Flight Dynamic Analysis of a Small Hypersonic Plane

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BLUE Engineering ITALY

3rd International Symposium on Hypersonic Flight

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AAA – Sez. Roma Due “Luigi Broglio”

Partner Involved

DIMEAS Flight Mechanic Team

The research group is expert in the development of flight simulators, advanced control systems, embedded systems and sensor fusion, computer vision and implementation of efficient image processing algorithms, UAV platforms, thermography and remote sensing.

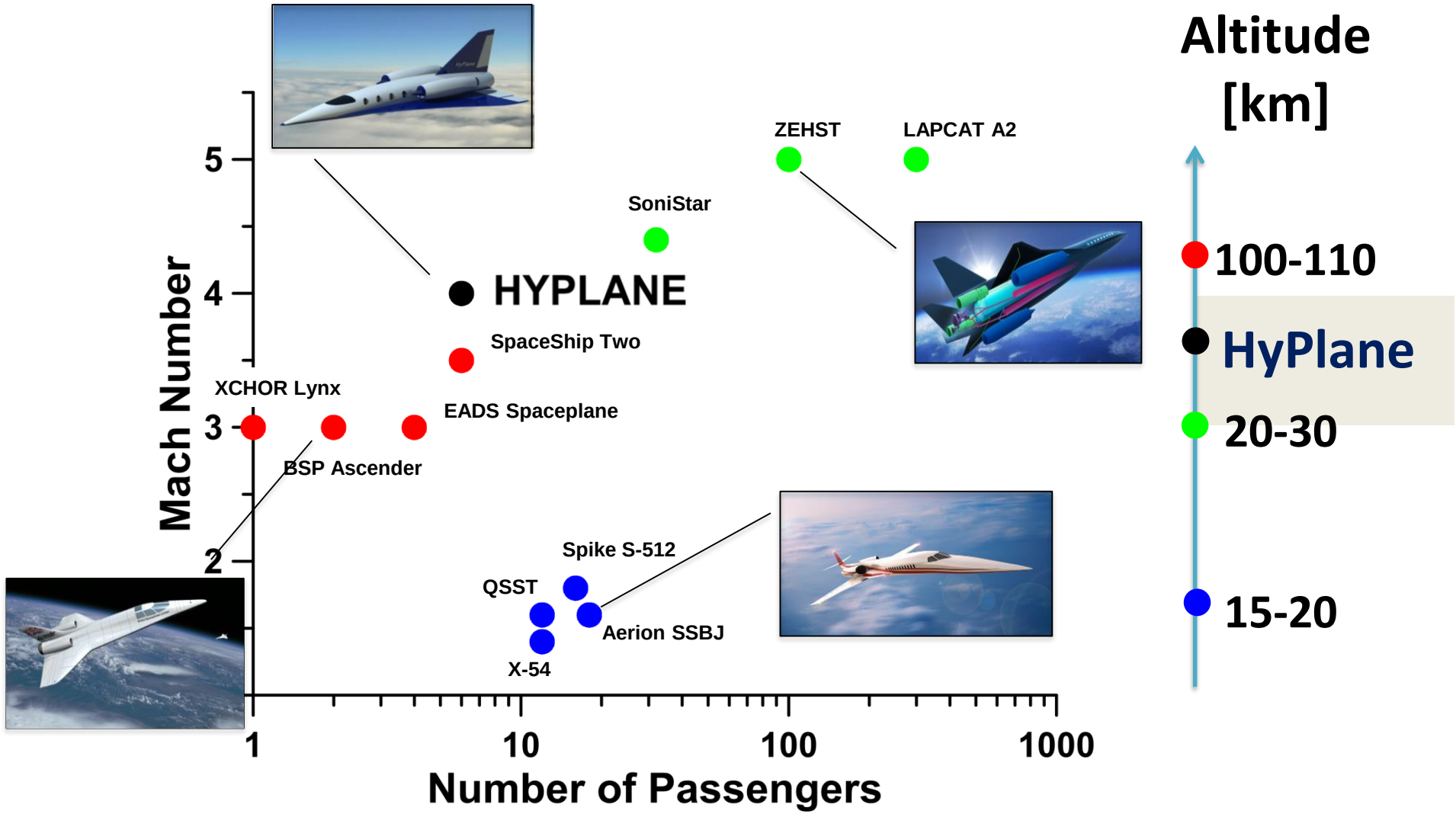
BLUE Engineering

Founded in 1993, provides specific services to fields of excellence, such as aerospace, automotive, railway. Blue is characterized by a strong multi-sector know-how and specialization in analysis and design. BLUE can provide at the highest quality level, during all of the development stages: style, design, engineering, virtual prototyping, testing and validating.

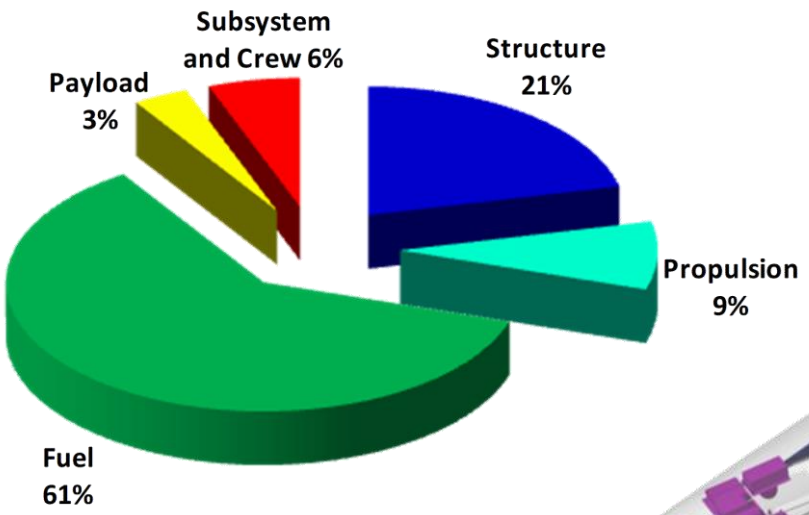
Space Tourism Plane

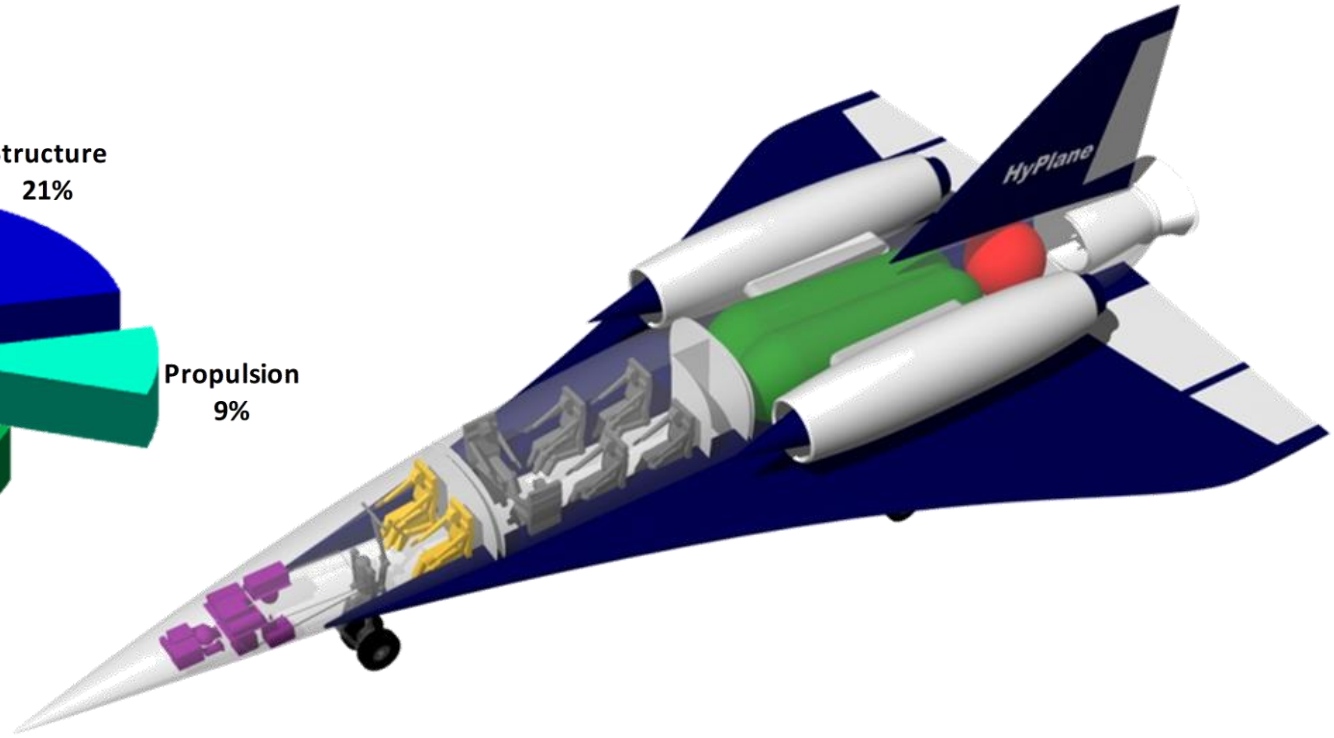
	X-COR Lynx	EADS SpacePlane	Virgin Galactic SS2	BSP Ascender
				
Crew + Passengers	1+1	1+4	2+6	1+2
Max. Altitude	100 km	100 km	110 km	100 km
Max. Mach Number	3	3	3.5	3
Max. Acceleration	4.5g	4.5g	6g	6g
Propulsion System	Rocket	Turbojets, Rocket	Rocket	Turbojets, Rocket
Takeoff/Landing	HTHL	HTHL	Air Launch, Glide Landing	HTHL
Cost/seat	95k$	200k€	200k€	100k$

Space Tourism Plane



Hyplane

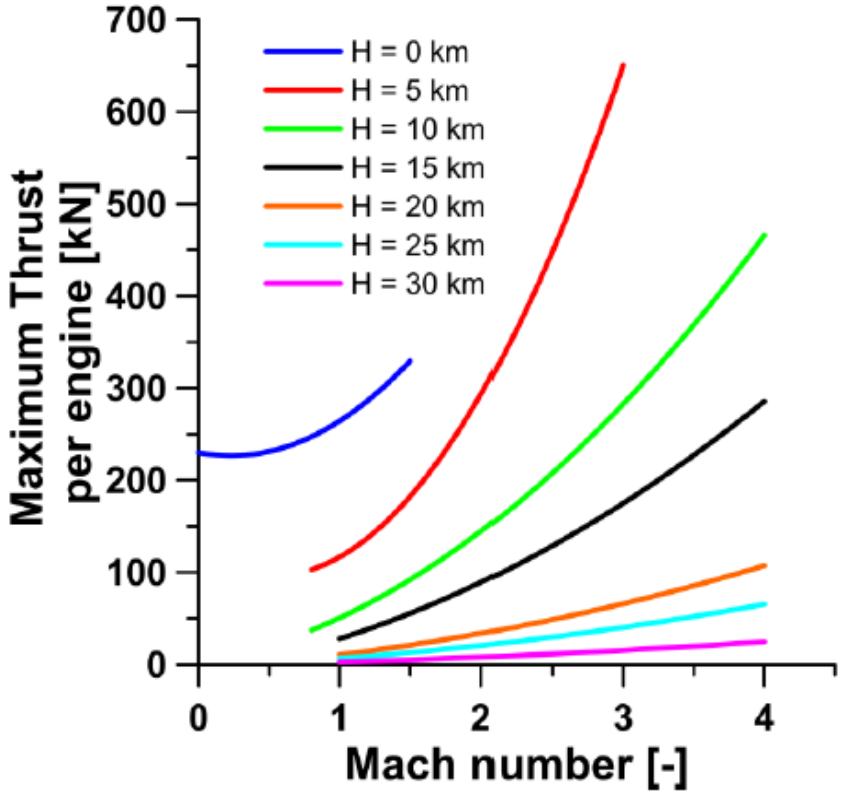


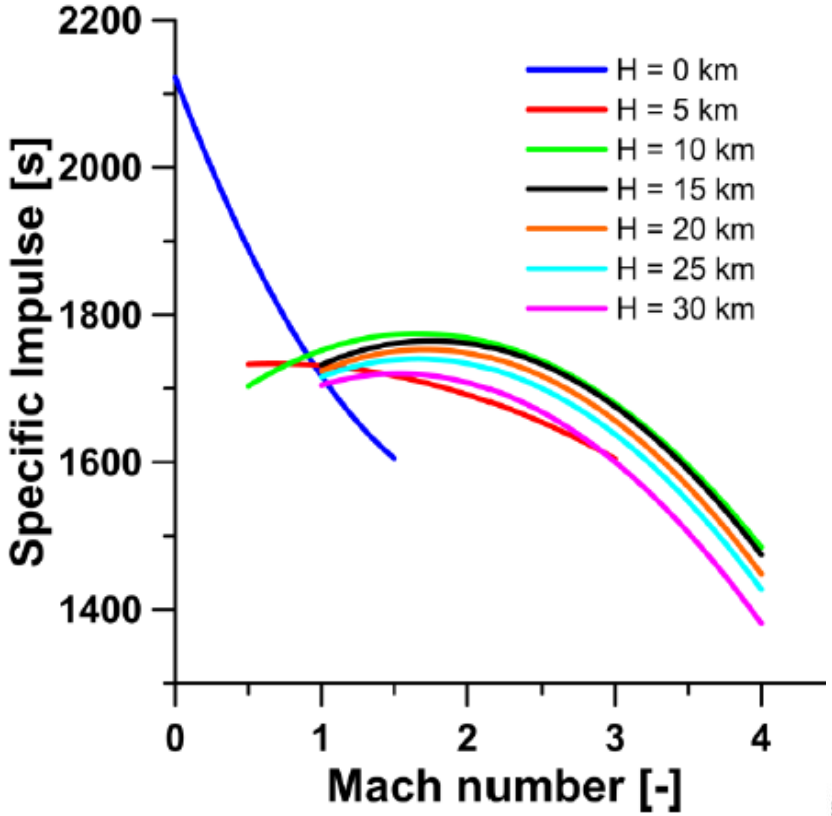


- Subsystems
- Pilots
- Passengers
- JP Tank
- H_2O_2 Tank

Seat	Alt. [km]	Mach	Propuls.	Range [km]
8	30	4-5	**2** TBCC **1** Rocket	6000

Turbine Based Combined Cycle Engine





M. A. Brock, Performance study of two-stage-to-orbit reusable launch vehicle propulsion alternatives (Master's Thesis), Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio (2004)

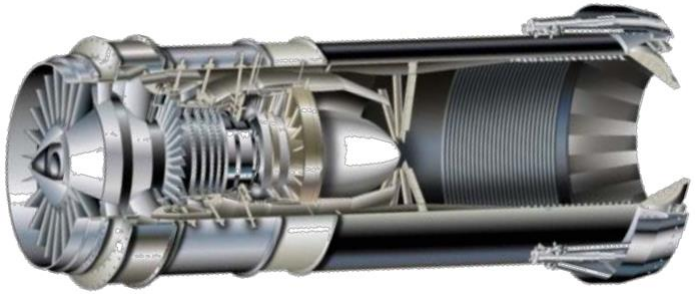
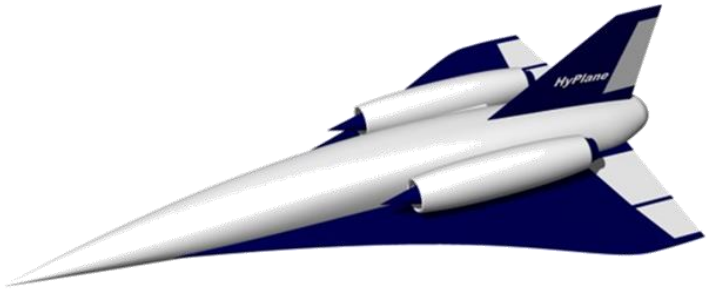


Image courtesy of NASA

Aerodynamic Database



GEOMETRY PARAM.

USAF DATCOM

DIGITAL

MISSILE

CAD

DATABASE

blue Group Engineering & Design

CFD

VALIDATION

CORRECTION

USAF Datcom Geometry

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CASEID HYPLANE

DIM M
DERIV RAD
DAMP


 $FLTCON NMACH=11.,
        MACH(1)=0.01,0.05,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,
        STMACH=0.92,TSMACH=1.4,
        NALT=10.0,
        ALT(1)=0.,5000.,10000.,20000.,25000.,30000.,35000.,40000.,50000.,60000.,
        NALPHA=20.0,
        ALSCHD(1)=-5.,-3.,-2.,-1.,0.,0.5,1.,2.,3.,5.,6.,7.,8.,
                  9.,10.,11.,13.,16.,20.,25.,
        HYPERS = .TRUE.,
        LOOP = 2.,$

 $OPTINS BLREF=16.,CBARR = 10.874, SREF = 140.259,$

 $SYNTHS XCG=13.257, ZCG=0.9,
        XW=3.6988, ZW=0., ALIW=0.0,$



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         11.4000,12.8000,14.3000,15.3461,16.9000,18.3000,19.9000,20.8000,
         21.3000,21.6000,21.8143,
       ZU(1) = -0.5109,-0.4821,0.1549,0.6469,1.0395,1.4232,1.5683,1.7053,
         1.8215,1.8757,1.8845,1.8533,1.8065,1.6988,1.5623,1.3600,1.2238,
         1.1418,1.0555,0.8563,
       ZL(1) = -0.5109,-0.5362,-0.4734,-0.4328,-0.4122,-0.4148,-0.4274,-0.4291,
         -0.4291,-0.4291,-0.4291,-0.4291,-0.4291,-0.4291,-0.4291,-0.4274,-0.3238,
         -0.1920,-0.0664,0.1121,
       R(1) = 0.0000,0.0504,0.3629,0.6273,0.8652,1.1430,1.2704,1.3462,1.4025,
         1.4267,1.4369,1.4432,1.4448,1.4342,1.4009,1.2843,1.0657,0.8726,
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       BTAIL =2.,
       DS=0.05,
       METHOD=2.0,
       ITYPE=2.0,$

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        SSPNOP=4.828,
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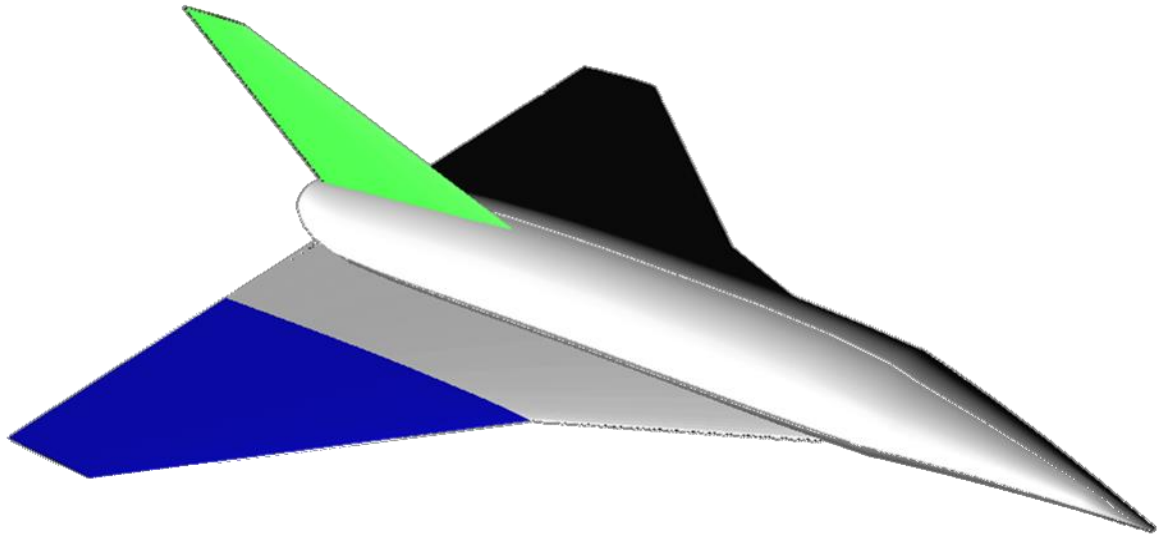
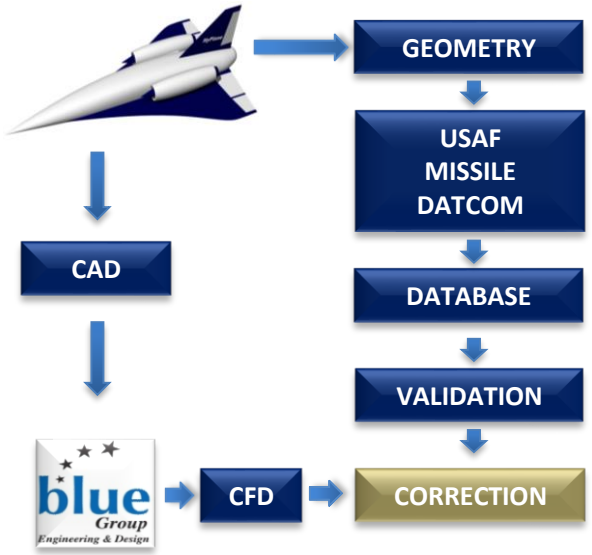
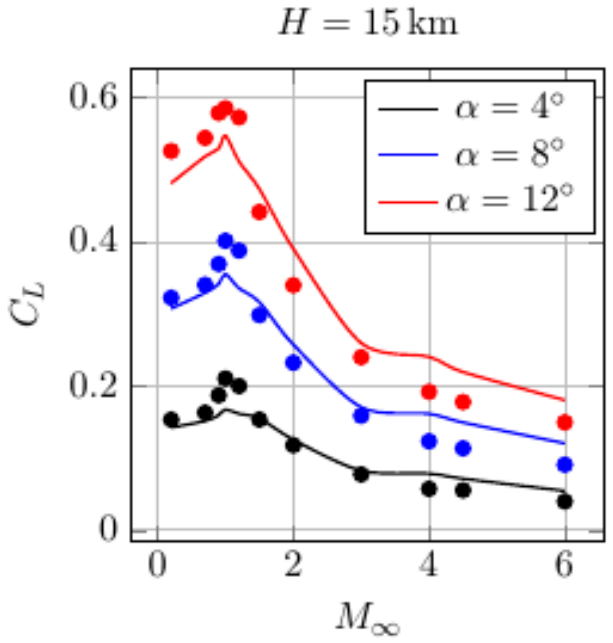
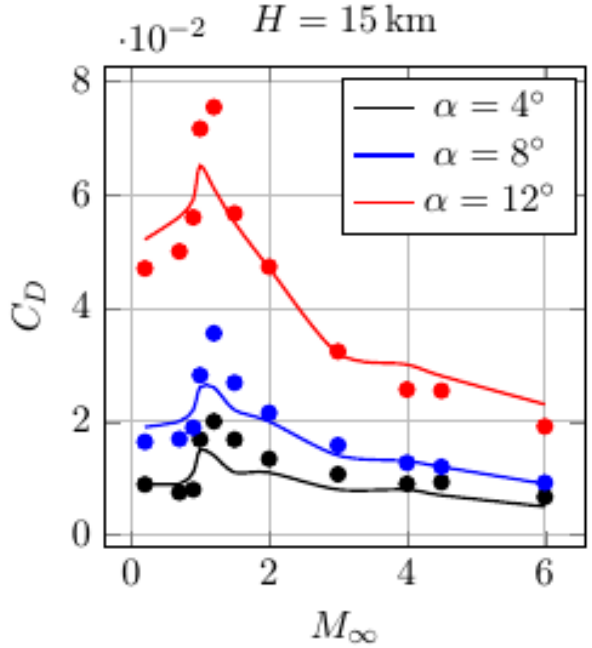
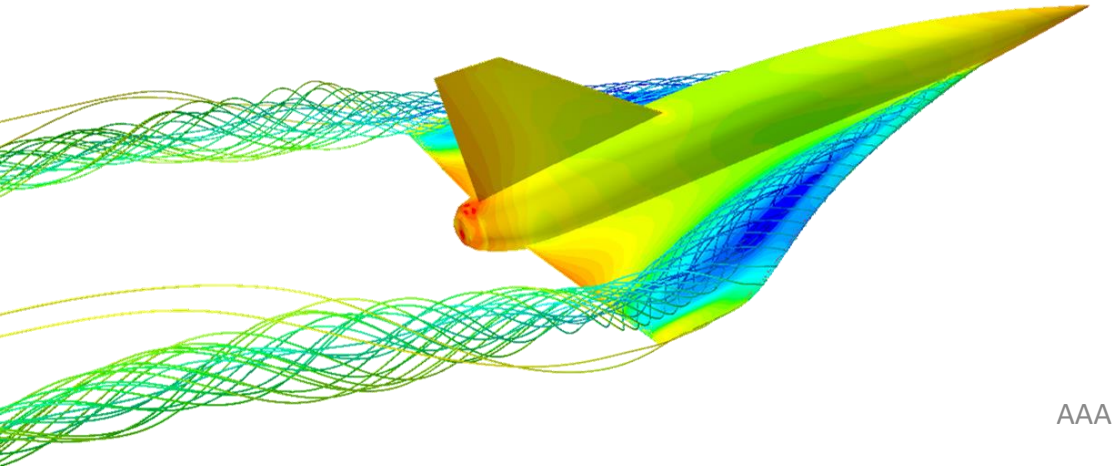


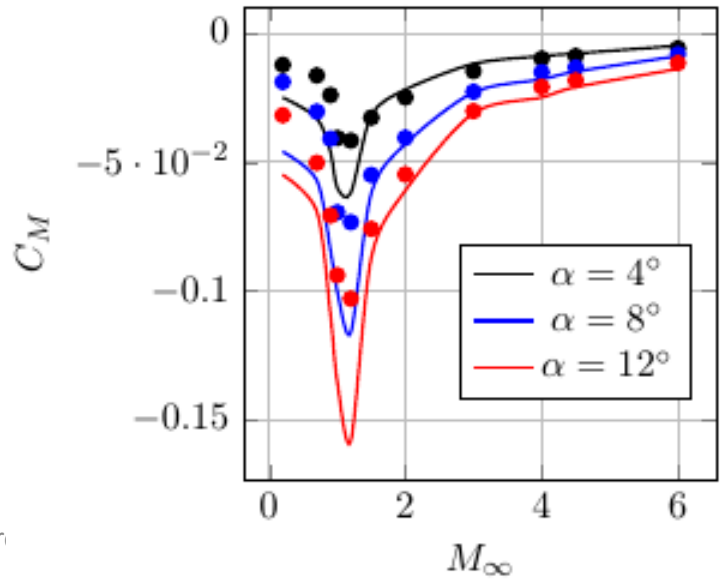
Aerodynamic Database





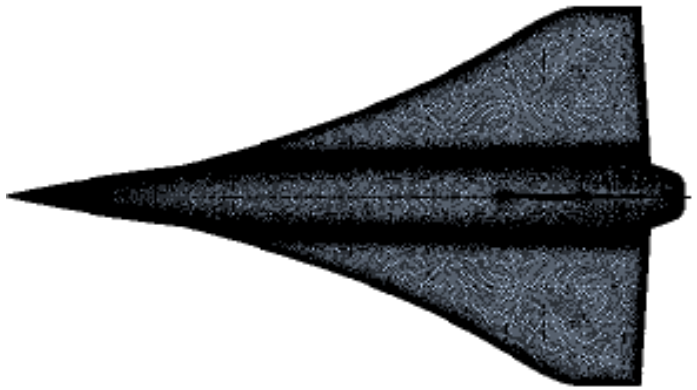


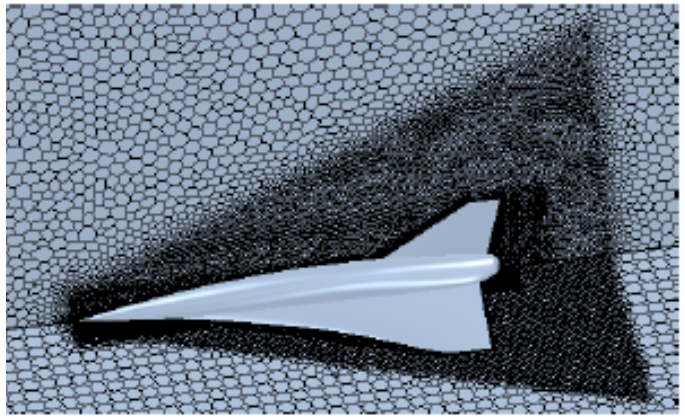




Aerodynamic Database

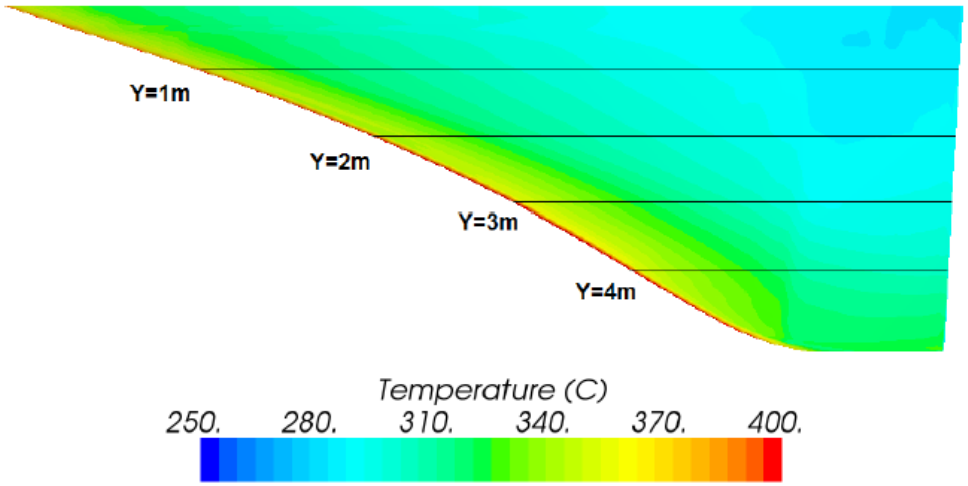
Regimes	Lift Deviation	Drag Deviation	Pitching Moment Deviation	Averaged Deviation
Subsonic	4.6%	15.1%	29.2%	19.0%
Transonic	20.3%	18.2%	39.0%	25.7%
Supersonic	14.4%	6.8%	12.0%	11.1%
Hypersonic	8.3%	12.1%	8.5%	9.6%

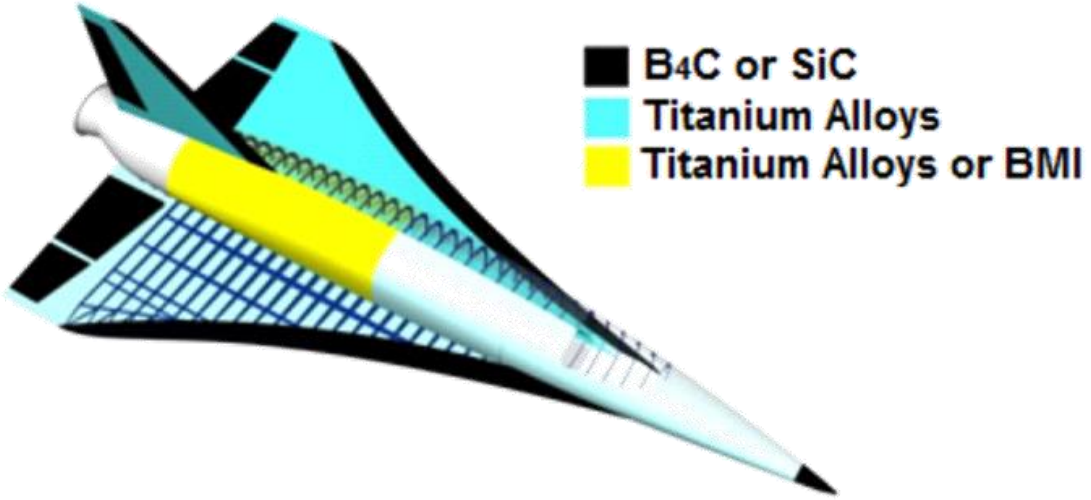


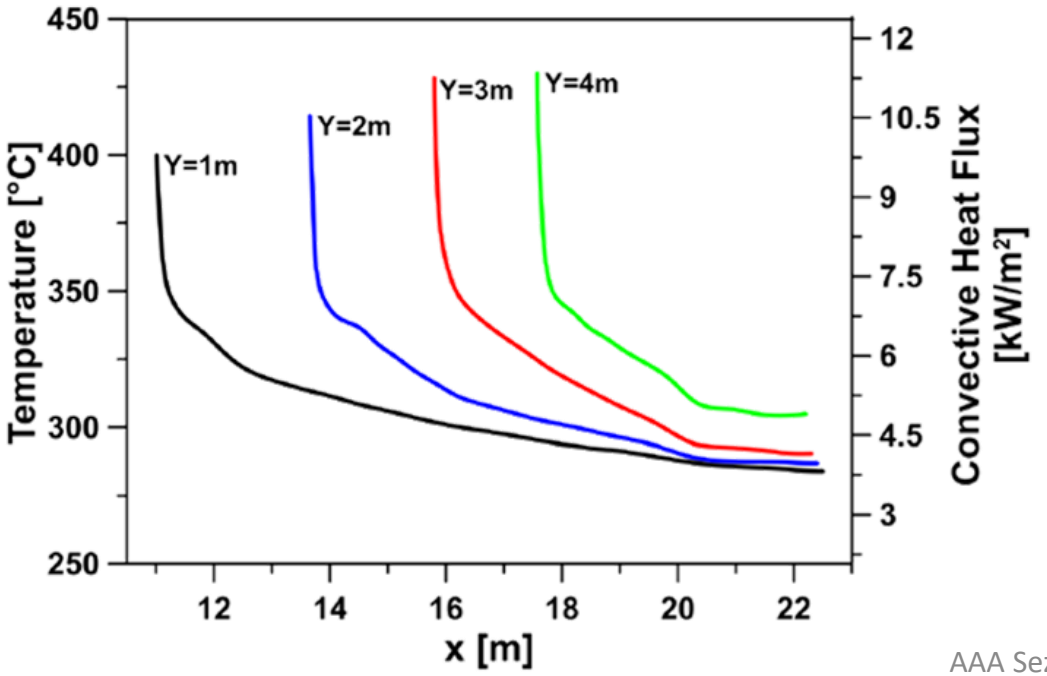


Mesh parameters	
Number of Cells	13.5 M
Number of Surface Faces	1.5 M
Number of Prism Layers	25

Aerodynamic Database







High Temperature parts:

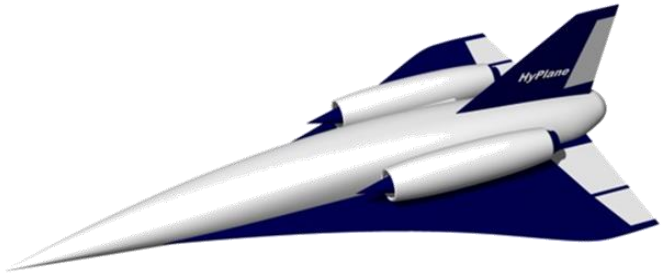
- Boron Carbide
- Silicon Carbide

➢ Mach = 4

➢ H = 30 km

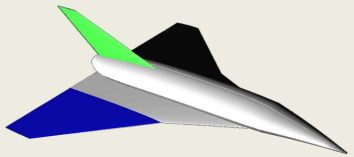
➢ AoA = 0°

Configuration Optimisation



GEOMETRY PARAM.

USAF DATCOM



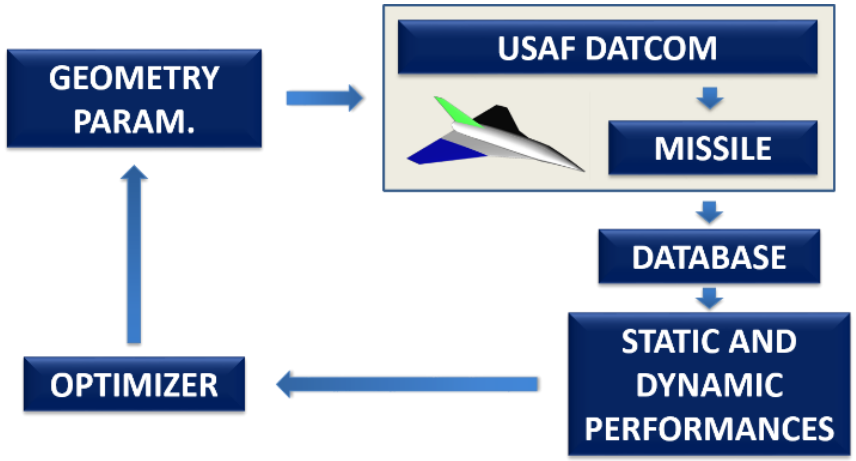
MISSILE

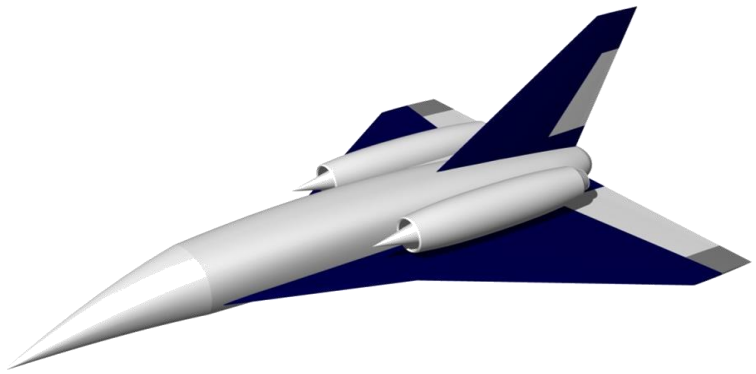
DATABASE

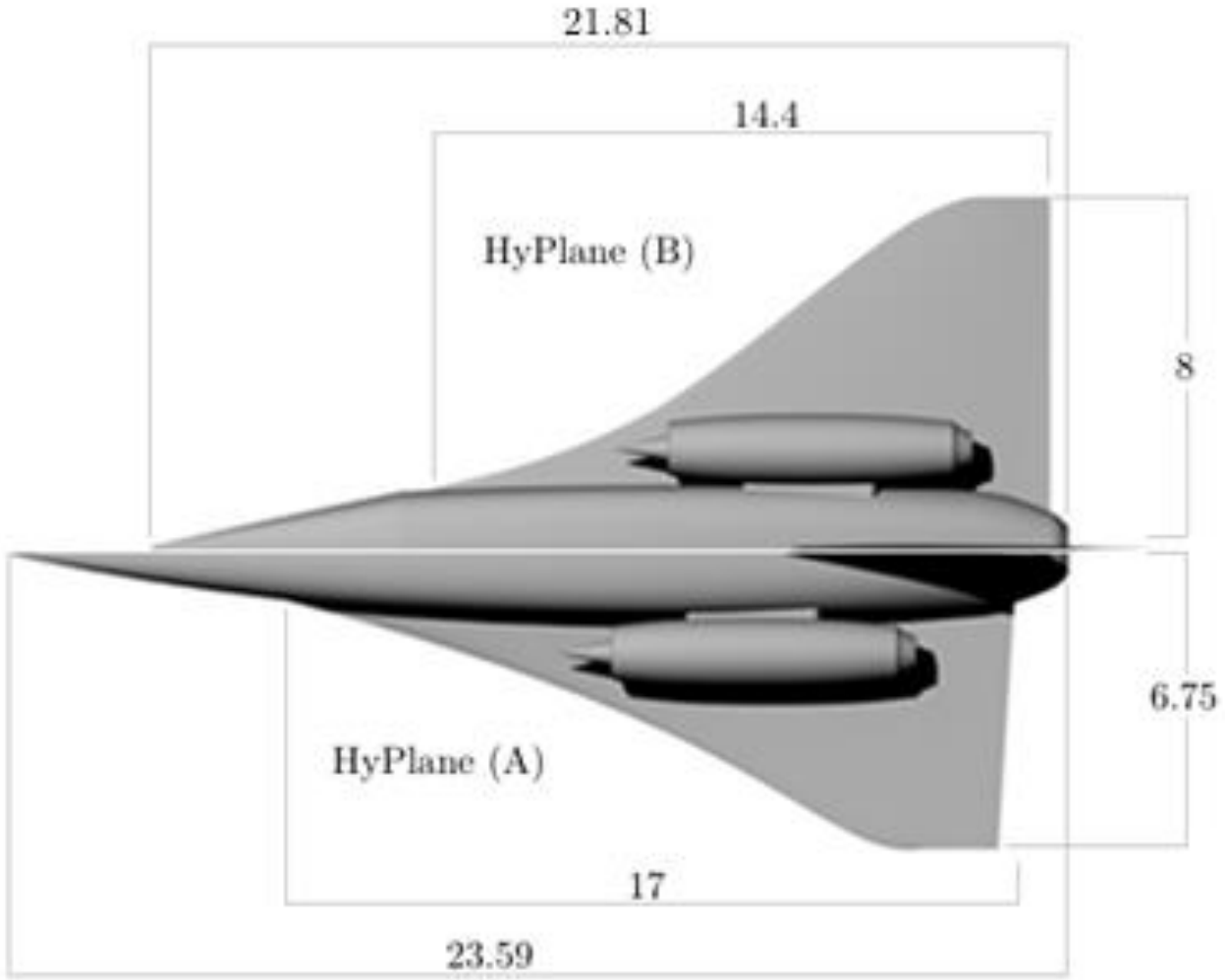
STATIC AND DYNAMIC PERFORMANCES

OPTIMIZER

Configuration Optimisation

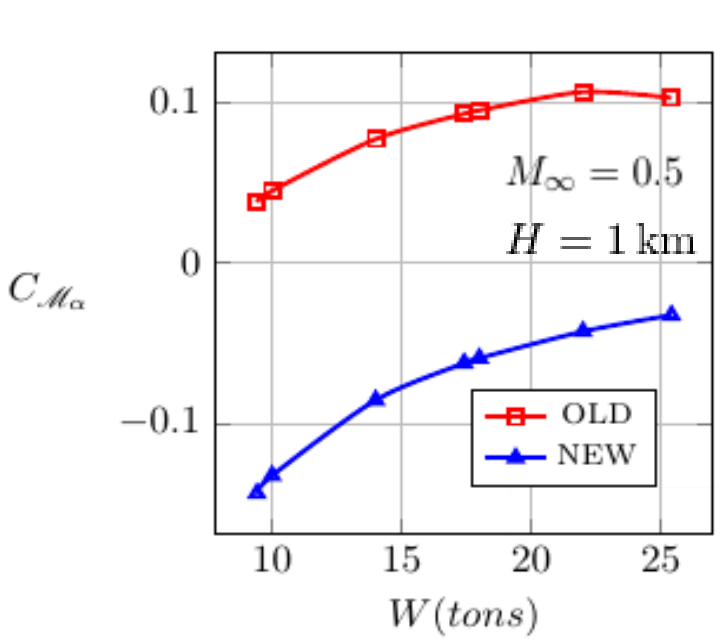


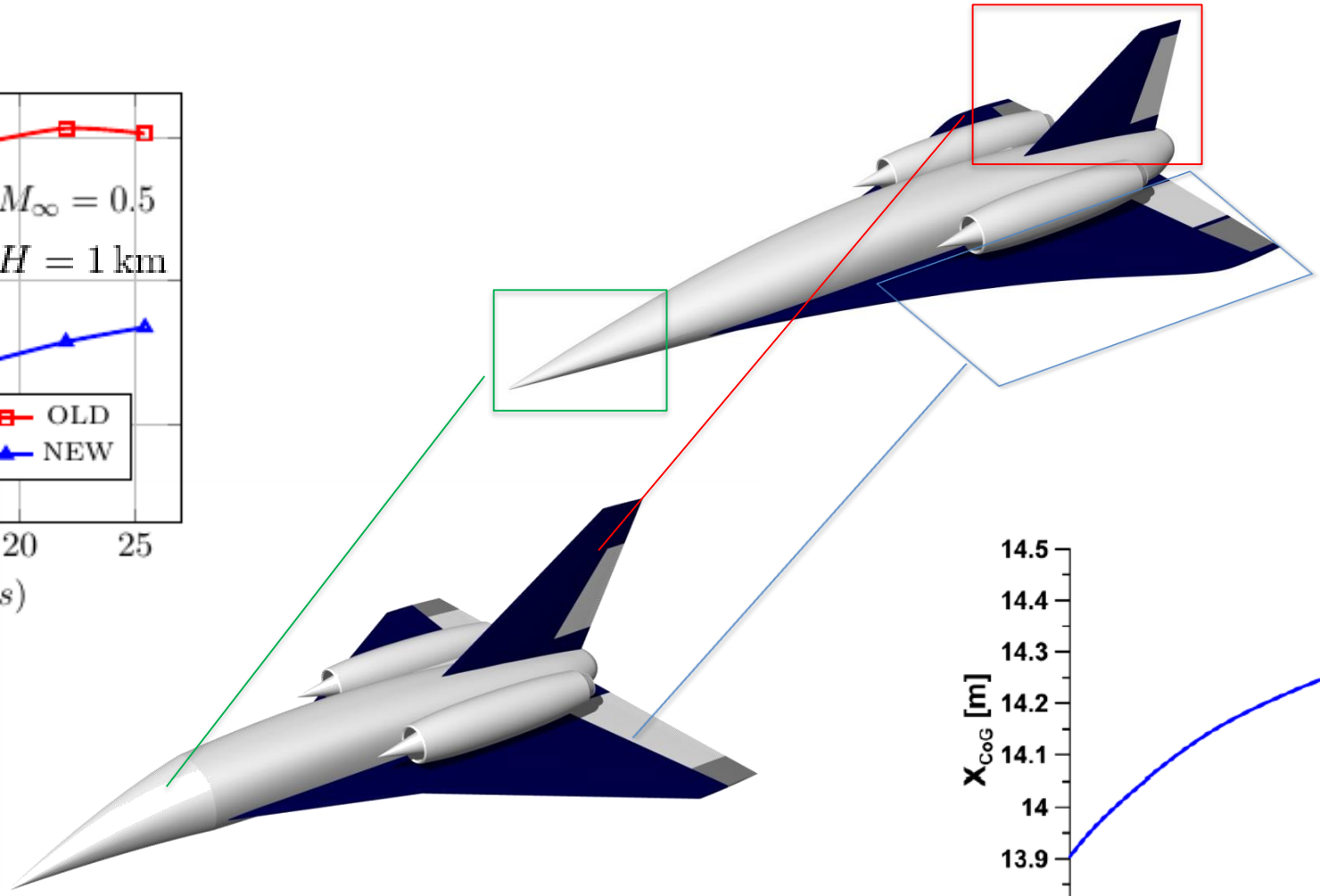


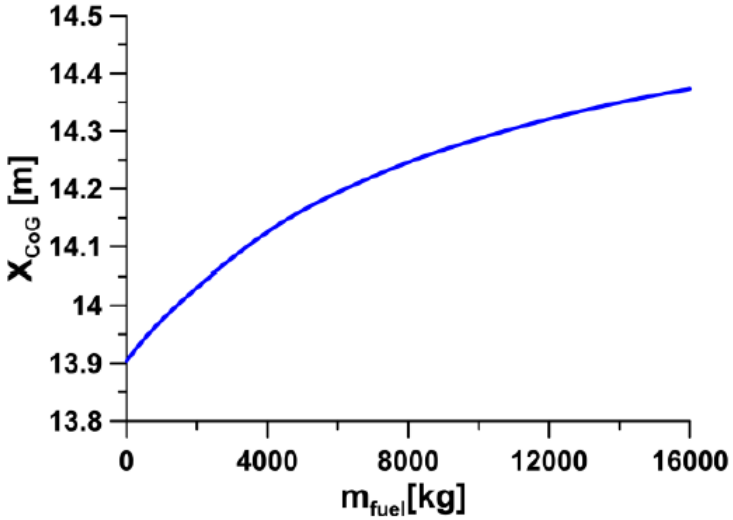


Configuration Optimisation

UNSTABLE

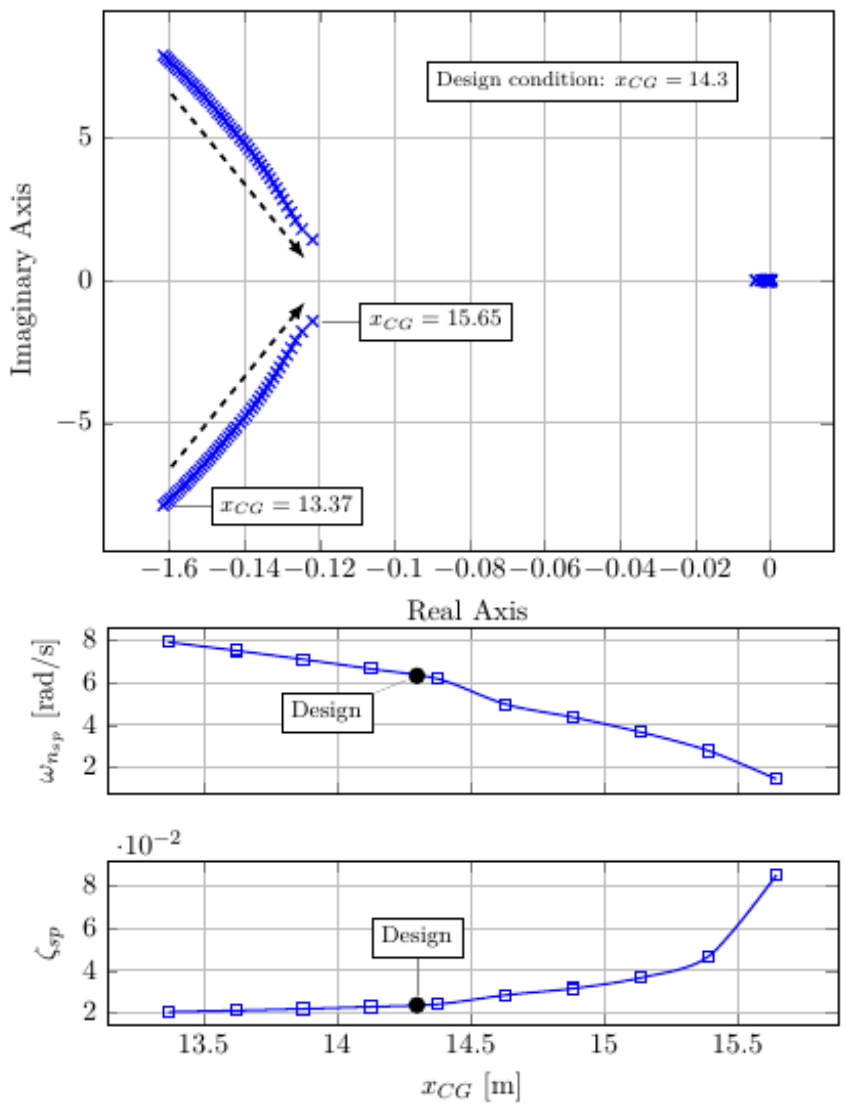


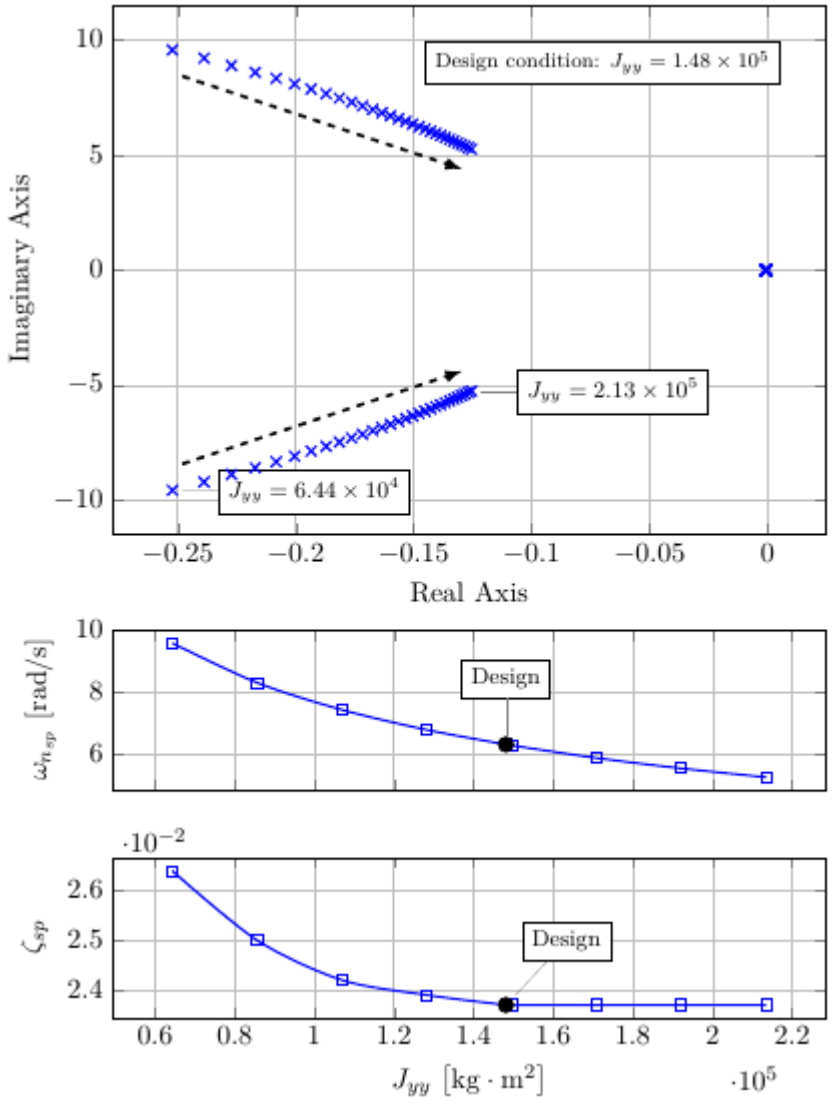




STABLE

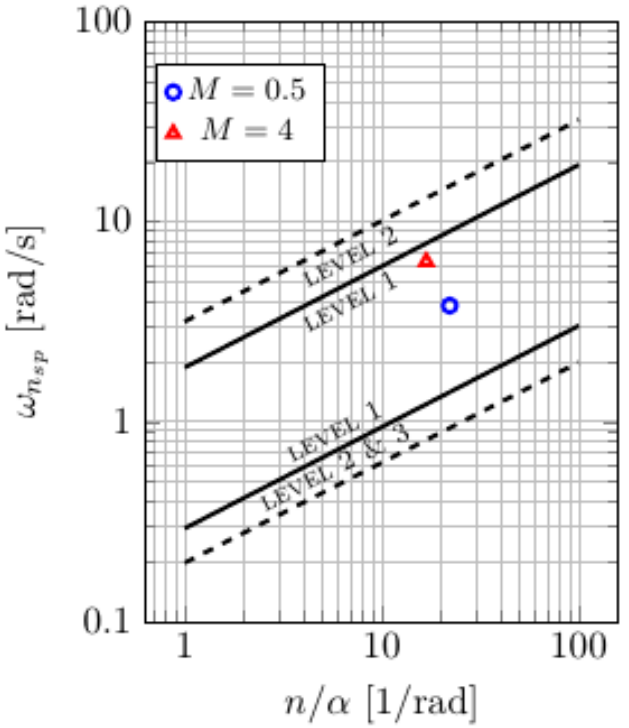
Stability and Handling quality analisys





Stability and Handling quality analisys

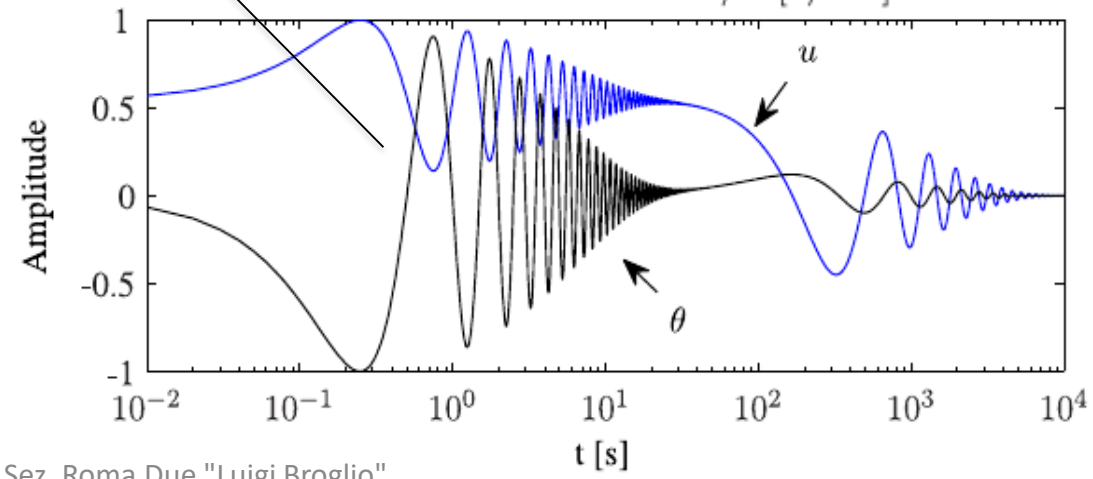
	$M_\infty = 0.5$ $H = 1\ km$	$M_\infty = 4$ $H = 28\ km$
$\omega_{n_{ph}}$ (rad/s)	0.082	0.01
ξ_{ph}	0.05	0.067
$\omega_{n_{sp}}$ (rad/s)	3.8	6.34
ξ_{sp}	0.71	**0.024**



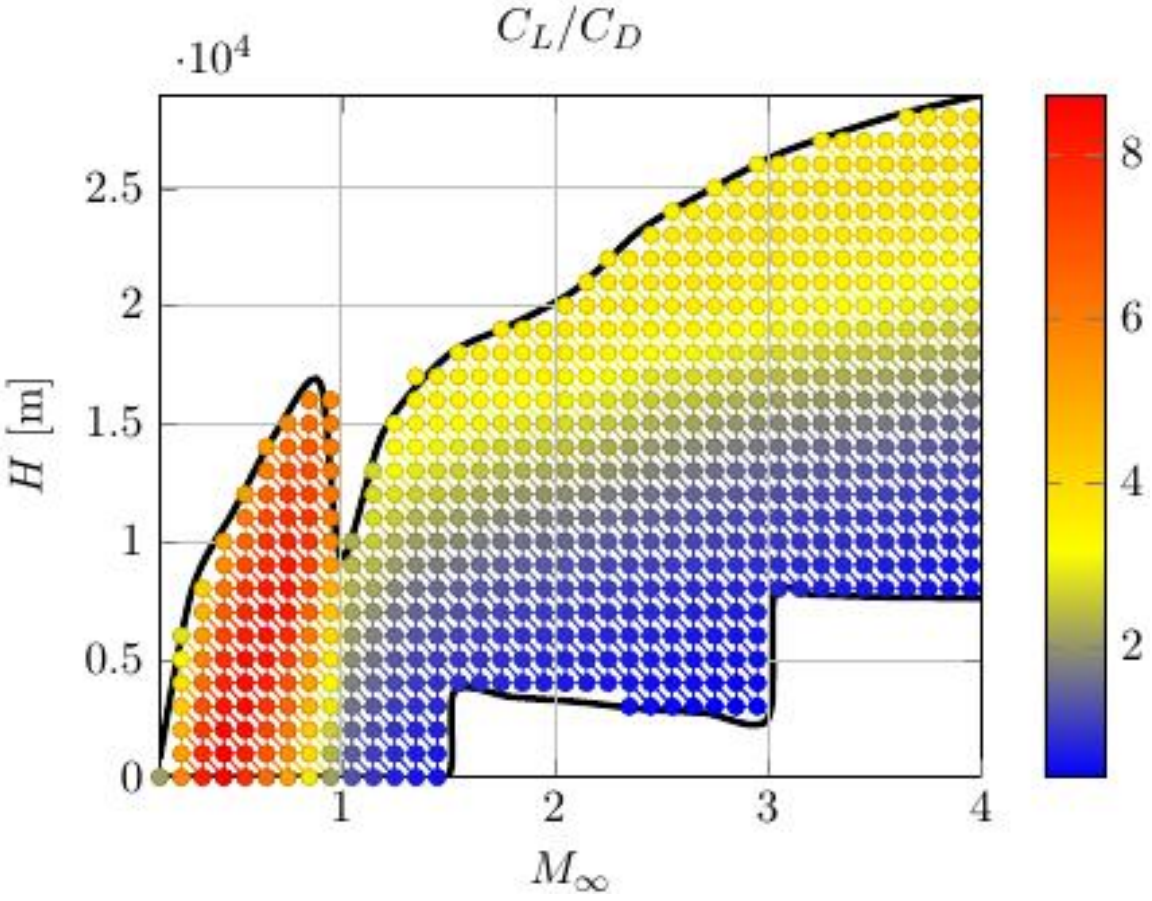
MIL-F-8785C

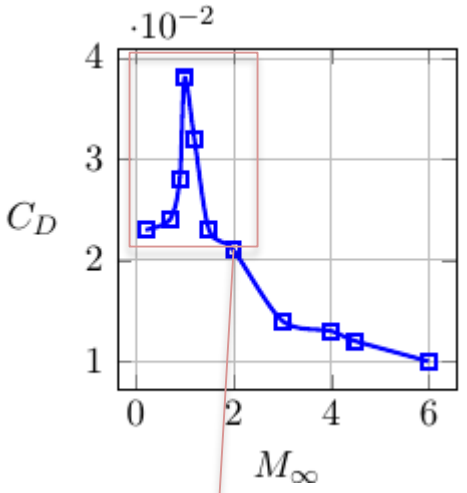
LEVEL	CATEGORY A AND C		CATEGORY B	
	MIN	MAX	MIN	MAX
1	0.35	1.30	0.30	2.00
2	0.25	2.00	0.20	2.00
3	0.15*		0.15*	

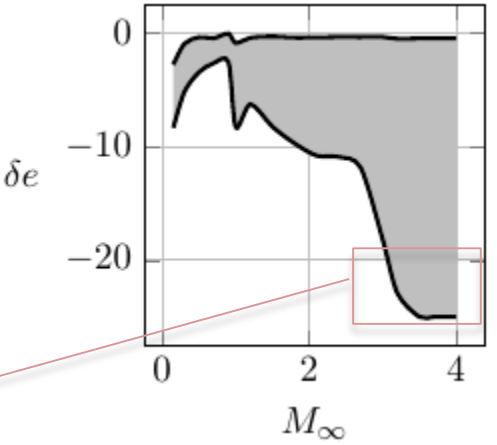
* May be reduced at altitudes above 20 000 ft if approved by the procuring activity

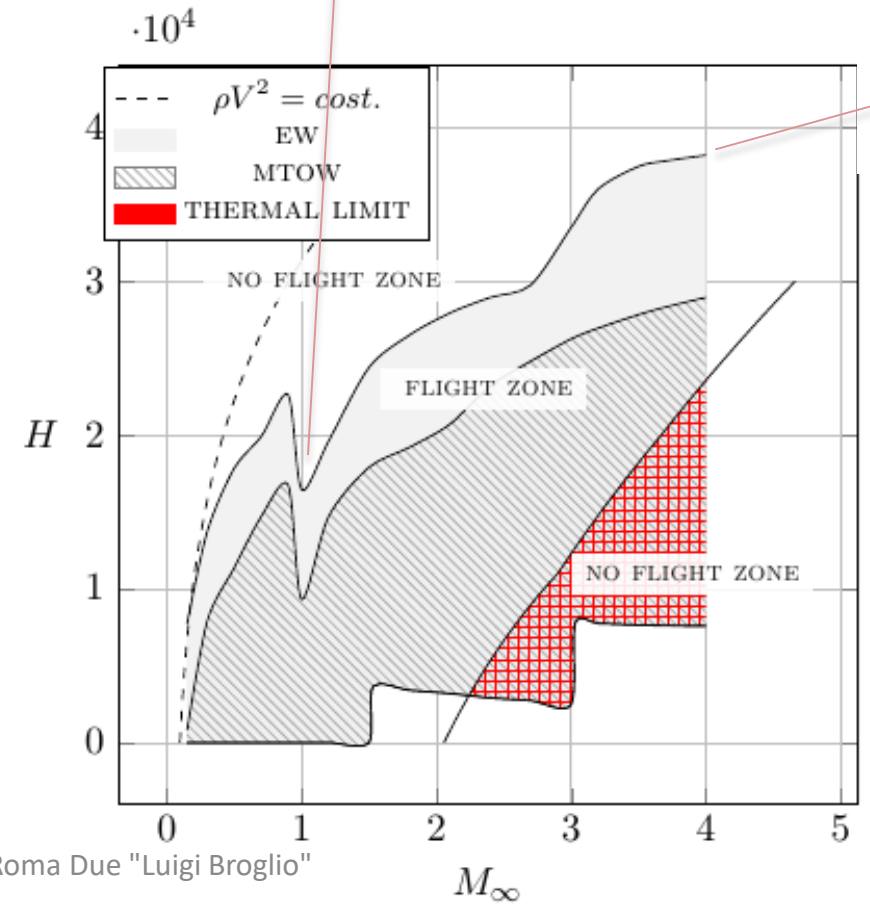


Flight Envelop

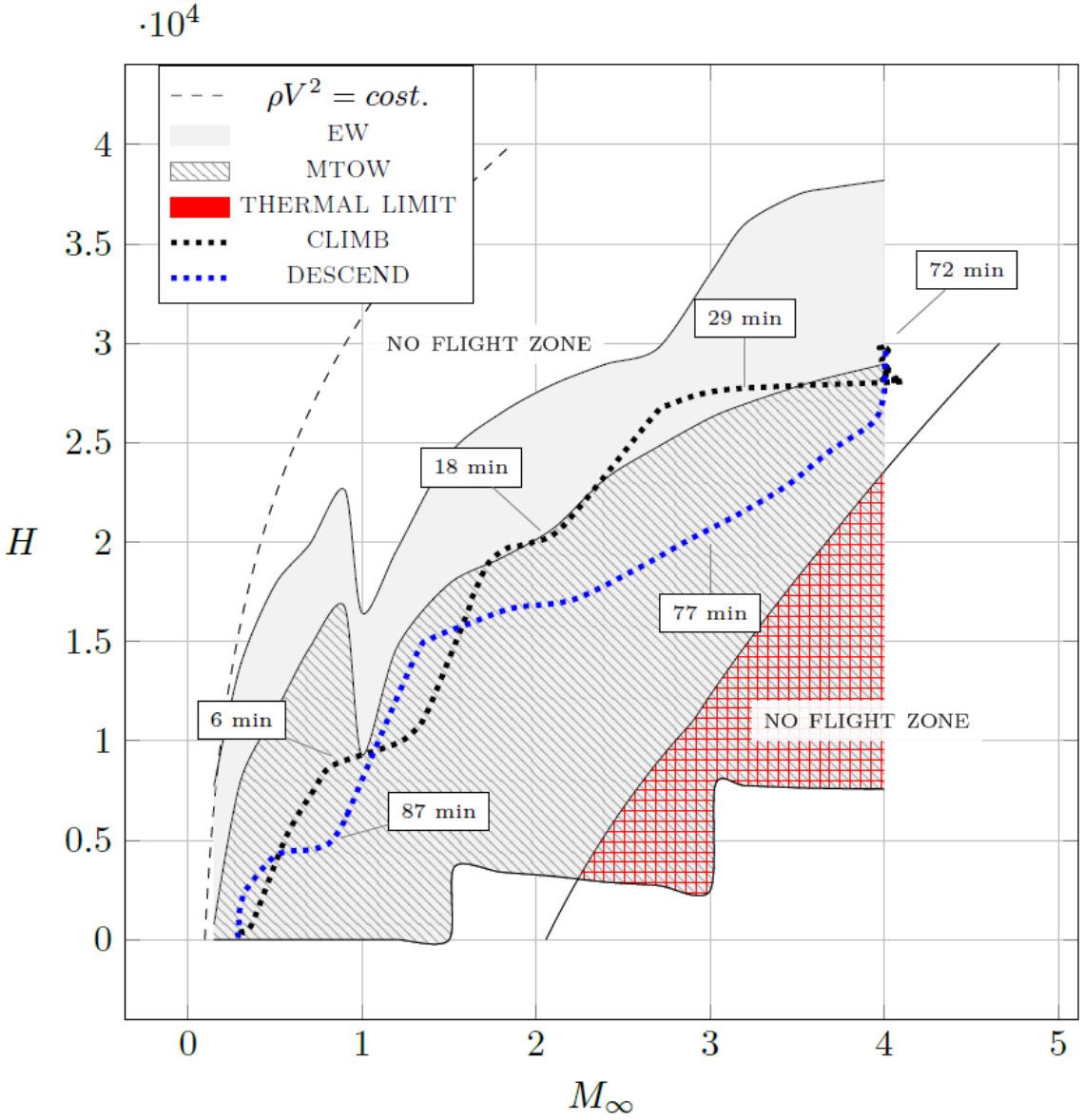


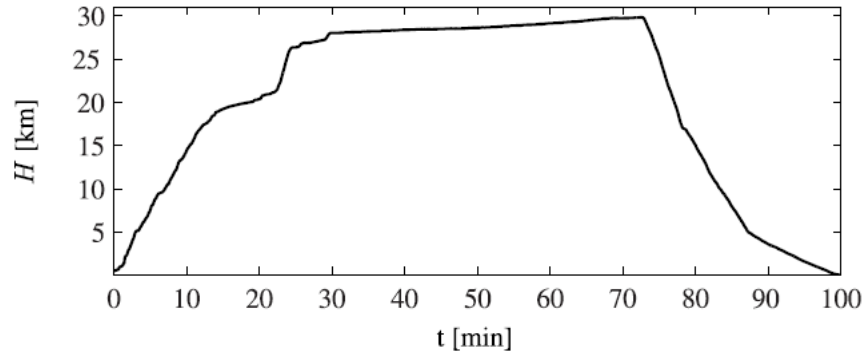


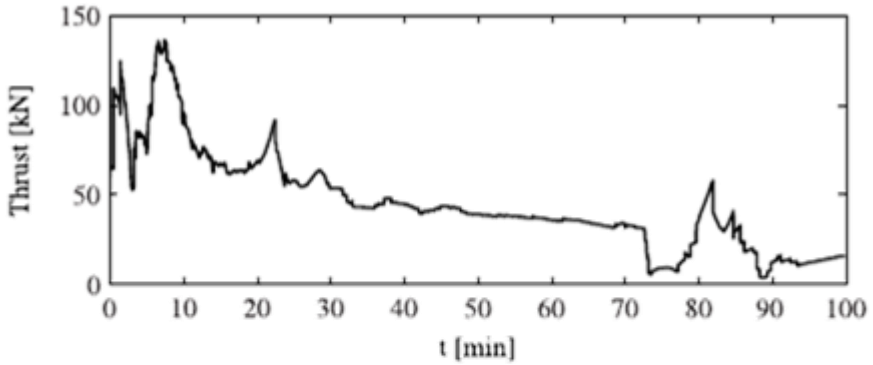


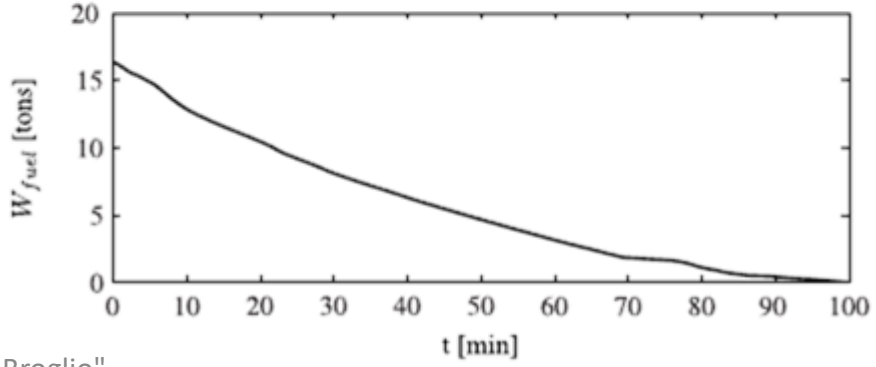


PTP mission


$\cdot 10^4$
$\rho V^2 = cost.$
EW
MTOW
THERMAL LIMIT
CLIMB
DESCEND
NO FLIGHT ZONE
NO FLIGHT ZONE
6 min
18 min
29 min
72 min
77 min
87 min
H
M_∞


H [km]
t [min]


Thrust [kN]
t [min]


W_{fuel} [tons]
t [min]

Conclusions

- Development of a software to automatically and quickly build-up an aerodynamic database
- Static and dynamic stability analysis: re-design of fuselage wing and vertical tail
- Performaces analysis: flight envelop
- Simulation and handling quality parameters analysis

Future Development

- Validation of stability and damping coefficients for lateral-directional stability and control;
- Development of a SAS;
- Trajectory optimisation;

References.

- De Vivo, F., «*Flight Dynamic Analysis of a Small Hypersonic Plane*», Master Thesis, University of Naples Federico II, 2015;
- D'Oriano, V., «*Aerodynamic study of a small hypersonic plane*», PhD Thesis, University of Naples Federico II, 2015;
- D'Oriano V., Visone M, Savino R., Aerothermodynamic study of a small hypersonic plane, Aircraft Engineering and Aerospace Technology, International Journal, Vol. 90 Issue: 2, pp.471-480, March 2018
- Blake W.B. «*Missile Datcom-User's Manual*», Air Force Research Laboratory, Wright-Patterson Air Force Base, Ohio 4533-7531, 1997;
- R. Savino et al. « HyPlane: Challenges for Space Tourism and Business Transportation», in: *Journal of Aeronautics and Aerospace Engineering* (2013);
- R. Savino et al. « Performances of a small hypersonic plane», in: *65th international Astronautical Congress*. Beijing, China, 2014.