ❑ Optimising aerodynamic efficiency in climb and other off-design conditions***
- ❑ Alleviate loads to optimise wing structural design for weight savings***

Optimising aerodynamic efficiency at cruise condition ... **NATURAL LAMINAR FLOW Technology**

The reduction of friction and viscous pressure drag resulting from the laminar flow characteristics versus turbulent flow ones can produce a significant improvement on the aerodynamic performance, provided that the laminar flow surface extent is large enough.



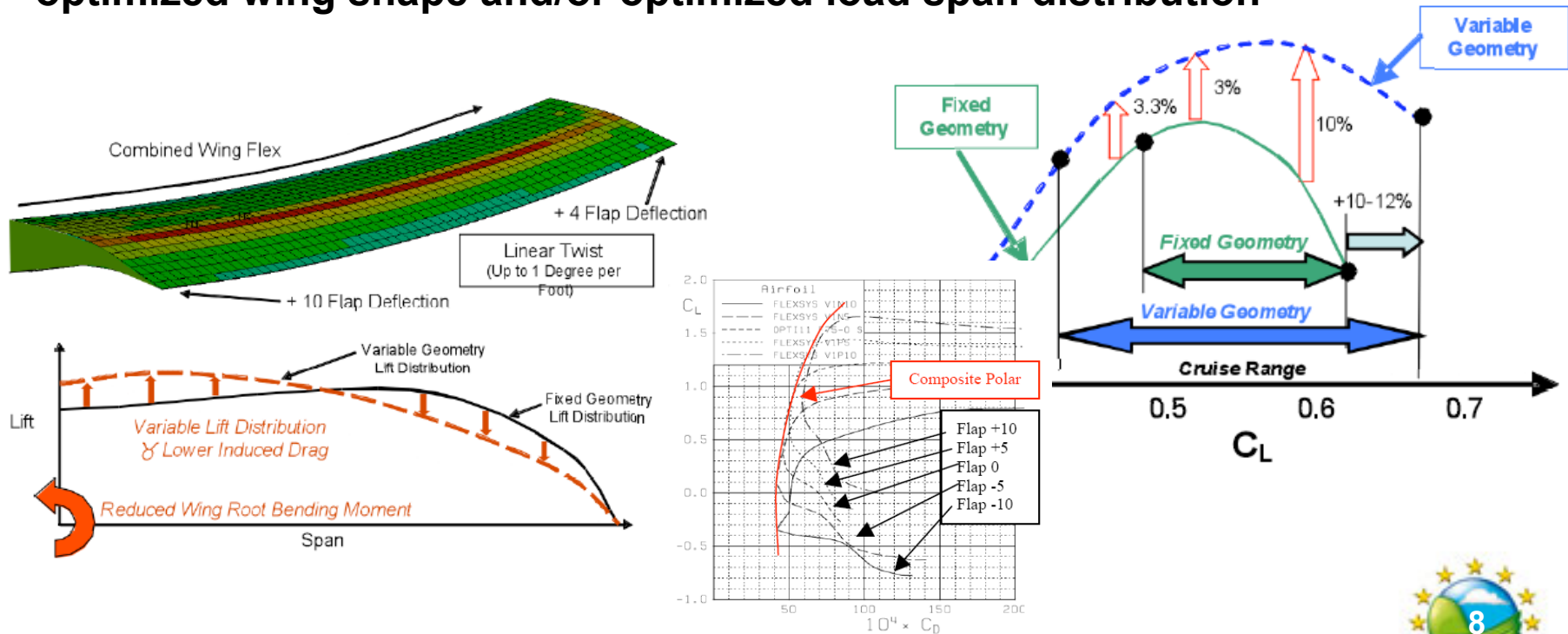
Within the GRA ITD, Natural Laminar Flow (NLF) technology has been selected, in order to avoid complexity and weight arising from active laminar flow control.



Highlights from GRA technology studies on a similar NLF wing configuration

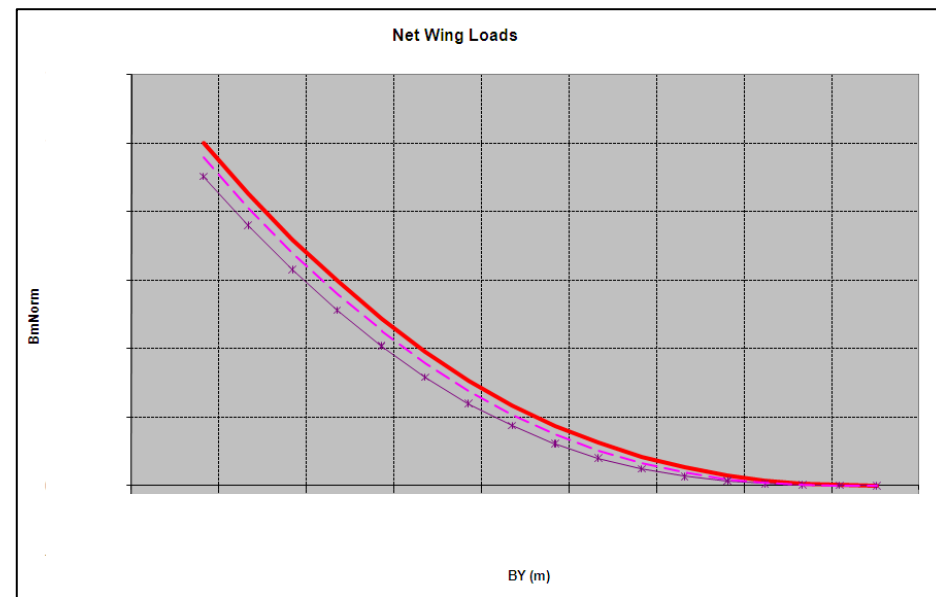
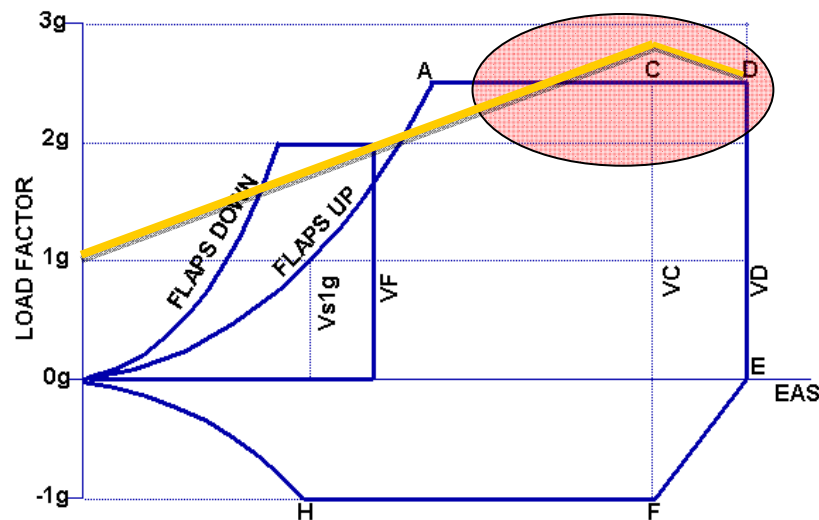
Optimising aerodynamic efficiency in cruise, climb and other off-design conditions ... **LOAD CONTROL Technology**

Investigation of benefits on drag reduction by means of aerodynamically optimized wing shape and/or optimized load span distribution



Alleviate loads to optimise wing structural design for weight saving ... **LOAD ALLEVIATION Technology**

Investigation of wing loads reduction at the extreme of flight envelope (gust and high load factors manoeuvres)



Concepts will be developed and their experimental assessment will be carried out relying on two main WT models:

- ❑ *Transonic, **flexible** model to assess laminarity and LC&A devices “static” performance at high-speed flight conditions.*

D&M and Testing of this model are planned to be carried out within the concerned Collaborative Project.

- ❑ *Subsonic, flexible model, with actuated control surfaces and active control system to assess capability to control and alleviate aerodynamic loads.*

Aim of both tests is to reach a Technology Readiness Level = 5

Next slide provides TRLs definition and relevant means of compliance applicable to GRA ITD work programme.

DEFINITIONS

A high-fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.

A mid-level fidelity system/component breadboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrates overall performance in critical areas. Performance predictions are made for subsequent development phases.

A low fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments and associated performance predictions are defined relative to the final operating environment.

Analytical studies place the technology in an appropriate context and laboratory demonstrations, modeling and simulation validate analytical prediction

TRL

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- a) Full scale integration mock-up ground test
- b) Sub-system flight test to demonstrate partial performance and engineering feasibility
- c) Full Scale Ground Test-rig H/W in-the-loop

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- a) Aerodynamic data based on complete Wind Tunnel Models tested at Reynolds numbers 1/ 5 w.r.t. full scale, where necessary with thrust simulation.
- b) Aerodynamic data based on partial Wind Tunnel Models tested at Reynolds numbers very close to full-scale conditions
- c) Large Scale structural stiffened panel testing
- d) Large scale realistic integrated functional mock-up
- e) Large scale integration test-rig
- f) S/W tested and validate on an Operational Simulator

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- a) Aerodynamic data based on CFD and basic Wind Tunnel Models tested at Reynolds numbers 1/ 10 w.r.t. full scale, where necessary with thrust simulation
- b) Structural Coupon and/or Small Panel Test
- c) Reliable and validated multidisciplinary and specific simulation tools
- d) Sub-system prototype laboratory tested on test-rig
- e) S/W testing on a Simulation Platform

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- a) Aerodynamic data based on CFD and small scale basic Wind Tunnel Models at Reynolds numbers less than 1/20 w.r.t. full scale without thrust simulation.
- b) Lab Functional tests on concepts prototypes

Wing Transonic Cruise Configuration WTT Validation: **TRL 5**

- ❑ The model will be specifically designed to assess that, at Reynolds / Mach numbers close to Full Scale cruise condition ($Re \approx 20 \cdot 10^6$ @ Mach = 0.78), boundary layer is still laminar over large portions of the wing surface.
- ❑ Main target of the testing is to reach a TRL 5, higher than that usually given to High Reynolds Tests (TRL 4) in order to assess the viability of the whole laminar wing concept, thus validating not only the aerodynamic design itself but also the interaction between the stiffness and the manufacturing / technological standard.
- ❑ Therefore, the model shall be shaped not only to reproduce the external lines of the outer portion of the Laminar Wing but also its expected stiffness and all steps and gaps venial of the selected manufacturing technology / process as well as of roughness due to insects smashing.
- ❑ The model shall be also designed to allow rational integration of trailing edge control surfaces for Load Control and aerodynamic enhancement.

Topic Description

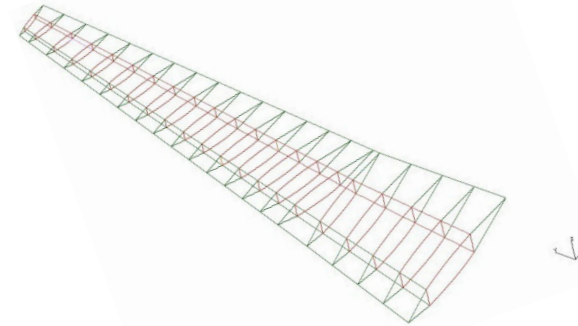
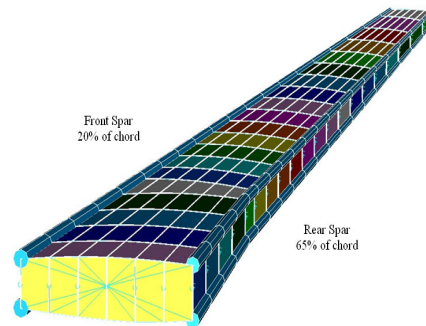
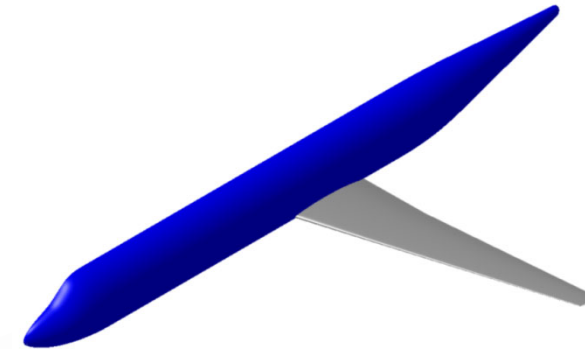
□ INPUTS

□ PROJECT PARTS

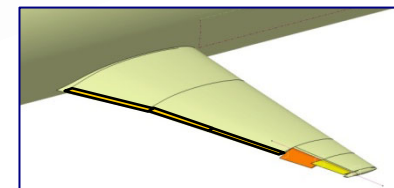
1. LC&A concepts optimisation / development
2. Wind Tunnel Experimental Activities
 - WT Model Design & Manufacturing
 - WT testing

INPUTS

- NLF Wing Aerodynamic Design CAD model
- NLF Wing Box Aero-elastic FEM Model



- Initial configuration (position, size & setting) of control devices for Load Control & Alleviation



WING MODELS NOTIONAL PICTURES ARE SHOWN

PROJECT PARTS

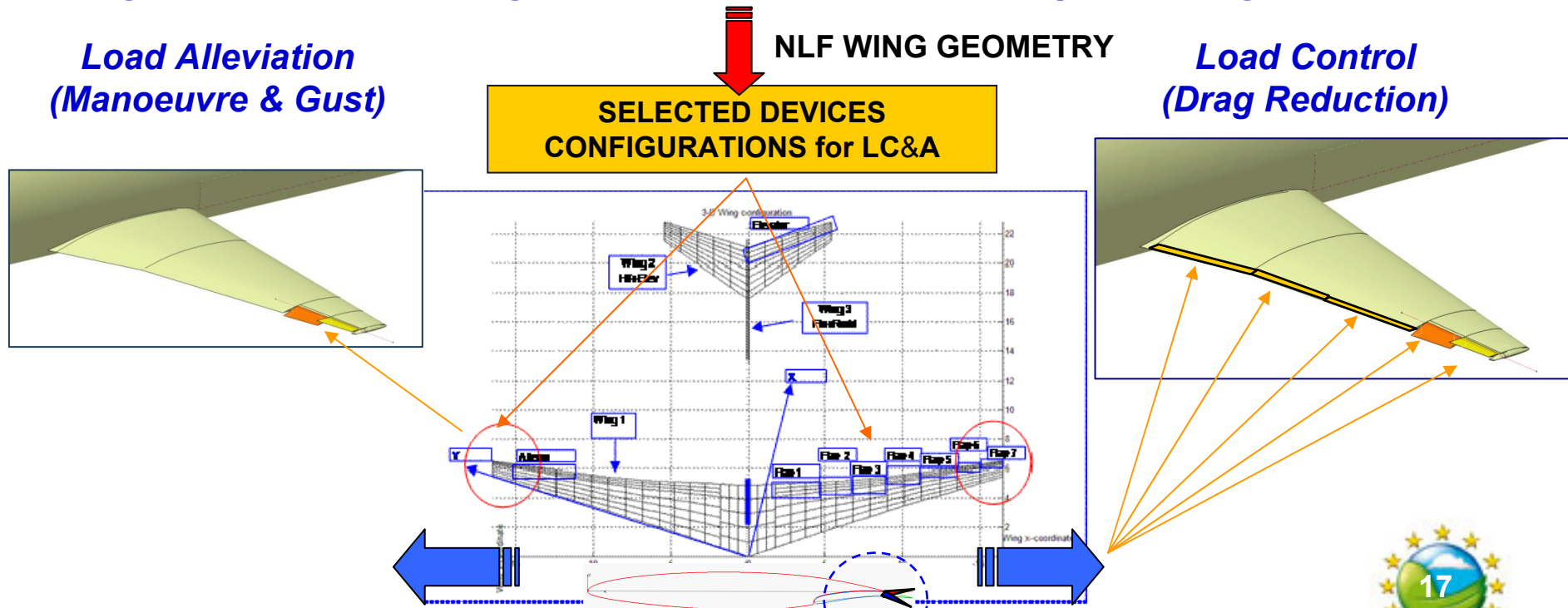
- 1 Optimisation of input wing control movables and Development of new effectors for LC&A aimed at achieving optimal loads distributions, in order to enhance aerodynamic efficiency in climb and other off-design conditions and also alleviate wing bending moment.
- 2a Design and manufacturing of a flexible WT wing model representative of the full-size wing aerodynamic performance and structural response in cruise and off-design conditions, as predicted by computational analyses.
- 2b WT tests at transonic speed and high Reynolds number, in order to validate at cruise, climb and over-speed off-design conditions:
 - **NLF wing design (namely laminar flow extent), considering nominal shape, steps/gaps, distributed roughness**
 - **devices effectiveness in getting reduced aerodynamic static loads or drag in both cruise and off-design conditions**

PART #1

Optimisation / Development of Load Control & Alleviation concepts

Initial configuration (position, size & setting) of devices from LC&A concepts under study within GRA ITD will be provided as **input data**.

The applicant should optimize such configurations for several flow conditions without modifying neither the wing aerodynamic shape nor the FEM model, but taking account of the wing aero-elastic behaviour and preserving laminar flow.

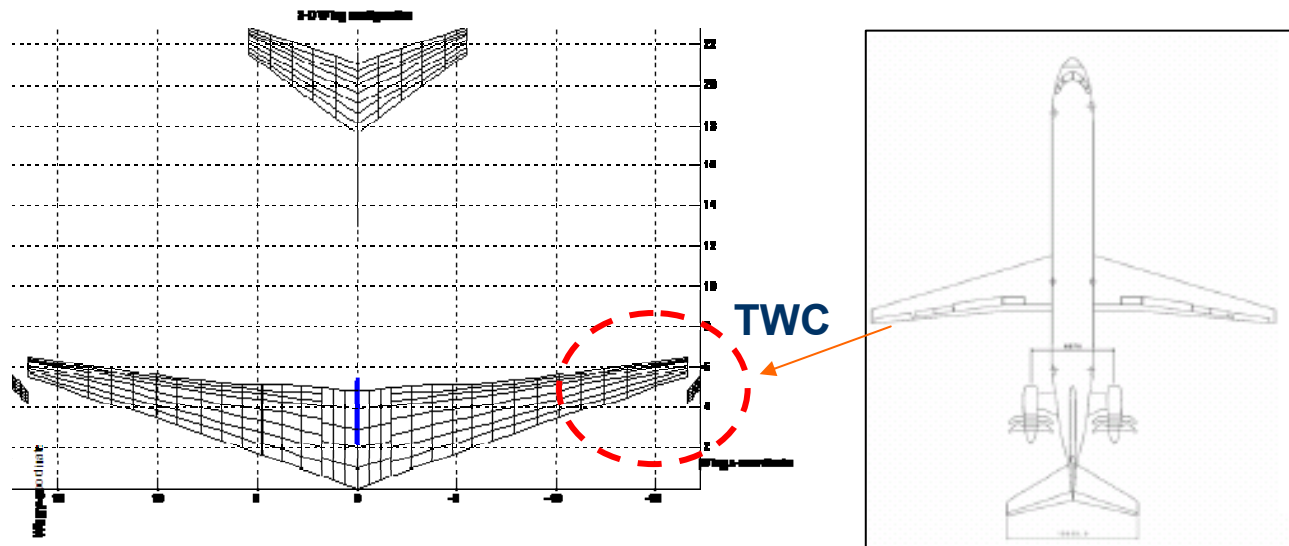


Proposition for other solution(s) of LC&A devices is expected by the Applicants.

An example of innovative flight control concepts which could be explored is given in the following picture.

Possible Additional Concepts for Innovative Flight Control devices

Wing tip devices (TWC), being placed in a forward position wrt the wing LE but out of wing tip, are not affected by possible reduction of effectiveness due to wing flexibility, as well as ailerons at high speed. Moreover, they can “drive” wing bending and torque levels, in particular for the wing outboard region.



Therefore they can also drive wing tip flexible twist in order to improve statically the effects of structural aero-elastic tailoring (load control), and to increase rolling A/C capability totally replacing or reducing size of classical aileron.

PART #2

Wind Tunnel Tests Experimental Activities

Main Goals of the Testing

- **Phase #1: Assessment of the persistence of laminar boundary layer over a large extent of wing chord at Reynolds and Mach numbers of interest for Regional Aircraft reproducing also:**
 - ✓ the airframe deformation
 - ✓ the presence of contaminants
 - ✓ manufacturing peculiarities (steps, gaps, etc.)
- **Phase #2: Assessment of the effects that innovative trailing edge devices have in reducing the induced drag and the wing root bending moment.**

ORGANISATION

WT Model D&M Phases

The WT Model D&M activity will be split according to the following phases:

- **Feasibility / Preliminary Design Phase**
- **Design Development Phase**
- **Manufacturing / Assembly**

Progress Reviews will be held at the end of each Phase to assess that maturity of the project allows to make a step forward.

ORGANISATION

WT Model Preliminary Design Review

Purpose of PDR is assessing that all the technical requirements and relevant potential issues have been correctly addressed and pertinent practical solutions have been identified.

PDR will be held at the end of Feasibility / Preliminary Design Phase; positive conclusion of PDR will allow to start the Design Development Phase.

WT Model Critical Design Review

Purpose of CDR is assessing that the Design is such that all technical requirements are fulfilled and no issues are still open.

CDR will be held at the end of Design Development Phase; positive conclusion of CDR will allow to start the Manufacturing / Assembly Phase.

WT Model Acceptance Review

Purpose of AR is assessing that the “as built” Model is such that all requirements are fulfilled and all model acceptance tests were performed without open issues left behind.

ORGANISATION (*cont'd*)

Lab/ Experimental Set Up Preliminary Design Review

Purpose of this PDR is assessing that all test requirements have been covered, relevant potential issues have been correctly addressed and feasible solutions have been identified.

PDR will be held at the end of Feasibility / Preliminary Design Phase; positive conclusion of PDR will allow to start the Model Design Development Phase.

Lab/ Experimental Set Up Critical Design Review

Purpose of this CDR is assessing that all test requirements are fulfilled and no issues are still open.

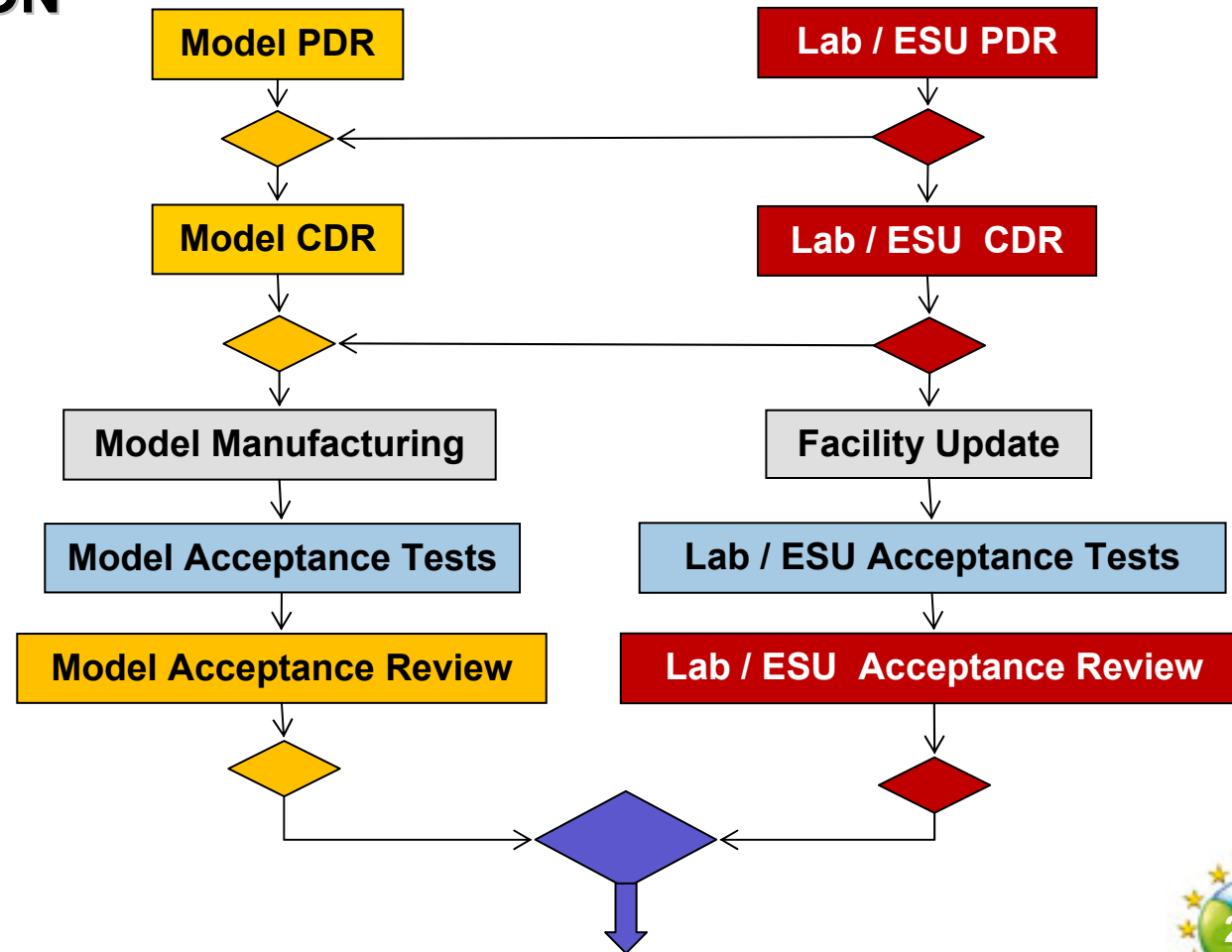
CDR will be held at the end of Design Development Phase; positive conclusion of CDR will allow to start the Model Manufacturing / Assembly Phase.

Lab/ Experimental Set Up Acceptance Review

Purpose of this AR is assessing that the facility updated or modified for specific test purpose fulfils all test requirements.

ORGANISATION

Flow Chart



INNOVATIVE CONTENTS

Innovation envisaged applicable to Project Organisation and Management is the availability of an advanced software environment able to:

- *trace all technical requirements,*
- *their relevant solutions,*
- *the possible mismatches between each requirement and its solution along the different project phases to minimise the risk and cost.*

Extensive use of virtual mock ups and virtual testing techniques is sought as essential.

WT Model D&M

The full-size wing aero-elastic model has to be scaled down, by taking into account the WT model type and size, so as the model be representative of the actual wing deformation.

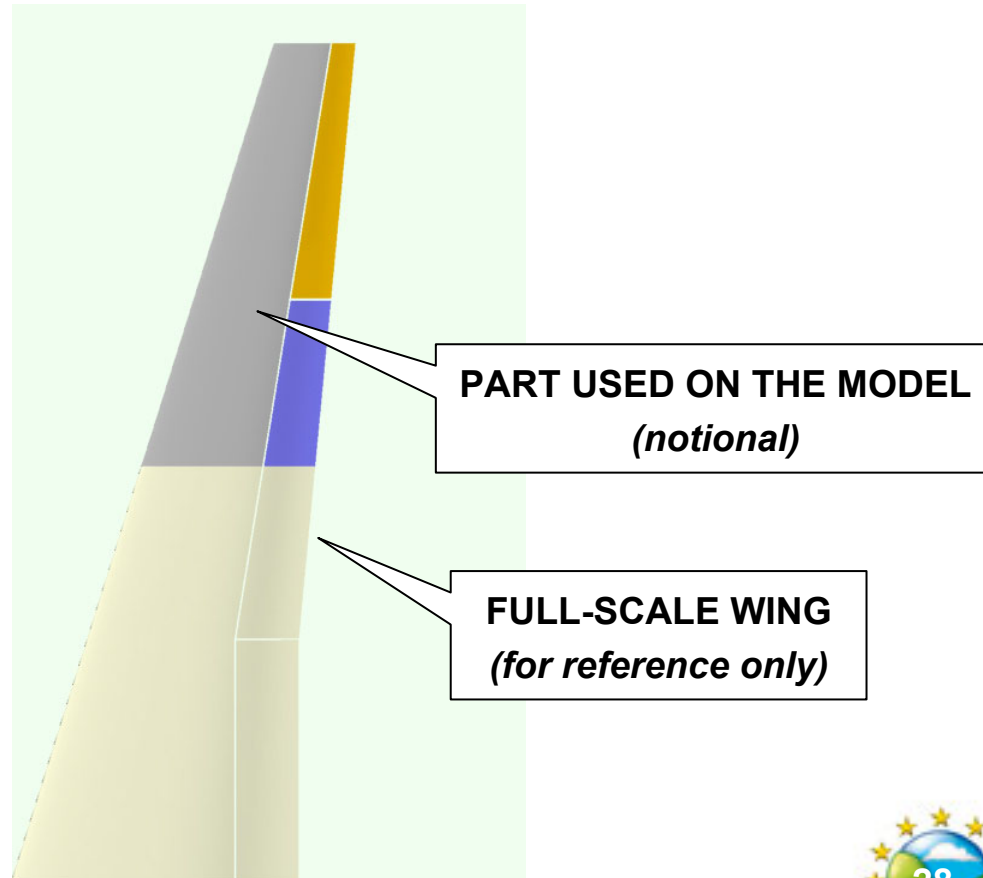
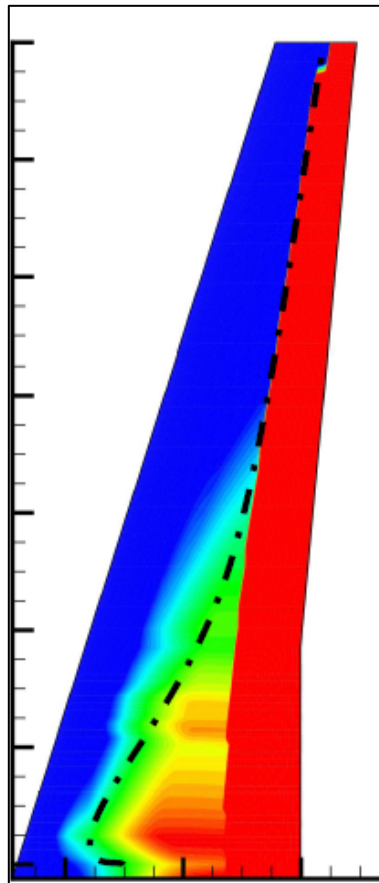
Similar activity has to be performed relatively to LC&A solutions at various flight conditions.

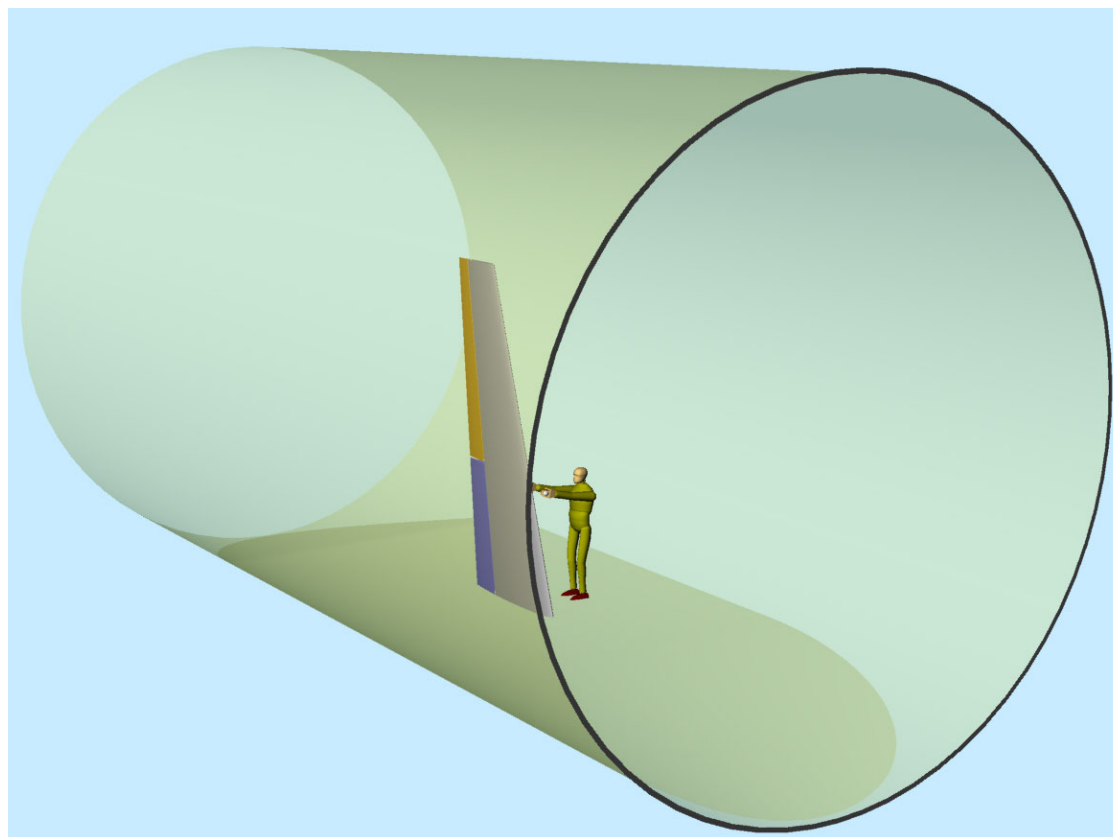
In this respect it has to be taken account that, since the WT model has to house sensors, cables and equipment, the mass distribution and inertia change depending on the inner structural WT model features.

For the above reason it is suggested that the WT model aero-elastic and mechanical design be part of an iterative process.

Prior the WT Testing Ground static tests and Ground dynamic tests should be carried out on the wing model.

WT Model possible solution: partial wing model





Possible solution for Model Installation in the WT test section

WT Model D&M

The model shall allow testing of the following configurations:

1. Baseline

The wing model in its “baseline” configuration does not feature any step / gap over its surface other than those due to trailing edge control surfaces.

Negative steps and gaps as from following points will be closed/faired with adequate filler to provide smooth finishing able to match tolerances.

2. Steps / Gaps Variant 1

Steps / gaps scaled from those foreseen to be present on the full scale wing due to its specific manufacturing technologies will be present over the model surface.

Filler placed to provide smooth finishing will be removed.

3. Steps / Gaps Variant 2

Steps / gaps enlarged with respect to those foreseen within Variant 1 will be present over the model surface.

WT Model D&M

Envisaged Model Features (cont'd)

4. Contaminants Variant 1

Contaminants representative of average insects smashing at leading edge are added at Steps / Gaps Variant 1.

5. Contaminants Variant 2

Contaminants representative of severe insects smashing at leading edge are added at Steps / Gaps Variant 1.

6. LC&A Devices

Devices will be added on the model to assess their contribution to drag, lift, pitching moment for Load Control & Alleviation.

WT MODEL INSTRUMENTATION

1. Thermal coating

Laminarity of the boundary layer should be assessed by thermal imaging, using systems such as those widely validated by ONERA into S1MA.

This requires the model skin be covered, or be equivalent to, an Epoxy coating at least 1 mm thick.

WT MODEL INSTRUMENTATION (*cont'd*)

2. Static Pressure taps

Rows of pressure taps for a total of not less than 150 taps will be present on the model.

Positioning of the taps will be defined during the Feasibility Phase and optimized during the development taking into account the need of balancing the best location for modeling pressure distribution and installation / handling constraints.

Taps diameter shall be at least 0.4 mm minimum.

Tubing of the pressure ports will use flexible pipes in vinyl (diameter 0.8 – 1.7 mm) or in annealed stainless steel tube (diameter 0.6mm – 1mm); use of silicone tubes is forbidden.

Interfaces shall be compatible with PSI standard modules. Preference is given to installation of PSI transducers inside the model.

WT MODEL INSTRUMENTATION (*cont'd*)

3. Unsteady Pressure taps

Some 15 – 20 sensors able to gather unsteady pressure variation, such as Kulites, will be present on the model to complement boundary layer transition assessment.

Some of them will be placed ahead and on the LC&A devices to support Buffeting assessment.

Miniature dynamic pressure transducer, such as Kulite models, can be assumed as reference.

WT MODEL INSTRUMENTATION *(cont'd)*

4. Accelerometers

At least two accelerometers measuring wing tip accelerations will be present for test security reasons in order to prevent possible occurrence of dynamic aero-elastic instability phenomena. These transducers shall be connected to an emergency test shut down system to cut off divergence development.

Other accelerometers will be placed on LC&A devices to gather possible buffeting.

WT MODEL INSTRUMENTATION (*cont'd*)

5. Aerodynamic loads measurements

During second phase test wing loading (total and distributions) measurement capability is mandatory.

Preference is given to advanced pressure plotting techniques such as PSP without adding additional wing pressures taps with respect to those necessary for the first test phase. Pressure plotting will be complemented by control surfaces direct hinge moments measurements.

In addition to pressure and hinge moments measurements, a total wing load measurement system able to gather Lift, Drag, Pitching and Bending (Roll) Moments is required.

Remote monitoring/control of wing movables deflections could be necessary.

WT MODEL INSTRUMENTATION *(cont'd)*

6. Wing displacements

During second test phase, the capability to measure wing model static displacement is mandatory.

In particular vertical displacements (orthogonal to wing plane), bending rotations, twist rotations pertinent to at least 4 sections along the wing span shall be monitored.

Capability to monitor wing displacement also in non steady conditions is highly desired.

TEST CONDITIONS

Mach number is expected to range between 0.6 and 0.83 to cover transonic cruise and off-design conditions.

Incidence will range between -0.5° and $+2^\circ$ with a step of 0.5° .

Reynolds will follow its natural variation with Mach.

GRA ITD – Collaborative Project Wind Tunnel Experimental Activities

OVERVIEW

