Challenges for new Regional Turboprop Configuration

Pierluigi Della Vecchia, PhD.

5th SCAD (Symposium on Collaboration in Aircraft Design)
(12th -14th October, 2015)

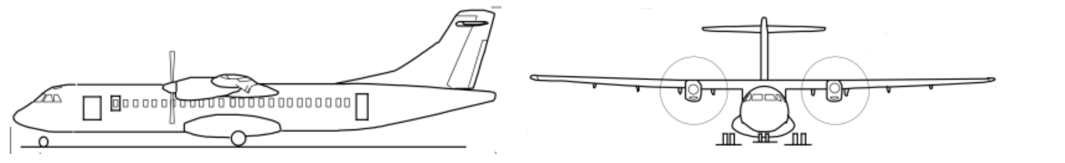
University of Naples Federico II
Department of Industrial Engineering
Via Claudio, 21, 80125 Naples
pierluigi.dellavecchia@unina.it
http://wpage.unina.it/pierluigi.dellavecchia/
http://wpage.unina.it/fabrnico/DAF/

Table of Contents

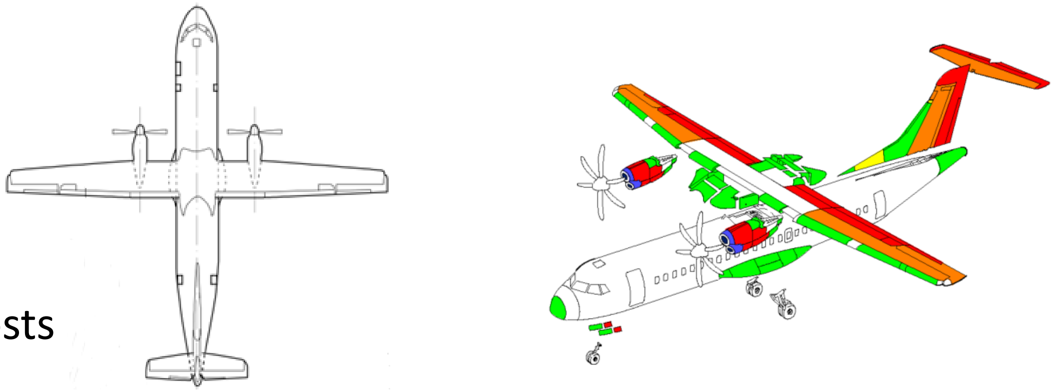
- Introduction
- Aircraft Components Design and Optimization
  - Nose
  - Wing-Fuselage junction
  - Nose
  - Wing Laminar flow
  - Winglet Design
  - Vertical Empennage Design
- Effects on Aircraft Performance
- Conclusions

Introduction

Typical regional turboprop aircraft configuration



- High wing
- T-tail
- Twin Engine on wing
- Aluminum alloy
- Easy access on cabin
- Low maintenance and operability costs



(a) ATR-72-600

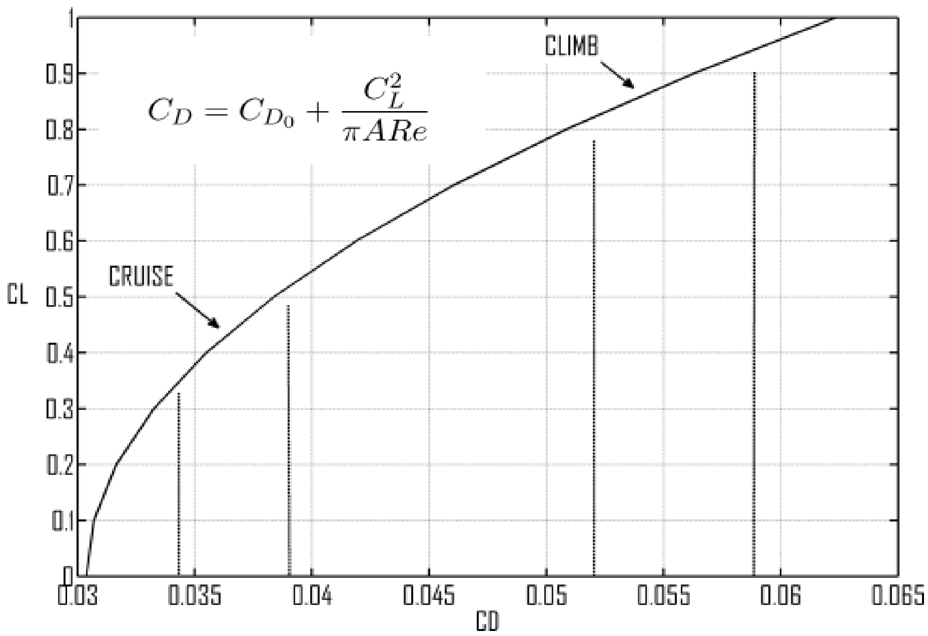
(b) DASH8 Q-400

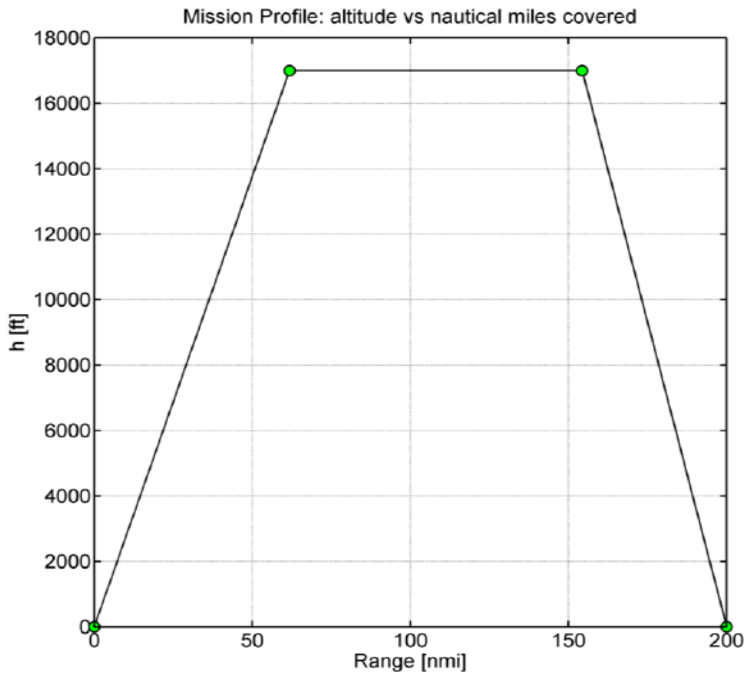
Introduction

Drag polar and typical mission profile

CD0 = 0.0300
e = 0.83
AR = 12

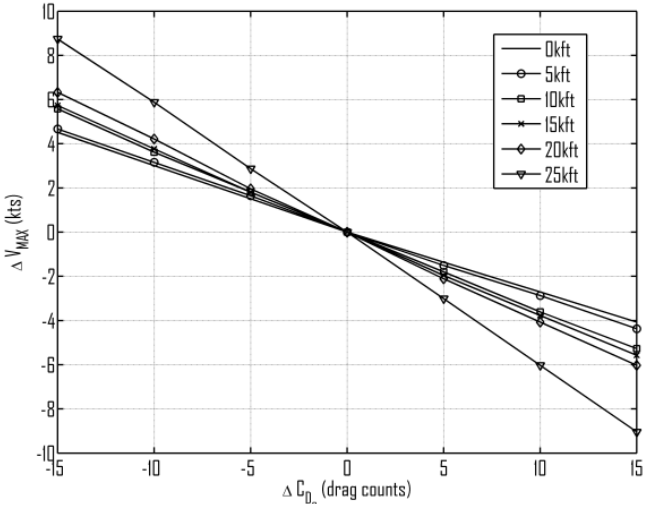
TOTAL MISSION = 200 nm
climb = 50 nm
descent = 50 nm
Vcruise = 270 kt

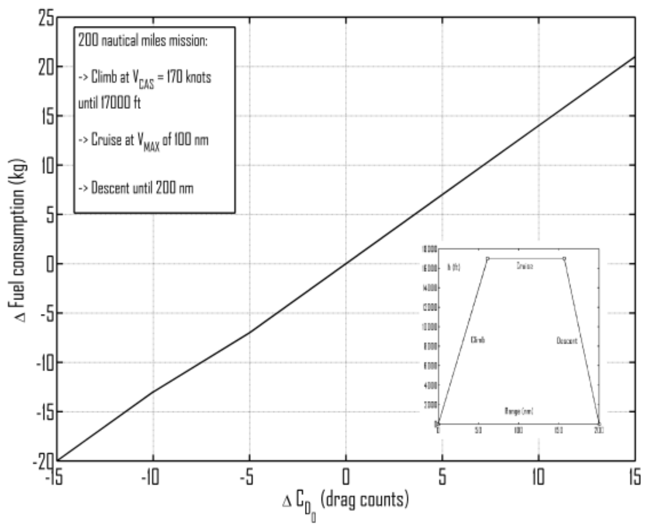




Introduction

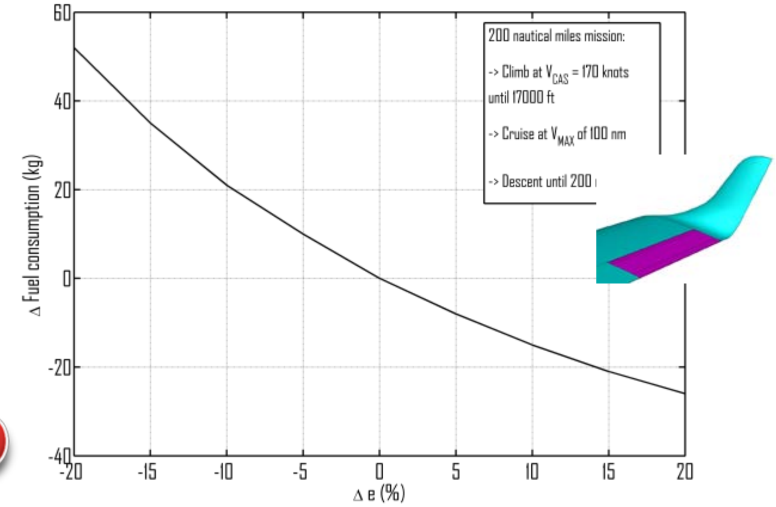
Effects of CDo

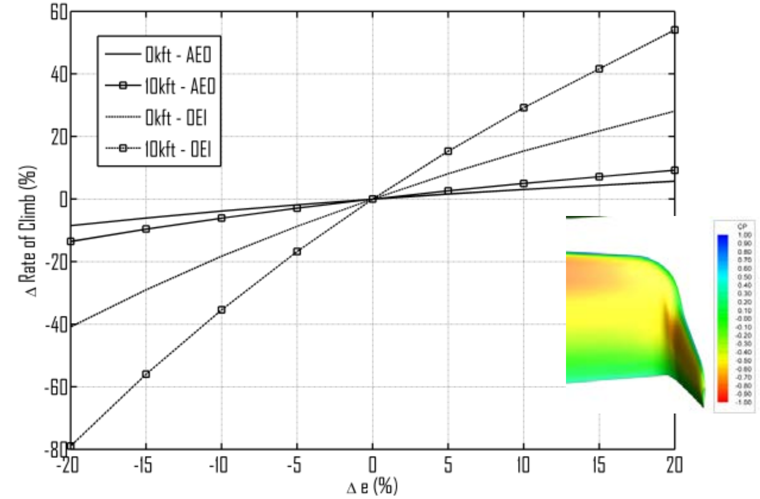




How ?

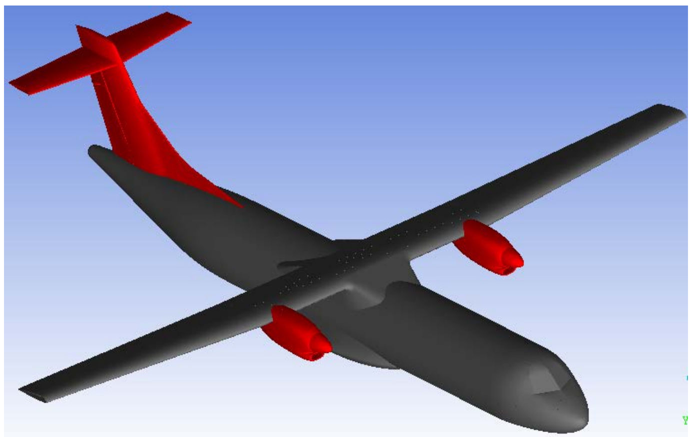
Effect of Oswald e

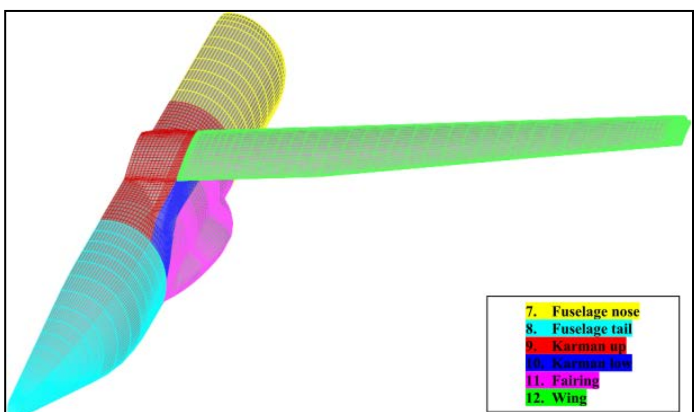




Aircraft Components Optimization

Typical regional turboprop aircraft – 70 seats





Geometrical characteristics

W_{TO}	b	S	L_f	$D_{MAX,f}$
23000 kg	27 m	61 m^2	27 m	2.5 m

Characteristics to estimate drag polar

AR	e	C_{D0}
12	0.83	0.0306

Engine Performance characteristics

SBP	N° of engines	η_p	Cruise altitude
2750 hp	2	0.85	20000 ft

Reference aerodynamic analysis conditions

Condition	α	β	M	Re
Cruise	0°	0°	0.43	$11.5 \cdot 10^6$
Climb	6°	0°	0.3	$8.0 \cdot 10^6$

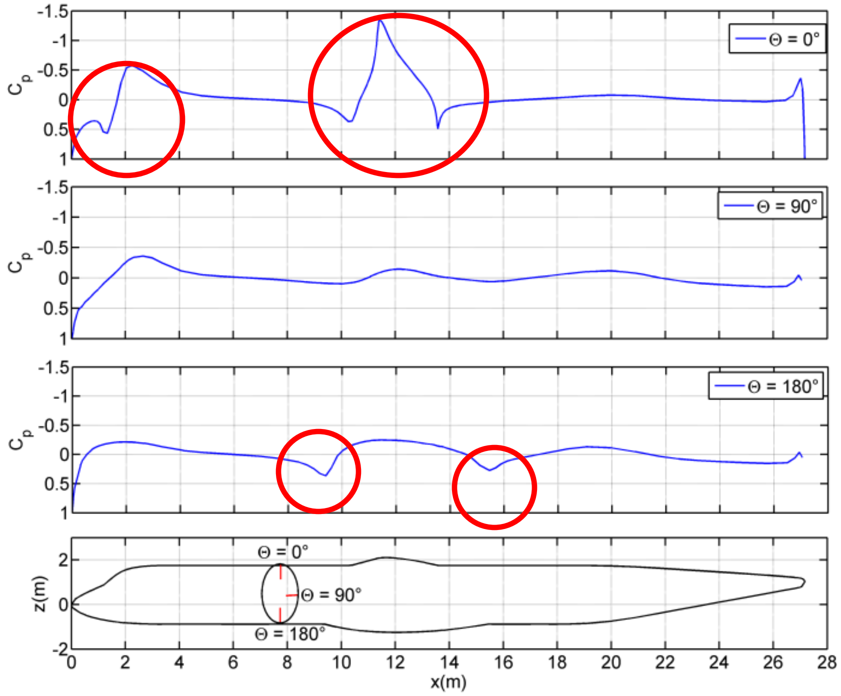
Aircraft Components Optimization

Condition	α	β	M	Re
Cruise	0°	0°	0.43	$11.5 \cdot 10^6$

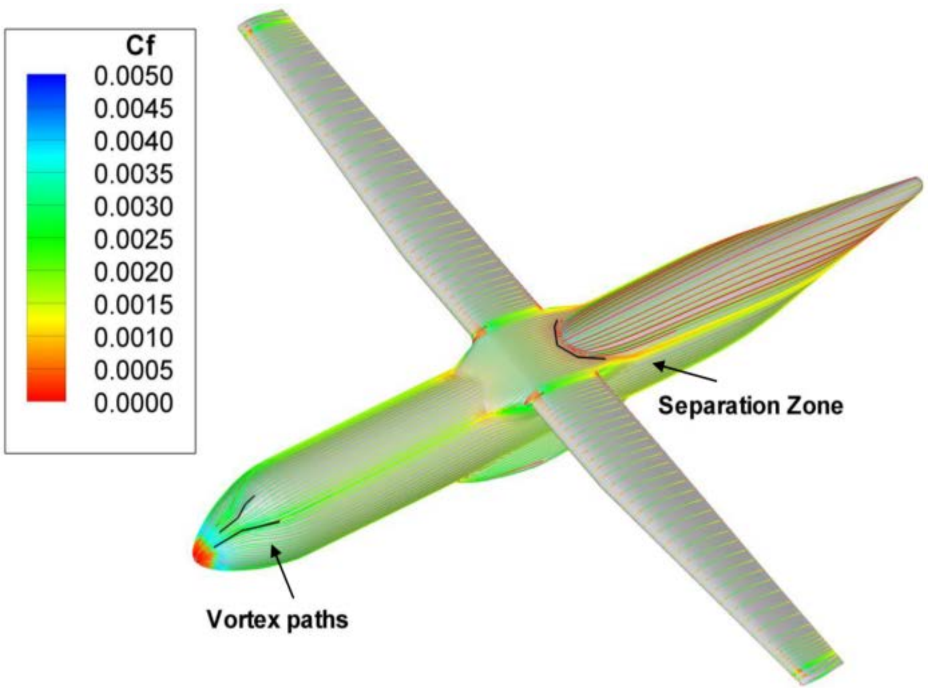
Pressure coefficient in cruise condition

Rapid variation in Cp on the **Nose, wf intersection** and **Fairing** components

Fuselage upper, mid and lower streamlines

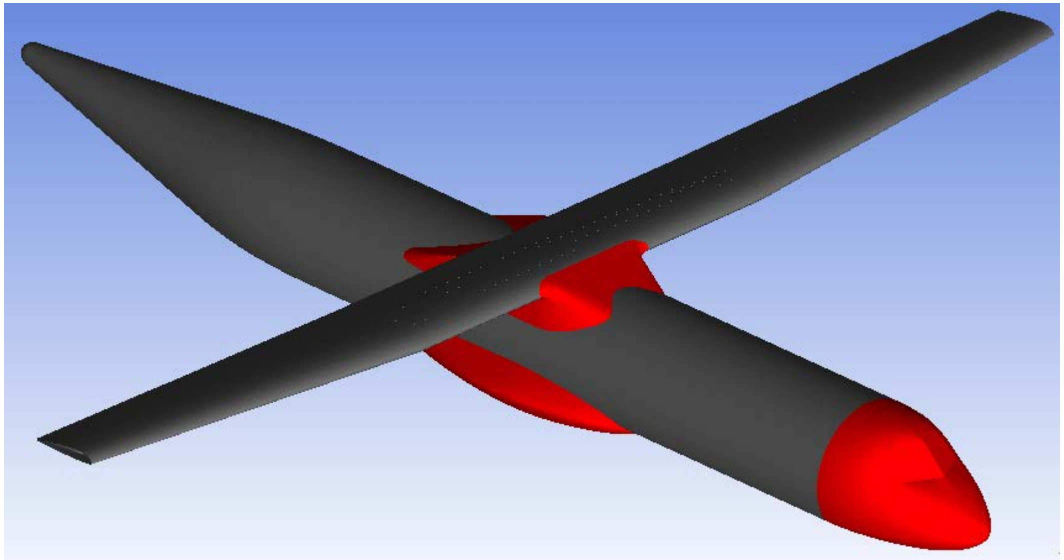


On body streamlines, isometric view

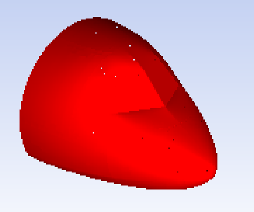


Aircraft Components Optimization

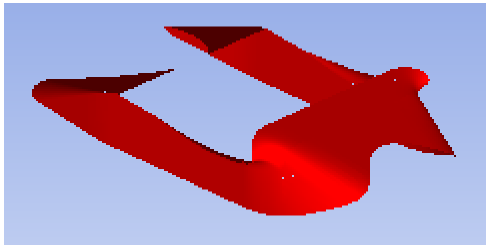
CHOSEN COMPONENTS TO BE OPTIMIZED ON THE BASELINE WING-BODY



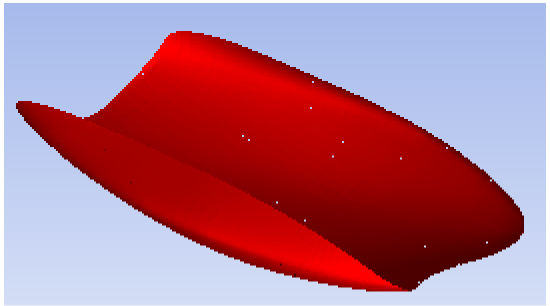
NOSE



WF JUNCTION

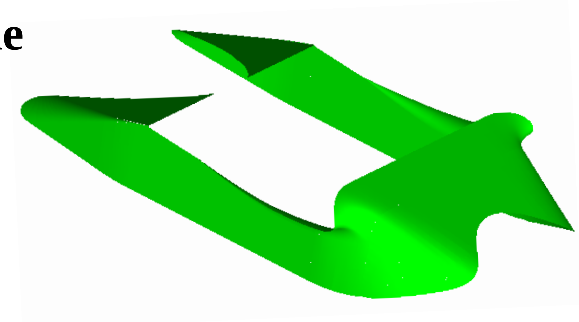


FAIRING

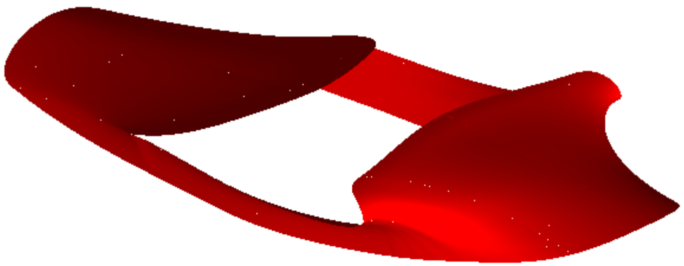


Wing-Fuselage junction Optimization

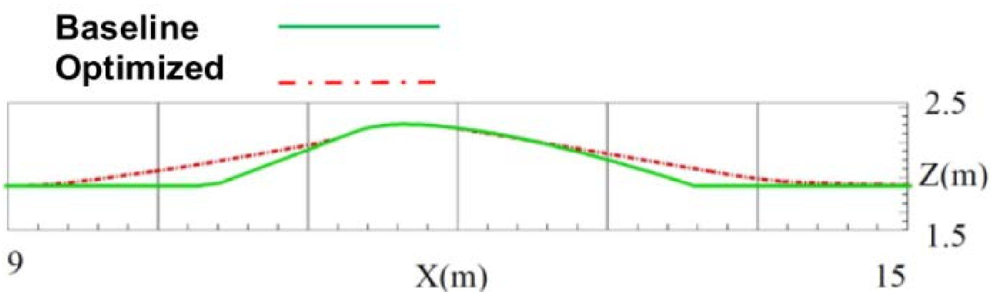
Baseline



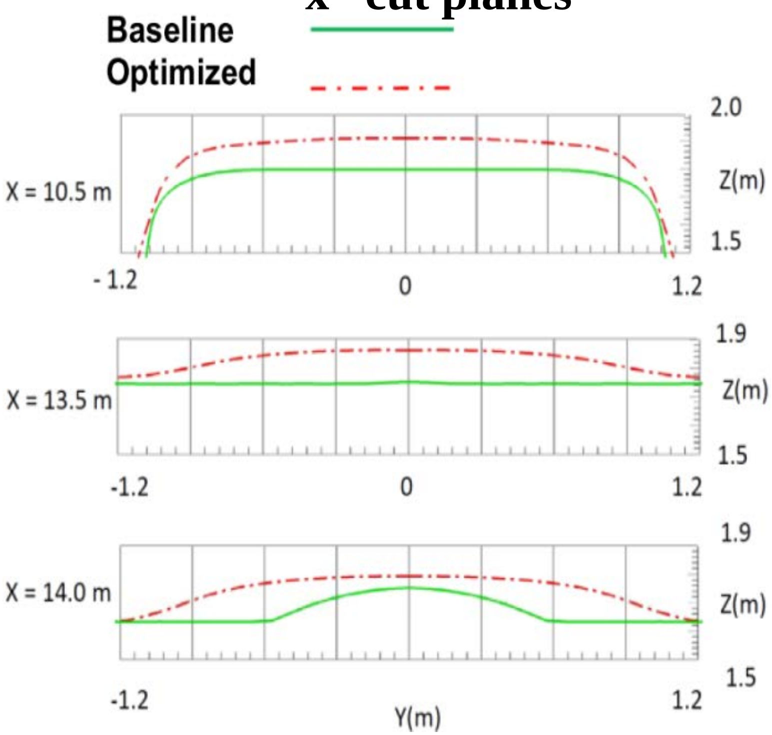
Optimized



Symmetry plane y = 0 m

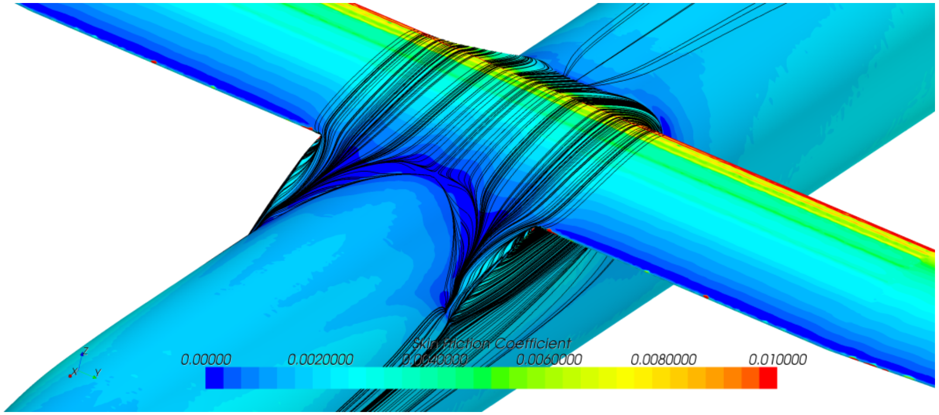


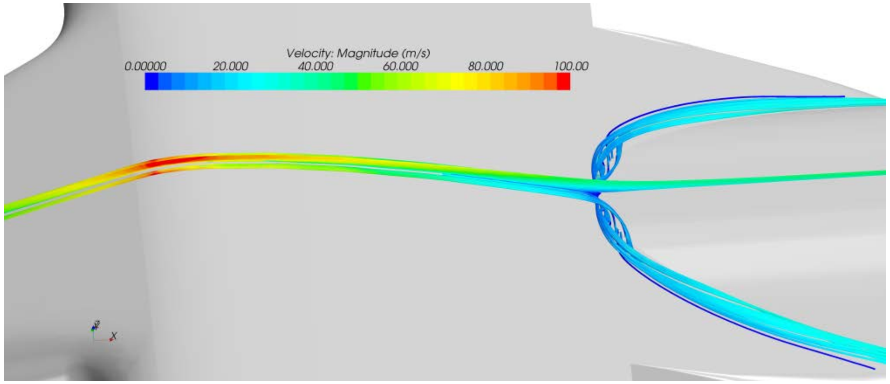
"x" cut planes



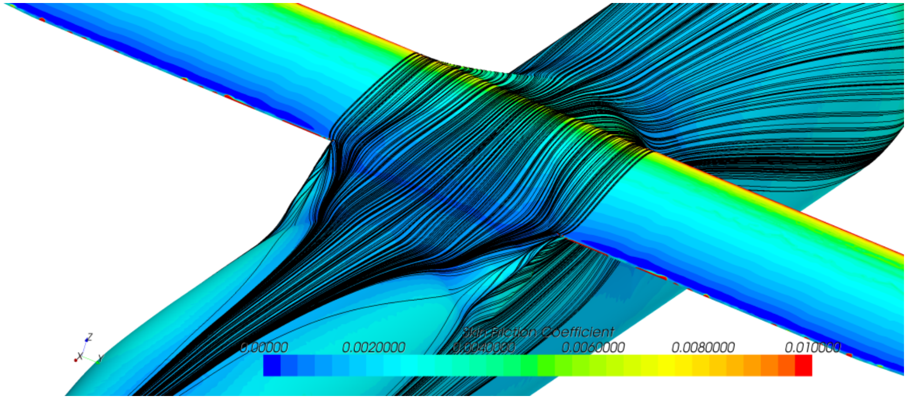
Wing-Fuselage junction Optimization

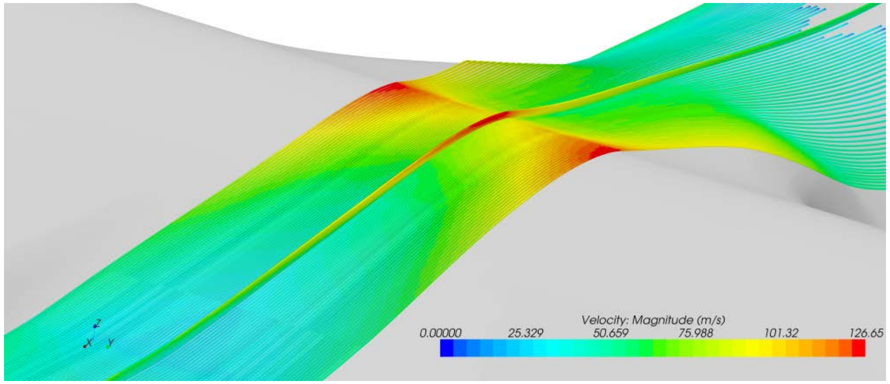
Baseline





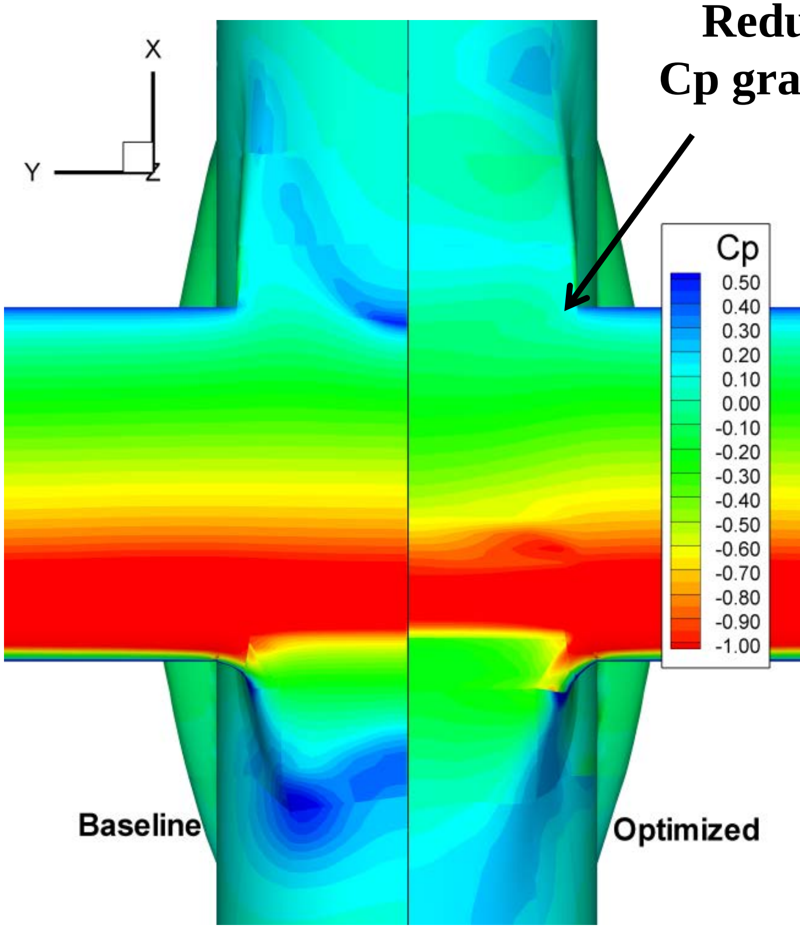
Optimized

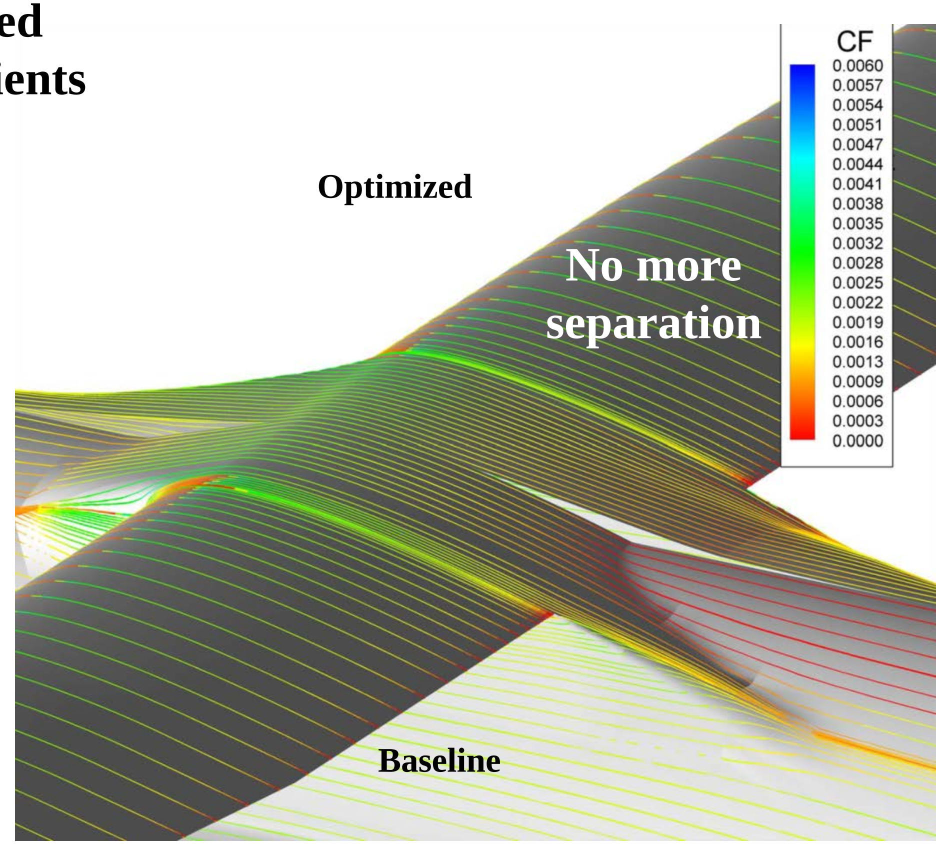




Wing-Fuselage junction Optimization

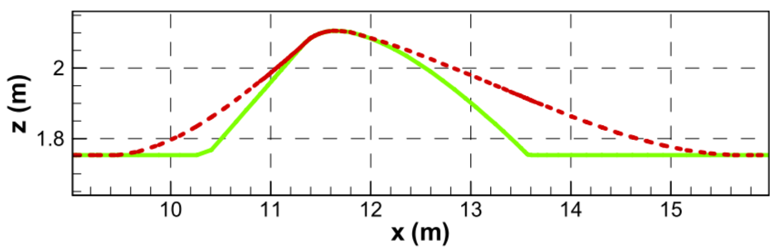
Reduced Cp gradients

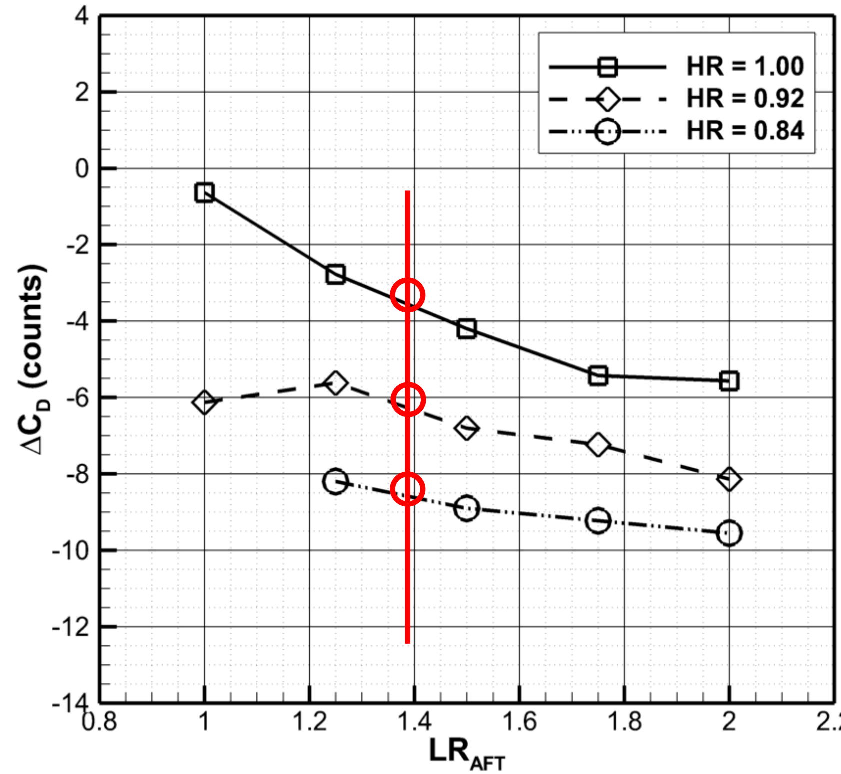




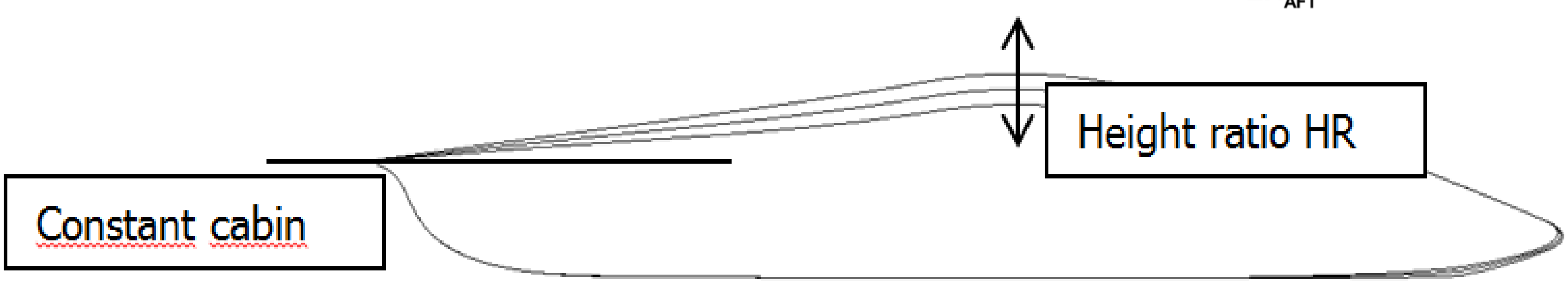
$\Delta C_D = 6.7\, counts \;\; in \;\; Cruise \qquad \Delta C_D = 8.2\, counts \;\; in \;\; \text{Climb}$ $\boxed{\Delta V_{MAX} = 3.3\, kts}$

Wing-Fuselage junction Optimization



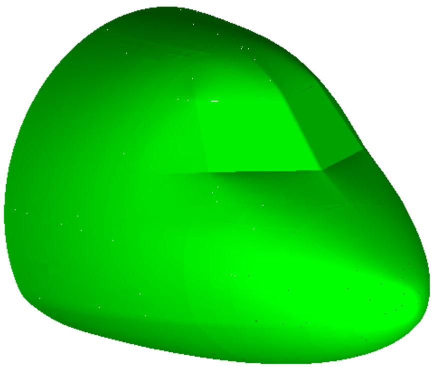


Δv_{max} (h=20kft)	**+4kts**
$\Delta fuel_{saved}$ (**200nmi, typical mission profile**)	**-10kg**

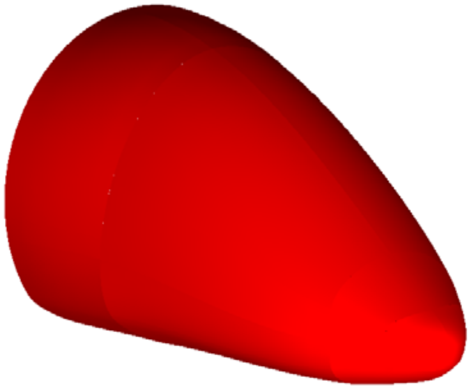


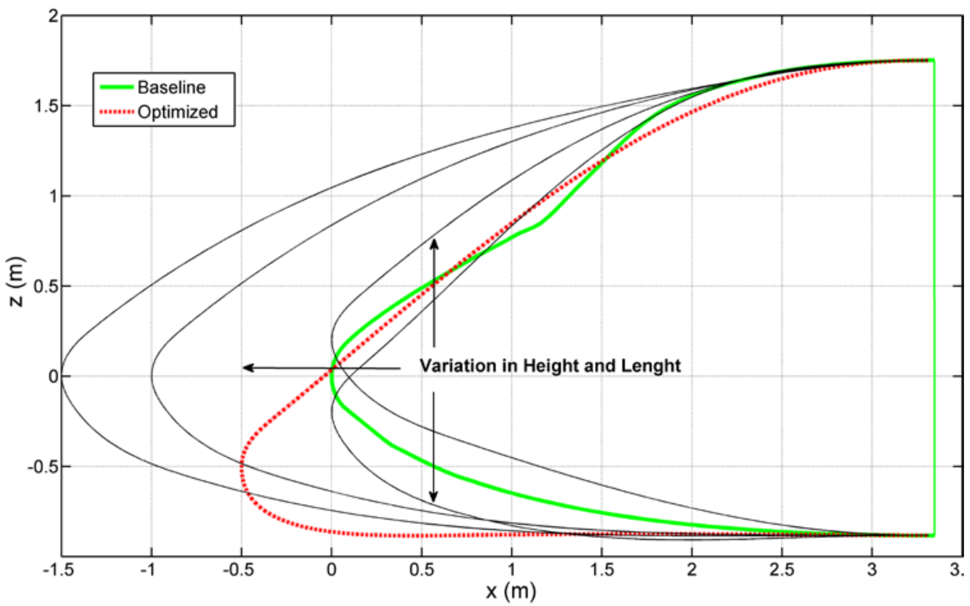
Nose Optimization

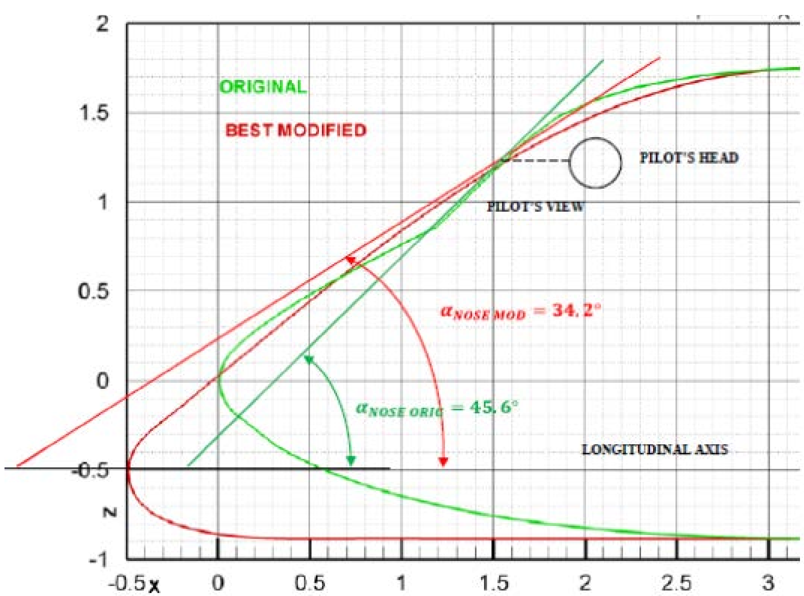
Baseline



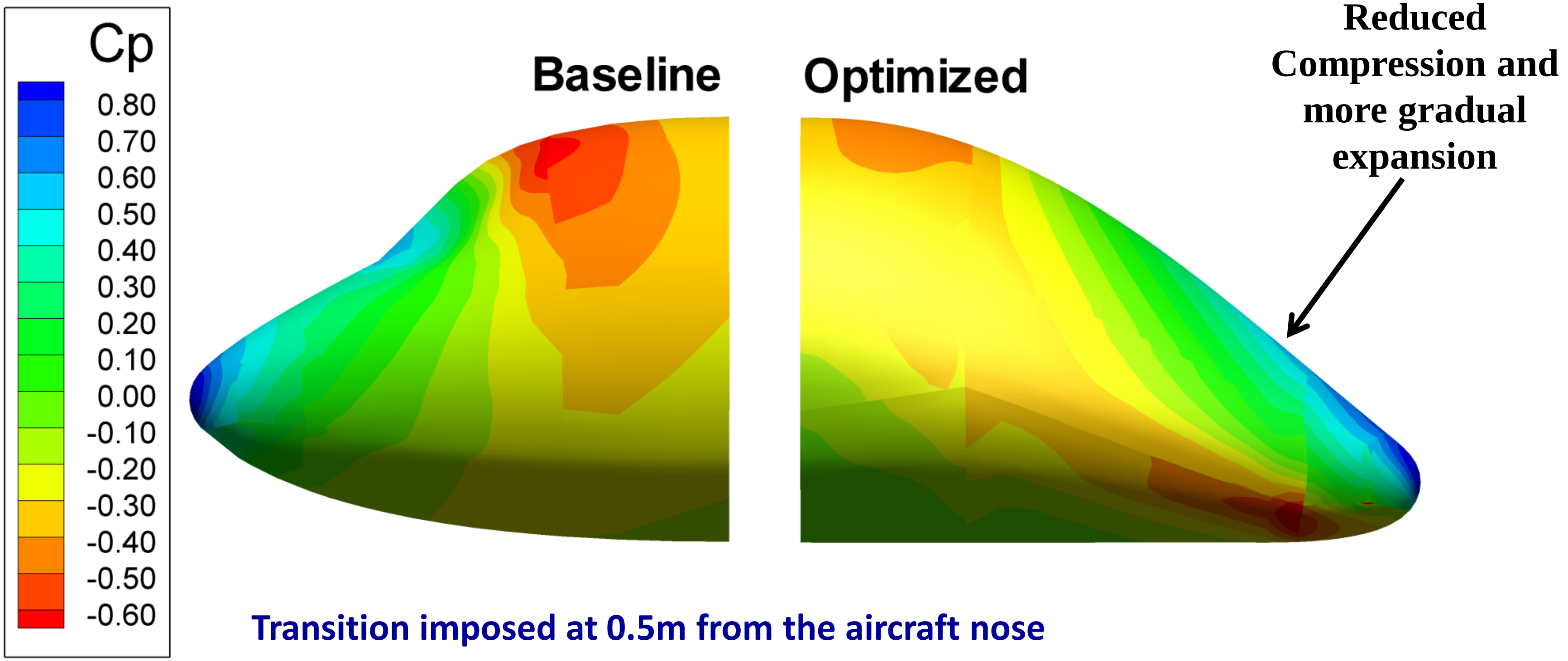
Optimized







Nose Optimization



Transition imposed at 0.5m from the aircraft nose

WB Config.	CD pressure (counts)	CD skin frition (counts)	CD Total (counts)
Baseline	62.8	117.8	180.7
Optimized	59.3	118.1	177.4

$$\Delta C_D = 3.3\, counts\, in\, Cruise$$

$$\Delta C_D = 3.5\, counts\, in\, Climb$$

$$\boxed{\Delta V_{MAX} = 1.6 kts}$$

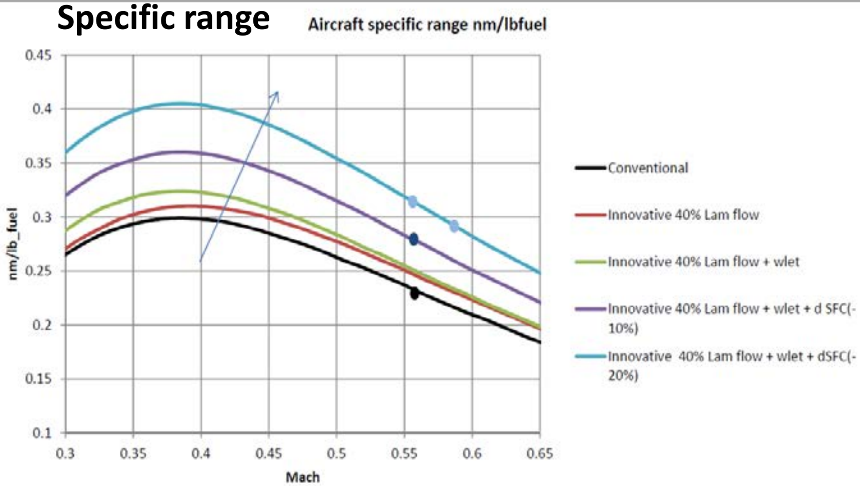
$$C_{M_\alpha} = +5\%$$

Wing Laminar Flow – Engine Integration

Conventional 90-seats

Innovative rear-propelled 90-seats

Specific range



Turboprop innovative configuration benefits

Data	Conventional	Innovative
CDo wing	0.0070	0.0051 (through 40% laminar flow)
CDo aircraft	0.0270	0.0251
e (Oswald efficiency factor)	0.78	0.85 (winglet installed)
Engine SFC [lb/(hp hr)]	0.40	0.36 or 0.32 -10% or -20%

up to about 8% fuel saving can be achieved only through laminar flow on the wing

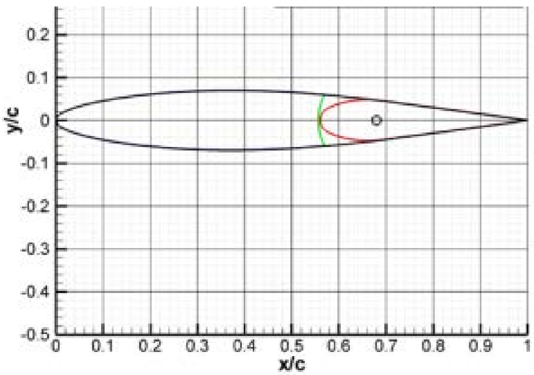
Data	Conventional	Innovative 1 (Laminar flow)	Innovative 2 (Laminar flow + SFC red -10%	Innovative 3 (Laminar flow + SFC red -20%
Specific Range @ M=0.56 (nm/lb_fuel)	0.23	0.25 (+9%)	0.275(+19%)	0.318(+38%)
Fuel @ 300 nm mission (lb)	1304 lb	1200 lb (-8%)	1091 lb (-16%)	943 lb(-28%)

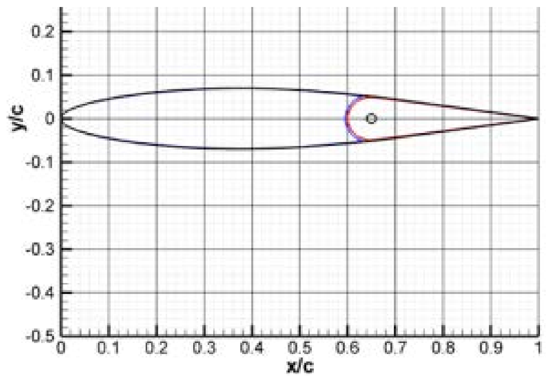
Vertical Empennage Design – Control Surface

$$\Delta C_D = 8 \text{drag counts (cruise)}$$

$$\Delta V_{\max} = 4kts$$

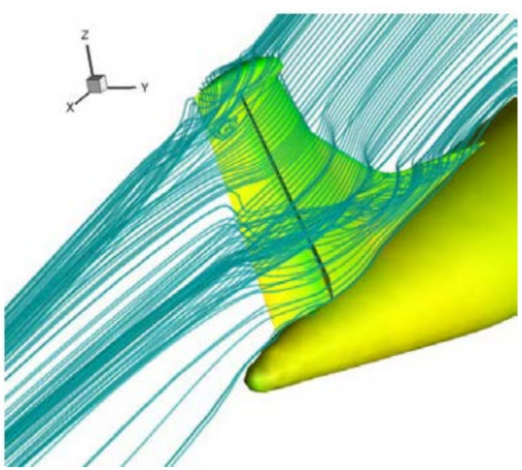
$$\Delta fuel_{saved} = 13kg \text{(200nmi mission profile)}$$

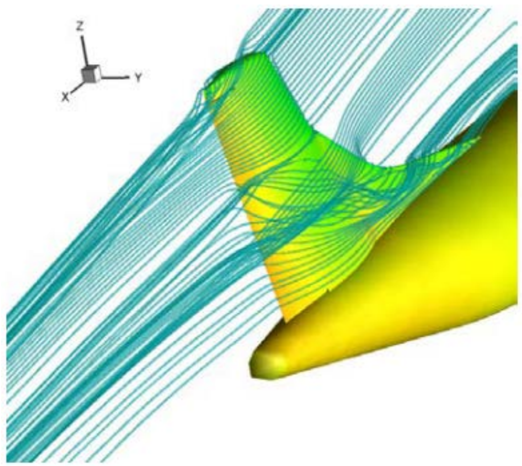


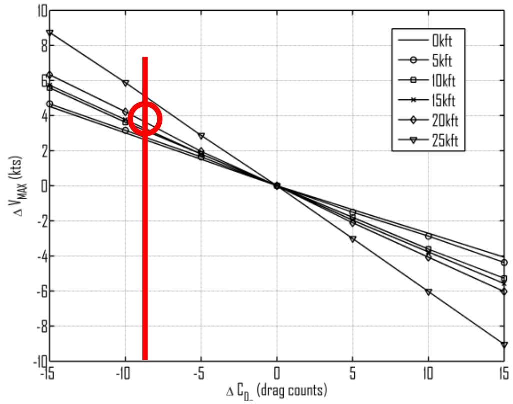


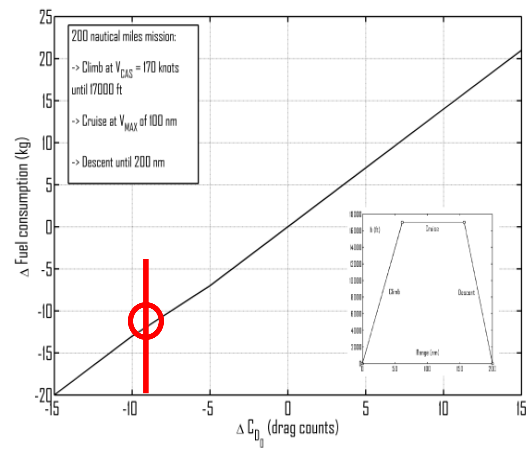
Conventional Turboprop Vertical Empennage

Innovative Turboprop Vertical Empennage



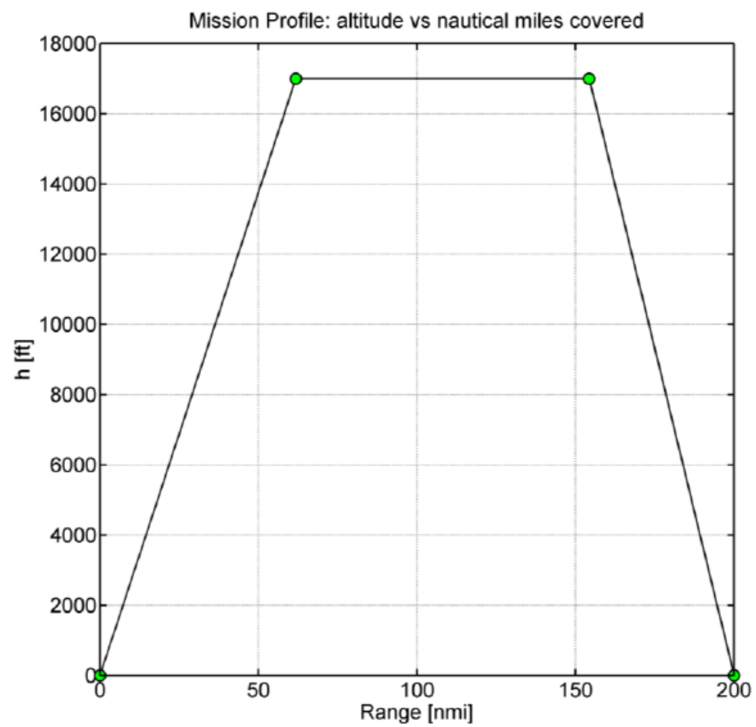


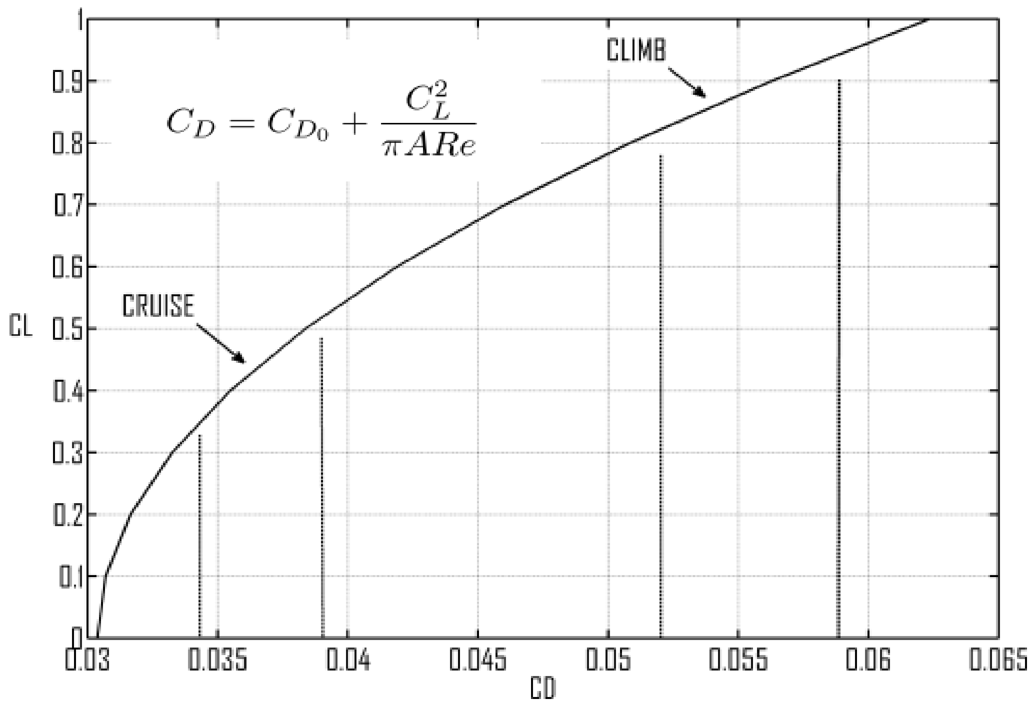




Winglet Design and Optimization

Mission Profile	Altitude [ft]	Distance [nm]	Time[min]	Fuel Mass Burned [kg]
Take-off	0	-	-	-
Climb	17000	61.8	18.1	264.8
Cruise	17000	154.3	38.7	516
Descent	0	200	50.1	592.2

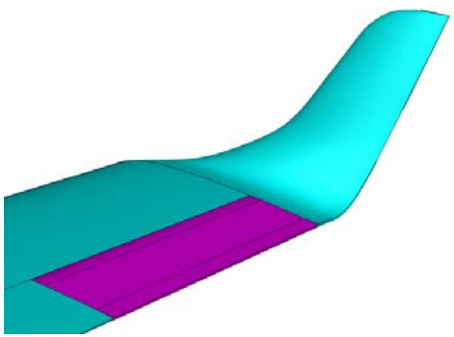


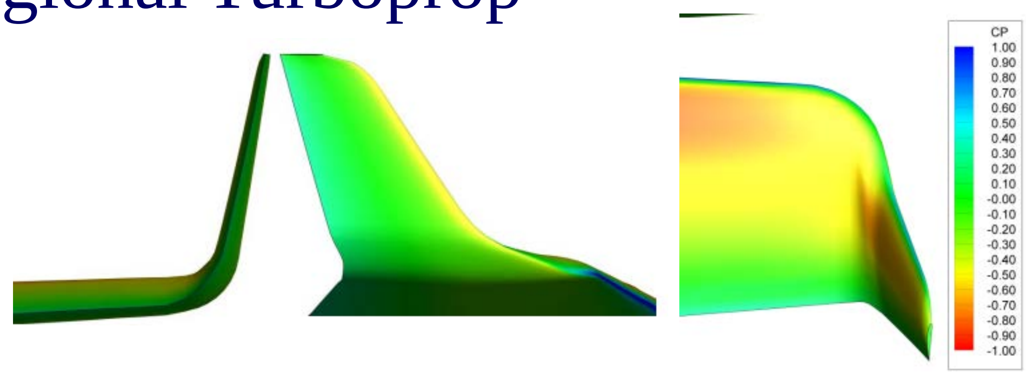


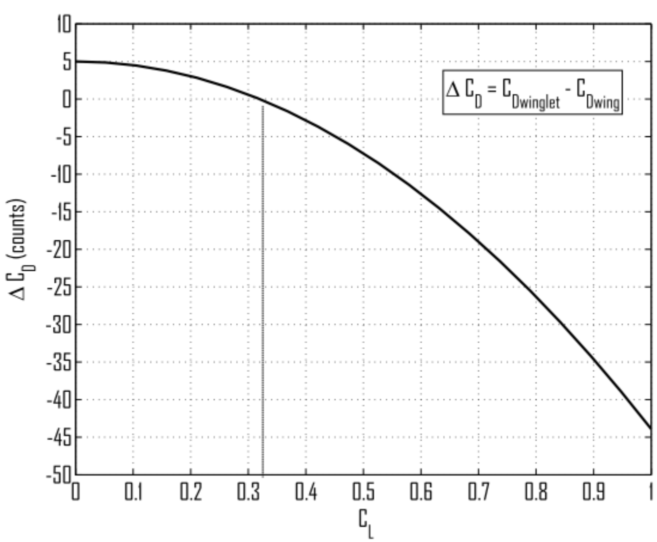
A turboprop aircraft spends 50% of its life time during climb and descent phases.
About 50% of fuel during climb

Wing Tip Design for a Regional Turboprop

Possible New Turboprop wing-tip assessment



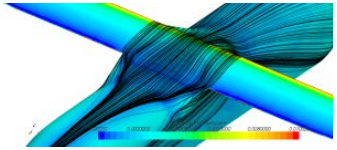




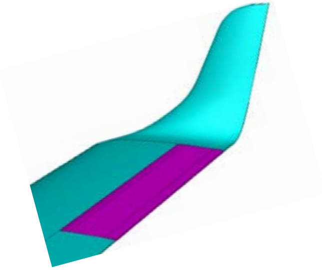
Aircraft configuration	Original	Winglet	
C_{D_0}	0.03060	0.0311	
e	0.85	0.971	
Performance			% of variation
FAR S_{TO} (ft)	4065	4039	−0.7%
FAR S_{LAN} (ft)	3176	3150	−0.1%
R/C s.l. AEO (ft/min)	1437	1508	+4.9%
R/C 10 kft AEO (ft/min)	1063	1149	+8.1%
R/C s.l. OEI (ft/min)	345	434	+25.8%
R/C 10 kft OEI (ft/min)	209	312	+49.2%
Net Ceiling AEO (ft)	23561	25489	+8.2%
Net Ceiling OEI (ft)	10968	13177	+20.1%
Maximum V_{TAS} at 20kft (kts)	262	267	+1.9%
Fuel consumption for a 200 nm mission (kg)	594	576	−3.1%
Wing root bending moment			+3.5%

Conclusions

A novel turboprop can achieved the following improvements:



- 3% drag reduction (**11 counts**) nose, wf-junction and fairing
- 4% drag reduction (**20 counts**) wing laminar flow (rear engine)
- 3% drag reduction (**15 counts**) not balanced control surfaces
- +10% on Oswald factor with winglet



TOTAL OF 40 DRAG COUNTS REDUCTION

→ MAXIMUM SPEED IMPROVEMENT OF **V_TAS > 15 kt**

→ FUEL CONSUMPTION REDUCTION OF **60 kg** (i.e 11% during typical 200 nm mission)

→ **+30% RATE OF CLIMB** IN ONE ENGINE INOPERATIVE OEI

Challenges for new Regional Turboprop Configuration

Pierluigi Della Vecchia, PhD.

Questions ?

University of Naples Federico II
Department of Industrial Engineering
Via Claudio, 21, 80125 Naples
pierluigi.dellavecchia@unina.it
http://wpage.unina.it/pierluigi.dellavecchia/
http://wpage.unina.it/fabrnico/DAF/