STRUCTURAL AND THERMAL LOADS FOR HYPERSONIC HEXAFLY-INT VEHICLE

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3rd International Symposium on Hypersonic Flight

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AAA – Sez. Roma Due “Luigi Broglio”

Objective

During trajectory, the structure is subjected to the static, random, sinusoidal acceleration (due to launcher environment) and to the thermal loads.

Modal analysis for stiffness requirement

Frequency Response Analysis for random and sine vibration requirement

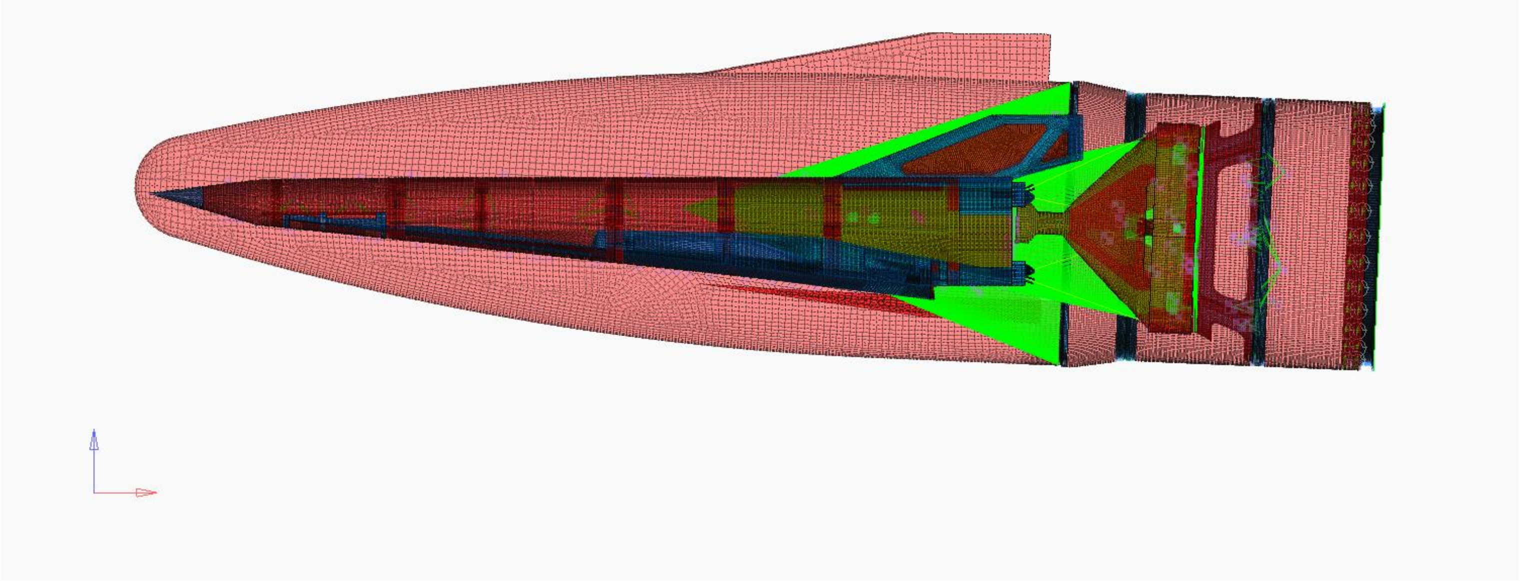
Transient thermal analyses

These analyses lead to:

1. a proper material selection namely: titanium alloy, copper, C/C-SiC and zirconia for surface coatings.
2. A structural global layout definition

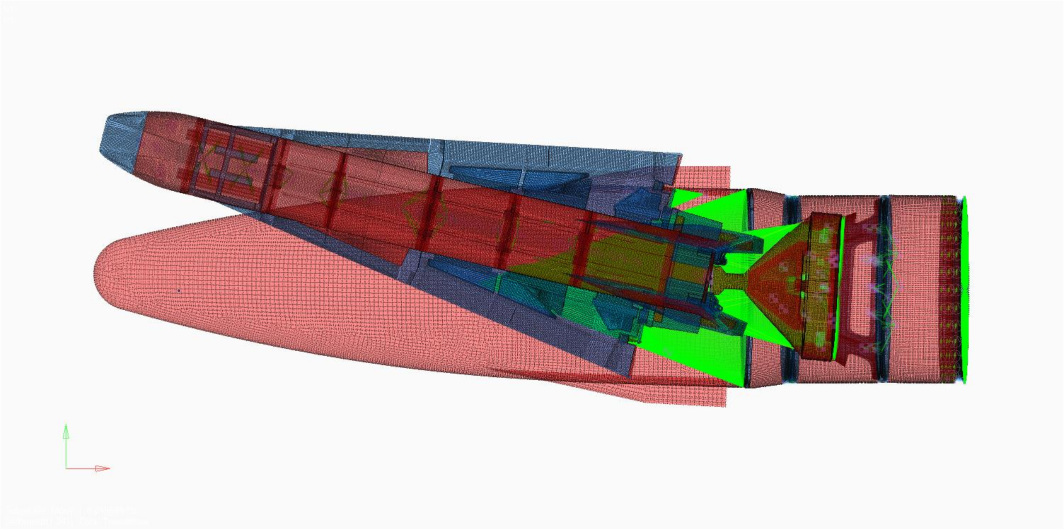
FE Model Description

- The FE Model has been provide by ESA on the full stack: EFTV+ESM+LVSM+fairing



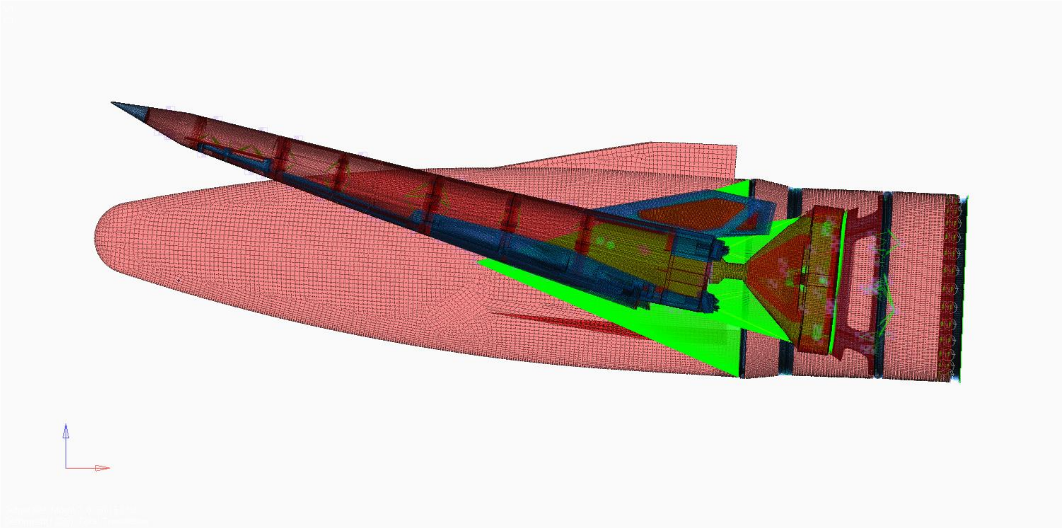
- BAR: 108
- SHELL: 284051
- SOLID: 575442
- RIGID: 1588
- CONM2: 153
- DAMPER: 144

Real Eigenvalue Analysis 1/4

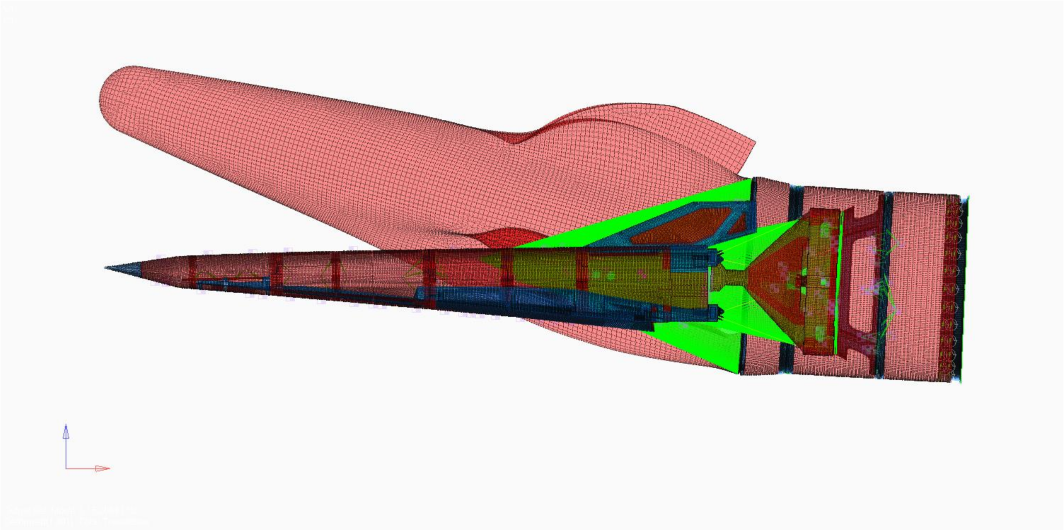


MODAL EFFECTIVE MASS FRACTION [%]	
MODE ID	1
Freq [Hz]	8.25
X DIR	0.000
Y DIR	39.035
Z DIR	3.169

MODAL EFFECTIVE MASS FRACTION [%]	
MODE ID	2
Freq [Hz]	8.36
X DIR	0.010
Y DIR	3.291
Z DIR	38.676

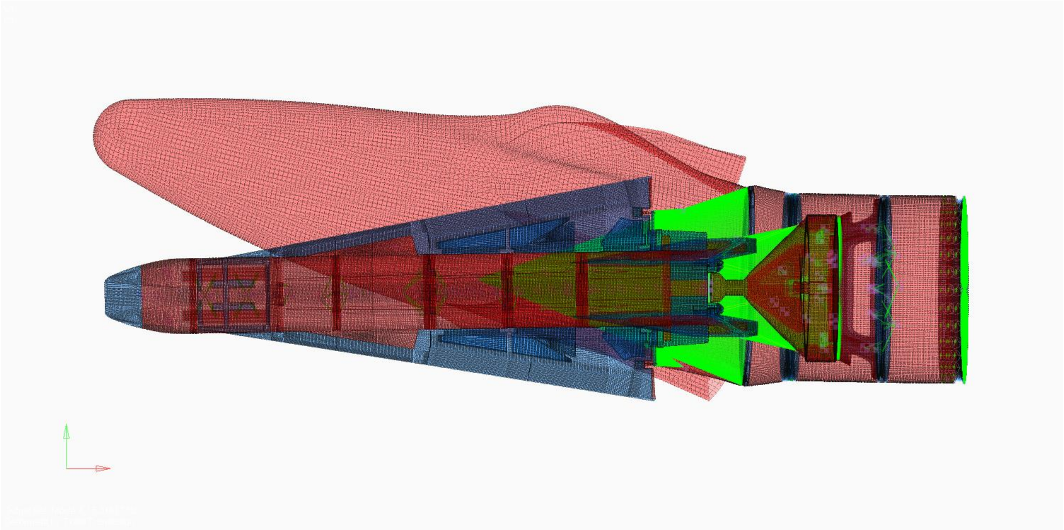


Real Eigenvalue Analysis 2/4

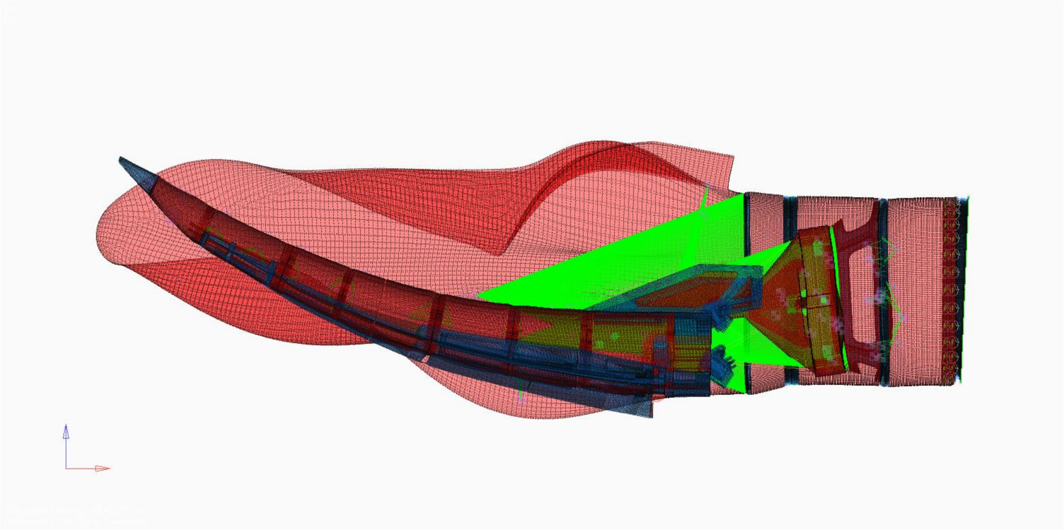


MODAL EFFECTIVE MASS FRACTION [%]	
MODE ID	3
Freq [Hz]	15.21
X DIR	0.021
Y DIR	0.004
Z DIR	11.472

MODAL EFFECTIVE MASS FRACTION [%]	
MODE ID	4
Freq [Hz]	15.32
X DIR	0.000
Y DIR	11.503
Z DIR	0.002

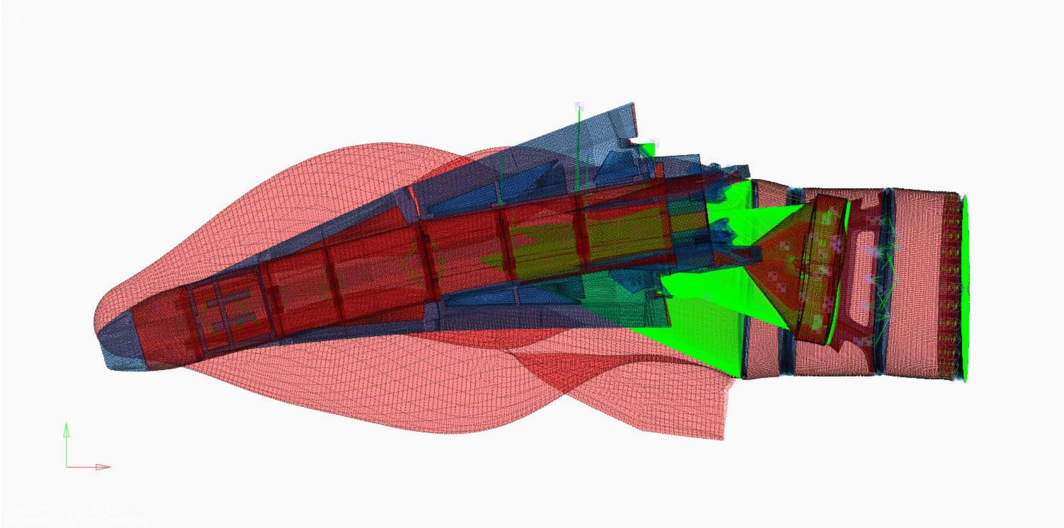


Real Eigenvalue Analysis



MODAL EFFECTIVE MASS FRACTION [%]	
MODE ID	27
Freq [Hz]	43.92
X DIR	0.468
Y DIR	0.049
Z DIR	14.526

MODAL EFFECTIVE MASS FRACTION [%]	
MODE ID	28
Freq [Hz]	45.45
X DIR	0.102
Y DIR	19.676
Z DIR	0.012

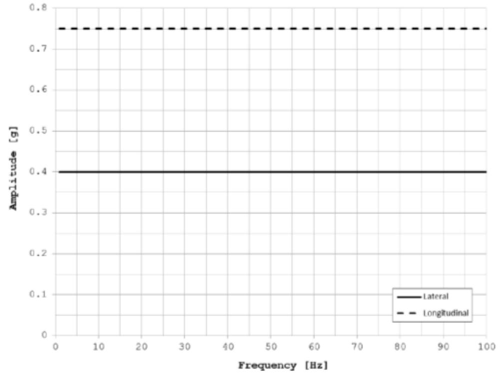


Inputs for Loads Calculation

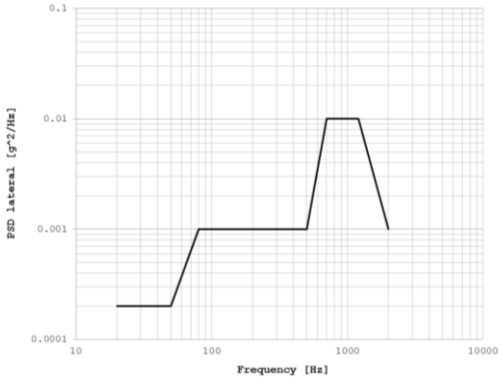
- The values of **Steady State Acceleration** are reported in the following table:

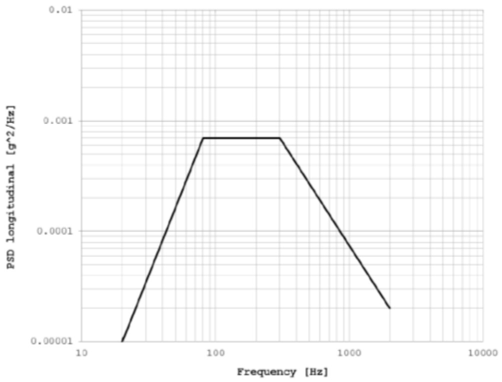
Static Acceleration	
Longitudinal [g]	Lateral [g]
10	1

- For **Sinusoidal Vibration** analysis the following table is used as input:



- For **Random Vibration** analysis the following table is used as input:



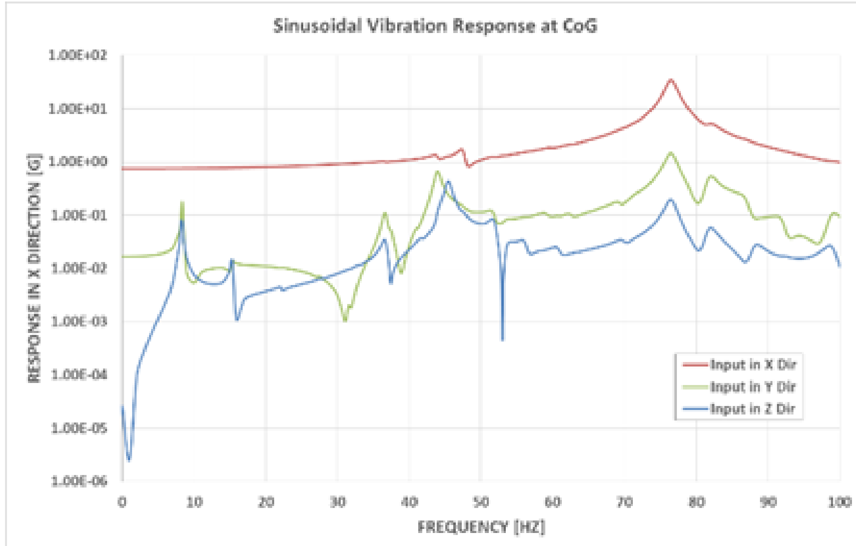


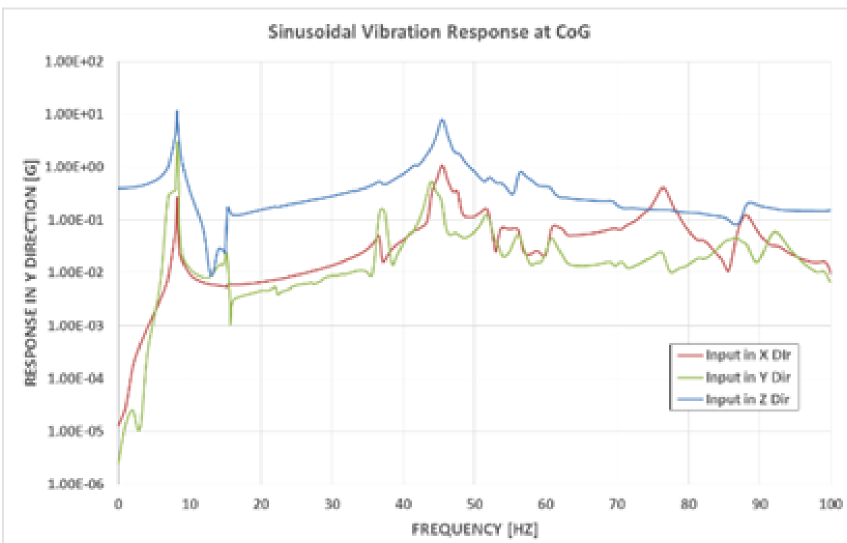
Equivalent Static Loads

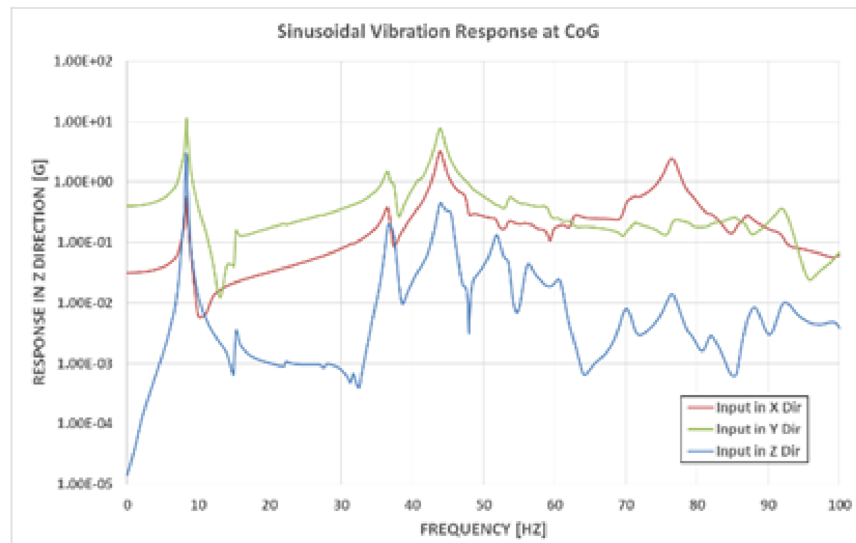
Sine Vibration Response	Load Application Direction	Response Direction	Values [g]	Combination Loads [g]	
	X Direction [g]	X	34.65	36.57	X Direction [g]
		Y	1.08		
		Z	3.24		
	Y Direction [g]	X	1.47	15.83	Y Direction [g]
		Y	3.04		
		Z	11.33		
	Z Direction [g]	X	0.44	17.52	Z Direction [g]
		Y	11.72		
		Z	2.95		

Random Vibration Response								
RMS VALUES [g]								
X Direction Input			Y Direction Input			Z Direction Input		
X Direction Response	Y Direction Response	Z Direction Response	X Direction Response	Y Direction Response	Z Direction Response	X Direction Response	Y Direction Response	Z Direction Response
1.76	0.05	0.15	0.19	0.13	0.39	0.04	0.45	0.09
3 SIGMA VALUES								
5.29	0.16	0.46	0.56	0.38	1.17	0.12	1.34	0.28
Combination Loads [g]								
5.32			1.40			1.29		

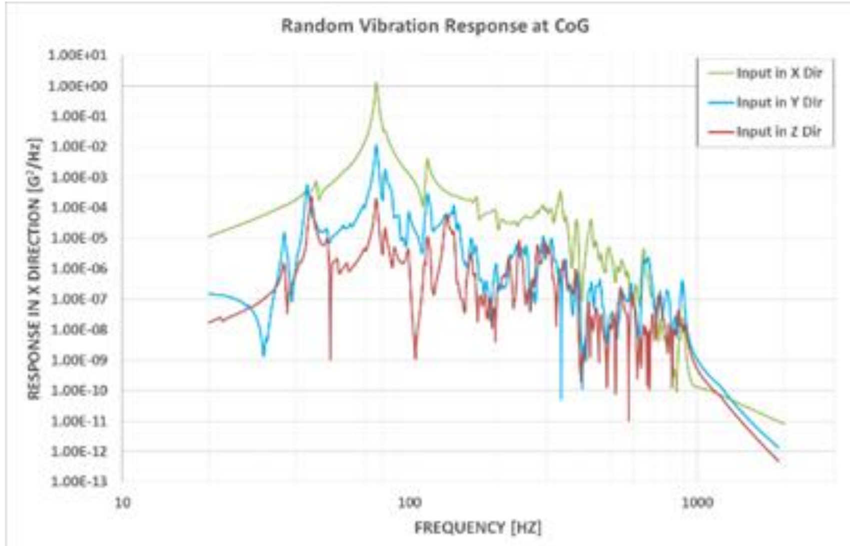
EFTV+ESM - Sinusoidal Vibration

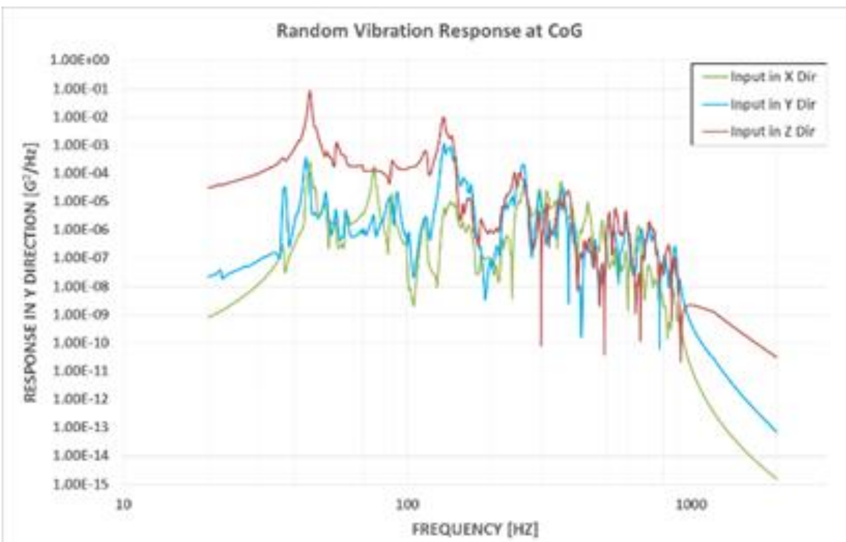


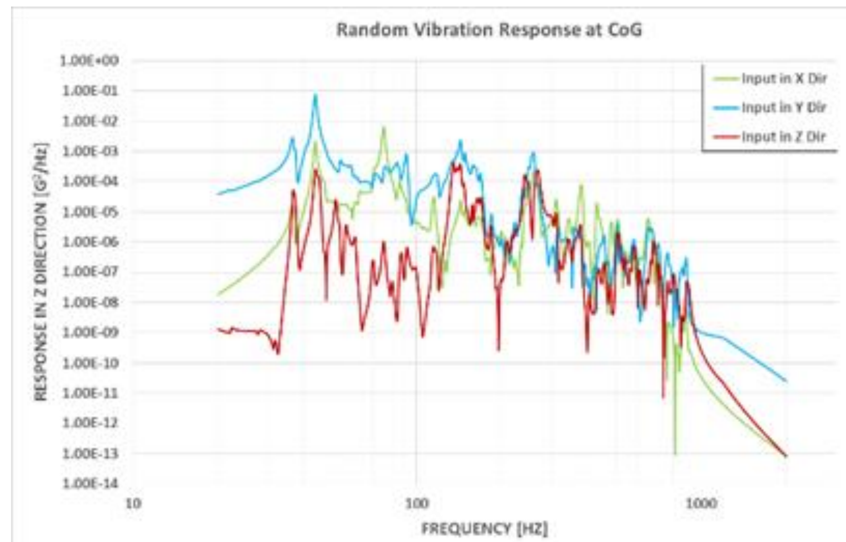




EFTV+ESM - Random Vibration







Dynamic Loads Combination

- **Sinusoidal Vibrations (SL_{SINE}) and Random Vibrations (RVL) Combination**

$$DYNAMIC\ LINEAR\ (QD) = \sqrt{(SL_{SINE})^2 + (RVL)^2}$$

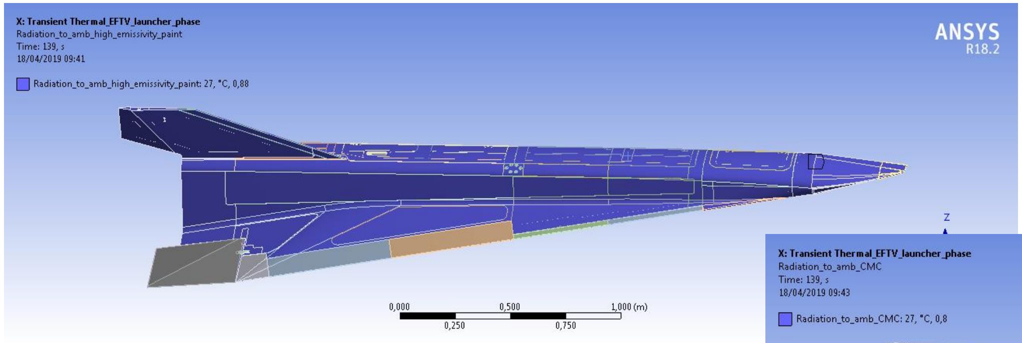
- **Quasi-Static Load (Q_{SL}) and Dynamic Loads Q_D Combination**

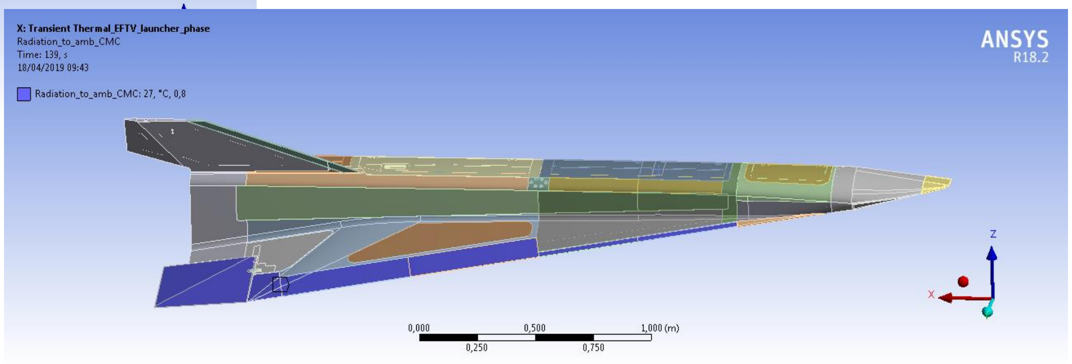
Lateral Direction (Y)	Lateral Direction (Z)	Axial Direction (X)
$\pm(Q_{SL}(Y) \pm Q_D)$	$\pm(Q_{SL}(Y) \pm Q_D)$	$\pm(Q_{SL}(Y) \pm Q_D)$

Design Limit Loads [g]					
X Direction		Y Direction		Z Direction	
±	70.43	±	25.34	±	27.86
±	70.43	±	25.34	±	24.86
±	70.43	±	22.34	±	27.86
±	70.43	±	22.34	±	24.86
±	40.43	±	25.34	±	24.86
±	40.43	±	25.34	±	27.86
±	40.43	±	22.34	±	27.86
±	40.43	±	22.34	±	24.86

Thermal analysis input

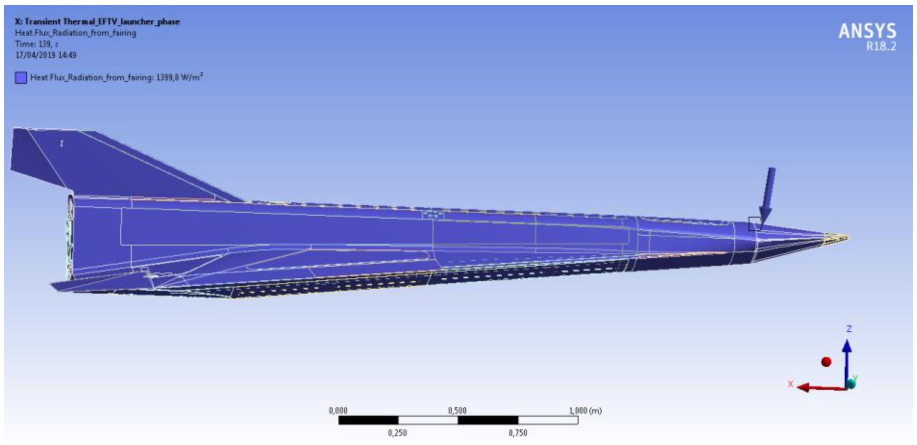
- Initial temperature of 20°C;
- Radiation to external ambient for all the materials (emissivity of 0.8 for CMC components and 0.88 for the other components coated by an high emissivity paint)

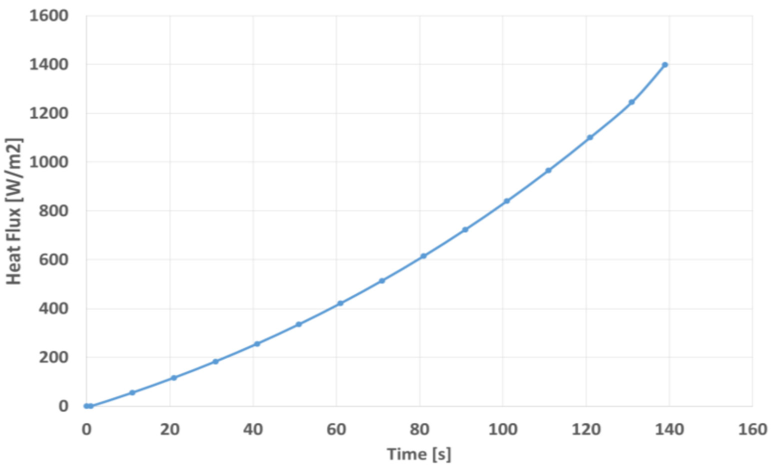




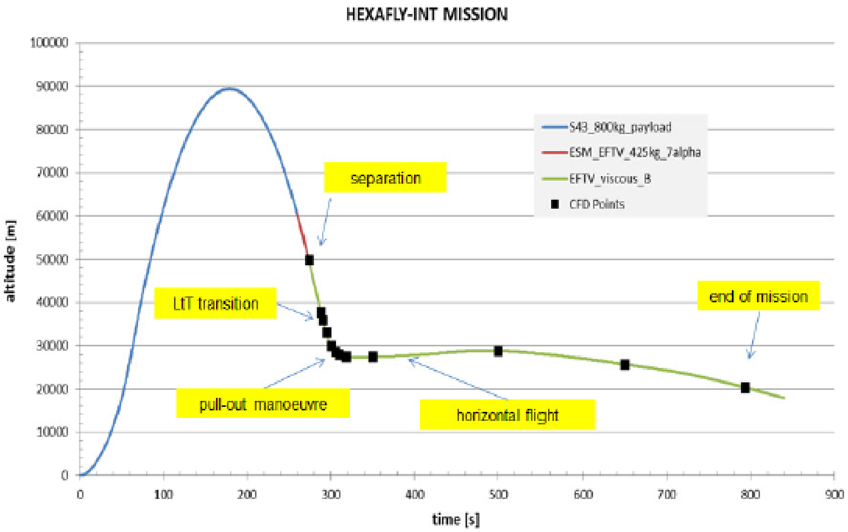
Thermal analysis input

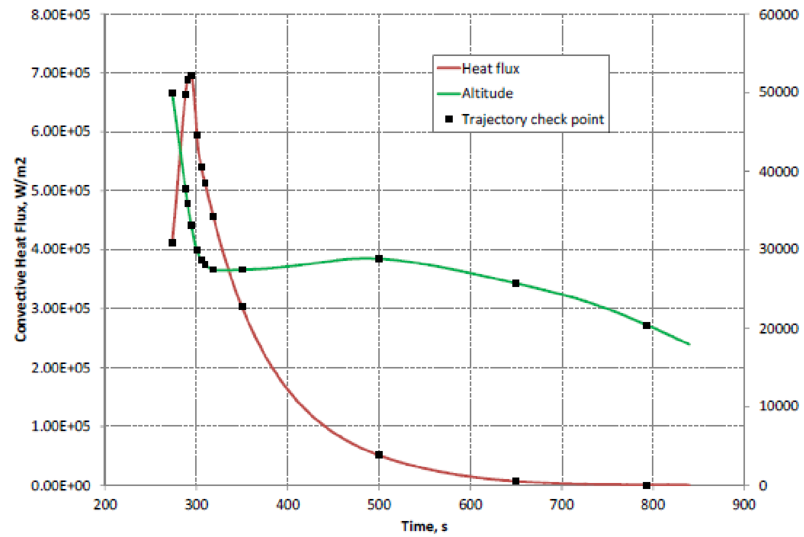
- Radiative heat flux from fairing internal wall ($T_{fairing}$ from 20°C to 150°C from take-off -0 s to fairing opening -139 s) to uniformly applied on EFTV from 0 to 1400 W/m²





Trajectory B-Viscous

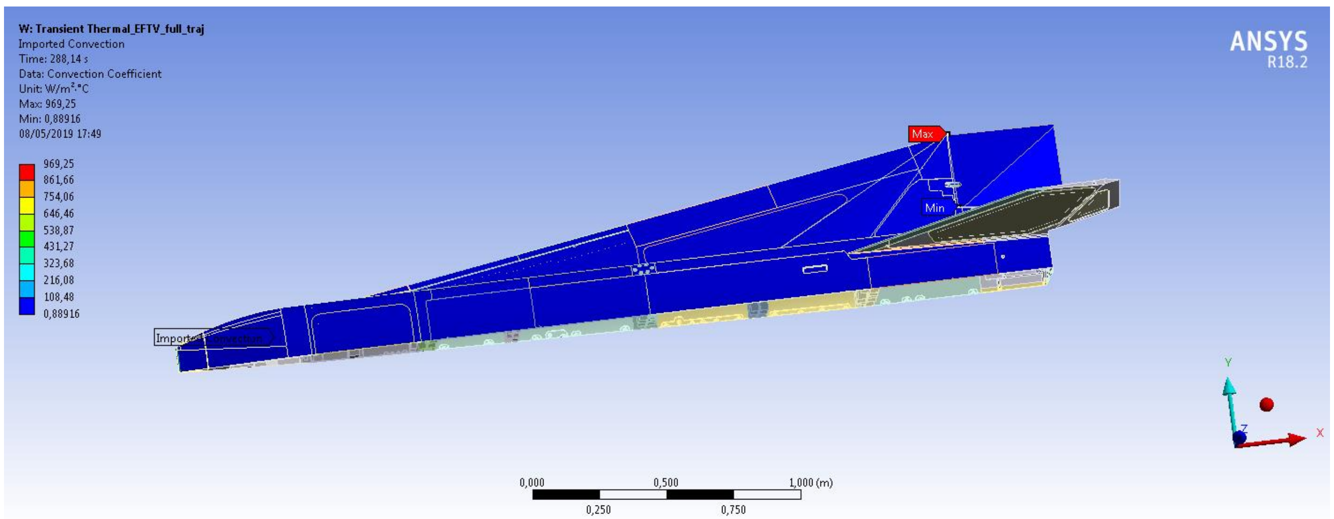




0 s < t < 139 s	**Vehicle under fairing (only radiative heat transfer between surfaces)**
139 s < t < 300.52 s	**Vehicle exposed to fully laminar flow**
300.52 s < t < 840 s	**Vehicle exposed to fully turbulent flow**

INPUTS: CFD Test Matrix Block #9 for B_viscous trajectory

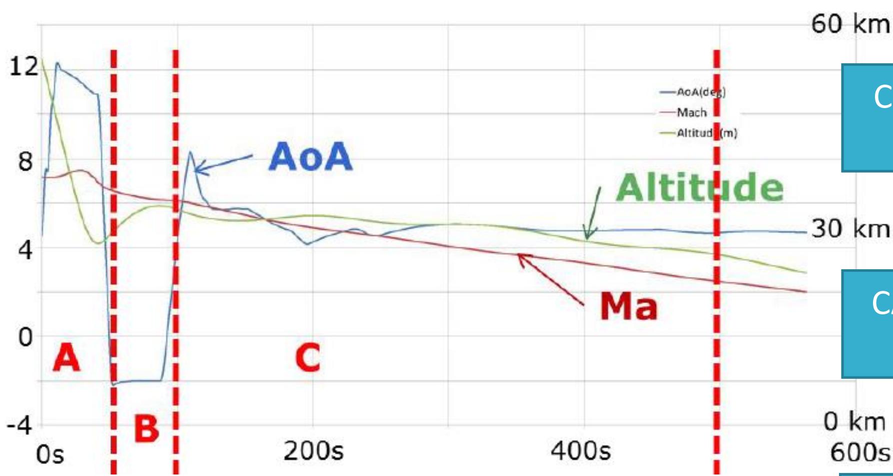
	Run ID	time (s)	Altitude (m)	Vel (m/s)	FPA (deg)	Pdyn (kPa)	ho (kg/m3	T(K)	Mach no.	AoA (deg)	P (Pa)	delta (deg)	ReL	H0 (MJ/kg)
EFTV/ESM separation	EFTV-065	273,50	49942,00	2333,80	-20,53	2,82	0,00104	270,65	7,076	6,83	80,359	-5,46	4,665E+05	2,99
	EFTV-066	288,14	37716,85	2337,68	-20,13	15,30	0,00560	244,03	7,465	12,00	392,181	-15,44	2,746E+06	2,98
maximum Mach	EFTV-067	290,39	35947,24	2325,39	-19,20	19,78	0,00732	239,14	7,501	12,00	502,252	-15,39	3,630E+06	2,94
maximum heat flux@nosetip	EFTV-068	294,44	33059,99	2288,09	-16,49	30,01	0,01147	231,14	7,507	12,00	760,605	-15,38	5,754E+06	2,85
maximum AoA, g-load	EFTV-069	300,52	29936,43	2187,90	-9,36	44,50	0,01859	226,45	7,253	12,00	1208,457	-15,72	9,075E+06	2,62
maximum L/D	EFTV-070	305,49	28652,17	2136,93	-5,12	51,75	0,02267	225,17	7,104	3,62	1465,014	-2,02	1,086E+07	2,51
	EFTV-071	309,55	28040,09	2112,00	-3,13	55,58	0,02493	224,57	7,030	1,63	1606,457	-0,68	1,182E+07	2,46
maximum dyn. pressure, ReL	EFTV-072	318,37	27461,55	2066,64	-0,84	58,23	0,02727	223,99	6,888	-0,66	1753,112	0,41	1,269E+07	2,36
	EFTV-073	350,00	27444,96	1928,32	0,13	50,82	0,02734	223,98	6,427	-1,63	1757,515	0,64	1,187E+07	2,08
	EFTV-074	500,05	28854,96	1446,28	-0,27	22,97	0,02197	225,37	4,806	0,51	1421,038	-2,25	7,115E+06	1,27
	EFTV-075	649,95	25720,26	1034,27	-1,51	19,14	0,03580	222,27	3,461	0,97	2283,671	-5,04	8,388E+06	0,76
end of mission	EFTV-076	793,56	20384,69	591,17	-4,91	14,61	0,08360	216,97	2,002	1,31	5206,060	-6,17	1,142E+07	0,39



1. fairing ejection at about 82 Km
2. payload release at apogee (90 Km)
3. ESM separation at about 50 Km

INPUT from ESA: Curved Trajectory

This trajectory follows a banking manoeuvre.
Load case is **not symmetrical**.



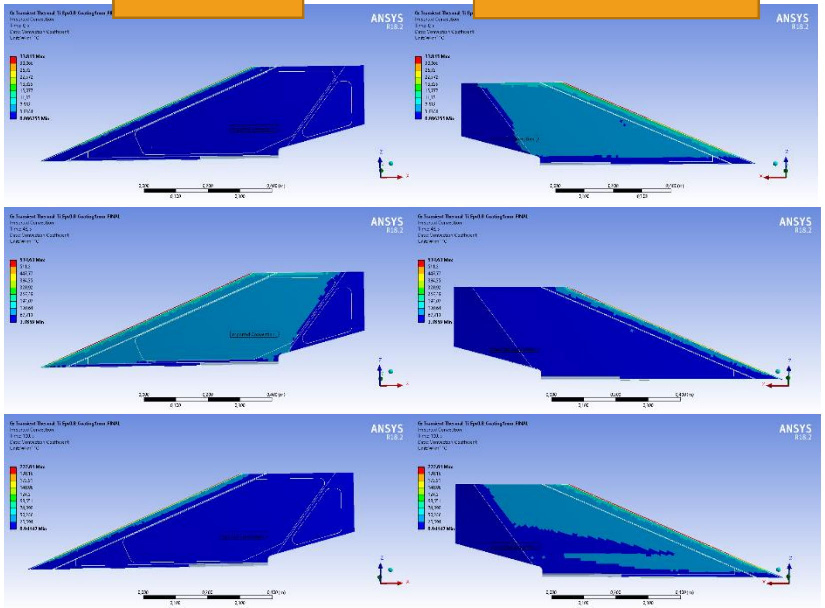
PORT-SIDE

STARBOARD SIDE

CASE A

CASE B

CASE C

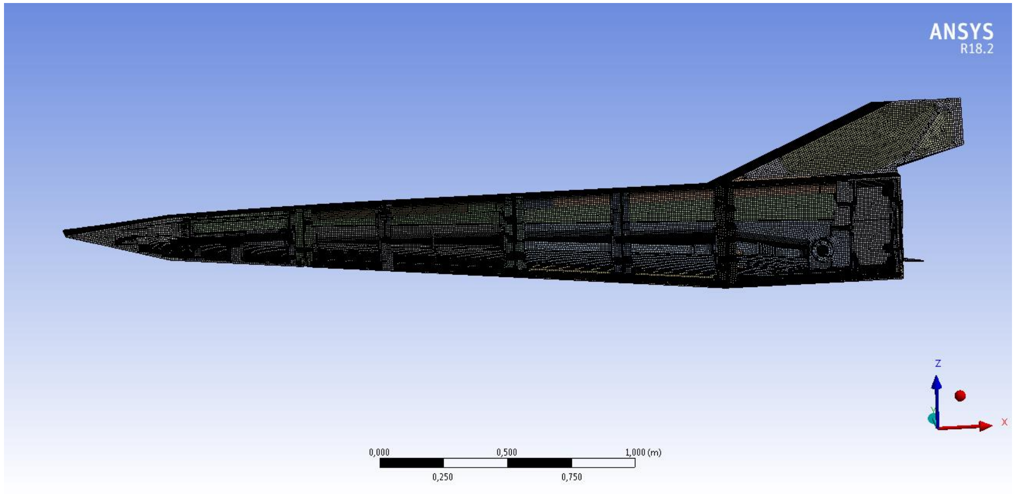


0 s < t < 47 s **CASE A**

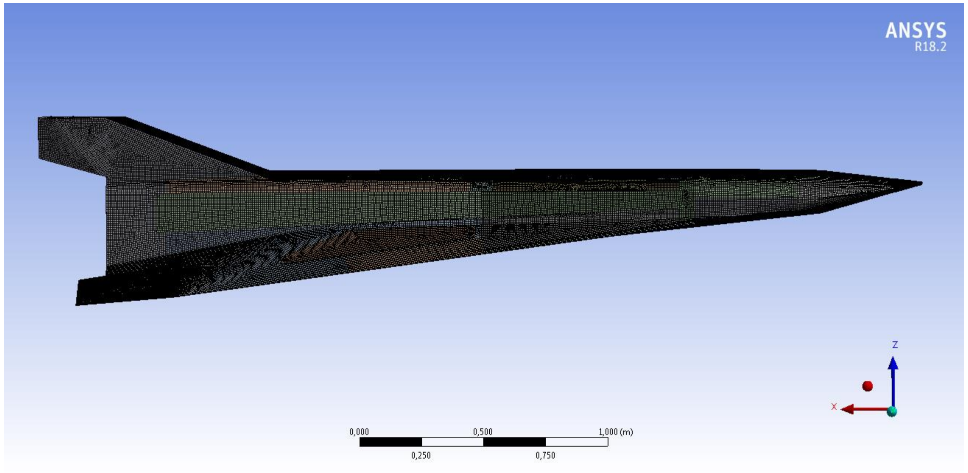
47 s < t < 98 s **CASE B**

98 s < t < 561 s **CASE C**

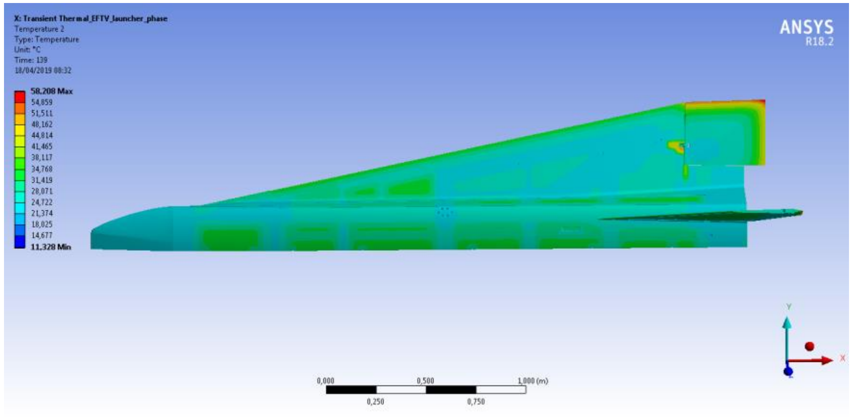
3D Mesh implemented

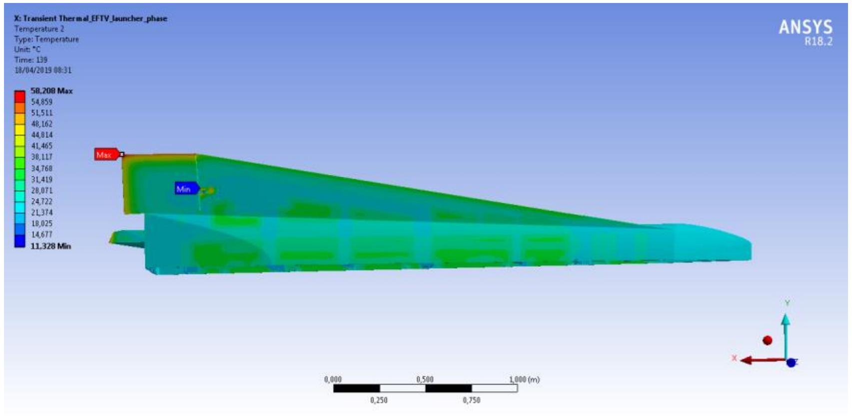


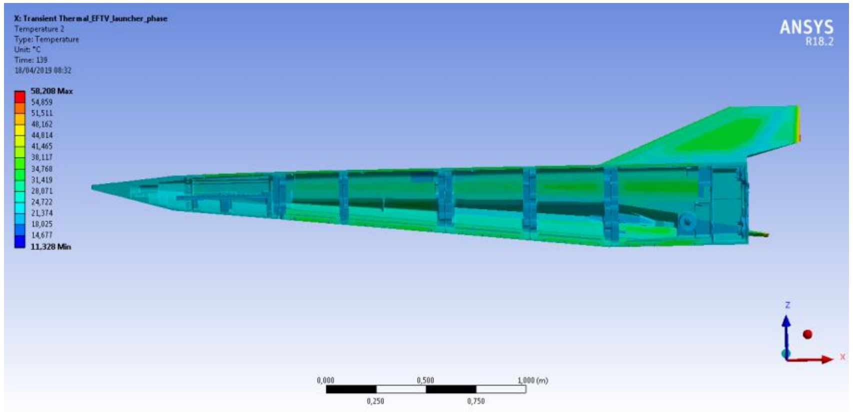
HEX20, Pyr13, Wed15 and TET10 are used. More than 50% of elements has an element quality superior than 0.95. Finally, about 3 million nodes and 800000 elements have been implemented



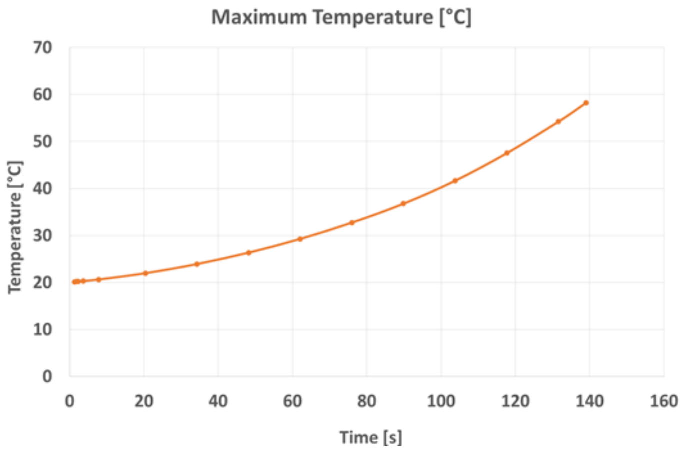
Launcher phase (t=0 s up to t = 139s)



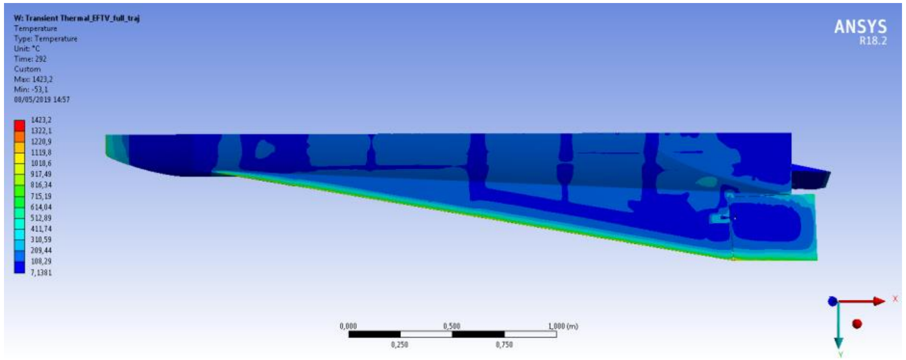


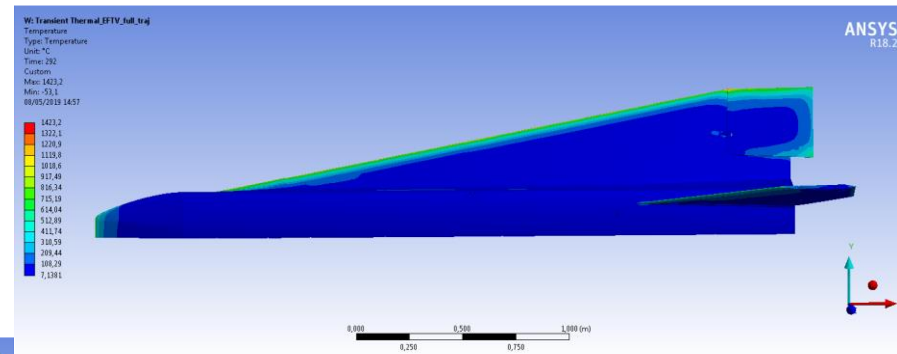


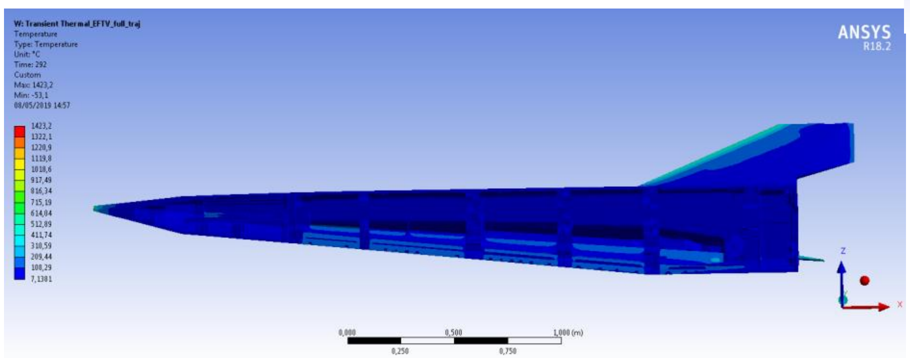
Temperature map for the different point of view at fairing open instant (t=139s)



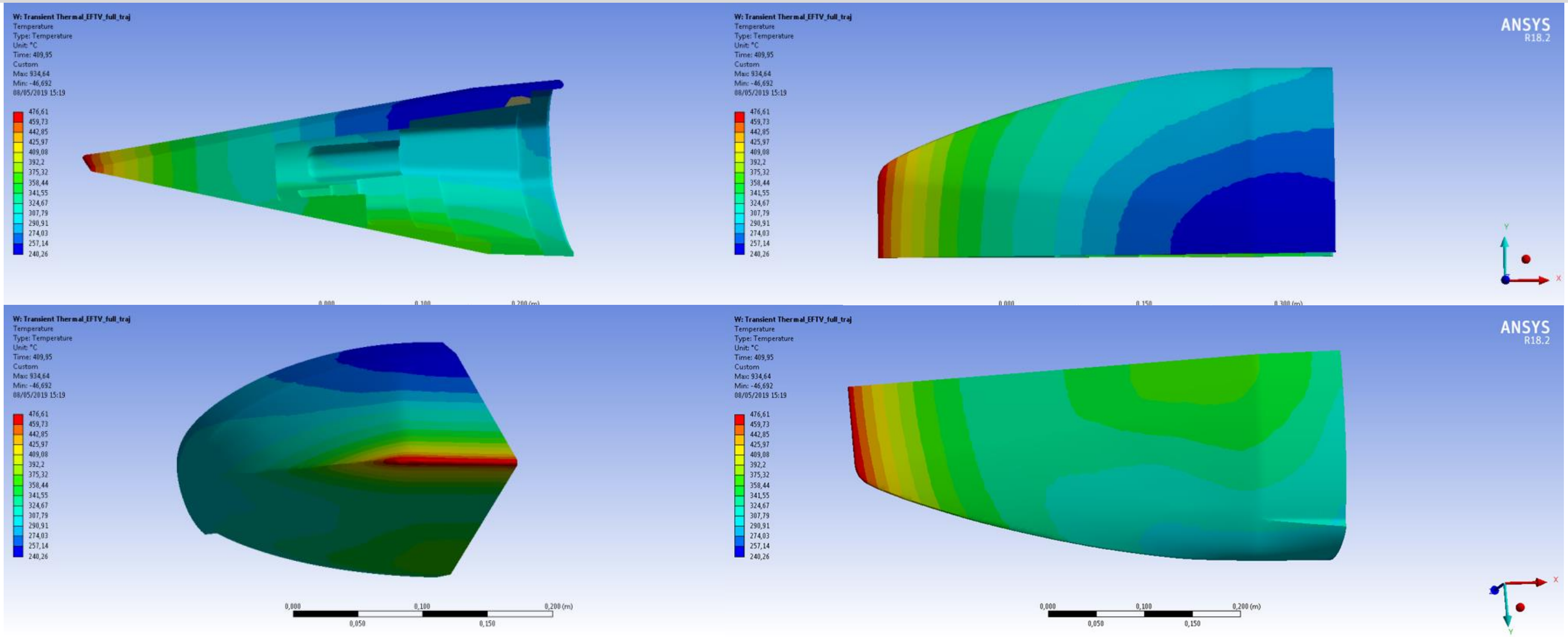
Thermal map at maximum temperature time t=292s

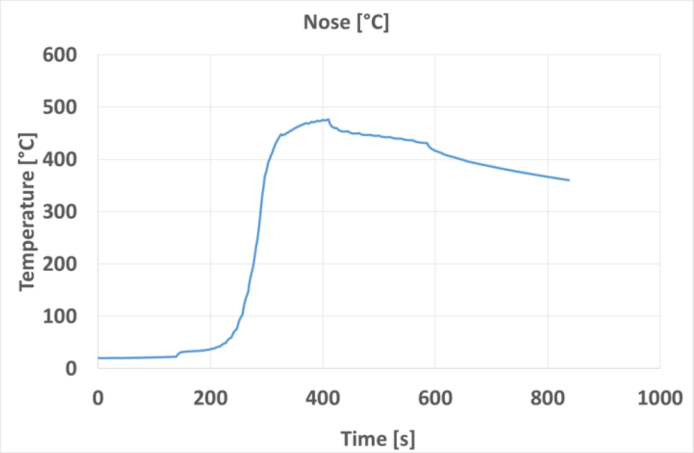




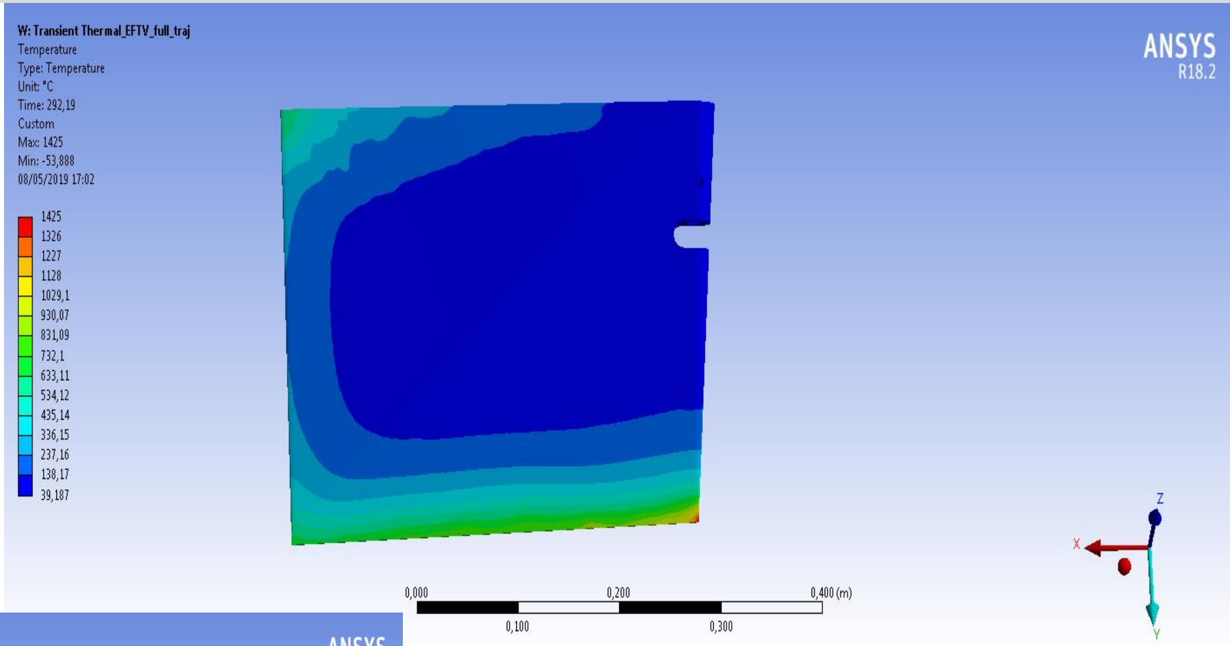


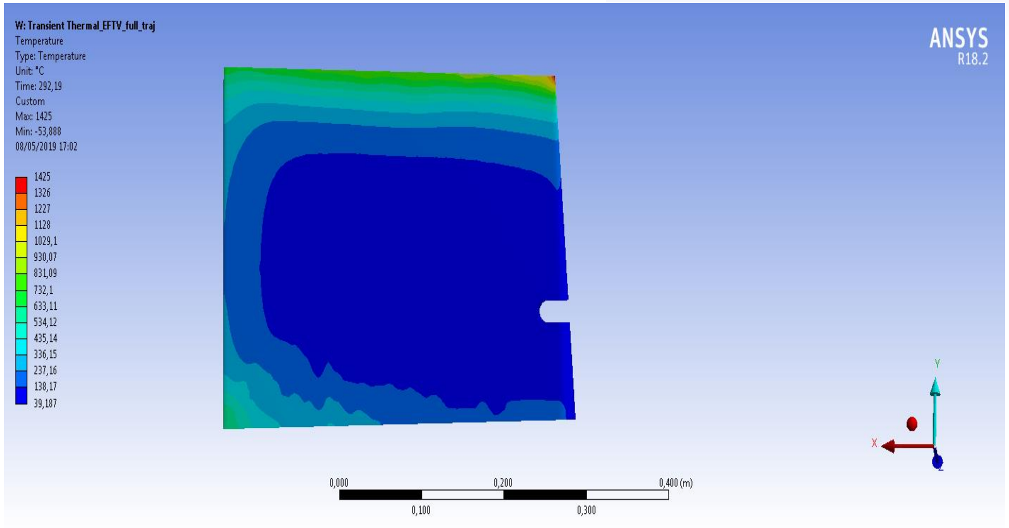
Component Thermal Assessment: Nose @ time= 409.95 s

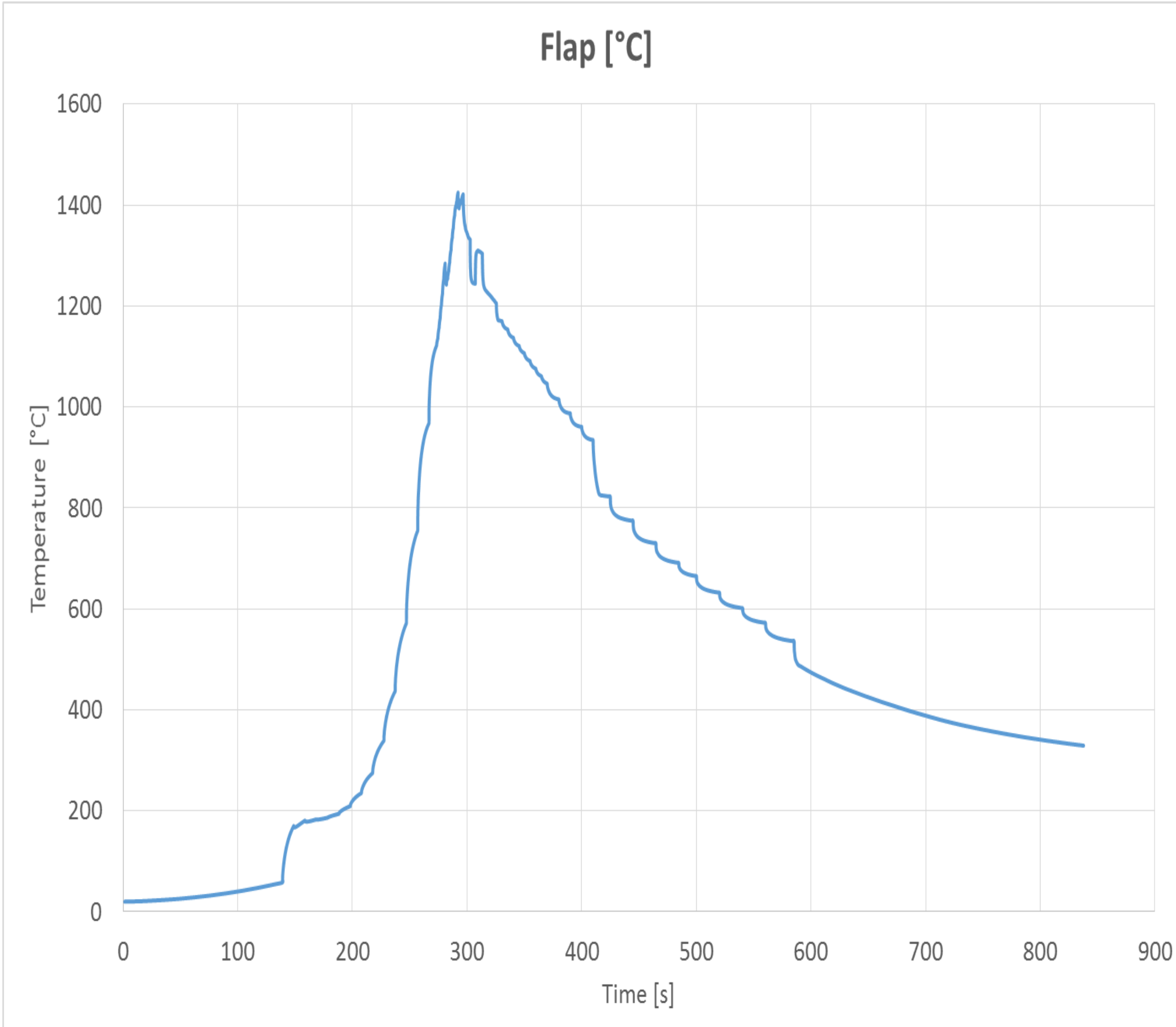




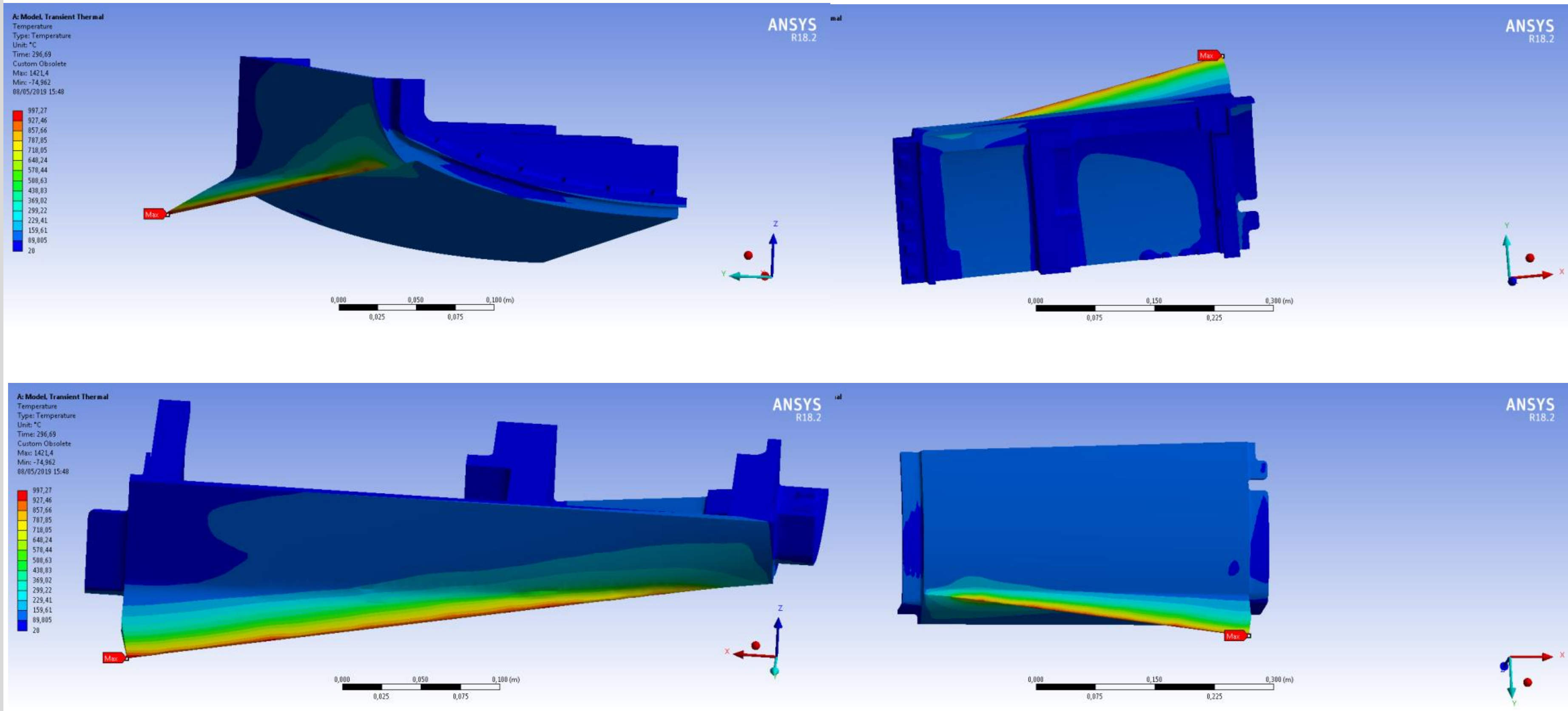
FLAP at t=292s






Flap [°C]
1600
1400
1200
1000
800
600
400
200
0
Temperature [°C]
0
100
200
300
400
500
600
700
800
900
Time [s]

Component Thermal Assessment: Wing critical area t= 269,69

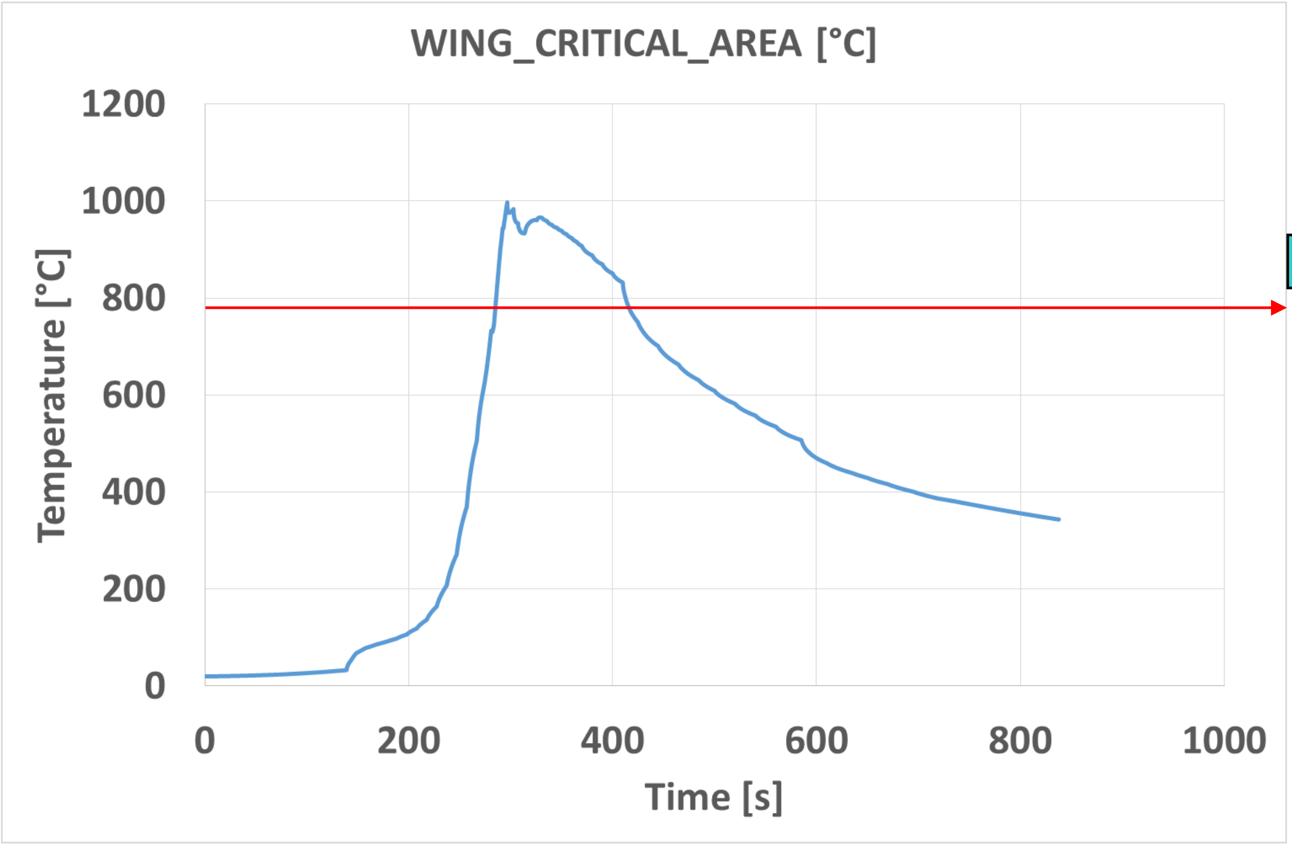


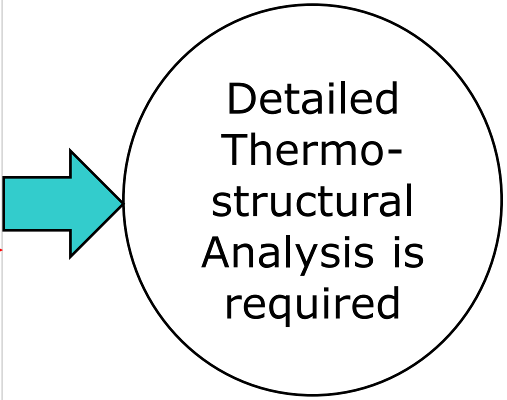
Italian Aerospace Research Centre

3rd Internation Symposium on Hypersonic Flight. May 30, 2019

HEXAFLY-INT

Component Thermal Assessment: Wing critical area @ t= 269,69





Conclusions

- The dynamic response of the system was obtained and showed that:
  - Launcher loads are in line with literature similar cases;
  - The most significant contribution to structural loads is due to sinusoidal vibration input.
  - Thermal loads have been evaluated and the actual structural configuration works on the thermal point of view
    - Only some specific critical area must be further analyzed