Il Ciclo di Vita dei Materiali Compositi

16 APRILE 2016, NAPOLI

MAGNAGHI AERONAUTICA SpA

Certificazione e Controlli non Distruttivi

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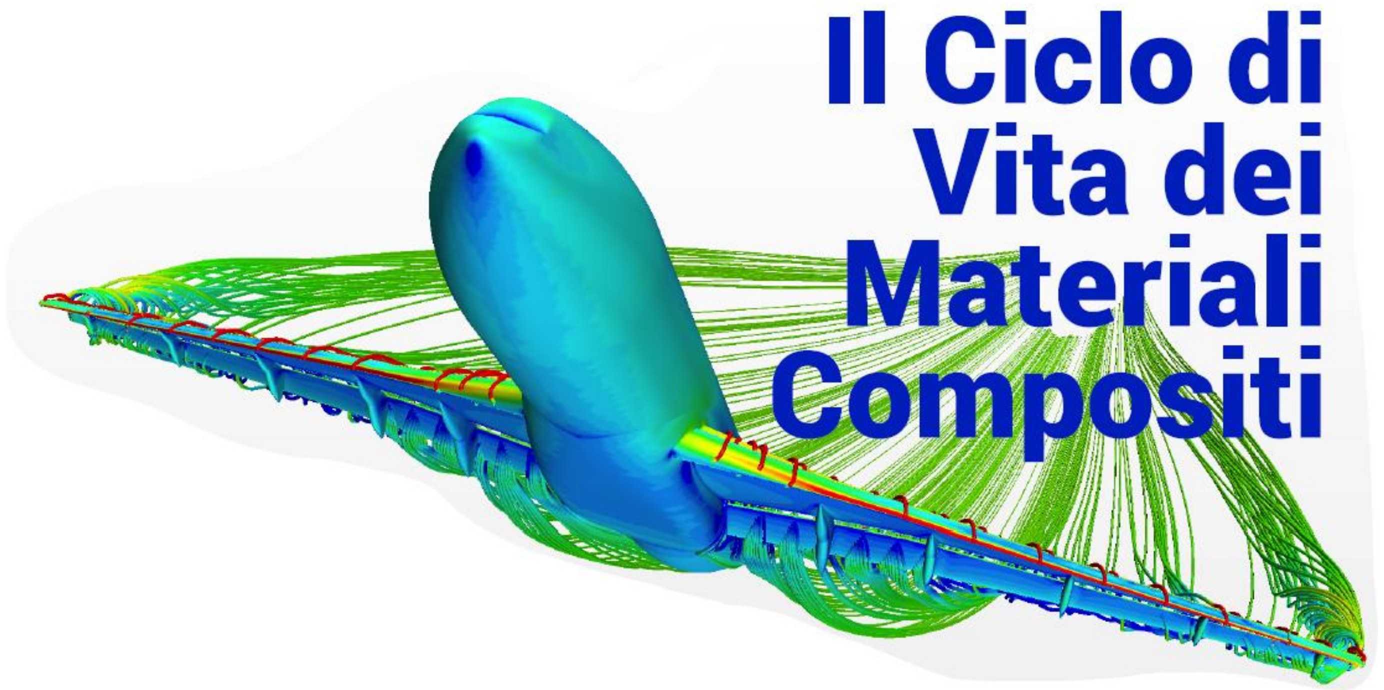
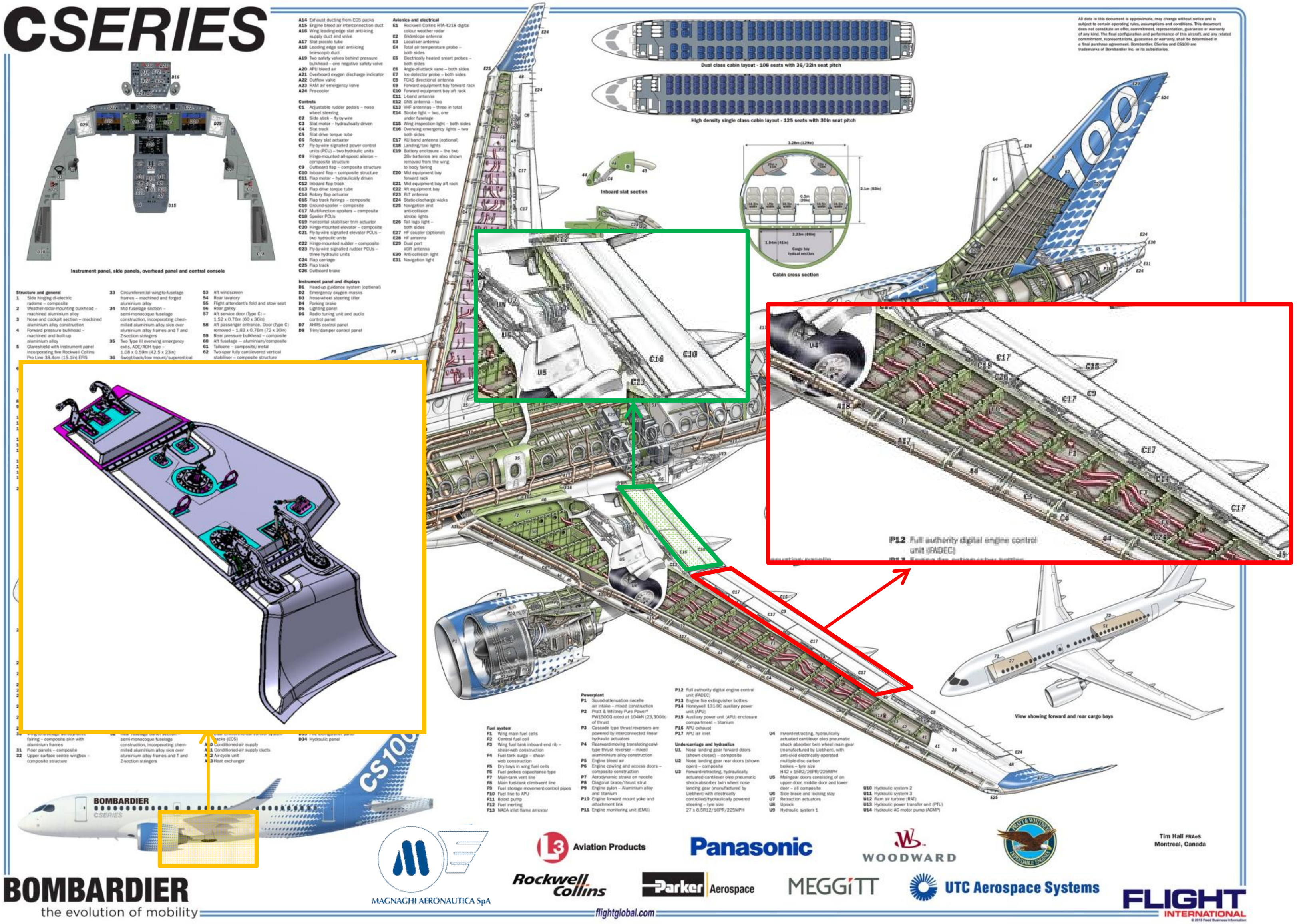


Keywords:
- Composite material certification
- Structure certification
- Dynamic analysis
- Non destructive inspection (NDT)

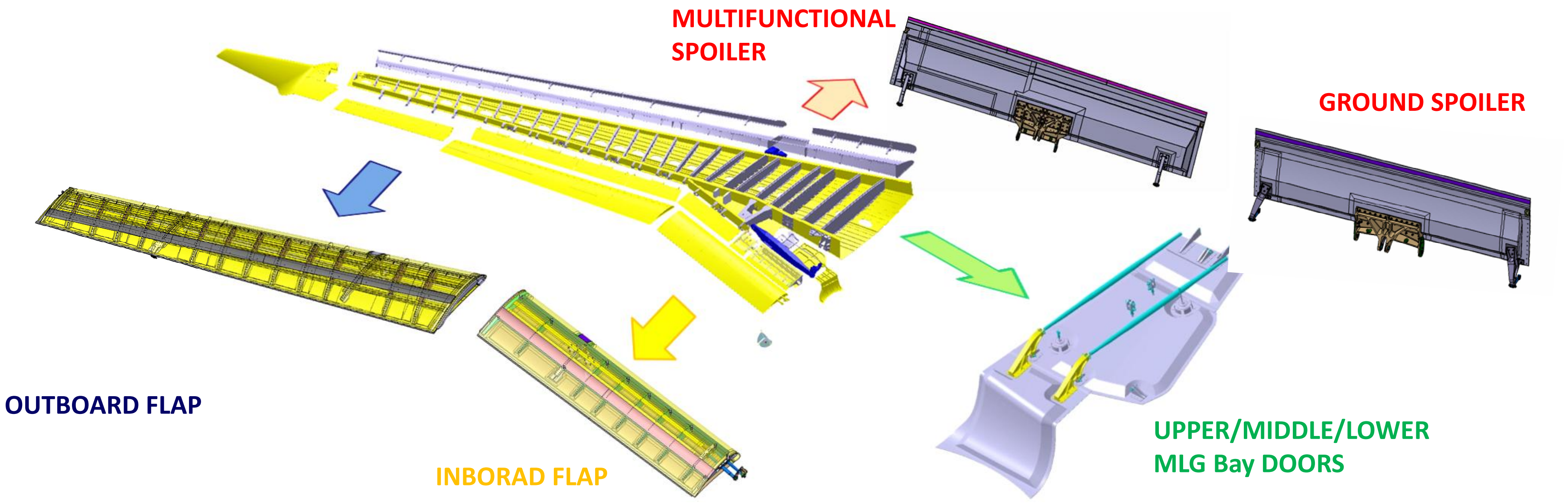
Certificazione e Controlli non Distruttivi



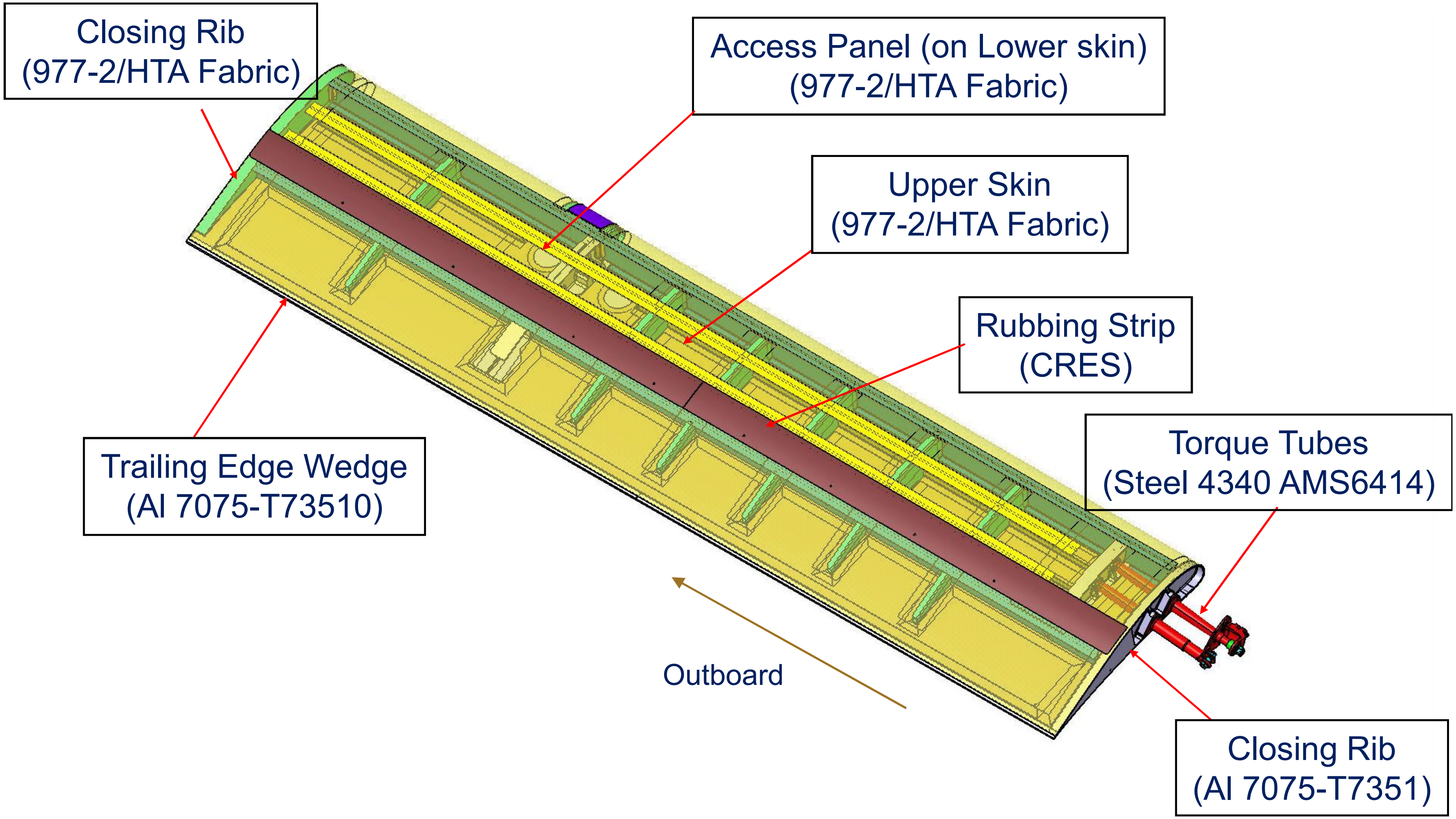
Certificazione e Controlli non Distruttivi

Magnaghi is **Bombardier Aerospace** TIER1 **Supplier** for CSERIES program (CS100 and CS300) providing the following fully qualified CFRP primary structure components:

— LH/RH Inboard Flaps
— LH/RH Outboard Flaps
— LH/RH Ground Spoilers
— LH/RH Multifunctional spoilers 8-off (4 off LH – 4 off RH)
— MLG Upper-Middle-Lower Doors



Inboard Flap Overview – “Baseline” Architecture



Closing Rib
(977-2/HTA Fabric)

Access Panel (on Lower skin)
(977-2/HTA Fabric)

Upper Skin
(977-2/HTA Fabric)

Rubbing Strip
(CRES)

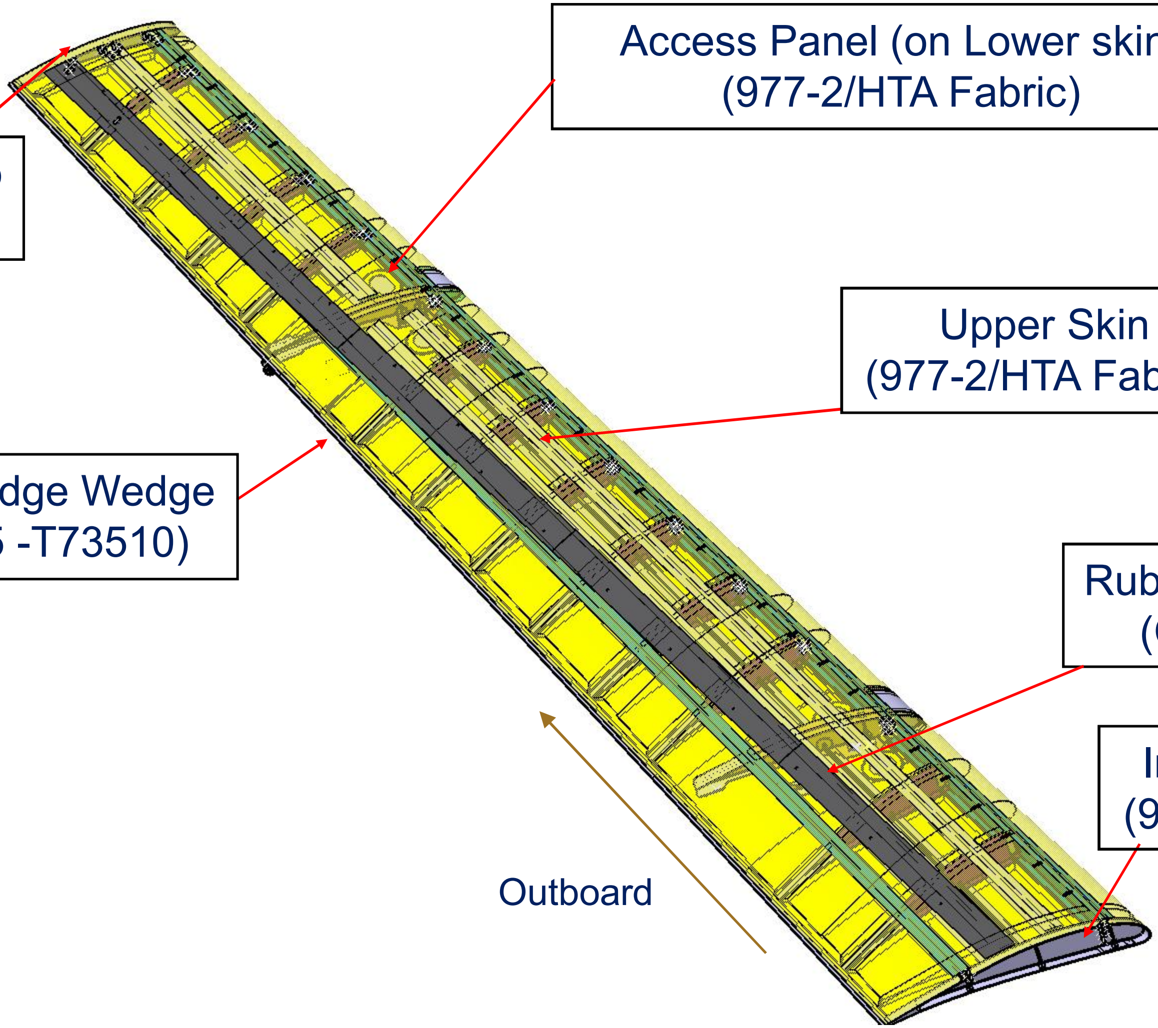
Torque Tubes
(Steel 4340 AMS6414)

Trailing Edge Wedge
(Al 7075-T73510)

Outboard

Closing Rib
(Al 7075-T7351)

Outboard Flap Overview – “Baseline” Architecture



Access Panel (on Lower skin)
(977-2/HTA Fabric)

Out’b Closing Rib
(Al 7075 -T7351)

Upper Skin
(977-2/HTA Fabric)

Trailing Edge Wedge
(Al 7075 -T73510)

Rubbing Strip
(CRES)

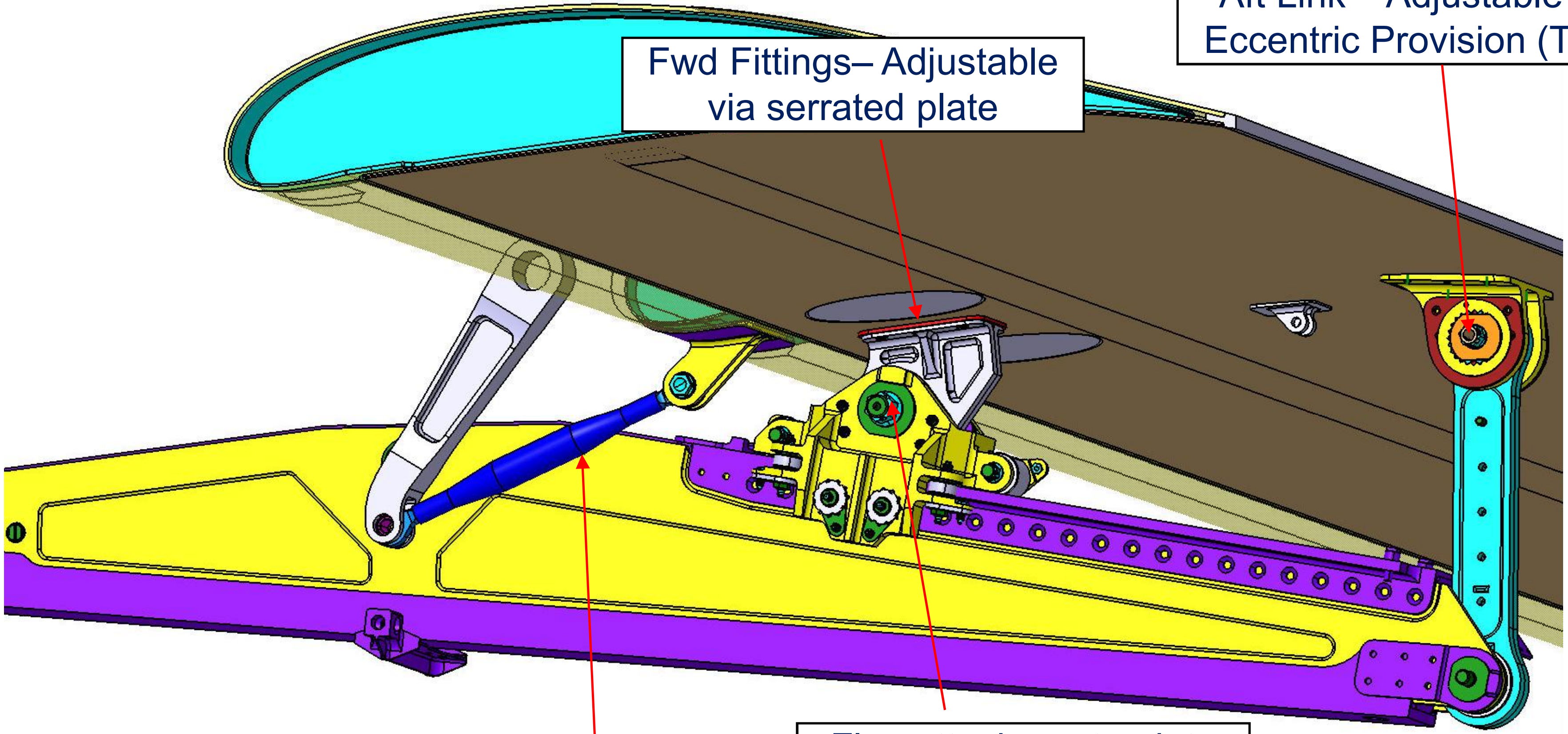
Inb’d Closing Rib
(977-2/HTA Fabric)

Outboard

Inboard Flap Overview – Rigging

* Rigging Required to Achieve Aero smoothness Criteria

FLAP TRACK #2 Schematic Section



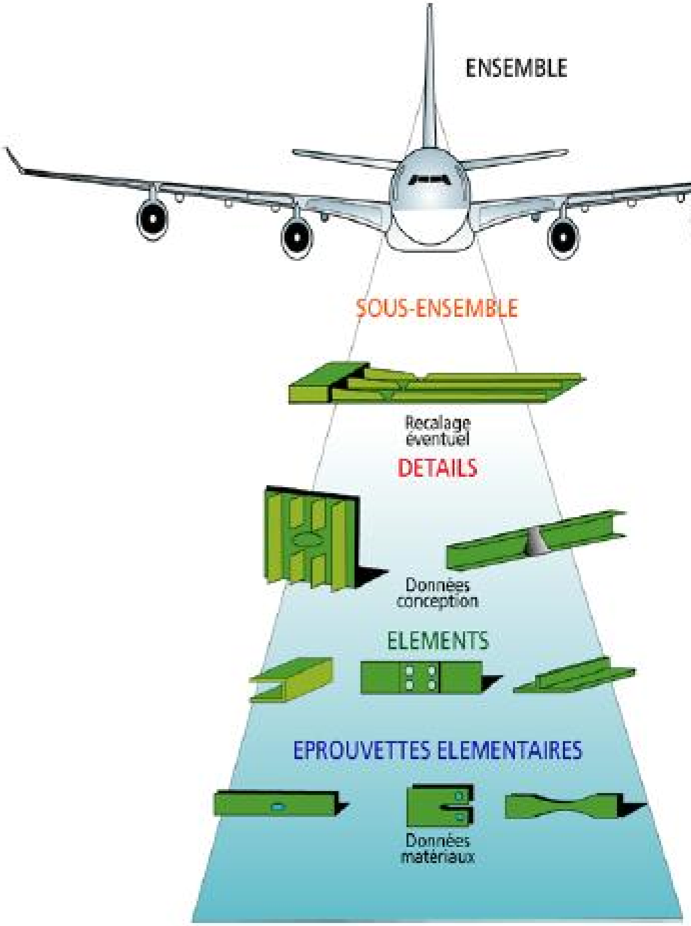
Aft Link – Adjustable via Eccentric Provision (TBD)

Fwd Fittings– Adjustable via serrated plate

Flap – Adjustable Link Rod

Flap attachment point– Adjustable via Eccentric Provision (TBD)

Certification Blocking Approach



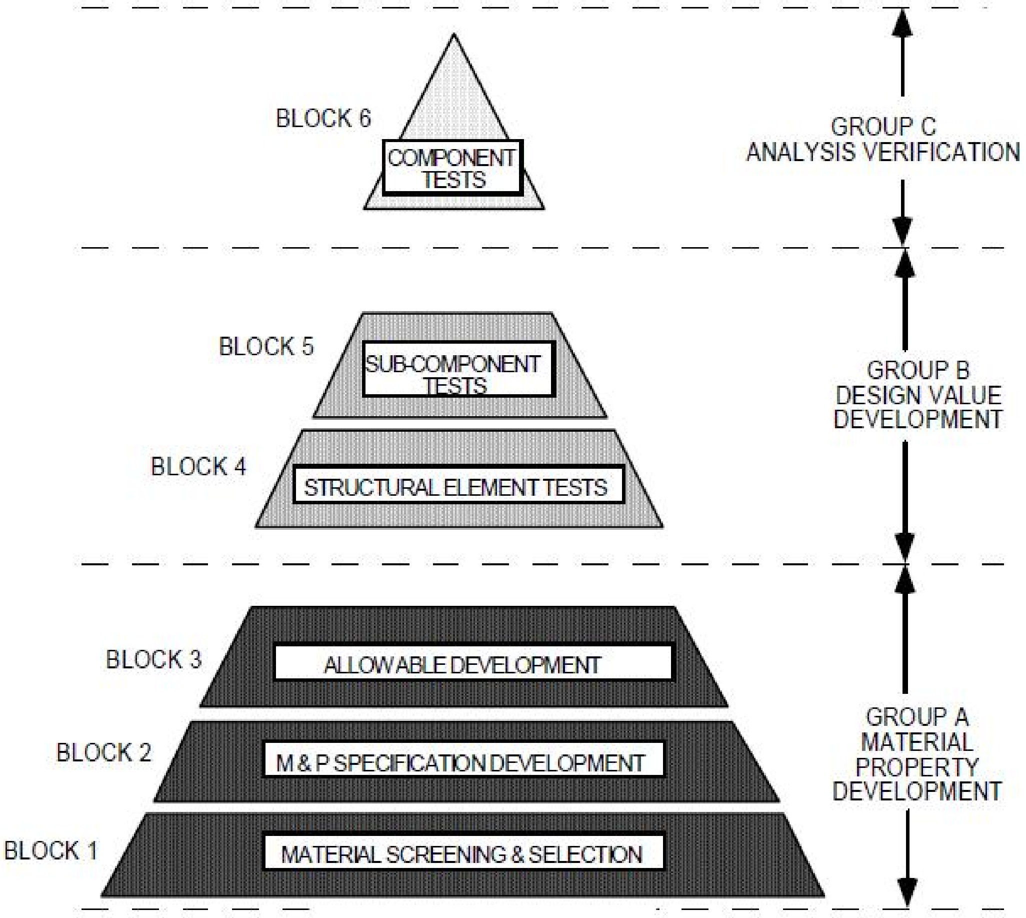
- Final checking by integration of all the parameters
- Compliance with regulatory requirements

- Risk mitigation
- Sizing preliminary checking
- Assessment for future developments

- Generation of allowables for non generic design features, or details showing low accessibility to calculation

- Generation of allowables for materials or generic design features

Certification Blocking Approach from “field” point of view



The pyramid of tests, Why more tests with composite materials ?

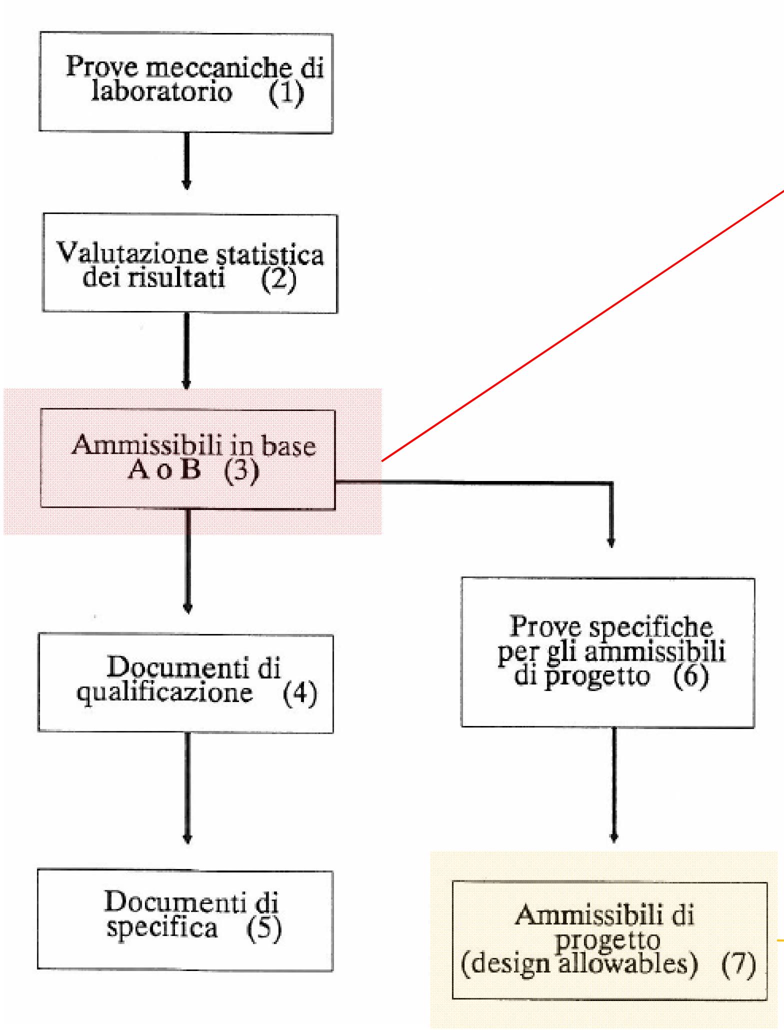
- **Low accessibility to calculation**, then need to generate design values through complex test articles.

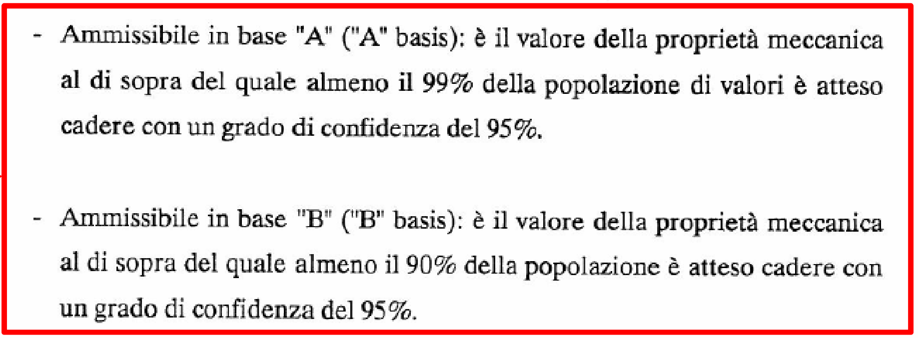
- **Sensitivity to environment**, then need to duplicate some tests in order to derive the ageing related knock down factors.

- **Material anisotropy**, then need to increase the test matrix at the coupon level to investigate various stacking sequences.

- **Higher mechanical property variability than for metals**, then need to increase the sample size in order to lower the knock down factors imposed in the derivation of the allowables (e.g. B values).

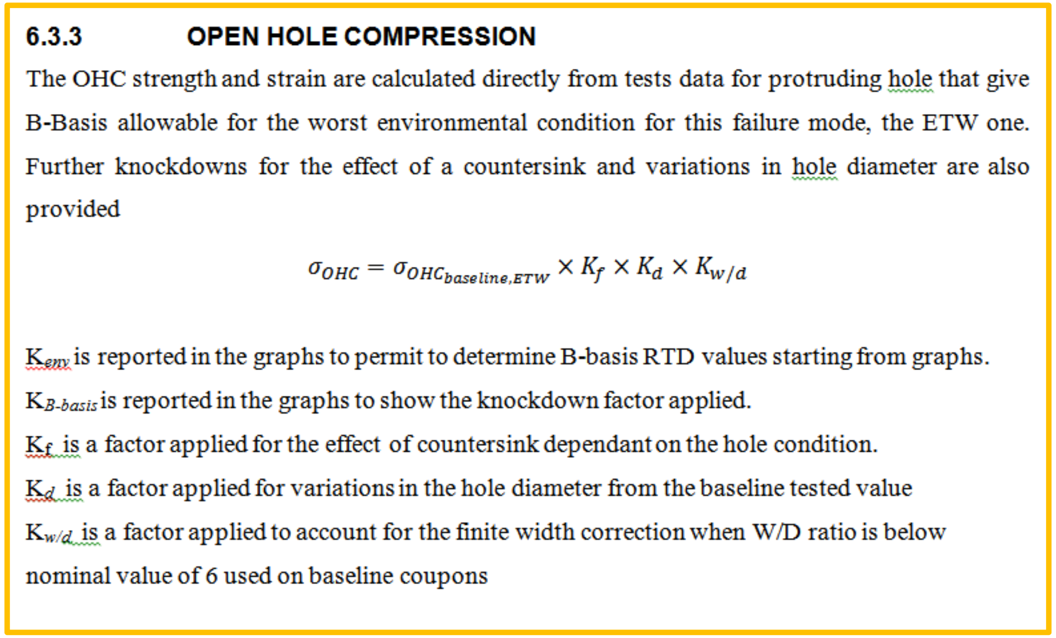
Allowable





- Ammissibile in base "A" ("A" basis): è il valore della proprietà meccanica al di sopra del quale almeno il 99% della popolazione di valori è atteso cadere con un grado di confidenza del 95%.

- Ammissibile in base "B" ("B" basis): è il valore della proprietà meccanica al di sopra del quale almeno il 90% della popolazione è atteso cadere con un grado di confidenza del 95%.



6.3.3 OPEN HOLE COMPRESSION

The OHC strength and strain are calculated directly from tests data for protruding hole that give B-Basis allowable for the worst environmental condition for this failure mode, the ETW one. Further knockdowns for the effect of a countersink and variations in hole diameter are also provided

$$\sigma_{OHC} = \sigma_{OHC_{baseline,ETW}} \times K_f \times K_d \times K_{w/d}$$

K_{env} is reported in the graphs to permit to determine B-basis RTD values starting from graphs.

$K_{B\text{-}basis}$ is reported in the graphs to show the knockdown factor applied.

K_f is a factor applied for the effect of countersink dependant on the hole condition.

K_d is a factor applied for variations in the hole diameter from the baseline tested value

$K_{w/d}$ is a factor applied to account for the finite width correction when W/D ratio is below nominal value of 6 used on baseline coupons

Allowable

Basic material allowable, are developed at the laminate level, using MIL-HDBK-17 statistical procedures:

- **Unnotched**
- **Filled-hole**
- **Open-hole**
- **Representative laminates**
- **Five to 16 batches**
- **Environmental effects accounted for with factors based on ratio of average values at environmental and room temperatures**

Allowables

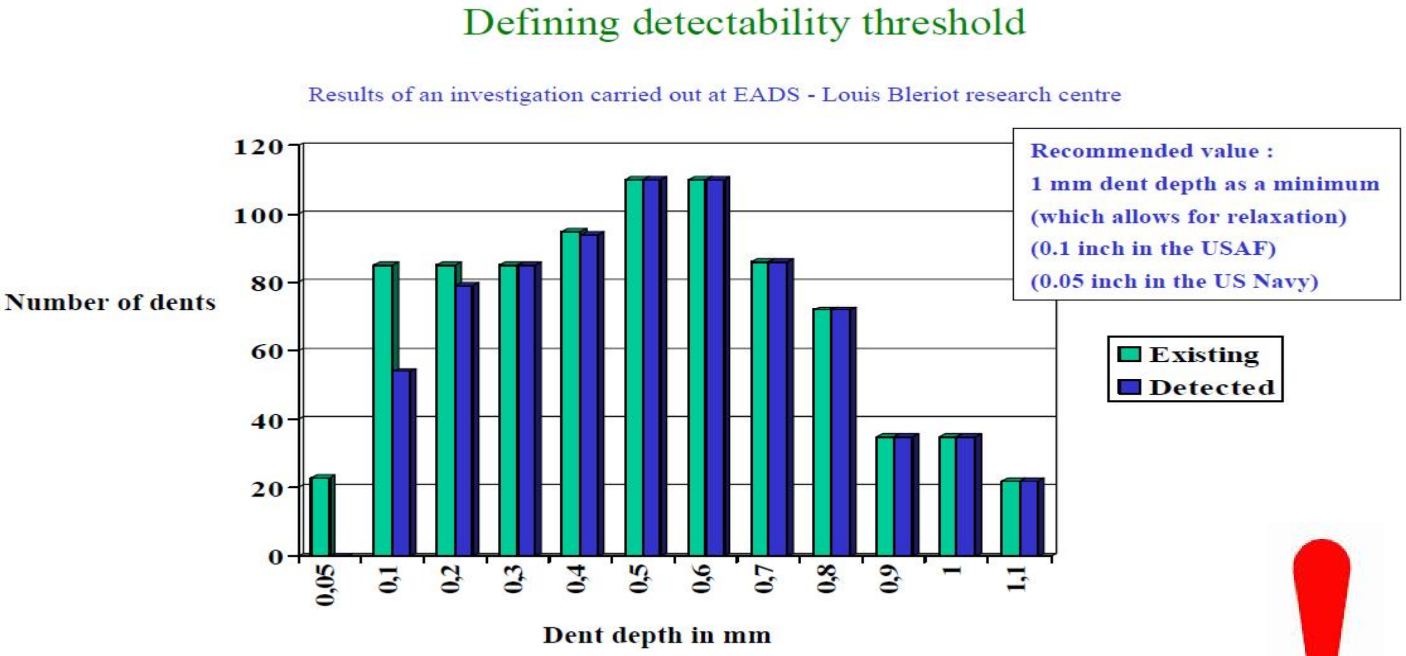
Design values test database includes:

- Coupon, elements, and subcomponents specimens
- Variations of temperature and moisture
- Variation within the manufacturing specification acceptance limits
- Laminates, effects of holes, fasteners, and environments representative of the C-Series structure and environment
- For design values derived from element and coupon level tests, average test data is calculated and a typical value is derived. Typical values are then reduced to get design values
- Design values derived from subcomponent tests are set at or below the test data

Up today for the C SERIES PROGRAM more than 1000 coupons have been tested. Additional test are still in progress (design modification and weight reduction)

DAMAGE IMPACT ALLOWABLES

ACJ 25 603 § 5.8 : It should be shown that impact damage that can be realistically expected from manufacturing and service, but not more than the established threshold of detectability for the selected inspection procedure, will not reduce the structural strength below ultimate load capability.


Defining detectability threshold

Results of an investigation carried out at EADS - Louis Bleriot research centre

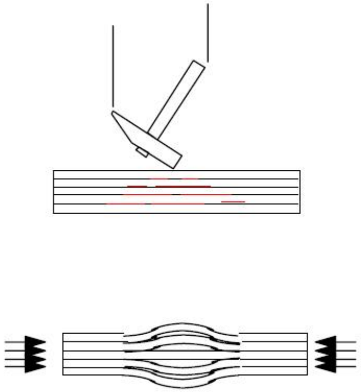
Recommended value :
1 mm dent depth as a minimum
(which allows for relaxation)
(0.1 inch in the USAF)
(0.05 inch in the US Navy)

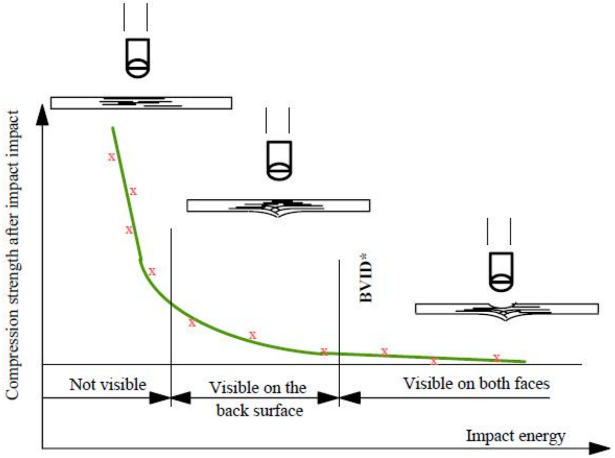
-the maximum size that a normal inspector may overlook?

Additional tests have been performed on coupons to establish the strength and strain capability when impacts giving an indentation greater then BVID, more than 1.5 mm

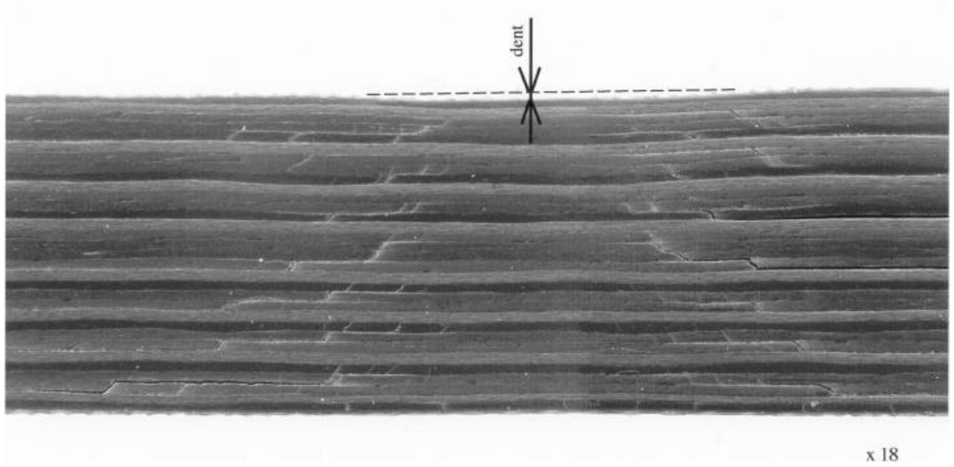
COMPOSITE SENSITIVITY TO LOW VELOCITY IMPACT DAMAGE

LARGE STATIC STRENGTH REDUCTIONS MAY OCCUR BEFORE DAMAGE BECOMES DETECTABLE





* BVID = Barely Visible Impact Damage



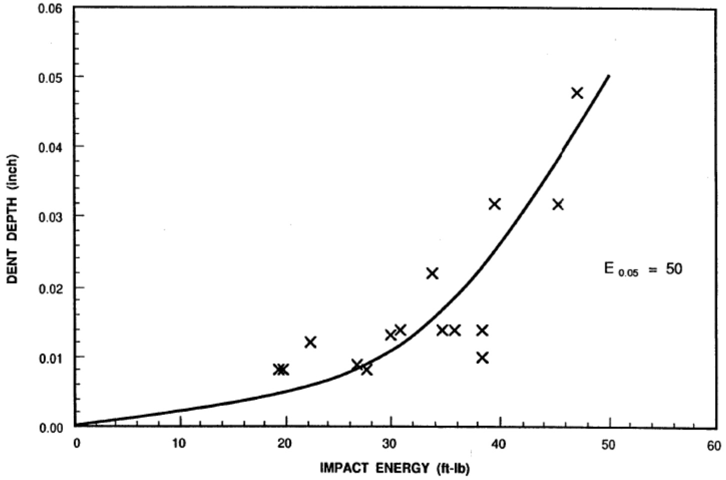


Figure 11. Relationship Between Dent Depth and Impact Energy for 0.20 ≤ t ≤ 0.25 inch.

CATEGORY 1 DAMAGE

Category 1 damage covers potential defects that can occur from the composite manufacturing process and Barely Visible Impact Damage (BVID) from assembly and in service. Category 1 Damage should cover all potential inherent defects in the structure, together with damage that is not expected to be detected, and is introduced into the test article for all static and composite fatigue testing.

CATEGORY 2 DAMAGES

Introduce Visible Impact Damage (VID), increased scratch depths and missing fasteners to the structure. Category 2 impacts are applied to specified locations in the composite flap structure to create VID up to cut-off energies (100 joule typically) specified for the C-series programme.

CATEGORY 3 DAMAGE

Introduced to the structure for the residual strength check, up to limit load with ECLF, and has been targeted at areas of high strain

CATEGORY 4 DAMAGE

discrete source damage is introduced to the structure required based on threat assessment and DSD component test results. It is used to test the structure to 70% limit load or DSD loads.

INCLUSIONS /DEFECT /SCRATCH

Inclusions are introduced throughout the outboard flap composite structure. It is intended to use inclusions to substantiate the effects of voids, delamination or porosity defects.

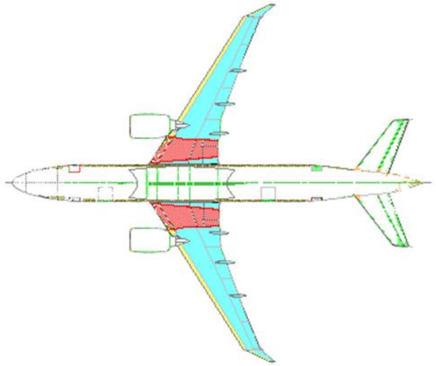
BARELY VISIBLE IMPACT DAMAGE (BVID) (CATEGORY 1)

Composite structures shall be capable of sustaining BVID at Ultimate Load to the Design Service Goal without temporary or permanent repair.

The impact energy cut-off values for the control surfaces are based on deterministic approach, generally from 30 to 60 J.

The dent depth thresholds of detectability for BVID are:

- 1mm applied under Detailed Visual Inspection (DVI)
- 2.5mm General Visual Inspection (GVI)



Additional Category 1 Damage Types:

Composite structures shall be capable of sustaining the additional damage types <u>at Ultimate Load</u> to the Design Service Goal without temporary or permanent repair.

Scratch damage – typ max 4.00” scratch in any direction (1 ply deep about)

VISIBLE IMPACT DAMAGE (VID) (CATEGORY 2 & 3)

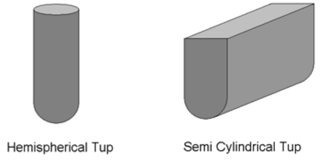
Composite structures shall be capable of sustaining external VID at Limit load and for a period of operation before detection. Categories 2 & 3 are damage levels which exceed BVID

Category 2 damage must not degrade the structure below “k x Limit Load” capability.

Category 3 damage must not degrade the structure below Limit Load capability but Level 2 Damages, less detectable than Level 3 must sustain the ability to carry limit load between more detailed maintenance checks as they are deemed to be less detectable.

Hence VID can range from damages just exceeding the BVID visibility criteria up to large through penetrations

Category 2 and 3 damages are subject to an energy cut off of >=100J



The simulation of Category 2 and 3 damages will include the use of impacting equipment of different diameter tips and the use of high velocity / low mass impactors to simulate impacts caused by runway debris or hail. The effect of VID will be investigated in Levels 4 (Sub-Component and bench tests) and 5 (Full-Aircraft) Tests

VISIBLE IMPACT DAMAGE (VID) (CATEGORY 2 & 3)

ADDITIONAL CATEGORY 2 & 3 DAMAGE TYPES

Composite structures shall be capable of sustaining the additional damage types, listed below, at Limit Load between major inspections.

- Scratch damage – 4.00” scratch in any direction, up 2 two plies deep (depth dependant on cured ply thickness)
- Lightning strike – typical damage for max voltage strike on component
- Fastener damage – Missing fastener or visible mis-installation

DISCRETE SOURCES OF DAMAGE (CATEGORY 4)

These damages are not subject to energy cut offs and often have unique impact foot prints. As a result, these damages will be substantiated by analysis and specific testing at the highest levels of the testing pyramid.

An assessment of potential sizes and energies for these damages will be performed by analysis. In most instances these will be covered by specific tests or specific damages applied to Level 4 and level 5 test articles in the testing pyramid

- Tyre Burst (by Analysis)
- Impact damage – ground collision to trailing edge and flight components (by Analysis)
- Lightning Strike (by Test)
- Bird strike (by Analysis/Test)
- Rotor Disk Burst (not applicable)

IMPACT TRIAL TEST SETUP

- Two Impactors have been used
- Manual gun impactor, capable to apply impact energies up to 110 J
- Tower impactor, capable to apply impacts energies up to 290 J

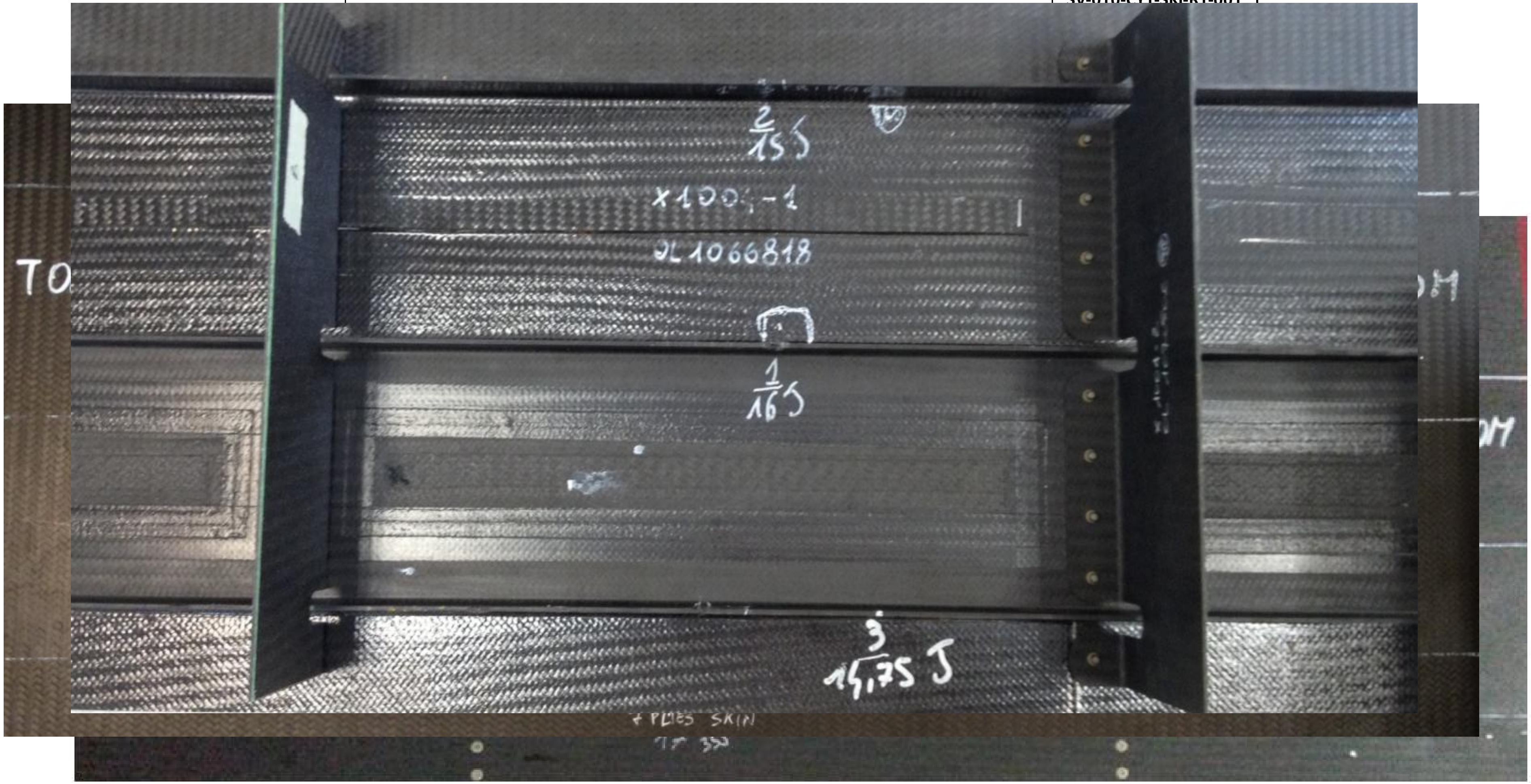
Manual Tower Impactor

Gun Impactor

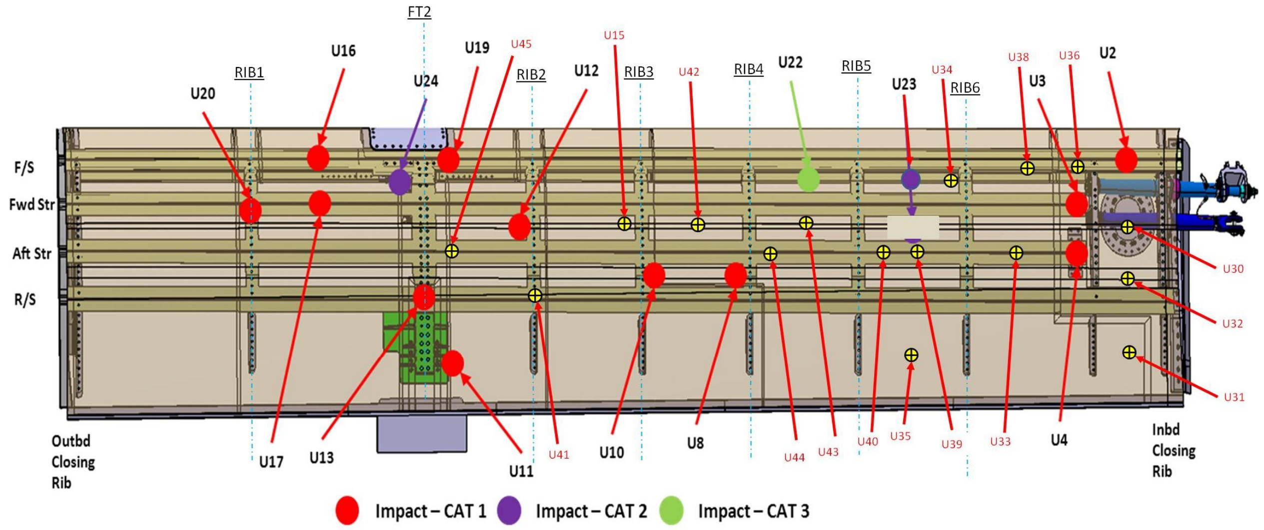
IMPACT TEST SETUP (USING CANTILEVER MACHINE)

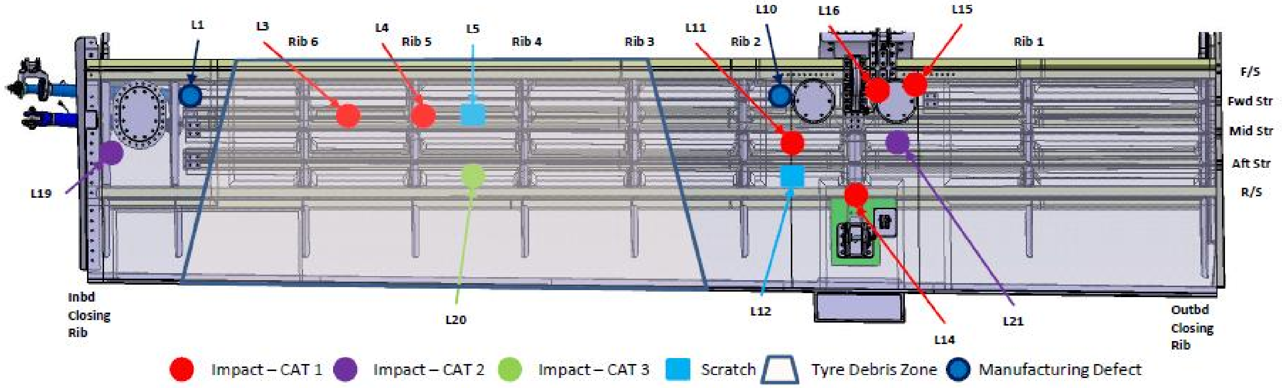
IMPACT TEST SETUP (USING GUN)

Impact Test X1004-1	OL 1066818 SV-010-CYT-SKI-RT-001

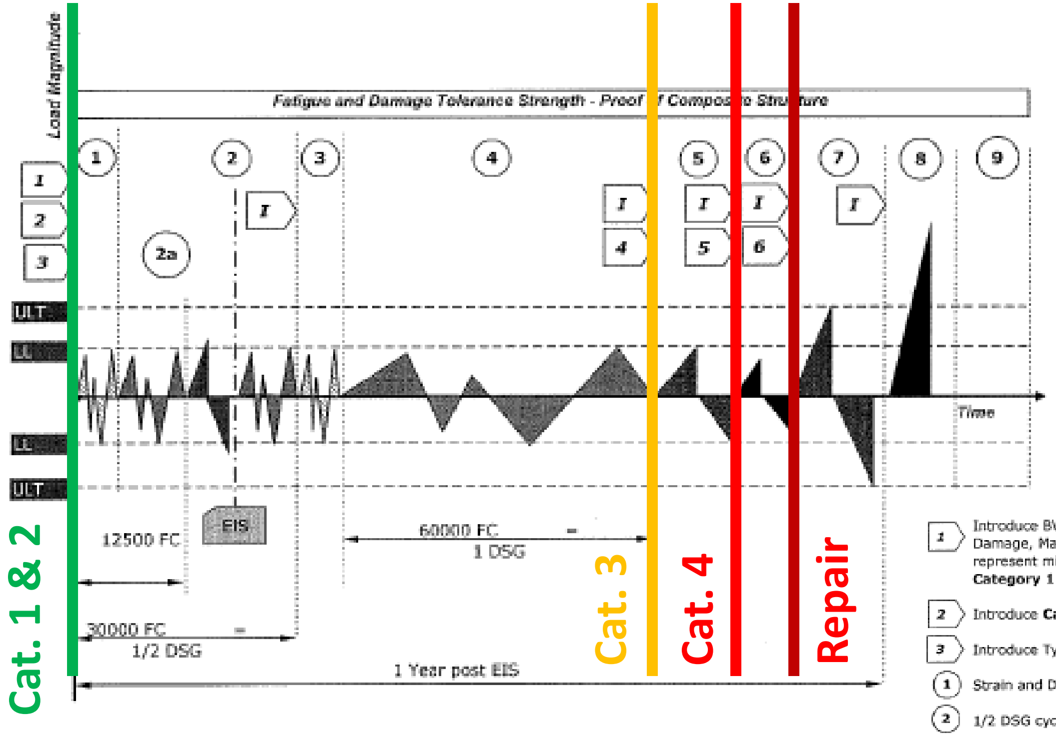


IB Flap Impact locations





STATIC AND FATIGUE TEST PLAN



1	Introduce BVID, Anticipated Lightning Strike Damage, Manuafacturing Damage/Defects to represent minimum quality production configuration - **Category 1** Damage.
2	Introduce **Category 2** Damage
3	Introduce Typical Repair
①	Strain and Deflection Survey
②	1/2 DSG cycling to 30000FC with **LEF**
(2a)	12500 FC of cycling followed by the LIMIT Load Tests with **ECLF**.
③	Strain and Deflection Survey
④	1 DSG cycling to 60000 FC with **LEF**
4	Introduce **Category 3** Damage
⑤	Residual Strength Test to LL with **ECLF**
5	Introduce Discrete Source Damage (**Category 4**) if required based on threat assessment and DSD component test results
⑥	Static Test to ~70% LL if required ("Get Home" loads)
6	**Repair** all Category 2 & Category 3 and Category 4 (if present) Damages
⑦	Ultimate Load Validation with **ECLF**
⑧	Test to Destruction
⑨	Teardown Inspection
I	Inspection

EFFECTS OF DEFECTS

Effects of manufacturing anomalies within and outside the process specification limits were evaluated in tests with coupons, elements, and subcomponents

- **Porosity**
- **Fiber waviness**
- **Delamination**
- **Ply gaps**
- **Foreign material inclusions**

Inclusions are introduced throughout the outboard flap composite structure. It is intended to use inclusions to substantiate the effects of voids, delamination or porosity defects. A double stack of Teflon inserts shall be placed in the critical parts established from stress analysis.

Two types of insert have been defined and the sizes and shapes are detailed below:

- 1.Round Dia= 0.50in thickness 0.015in
- 2.Square 0.50in x 0.50in thickness 0.015in

Topics to be addressed when presenting a certification plan to the Airworthiness Authorities

- **STRUCTURE DESCRIPTION**
- **STRUCTURAL SUBSTANTIATIONS**
- **FABRICATION METHODS**
- **QUALITY ASSURANCE**
- **AIRWORTHINESS**

This documentation will include at least :

The Certification plan (with the associated test plans)

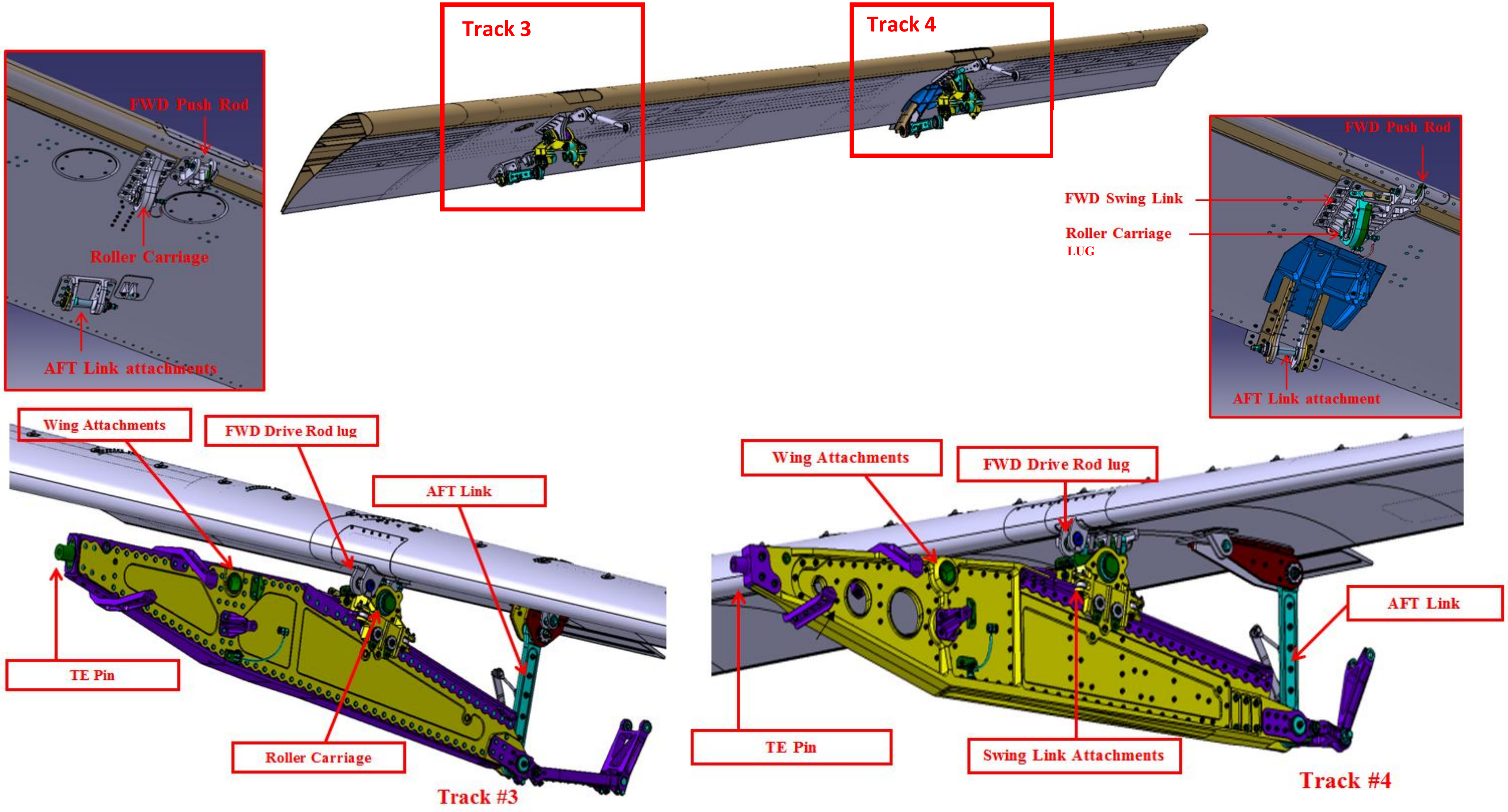
The Composite Summary Plan and Report

The Airframe Certification Documents

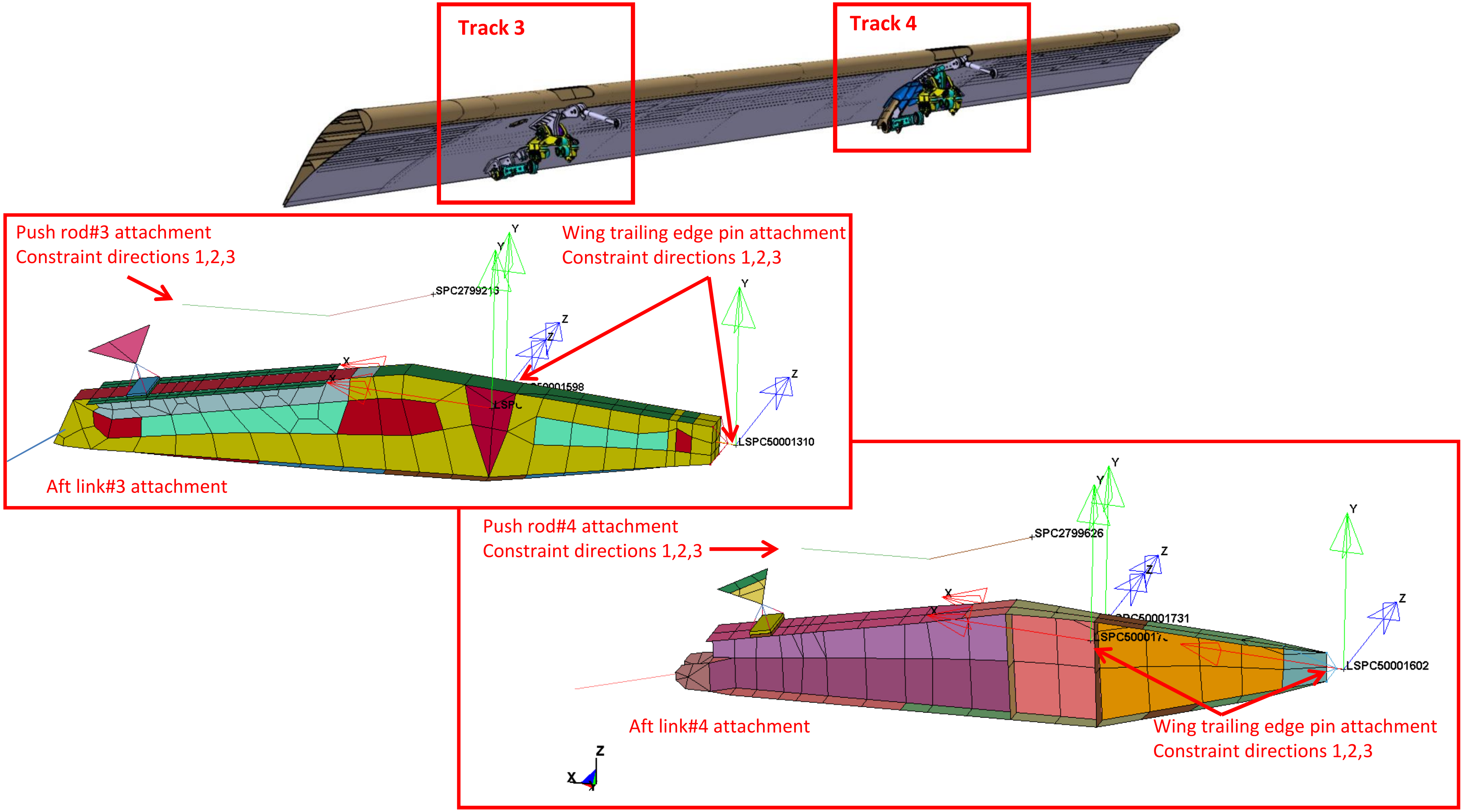
**The Composite Summary Report is the Composite Summary Plan updated with test results*

BIRD IMPACT ANALYSIS AND CERTIFICATION PROCESS

Description of Flap track attachment



FEM External Constraints



Push rod#3 attachment
Constraint directions 1,2,3

Wing trailing edge pin attachment
Constraint directions 1,2,3

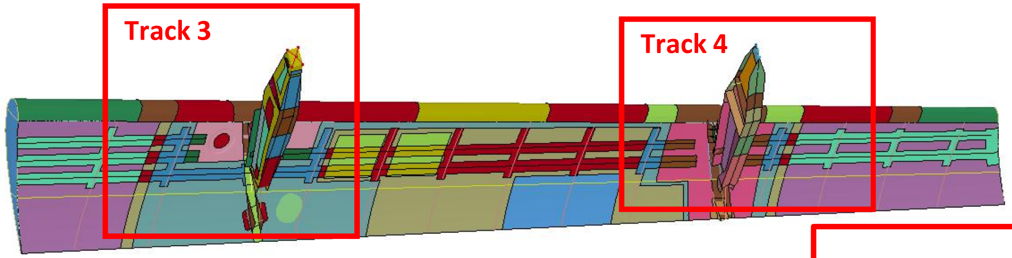
Aft link#3 attachment

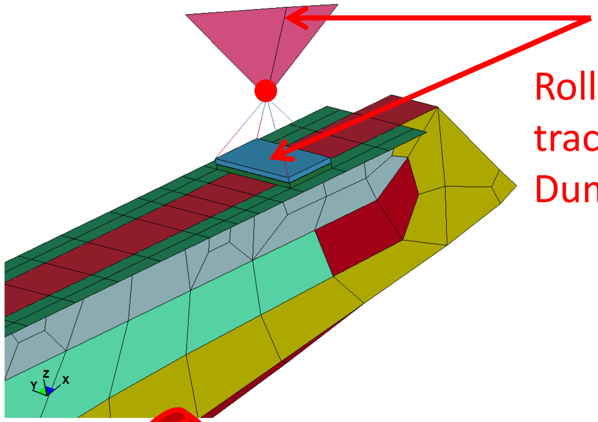
Push rod#4 attachment
Constraint directions 1,2,3

Aft link#4 attachment

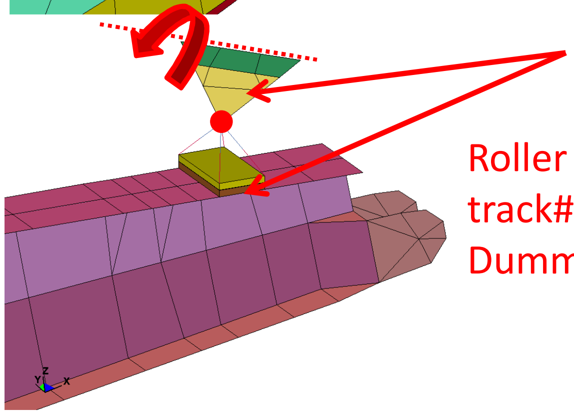
Wing trailing edge pin attachment
Constraint directions 1,2,3

Internal Constraints

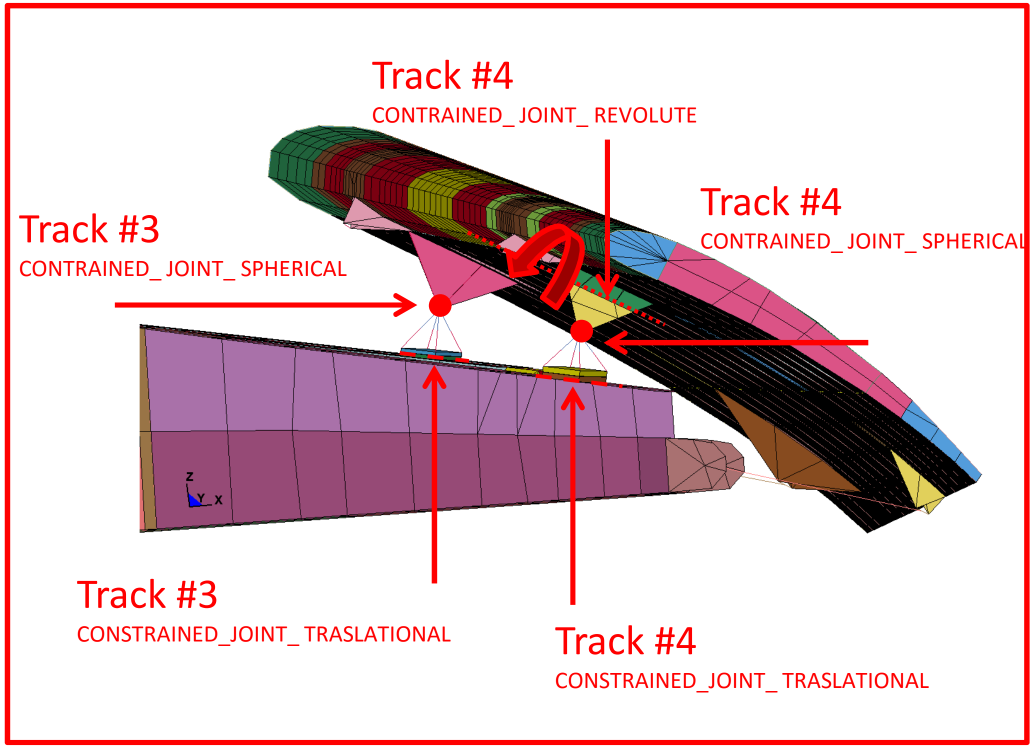




Roller carriage of track#3
Dummy Rigid Part



Roller carriage of track#4
Dummy Rigid Part



Track #4
CONTRAINED_ JOINT_ REVOLUTE

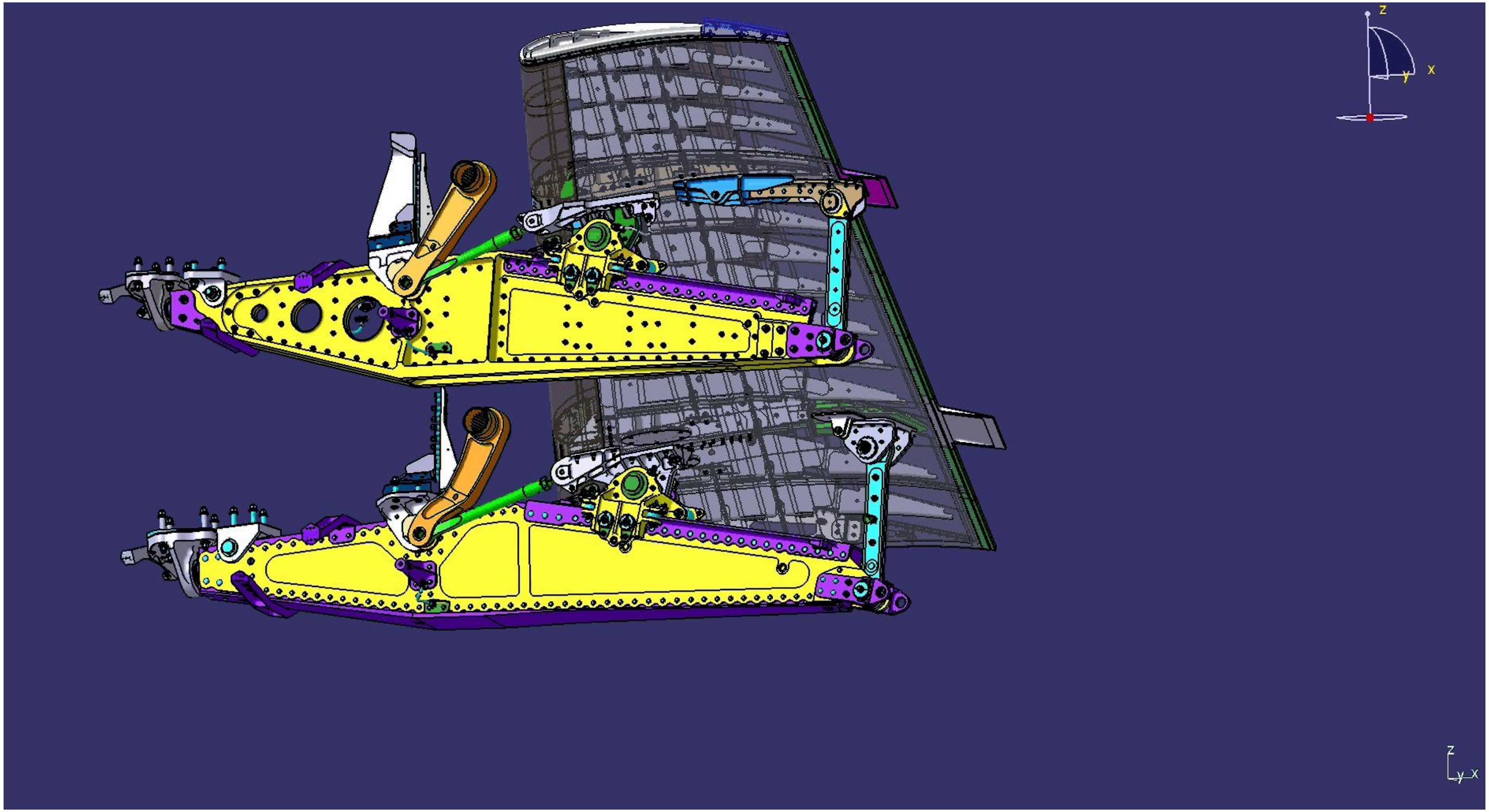
Track #4
CONTRAINED_JOINT_ SPHERICAL

Track #3
CONTRAINED_ JOINT_ SPHERICAL

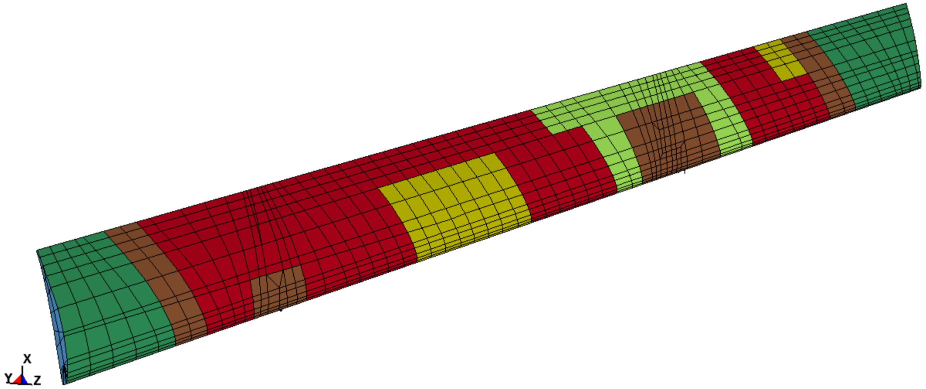
Track #3
CONSTRAINED_JOINT_ TRASLATIONAL

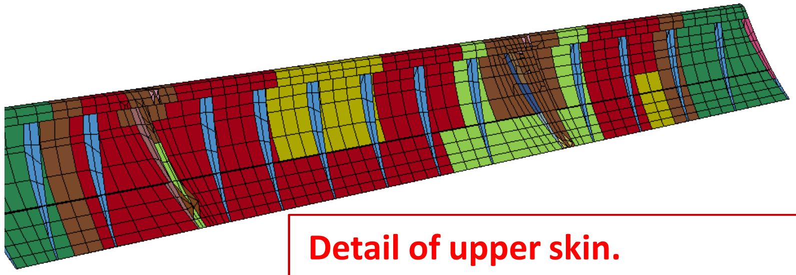
Track #4
CONSTRAINED_JOINT_ TRASLATIONAL

Flap Kinematics

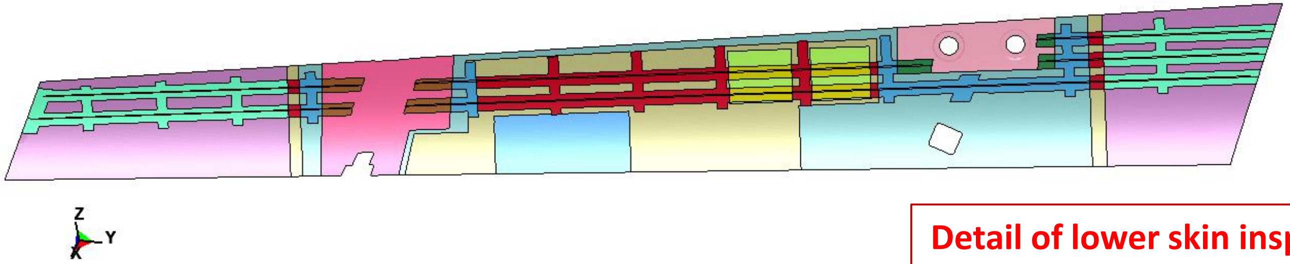


Coarse to fine mesh





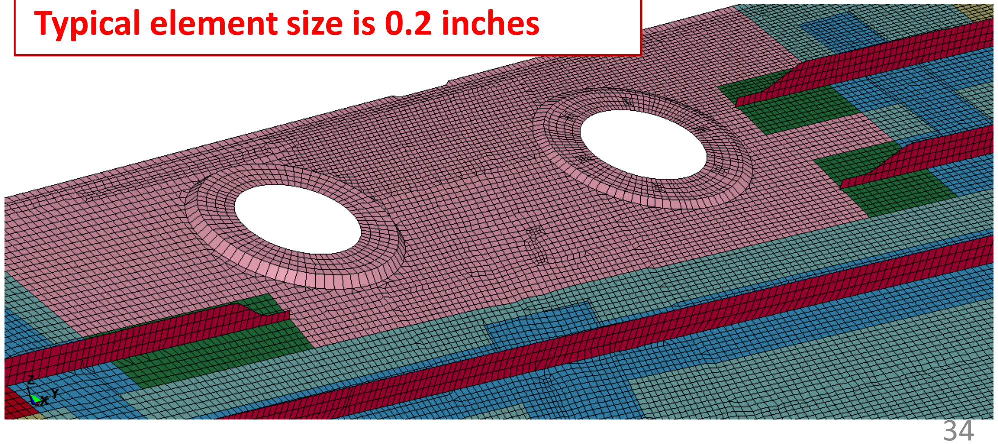
Detail of upper skin.
Typical element size is: 4 to 5'' inches



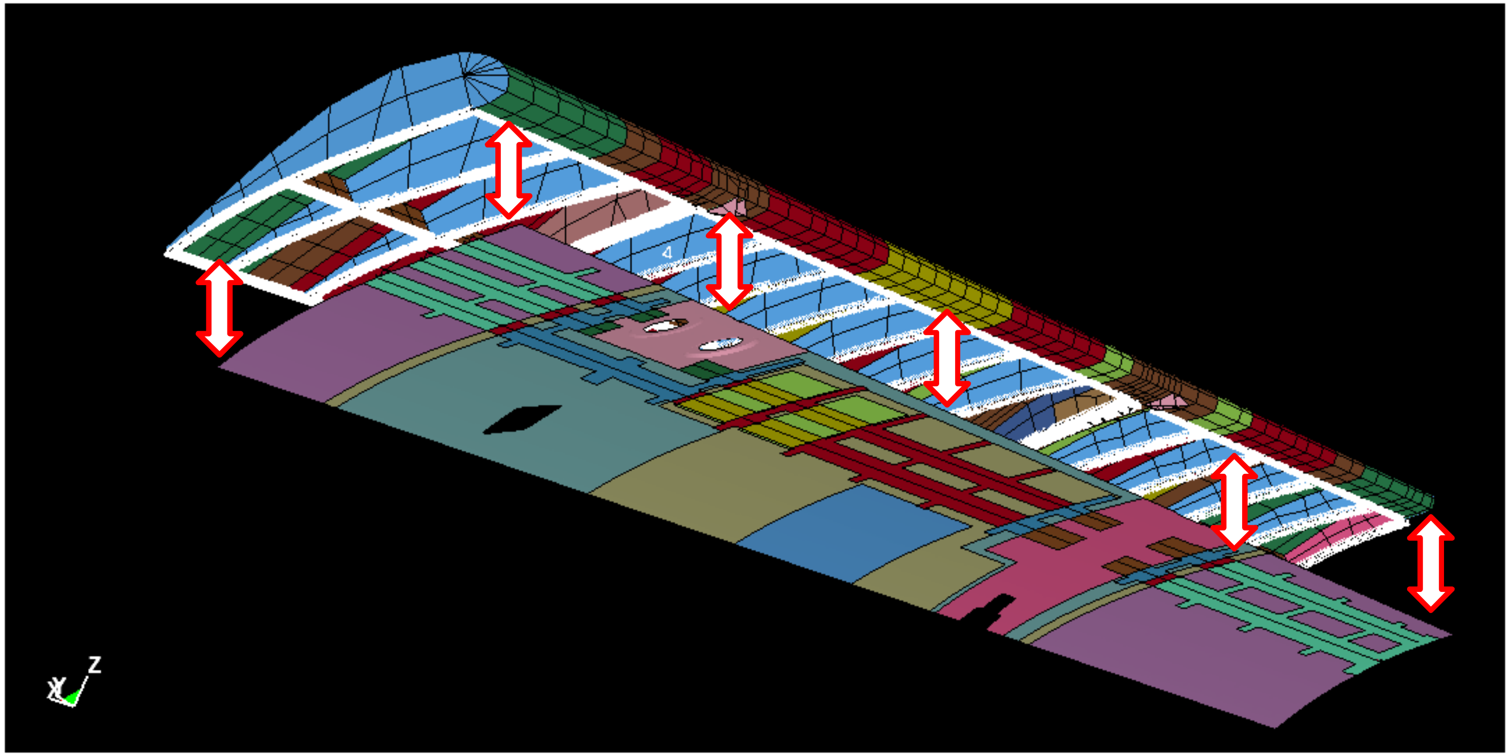
Detail of lower skin inspection holes
Typical element size is 0.2 inches

Upper skin including ribs, stringer and co-cured spars are modelled as "coarse" mesh.

Lower skin subject to impact event are meshed as "fine" and includes stringer web, inspection holes and stringer runout



Coarse to fine mesh



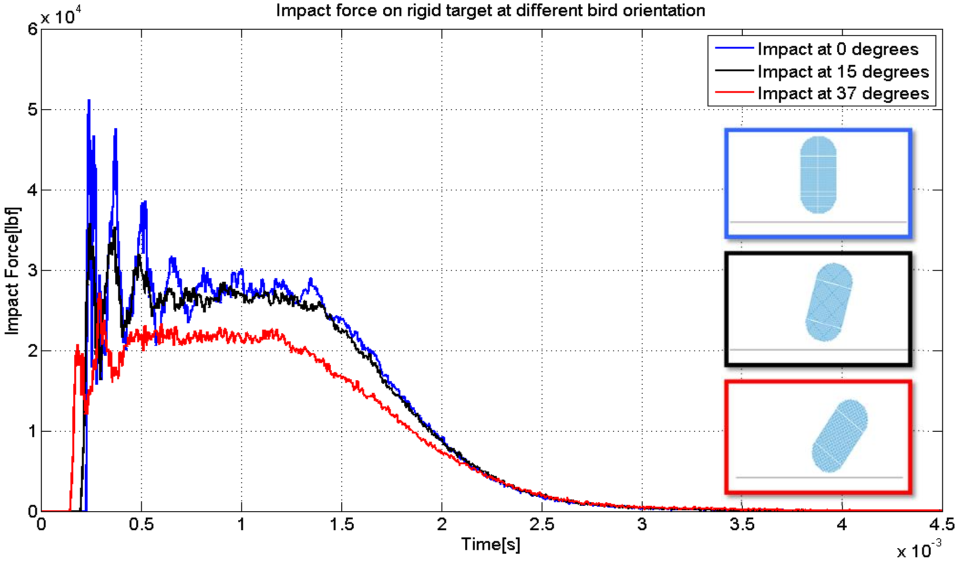
TIED_SHELL_EDGE TO_SURFACE_OFF-SET contact formulation is used to allow shear load transmission between lower skin, ribs, and spar feet.

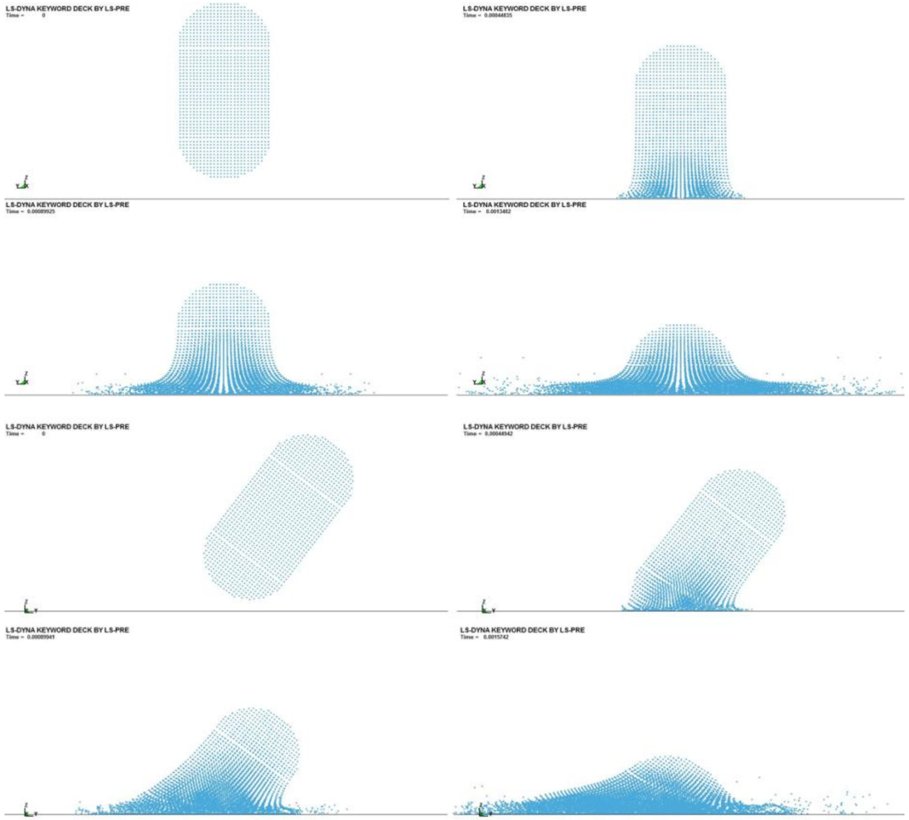
This approach allows to increase the level accuracy where a detailed investigation is required.

It ensures a very high mesh density gradient going from 5'' to 0.2''.

Calibration of bird impact model

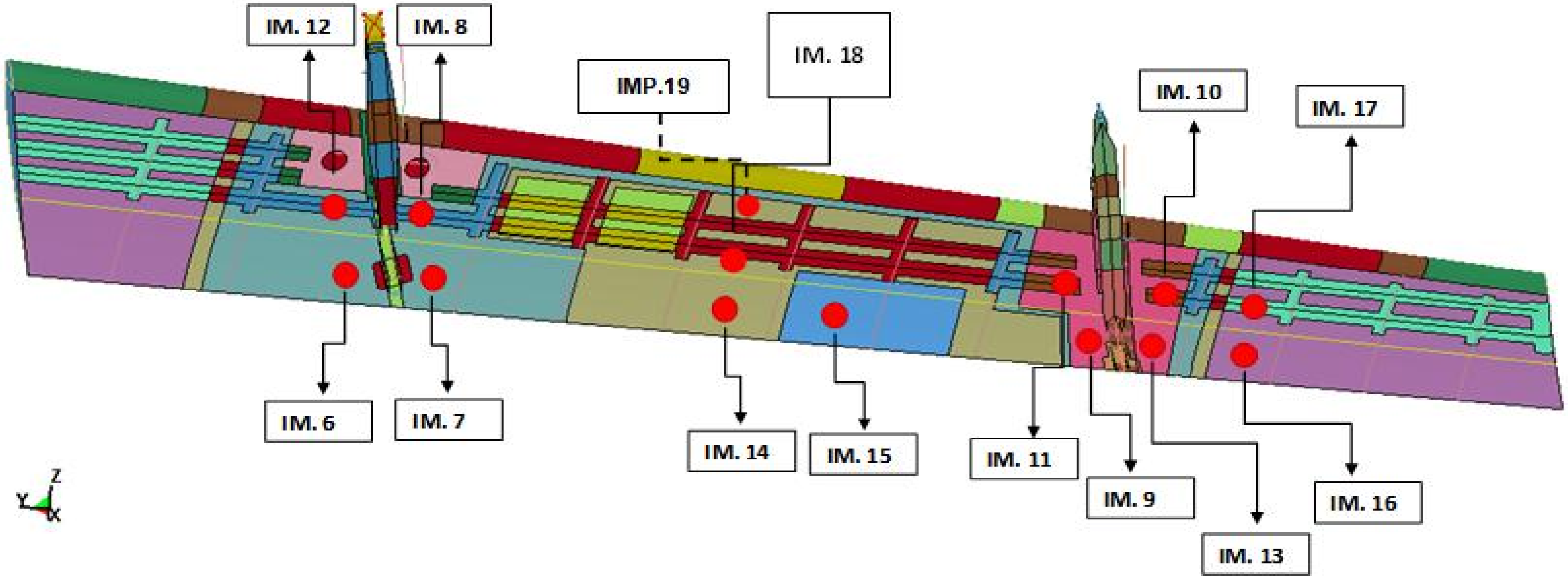
IMPACT @ 219 KTS (113 M/S)





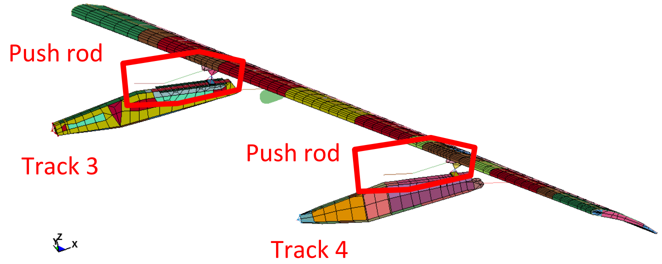
Velocity=219 Knot, Bird Mass=4 lb	Momentum Transfer [lbf]	Empirical Formula [lbf]	LS-DYNA MAT_RIGID [lbf]	LS-SYNA MAT_ELASTIC [lbf]
0°	48596	37790	51228	60199
15°	46940	36502	35776	54807

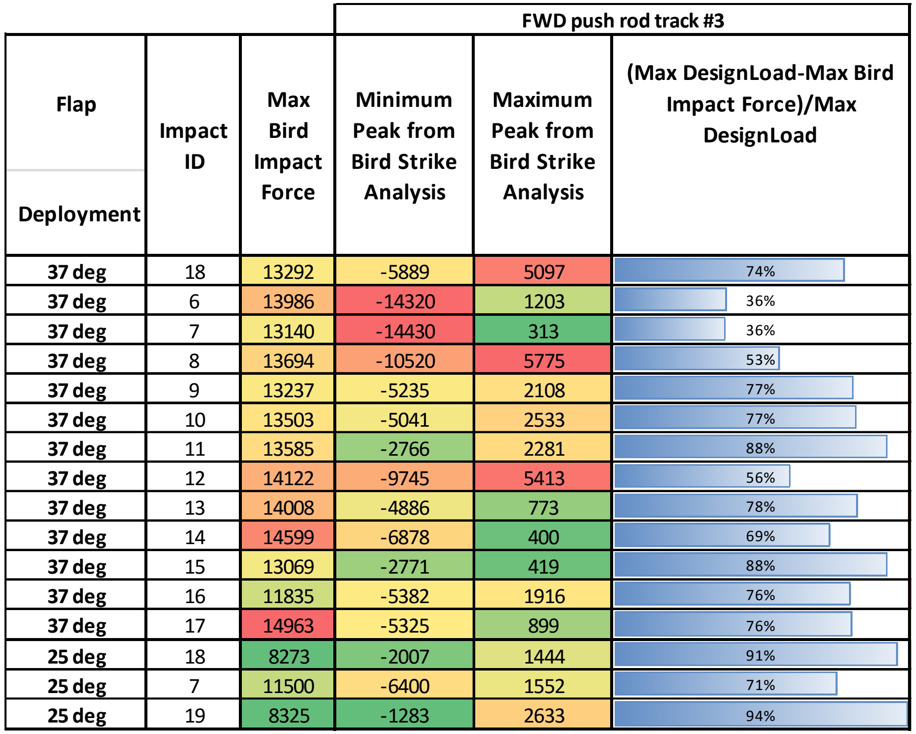
BIRD IMPACT ANALYSIS. PLAN OF SIMULATION IMPACT



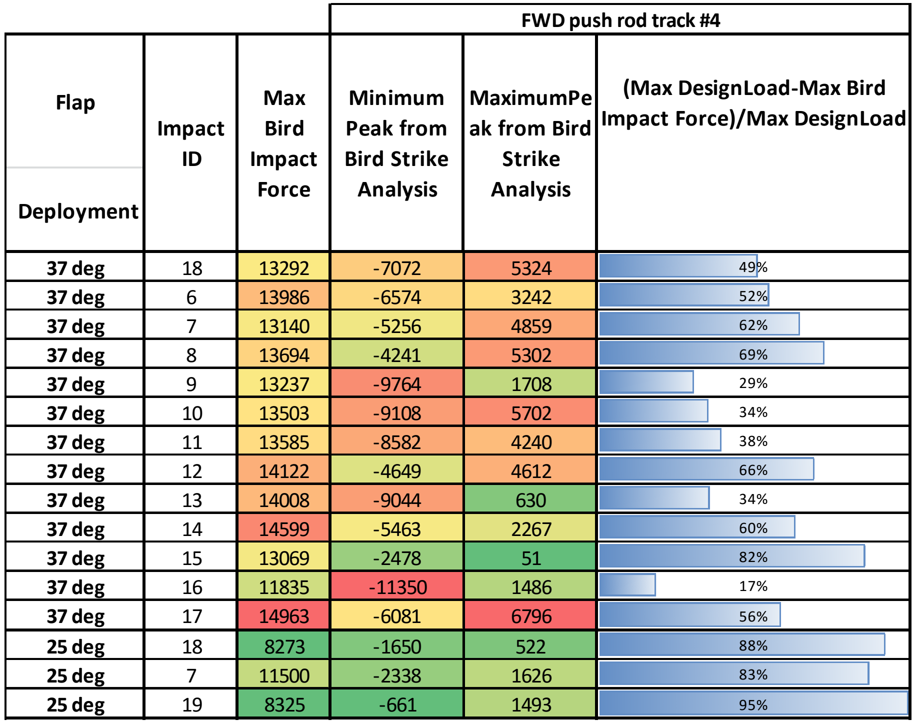
The selection criteria of the Test Impact Point is based on the most severe skin and metallic attachments damage resulting from the model simulation.

Bird Impact analysis. Result



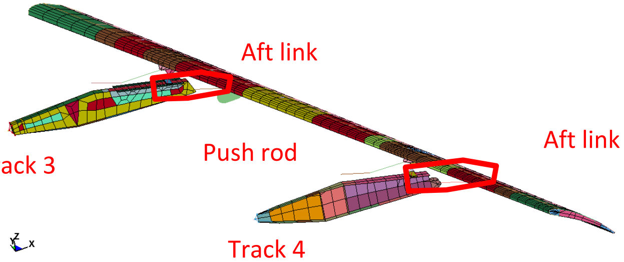


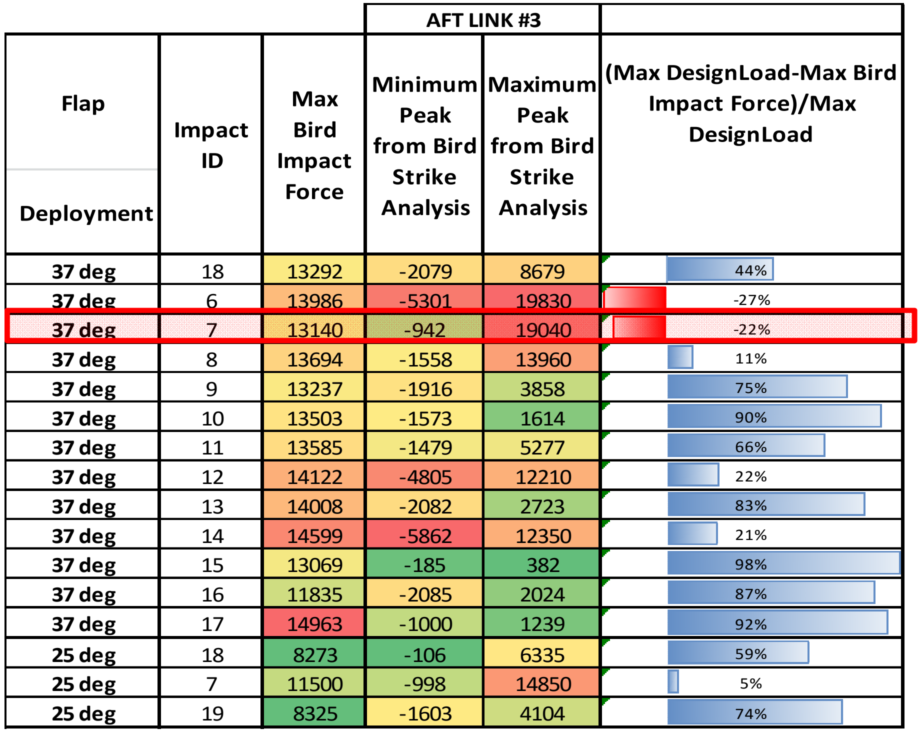
			FWD push rod track #3		
Flap Deployment	Impact ID	Max Bird Impact Force	Minimum Peak from Bird Strike Analysis	Maximum Peak from Bird Strike Analysis	(Max DesignLoad-Max Bird Impact Force)/Max DesignLoad
37 deg	18	13292	-5889	5097	74%
37 deg	6	13986	-14320	1203	36%
37 deg	7	13140	-14430	313	36%
37 deg	8	13694	-10520	5775	53%
37 deg	9	13237	-5235	2108	77%
37 deg	10	13503	-5041	2533	77%
37 deg	11	13585	-2766	2281	88%
37 deg	12	14122	-9745	5413	56%
37 deg	13	14008	-4886	773	78%
37 deg	14	14599	-6878	400	69%
37 deg	15	13069	-2771	419	88%
37 deg	16	11835	-5382	1916	76%
37 deg	17	14963	-5325	899	76%
25 deg	18	8273	-2007	1444	91%
25 deg	7	11500	-6400	1552	71%
25 deg	19	8325	-1283	2633	94%



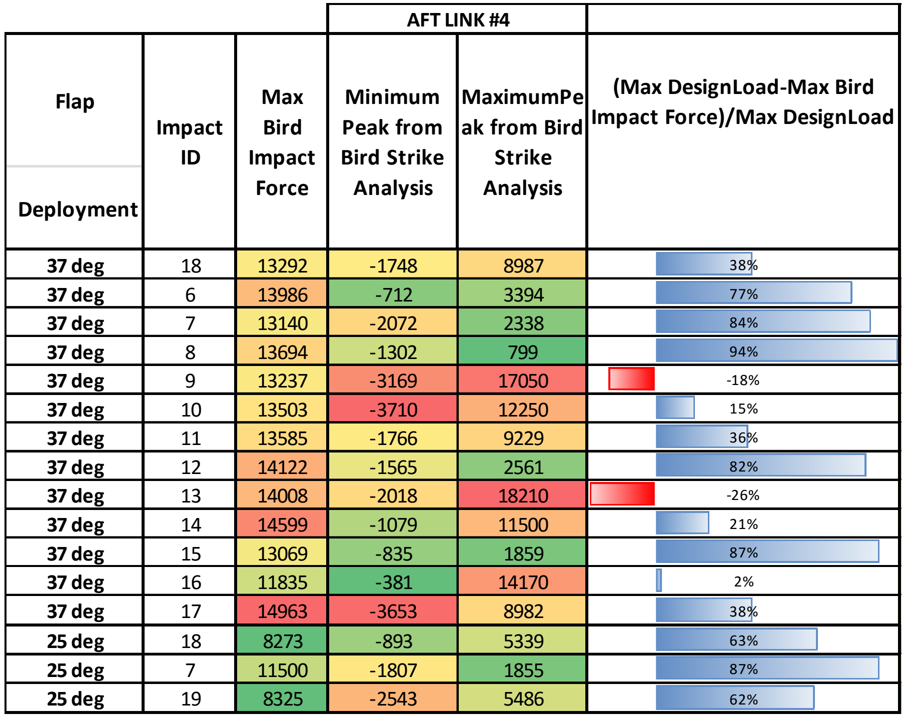
			FWD push rod track #4		
Flap Deployment	Impact ID	Max Bird Impact Force	Minimum Peak from Bird Strike Analysis	MaximumPeak from Bird Strike Analysis	(Max DesignLoad-Max Bird Impact Force)/Max DesignLoad
37 deg	18	13292	-7072	5324	49%
37 deg	6	13986	-6574	3242	52%
37 deg	7	13140	-5256	4859	62%
37 deg	8	13694	-4241	5302	69%
37 deg	9	13237	-9764	1708	29%
37 deg	10	13503	-9108	5702	34%
37 deg	11	13585	-8582	4240	38%
37 deg	12	14122	-4649	4612	66%
37 deg	13	14008	-9044	630	34%
37 deg	14	14599	-5463	2267	60%
37 deg	15	13069	-2478	51	82%
37 deg	16	11835	-11350	1486	17%
37 deg	17	14963	-6081	6796	56%
25 deg	18	8273	-1650	522	88%
25 deg	7	11500	-2338	1626	83%
25 deg	19	8325	-661	1493	95%

Bird Impact analysis. Result



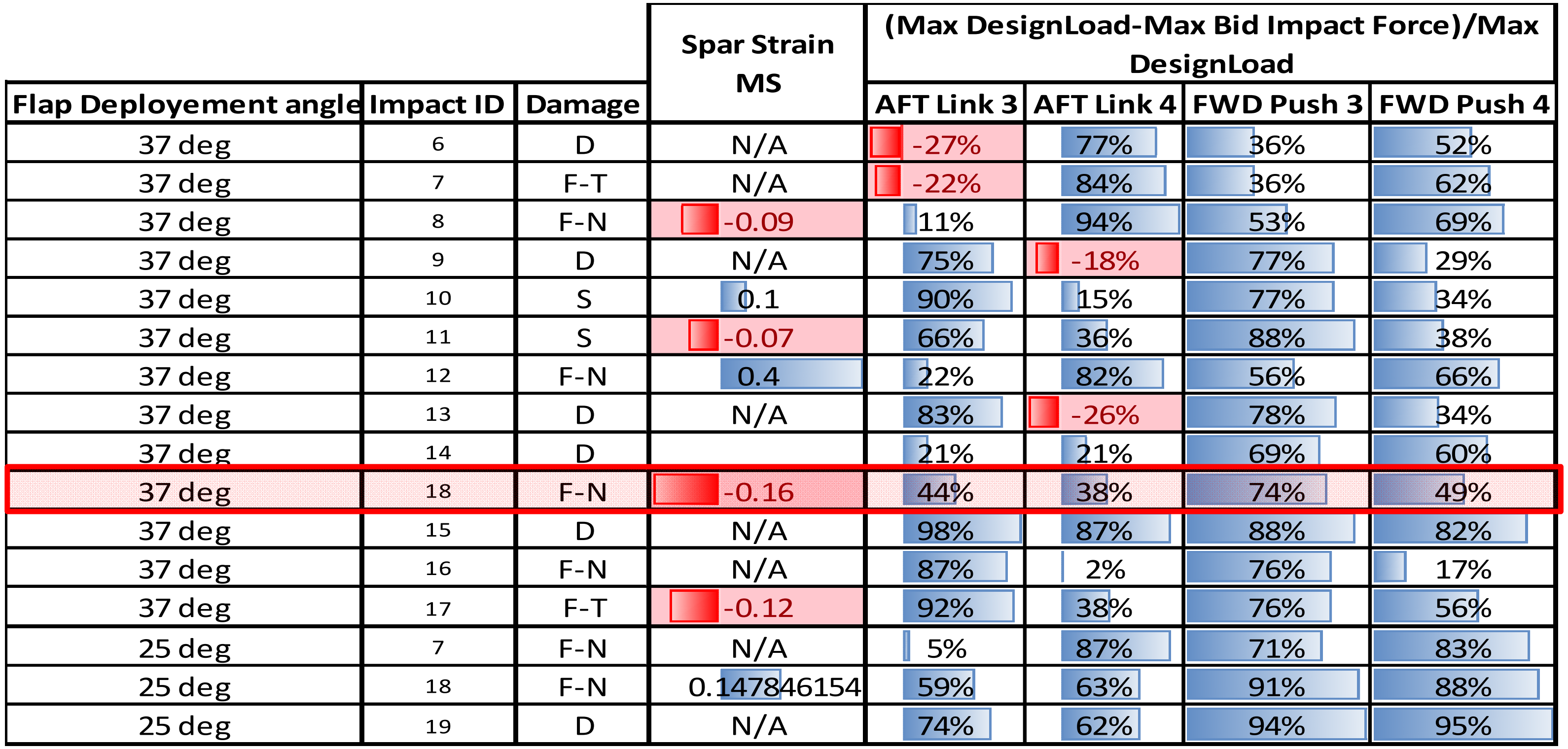


Flap Deployment	Impact ID	Max Bird Impact Force	AFT LINK #3		
			Minimum Peak from Bird Strike Analysis	Maximum Peak from Bird Strike Analysis	(Max DesignLoad-Max Bird Impact Force)/Max DesignLoad
37 deg	18	13292	-2079	8679	44%
37 deg	6	13986	-5301	19830	-27%
37 deg	7	13140	-942	19040	-22%
37 deg	8	13694	-1558	13960	11%
37 deg	9	13237	-1916	3858	75%
37 deg	10	13503	-1573	1614	90%
37 deg	11	13585	-1479	5277	66%
37 deg	12	14122	-4805	12210	22%
37 deg	13	14008	-2082	2723	83%
37 deg	14	14599	-5862	12350	21%
37 deg	15	13069	-185	382	98%
37 deg	16	11835	-2085	2024	87%
37 deg	17	14963	-1000	1239	92%
25 deg	18	8273	-106	6335	59%
25 deg	7	11500	-998	14850	5%
25 deg	19	8325	-1603	4104	74%



Flap Deployment	Impact ID	Max Bird Impact Force	AFT LINK #4		
			Minimum Peak from Bird Strike Analysis	MaximumPeak from Bird Strike Analysis	(Max DesignLoad-Max Bird Impact Force)/Max DesignLoad
37 deg	18	13292	-1748	8987	38%
37 deg	6	13986	-712	3394	77%
37 deg	7	13140	-2072	2338	84%
37 deg	8	13694	-1302	799	94%
37 deg	9	13237	-3169	17050	-18%
37 deg	10	13503	-3710	12250	15%
37 deg	11	13585	-1766	9229	36%
37 deg	12	14122	-1565	2561	82%
37 deg	13	14008	-2018	18210	-26%
37 deg	14	14599	-1079	11500	21%
37 deg	15	13069	-835	1859	87%
37 deg	16	11835	-381	14170	2%
37 deg	17	14963	-3653	8982	38%
25 deg	18	8273	-893	5339	63%
25 deg	7	11500	-1807	1855	87%
25 deg	19	8325	-2543	5486	62%

Bird Impact analysis. Result

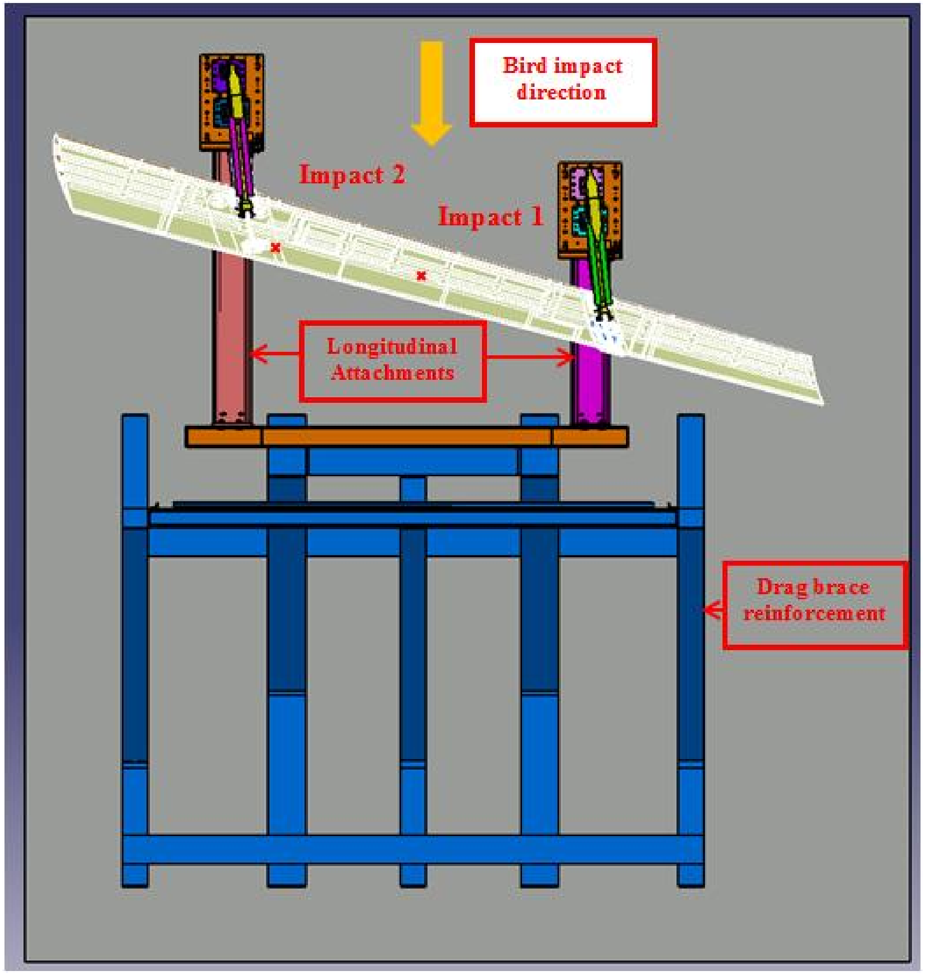


			Spar Strain MS	(Max DesignLoad-Max Bid Impact Force)/Max DesignLoad			
Flap Deployement angle	**Impact ID**	**Damage**		**AFT Link 3**	**AFT Link 4**	**FWD Push 3**	**FWD Push 4**
37 deg	6	D	N/A	-27%	77%	36%	52%
37 deg	7	F-T	N/A	-22%	84%	36%	62%
37 deg	8	F-N	-0.09	11%	94%	53%	69%
37 deg	9	D	N/A	75%	-18%	77%	29%
37 deg	10	S	0.1	90%	15%	77%	34%
37 deg	11	S	-0.07	66%	36%	88%	38%
37 deg	12	F-N	0.4	22%	82%	56%	66%
37 deg	13	D	N/A	83%	-26%	78%	34%
37 deg	14	D		21%	21%	69%	60%
37 deg	18	F-N	-0.16	44%	38%	74%	49%
37 deg	15	D	N/A	98%	87%	88%	82%
37 deg	16	F-N	N/A	87%	2%	76%	17%
37 deg	17	F-T	-0.12	92%	38%	76%	56%
25 deg	7	F-N	N/A	5%	87%	71%	83%
25 deg	18	F-N	0.147846154	59%	63%	91%	88%
25 deg	19	D	N/A	74%	62%	94%	95%

F	Damage
P	Bird penetration
N	Not penetration
T	Partially penetrated
S	Stringer failure
D	Diverted

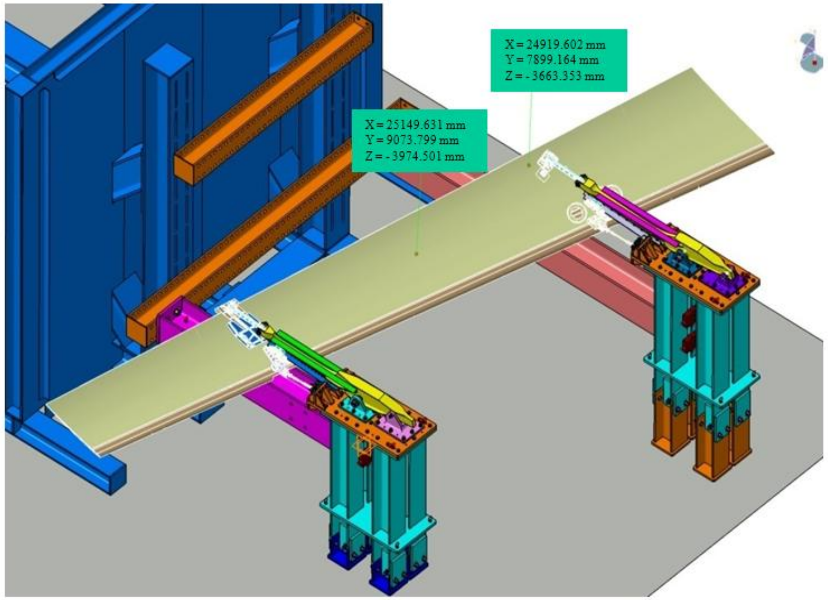
Bird Impact Test

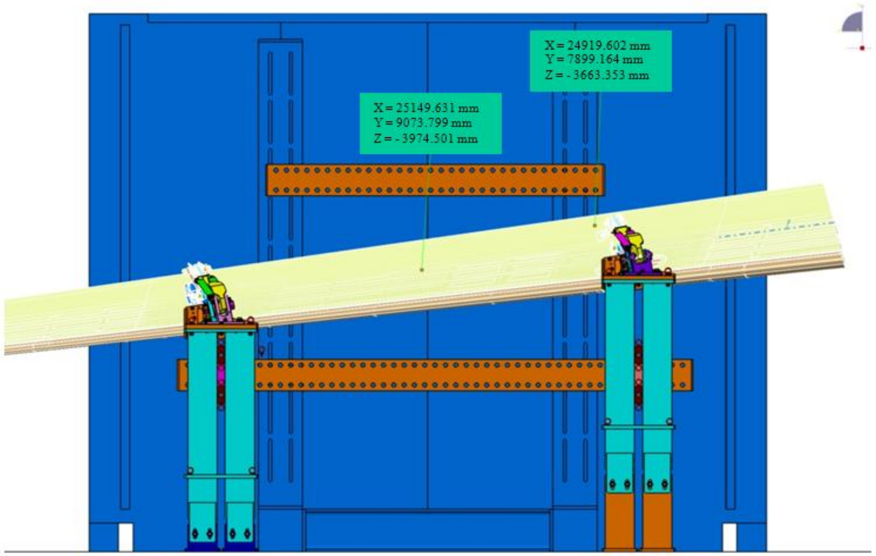
AleniaAermacchi have been selected by **Magnaghi** as LAB test supplier for bird strike test execution



Bird Impact Test Rig Layout

«Dummy tracks» fully reflecting actual aircraft attachment in terms of stiffness and constraints have been provided to LAB test supplier

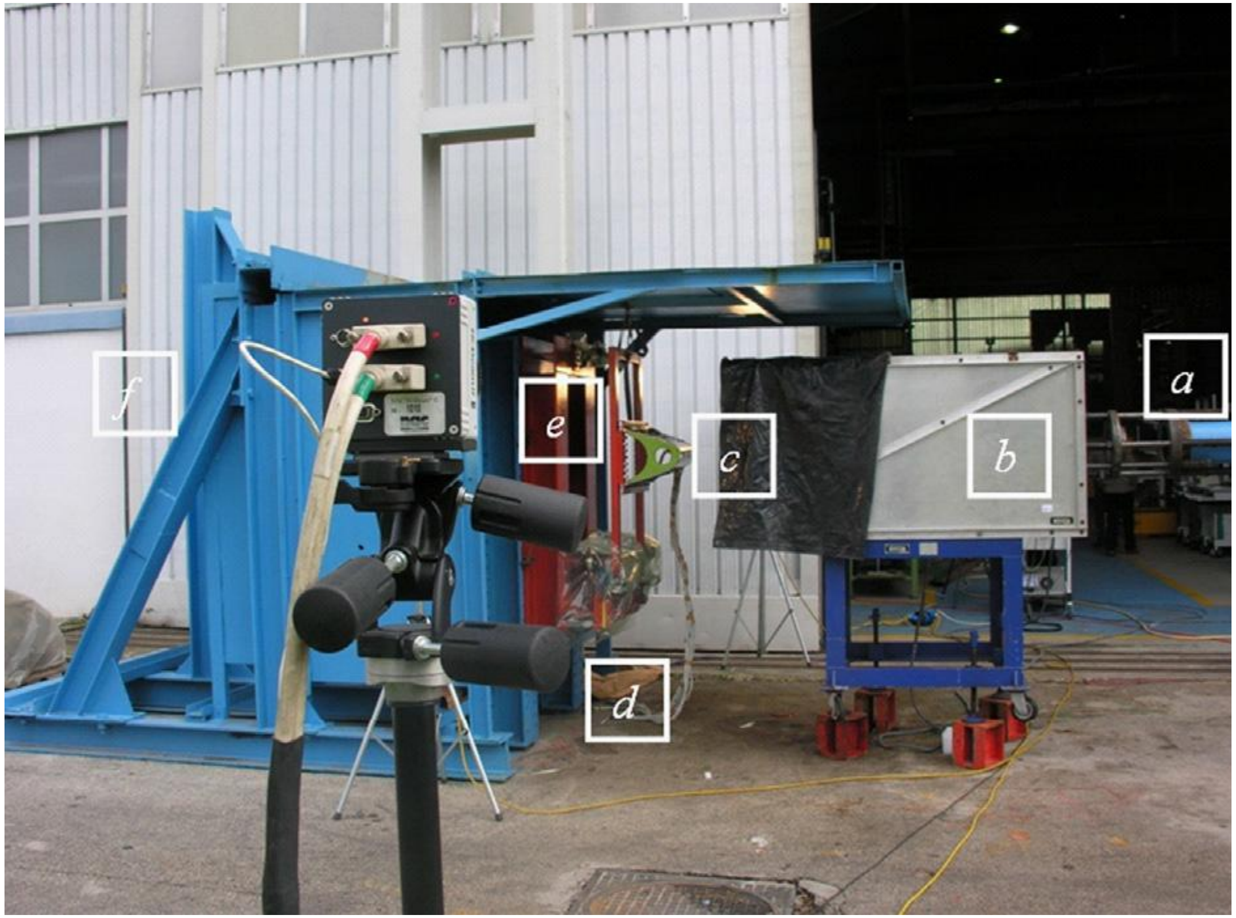




Bird impact test on TRACK+FLAP has been performed on the basis of the most critical impact point selected by analysis

Bird Impact Test Facilities

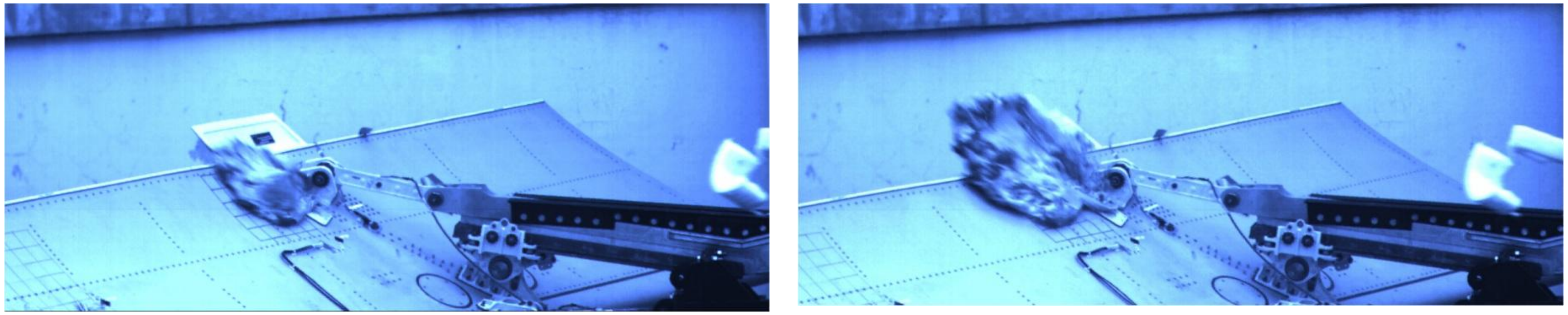
Bird Impact Test high speed acquisition camera

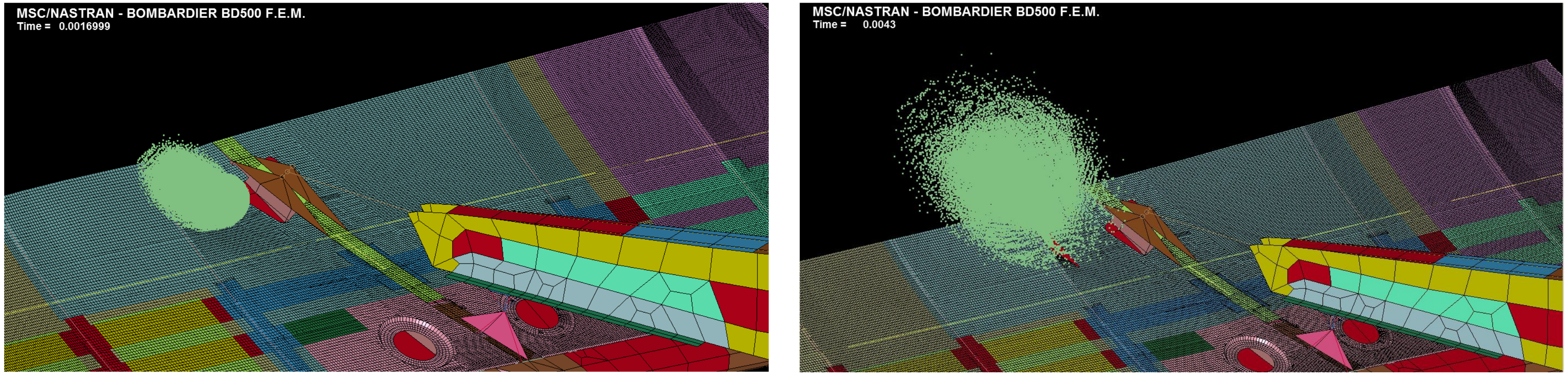


Fixture and scenario of a bird-strike test.

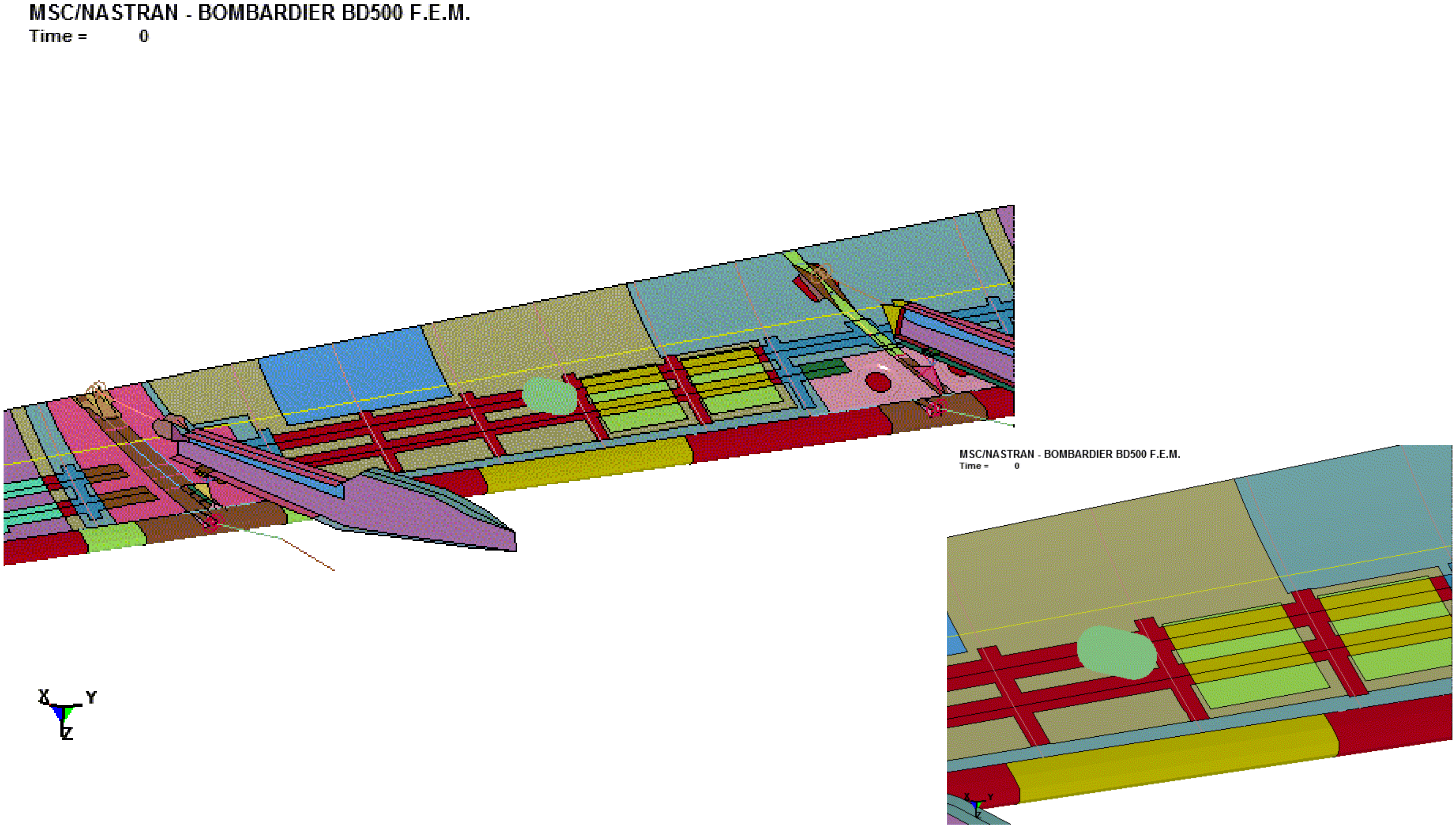
a – air cannon bore;
b – velocity measure device;
c – test article;
d – high speed camera;
e – test bed;
f - safeguard screen;
g – load cell.

Bird Impact Test – Impact Point 1

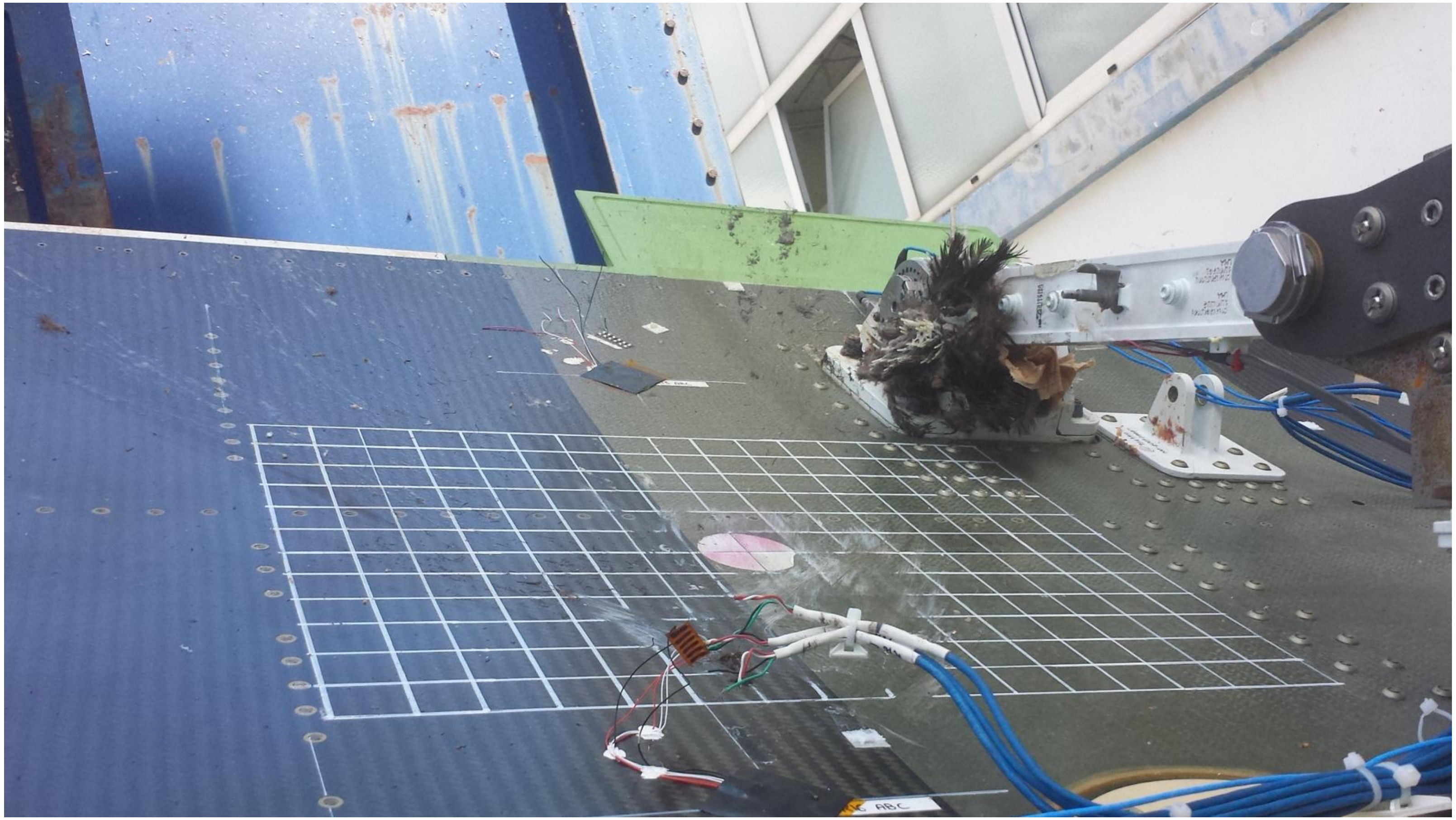




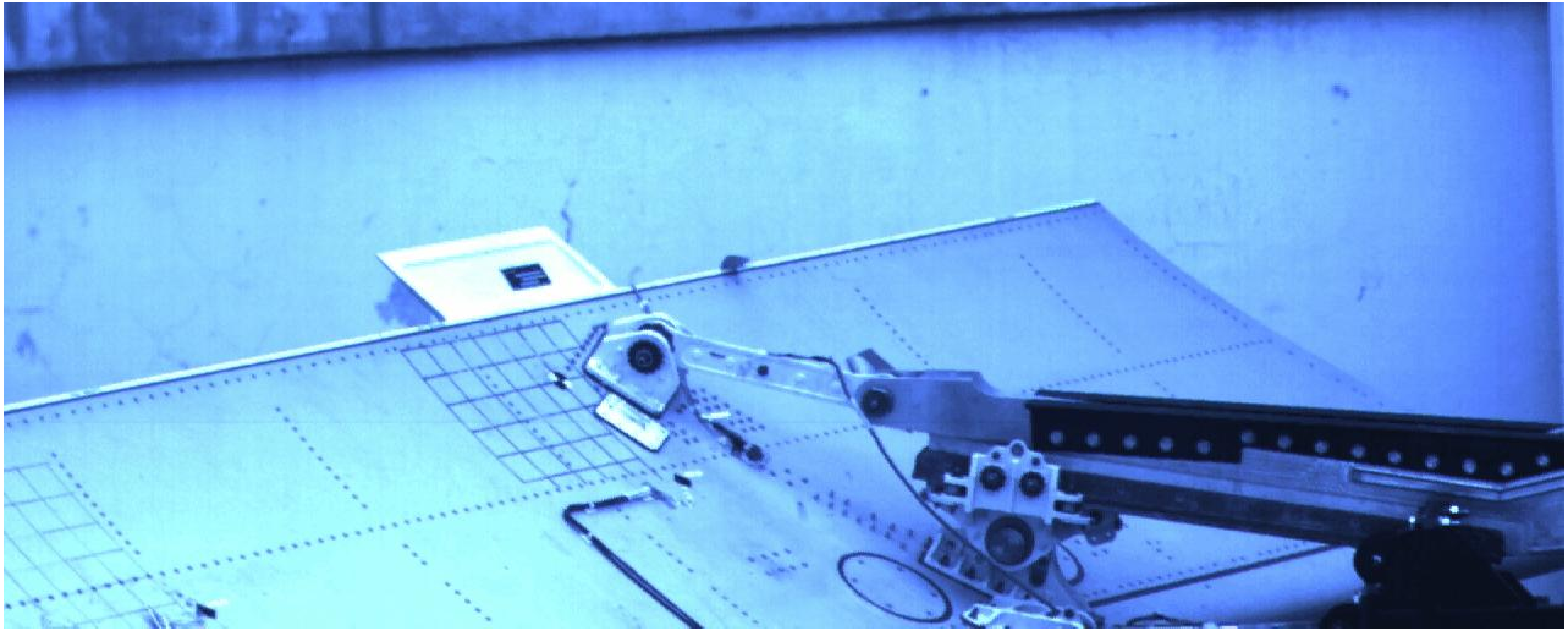
Bird Impact analysis



Bird Impact Test – Impact Point after impact



C-Series Bird Impact Test
Inboard Flap

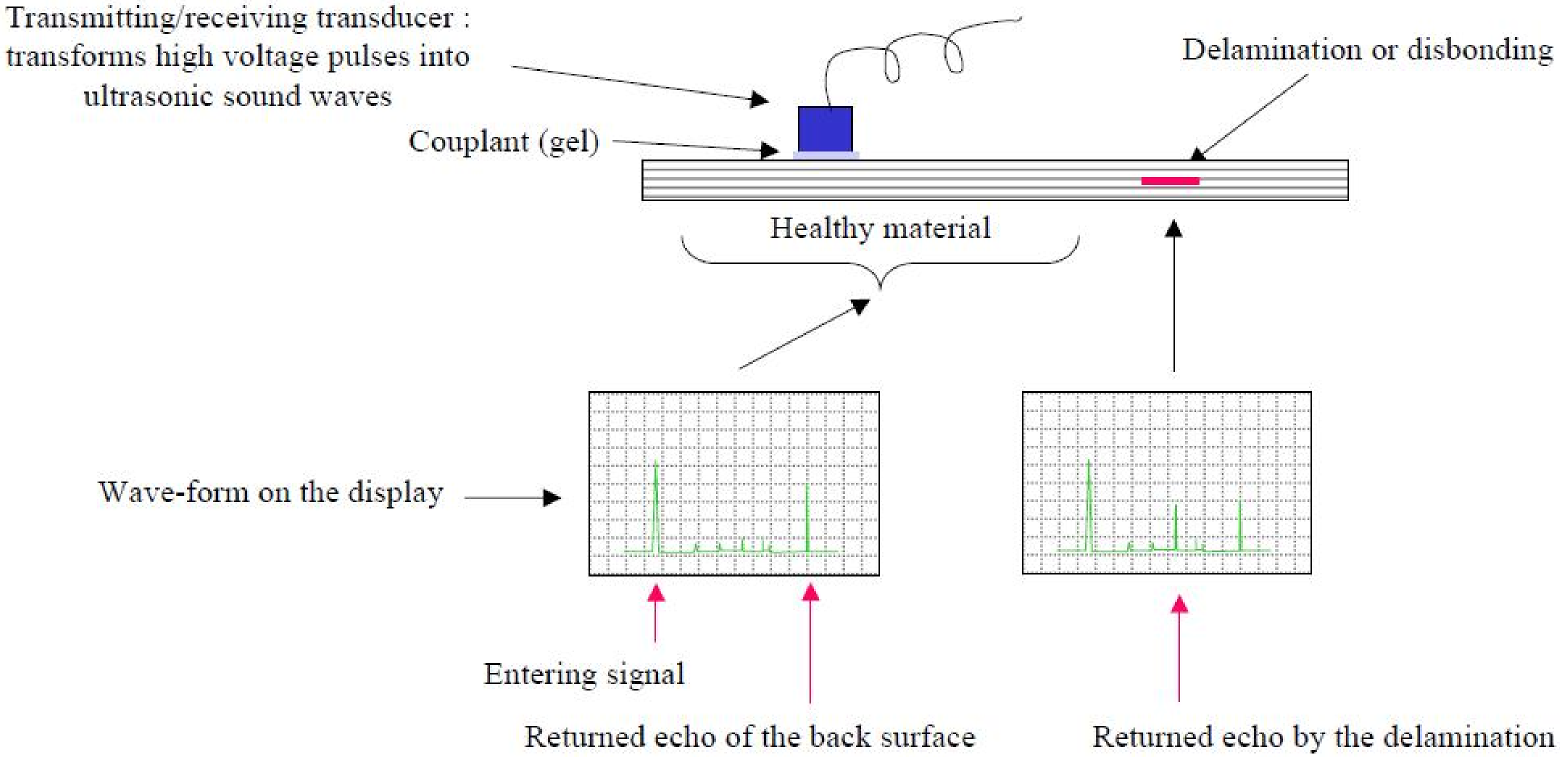


NDT inspection after the Impact

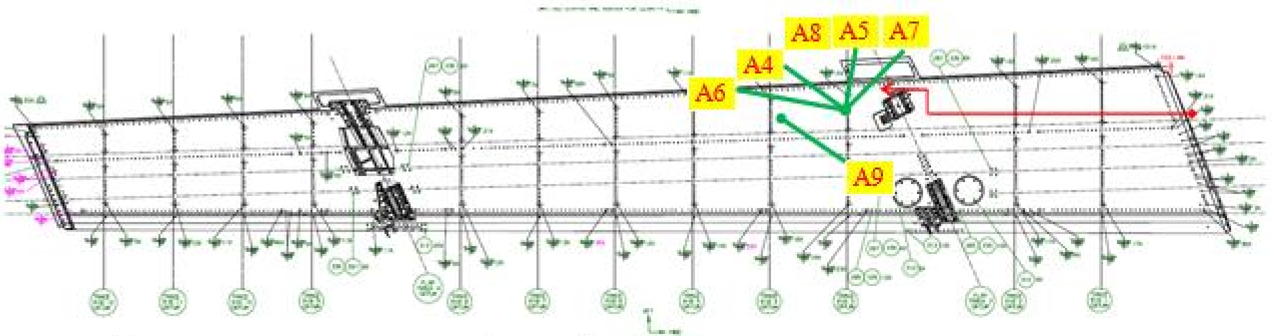
After the each impact all internal and external parts need to be subjected to inspection for:

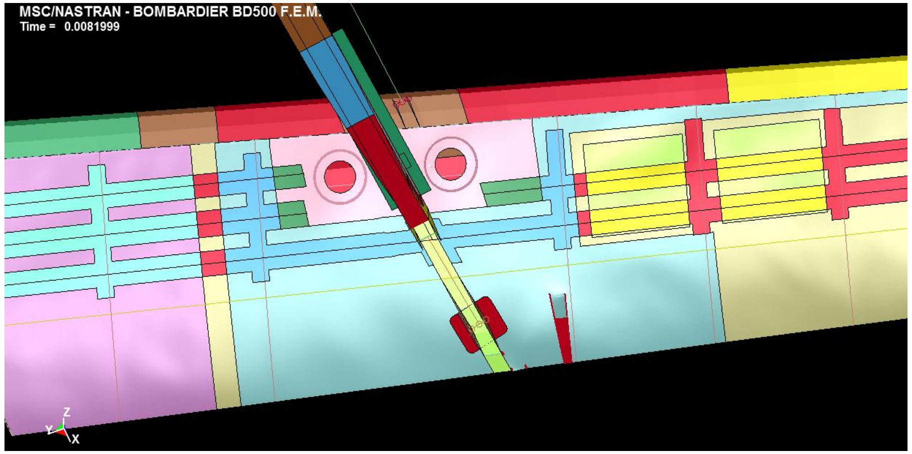
-delamination (ultrasonic inspection)
-crack and failure (Borescope Probe)

Ultrasonic inspection principles of composite structures: the pulse-echo technique



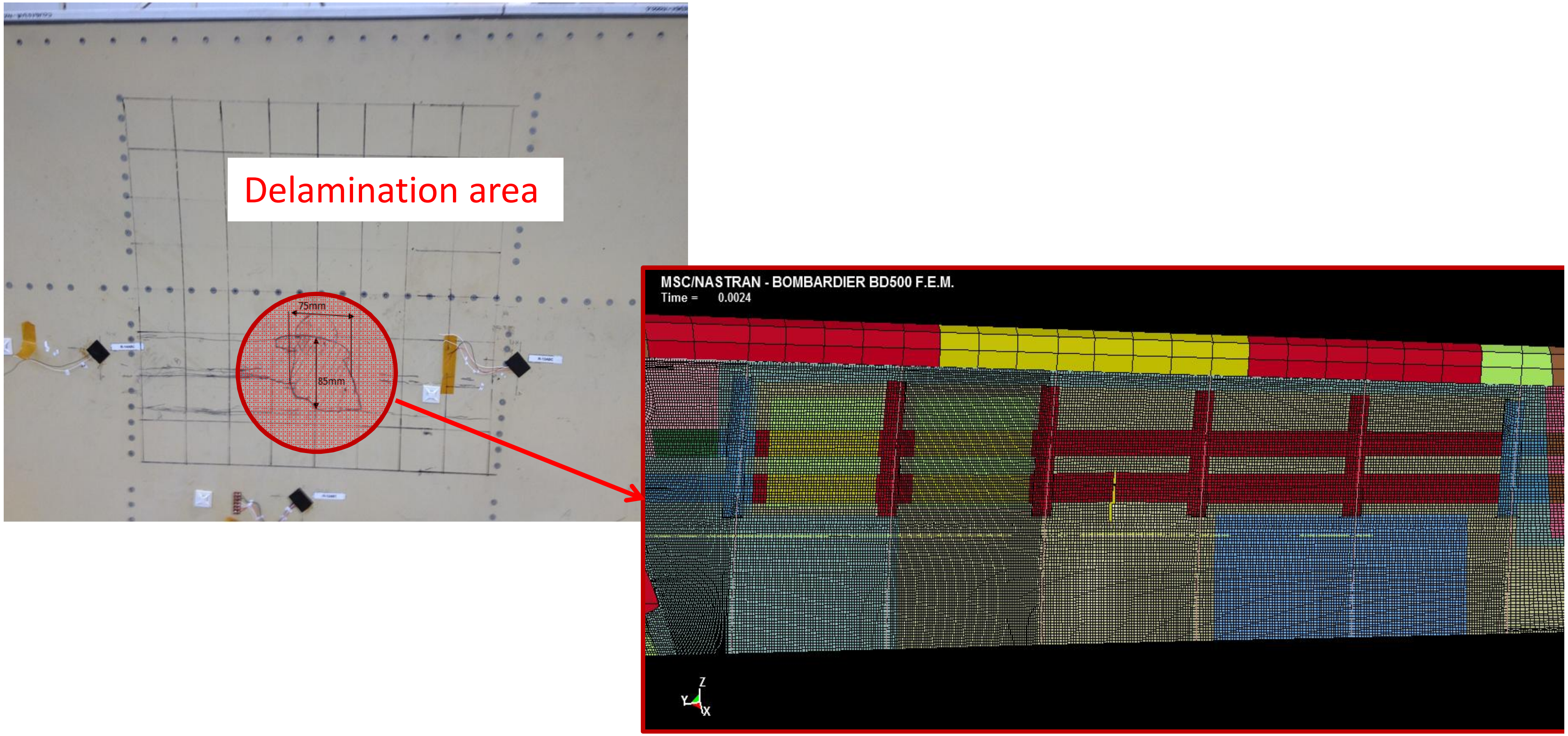
VISUAL INSPECTION BY USING BORESCOPE PROBE





Failure of composite lower skin+trailing edge rib foot was predicted by model simulation

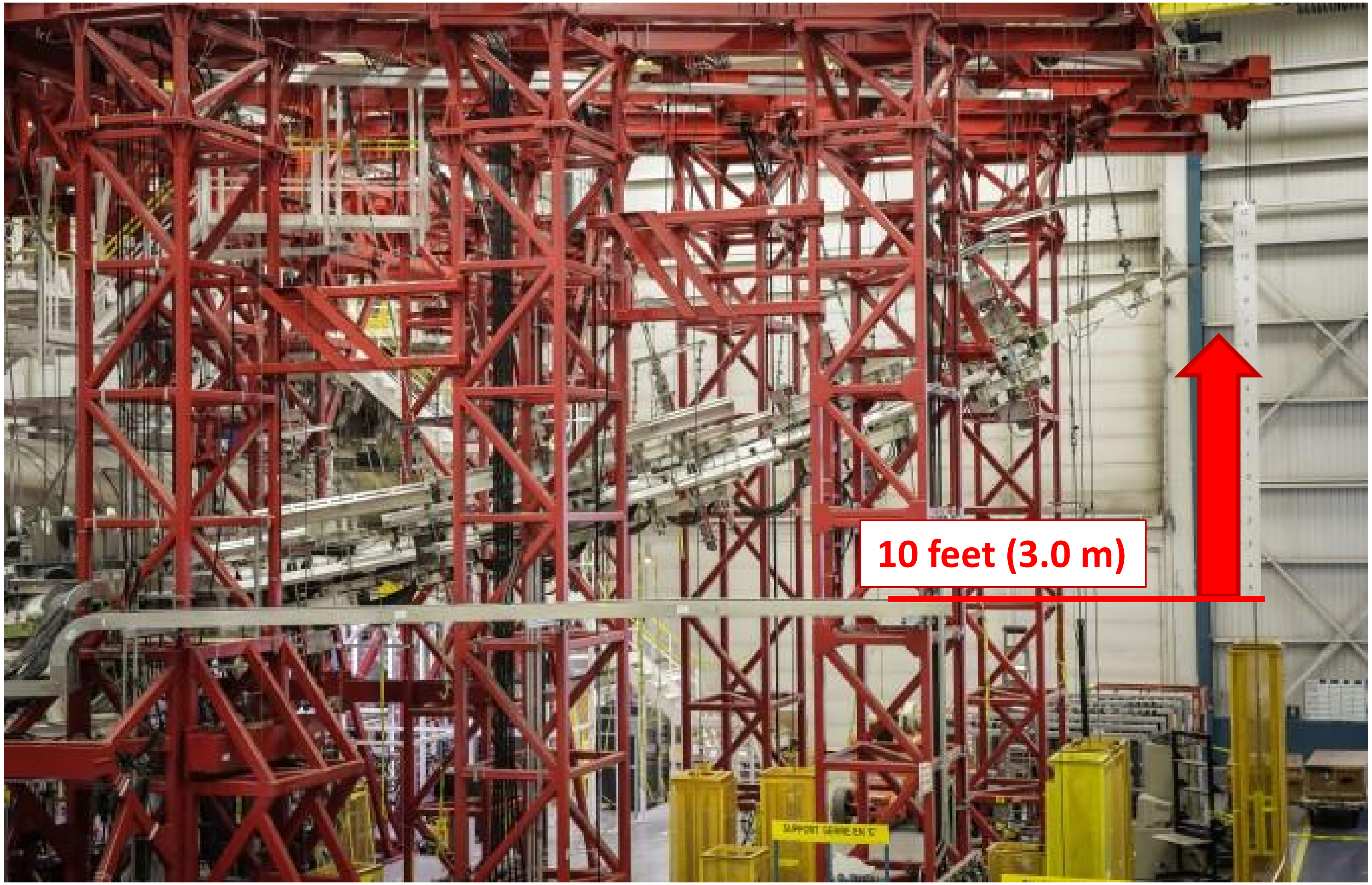
VISUAL INSPECTION BY USING OF HIGH DEFINITION BORESCOPE PROBE COMPARISON WITH PREDICTION



Failure of web stringer (including foot and lower skin) was predicted by model simulation

VIDEO

C-SERIES TEST VEHICLE #1 take-off from Montreal on September 16th, 2013



10 feet (3.0 m)

0 deg timelapse 001.MOV

37 Deg Time Lapse.MOV

175 time lapse.MOV


Спасибо
Gracias
شكرا
Obrigado
Спасибо
Dank U
Grazie
Ευχαριστώ
Danke
Merci
Ngiyabonga
Thank You
Dank U
Diolch
Obrigado
Thank You
Merci
Tack
Dzięki
Danke
Grazie
תודה
Dank U
Terima Kasih
Diolch
Grazie
Tack
Dzięki
Diolch
Gracias
Merci
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