Italian Aerospace Research Centre

MOVE THE FUTURE
CAPUA, April 23-24

ANSYS

Future Transport Challenges Workshop:
Energy Efficiency and The Environment

Current methods for aircraft aerodynamics

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THE RESEARCH GROUP

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  - DMA: Lina MALLOZZI Prof.
  - JAXA: Makoto UENO Sr. Researcher
  - CIRA: Pietro CATALANO Ph. D.
  - FLUERE: Paolo CACCAVALE Ph. D. (http://www.fluere.it/)
- SECONDA UNIVERSITÀ DI NAPOLI - SUN
  - DIII: Massimiliano MATTEI Prof., Giuliano DE STEFANO Prof., Giovanni Paolo REINA Ph.D. student
- UNIVERSITÀ DI SALERNO - UNISA
  - DIIN: Paolo LUCHINI Prof., Flavio GIANNETTI Prof.
- REPARTO SPERIMENTALE DI VOLO (ITALIAN AIRFORCE) - RSV
  - S. Ten Alessandro D’ARGENIO, Capt. Pierluigi DE PAOLIS
- ACCADEMIA AERONAUTICA DI POZZUOLI (ITALIAN AIRFORCE)
  - Aerodynamic experimental facilities: the «VALENTINO LOSITO» WIND TUNNEL

AGENDA

- APPLIED AERODYNAMICS: SOME RECENT R&D COOPERATIONS AND AERODYNAMIC PROBLEMS;
- FLUID DYNAMIC MODELS;
- METHODS;
- A HYBRID METHOD FOR THE PREDICTION OF THE TRANSITION;
- AERODYNAMIC FORCE BREAKDOWN;
- DYNAMIC MESH FOR MOVING SURFACES;
- ADVANCED PANEL METHODS;
- ACADEMIC FALLOUT.

APPLIED AERODYNAMICS: SOME RECENT R&D COOPERATIONS... (1/2)

- RSV (UNINA)
  - Safe separation;
  - Effects of the variation of the configuration (drag coefficient, stability derivatives);
  - In-flight refueling (aerodynamic effects of the tanker on the receiver);
  - Numerical fluid dynamic support ;
  - Optimization of flight test: game theory; the aerodynamic DB comes from flight test measurements and theoretical methods.

- CIRA
  - Global stability approach applied to RANS simulations with immersed boundary techniques – UNINA/UNISA;
  - Prediction of the transition on wing-body configuration - UNINA;
  - Dynamic stall alleviators - UNINA.

- ITALIAN INDUSTRIES
  - UAV aerodynamics (cruise, vertical take-off and transition to horizontal flight analysis) – UNINA/SUN;
  - Movable and moving surfaces: aerodynamics and dynamic forces during the actuating – UNINA/SUN/CIRA.

… AND AERODYNAMIC PROBLEMS (2/2)

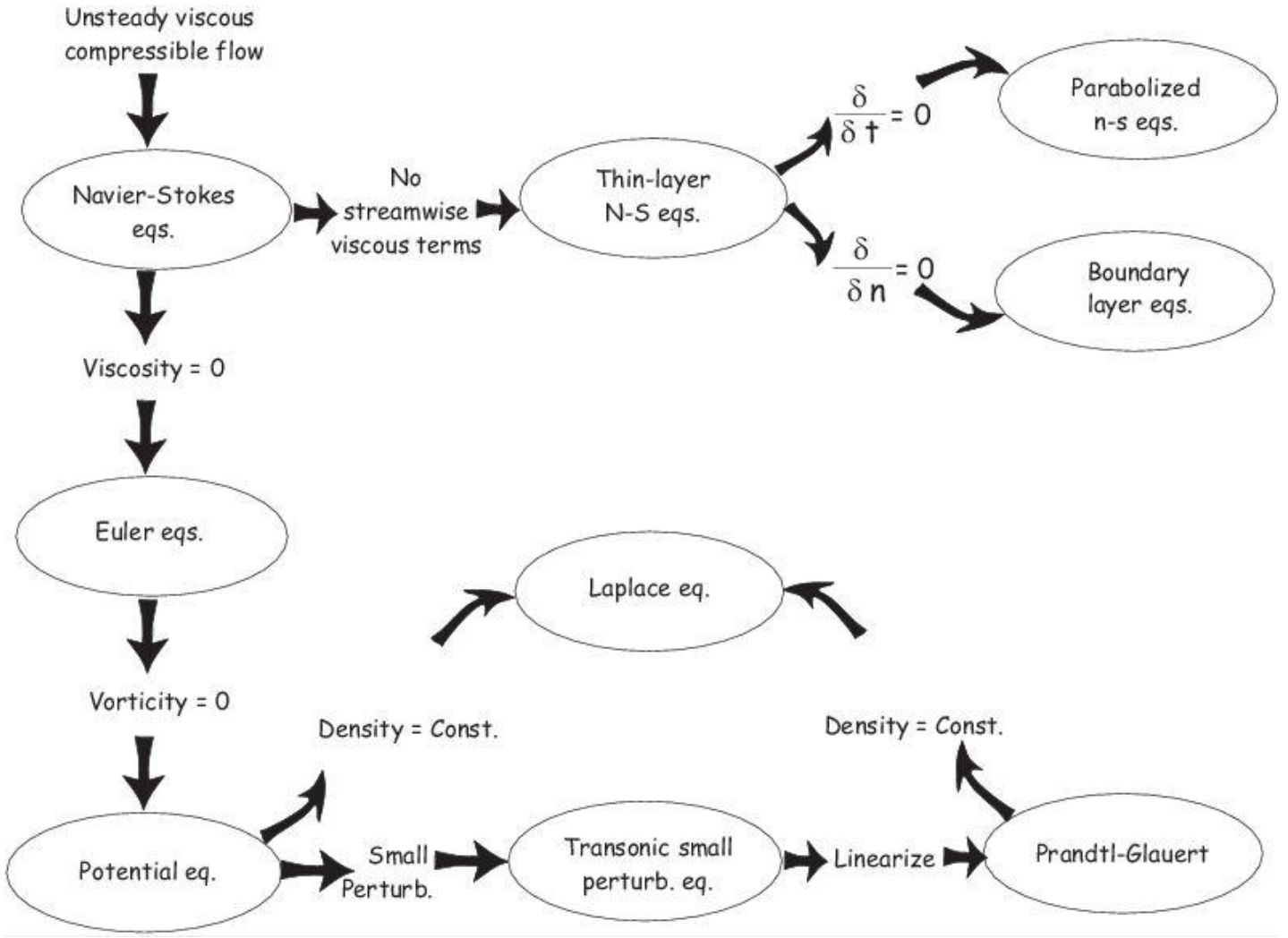
- CRUISE AERODYNAMICS

  - Forces, moments and drag breakdown;
  - Wing-body: transition prediction with hybrid techniques (boundary layer + RANS);
  - Full configuration of aircraft (empennage settings).

- MOVING SURFACES

  - Dynamics of high-lift and control systems (flap, ailerons, spoilers, empennage, airbrakes, Gurney flap); landing gear system.
  - Safe separation: Wind tunnel tests and theoretical prediction, aeroelastic effects on the wing, Jettison.
  - Propellers and interactions: axial and non-axial flows (P-factor); contra-rotating configurations; Interactions: wake/wing, wake/tailplane, wake/ground, airplane/propeller.

FLUID DYNAMIC MODELS (from Fletcher)



METHODS

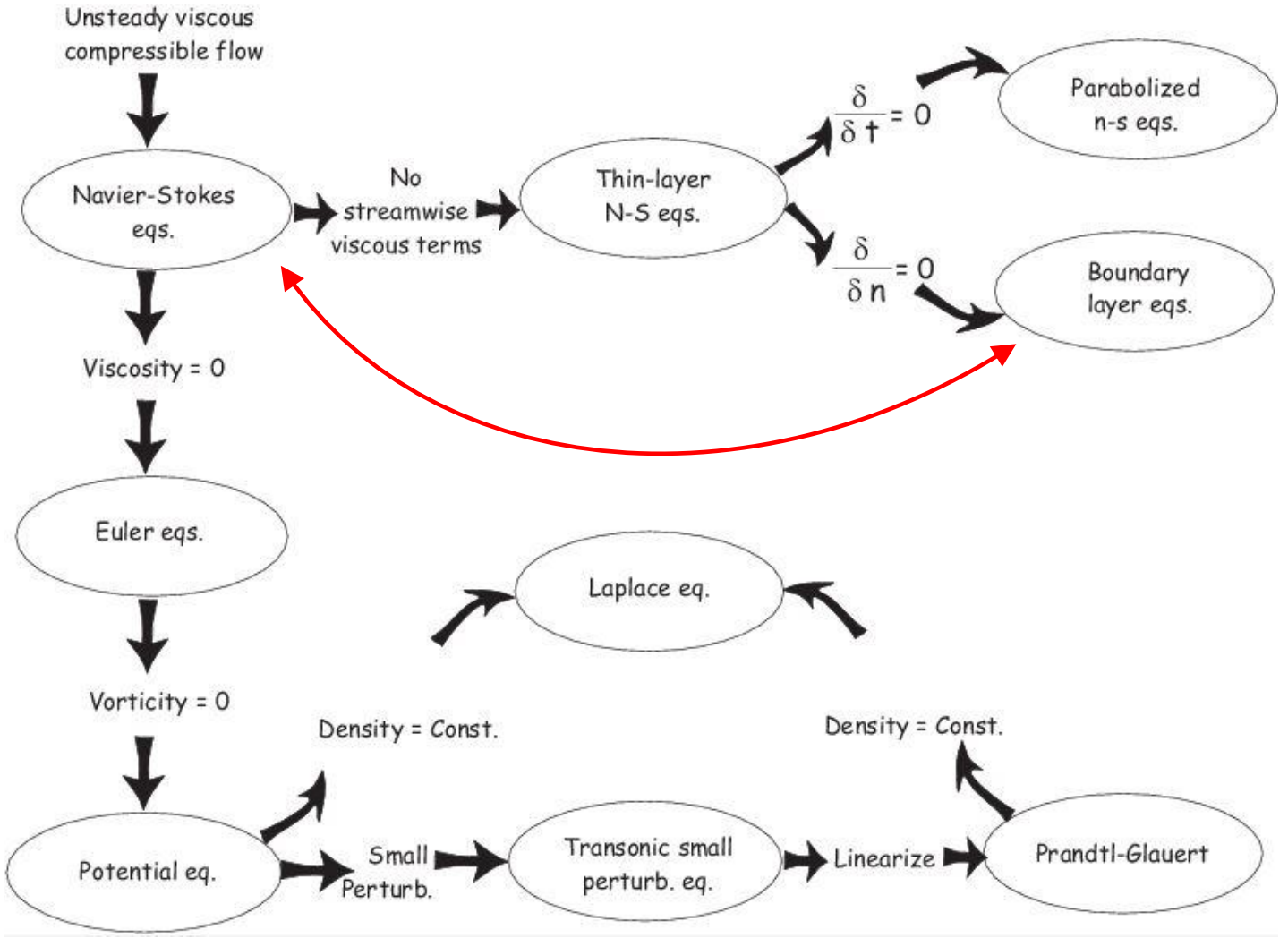
- URANS;
- POST-PROCESSING OF CFD SOLUTIONS;
- LAMINAR BOUNDARY LAYER AND TRANSITION;
- GLOBAL STABILITY ANALYSIS;
- VORTON-BASED PANEL METHODS;
- EXPERIMENTAL TESTS IN THE “VALENTINO LOSITO” WIND TUNNEL OF THE ITALIAN AIR FORCE ACADEMY.

A HYBRID METHOD FOR THE PREDICTION OF THE TRANSITION - UNINA/CIRA (1/3)

HYBRID TECHNIQUE: BOUNDARY LAYER EQUATIONS + RANS

- TRANSONIC AIRPLANES: WHY;
- AT LEAST 3 DIFFERENT TRANSITION MECHANISMS: TOLLMIEN-SCHLICHTING, CROSSFLOW, L.E. CONTAMINATION;
- THE PREDICTION OF THE TRANSITION IS AN OPEN PROBLEM: THE FOCAL POINT IS THAT THE TRANSITION IS A BOUNDARY LAYER PHENOMENON;
- THE NAVIER-STOKES MODEL «IGNORES» WHAT THE BOUNDARY LAYER IS: WHAT IS Re_θ FOR RANS? IF THE BOUNDARY LAYER WERE KNOWN, TRANSITION COULD BE CALCULATED…

SOLID TRANSITION TECHNIQUES – COMING FROM BOUNDARY LAYER STUDIES – ARE UNFIT FOR RANS SOLVERS


Unsteady viscous compressible flow
Navier-Stokes eqs.
No streamwise viscous terms
Thin-layer N-S eqs.
δ/δt = 0
Parabolized n-s eqs.
δ/δn = 0
Boundary layer eqs.
Viscosity = 0
Euler eqs.
Laplace eq.
Vorticity = 0
Density = Const.
Potential eq.
Small Perturb.
Transonic small perturb. eq.
Linearize
Density = Const.
Prandtl-Glauert

THE INITIAL TRANSITION LOCATION IS (ARBITRARILY) PRESCRIBED FOR THE RANS SOLVER;

THE RANS SOLVER CALCULATES THE PRESSURE SURFACE FIELD;

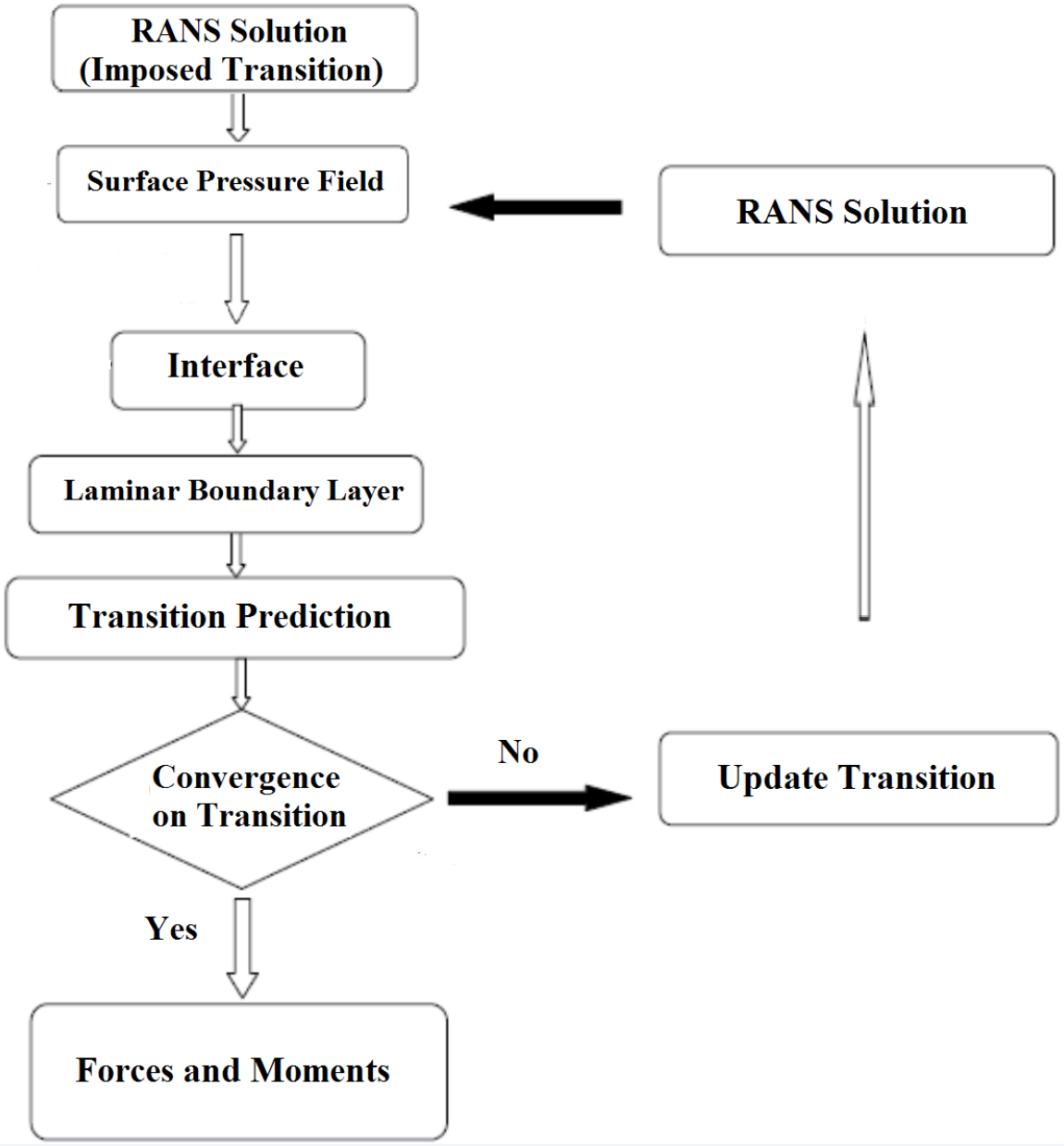
THE "EXTERNAL" VELOCITY FIELD IS EVALUATED FROM THE SURFACE PRESSURE (BOUNDARY LAYER HYPOTESIS);

THE ACTUAL LAMINAR BOUNDARY LAYER IS CALCULATED TOGETHER WITH THE ACTUAL LOCATION OF THE TRANSITION;

THIS TRANSITION LOCATION IS UPDATE FOR THE RANS SOLVER;

THE PROCEDURE IS ITERATED UP TO A PRESCRIBED CONVERGENCY.

THE PROCEDURE HAS SHOWN TO BE ROBUST.
RESULTS ARE ACCURATE.



AERODYNAMIC FORCE BREAKDOWN – UNINA (1/3)

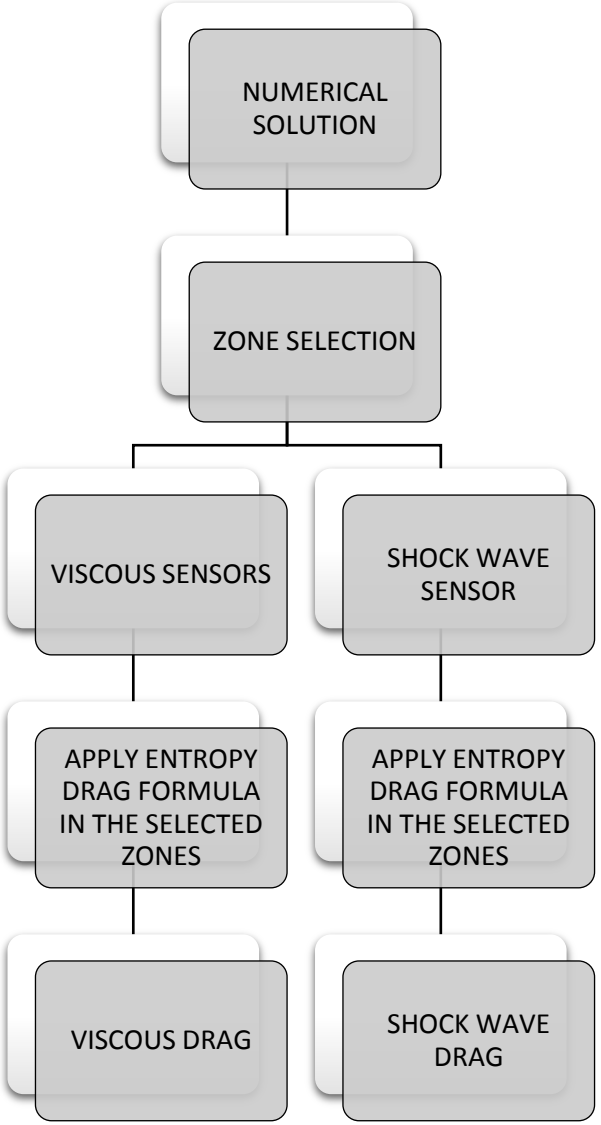
THE ACCURATE PREDICTION OF THE AERODYNAMIC DRAG IS STILL A CRITICAL ISSUE AS REMARKED BY THE 5TH AIAA WORKSHOP (2012):

YOU GAIN 1 PAX BY SAVING 4 DRAG COUNTS (I.E. REDUCING THE VALUE OF THE DRAG COEFFICIENT OF .0004).

- NEAR-FIELD METHODS (CURRENT CFD CODES)
  - DO NOT ALLOW THE USER TO DECOMPOSE THE DRAG IN ITS PHYSICAL COMPONENTS (I.E. VISCOUS, WAVE AND WING-LOAD INDUCED);
  - STRONGLY DEPENDENCE ON THE MESH SIZE AND QUALITY (RETURNING A NUMERICAL OR SPURIOUS DRAG).

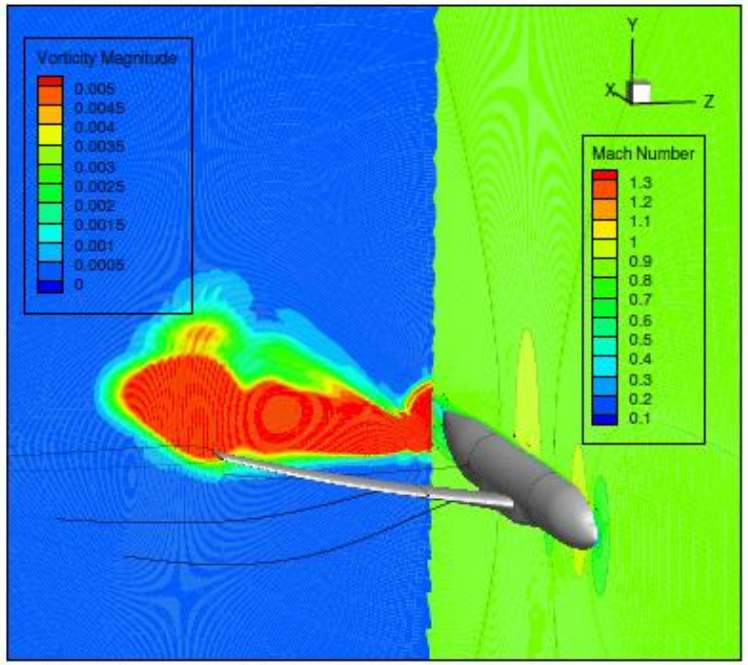
- FAR-FIELD AND MID-FIELD METHODS – UNINA: THE AIM IS THE PREDICTION AT 1 DRAG COUNT OF ACCURACY
  - ALLOW THE USER TO DECOMPOSE THE DRAG IN ITS PHYSICAL CONTRIBUTIONS (THE SPURIOUS DRAG CAN BE IDENTIFIED AND REMOVED);
  - MID-FIELD METHODS:
    - BASED ON SOME VOLUME INTEGRALS OF FLUID DYNAMIC PROPERTIES THAT ARE NON NEGLIGIBLE IN LIMITED PARTS OF THE DOMAIN;
    - THE SOURCE OF THE AERODYNAMIC FORCE IS LINKED TO LOCAL PROPERTIES OF THE FLOW DOMAIN;
    - AN UNAMBIGOUS DEFINITION OF INDUCED DRAG, ALSO IN COMPRESSIBLE FLOW.

Far-field method



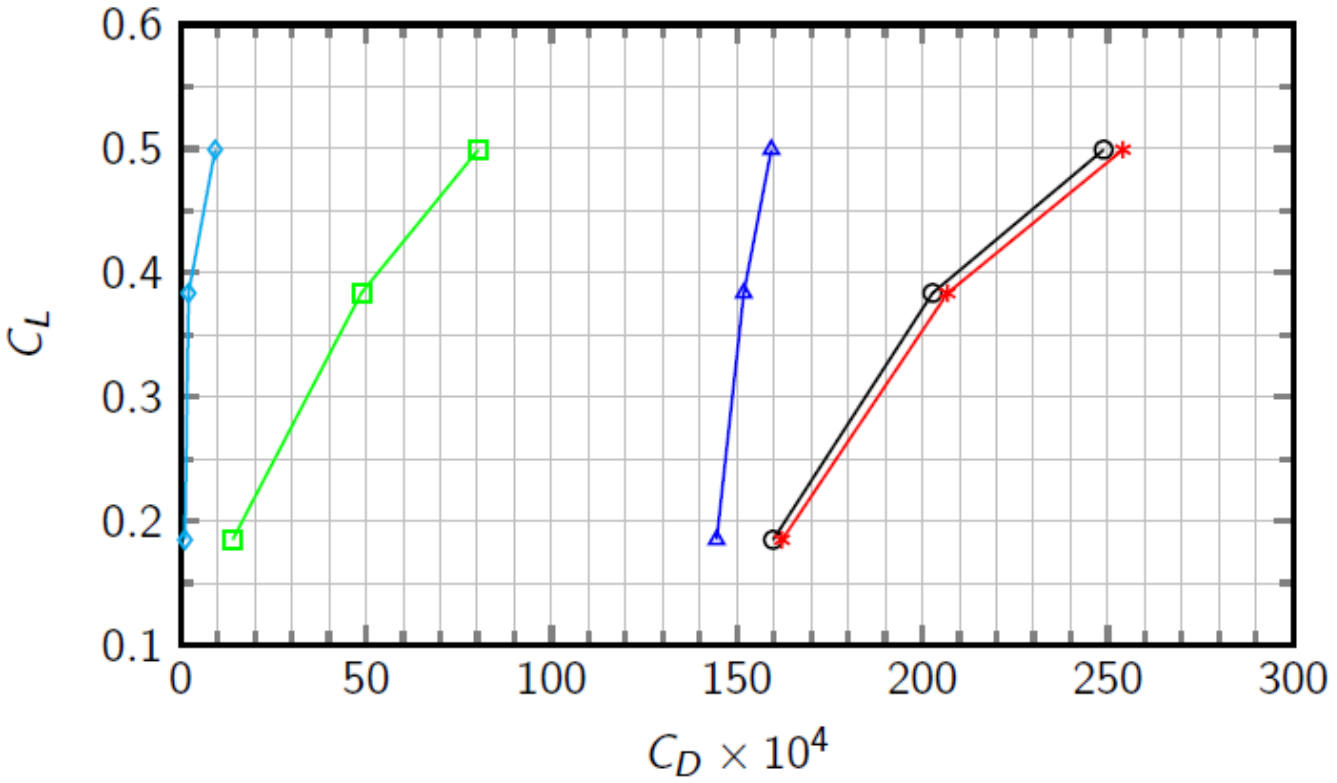
NASA CRM WING BODY TEST CASE

5TH AIAA WORKSHOP



$M_\infty = 0.85,\ Re_\infty = 5 \times 10^6,\ \alpha = 2.3°.$

$M_\infty = 0.85,\ Re_\infty = 5 \times 10^6$



– ∗ –: near-field. – ○ –: far-field. – △ –: viscous drag.

– □ –: induced drag. – ◇ –: wave drag.

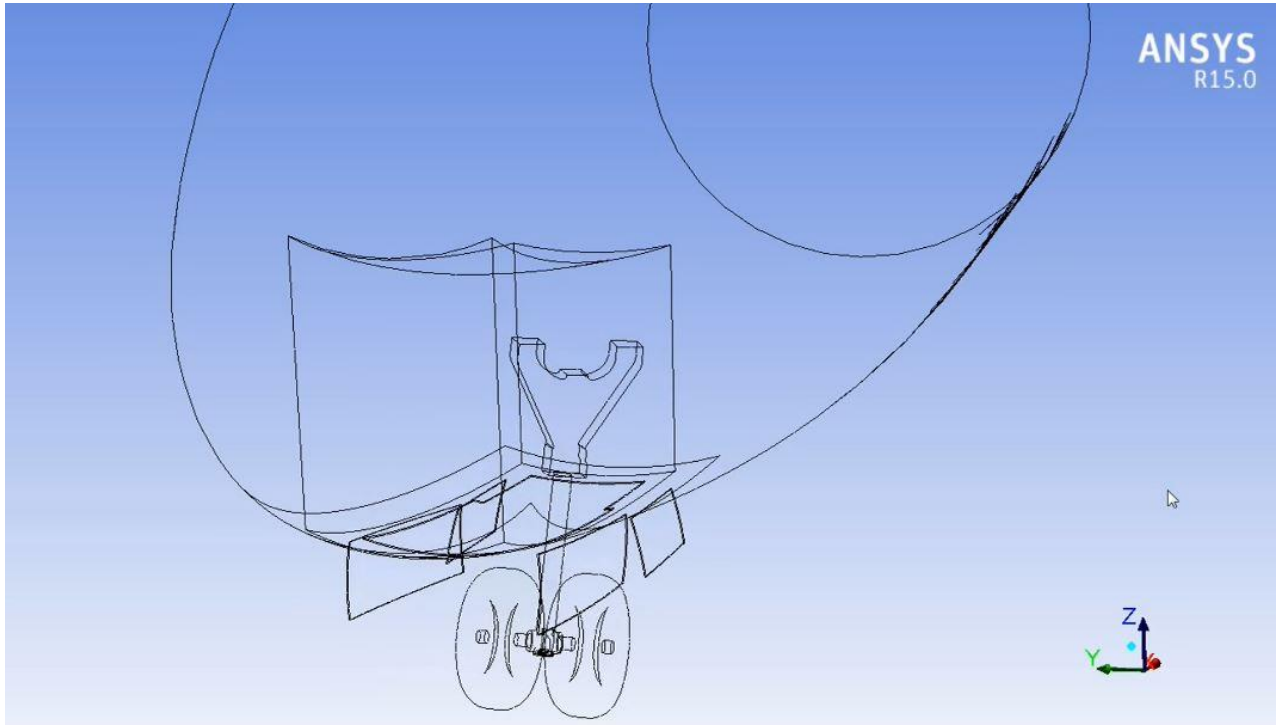
MOVABLE AND MOVING AIRCRAFT SURFACES
CFD DYNAMIC MESHING & ADVANCED PANEL METHODS

DYNAMIC MESH FOR MOVING SURFACES (1/3)

MAIN GOAL: STUDY OF FORCES AND MOMENTS DURING THE TRANSITIONAL PHASES TO SIZE KINEMATIC MECHANISM AND ACTUATORS

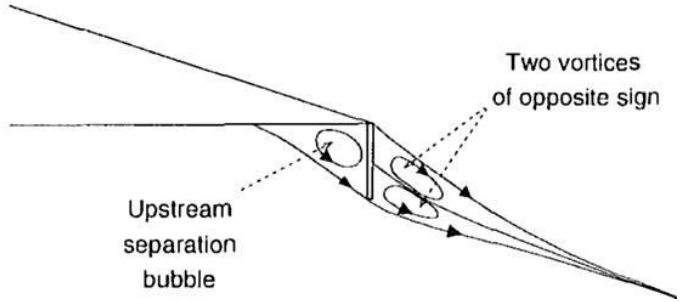
- LANDING GEAR: COMPLETE CYCLE OF OPENING AND CLOSING (BAY + LANDING GEAR LEGS);
- OPENING OF HIGH LIFT DEVICES WITH ASSIGNED CONFIGURATIONS;
- DEFLECTION OF CONTROL SURFACES (AILERONS, TAILPLANE, SPOILERS, AIRBRAKES);
- GURNEY FLAP.

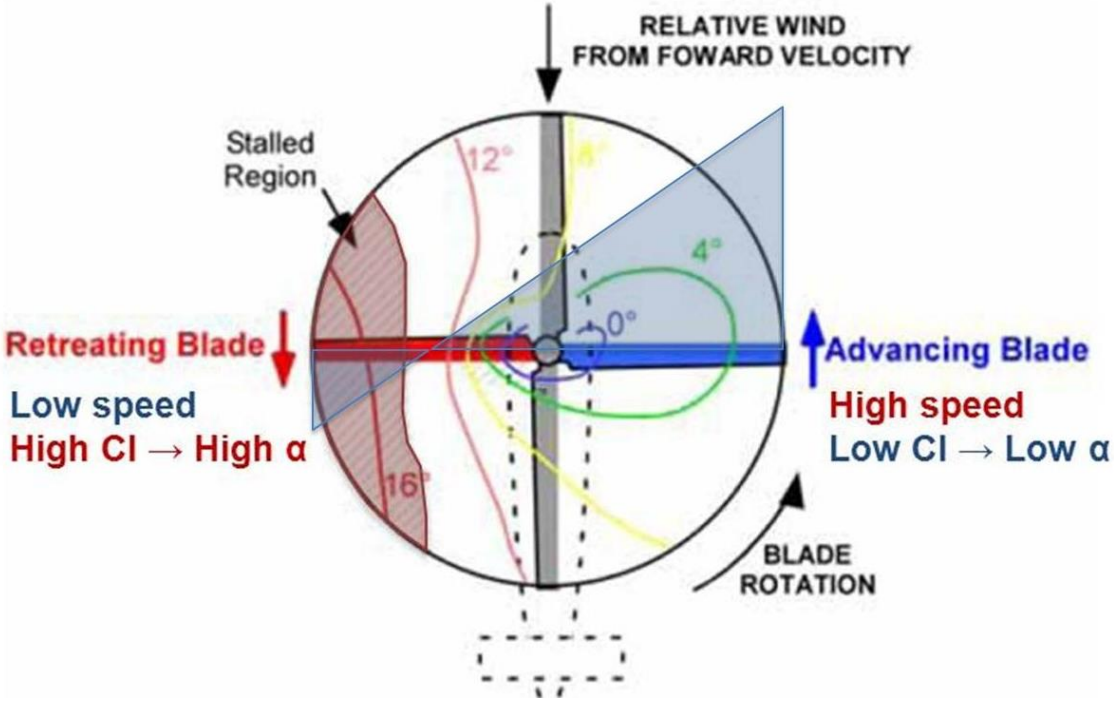
Landing gear

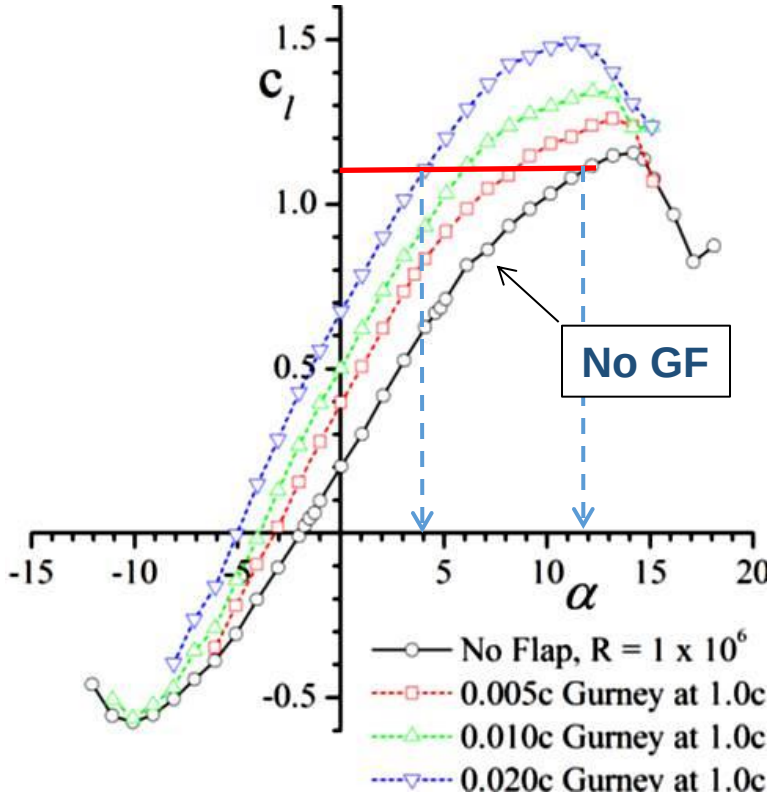


Gurney flap

- SHIFT THE DYNAMIC STALL AT HIGHER LIFT COEFFICIENTS
- ACTIVATION OF THE GURNEY FLAP ON THE RETREATING BLADE, TO KEEP CONSTANT THE PERFORMANCES OF THE ADVANCING BLADE







ADVANCED PANEL METHODS

An aerodynamic problem: the Terrafugia sky-car case (1)

Oggetto:sky-car
Data: Fri, 11 May 2007 17:07:51 +0200
Mittente: Giuseppe Mingione <g.mingione@cira.it>
A:'Carlo de Nicola' <denicola@unina.it>

Come preannunciato telefonicamente, in allegato c'è una foto del 'coso' sia in configurazione aperta che in configurazione con ali chiuse.

Altre informazioni sono sul sito:

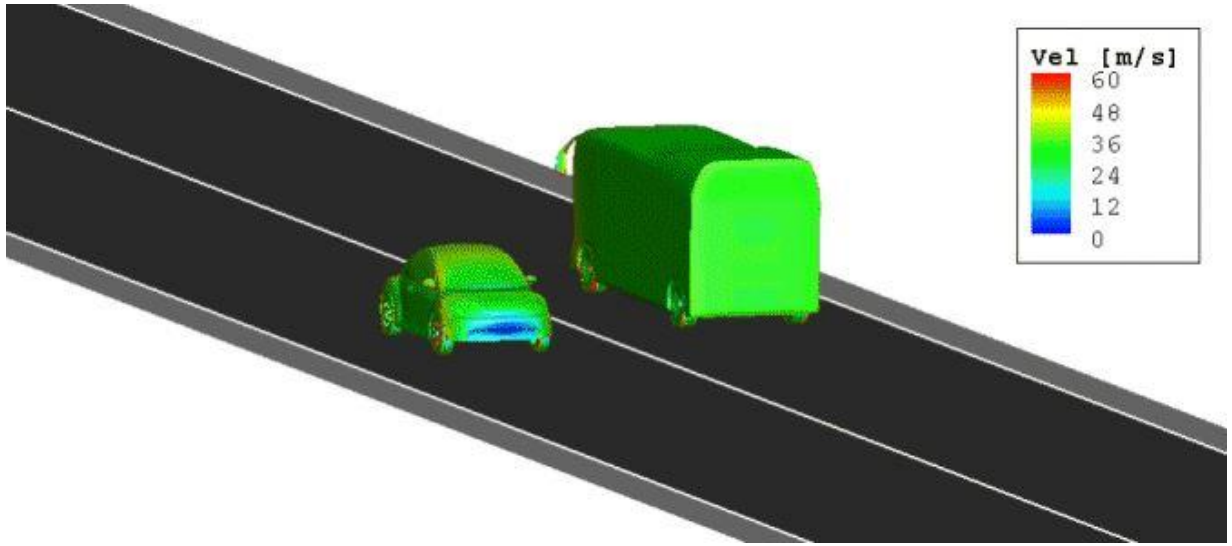
www.terrafugia.com

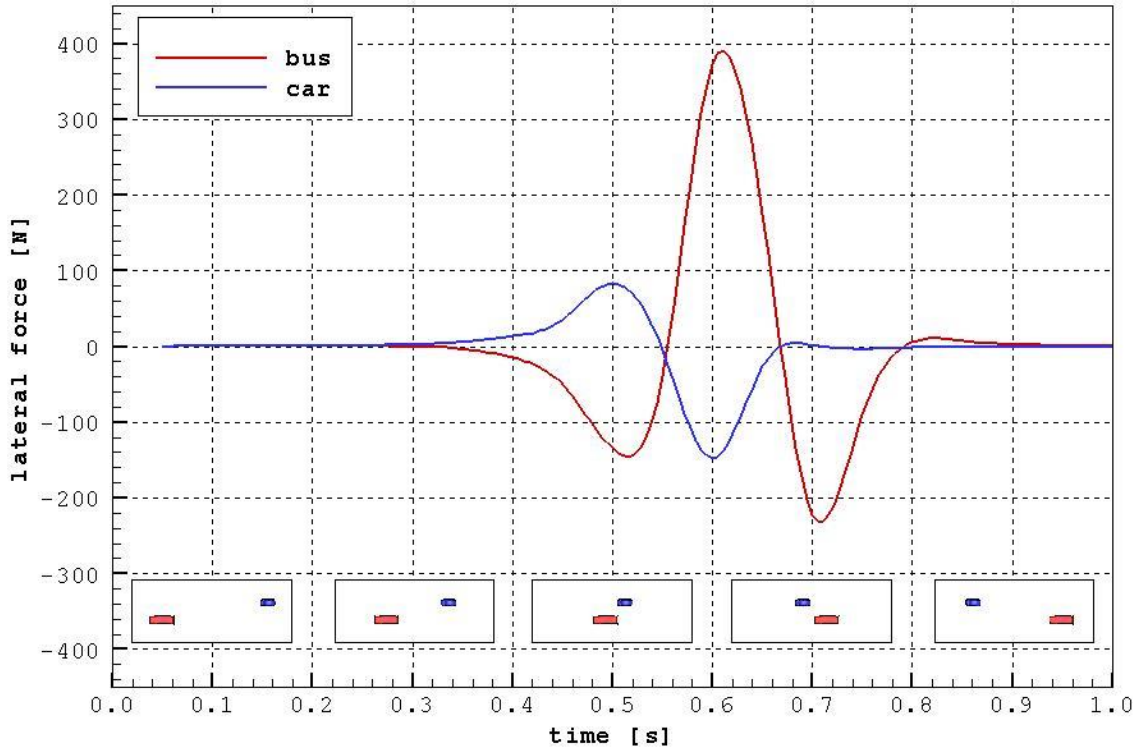
Peppe

An aerodynamic problem: the Terrafugia sky-car case (2)

One Friday of 9 years ago a researcher from CIRA asked me an idea about the feasibility of the evaluation of the aerodynamic interference between the Terrafugia Sky Car and a truck crossing on a highway at high speed.
The CIRA CFD people estimation was about 2 months (with the technology of that age!).
The Tuesday after that Friday the CIRA researcher found an e-mail with this solution…

An aerodynamic problem: the Terrafugia sky-car case (3)





An aerodynamic problem: the Terrafugia sky-car case (4)

Oggetto:R: aggiornamento sky-car
Data: Wed, 16 May 2007 11:02:56 +0200
Mittente: Giuseppe Mingione <g.mingione@cira.it>
A:farolito@tiscali.it
CC:denicola@unina.it

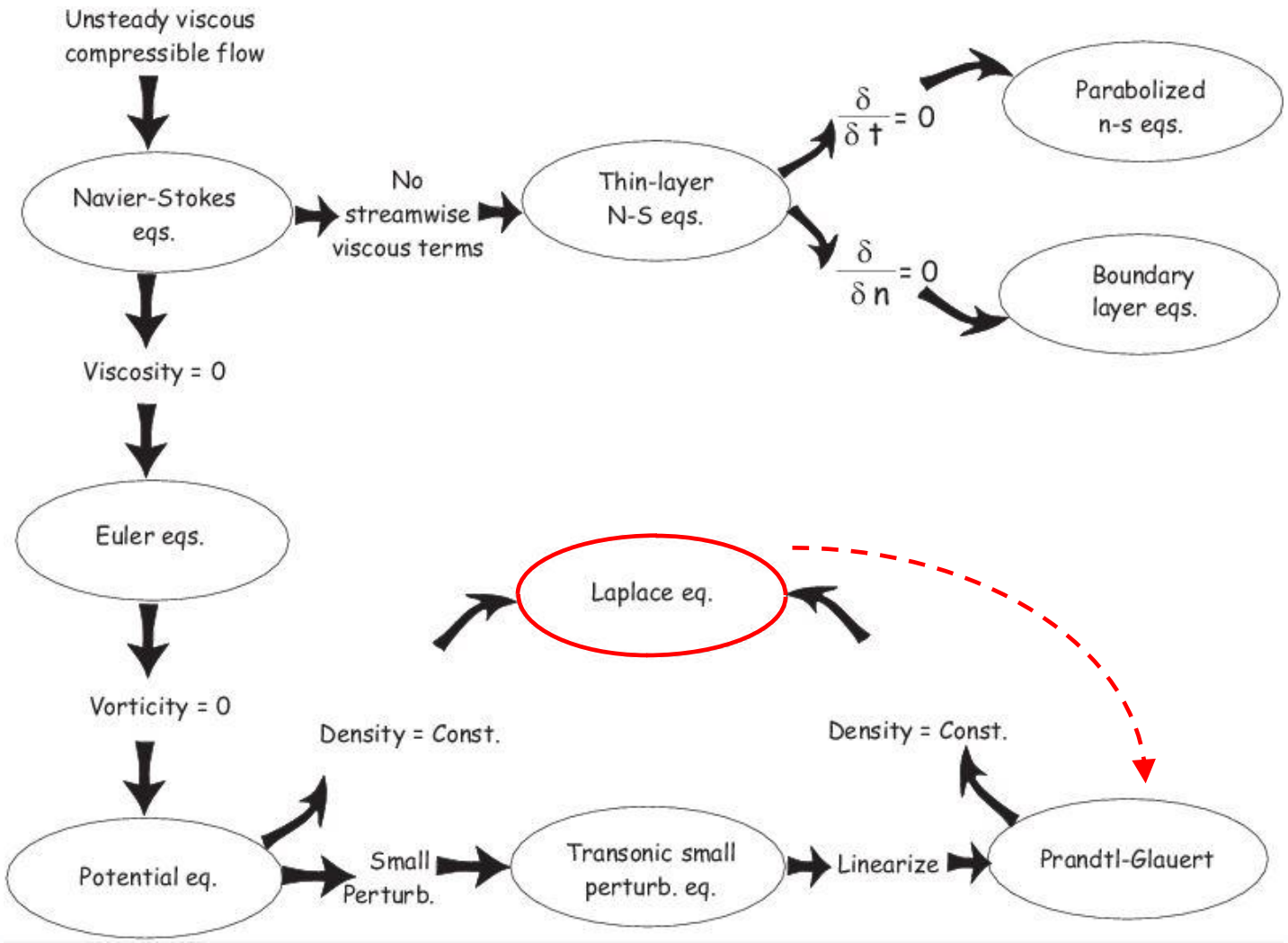
Incredibile e complimenti, sei stato più veloce della luce,

grazie mille
Peppe

-----Messaggio originale-----
Da: farolito@tiscali.it [mailto:farolito@tiscali.it]
Inviato: mercoledì 16 maggio 2007 8.48
A: g.mingione@cira.it
Cc: denicola@unina.it
Oggetto: aggiornamento sky-car

...alla fine ho trovato un pò di tempo e ne ho approfittato per fare subito un test!
in allegato troverai una gif animata indicativa della simulazione fatta, un'immagine con la pannellazione e una con l'andamento del carico laterale sulla sky-car.
Naturalmente ho dovuto fare una serie di assunzioni, a partire dalla geometria, ricavata a occhio, ma anche per alcune impostazioni del codice. Comunque sia si tratta di dettagli che possiamo rimandare al caso reale. Spero che come demo possa essere significativa, ma se hai altre idee o richieste, o semplicemente necessità di altre immagini, basta chiedere!
ciao
paolo

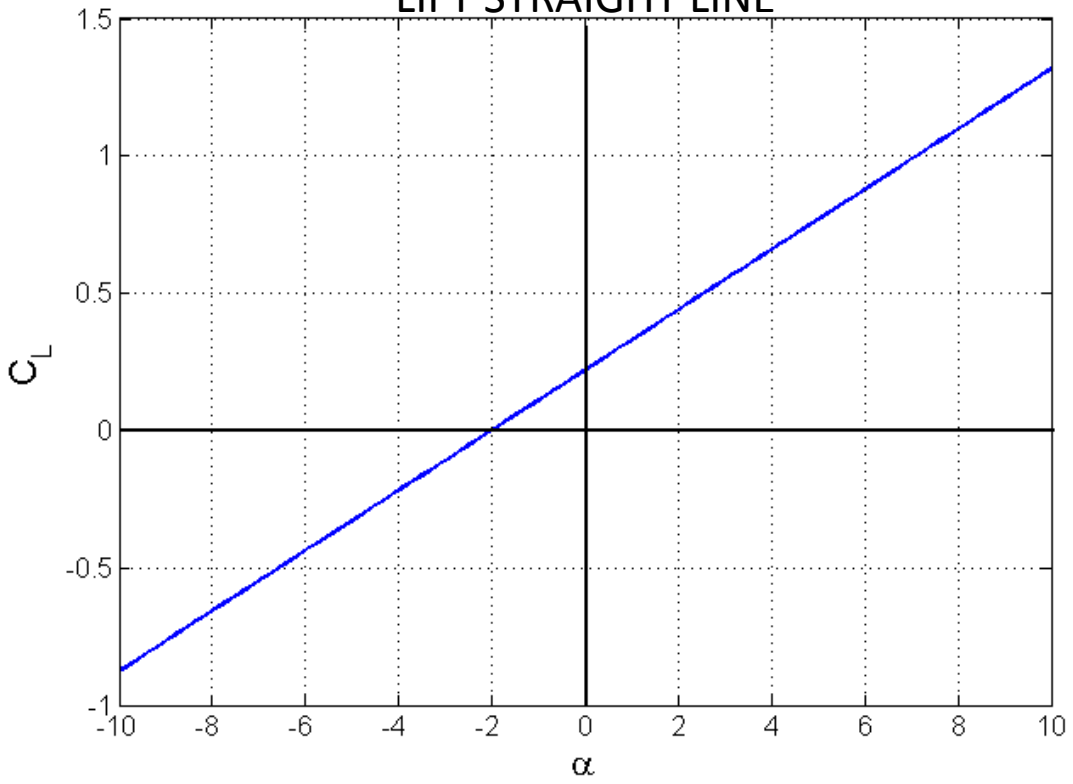
The Vorton Panel Methods Collocation



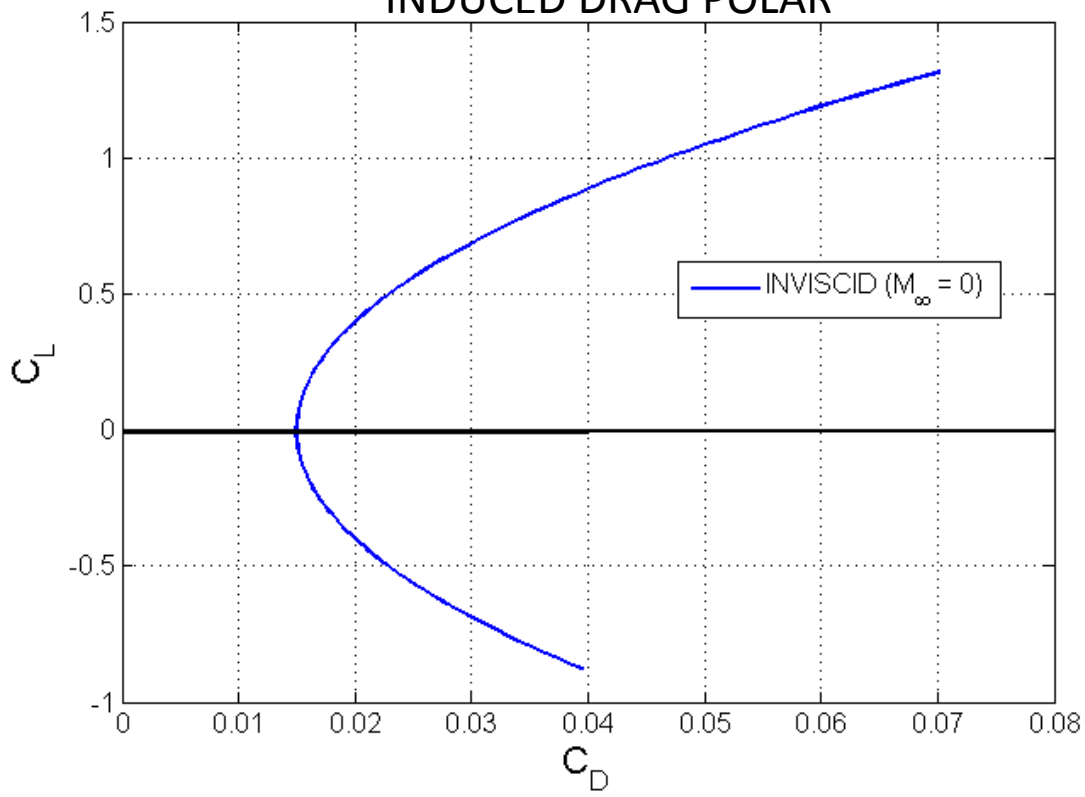
NOTE: THE LAPLACE PROBLEM SOLUTIONS ARE PROJECTED ON THE PRANDTL-GLAUERT MODEL FOR LINEARIZED COMPRESSIBLE FLOW FIELDS:

- SUBSONIC FLOW FIELDS (EVERY AIRPLANE, SUBSONIC CRUISE)
- SUPERSONIC APPLICATIONS (CONCORDE!)

LIFT STRAIGHT LINE



INDUCED DRAG POLAR



The Vorton Panel Method

WAKES SHOULD BE MODELED WITH THE PROPER SINGULARITY DISTRIBUTIONS: VORTICITY, DOUBLET OR VORTONS

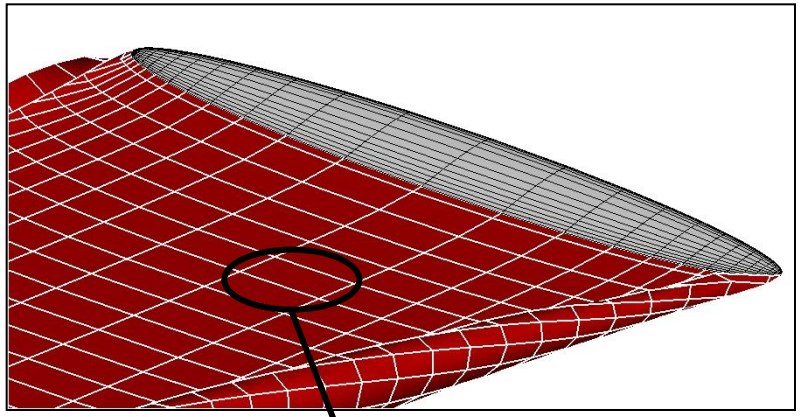
NOTE: IN THE EXACT APPROACH (NOT THE PRANDTL THEORY!) THE PROBLEM IS NON-LINEAR (WAKES ARE NOT KNOWN A PRIORI)

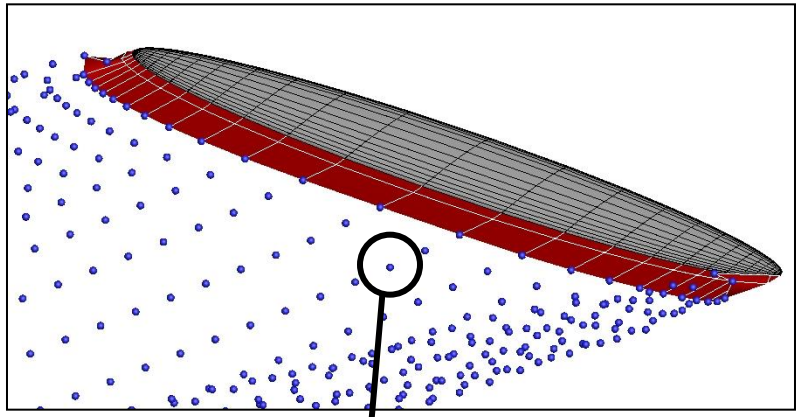
WE CURRENTLY USE AN ADVANCED PANEL METHOD BASED ON

- SOURCES AND DOUBLETS FOR SURFACE PANELS AND
- VORTONS, I.E. CONCENTRATED VORTICITY ELEMENTS, FOR THE PROPER TREATMENT OF THE INTERACTIONS

THE WAKE IS REPRESENTED BY A GRID OF VORTONS, OR VORTICITY BLOBS. VORTONS ARE NEEDED TO AVOID THE "CLASSICAL" SHORTCOMINGS DUE TO THE WAKE INTERACTIONS (WAKE-BODY, WAKE-WAKE) THAT GIVE NUMERICAL INSTABILITIES LEADING TO THE EXPLOSION OF THE SOLUTION PROCEDURE

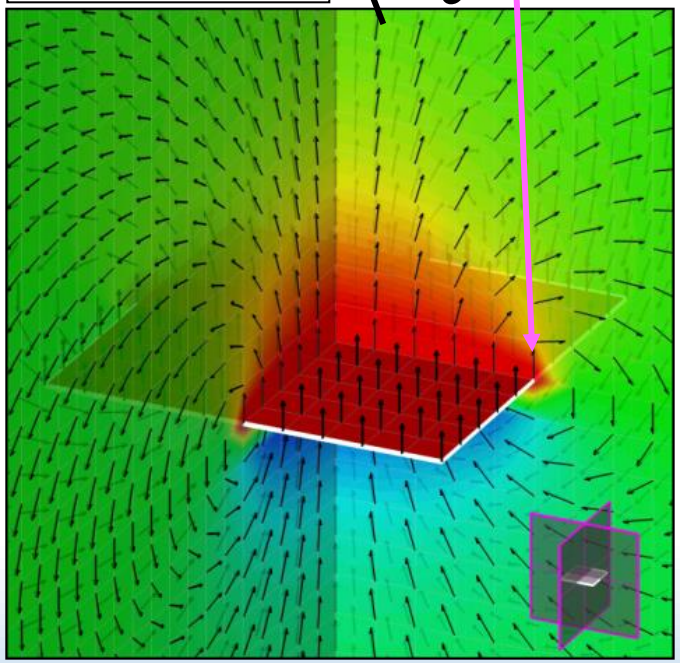
The Vorton Panel Method: Doublet wake vs Vorton wake



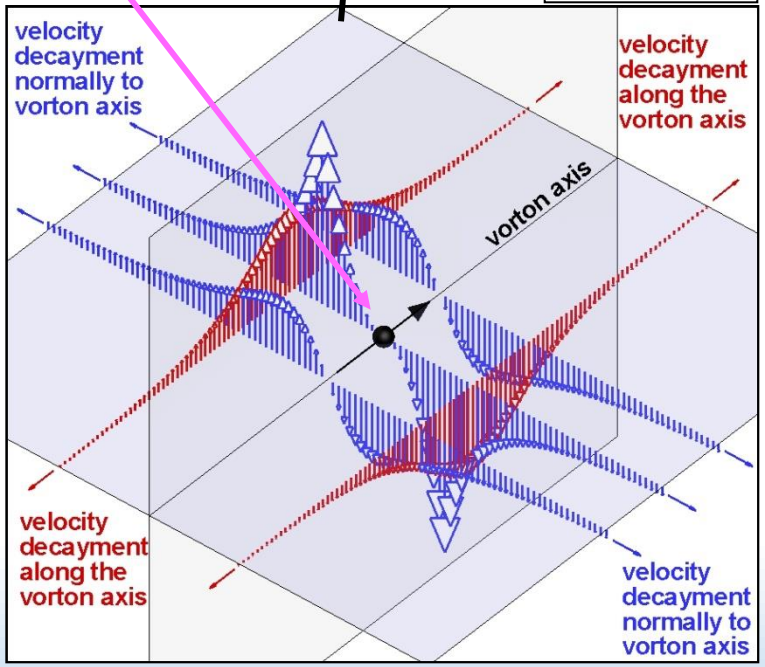


$$\int \Gamma(t)\underline{ds} = \underline{\omega}_v(\underline{r},t)$$

Vortex ring

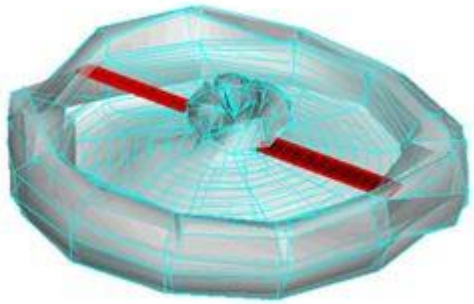


Vorton

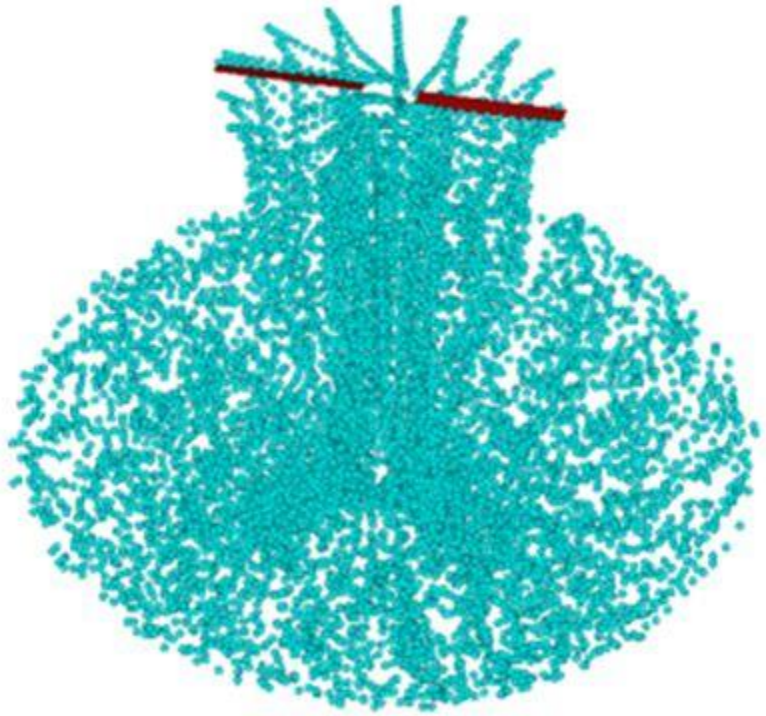


The Vorton Panel Method: Doublets vs Vortons

CLASSICAL DOUBLET WAKES CAN BE DIFFICULT (OR IMPOSSIBLE) TO MANAGE…



…VORTONS ARE EASIER TO MANAGE

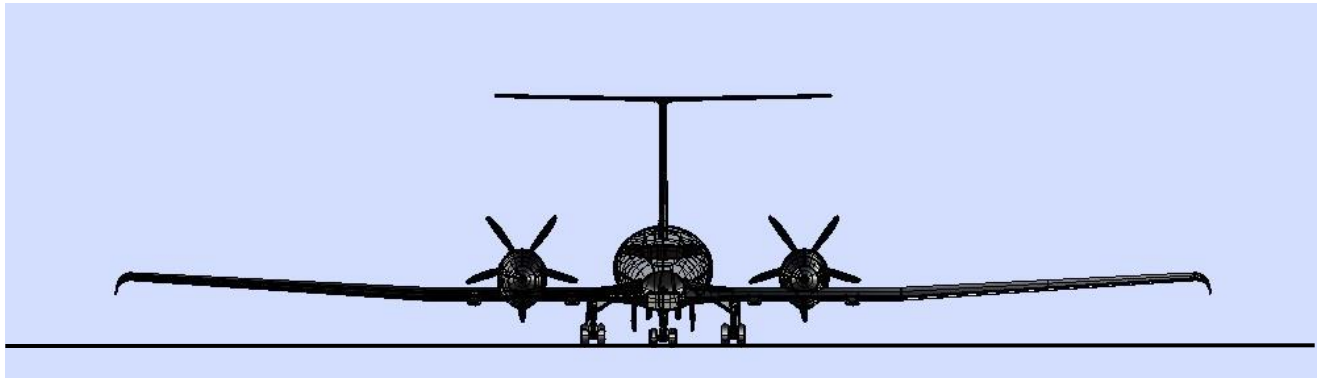


THE ANIMATION ON THE LEFT SHOWS THE DIFFICULTIES OF THE CLASSICAL DOUBLET WAKE MODEL AFTER FEW REVOLUTIONS WHILE THE VORTON WAKE HAS NO DIFFICULTIES ALSO AFTER 20 REVOLUTIONS

Another aerodynamic problem: an accident at take-off (1)

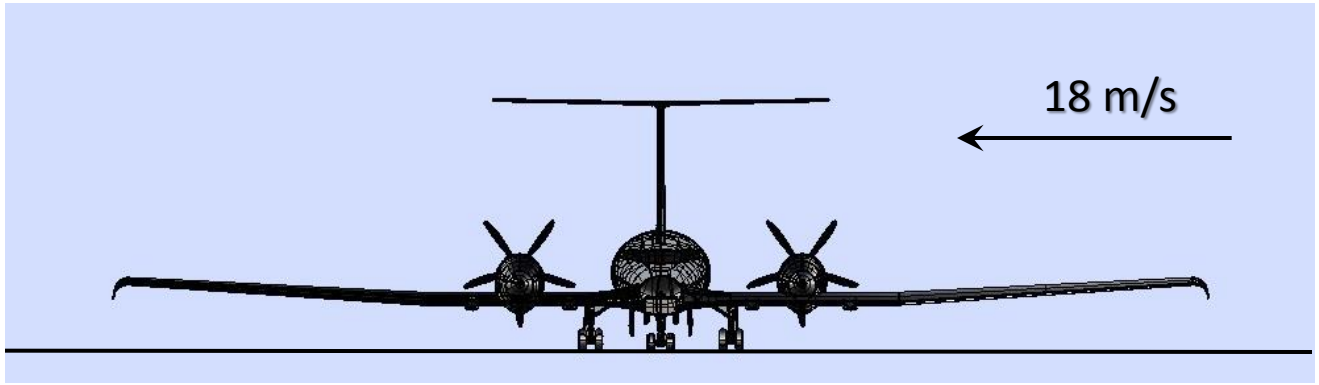
Another aerodynamic problem: an accident at take-off (2)

- AIRPLANE AT REST
- MAX THRUST
- BRAKES ON



+

A SUDDEN LATERAL GUST



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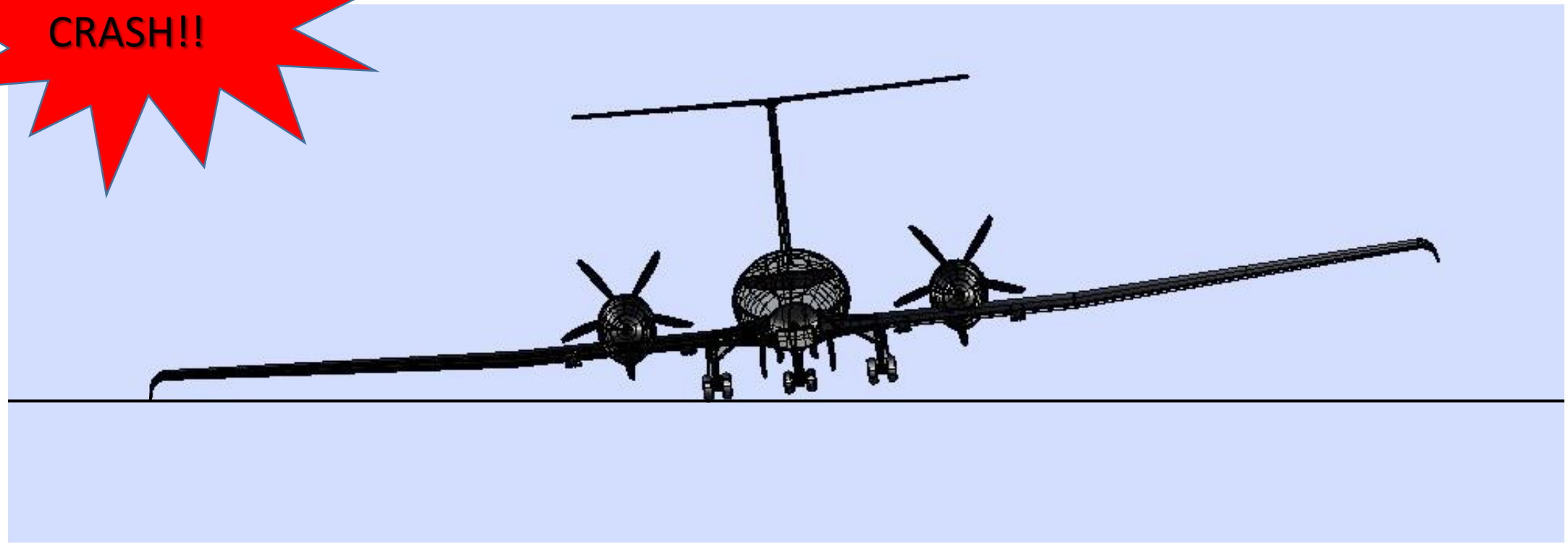
Another aerodynamic problem: an accident at take-off (3)

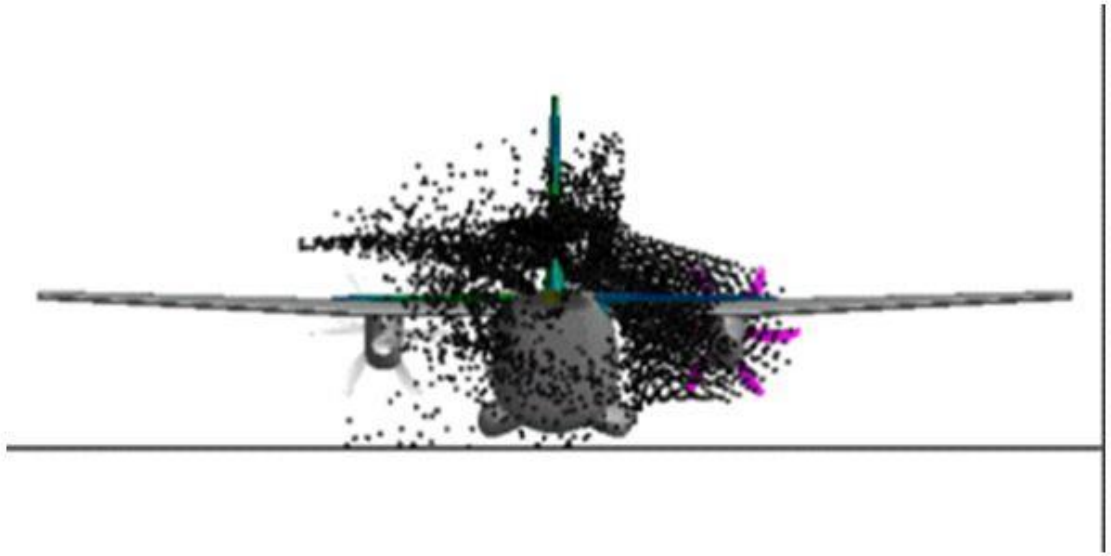
THE EFFECT…

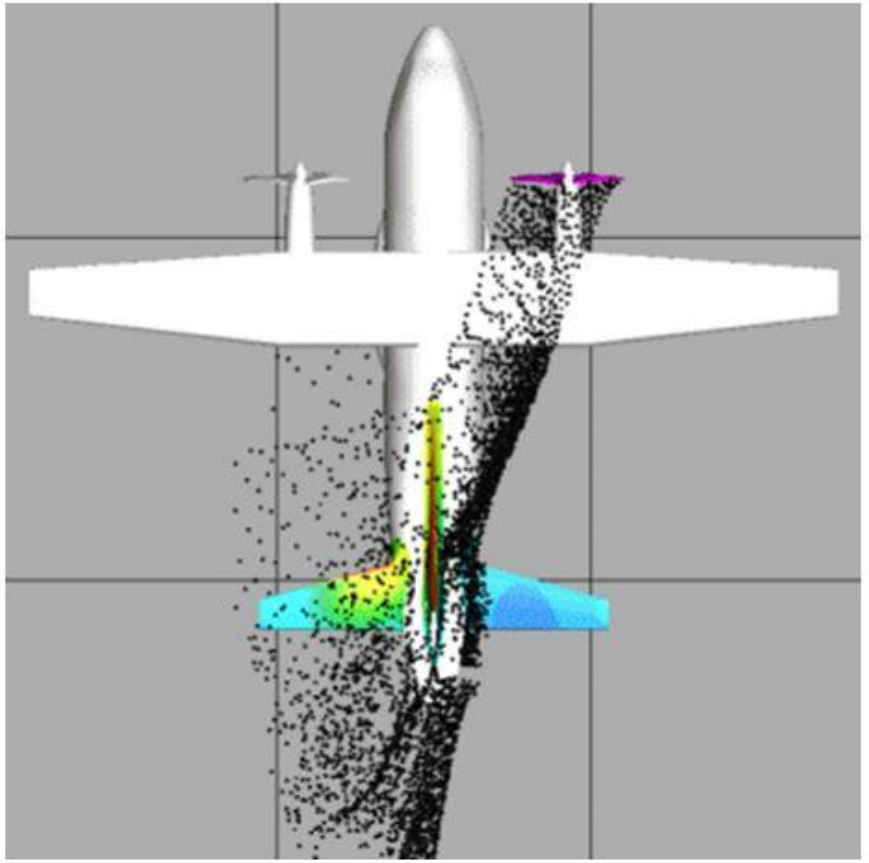


…WITH NON MINOR DAMAGES: WHY?

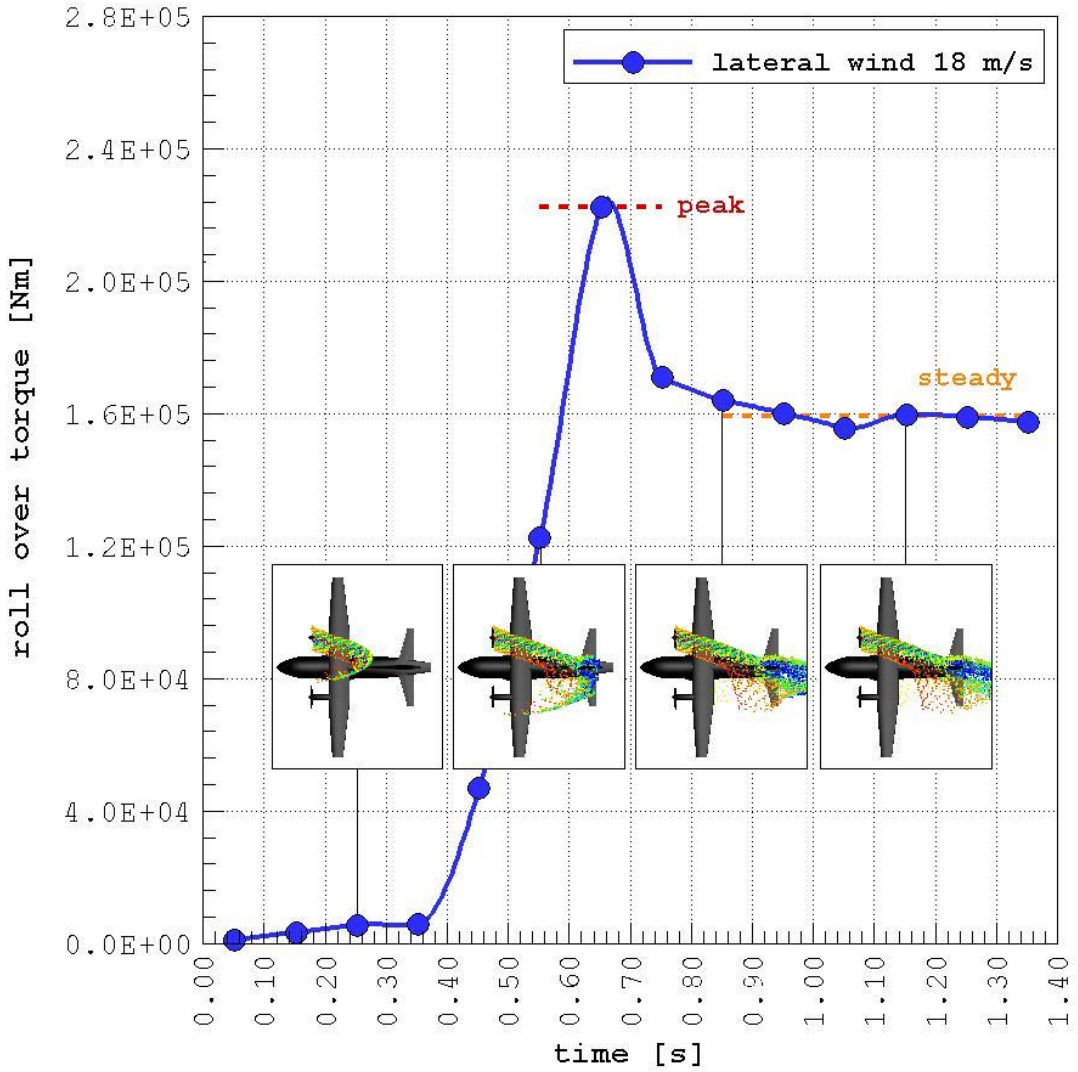
Another aerodynamic problem: an accident at take-off (4)

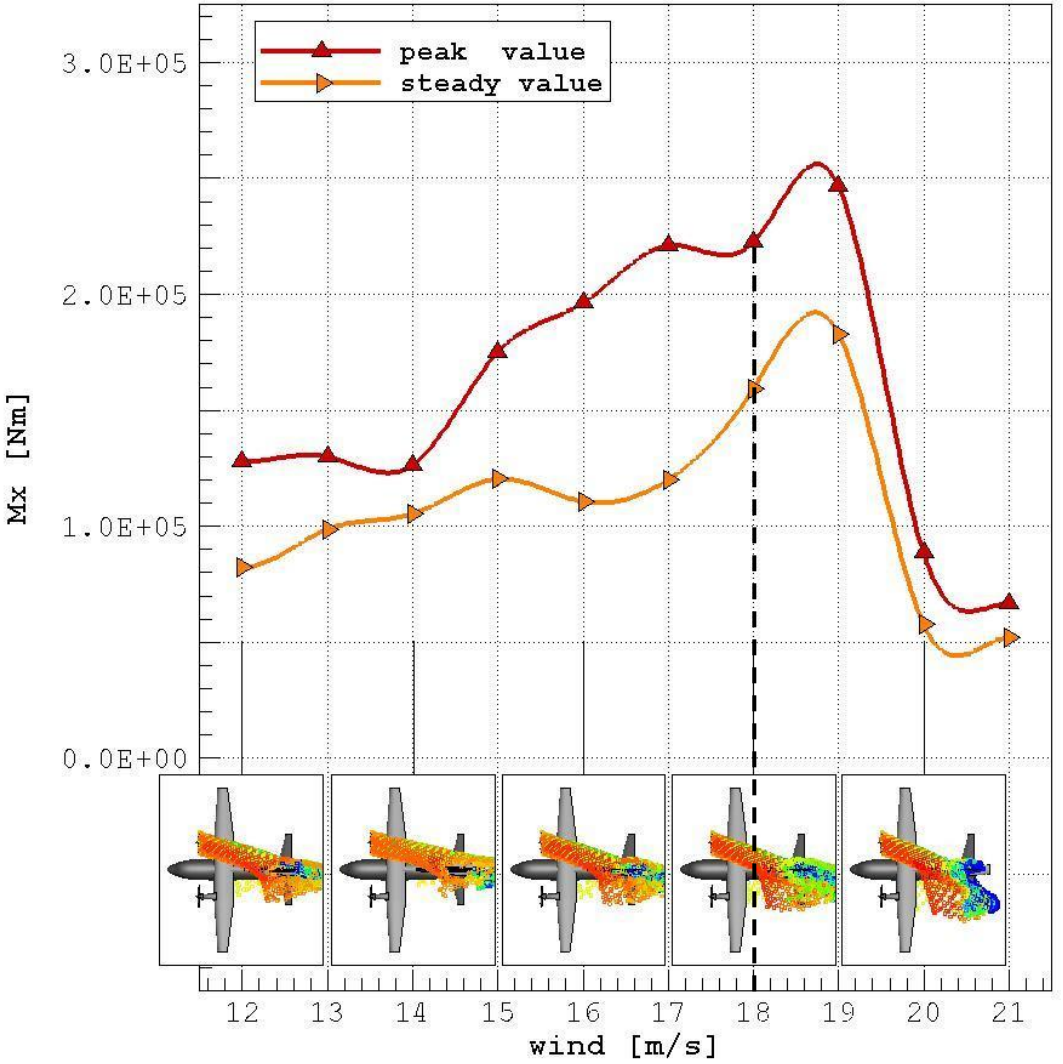
AN EXPLANATION





Another aerodynamic problem: an accident at take-off (5)

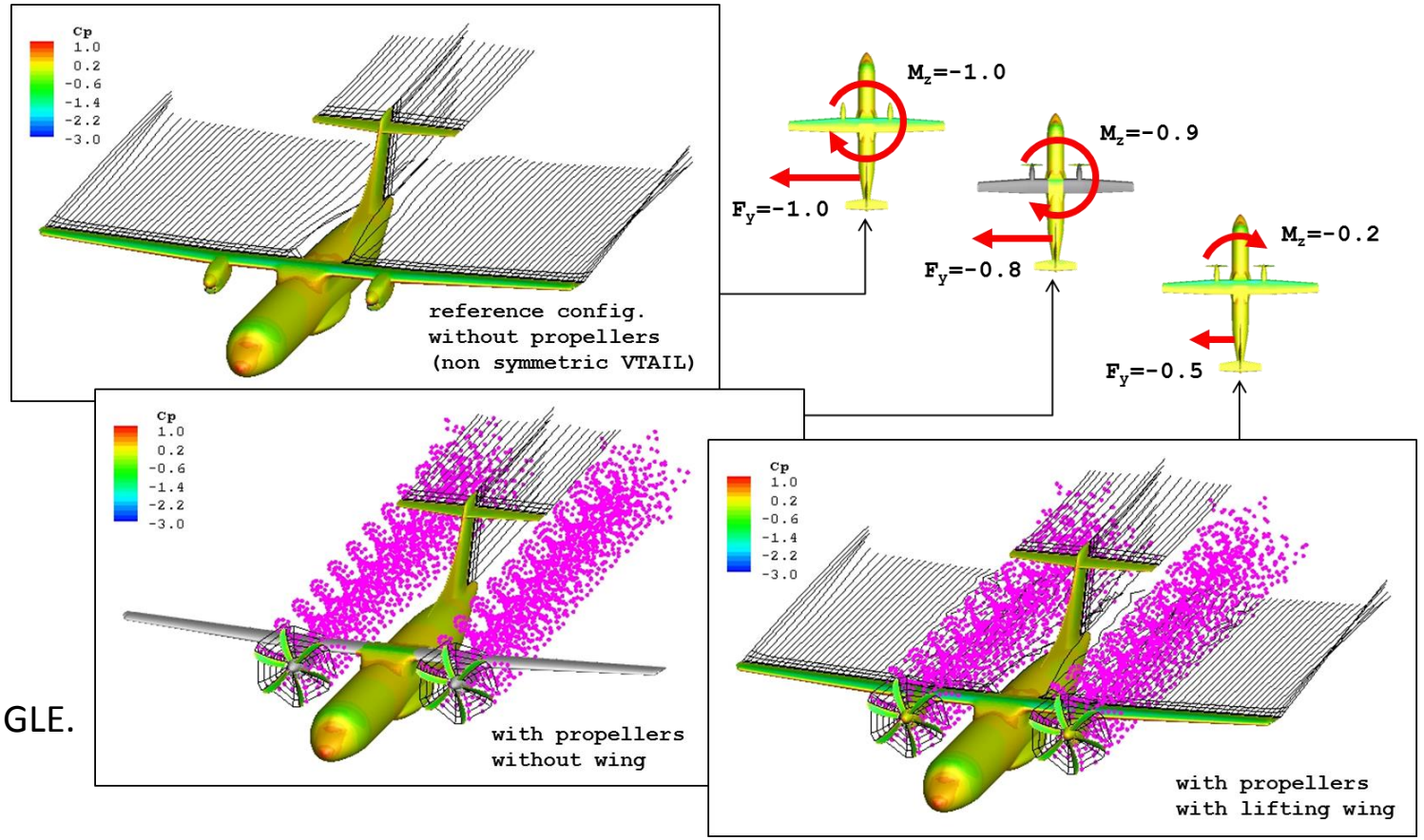




Current applications

- AIR REFUELING (RSV): CERTIFICATION OF A TURBOPROP AIRCRAFT REFUELING (TANKER: JET OR TURBOPROP);
- CONVENTIONAL ROTORS;
- TILT ROTOR;
- PRELIMINARY DESIGN.

Preliminary design: choice and setting of the vertical tail of an airplane equipped with two co-rotating propellers



TYPICALLY DIFFERENT ENGINEERING SOLUTIONS ARE

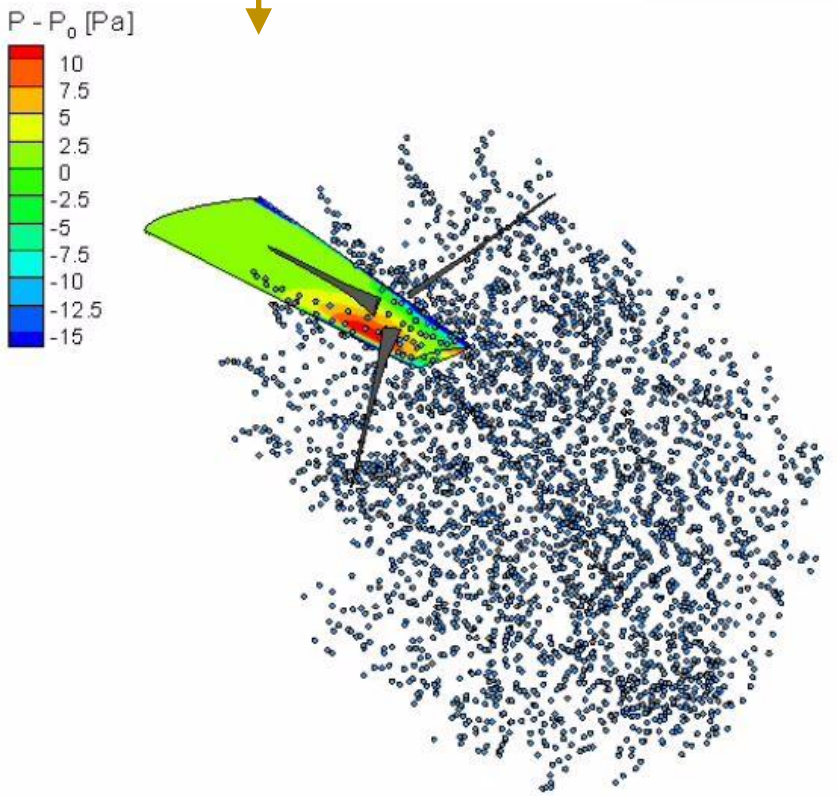
- THE SECTION IS A NON-SYMMETRIC AIRFOIL;
- THE (SYMMETRICAL) SECTION HAS AN INCIDENCE ANGLE.

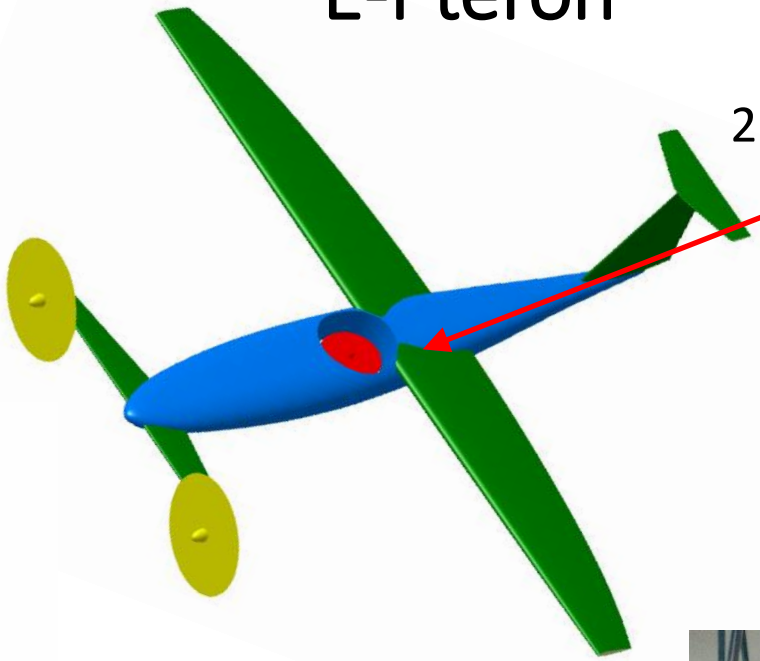
A PROPER STUDY OF THE STABILITY DERIVATIVES AND AN INVESTIGATION ON THE INTERFERENCE BETWEEN THE WAKE OF THE PROPELLERS AND THE TAIL, IN ANY FLIGHT CONDITION, ARE NEEDED FOR A CORRECT DESIGN AND FOR THE CERTIFICATION PROCEDURE.

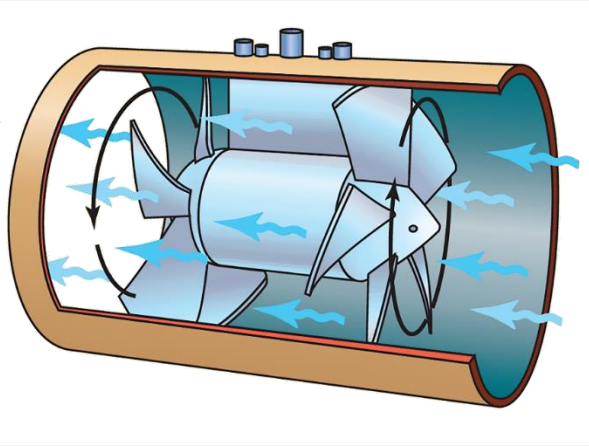
E-Pteron

2 TILT ROTORS

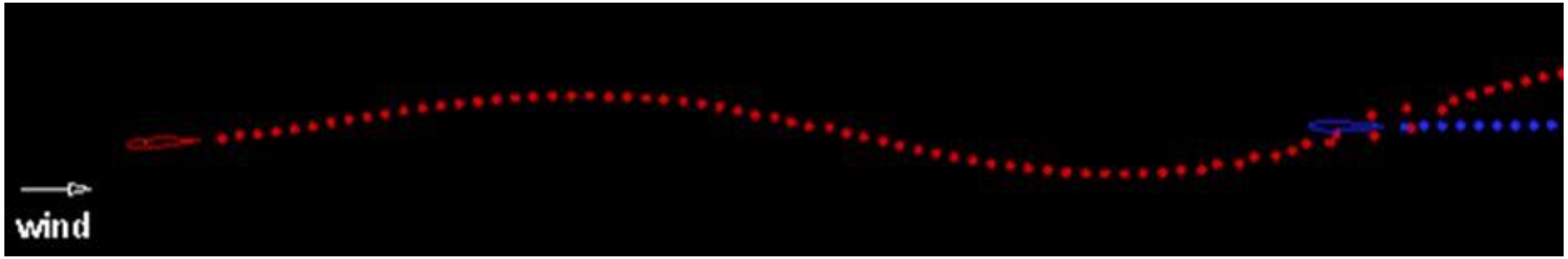
2 CO-AXIALLY-CONTRA-ROTATING ROTORS







Air refueling



POSSIBLE APPLICATION

EVALUATION OF THE TANKER WAKE EFFECTS ON THE RECEIVER PROPELLERS IN ORDER TO VERIFY IN-FLIGHT REFUELING MANOEUVRE.

ACADEMIC FALLOUT - UNINA

A NUMBER OF PEOPLE ATTENDING THIS MEETING COMES FROM UNIVERSITY OF NAPLES AND SHOULD BE INTERESTED TO THIS SHORT REMARK CONCERNIG E-LEARNING.

COURSE OF AIRCRAFT AERODYNAMICS -FUNDAMENTAL: 1 CREDIT (OF 9) IS ON NUMERICAL AERODYNAMICS (I INTRODUCED THIS NOVELTY EIGHT YEARS AGO WHEN THE OFFICIAL CFD COURSE WAS CONVERTED TO OPTIONAL).

NEXT ACADEMIC YEAR (OCTOBER 2015) APPLICATIONS OF THIS CREDIT WILL BE PERFORMED BY USING A CLOUD ENVIRONMENT. THIS SEEMS NOTEWORTHY: ABOUT 120 STUDENTS SIMULTANEOUSLY OPERATING BY USING CFD CLOUD FACILITIES.

THESE CLOUD CFD FACILITIES WILL ALSO BE USED DURING THE COURSE OF ROTARY WING AERODYNAMICS (OPTIONAL, 6 CREDITS ON THEORY + 3 CREDITS ON NUMERICS, ABOUT 20 STUDENTS PER YEAR). MOREOVER THE VORTON TECHNOLOGY IS FUNDAMENTAL FOR THIS COURSE.