Università degli Studi di Napoli Federico II

DIPARTIMENTO DI INGEGNERIA INDUSTRIALE
SEZIONE INGEGNERIA AEROSPAZIALE

**CEAS –TCAD 2014**
**4th Symposium of Collaborative Aircraft Design**

*Reference Aircraft*

# General Aviation Aircraft Design

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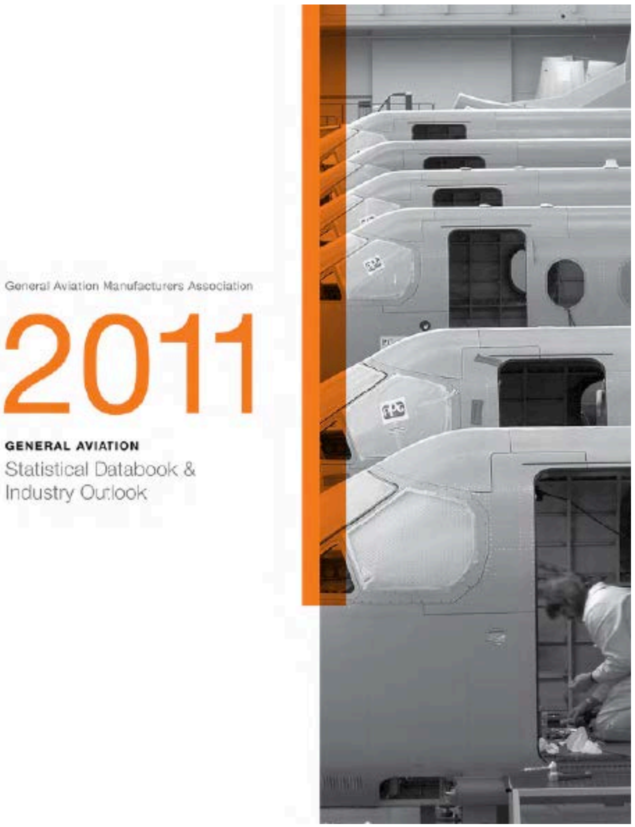
# GA and Commuter Aircraft Scenario

**GAMA** – General Aviation Manufacturers Association
Each Year Databook on General Aviation (Statistics & Industry Outlook)



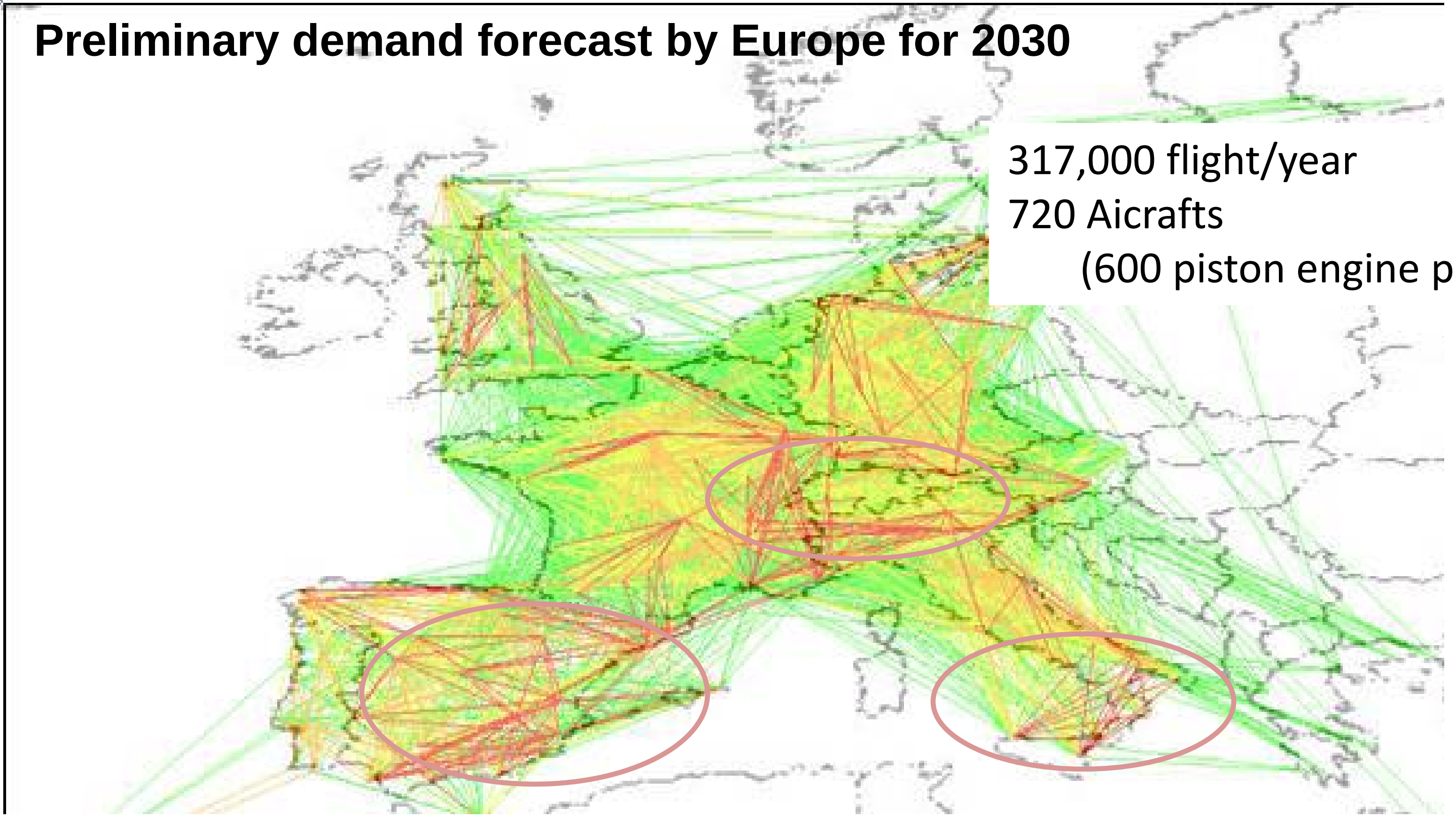

General aviation is defined as all aviation other than military and scheduled commercial airlines. Consider the scope of general aviation:

- Over 320,000 general aviation aircraft worldwide, ranging from two-seat training aircraft to intercontinental business jets, are flying today; over 223,000 of those aircraft are based in the United States.
- General aviation contributes more than $150 billion to the U.S. economy annually and employs more than 1,265,000 people.
- In the U.S., general aviation aircraft fly almost 25 million hours and carry 166 million passengers annually.
- There are nearly 4,000 paved general aviation airports open to the public in the U.S. By contrast, scheduled airlines serve less than 500 airports.
- Over two-thirds of all the hours flown by general aviation aircraft are for business purposes.
- General aviation is the primary training ground for most commercial airline pilots.

# Possible future Scenario

## SAT – Small Air Transport Roadmap (EC Research fin. Project)

**Preliminary demand forecast by Europe for 2030**



317,000 flight/year
720 Aicrafts
(600 piston engine prop)

# Commuter Aircraft Scenario

GAMA Data-book is an impressive source of data and statistics for those interested in GA, and it is mainly related to US.

## Average Age of Registered General Aviation Fleet

2.9 Average Age of Registered General Aviation Fleet (2005-2010)

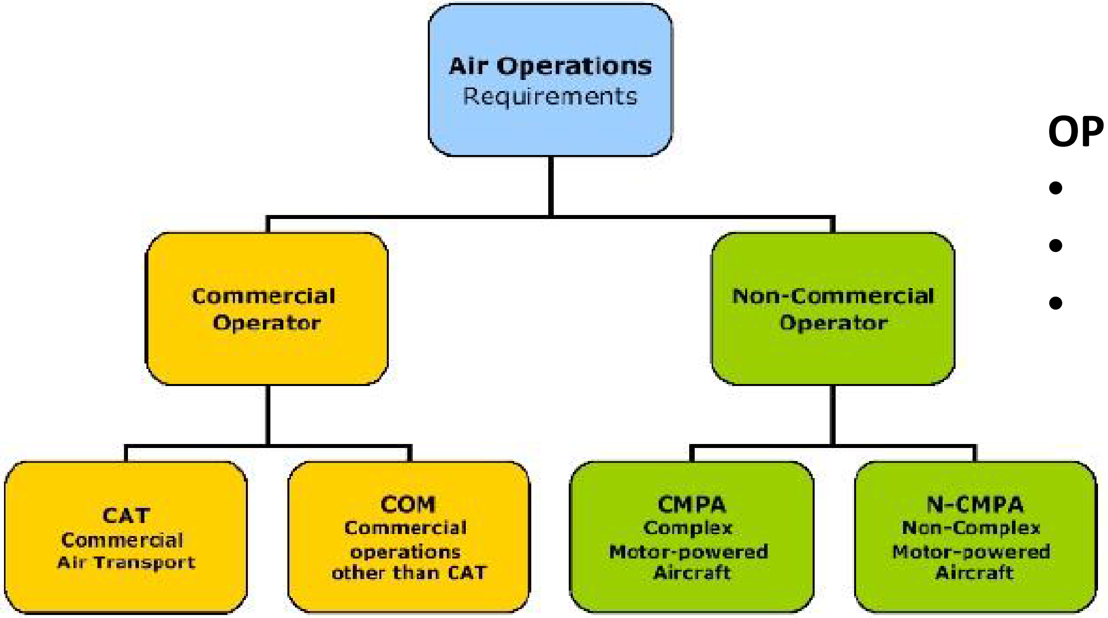
| Aircraft Type | Engine Type | Seats | Average Age in 2005 in Years | Average Age in 2006 in Years | Average Age in 2007 in Years | Average Age in 2008 in Years | Average Age in 2009 in Years | Average Age in 2010 in Years |
|---|---|---|---|---|---|---|---|---|
| **Single-Engine** | Piston | 1-3 | 37 | 38 | 38 | 48.1 | - | - |
| | | 4 | 35 | 36 | 36 | 38.2 | - | - |
| | | 5-7 | 30 | 31 | 32 | 33.5 | - | - |
| | | 8+ | 44 | 44 | 43 | 49.3 | - | - |
| | | All | - | - | - | - | 42.2 | 46.3 |
| | Turboprop | All | 13 | 10 | 14 | 13.6 | 16.1 | 15.2 |
| | Jet | All | 34 | 34 | 35 | 44.4 | 44.0 | 44.1 |
| **Multi-Engine** | Piston | 1-3 | 32 | 32 | 33 | 48.9 | - | - |
| | | 4 | 35 | 35 | 35 | 36.0 | - | - |
| | | 5-7 | 36 | 36 | 39 | 39.3 | - | - |
| | | 8+ | 38 | 39 | 40 | 41.6 | - | - |
| | | All | - | - | - | - | 41.2 | 39.0 |
| | Turboprop | All | 25 | 26 | 27 | 28.8 | 28.0 | 27.0 |
| | Jet | All | 16 | 16 | 16 | 16.2 | 17.0 | 16.2 |
| **All Airplanes** | | | **34** | **35** | **35** | **39.3** | **39.5** | **37.3** |

# Small Aircraft Operation

**Small Aircraft Transport will serve:**
- The need for low-intensity intercity routes
- Regions with less developed infrastructures
- The needs of European business travel

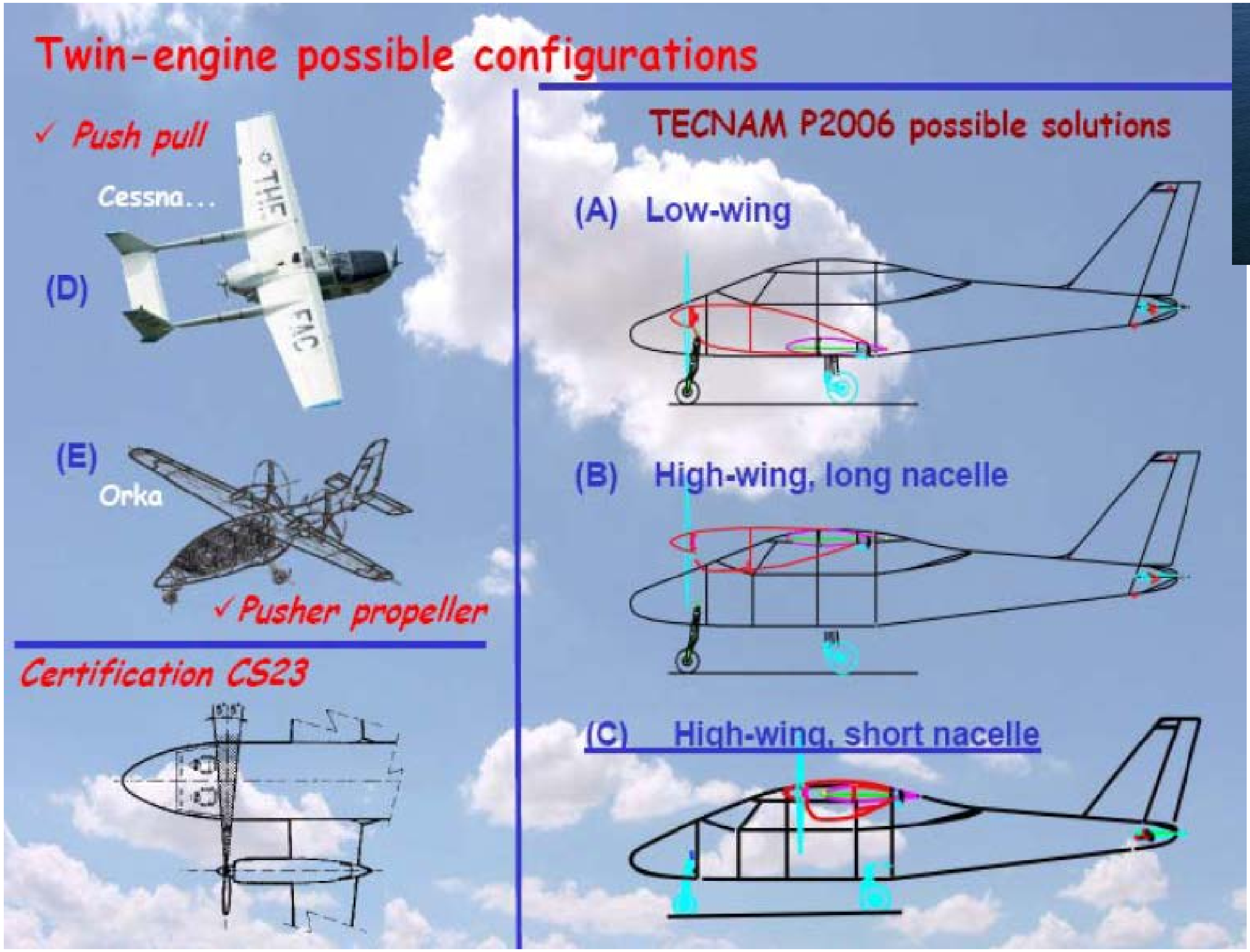
**Main Costraints**:
- REGULATORY
- OPERATIONAL
- FINANCIAL

**General Aviation** (**GA**) refers to all flights other than military and scheduled airline and regular cargo flights, both private and commercial.
**In USA the Regulatory framework is significantly different from the European one**




**OPERATIONAL CONSTRAINTS**
- **All weather** operations
- Low **maintenance** requirements
- Use of small **Airports** - **Security** issues - **Network** structure

# An example of design issues and drivers, P2006T 4-seat




**P2006T**

*Propeller location*
*Easy cabin access*
*Nacelle aerodynamic s*
*CG travel*
*Low drag*
*Wing-fus interference*
*Propeller noise*
*Engine cooling*

# Commuter Aircraft (7-20 seats)

## Some Typical Existing Airplanes


Cessna F-406


Twin Otter


Beechcraft King Air


Vulcanair A Viator

## Some Typical New or Future Airplanes


EV – 55

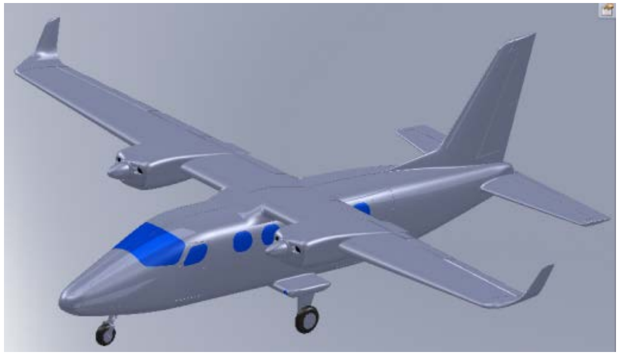

GECI Skylander

Tecnam P2012 Traveller

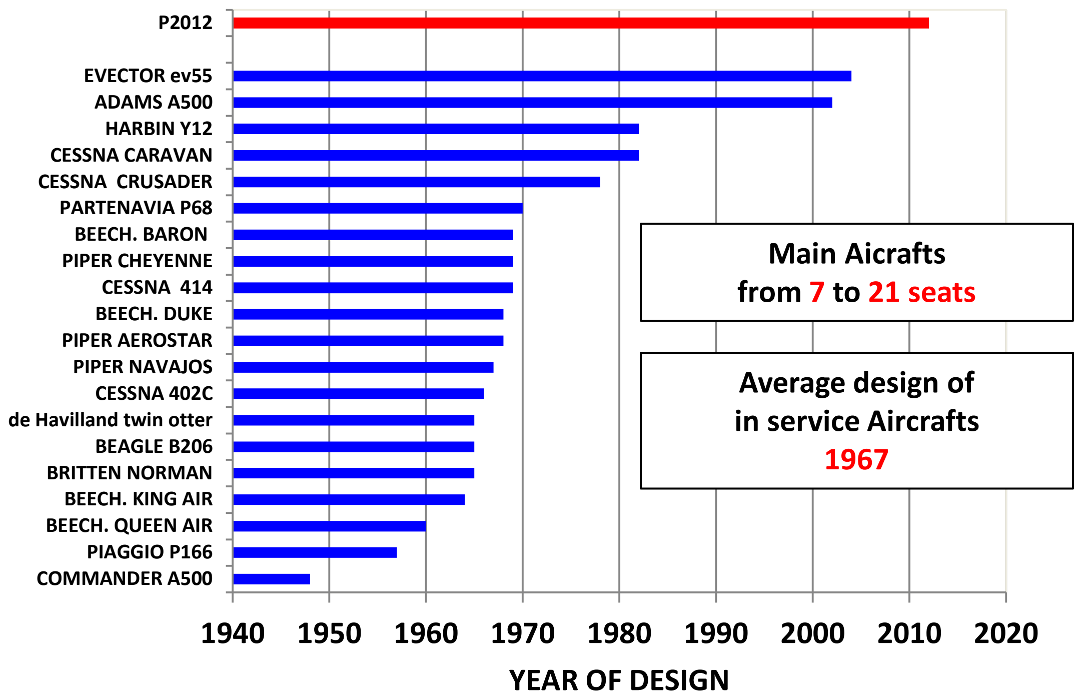
# GA and Commuter Aircraft General requirements

- Reduced Take-off and Landing distances from NOT PREPARED runways
- Engine with low SFC and possible use of MO Gas (mainly Piston Engine)
- Cruise speed of about 160-200kts
- Climb and OEI altitude operative limitations (OEI ceiling)
- Low Direct Operative Cost (DOC)
- Easy and low-cost Maintenance
- Glass cockpit
- Moderate use of composite
- FAR23, EASA CS-23 Certification
- Fixed Landing Gear (?)
- Easy to access, comfortable cabin and luggage
- Multi-purpose internal arrangement
- COMMONALITY 10 to 19 pax





# Commuter Aircraft Scenario



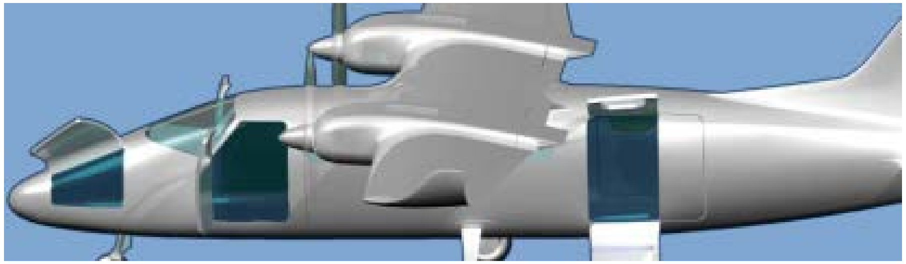


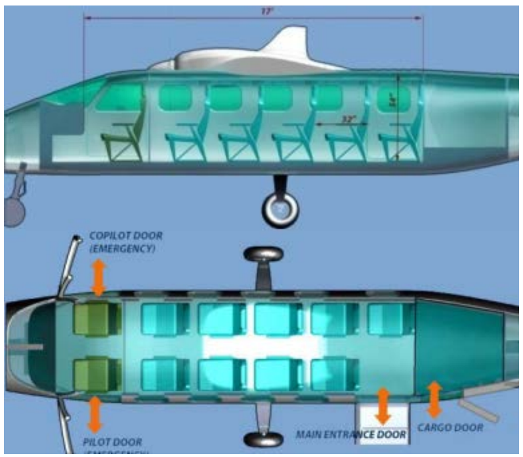


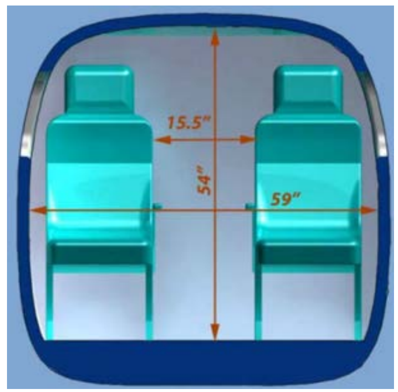

# P2012 Traveller Aircraft

QUALITY AIRCRAFT SINCE 1948 TECNAM

http://www.tecnam.com/



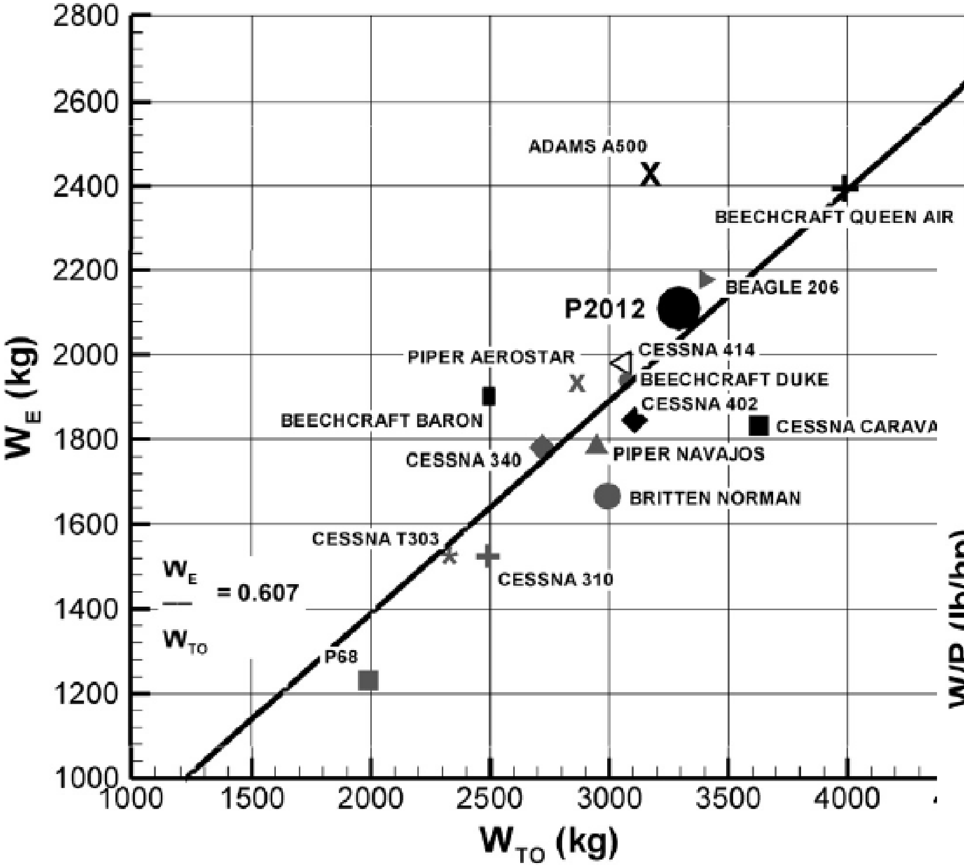


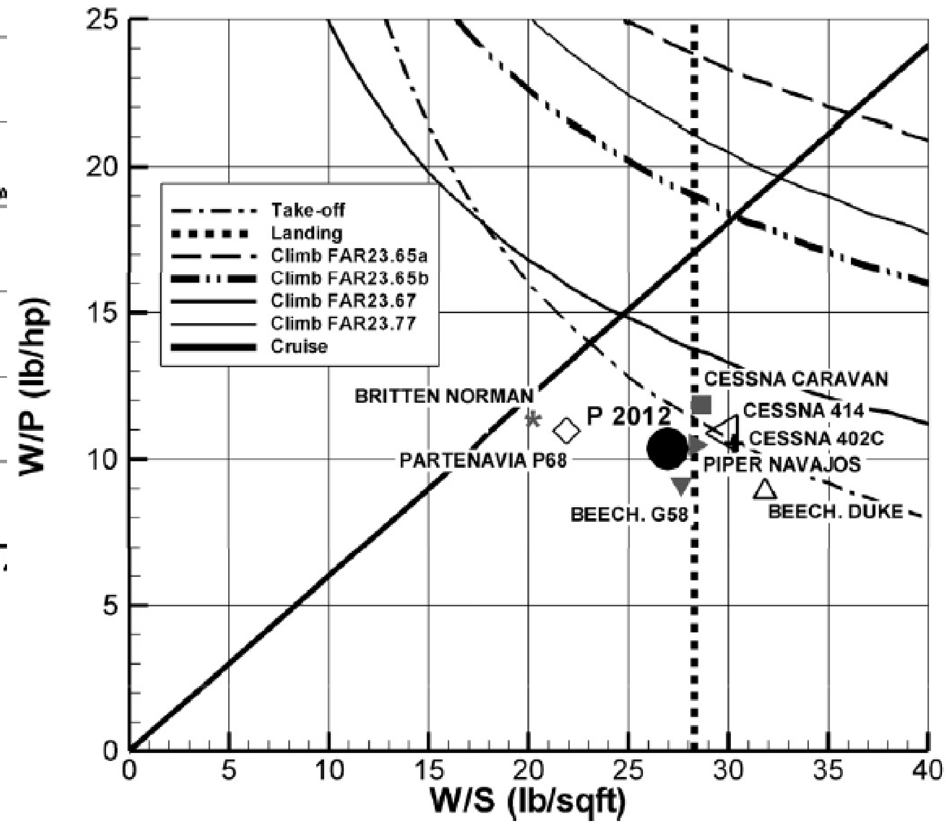




## P2012 Traveller Features:

- **Light 9-pax Aircraft**
- **High wing configuration (clearance, better accessibility, propeller location)**
- **Fixed landing gear (simple, light, low costs both operative and maintenance)**
- **Short take-off and landing distances also from not prepared surfaces**
- **Cabin design and improved cabin comfort**
- **Glass Cockpit**
- **TEO-540 Turbocharged Engine dual fuel capable (AVGAS/MOGAS) with low fuel consumption (114 l/h for 2 engines).**

# P2012 Conceptual Design

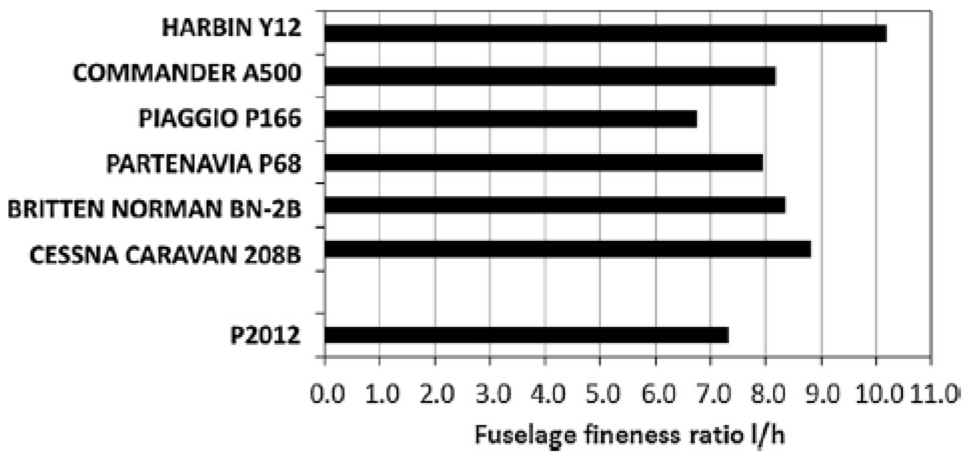


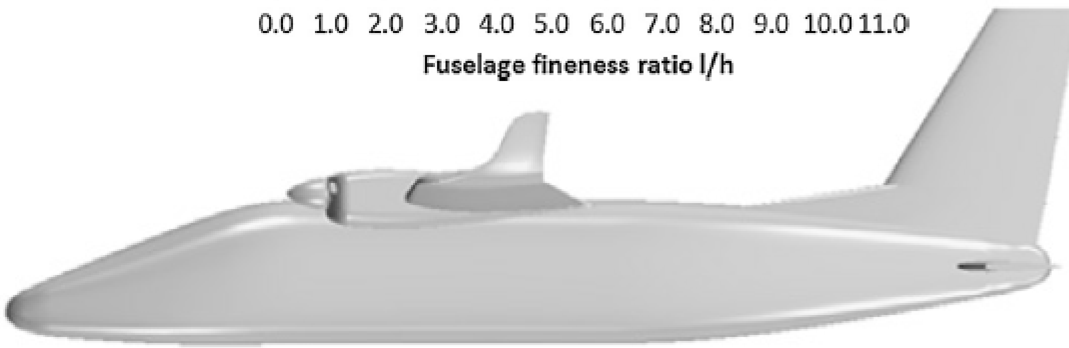



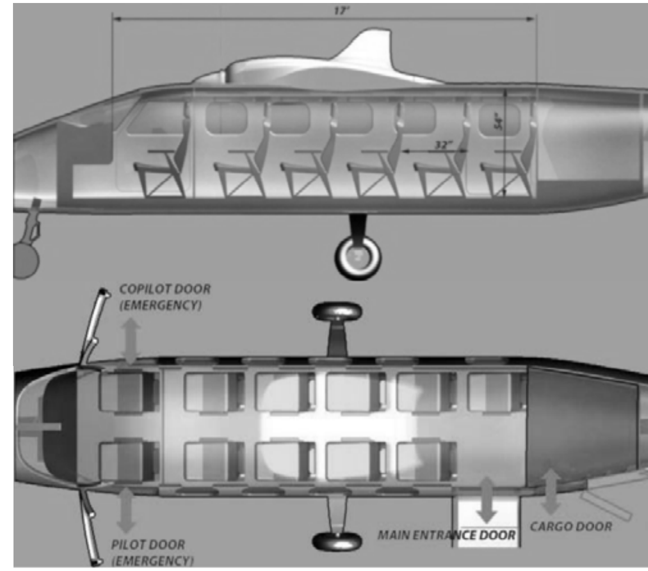

- **Weight similar to single-engine A/C**
- **Wing area and engine sizing mainly driven by Take-Off requirements**

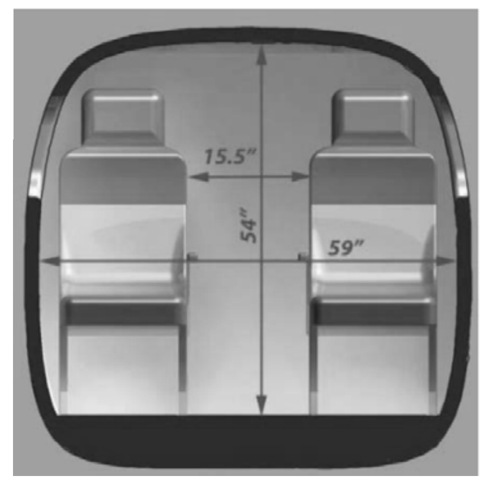
Nicolosi, F., Della Vecchia, P., Corcione, S., «Design and Aerodynamic Analysis of a Twin-engine Commuter Aircraft,» *Aerospace Science and Technology* 40(2015) 1-16

## FUSELAGE DESIGN



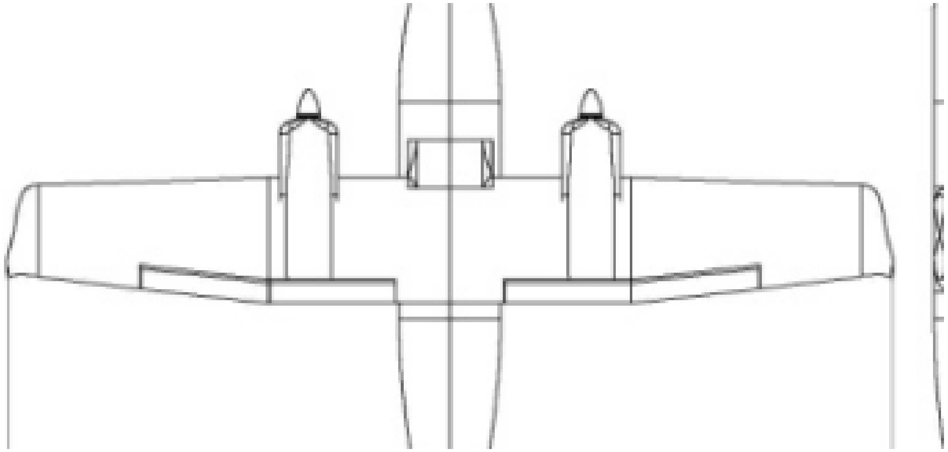



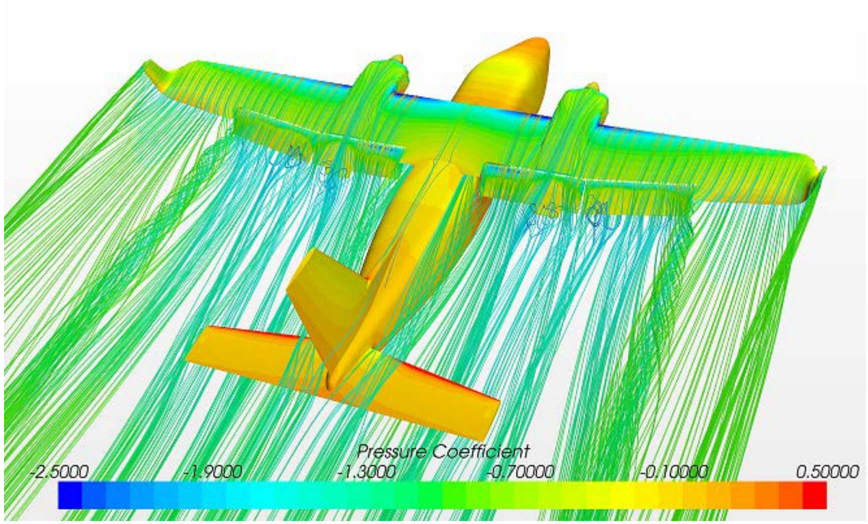


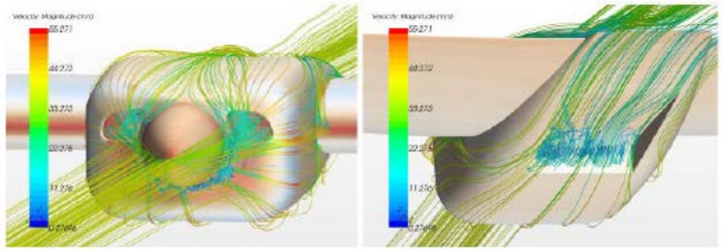




- **Pass. Comfort (32” seat pitch)**
- **Streamlined symmetrical tail shape (low drag)**
- **Upsweep carefully estimated for take-off rotation**
- **Careful aerodynamic design of Karman**

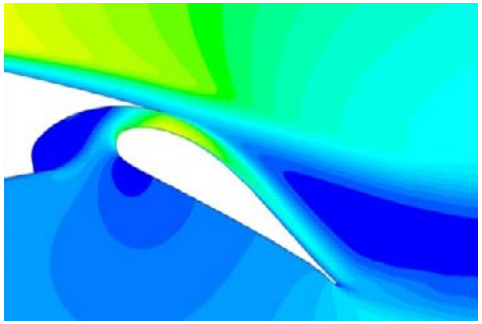
## WING DESIGN





(a) Front View (b) Back View

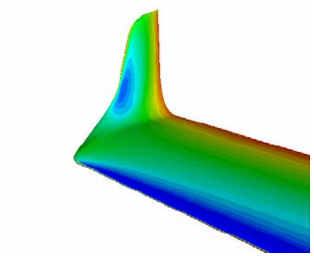


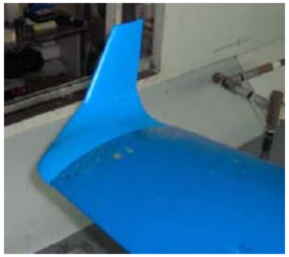
- **Wing area strongly dependent from max achievable lift coefficient (TAKE-OFF and LNDG)**
- **Integrated symmetrical nacelle (propeller clearance) => low drag and effect on lift**
- **Double tapered planform with rectangular shape for the inboard (simple inboard flap)**
- **Winglet essential for OEI climb performances**
- **Single slotted flap with sensible increase of chord => One of DESIGN DRIVERS**

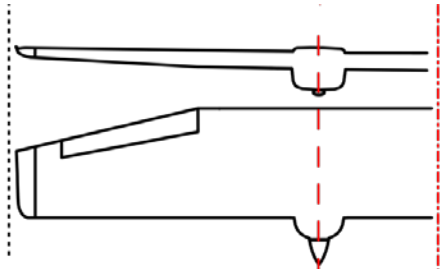
# P2012 Conceptual Design – Winglet Importance

**WINGLET EFFECT Flight Measured on P2006T**

Winglet designed through panel method opt., CFD analysis and wind-tunnel tests

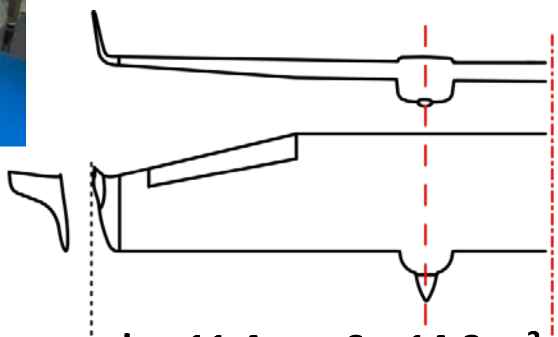






b = 11.2 m   S = 14.7 $m^2$

**First prototype, no winglets**

b = 11.4 m   S = 14.8 $m^2$

**Winglets installed**


**Oswald factor increase :**

**About +10-12%**

**Table 10  Geometrical and aerodynamic characteristics before and after winglet installation**

| | | | $C_{D0}$ | | Oswald factor, *e* | | | |
|---|---|---|---|---|---|---|---|---|
| | $S$, $m^2$ | AR | Estimated | Measured flight test | Estimated | Measured flight test | AR*e* | Max lev. speed, kt |
| No winglet | 14.74 | 8.46 | 0.0258 | 0.0248 | 0.72 | 0.71 | 6.0 | 153 |
| With winglet | 14.76 | 8.76 | 0.0260 | 0.0249 | 0.82 | 0.80 | 7.0 | 154 |

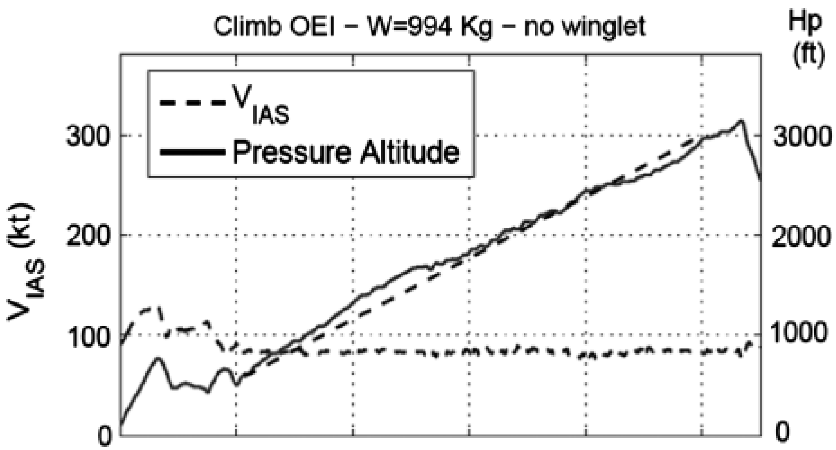
Nicolosi, F., De Marco, A., Della Vecchia, P., «Flight Tests, Performances, and Flight Certification of a Twin-Engine Light Aircraft,» *Journal of Aircraft,* Vol 48, N. 1 (2011)

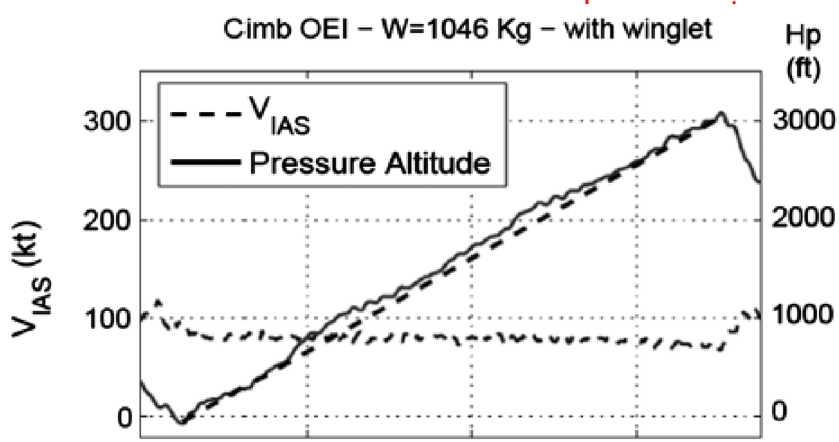
# P2012 Conceptual Design – Winglet Importance

## WINGLET EFFECT P2006T – Flight Tests

### No winglets

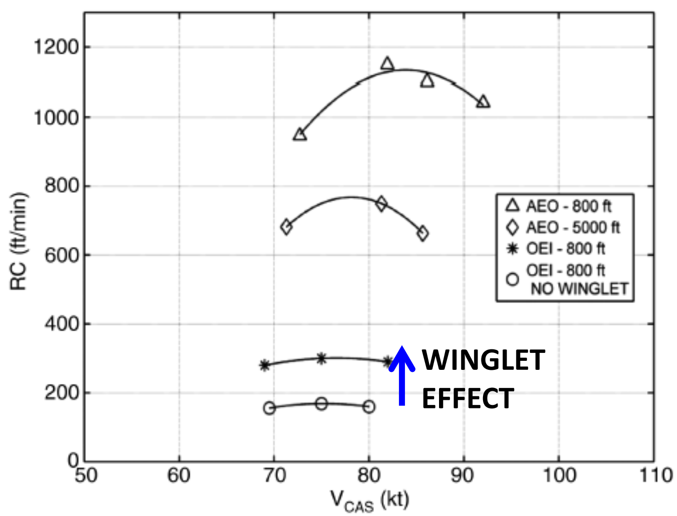
### With winglets

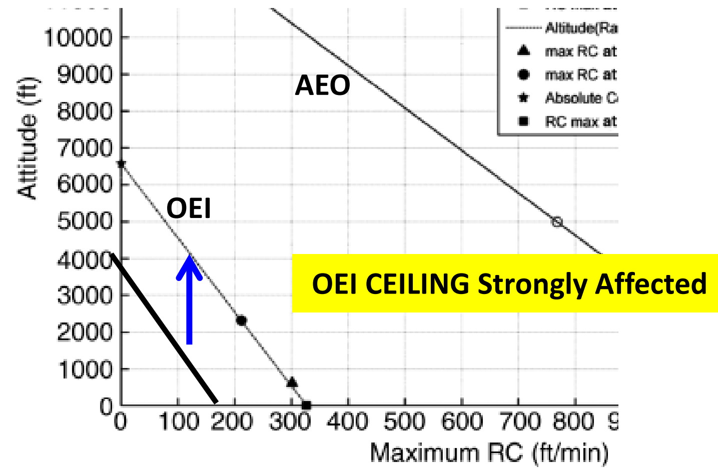



**OEI Ceiling:**

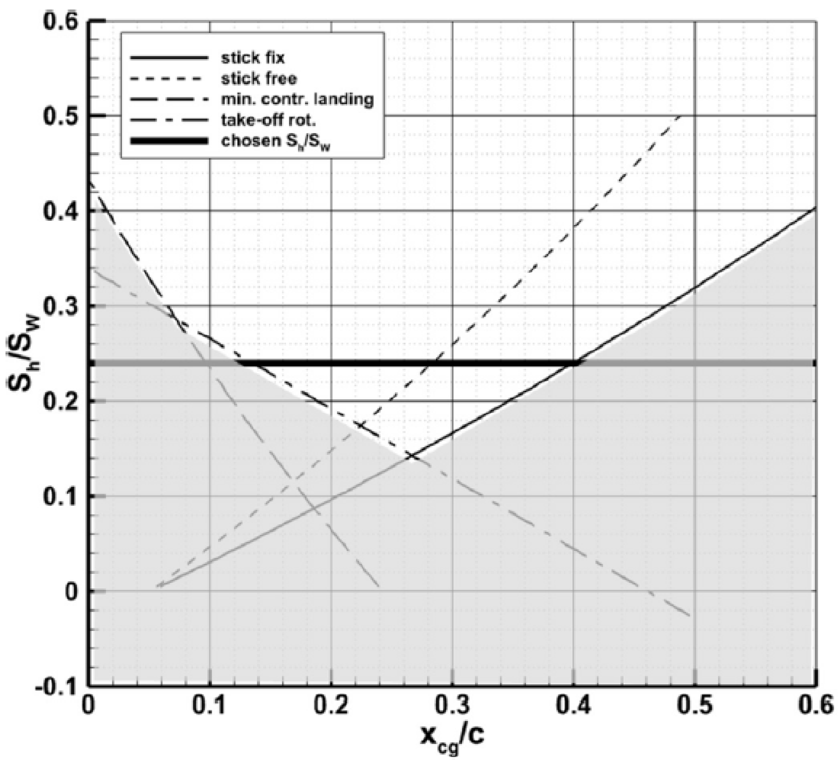
| | |
|---|---|
| **Winglet** | **No Winglet** |
| **6700 ft** | **3700 ft** |

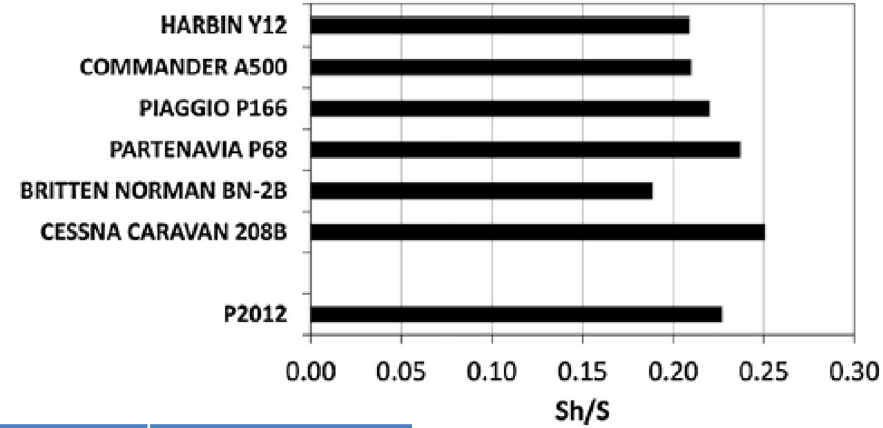


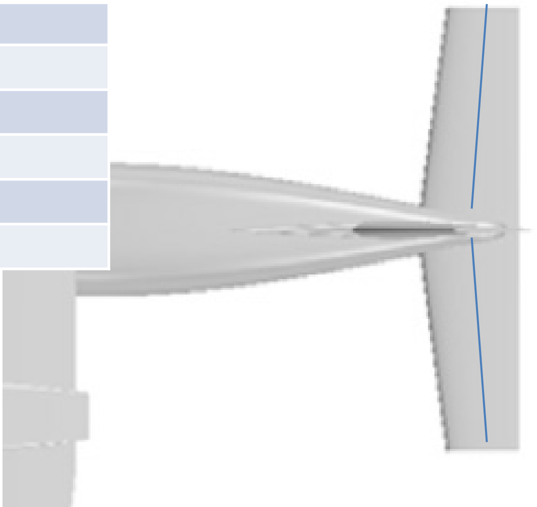
# P2012 Conceptual Design

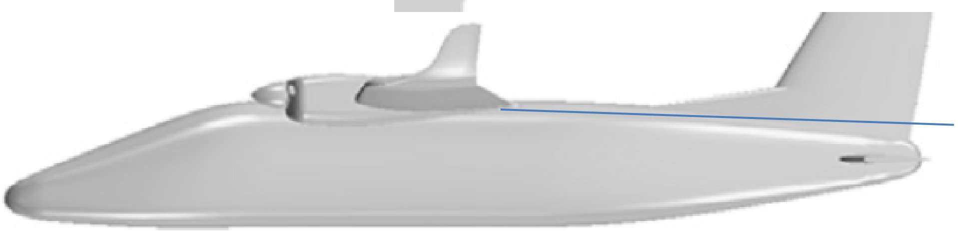
## HORIZONTAL TAIL DESIGN




| | Value |
|---|---|
| $AR_h$ | 5.32 |
| $\Lambda_{c/4}$ | 12.5° |
| $\lambda$ | 0.67 |
| $\eta_h$ | 0.9 |
| $c_e/c_h$ | 0.3 |
| $i_{t0}$ | -2° |

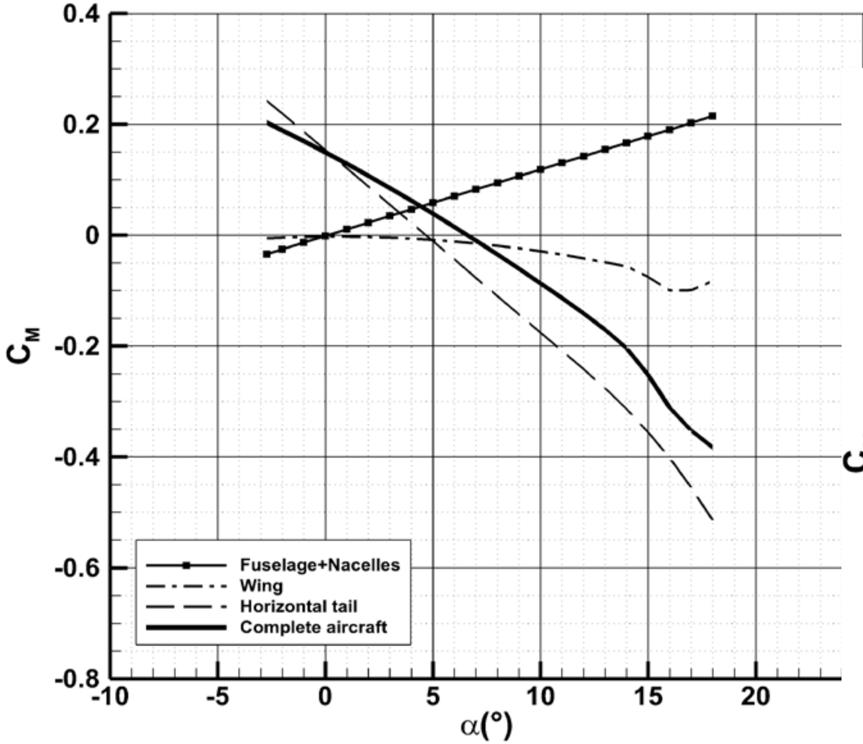




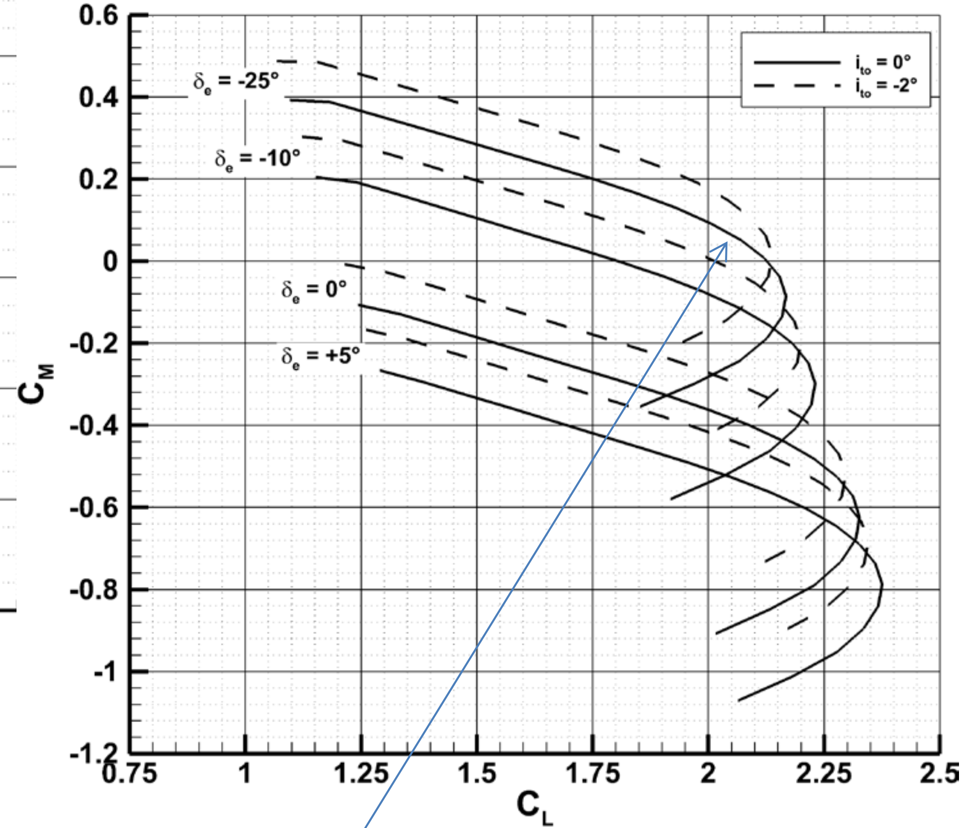
- High AR with moderate sweep
- Full-span elevator (ce/ch=0.30)
- Vertical position is extremely critical (possible interaction with wing wake, correct estimation of downwash, dyn. pres
- Pendular stability and all non-linearities to be considered for aircraft trim capab.

# P2012 Conceptual Design

## HORIZONTAL TAIL DESIGN



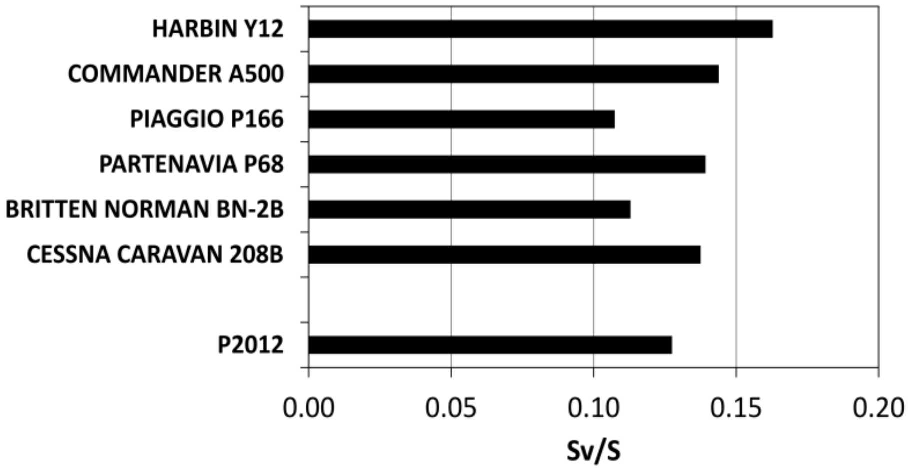

**Equilibrium curves CG max FWD Flap LDG**

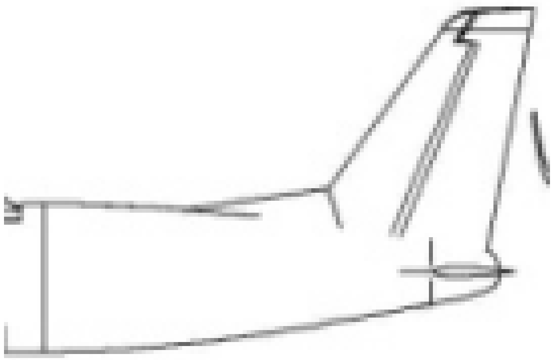



- **Check of max CL achievable with CG max FWD**
- **Non-linear elevator efficiency to be considered**
- **Pendular stability (non-linear slope) to be considered**
- **Correct estimation of downwash and dyn. pressure ratio**

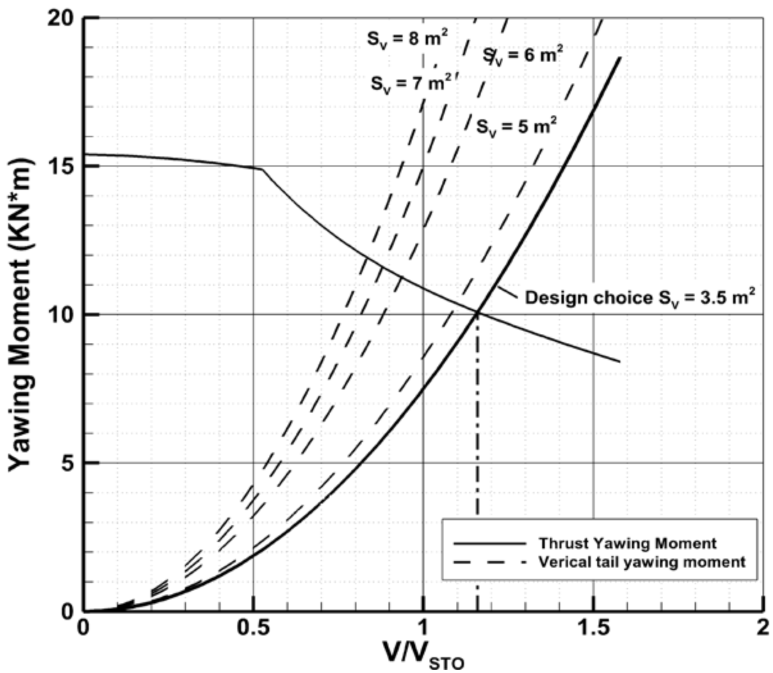
# P2012 Conceptual Design

## VERTICAL TAIL DESIGN



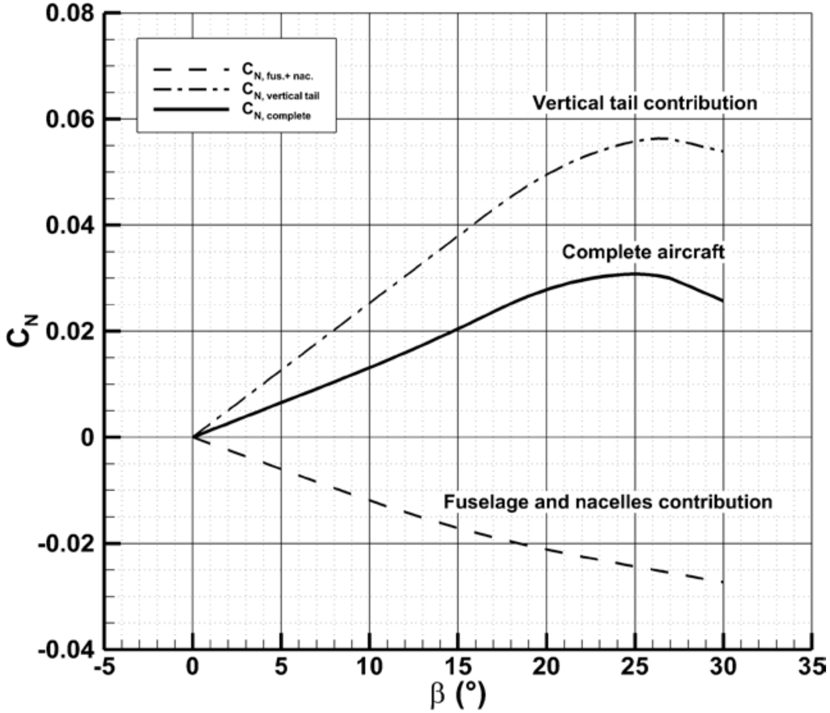
| | Value |
|---|---|
| $AR_v$ | 1.80 |
| $\Lambda_{c/4}$ | 30.0° |
| $\lambda_v$ | 0.35 |
| $\eta_v$ | 0.90 |
| $c_r/c_v$ (average value) | 0.38 |
| $\delta_{r,max}$ | 30° |



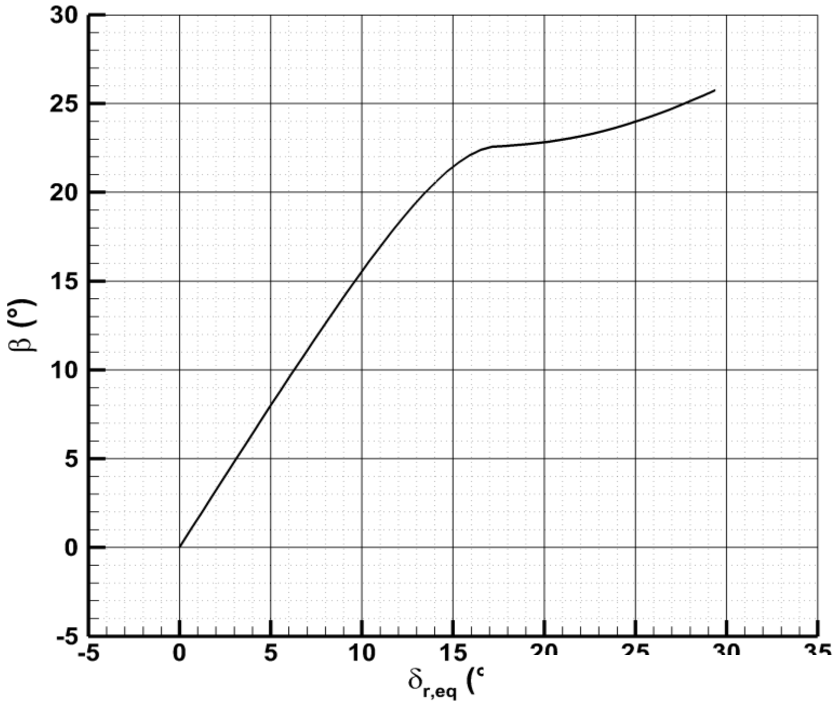

- Sizing driven by Vmc requirements
- Choice of Aspect ratio
- High rudder chord ratio
- Interference effects to be carefully considered
- Check of cross-wind capabilities in approach

# P2012 Conceptual Design

## VERTICAL TAIL DESIGN




## Check of cross-wind flight capabilities




- **Non-linear aerodynamic characteristics considered**
  **(Non-linearities in A/C directional stability + Non-linear rudder efficiency)**
- **Effect of dorsal fin in preliminary design phase (?)**
- **Interference effects to be carefully considered**

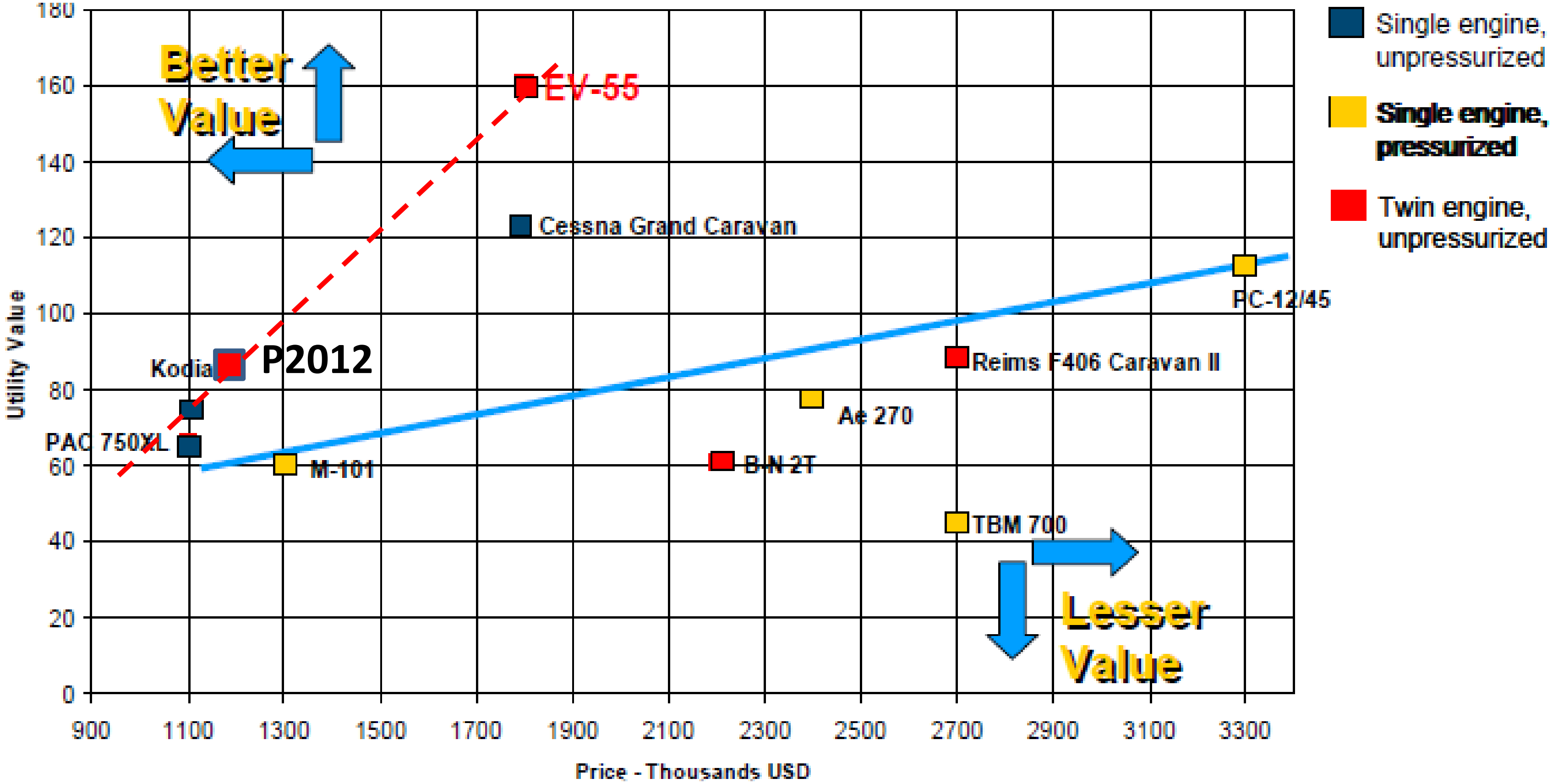
# Commuter Aircraft – Typical Performances and Characteristics

| | King Air | Twin Otter | Viator | Cessna Caravan | Cessna F406 | Cessna 402 | EV-55 | Skylander | P2012 Traveller |
|---|---|---|---|---|---|---|---|---|---|
| Ref. Year | 1961 | 1964 | 1980 | 1984 | 1983 | 1966 | 2011 | 2001 ann. | 2012 |
| MTOW Kg | 5352 | 5670 | 3000 | 3629 | 4246 | 3107 | 4600 | 8618 | **3290** |
| Power | 2 PT6 (850hp x2) | 2 PT6 (659hp x2) | 2 RR 250 (328hp x2) | 1 PT6A 675 hp | 2 PT6 (500hp x2) | 2 TSIO 520 2 x 325 | 2 PT6 (536hp x2) | --- | 2 Lycoming (350 hp x2) |
| Pax # | 13 | 20 | 8-10 | 8-13 | 12 | 9 | 14 | 19 | 9-10 |
| Max Range Km | 2455 | 1297 | 1575 | 1960 | 2135 | 2350 | 2258 | 2148 | 1100 |
| Max Speed Knots | 265 | 160 | 213 | 186 | 218 | 213 | 220 | 235 | 205 |
| Take-off (50ft) [m] | 643 | 411 | 490 | 626 | 823 | 670 | 450 | | 560 |
| | Pressurized | Fixed LG | | Fixed LG | | | | Fixed LG | Fixed LG |

Twin Otter end of production in 1988, 844 Airplanes sold in 80 countries.
Cessna Caravan => more than 2000 airplanes.

# Design goal and marketing driving factor

Utility Value = (kts x ft³ x usefu loadl) / (2 x T.O. over 50 ft x total power) plus 20% for either multi engine or pressurized




**Even MORE IMPORTANT Market DRIVERS:**

- Possibility to use MOGAS
- Low DOC (Low fuel consumption) => Efficient engine and Low Drag
- Short Take-Off from not prepared runway => High-wing prop and Vert Tail Design (Vmc)

# Commuter Aircraft main Aerodynamic Design Problems

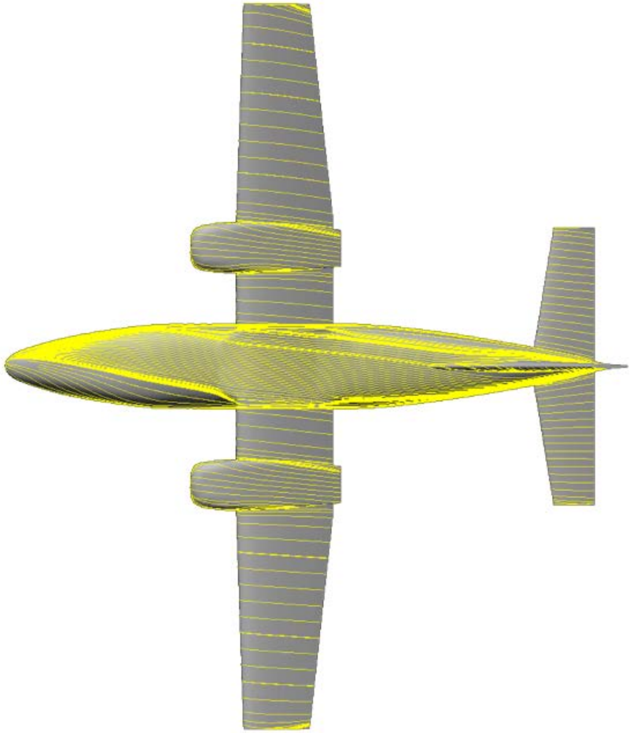
- WING DESIGN
  - Wing design and HIGH-LIFT System
  - Wing span loading (effect of nacelles and fuselage)
  - Winglet design

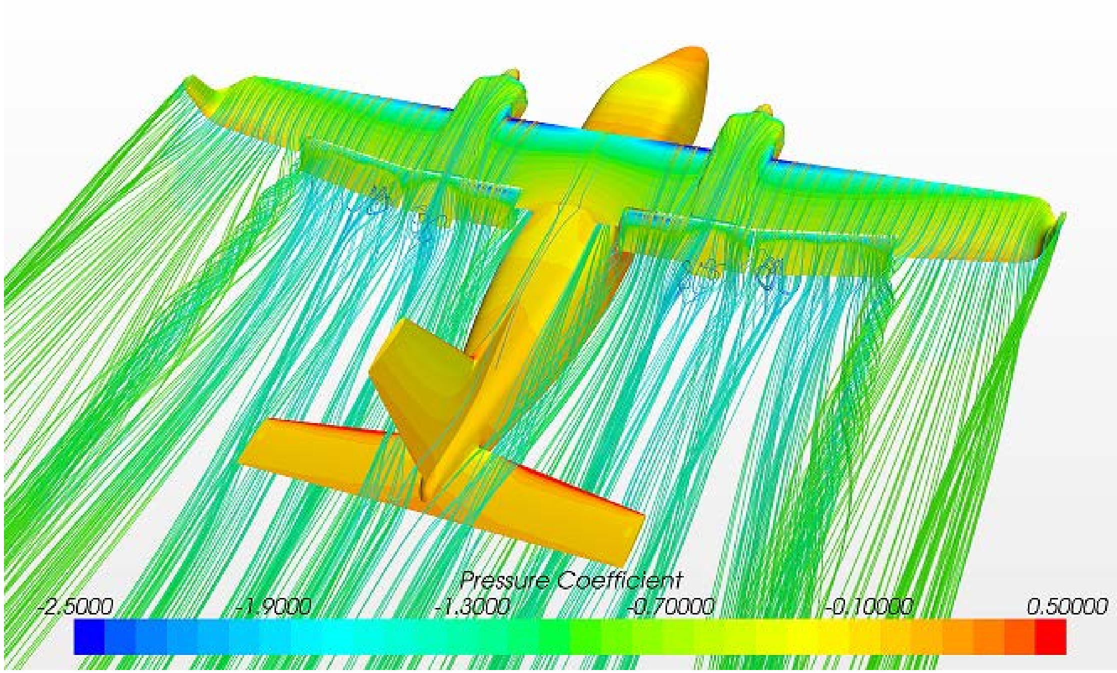
- FUSELAGE DESIGN
  - Passengers accomodation
  - Wing-Fuselage interaction
  - Low-Drag

- TAILPLANES DESIGN (Stability&Control)
  - Wing wake for **HT position**
  - VMC (accurate estimation of interf. effects for a right sizing of **Vertical tail**)

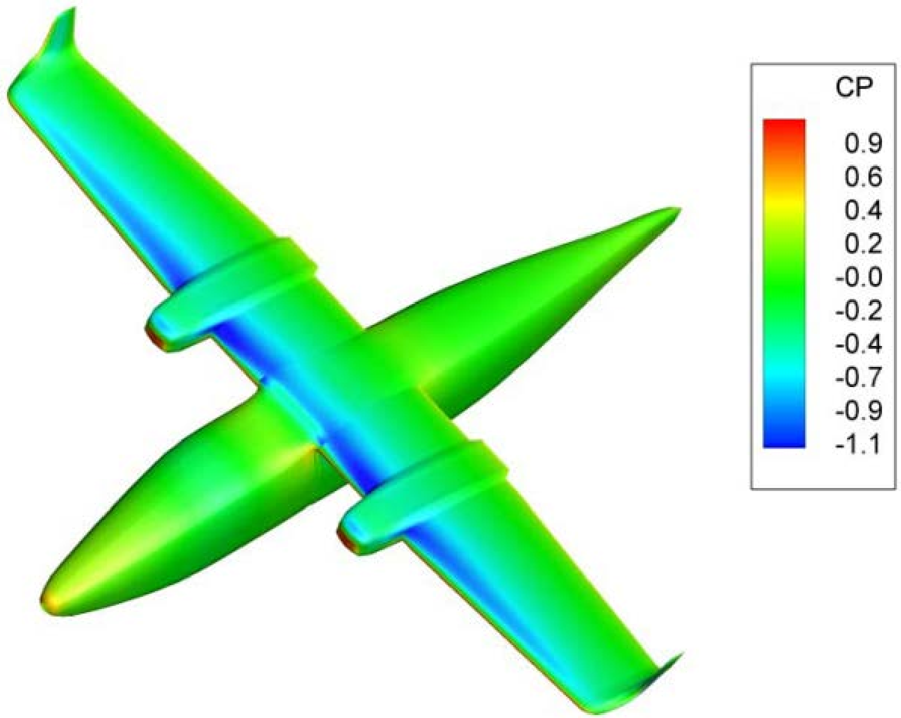
- LANDING GEAR
  - Fixed or rectractable ? Estimation of Landing-Gear DRAG contribution

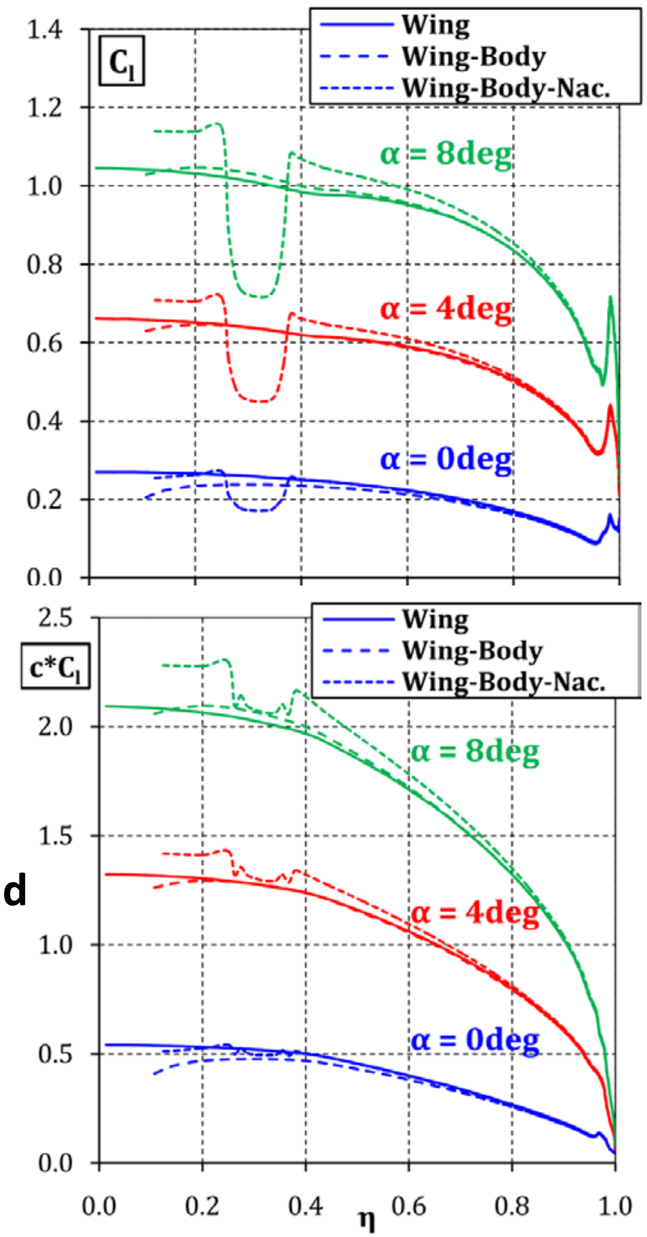
# Numerical Aerodynamic Analysis





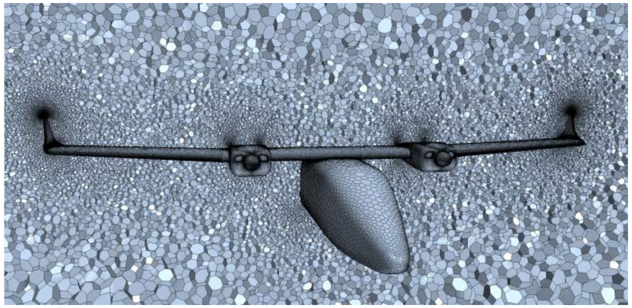
# Preliminary with Panel method



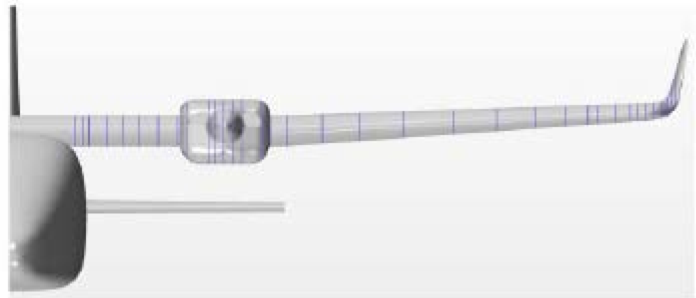



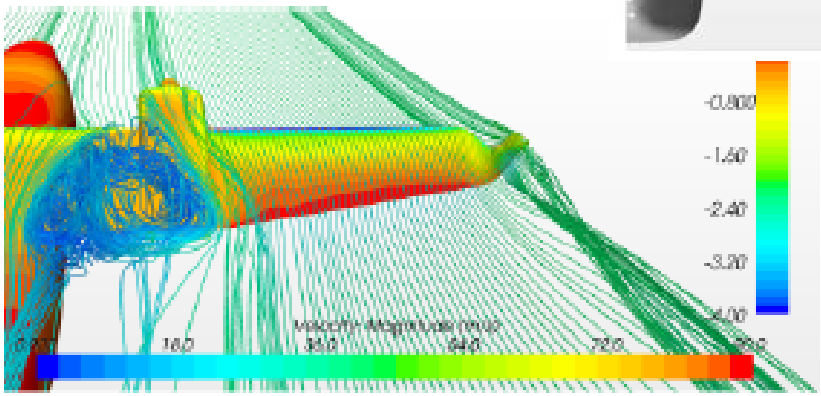

- **Preliminary estimation of lift curve slope**
- **Effect of fuselage and nacelles on spanwise aerodynamic load**
- **Effect of fuselage and nacelle on long stability**

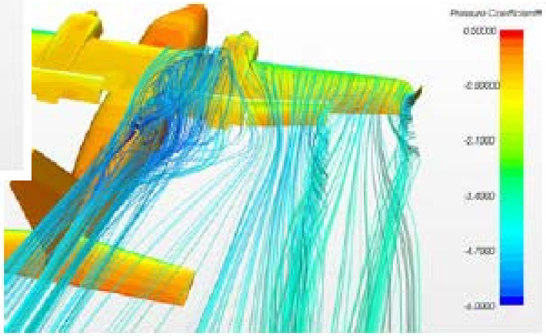
# CFD Navier-Stokes

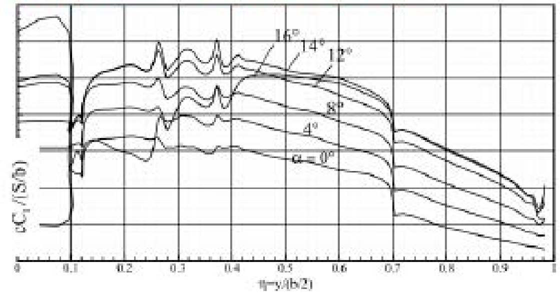


## Wing span loading analyses

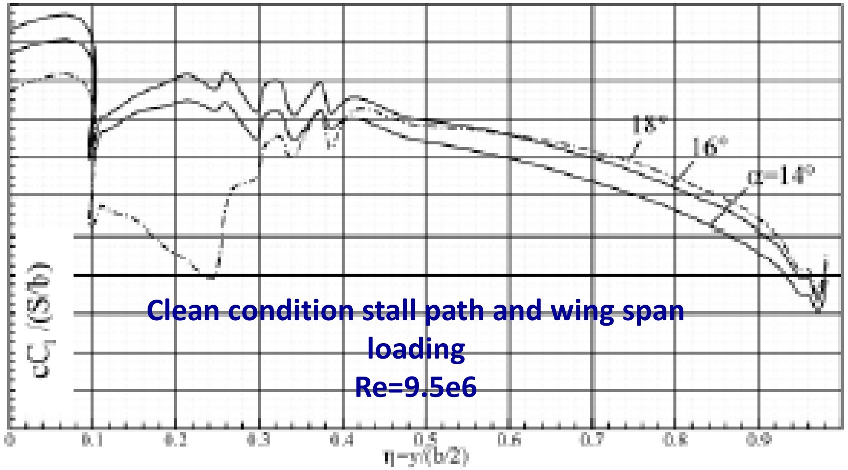







**Landing condition stall path and wing span loading**
**Re=4.5e6**

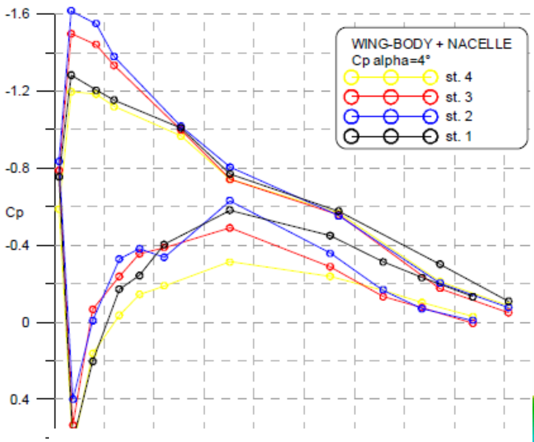


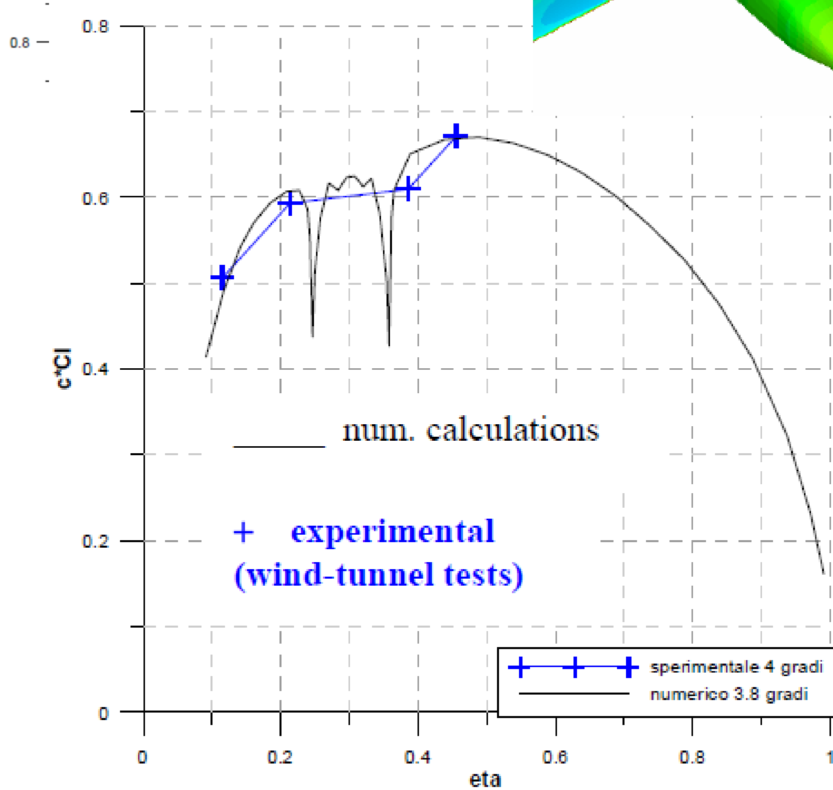

**Clean condition stall path and wing span loading**
**Re=9.5e6**

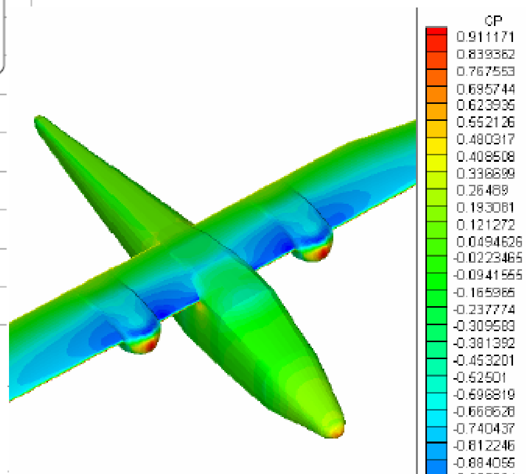
**Influence of reduced load at wing root and aerodynamic load produced by the fuselage on Wing root bending moment**

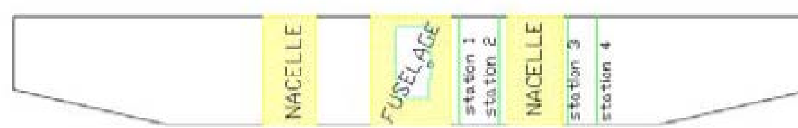
# Num/Exp investigation on wing-span loading

## P2006T Aircraft

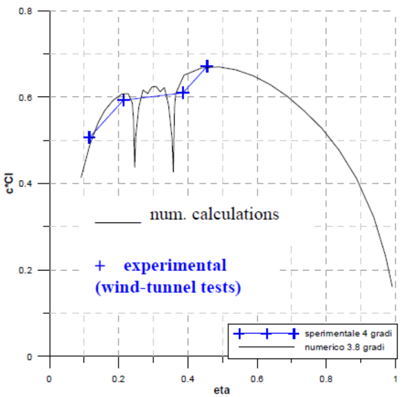


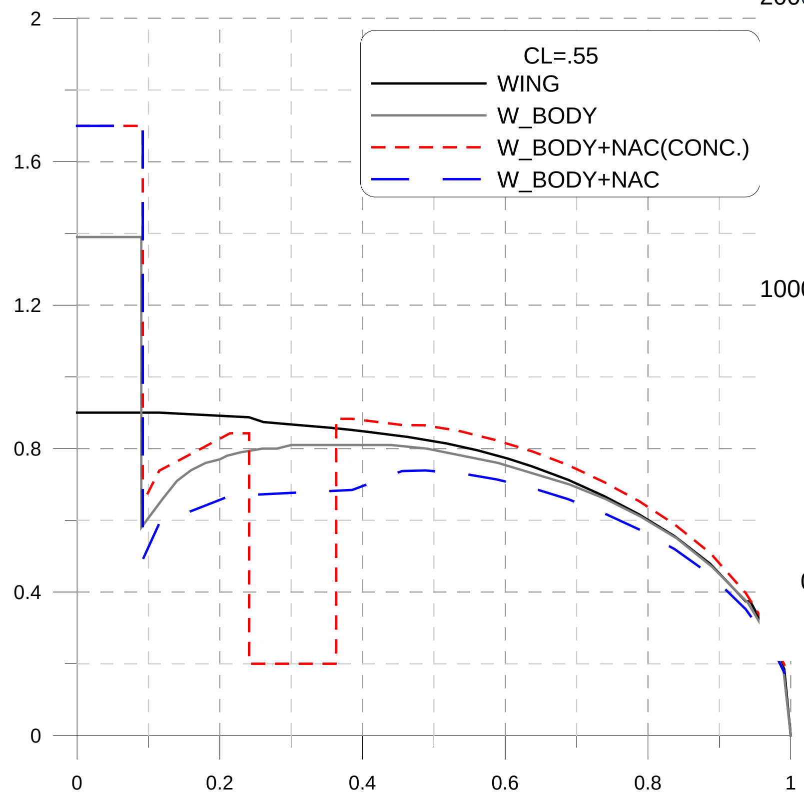



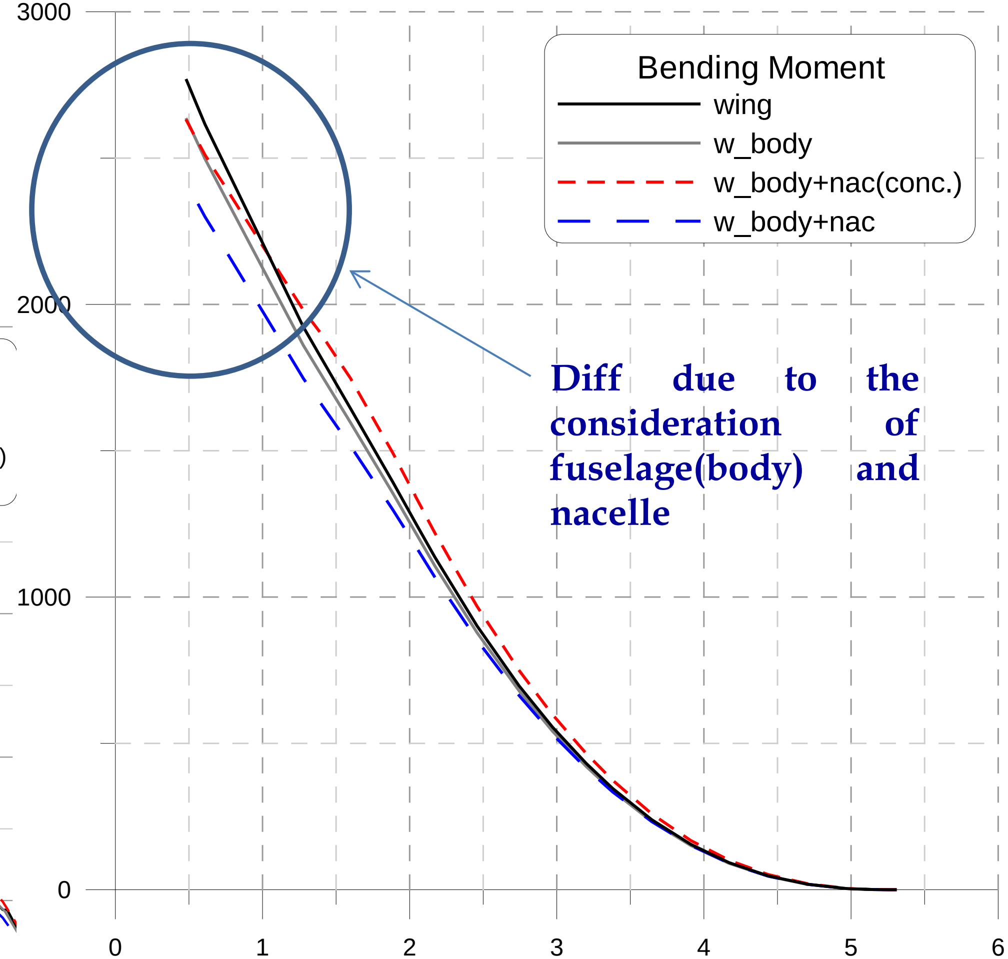



# Num/Exp investigation on wing-span loading



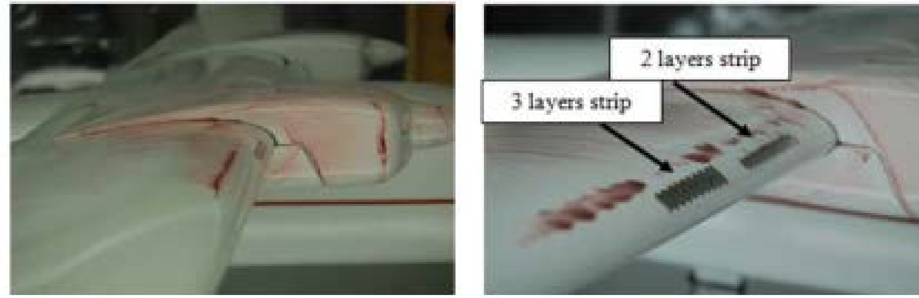

## P2006T Aircraft




**Diff due to the consideration of fuselage(body) and nacelle**

**Up to 10% difference in bending moment at wing root**

# Wind Tunnel Tests




**Flow visualization: laminar separation bubbles and transition strips**

**Isolated Body**

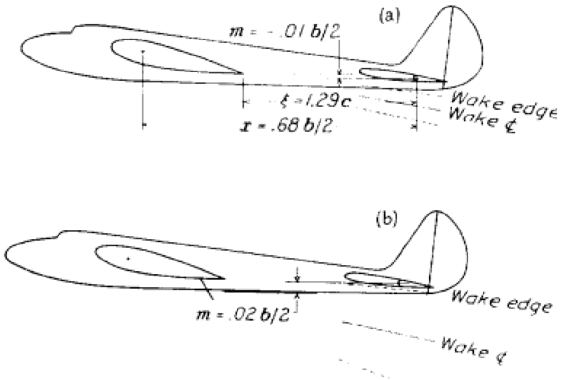
**Wing-Winglet-Body-Nacelles**

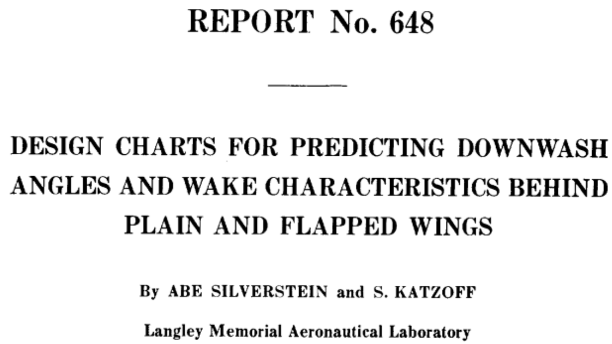
**Wing-Winglet-Body**

**Complete Aircraft Flap down**

# Wind Tunnel Tests:

## Experimental investigation about the vertical position of the horizontal tail



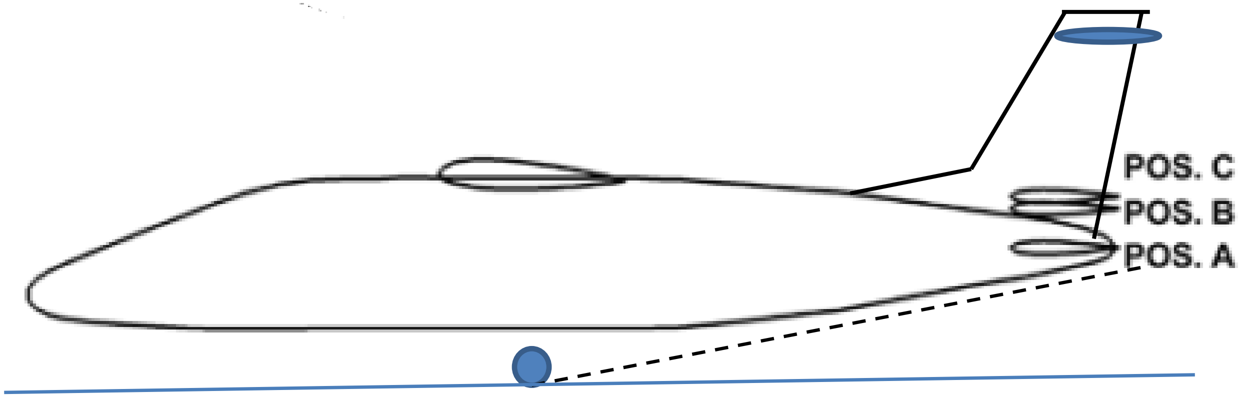



REPORT No. 648

DESIGN CHARTS FOR PREDICTING DOWNWASH ANGLES AND WAKE CHARACTERISTICS BEHIND PLAIN AND FLAPPED WINGS

By ABE SILVERSTEIN and S. KATZOFF

Langley Memorial Aeronautical Laboratory



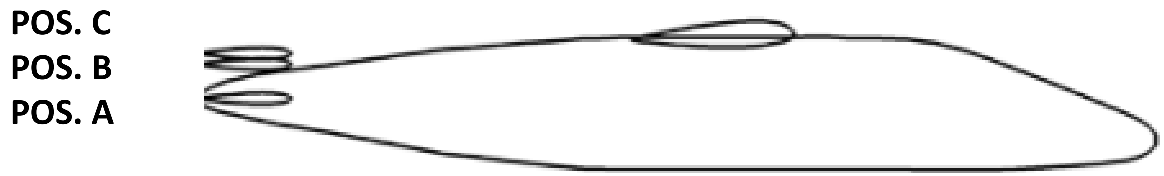

### Possible Configurations

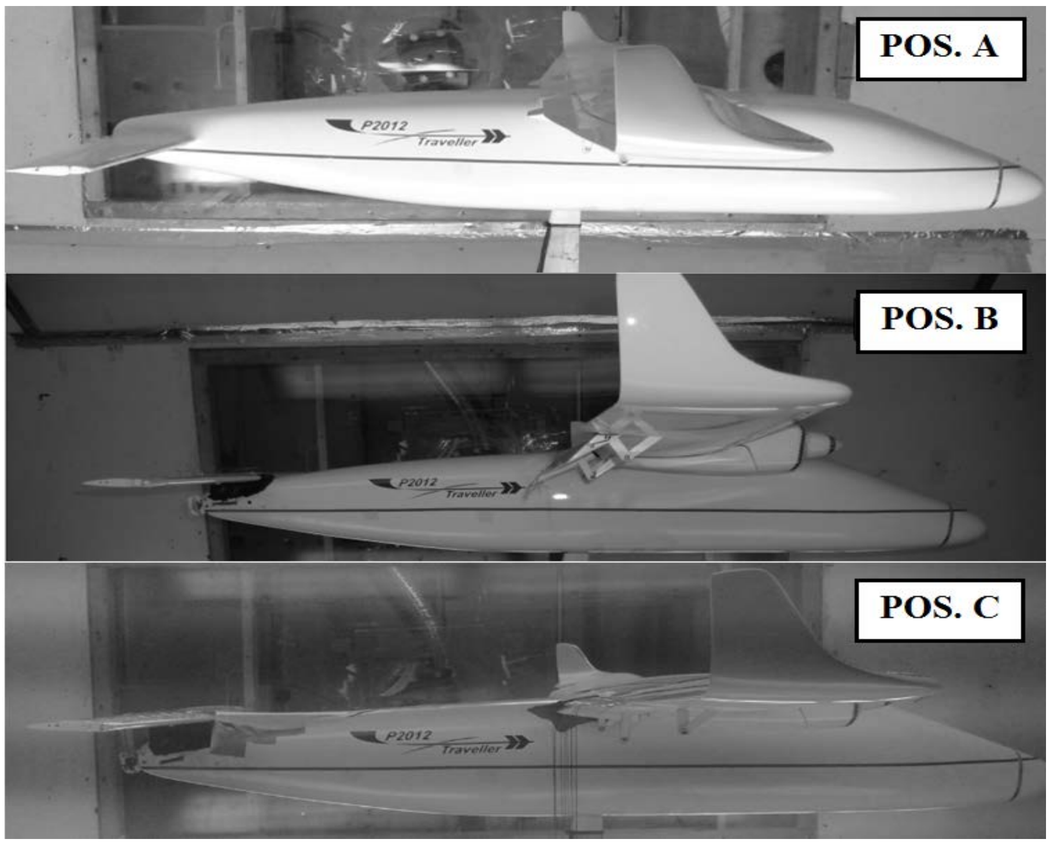



- Wing-wake interaction (reduced stab & control) + stick buffeting
- Fuselage tailcone shape linked to HT position
- Required angle for take-off rotation (landing gear type)
- Higher positions can lead to easier ground operation
- Vertical tail mounted complex and more expensive solution
- Cruciform tail lead to lower Vertical Tail aerodynamic performances
- Fuselage tailcone upsweep and HT position influences VT efficiency

# Wind Tunnel Tests:

## Experimental investigation about the vertical positioning of the horizontal tail

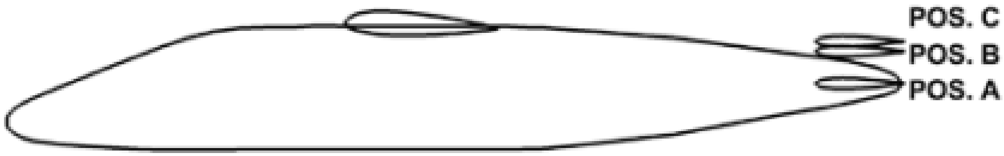


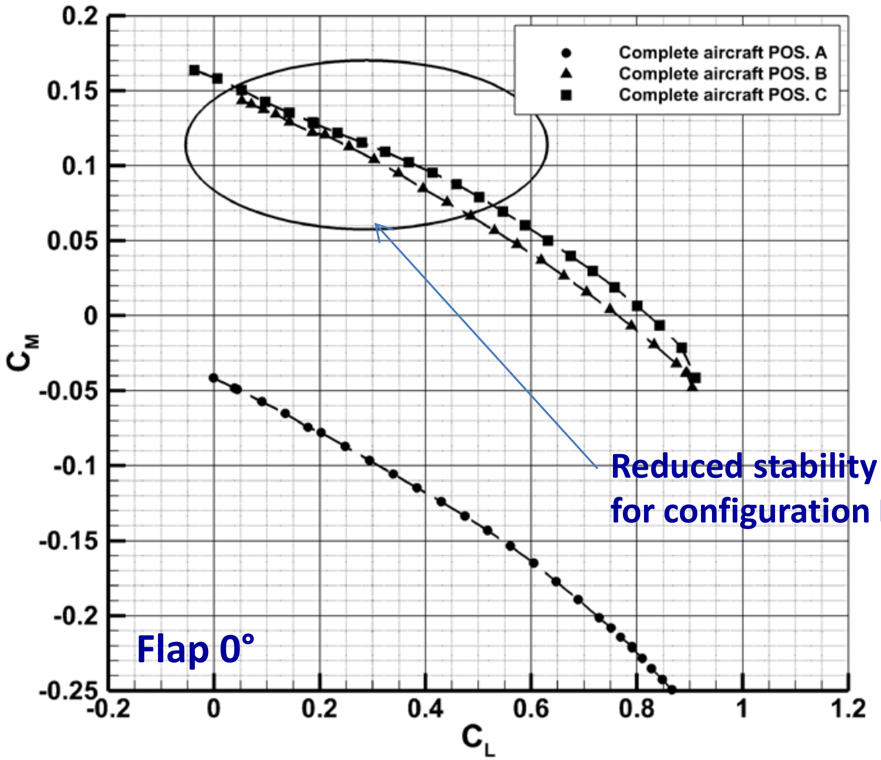



# Wind Tunnel Tests:

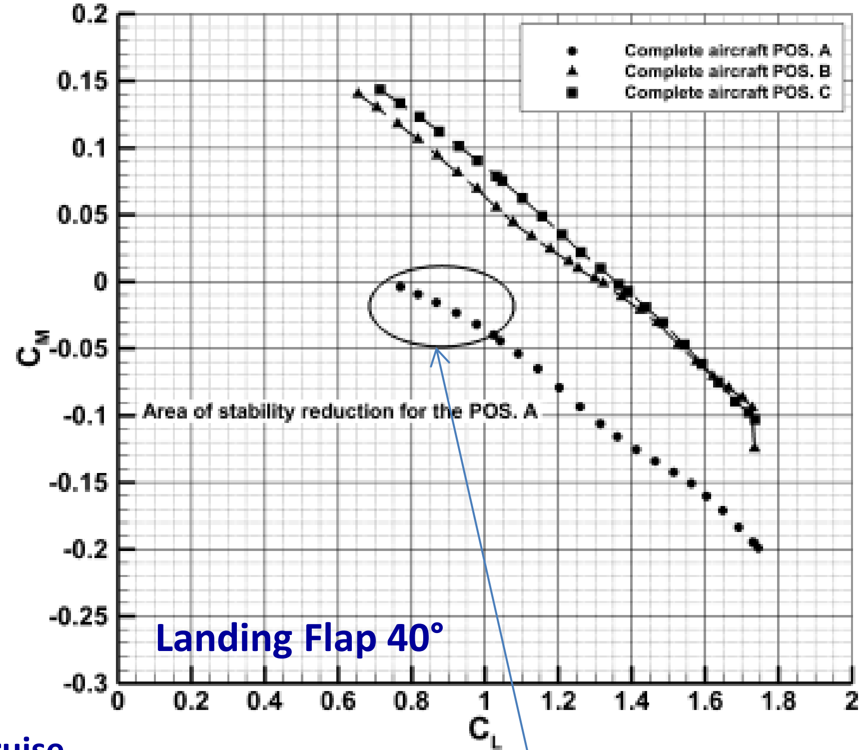
## Experimental investigation about the vertical positioning of the horizontal tail

### Horizontal tail tested positions




Reduced stability in cruise for configuration B and C




Reduced stability in full flap condition for configuration A, but at CL < 1 (alpha < -2 deg)

# Wind Tunnel Tests:

## Experimental investigation about the vertical positioning of the horizontal tail

### Wake visualization tests through tufts


**POS. B**
- flap 15deg
- aoa 0deg


**POS. B**
- flap 15deg
- aoa 10deg

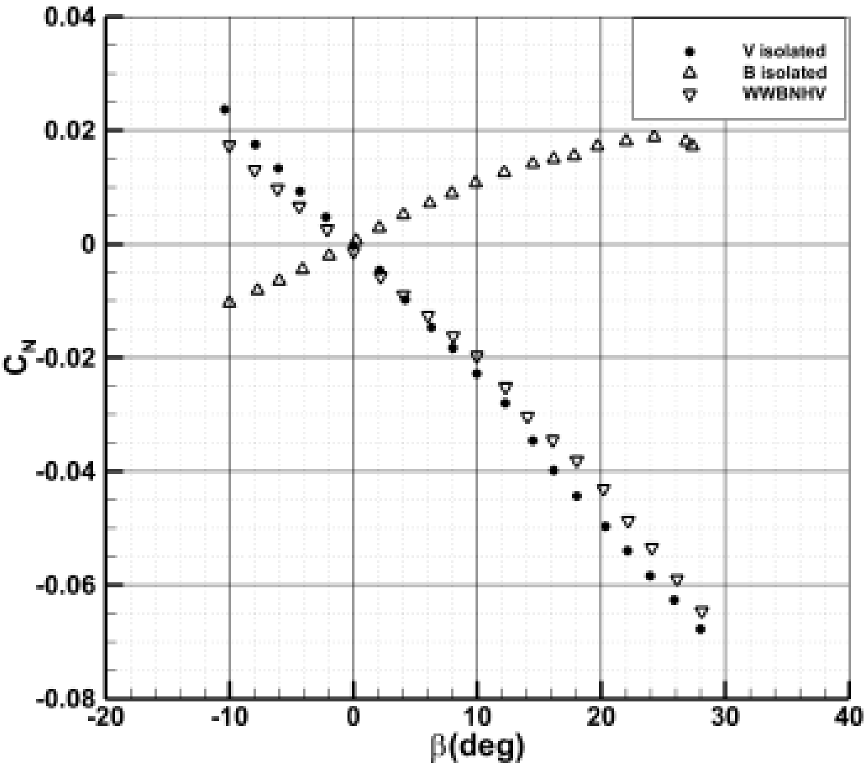
# Wind Tunnel Tests:

## Lateral-Directional Analysis

**Directional analysis : stability and control analysis**

**Tested configurations:**

- Isolated Vertical Tail
- Isolated Body
- Complete Aircraft

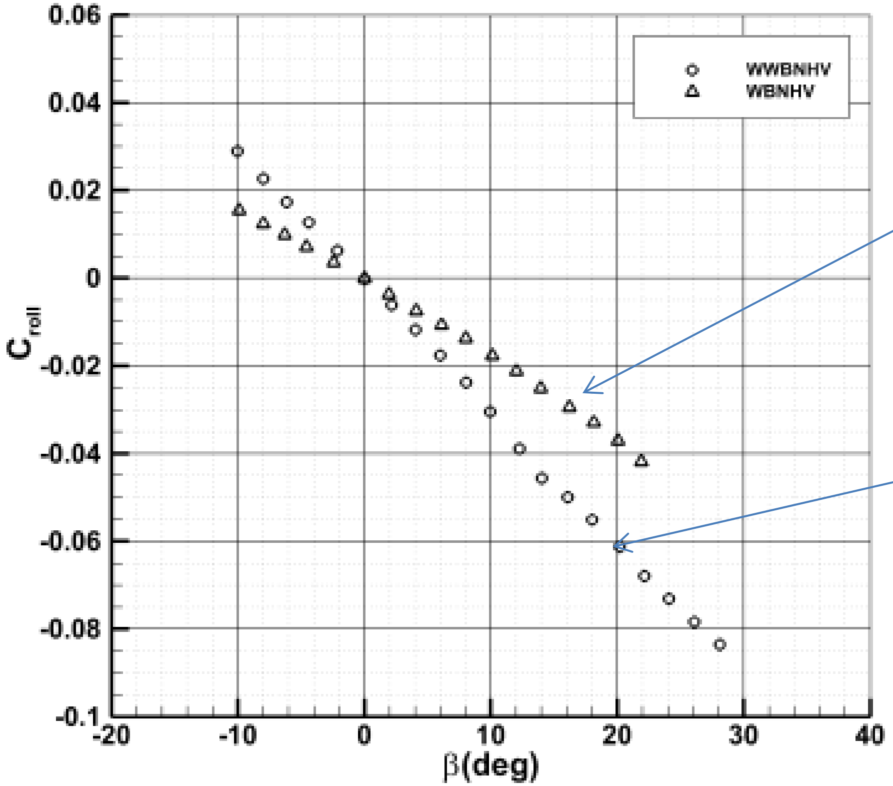



**Yawing moment vs. sideslip angle**

**Strong interference effects on vertical tail stabilizing efficiency**

# Wind Tunnel Tests:
## Lateral-Directional Analysis

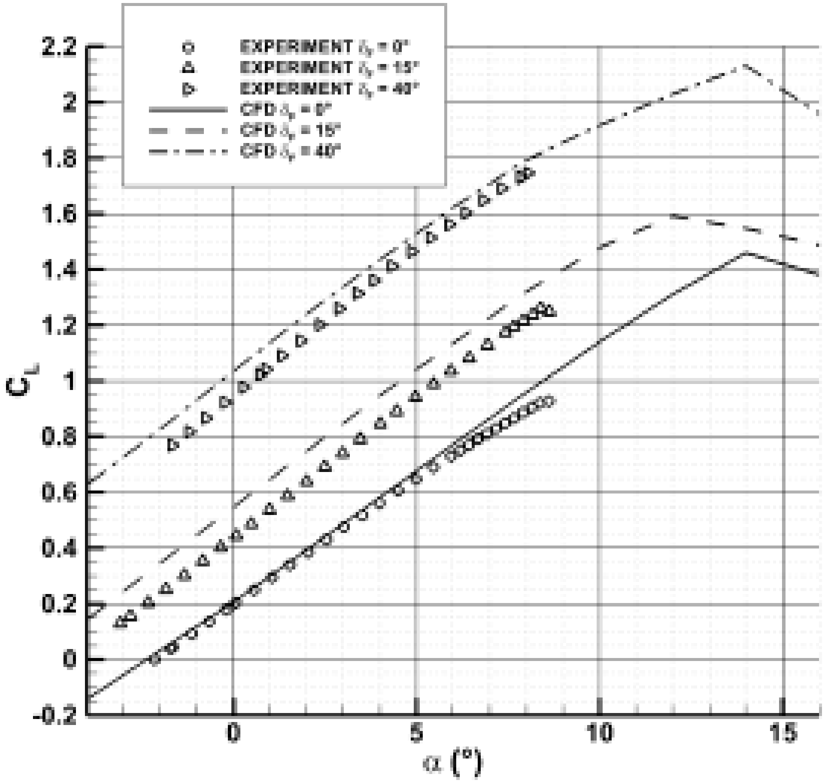
### Lateral stability: effect of winglets

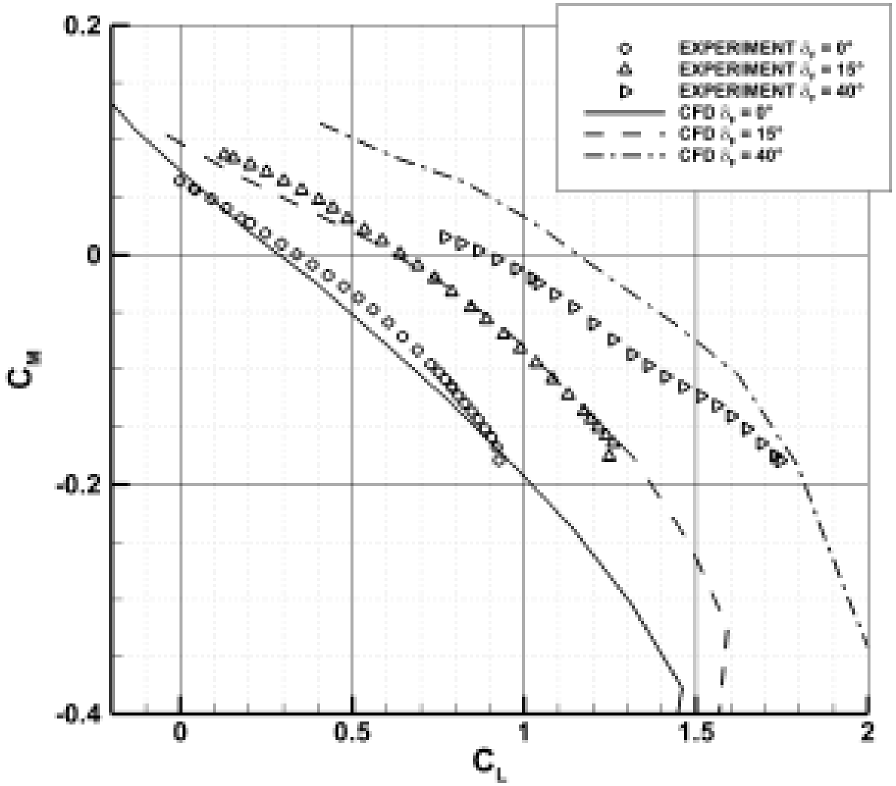



Rolling moment coefficient vs. sideslip angle


# CFD RANS ANALYSIS:

## Longitudinal Aerodynamic Analysis



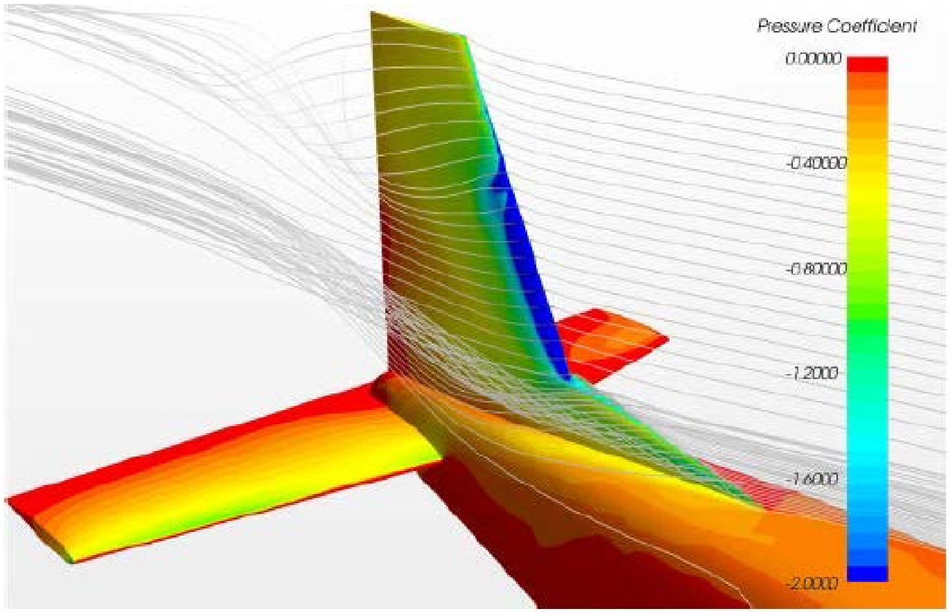




Very good agreement in terms of lift curve slope (in particular in clean condition)
Numerical and experimental data differ in $C_{Lo}$ : uncertainty of wind tunnel measured flap deflection and chocked flap channel due to the very low local Reynolds numbers
Differences arise from: geometry and incidence uncertainties of the experimental model, bending and twist of the model tail

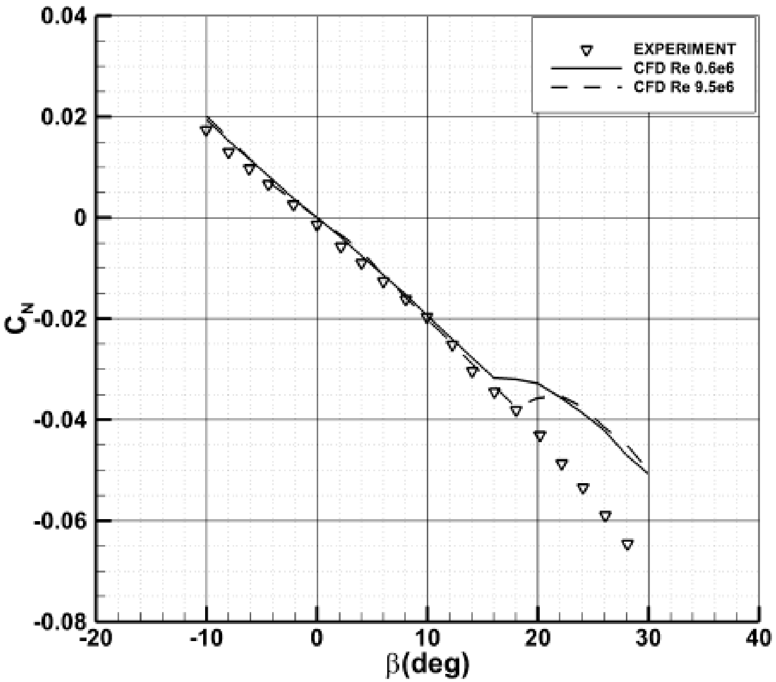
# CFD ANALYSIS:

## Lateral-Directional Aerodynamic Analysis

### Complete Aircraft Directional Analysis



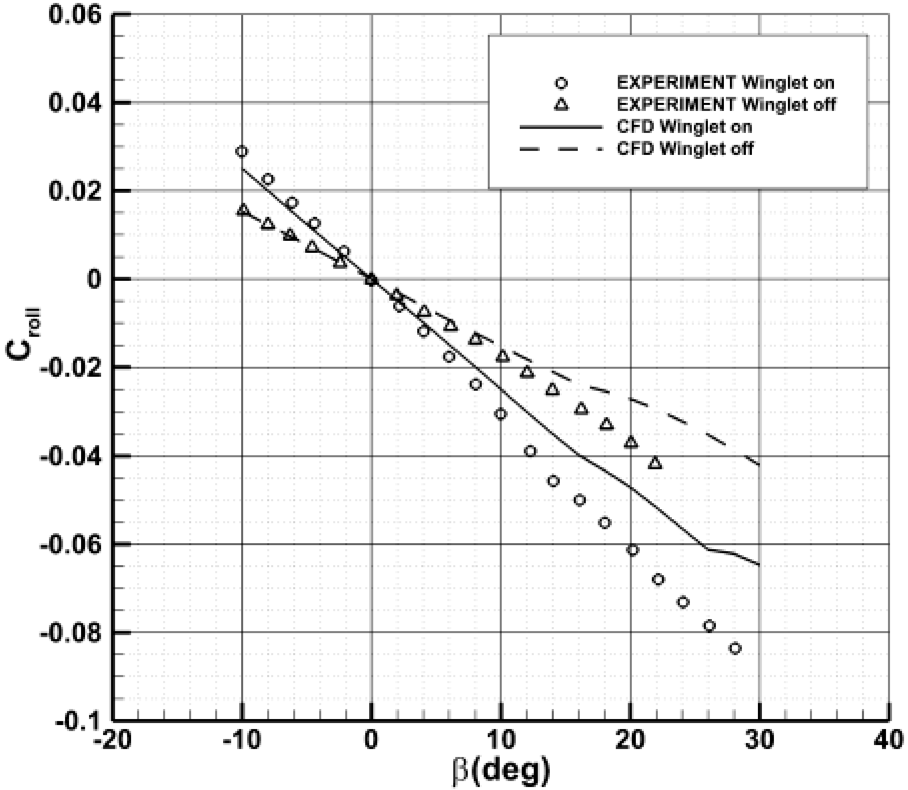

**Complete aircraft in sideslip, effect of dorsal fin vortices, β=20°, Re=0.6°6**



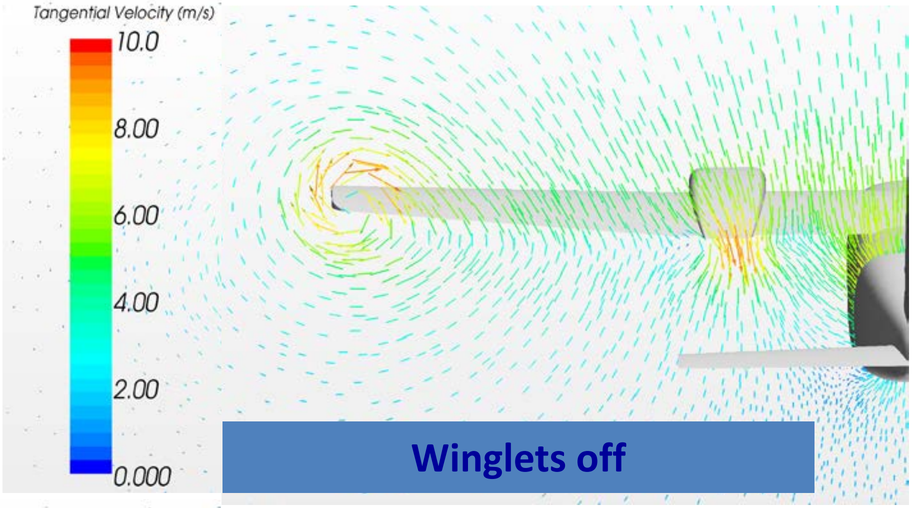

**CFD Results**

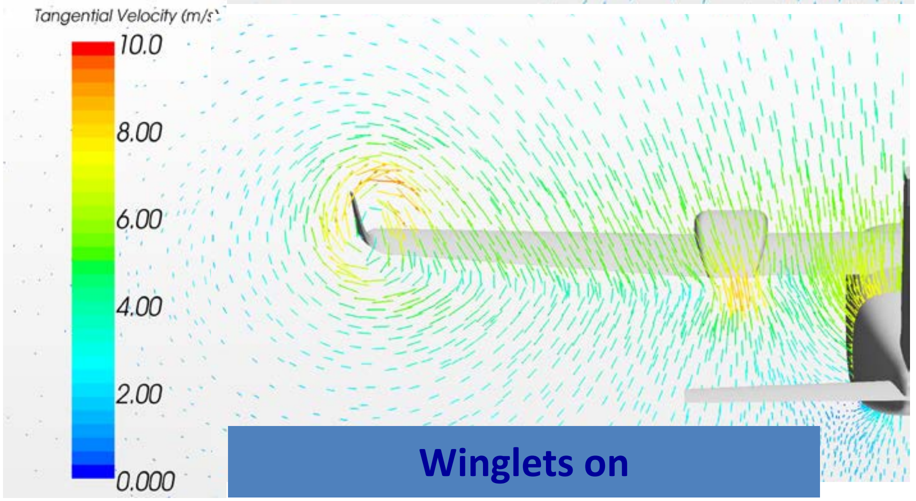
# Dihedral effect Navier-Stokes vs WT

## Complete Aircraft Lateral Analysis



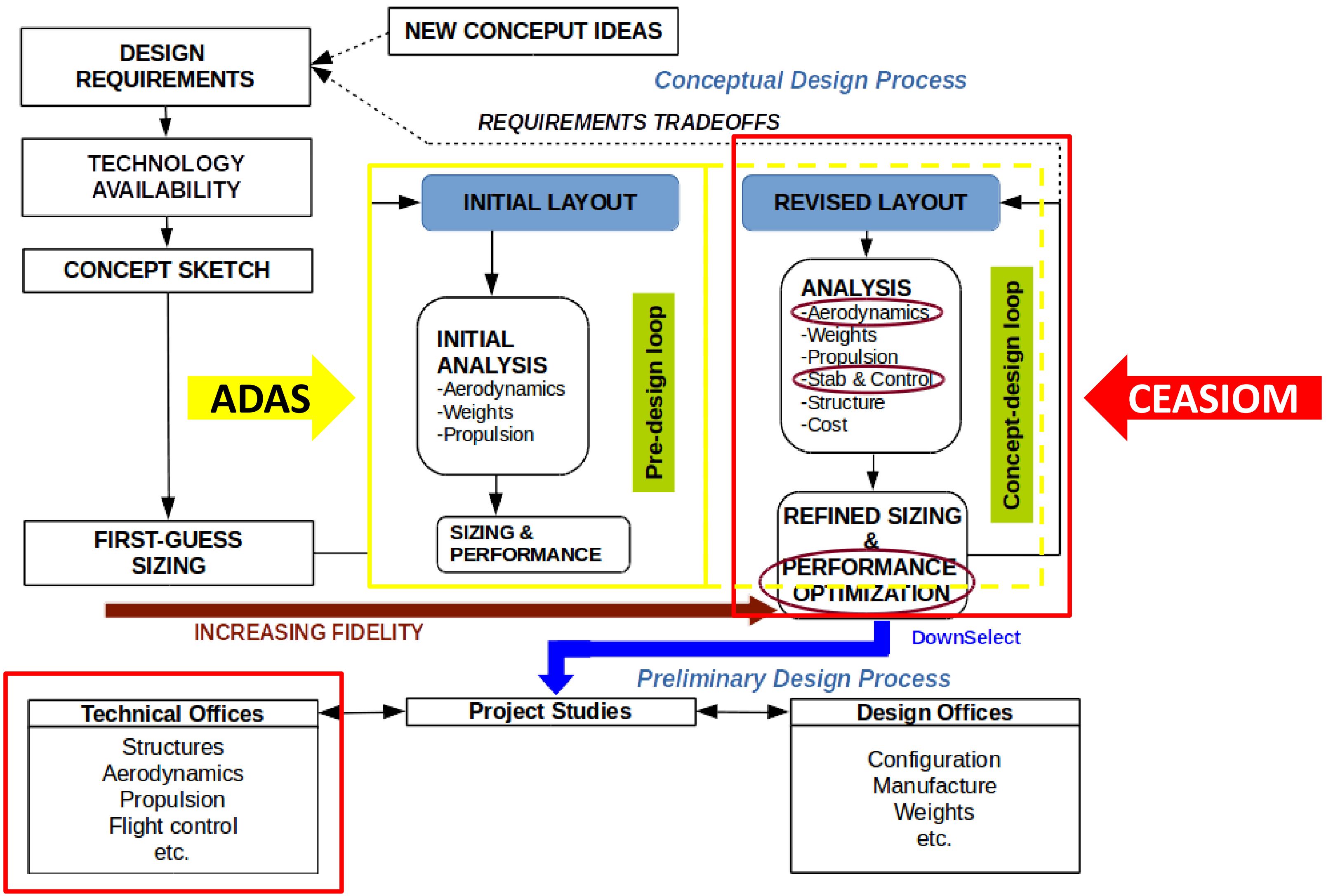

Complete aircraft rolling moment coeffcient with and without winglets



# Collaboration with A. Rizzi

## Design and complete aerodynamic analysis of a 16-seats aircraft



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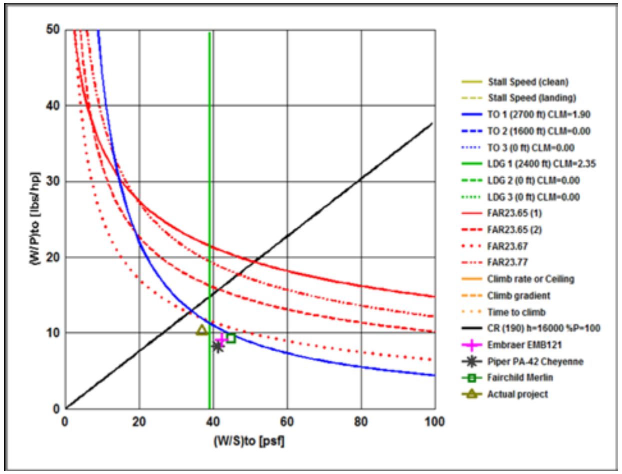
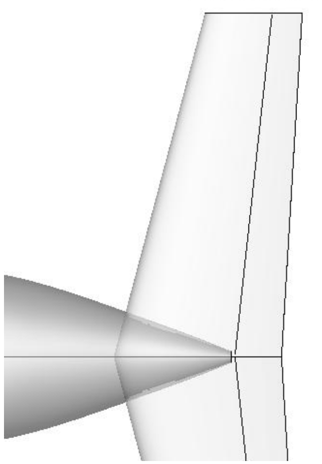
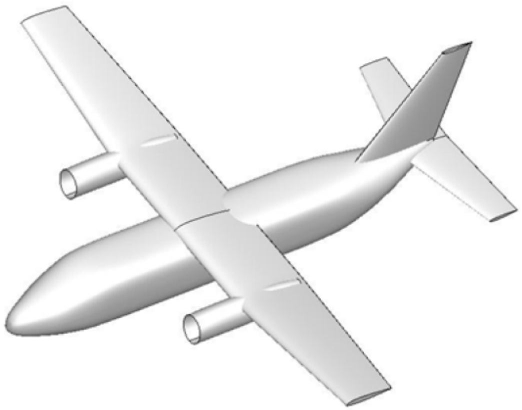
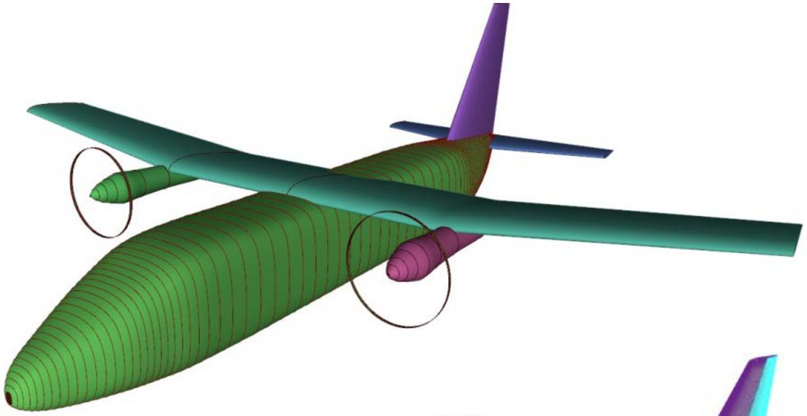
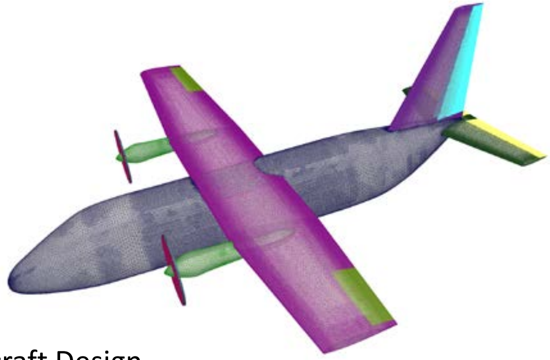




From ADAS ---------------------------------- > to CEASIOM



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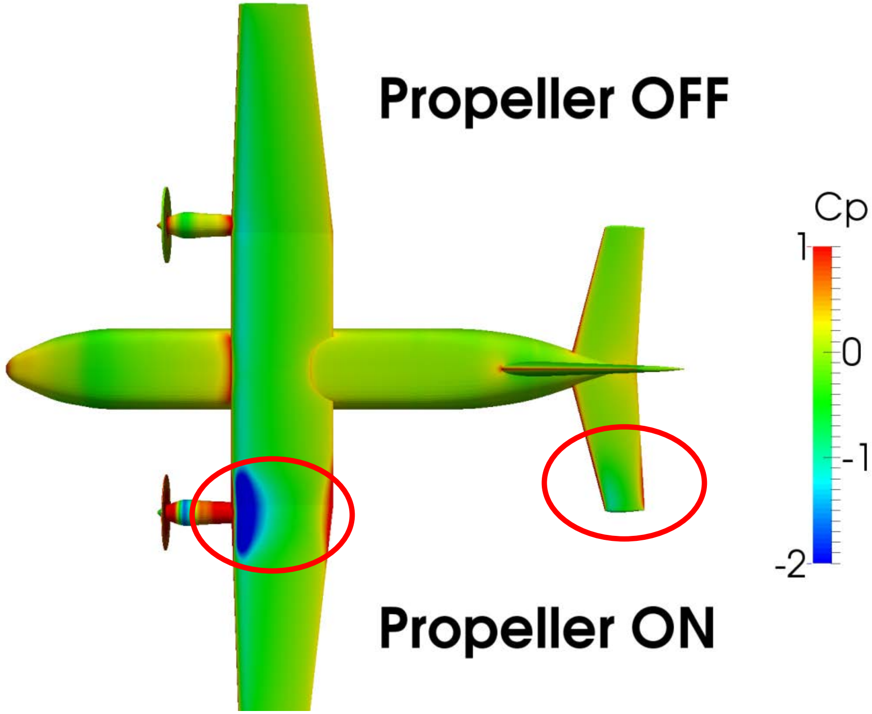
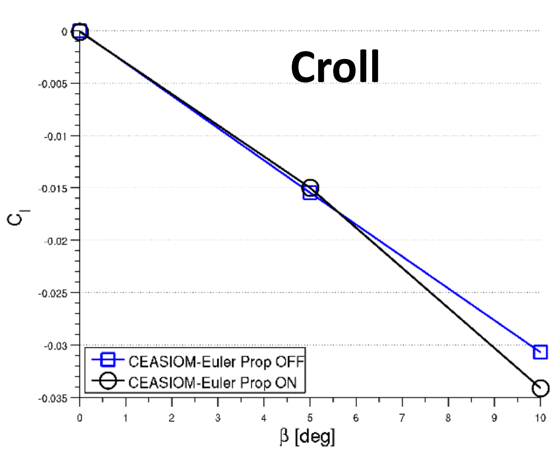
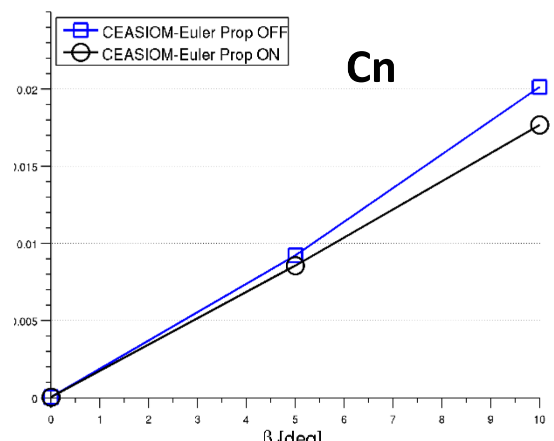
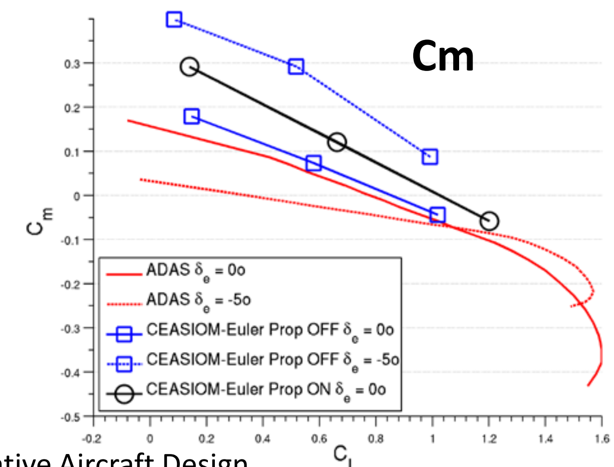
## Design and complete aerodynamic analysis of a 16-seats aircraft




**Upper Surface**

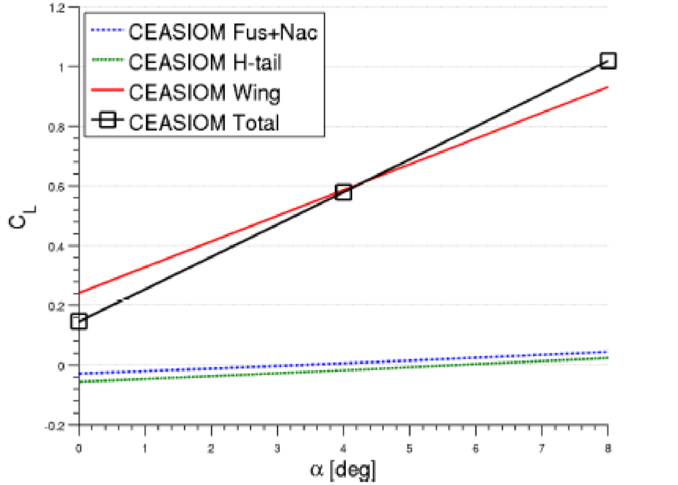


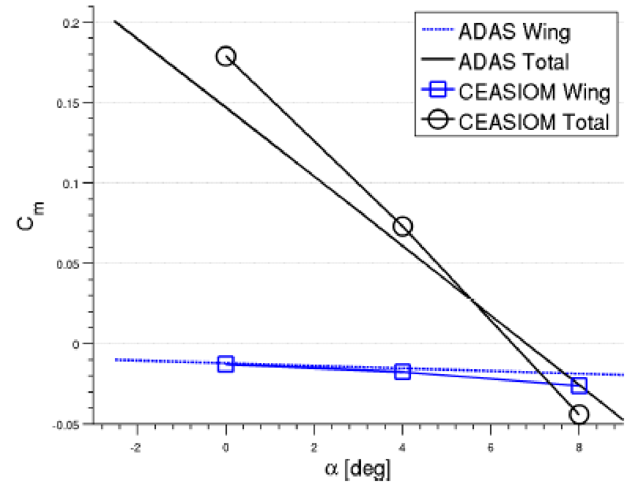



# Collaboration with A. Rizzi

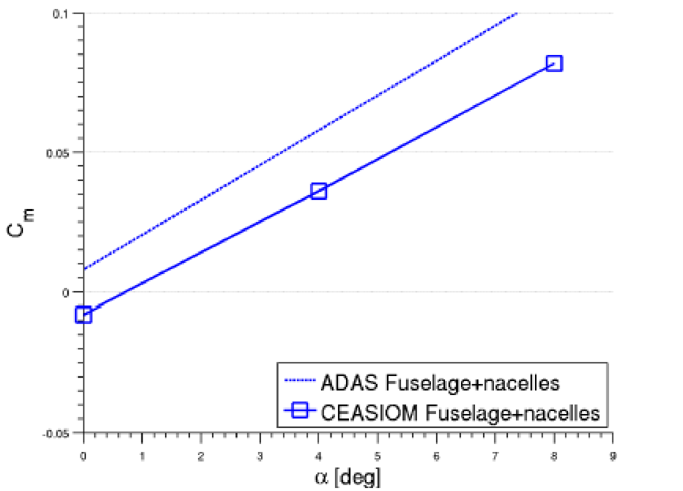
## Design and complete aerodynamic analysis of a 16-seats aircraft



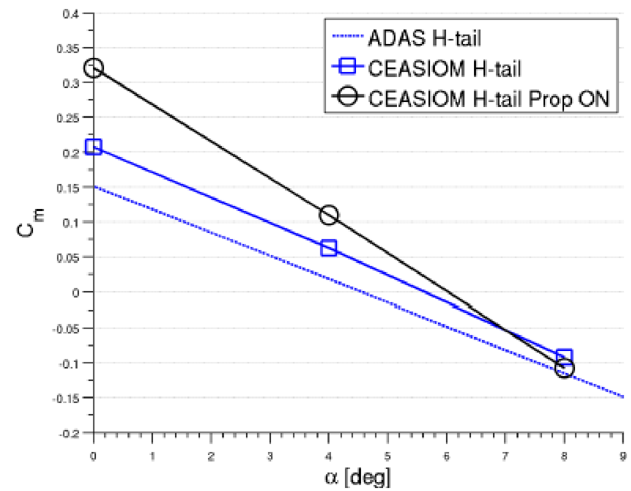

(a) Lift coefficient $C_L$ of each component from CEASIOM




(b) Pitching moment $C_m$ of wing and the total aircraft from CEASIOM and ADAS




(c) Pitching moment $C_m$ of fuselage and nacelle contribution from CEASIOM and ADAS




(d) Pitching moment $C_m$ of horizontal tail from CEASIOM and ADAS

# Conclusions

- **Despite light and simple Commuter aircraft presents critical design issues.**
- **Concerning aerodynamics, propulsive effects must be considered.**
- **Complementary use of CFD (even panel method) and wind-tunnel tests is very important.**