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On the wing design of NGCTR-TD

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T-Wing

Clean Sky 2

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Paper objective and scenario

- This work is focused on the wing design workflow of the innovative composite wing of the Next Generation Civil Tiltrotor Technology Demonstrator

- The Next Generation Civil Tiltrotor Technology Demonstrator (NGCTR-TD) is one of the Fast Rotorcraft Integrated Aircraft Demonstrator Platforms foreseen in H2020 Clean Sky 2 Program

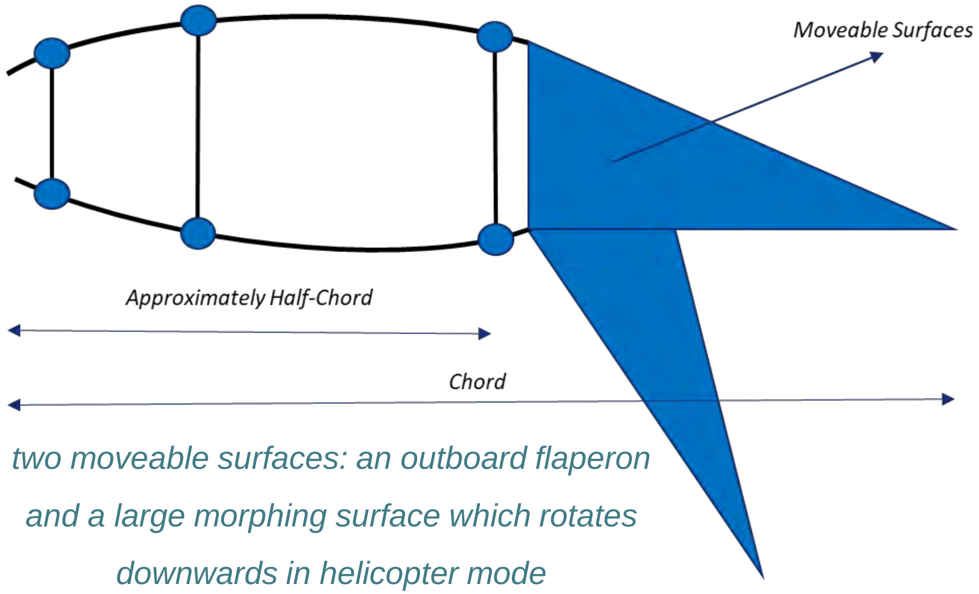
- The aim of NextGenCTR IADP is the design, construction and flying (TRL 6) of an innovative Civil Tiltrotor

- T-WING project is working on the composite wing of the NGCTR-TD planned to be flying in 2023: design, manufacturing, qualification and flight-testing of the wing and moveable surfaces of the NGCTR-TD.

T-WING Development logic

Scientific & Technical High Level Project-Goals

- **Challenges** for the wing of a tiltrotor (at the **minimum structural weight**): safety with respect to **strength** and **buckling** capability under loads, **aeroelastic** stability (flutter and whirl flutter), **crashworthiness**
- Peculiarities of NGCTR-TD wing architecture
  - *new high lift, low drag wing optimized to improve downwash impingement in helicopter mode (Hovering)*
  - *Compact structural wing box: almost half of the wing chord-length dedicated to the moveable surfaces*



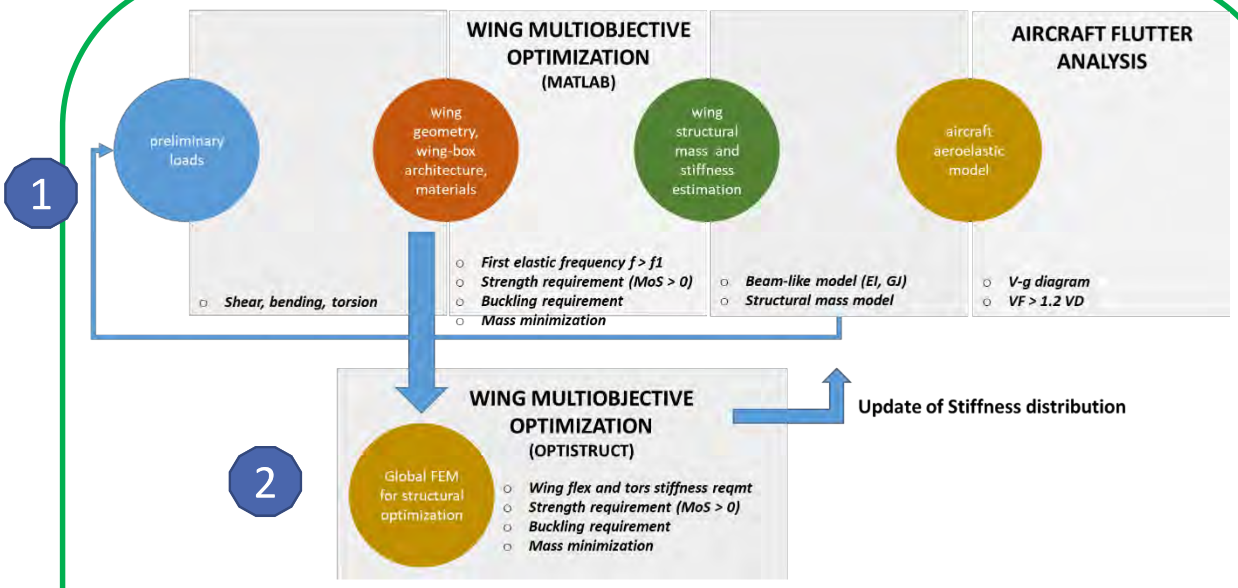
two moveable surfaces: an outboard flaperon and a large morphing surface which rotates downwards in helicopter mode

- **Manufacturing**: one-shot highly integrated composite wing structure
- Further challenges : **fuel capacity** (mission); **functionality** (systems installed inside the wing box), **accessibility** requirements, **segregation**

Main results of the design work flow of T-WING Critical Design Review are shown in the present paper

Design workflow

PRELIMINARY DESIGN PHASE → *DETAILED DESIGN PHASE*



STRESS AND BUCKLING ANALYSIS
MITIGATION OF NEGATIVE MS

UPDATE OF MASS DISTRIBUTION

UPDATE OF DIGITAL MOCK-UP

UPDATE OF SIZING LOADS

LOCAL REINFORCEMENTS FOR STIFFNESS REQUIREMENTS (flight mechanics and whirl flutter)

- UPDATE AEROELASTIC MODEL (2D FEM)
- UPDATE AEROELASTIC ANALYSES

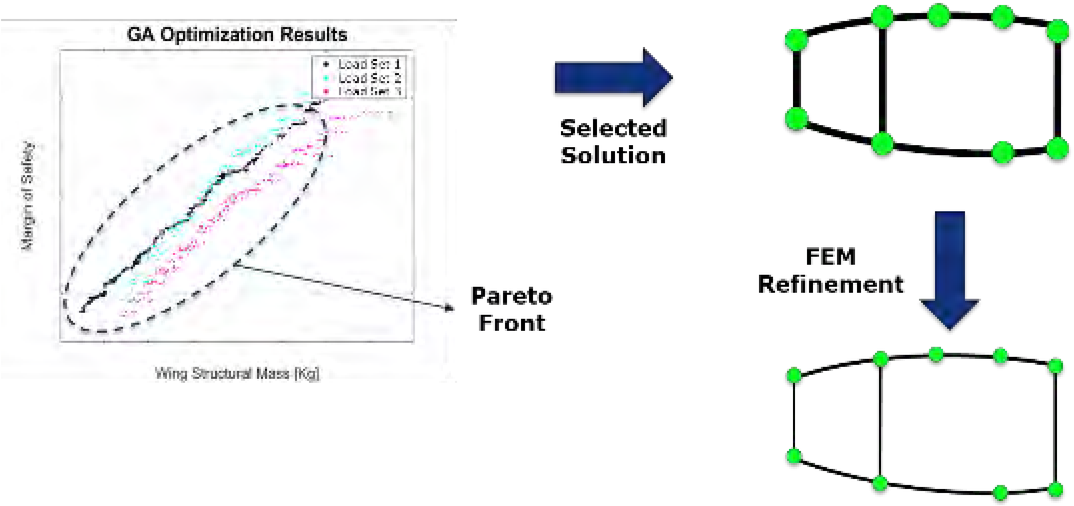
- UPDATE STRESS AND BUCKLING MODEL (DETAILED FEM)
- UPDATE ANALYSES

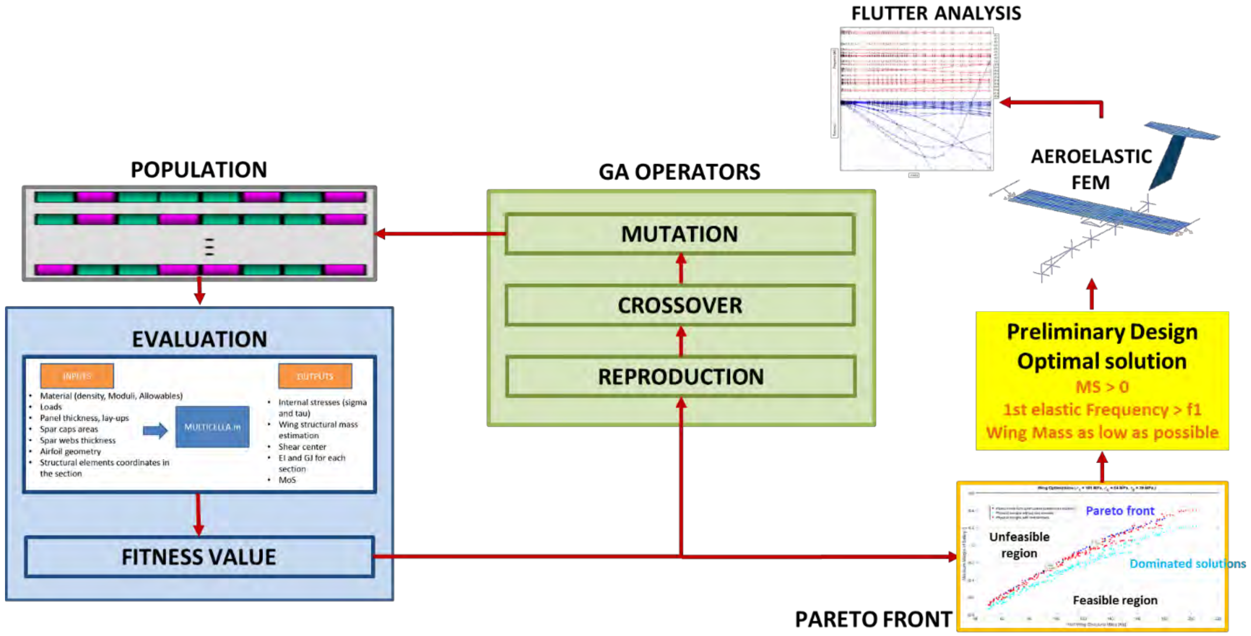
EMERGENCY CONDITIONS

functional and systems interface requirements

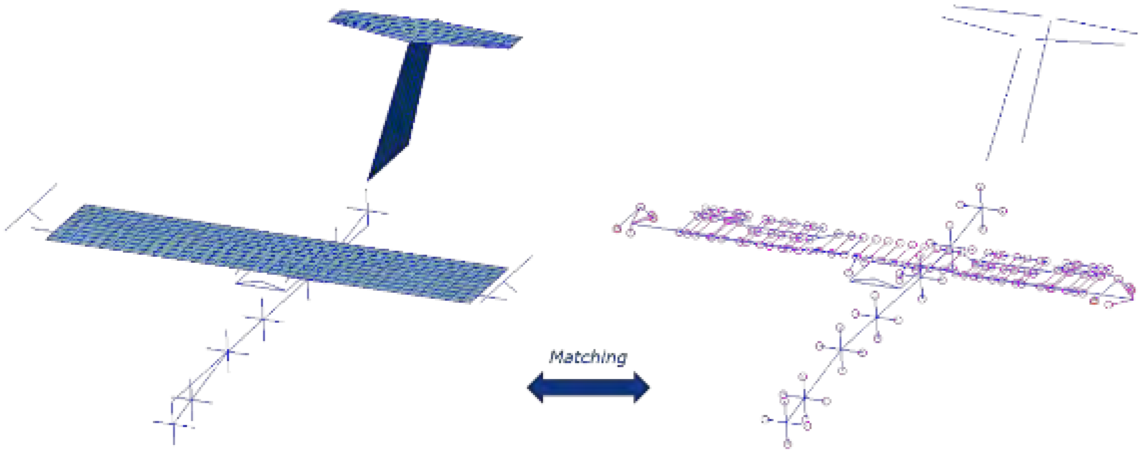
Preliminary sizing and optimization

- Multi-Objective Genetic Algorithm to optimize the wing-box structure
- Optimization variables: thicknesses and areas of the wing-box.
- Optimization objectives: wing structural mass minimization and safety margin maximization.

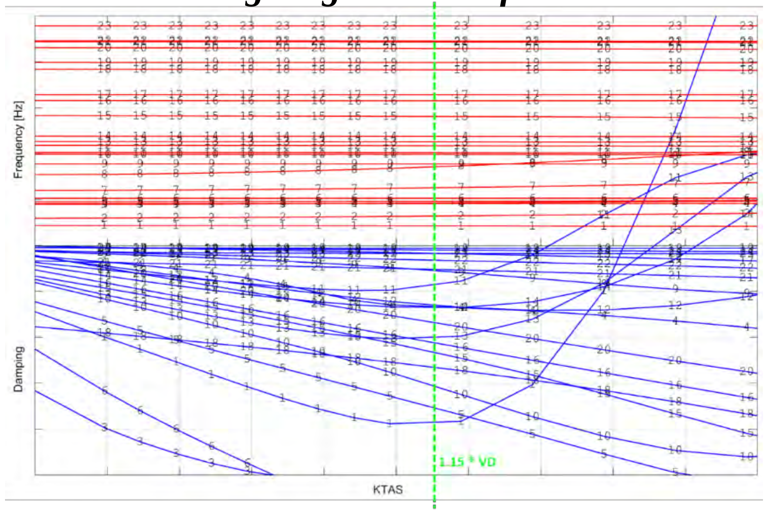




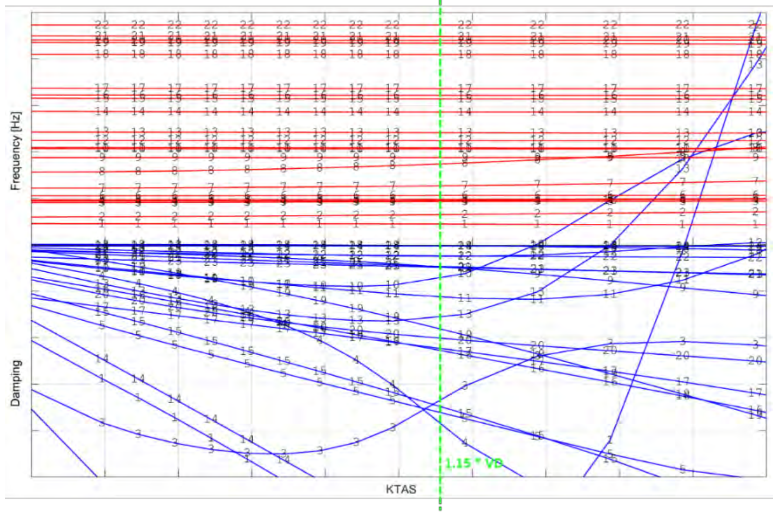
Preliminary Flutter analyses



V-g diagram: Full fuel case



V-g diagram: Zero fuel case



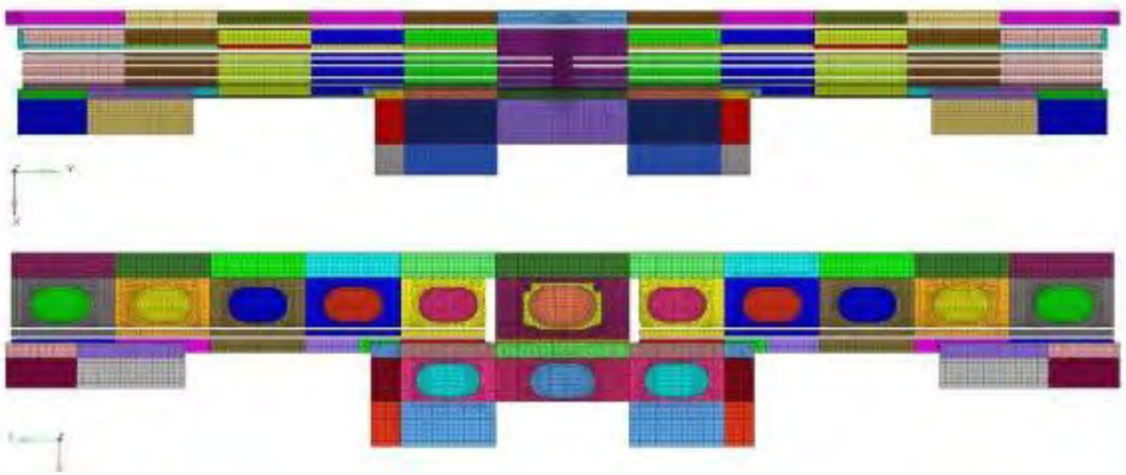
PDR AEROELASTIC MODEL

- Hybrid structural model: stick-beam model for wing and moveable surfaces, Nastran Super-Elements provided by the WAL for fuselage, tail and nacelles.
- DLM aerodynamic model: flat panels representing wing and tail and slender bodies/ interference elements representing fuselage and nacelles.
- Matching between dynamic and aerodynamic models achieved by the use of Infinite Plate Splines (IPS).

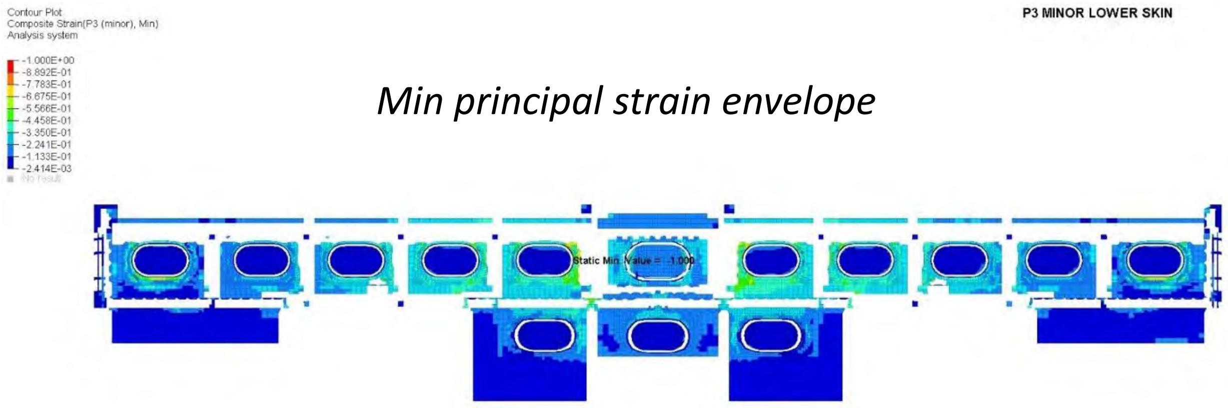
Multi-objective optimization (FEA)

optimization of the composite parts

zonal thickness optimization



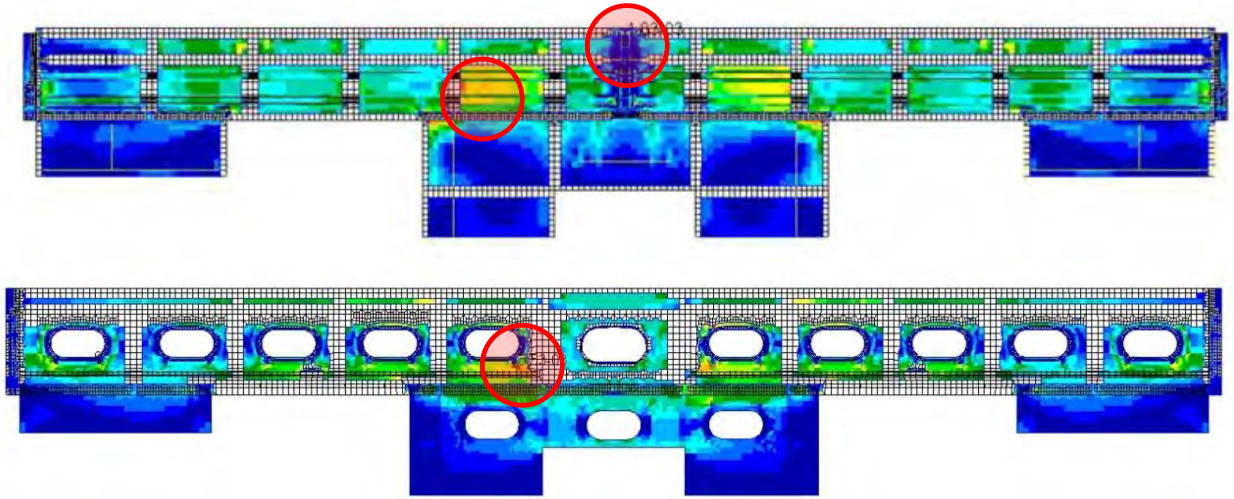
Min principal strain envelope



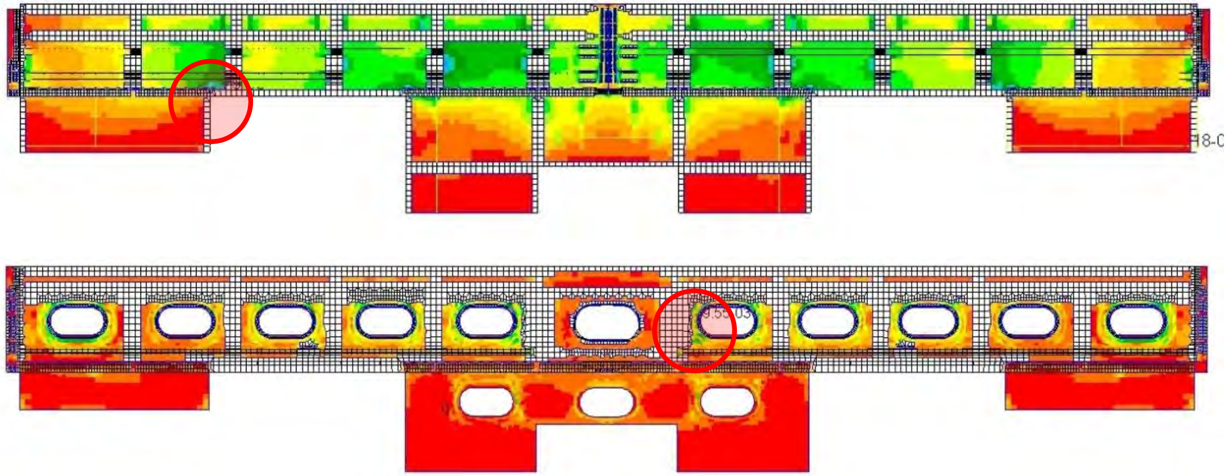
- Wing FEM - Altair **OptiStruct** environment - 2D and 1D Elements
- Optimization performed for the composite structures (skins and spars) – equivalent PSHELL
- Optimization constraints
  - No buckling up to 80% of Limit Load on skin and spars;
  - Strength Margin of Safety > 0 at Ultimate Load on composite parts (max strain criterion);
  - Max allowed wing tip flexural displacements and torsion angle
- gradient descent optimization algorithm
- no. 15 Loading conditions: no. 12 LC for strength and buckling + no. 3 LC for Flexural Out of Plane M_x, Torsional M_y and Flexural In Plane M_z
- design variables: thicknesses of the upper and lower skins and of the spars (CFRP)
- **Outcome**: **zonal optimization along the wingspan**
- Optimized FEM used to compute new stiffness distributions and update structural aeroelastic stick beam model and repeat analyses
- Zonal optimization is the starting point of an engineered model and a detailed FEM

Stress analysis

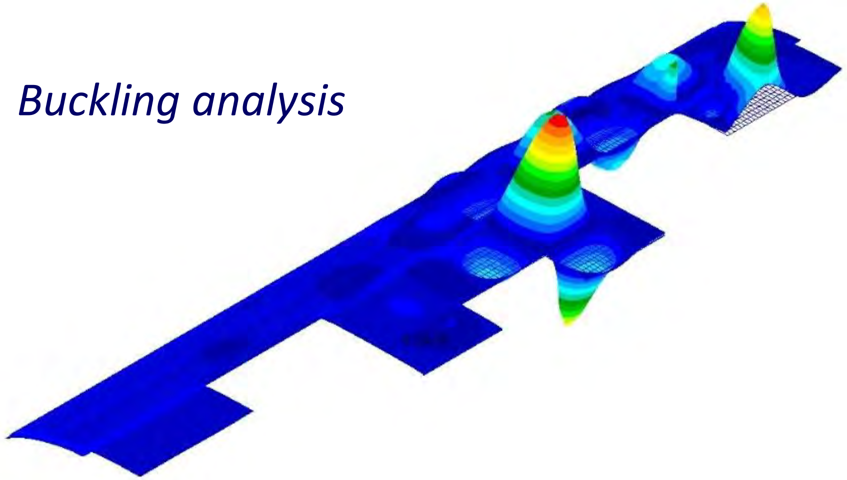
Envelope of tensile strains all over the sizing load conditions



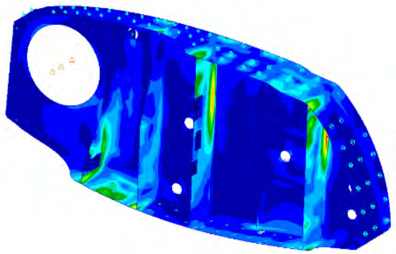
Envelope of compressive strains all over the sizing load conditions



Buckling analysis



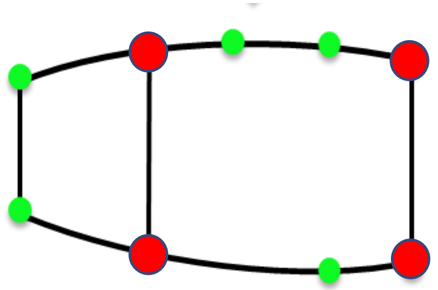
Tip rib stress analysis

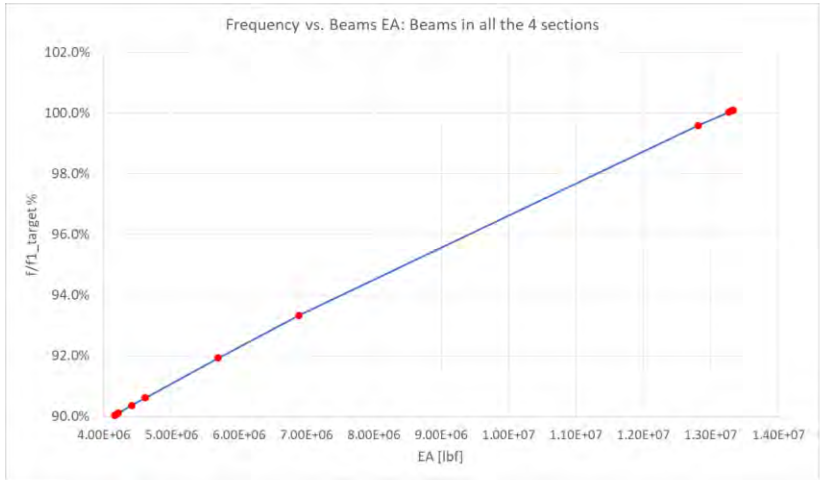


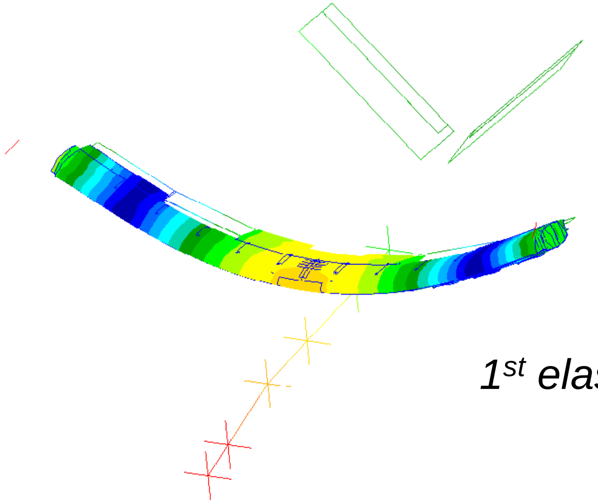
Tuning of stiffness

flight mechanics requirement

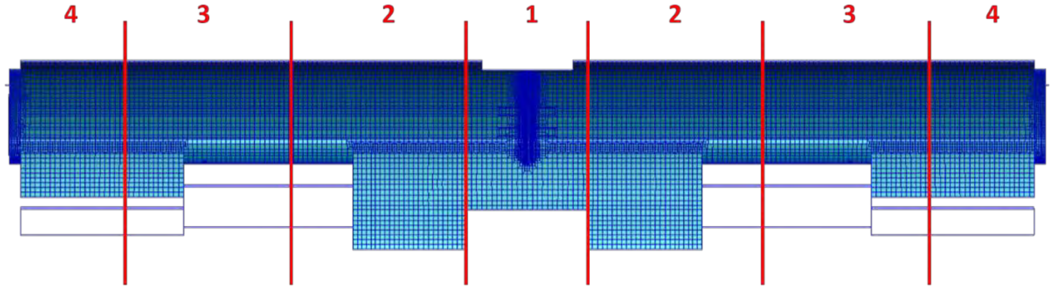
Preliminary study of a suitable set of reinforcement beams to be added to the wing box to increase the wing stiffness and match the dynamic requirement on the **first elastic frequency**







1st elastic mode (bending)

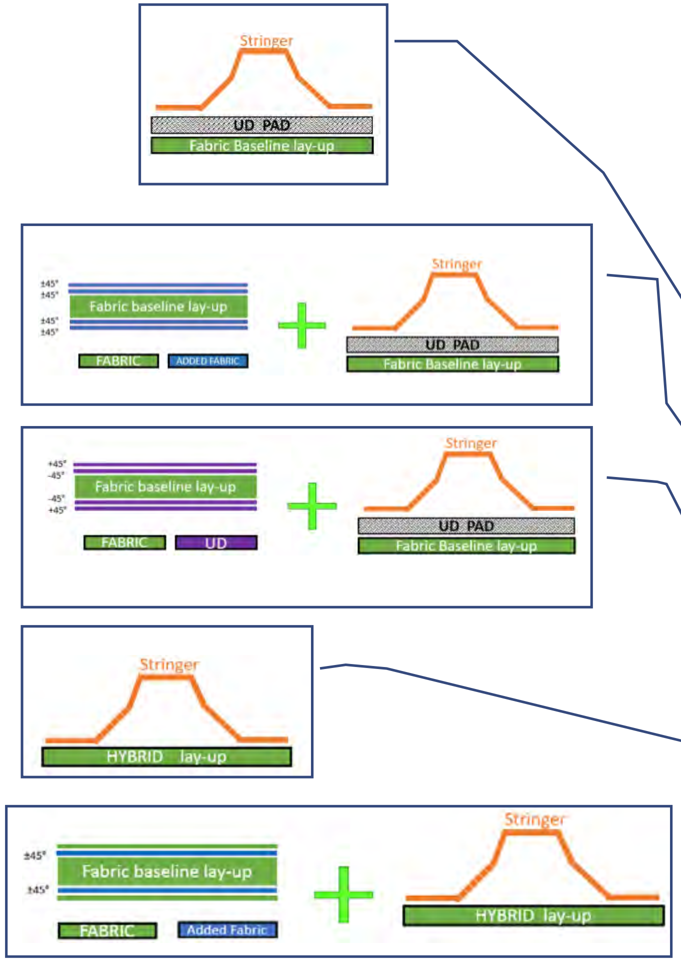


impact of removing certain groups of beams along the wing span

Sections	f/f1_target	Performance Reduction %	Performance Enhancement %
1,2,3,4	1.001	0.0%	6.7%
1,2,3	0.997	5.4%	6.4%
2,3,4	0.993	11.5%	6.0%
2,3	0.990	16.8%	5.6%
1,2	0.975	40.5%	4.0%
2	0.968	51.1%	3.3%
3	0.955	72.3%	1.9%
1	0.942	92.3%	0.5%
-	0.937	100.0%	0.0%

Tuning of stiffness

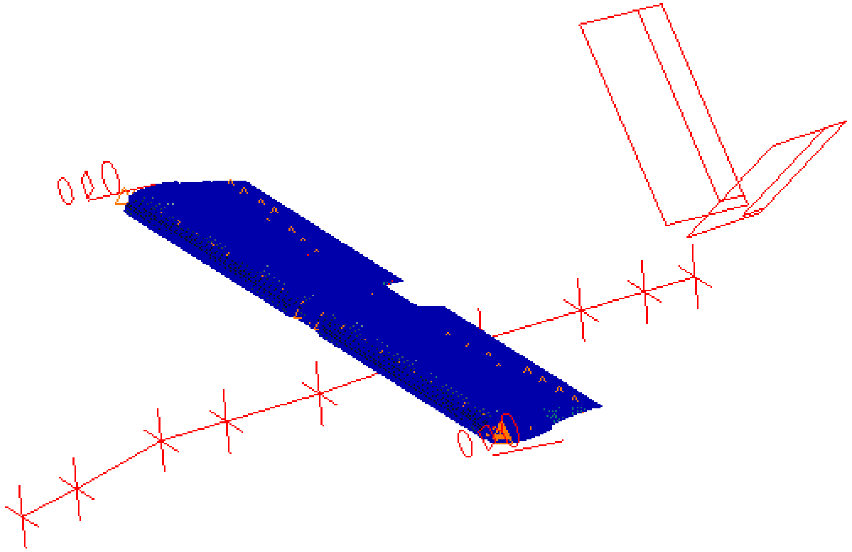
- A subsequent more detailed study was performed to properly reinforce the wing both in flexural and in torsional stiffness, to cope with flight mechanics and whirl flutter stability
- The study took in consideration weight constraints, manufacturability and allowables characterization campaign



		HELICOPTER MODE	AIRCRAFT MODE			
SOLUTION	**Added weight respect to baseline model (%)** (FEM ESTIMATION)	**Flexural frequency in helicopter mode F/F_TARGET**	**Flexural frequency in aircraft mode F/F_TARGET**	**Torsional frequency - symmetric mode F/F_TARGET**	**Torsional frequency - anti-symmetric mode F/F_TARGET**	**Fore and aft F/F_TARGET**
BASELINE MODEL	0	85%	89%	93%	97%	108%
Adding UD Stringers and UD Pad Reinforcement	3%	93%	99%	94%	98%	111%
SOLUTION 2W_1S(Adding 4 plies in high strain energy areas for torsional modes + UD PAD + UD stringers)	11%	100%	104%	102%	108%	115%
SOLUTION 6W_1S(Adding 4 plies in high strain energy areas for torsional modes + UD PAD + UD stringers)	8%	99%	104%	101%	107%	115%
GFEM_v1 (Design & Manufacturing reviewed solution to pursue ease of manufacturing avoiding ply drop)	1%	97%	100%	95%	99%	112%
GFEM_v2 (Design & Manufacturing reviewed solution to pursue ease of manufacturing avoiding ply drop) + 2 Fabric plies added	6%	98%	102%	100%	106%	114%

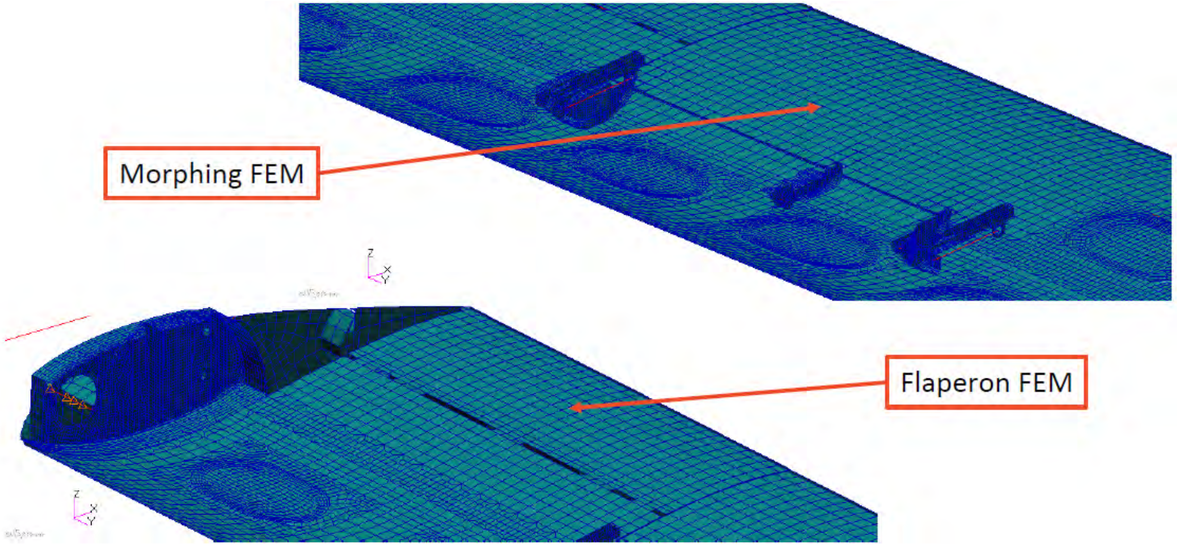
Flutter analyses 2D FEM

Aeroelastic model



A refinement of the aeroelastic model has been performed by including full wing and moveable surfaces coarse FEM

Details of moveable surfaces



CDR AEROELASTIC MODEL

- Hybrid structural model: **coarse FEM** for wing and moveable surfaces, Nastran Super-Elements provided by the WAL for fuselage, tail and nacelles.
- DLM aerodynamic model: flat panels representing wing and tail and slender bodies/ interference elements representing fuselage and nacelles.
- Matching between dynamic and aerodynamic models achieved by the use of Infinite Plate Splines (IPS).

Flutter analyses 2D FEM

Flutter of moveable surfaces

moveable surfaces actuation line **failure cases** have been analyzed

An example of one of the no. 15 failure cases analyzed

Type of Failure	Acronym/Symbol
Actuator Functional (Electro-Hydraulic System) Failure	AF
Actuator Mechanical Failure	AM
Flaperon - Hinge Mechanical Failure	HM
Morphing- Upstop failure	HM1
Morphing- fitting failure	HM2
No failure	-

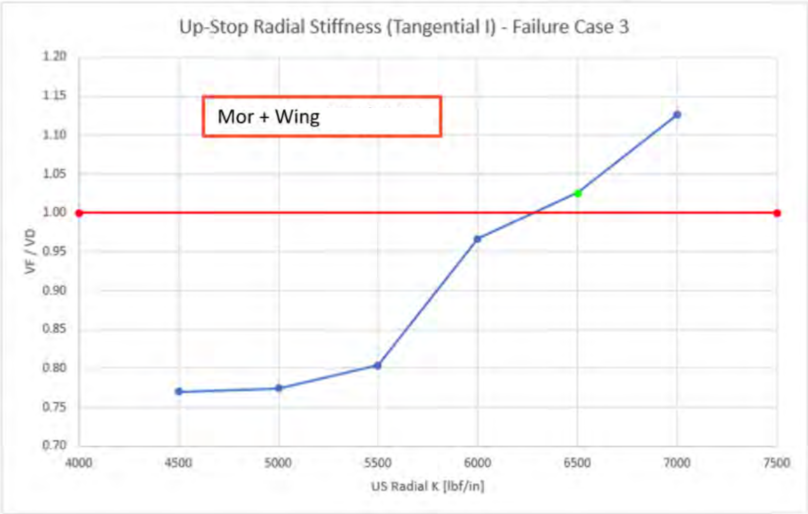
	Left Wing		Right Wing	
#	Flaperon	Morphing (US ON)	Morphing (US ON)	Flaperon
1	AF AF	AF	AF	AF AF

e.g. 2/3 flaperon actuators failed

- For the **No-Failure case**, flutter analysis performed at 1.15 Mach V_D (threshold 1.15 V_D).
- For the **Failure cases**, flutter analysis performed at Mach V_D (threshold 1.00 V_D)

Flutter sensitivity studies

An example of flutter speed sensitivity wrt morphing upstop radial stiffness

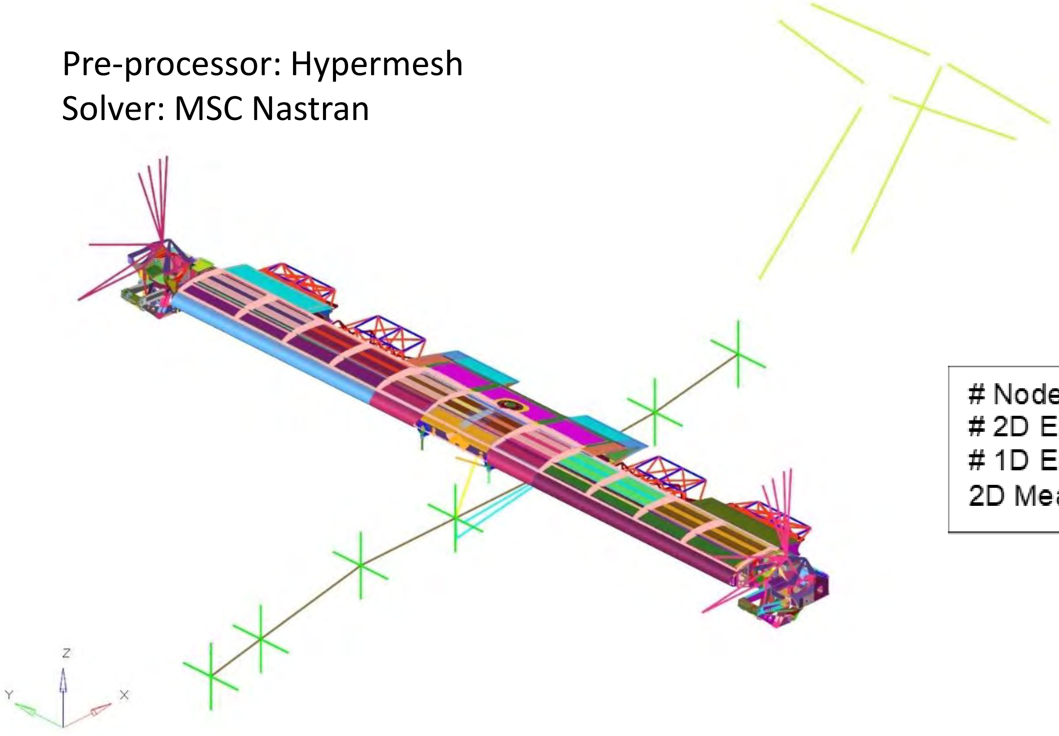


- ***A considerable number of sensitivity studies have been performed by taking into consideration different failure cases and different combination of stiffness values***
- ***The final outcome is a list of all the flutter cases identified and possible mitigation measures in terms of stiffness increase of the actuation line***

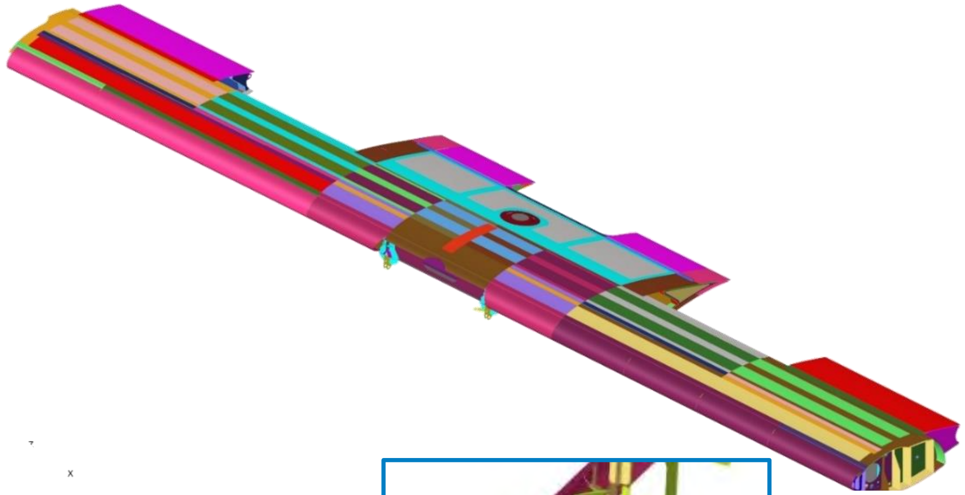
Detailed FEM

DFEM

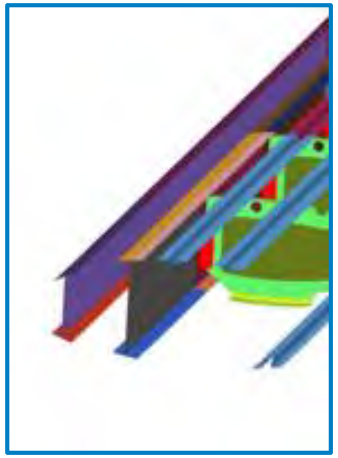
Pre-processor: Hypermesh
Solver: MSC Nastran



# Nodes:	1233030
# 2D Elements:	1182673
# 1D Elements:	26415
2D Mean size:	0.3 in



Internal details



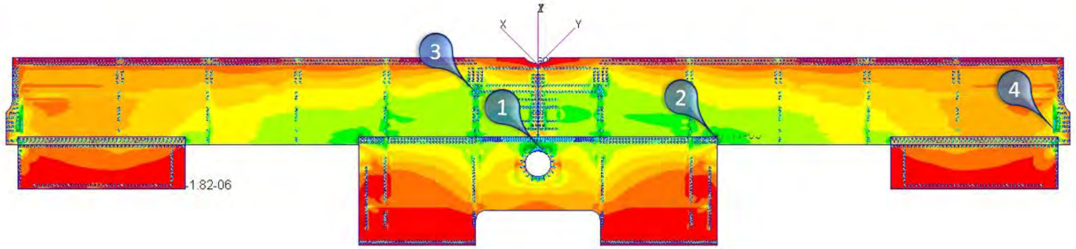
Detailed FE model of the wing

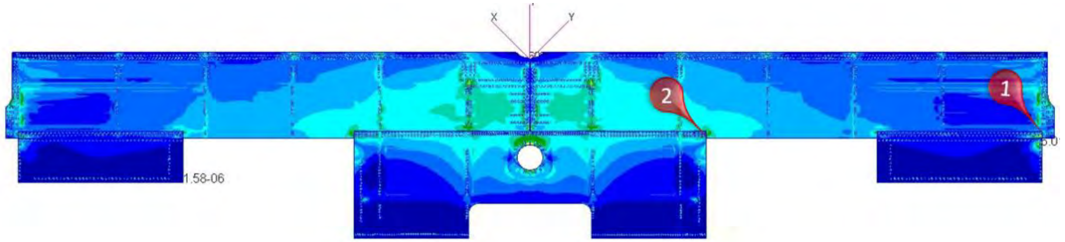
- Inertia relief model
- Fuselage and tail modeled as Nastran superelements
- Nacelle Primary structure introduced as FEM (provided by the WAL)
- Structural and non structural masses modelled by Concentrated mass (CONM2) properly connected to the structure by means of RBE3
- 50 Loads conditions modelled and analyzed

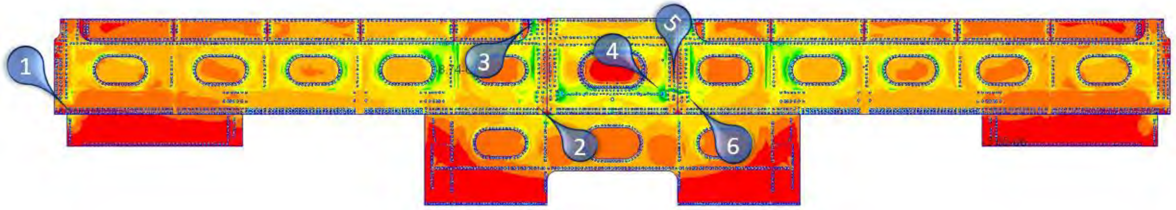
Detailed stress analysis

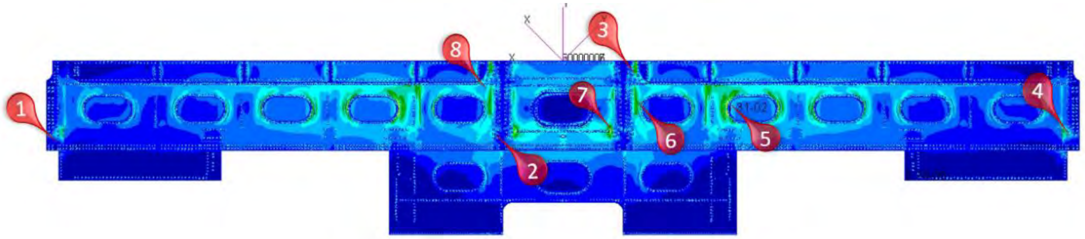
WING-LAMINATE-STRENGTH-ANALYSIS - All Loading Condition Envelope

SKIN

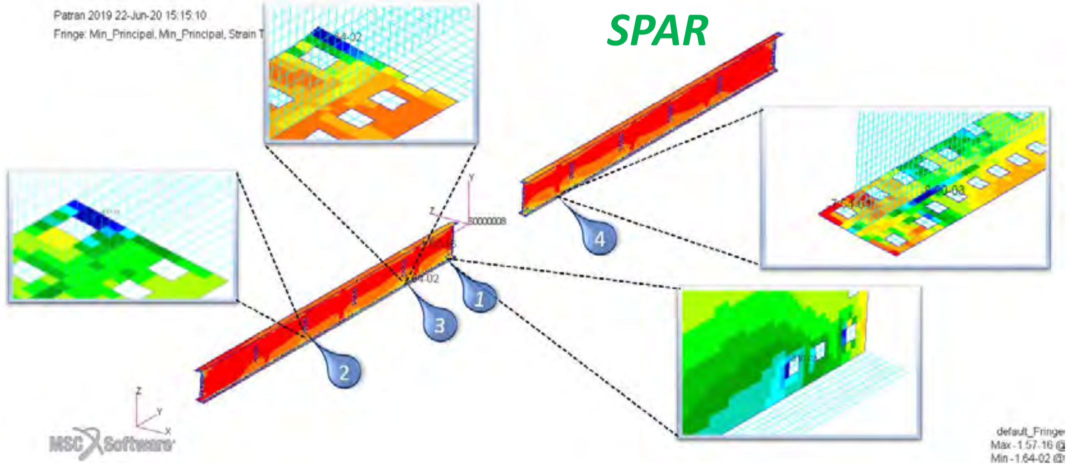


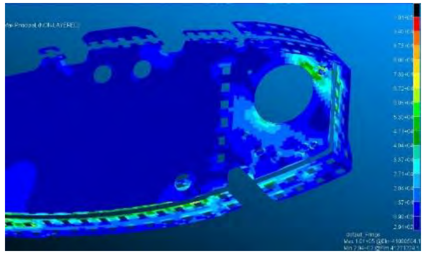




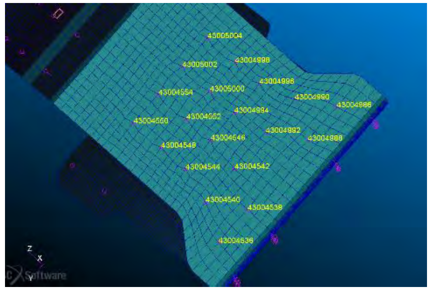


SPAR





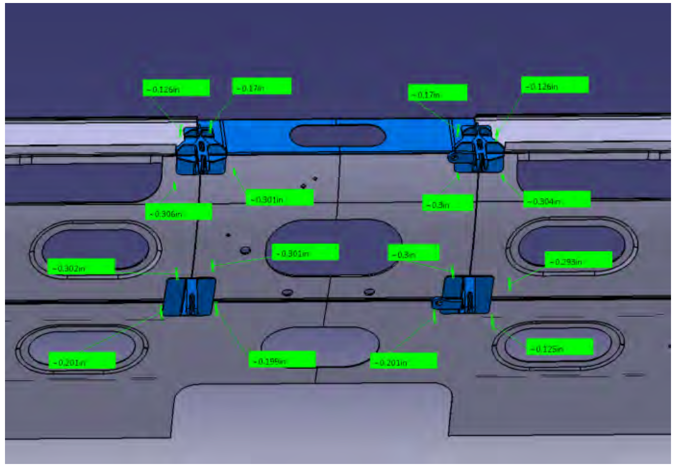
METALLIC RIBS



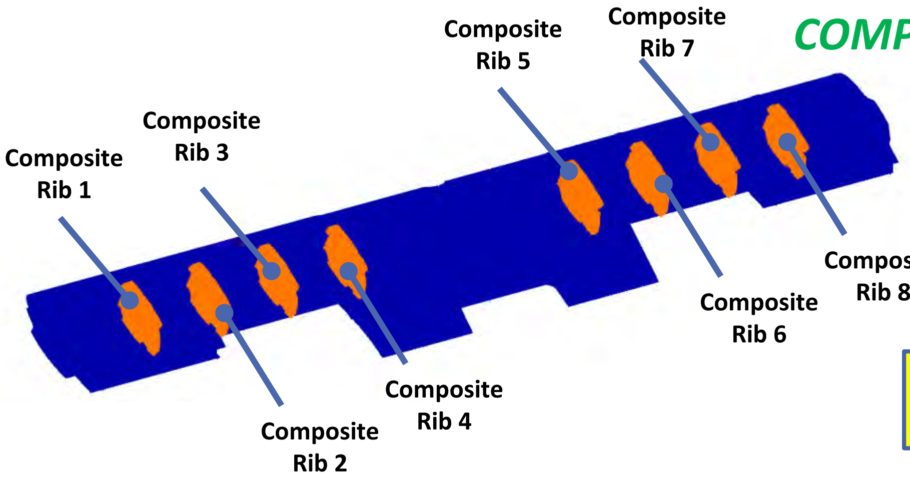
FASTENERS ANALYSIS

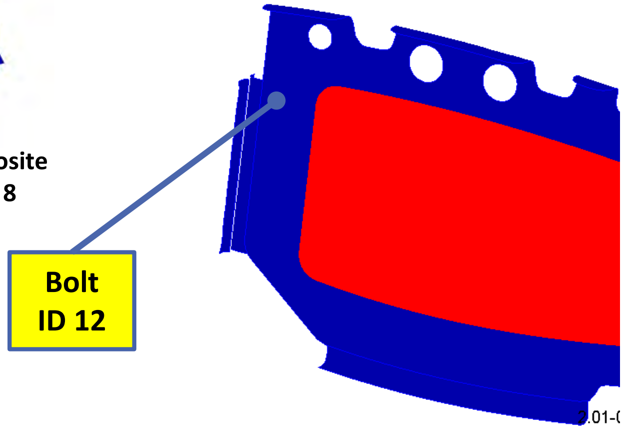
Detailed stress analysis

WING – FUSELAGE LUG ANALYSIS

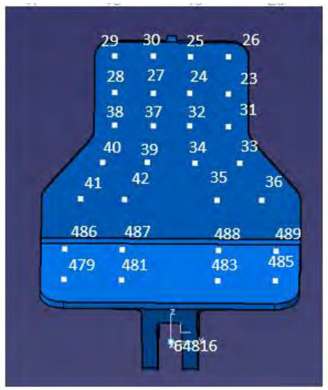


COMPOSITE RIBS INSTALLATION ANALYSIS

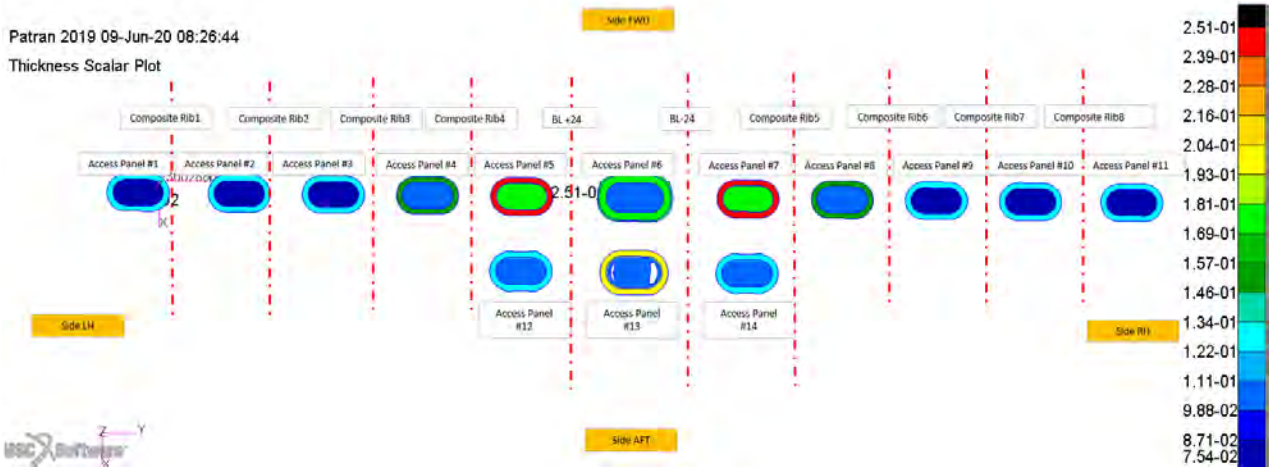




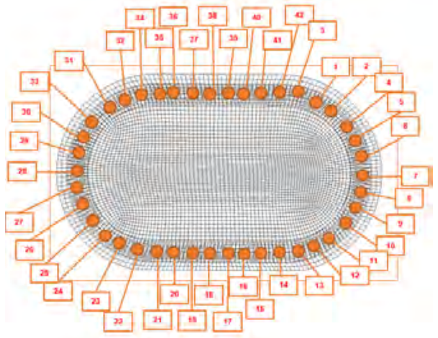
FASTENERS ANALYSIS



ACCESS PANELS INSTALLATION ANALYSIS

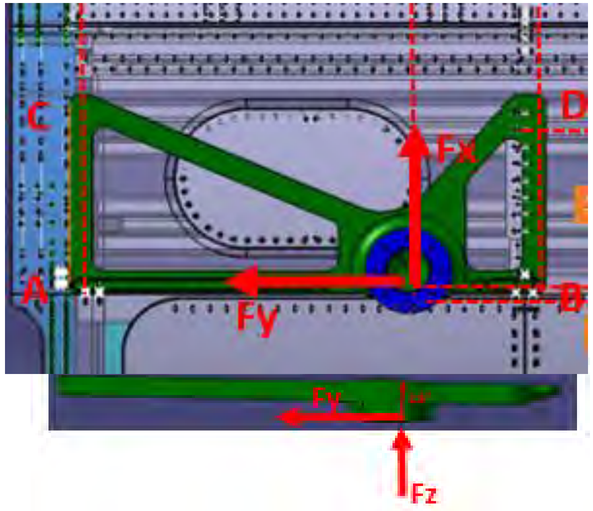


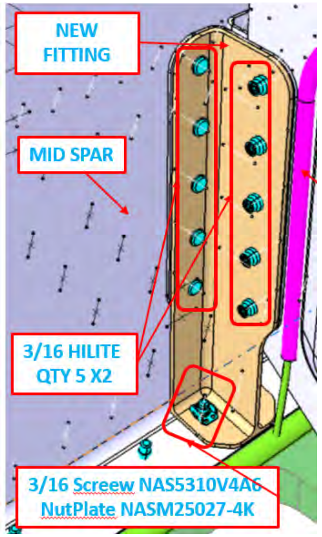
- *Bearing Bypass*
- *Fastener Shear-Tension*
- *Pull Through*

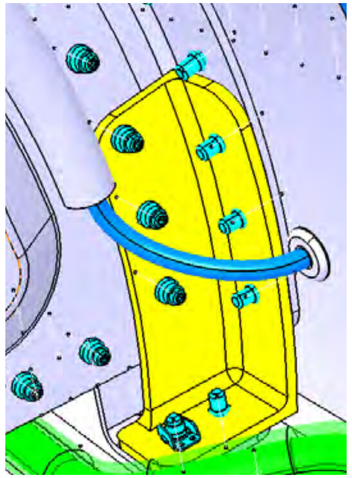


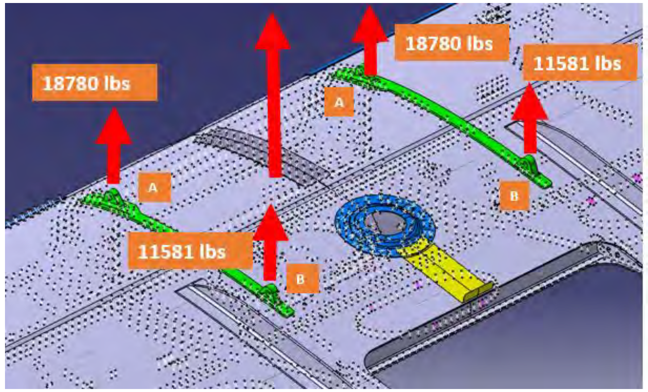
Detailed stress analysis

RAMP-FITTING-STRESS-ANALYSIS

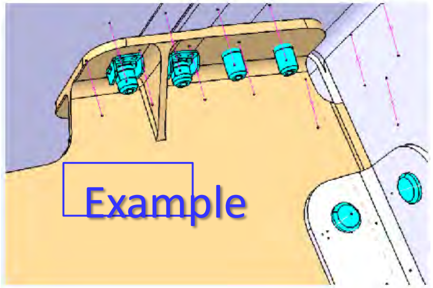




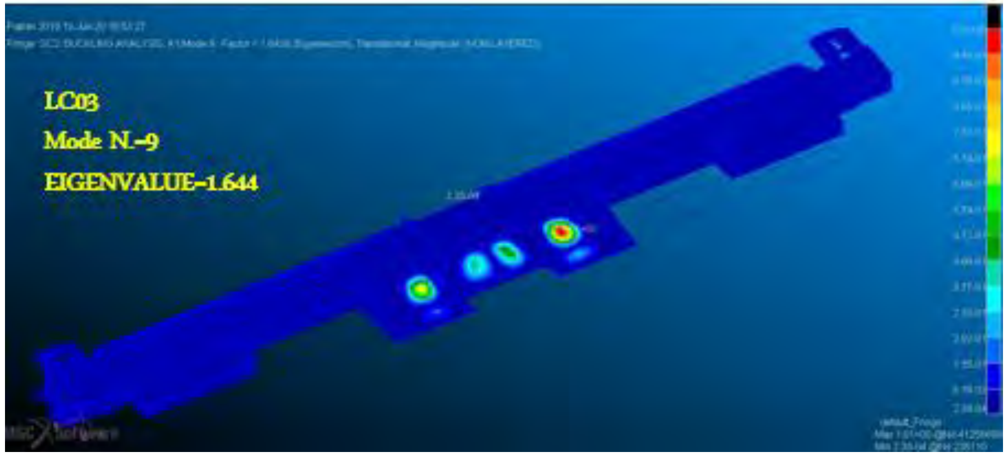




HOISTING-FITTING-STRESS-ANALYSIS

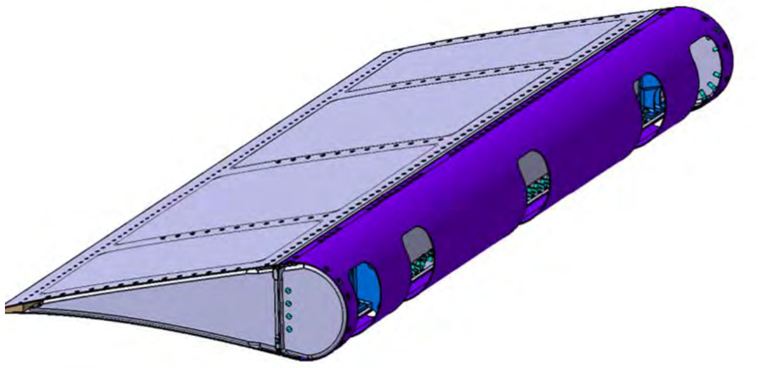


WING BUCKLING ANALYSIS

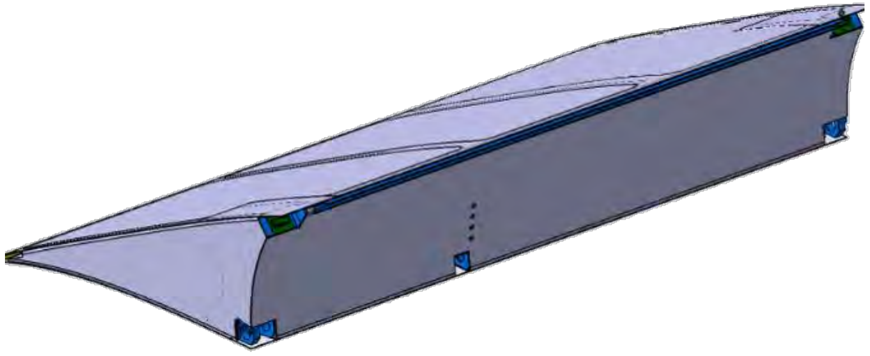


Moveable surfaces stress and buckling analysis

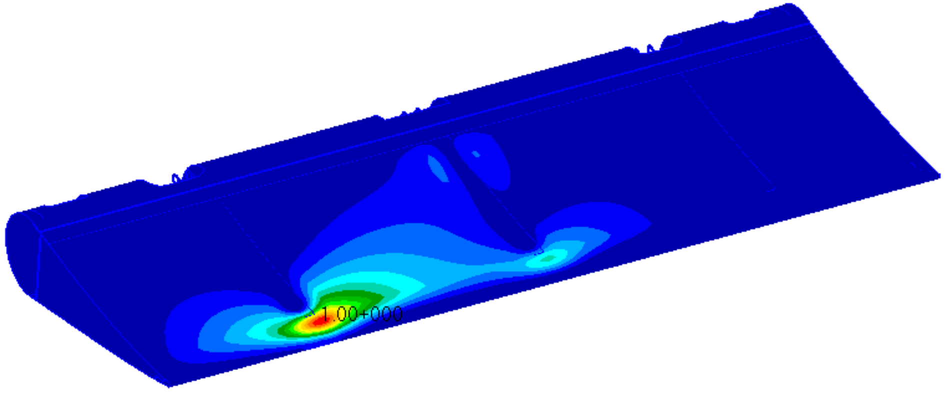
FLAPERON



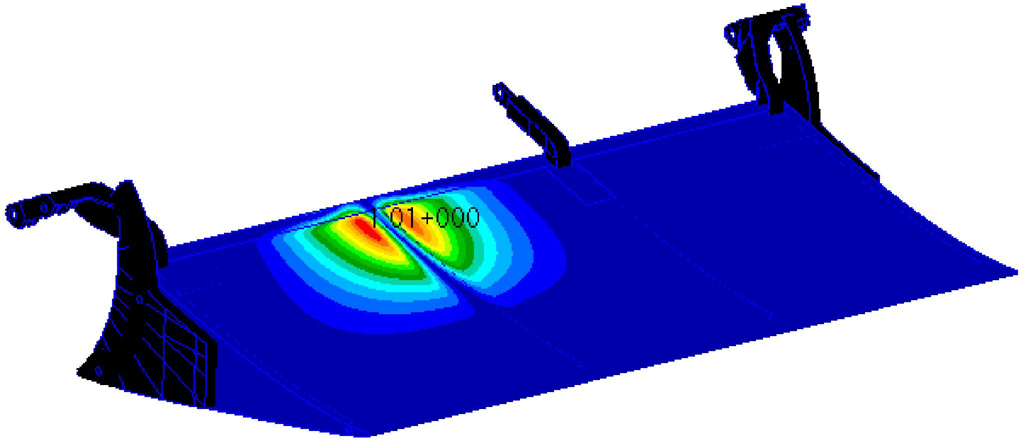
MORPHING SURFACE



Static ANALYSIS
Metallic Strength, Bearing By Pass, Metallic Joint and Fastener shear failure.



Buckling ANALYSIS



Fatigue (metallic parts)

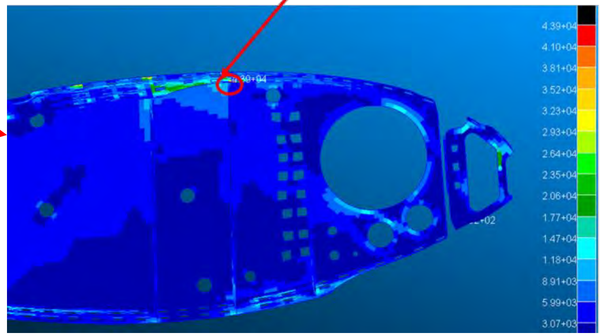
- Initial checks by means of ground-air-ground (GAG) cycle
- The GAG cycle is the envelope of the Sea Level, ISA, Limit load stress levels reduced at the agreed factor (80%)
- Maximum tension loads have been extracted for each point load cases
- 2 Ground-Air-Ground (GAG) cycles per hour have been assumed
- Fatigue life cycles have been evaluated with S/N curve from MMPDS -11
- For lugs analysis a Kt factor have been calculated and applied for bearing loads
- Safe life approaches is used (scatter factor of 10)

Critical details

LOC #10 elm 31003643 - z1 **LC 22**

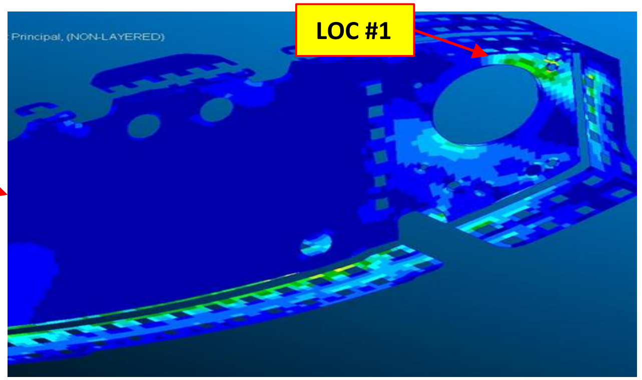
TIP RIB

Very high % operative life (OL)



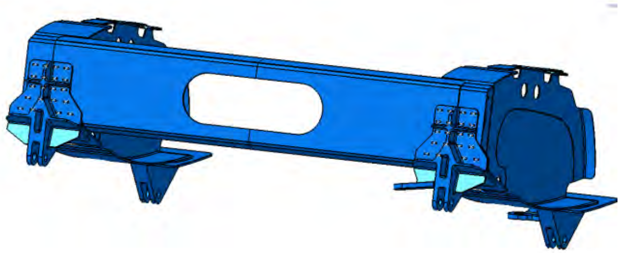
RIB at BL 24’’

157% OL



Wing to body
Fwd vertical right

106% OL

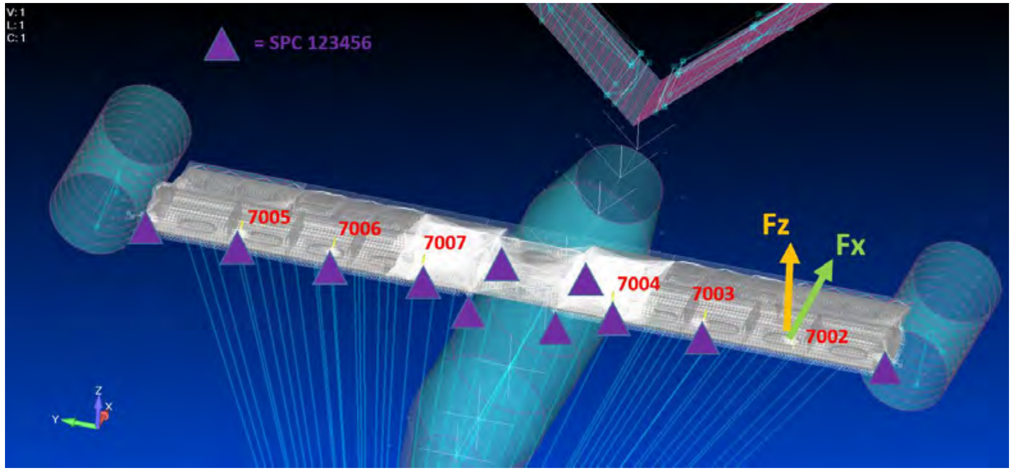


ICDS requirements

1. Requirement on minimum ***local radial stiffness*** *of the wing at the supports*

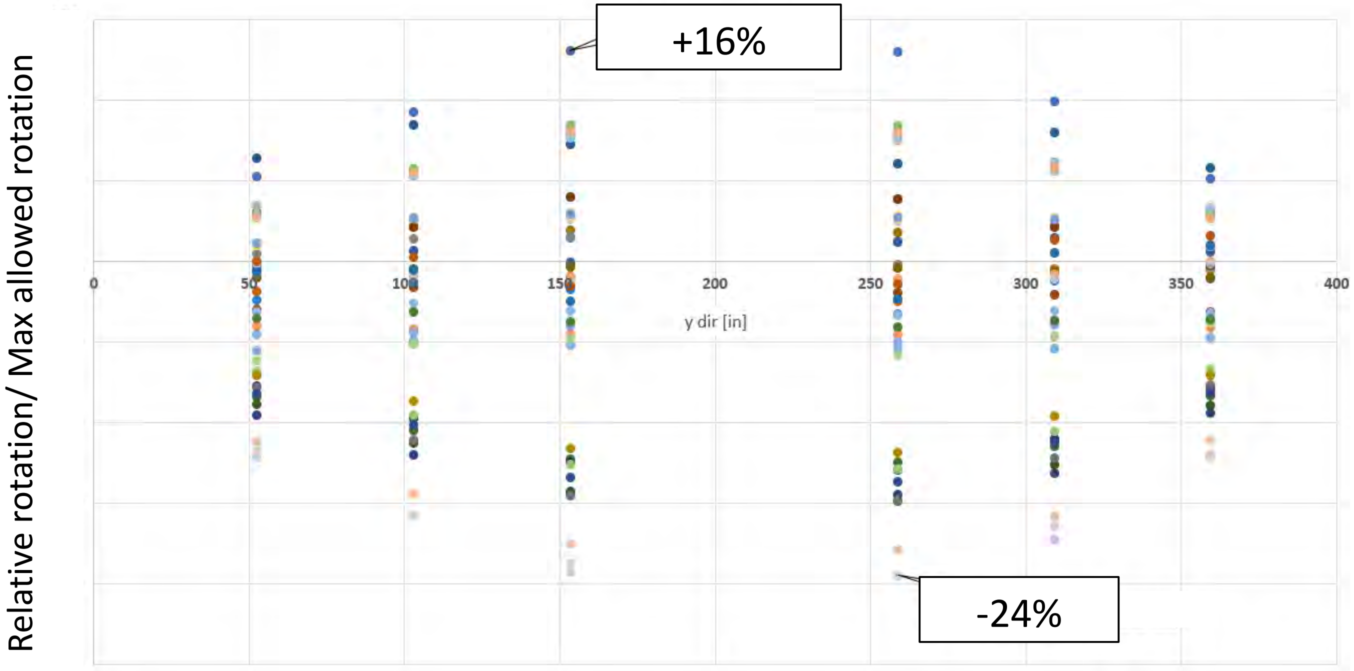
100% compliant

- *Static calculation*
- *Output: stiffness along X and Z directions*



2. The Wing shall provide the Inter-Connecting-Drive-Shaft with enough stiffness to ensure that the maximum ***angular misalignment*** *does not exceed a prescribed value at each of the coupling locations in operative conditions*

100% compliant



Emergency conditions: Ditching

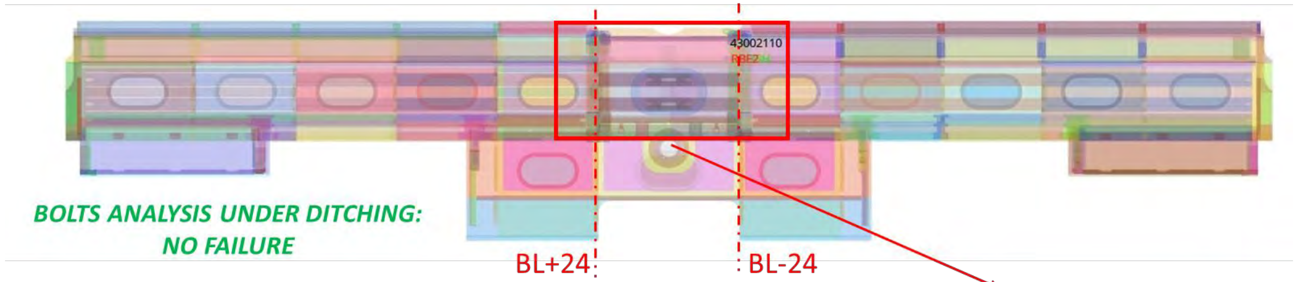
WING DITCHING ANALYSIS

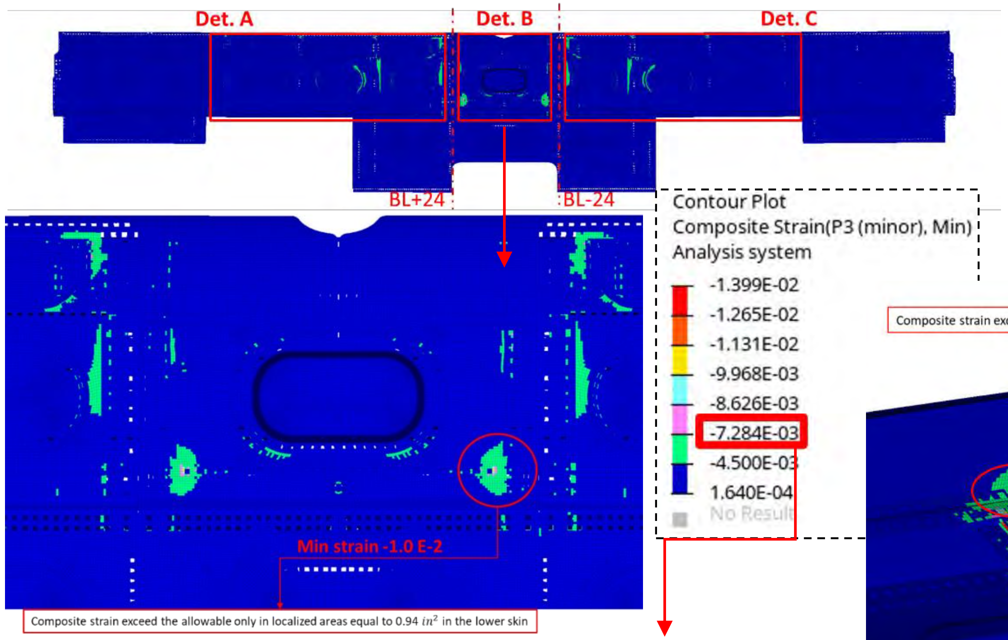
SOLVER: MSC NASTRAN

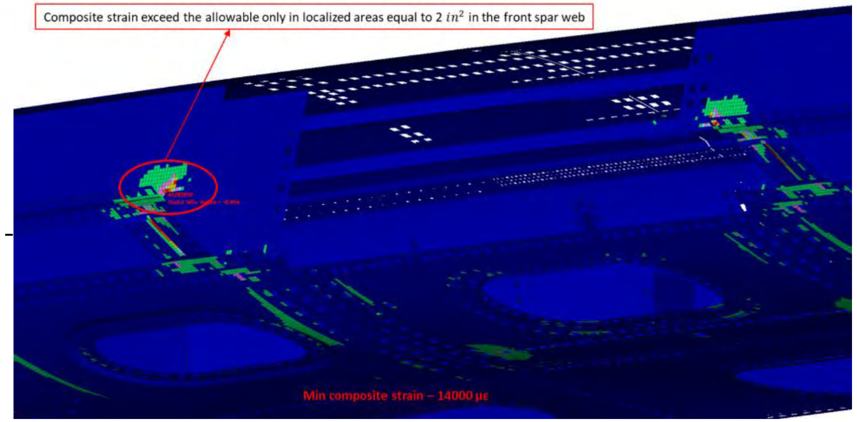
PERFORMED ANALYSIS: Results are based on Nastran SOL 101 – Inertia relief analysis type

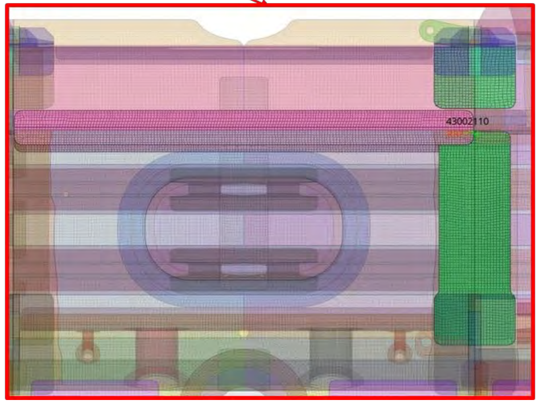
DITCHING LOAD CONDITIONS: Strain contours have been plotted considering all the 8 Ditching Load Conditions

MAIN HYPOTHESES: Ditching Loads are considered as ultimate loads, i.e. SF=1.0









OHC Mean Room Temperature Dry value (compressive strain allowable)

No catastrophic failure of composite under ditching

Emergency conditions: Crash

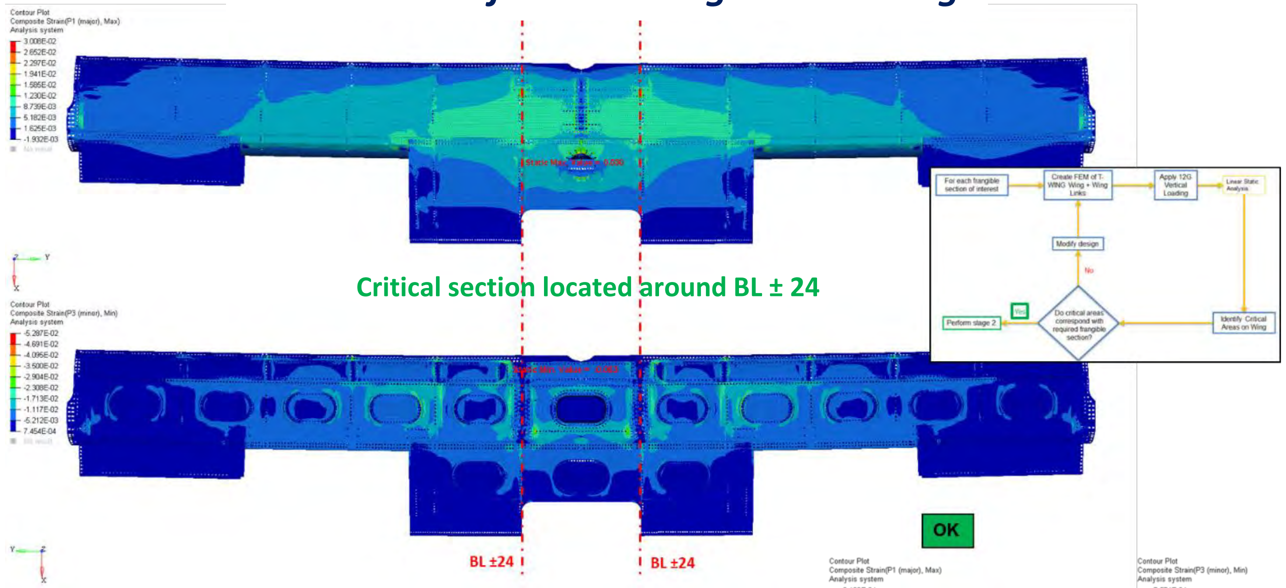
- Requirement: to show that any cabin occupants are protected in a crash situation (12g vertically down crash) from equipment mounted externally above the cabin including the wing
- Tiltrotor: NEED for a frangible section of the wing under crash, in order to detach the external wing and alleviate the mass insisting on the cabin
- Having defined the position of the frangible section the design shall ensure that this is the first area to buckle
- Still sufficient margin available for normal design cases and ditching loads

METHODOLOGY

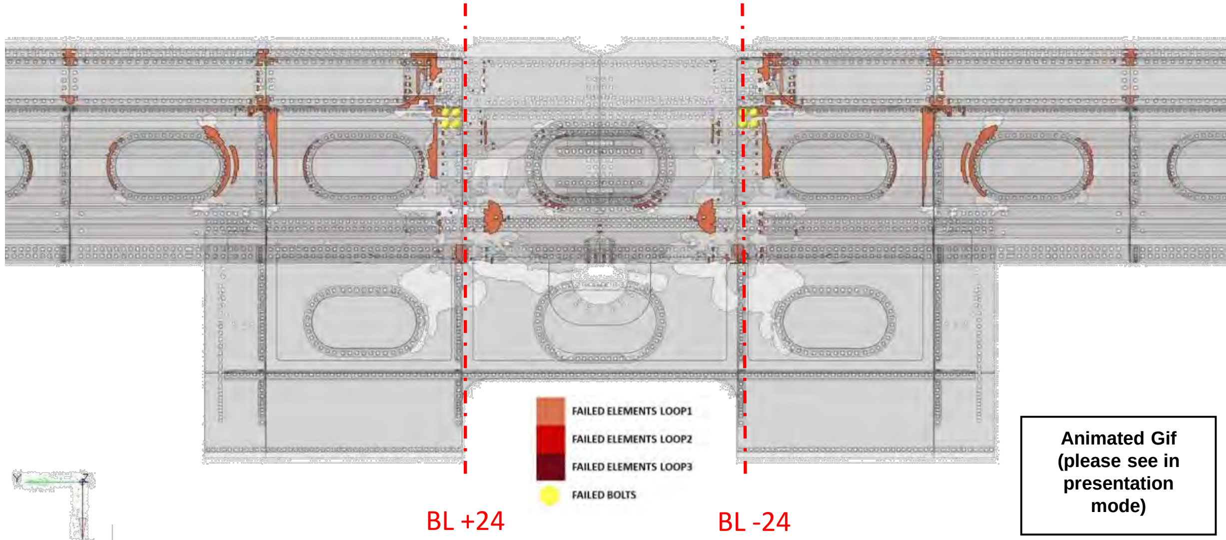
1. Selection of critical wing section: 12 g static analysis iterated until critical areas fall in the desired section
2. Progressive failure of the frangible section: static analysis iterated until complete failure of the section (removal of failed elements
3. Assessment of the wing-fuselage link loads
4. Assessment of wing strains/stresses in the remaining portion

Emergency conditions: Crash

1. Selection of critical wing section: 12 g



2. Progressive failure of frangible section

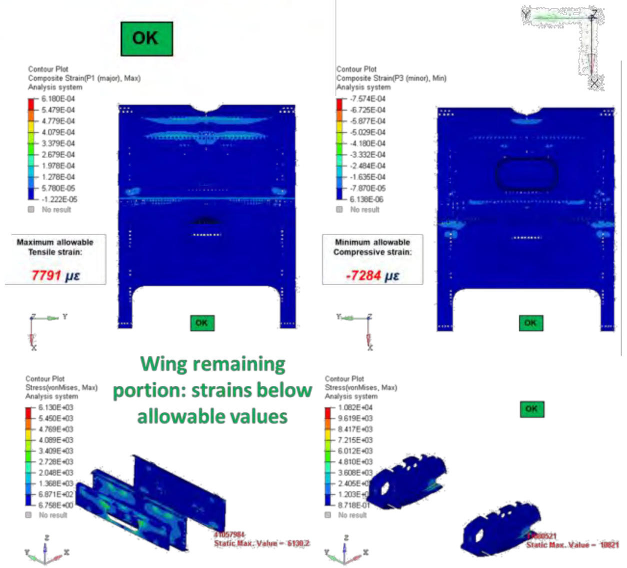


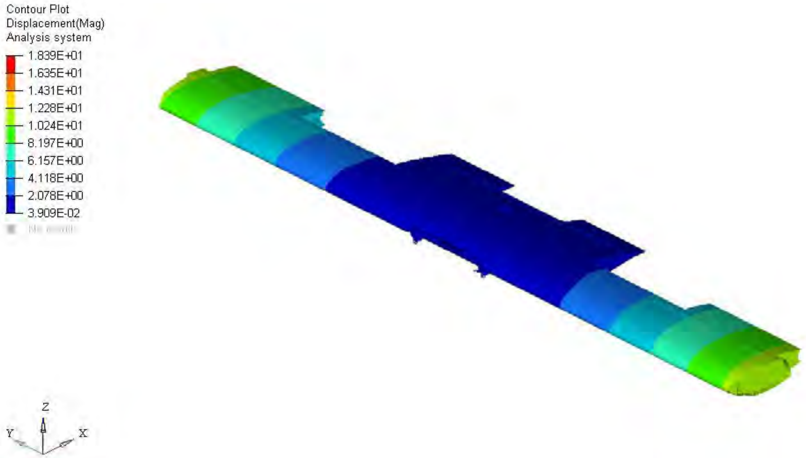
Animated Gif (please see in presentation mode)

3. Assessment of the wing-fuselage link loads
4. Assessment of wing strains/stresses in the remaining portion

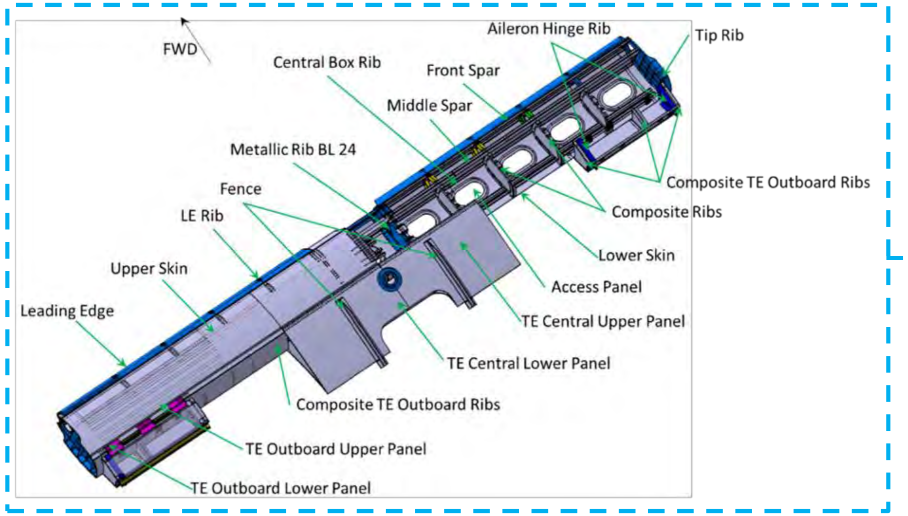
Rigid Links Check

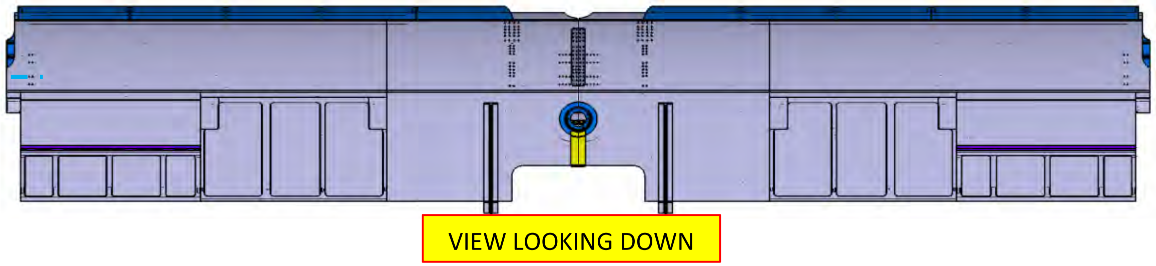
Link ID	LINK POSITION	ELEMENT ID	Stage 3 – Loop1 LOADS, lbf	Stage 4 LOADS, lbf
1	Fwd Lateral	64810	1623	-68
2	Aft Lateral	64811	-1600	67
3	LHS Fwd Vert	64813	-6643	-161
4	LHS Aft Vert	64814	-19080	-944
5	LHS Aft Drag	64815	1083	-46
6	RHS Fwd Vert	64816	-4889	-193
7	RHS Aft Vert	64817	-17550	-943
8	RHS Aft Drag	64818	-1116	47

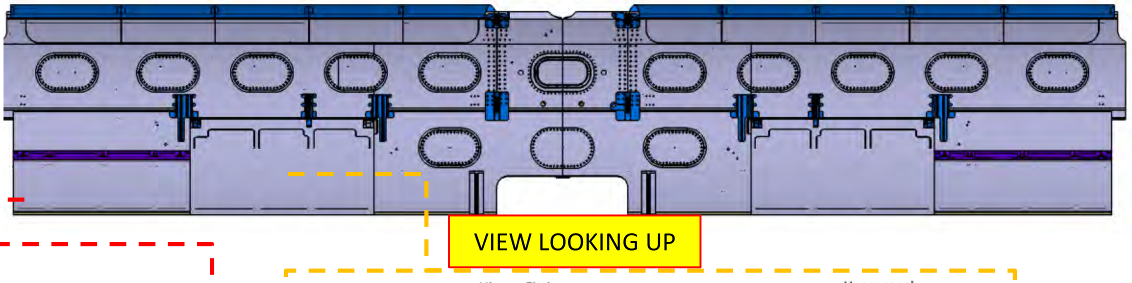


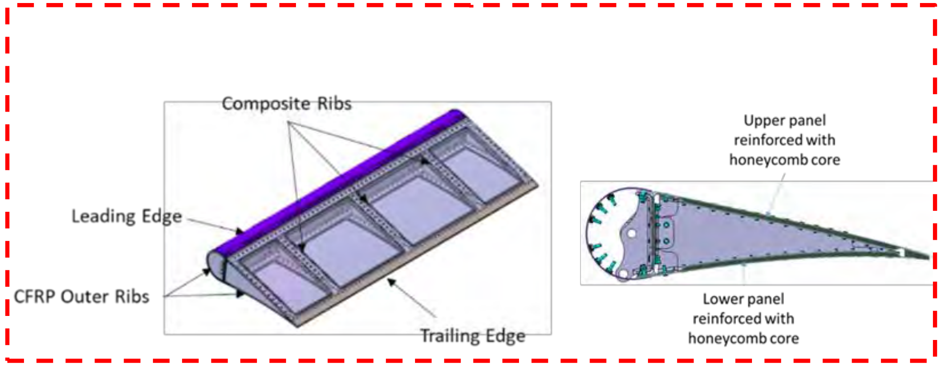


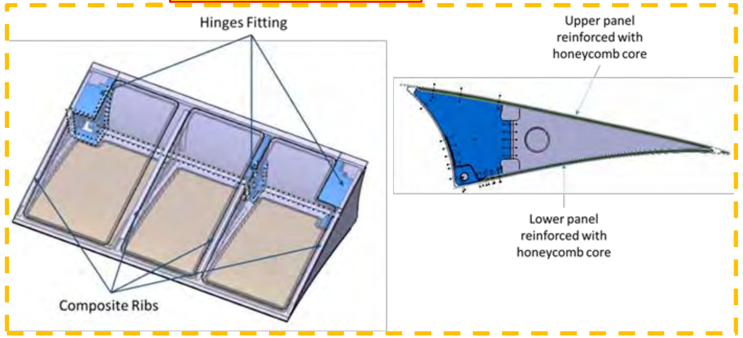
Digital Mock Up







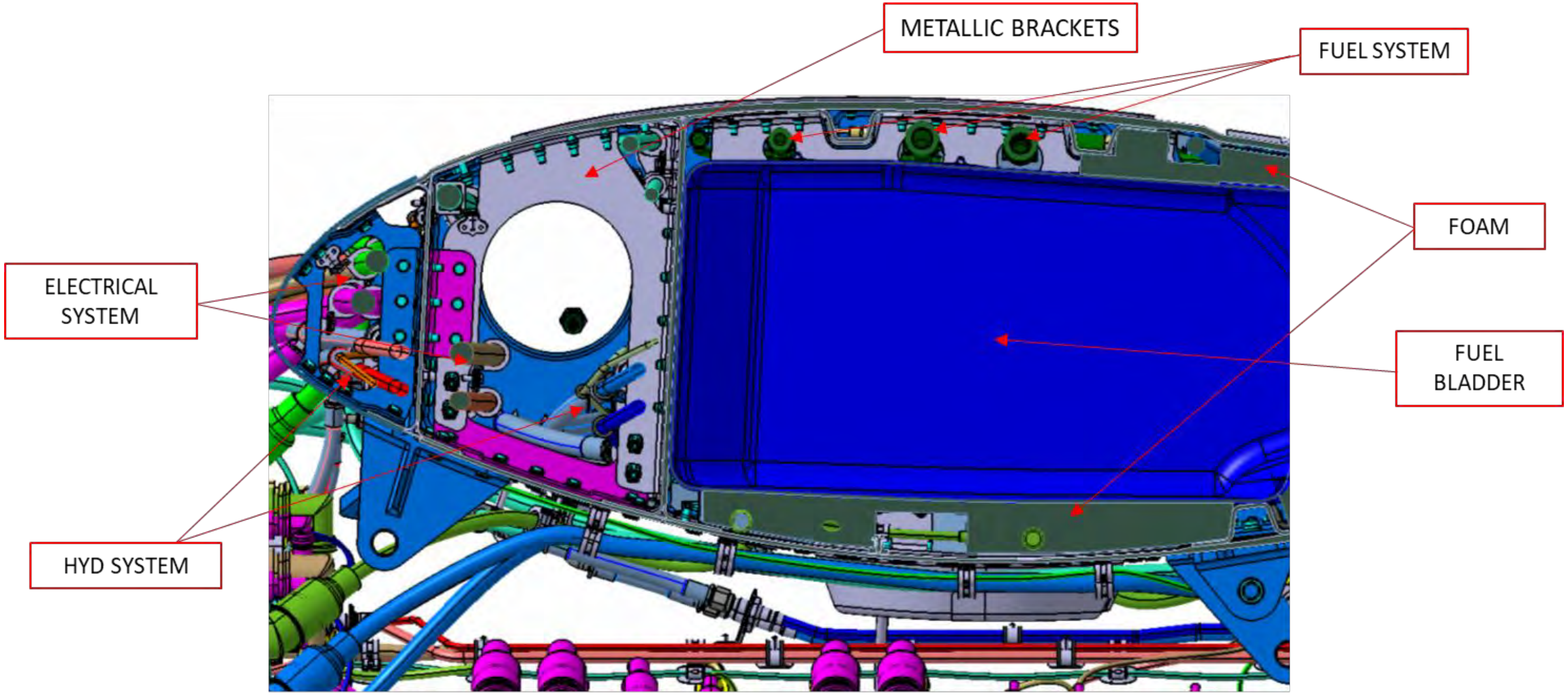




Wing and Moveable surfaces structures are made with an already certified composite material which, against the lighting strike, has shown a good behaviour without any additional protection (i.e. copper mesh).
Metallic leading edge and ribs, together CFRP electrical conductivity, should be adequate for electrical bonding requirements

Digital Mock Up

TYP SECTION



Infos

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