Test and simulation approach toward the certification of an aircraft structure subjected to a bird strike

F. Plassard[1], H.Abdulhamid[1],

Thiot-Ingenierie, Route Nationale - Puybrun F46130, France
recherche@thiot-ingenierie.com
www.thiot-ingenierie.com

1 Abstract

Thiot-Ingenierie worked with a compagny specialised in Retrofit packages for the aviation industry. To improve Satcom and connectivity systems, the compagny developed a dedicated structure able to handle a radome with communication means inside.
The goal of the project is to design and certify a structure that is an interface between the radome and fuselage. This radome can be subjected to a bird strike and the study aims is to ensure that the loads transmitted by the radome and its interface structure do not cause any critical damage on aircraft fuselage.
The challenge of this project was to design the structure within a time development less than 8 months and with only one shot certification test performed at Thiot-Ingenerie laboratory.
A development strategy mixing numerical simulations and experimental tests has been performed to get material behavior of composite materials and to numerically optimize the response of the structure. This mixed strategy allowed us to perform the certification test with an improved structure. This method improves the development efficiency to save time and money.

2 Introduction

Onboard network systems in aircraft become differentiation means for companies. To install specific antennas on actual aircrafts, new installations are designed to add radome on existing structures. This device needs to pass different certifications test including a case ofbird strike.
A company specialized on Retrofit packages for the aviation industry works with Thiot Ingenierie to design the interface structure between the Radome and the plane. Bird strike cases have been calculated with LsDyna to improve the interface structure behavior.
At the beginning of the study, composite materials parameters were not well known and it was impossible to get samples of radome material to perform characterization tests. That is why a strategy combining calculation and tests on radome has been performed in order allowing to pass the certification test with only one bird strike test.
The company accepted that Thiot-Ingenierie writes this paper provided that quantitative data obtained during the tests remain confidential.

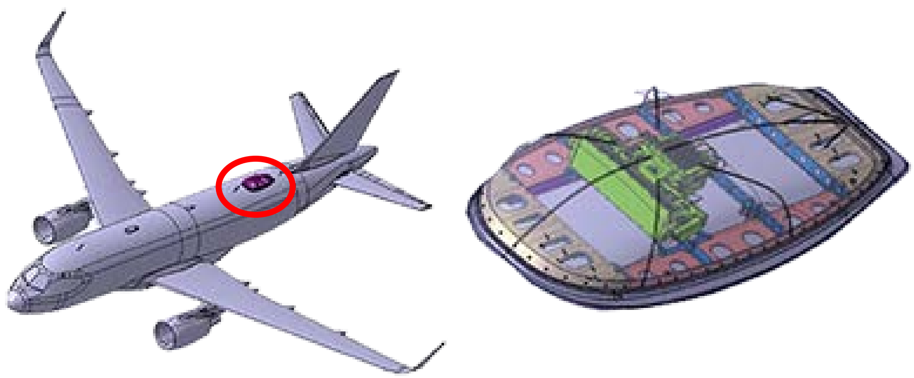


Fig.1: Antenna, radome and interface structure

3 Development strategy

The overall study aims to demonstrate with a bird strike on a full structure (radome, the interface structure and a piece of fuselage) that design respond to bird strike safety requirements.
An impact analysis is performed to reproduce the behavior during a bird impact. The main difficulty is to get dynamic characteristics of radome composite material.
To perform a one shot bird strike test, we planned a strategy mixing numerical simulations and experimental tests.
These are method allows to foresee the behavior of composite materials in order to implement the right data in numerical simulation.

This is the different steps of the new strategy:

- Simplified numerical simulation on radome:
  A bird strike test only on radome is simulated with mechanical properties provided by the company which designs the interface structure. The goal of this step is to determine loads and stresses that occur in the composite parts during the impact. Some lacks can be defined in the numerical model and this constitutes a starting point to design a test configuration on composite material samples.

- Design of a test rig to perform impact on radome to get material data:
  This step aims to design a test rig able to support the radome and perform measurements during the impact test. It is not equivalent to a dynamic characterization of ply behavior. However, the test will provide the global response of the composite material at the level of stress/strain reached during radome bird strike.

- Impact test on samples and experiments/calculation correlation:
  Numerical model of the composite is updated to fit with measurements. This step is a key point as we need to obtain the right behavior of the composite material to properly simulate the loads transmitted to the interface structure.

- Numerical simulation of bird strike on the radome and the interface structure for design iterations:
  Some calculations are performed to improve the interface structure during the bird strike. Several design solutions are studied.

- Final bird strike test on radome, interface structure and a piece of structure of Airbus A319:
  Experimental test and simulation comparison.

4 Simplified radome calculation

4.1 Material models

4.1.1 Composite data

The radome is made of laminate composite composed of three different materials: Quartz/Epoxy, Glass/Epoxy and Foam. The **`*MAT 22`** is used in LsDyna.

4.1.1 Bird material model

An homogeneous material model with a low yield strength has been used to model the bird. It allows keeping the consistency during the impact. The density of the material is 0.95 g/cm^3.
This model has been used and validated in previous studies ([1] to [8]).

4.2 Impact conditions

For simplified numerical simulations the radome is modeled without interface structure. Nodes of the holes for fasteners are fully constrained (Fig.2:). This condition is stronger than reality but it is enough to get the global behaviors of the composite parts.

The bird modeled with SPH formulation (Fig.3: and Fig.4:) is represented with a standard shape: 114 mm diameter cylinder with two hemispheric extremities. The total length is 228 mm and the numerical bird weights 1.8 kg (4lbs).

An initial velocity of 186 m/s is applied to SPH nodes of the bird and a contact interface (***Node_to_Surface**) is performed between the bird and the radome. The firing axis at 70 mm from the down size of the radome corresponds to the impact configuration of bird strike test.

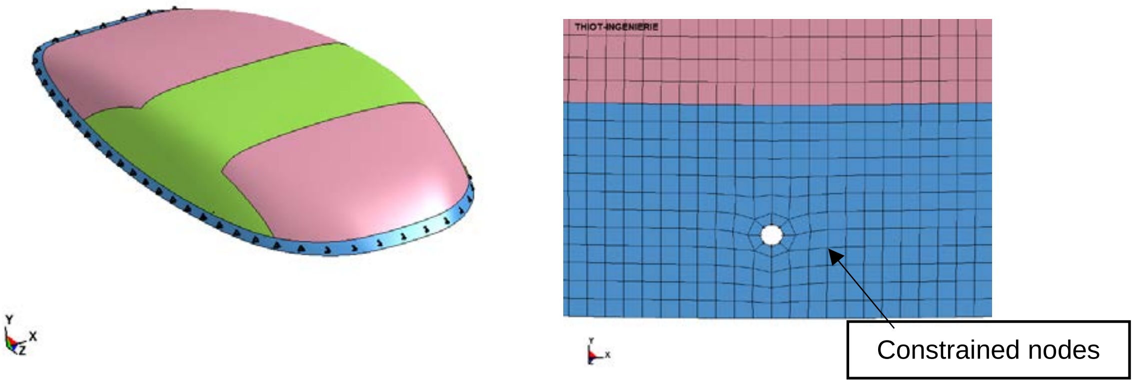


Fig.2: Boundary conditions

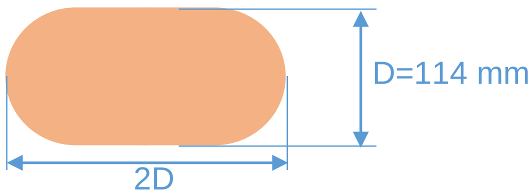


Fig.3: Bird shape model

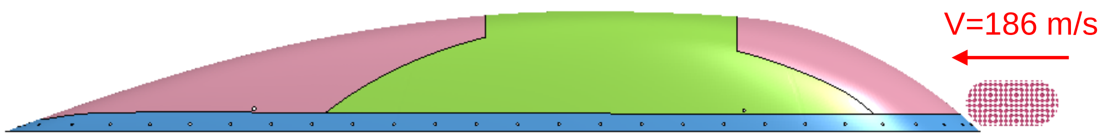
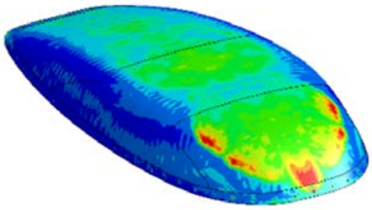


Fig.4: Initial conditions (velocity and position)

4.3 Preliminary calculation results

The bird impacts the radome with a strong deflection and it is deflected by the radome reaction.
Fig.5: shows minimum/maximum stress of lower and upper sides of the radome. These results become a reference for the test rig design in the following chapter.

At this time of the study, composite response is not well known. That is why the test campaign of the next section was designed.

σ_I	**Innerside**	

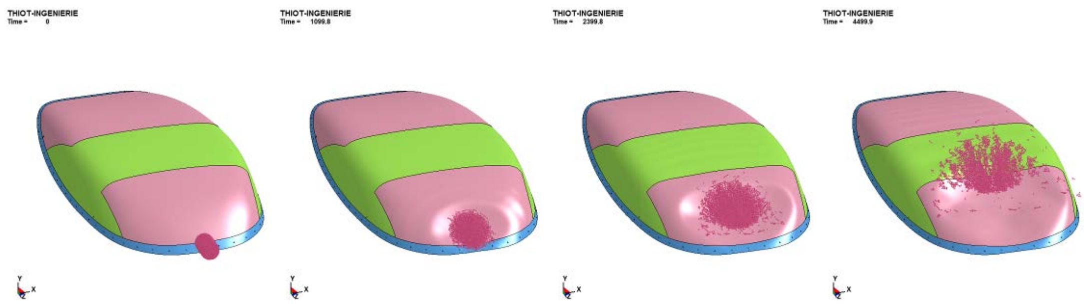
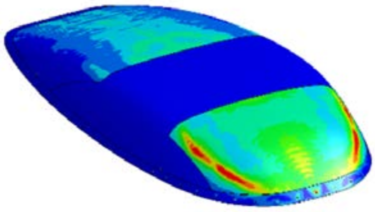
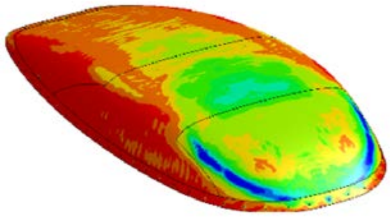
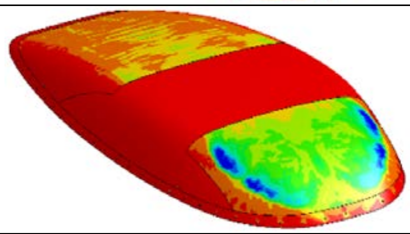


Fig.5: Bird strike simulation between 0 and 12 ms

	Outerside	
σ_{III}	**Innerside**	
	Outerside	

5 Composite material study

5.1 Design of a test rig to perform impact test on acomposite material sample

The previous section has shown that there is a lack of knowledge regarding the dynamic behavior of the radome composite material and force transmitted to the interface structure.
Toolings have been designed to perform the gelatin impact test. A frame holding the radome is screwed on an elevator table. (Fig.6: and Fig.7:)
Only some portions of the radome are connected to the frame to be able to measure local loads transmitted to the frame. If the radome would be totally connected to a rigid frame, loads measurements would be attenuated.
The rigidity of the frame is very high to get composite material data only. Numerical simulation of the system is performed before the test to validate the design. The frame behavior is taken into account for the calculations (Fig.8:)

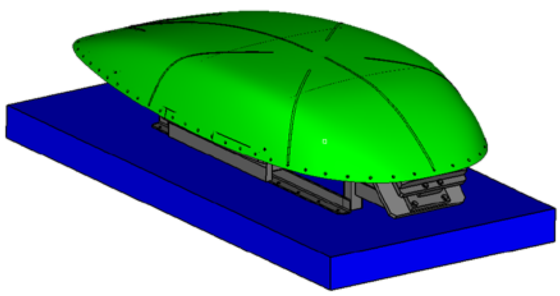


Fig.6: Test rig design

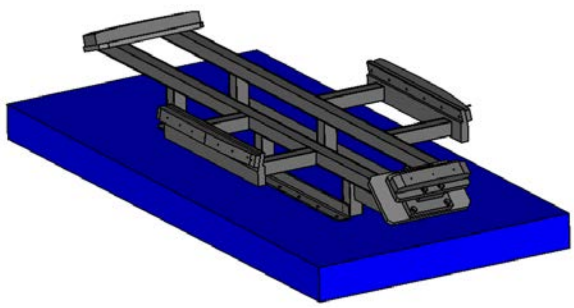


Fig.7: Frame details

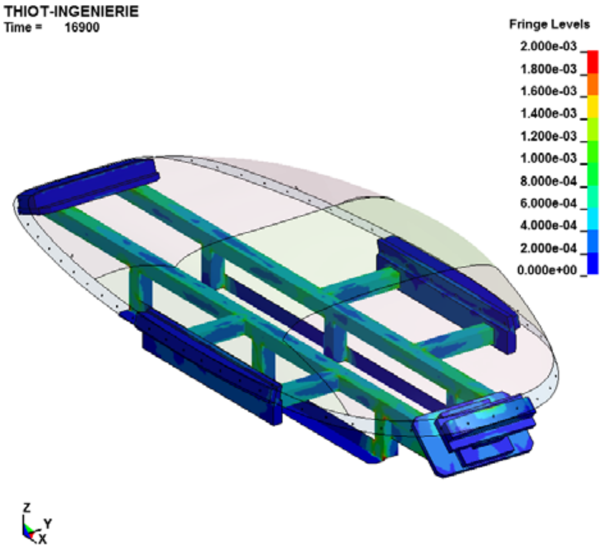


Fig.8: Maximum Von Mises stress in the frame

5.2 Gelatin characterization

In order to obtain an impact load close to that of a bird, we plan to perform impact tests with homemade gelatin. Fig.9: shows an example of gelatin made at Thiot-Ingenierie laboratory with a density around 0.95 g/cm^3. Gelatin has been tested to ensure that its model is well controlled.

Two tests have been performed:
- Direct impact on rigid plate mounted on a load sensor,
- Indirect impact on a deformable plate with rear plate velocity measurement and load measurement.

The test campaign has allowed to identify the material parameters of the gelatin used in the characterization tests. The following results show a good correlation of the simulation in terms of impact forces and indentation for the aluminum plate test.

Fig.9: Gelatin projectile

5.2.1 Direct impact correlations

Configuration:
- Gelatin mass: 66 g
- Impact velocity: 150 m/s

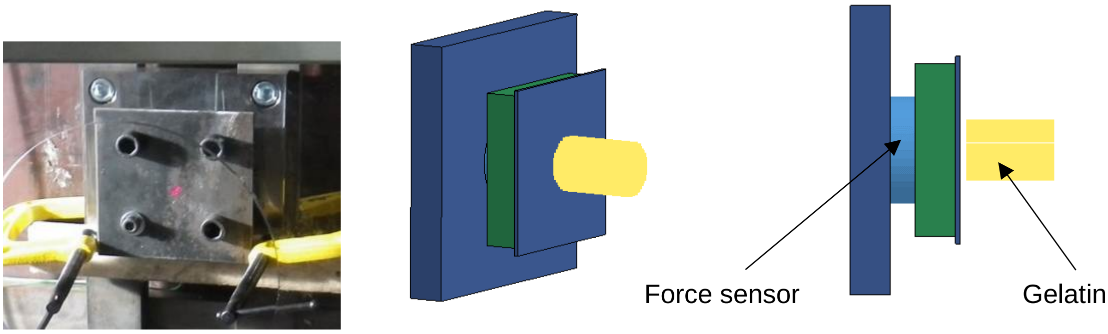


Fig.10: Test configuration

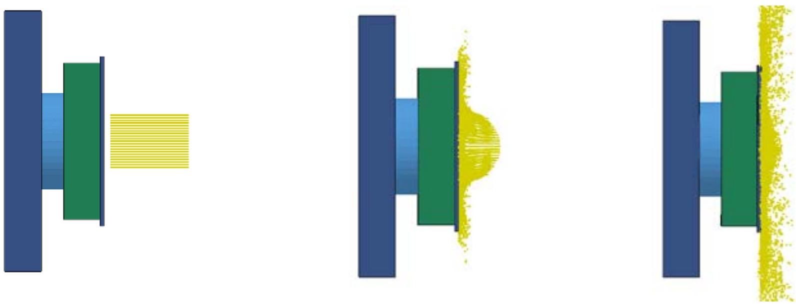


Fig.11: Gelatin impact test calculation

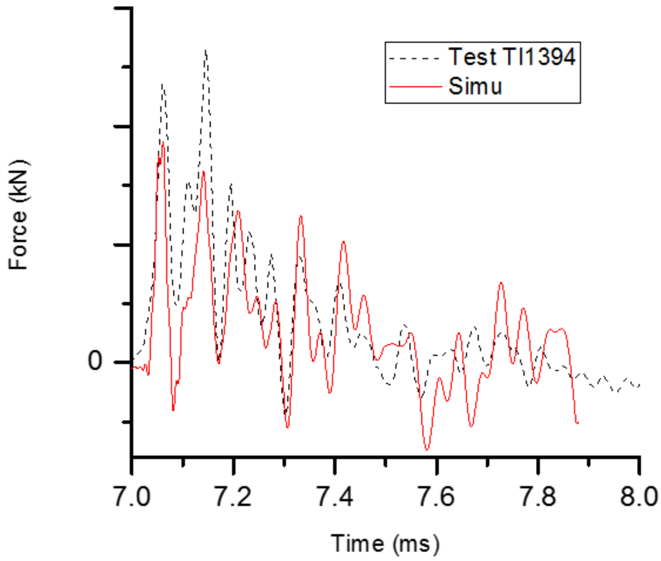


Fig.12: Comparison of impact force recorded at the level of the sensor

5.2.2 *Indirect impact correlation*

Configuration:
- Gelatin mass: 81 g
- Impact velocity: 300 m/s

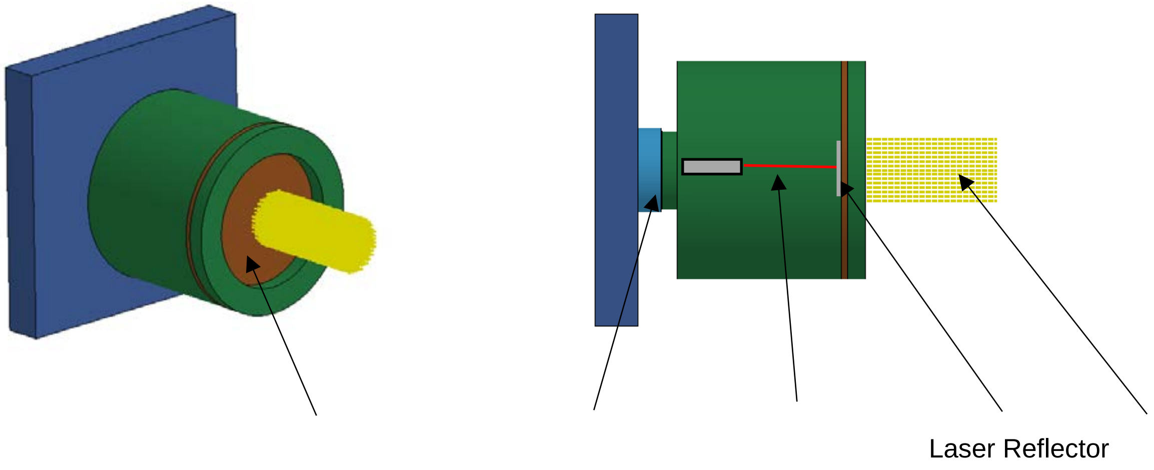


Fig.13: Test configuration

Fig.14: Pictures taken from high speed camera

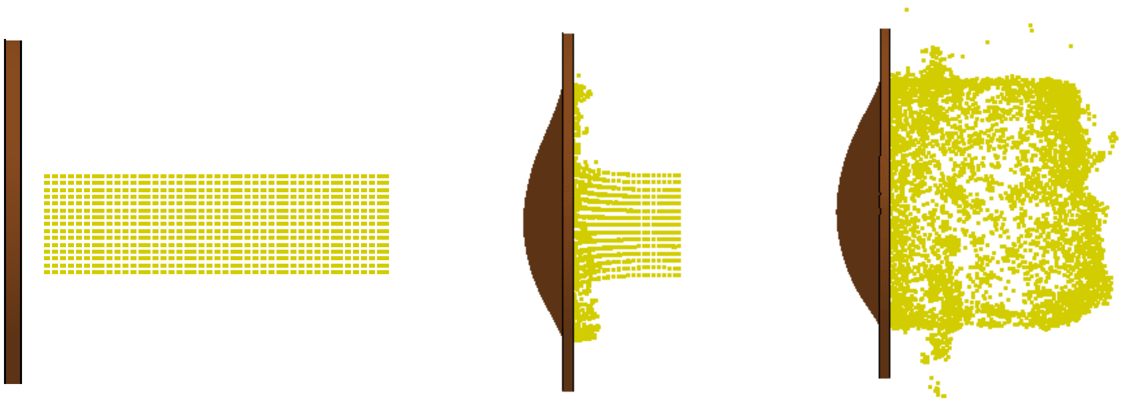


Fig.15: Gelatin impact test calculation

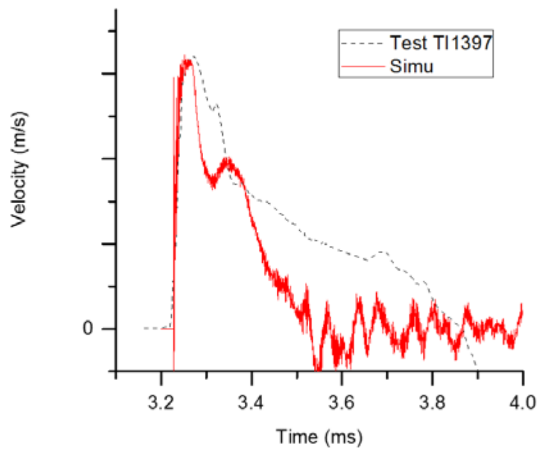


Fig.16: Comparison of the back plate velocity evolution

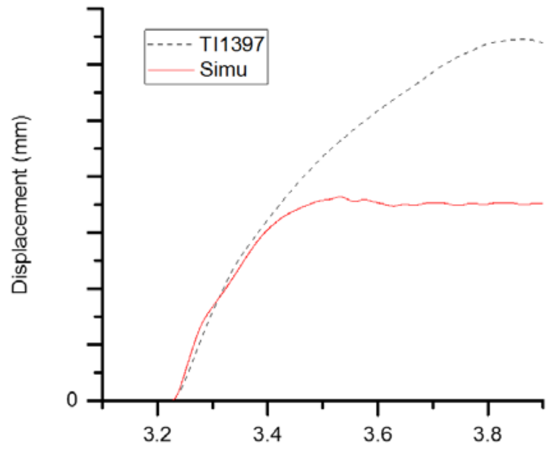


Fig.17: Comparison of the back plate displacement evolution

Remarks:
The maximum displacement computed from the experimental velocity is 31 mm. This value is too large compared to the residual indentation of the aluminum plate which is 20.2 mm. Therefore, there must have been a separation of the laser reflector from plate during the test. The computed velocity and displacement fit in better with the test residual indentation.

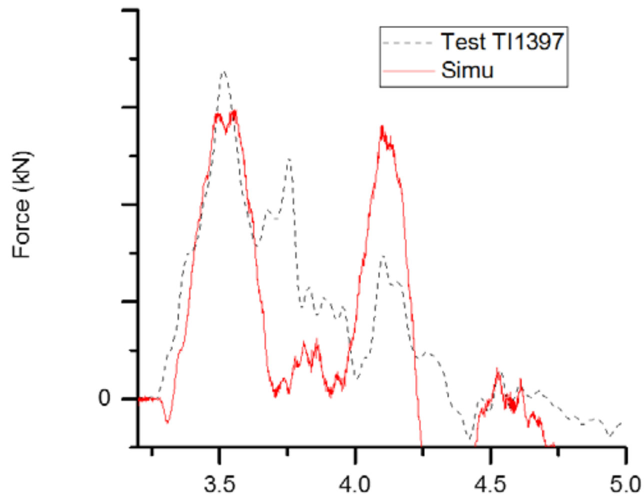


Fig.18: Comparison of impact force recorded at the level of the sensor

5.3 Gelatin impact test on radome and correlation

Fig.19: shows the setup configuration with metrology systems:
- Projectile velocity measurement,
- One load sensor,
- Deflection measurement on rear side of the radome,
- High speed camera,
- Strain gauges (2 Bi-directional, 2 Uni-directional).

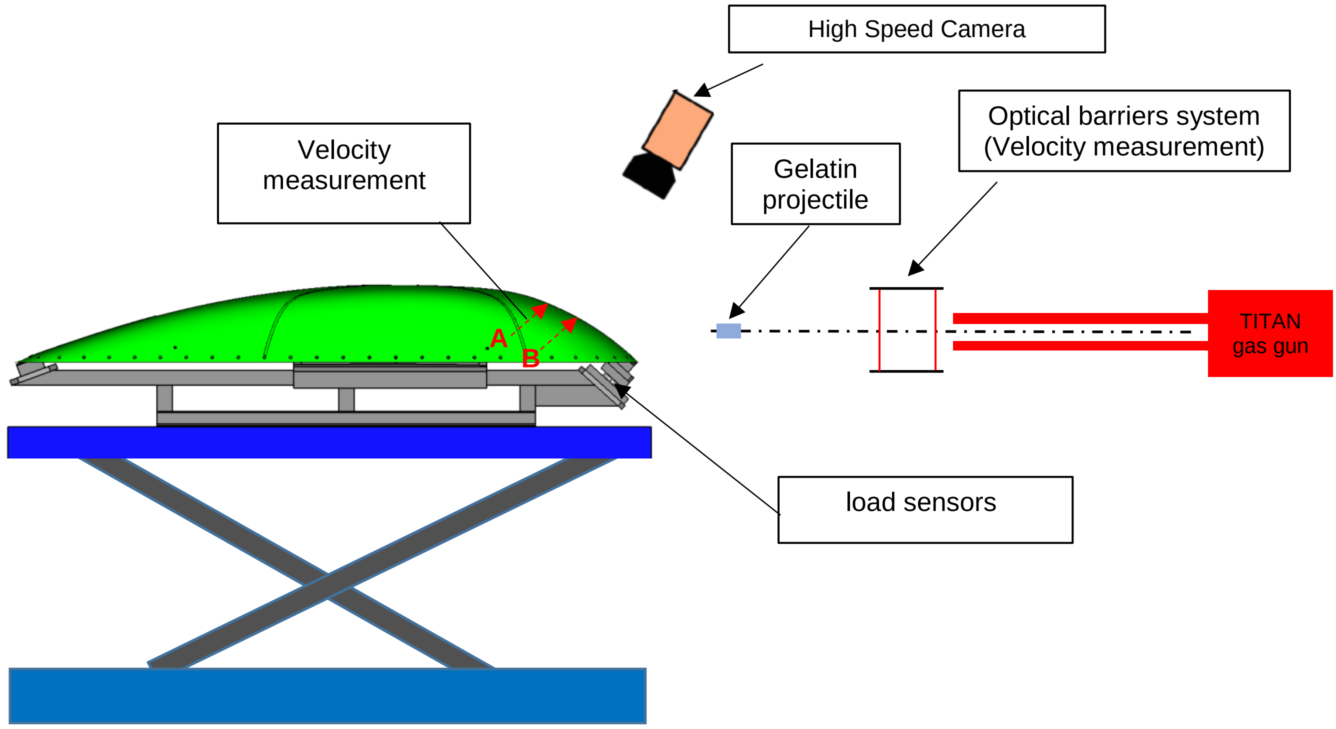


Fig.19: Test rig (tools and measurements)

The following test procedure has been performed :
- First test at low energy (80 g at 150 m/s) on the top side of the radome to evaluate a reference composite behavior. (Fig.20:)
- Second test at medium energy (80 g at 200 m/s) on the top side of the radome depending on the behavior of the first test.
- Third test at high energy (120 g at 300 m/s) on the bottom side of the radome to achieve damage of the radome and to study behavior around the screws. (Fig.21:)

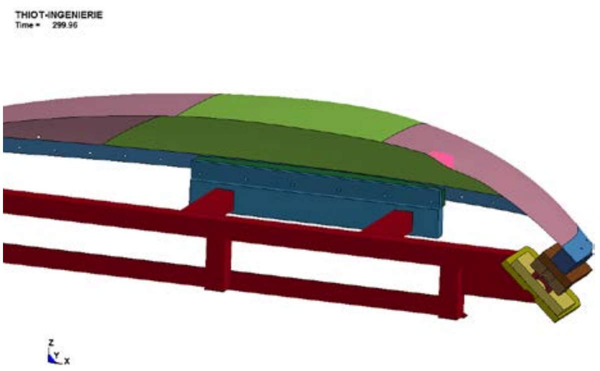


Fig.20: Low energy impact test

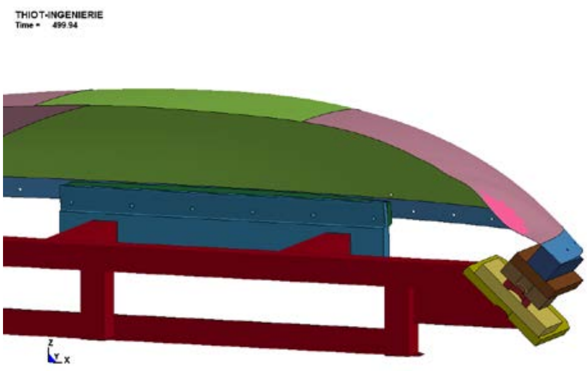


Fig.21: High energy impact test

Fig.22: Global setting

Tests are performed by a gas gun of the Thiot-Ingenierie shock physics laboratory. (Fig.23:)
TITAN Light Gas Gun (LGG) ([9]) is a single stage launcher (see Figure below) which can be configured using different barrel diameters: Ø60 mm, Ø100 mm, Ø 220 mm and Ø 350 mm. Thanks to this particularity, the LGG allows to obtain several impact velocities with various types of projectiles or targets.

Fig.23: TITAN LGG (60 mm version)

The following table shows the main parameters of the three shots.

Table 1 : Summary of the three shots

Thiot test number TI0XXX	Gelatin mass (g)	Impact velocity ($m.s^{-1}$)	Gelatin impact location
TI1399	59	151.1	Z = 250 mm
TI1400	62	207.5	Z = 250 mm
TI1401	90	273.5	Z = 70 mm

Fig.24: shows some frames of high speed camera for the shot TI1401. We can see that front fixtures are strongly loaded but there is no failure.
On following sections, force, velocities and strain measurements from sensors are plotted. The velocity signal is integrated to get the displacement of the measured points. There are more details for TI1401 because it is the case the closest from bird strike loading. All the curve are compared with simulation results of Fig.20: and Fig.21:.

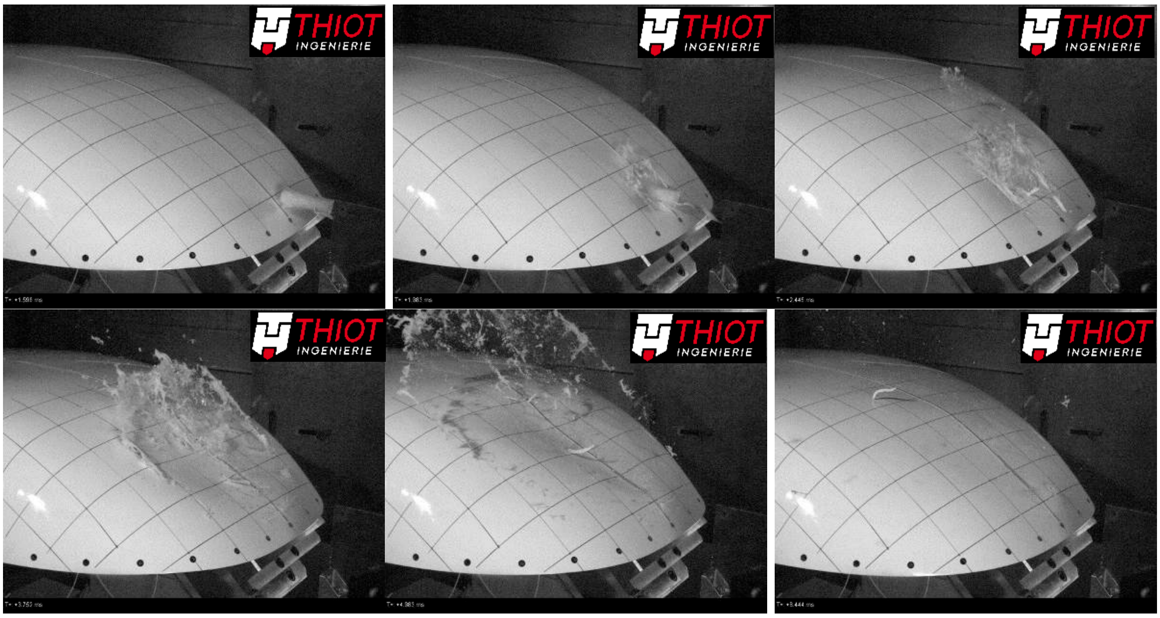


Fig.24: Pictures extracted from high speed camera (TI1411)

5.3.1 Impact radome Point High TI1399

- Gelatin mass: 59 g
- Impact velocity: 151 m/s

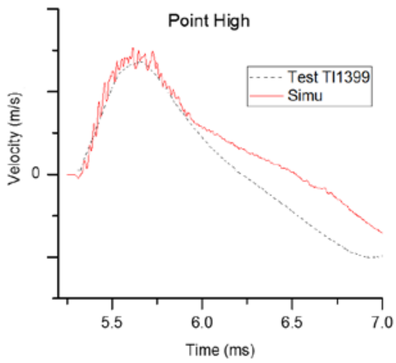


Fig.25: Comparison of radome velocity at point B

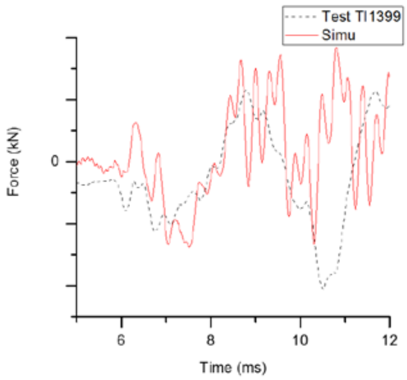


Fig.26: Comparison of impact force

<u>Remarks:</u>
The velocity recorded at point A is very low for this test and has not been entirely recorded.

5.3.2 Impact radome Point High TI1400

- Gelatin mass: 62 g
- Impact velocity: 207 m/s

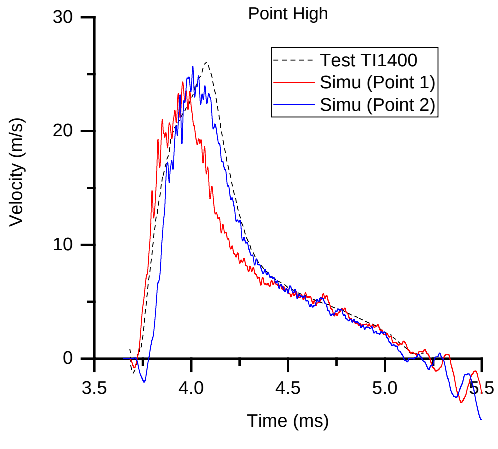


Fig.27: comparison of radome velocity at point B (point 1 and point 2 are two close nodes of the model)

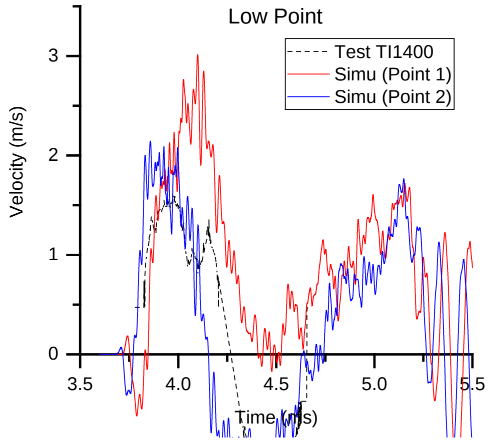


Fig.28: Comparison of radome velocity at point A (point 1 and point 2 are two close nodes of the model)

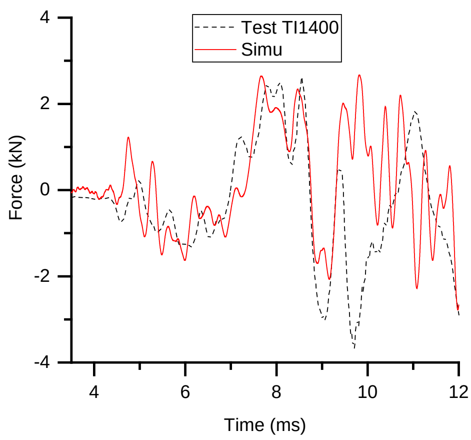


Fig.29: Comparison of impact force

Remarks:

The displacement measured at point B (near to the impact point) shows a good correlation with the simulation of both tests (TI1399 and TI1400). At point A, the numerical model overestimates the results. This difference can be explained by the damping effect of the foam layer which is taken into account in the model. A more detailled model of the radome, with 3D elements, is required for this phenomenon to be represented.

5.3.3 Impact radome Point Low (TI1401)

- Gelatin mass: 90 g
- Impact velocity: 273 m/s

Discussion:

The comparison of the displacement field (Fig.30:) with the high speed camera images shows that the model well reproduces the global evolution of the radome deformation. Beside, it is interesting to note the ability of the model to reproduce the blisters of the radome. Like in the test, two blisters are observed at a certain time which then converge into a single one.

Looking closely at the curves of velocity and displacement, some slight differences can be highlighted. For instance, there is some delay between the experimental and numerical velocity curves recorded at point A and point B (Fig.31: and Fig.33:). Also, the shape of the displacement profile recorded at point A does not match that of the test. After a detailed analysis of this matter and comparing the curves with the test video, it was found that, at this particular point, the displacement of the front side of the radome is different from the displacement of its inner side. There can be some delamination inside the laminate or an important thorough thickness compression of the foam which cannot be reproduced with a shell element model.

The comparison of the forces shows good agreement with the test (Fig.35:). This point is particularly important since it assures that the model is able to predict the load transmitted to the interface structure.

In all, the comparison of the deformation (Fig.37: to Fig.40:) shows also good agreement with the test. Exept, for point A4, at which delamination is clearly observed after the test, the numerical prediction is less accurate.

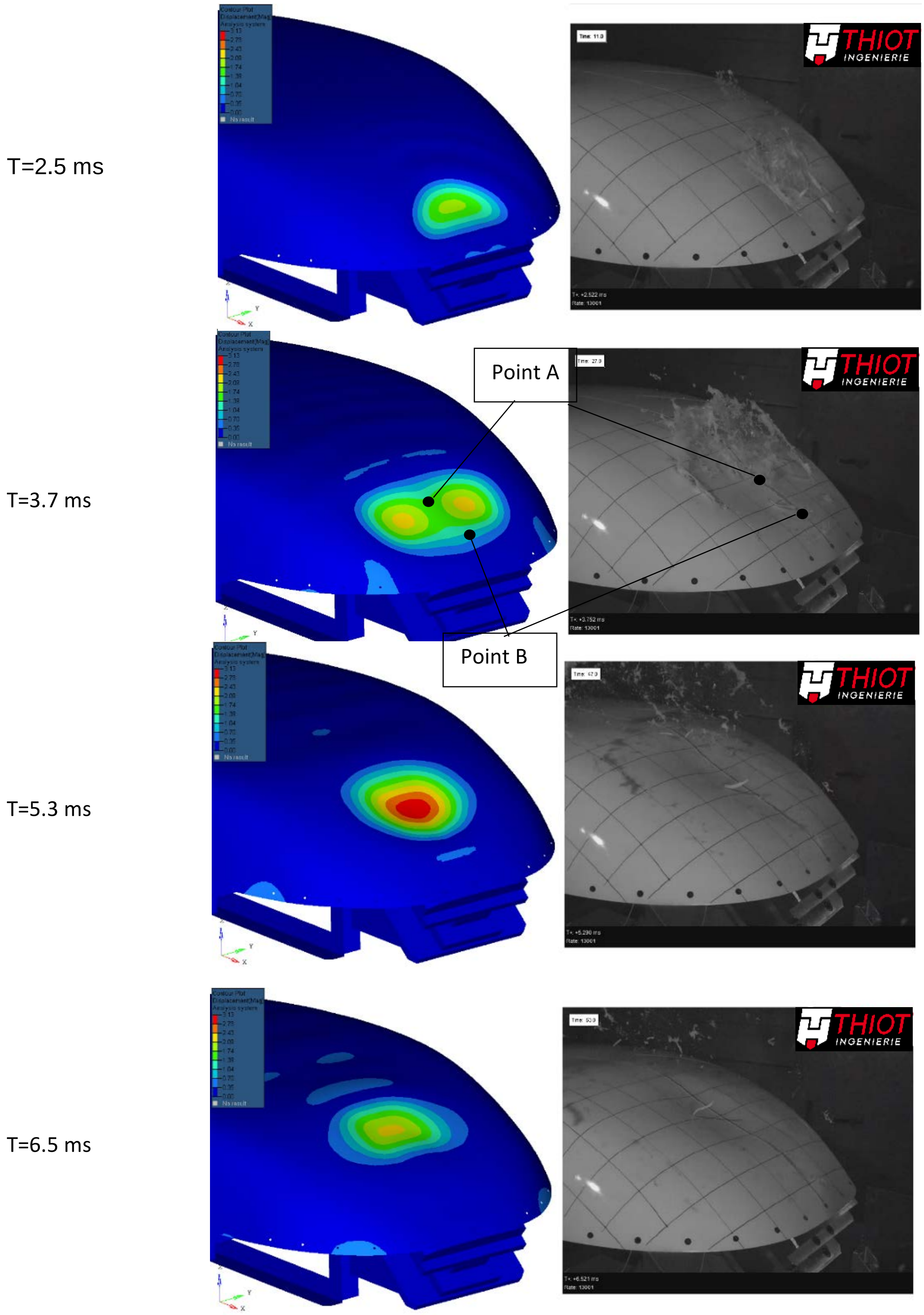


Fig.30: Comparison of the simulated displacement with high speed camera images

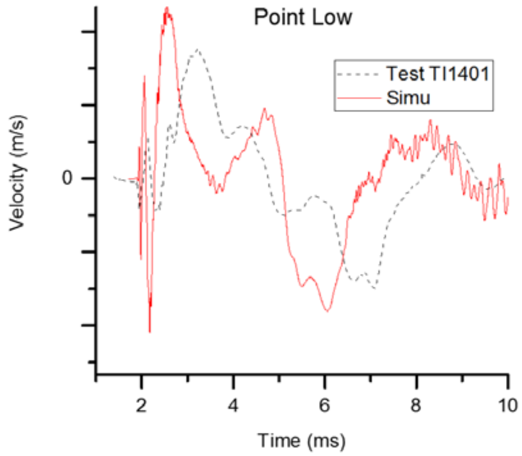


Fig.31: Comparison of velocity at point A

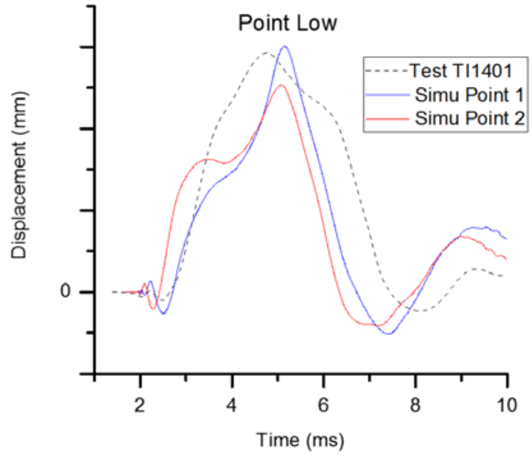


Fig.32: Comparison of displacement obtained from the integration of velocity at point A (point 1 and point 2 are two close nodes of the model)

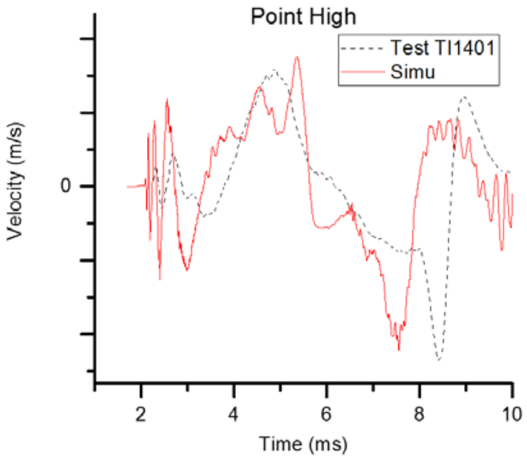


Fig.33: Comparison of velocity at point B

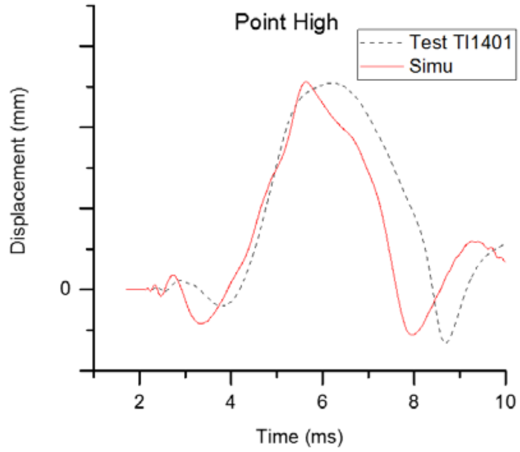


Fig.34: Comparison of displacement obtained from the integration of velocity at point B

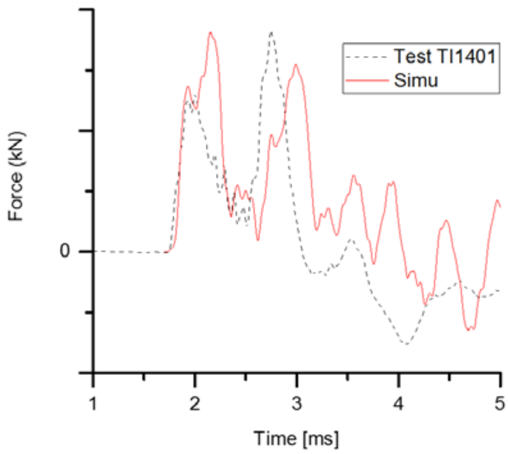


Fig.35: Comparison of impact force

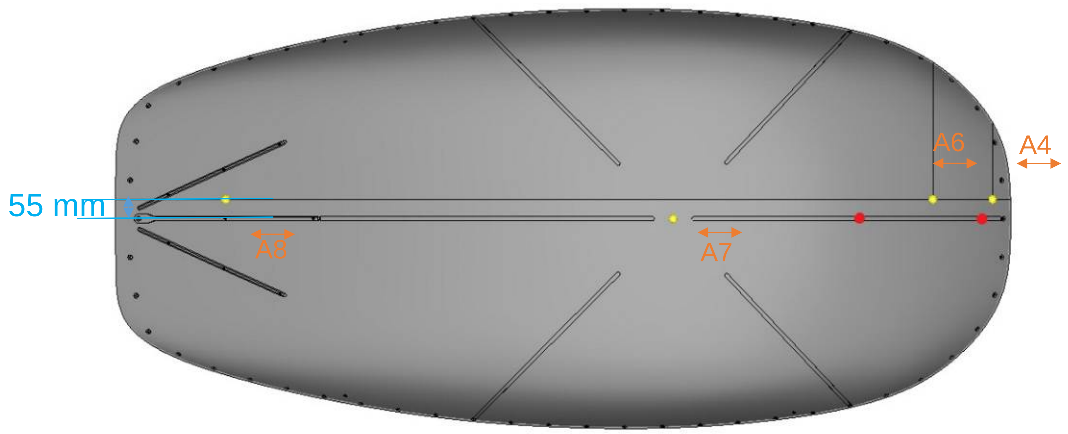


Fig.36: Gauges position

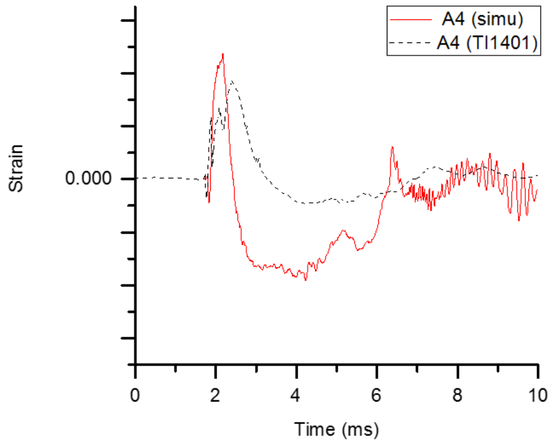


Fig.37: Comparison of strain for A4

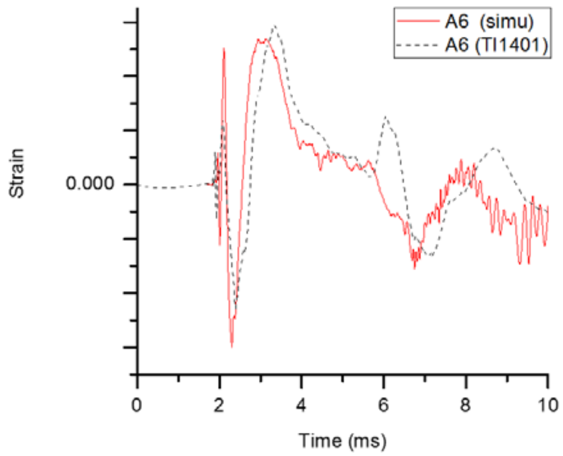


Fig.38: Comparison of strain for A6

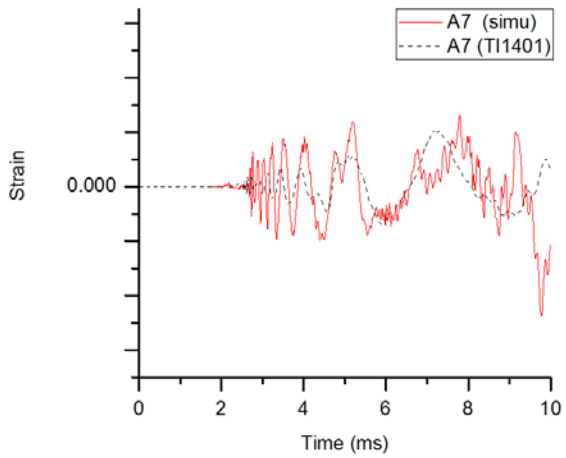


Fig.39: Comparison of strain for A7

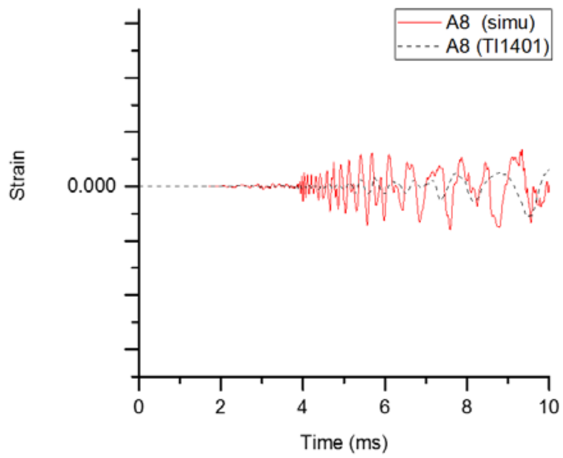
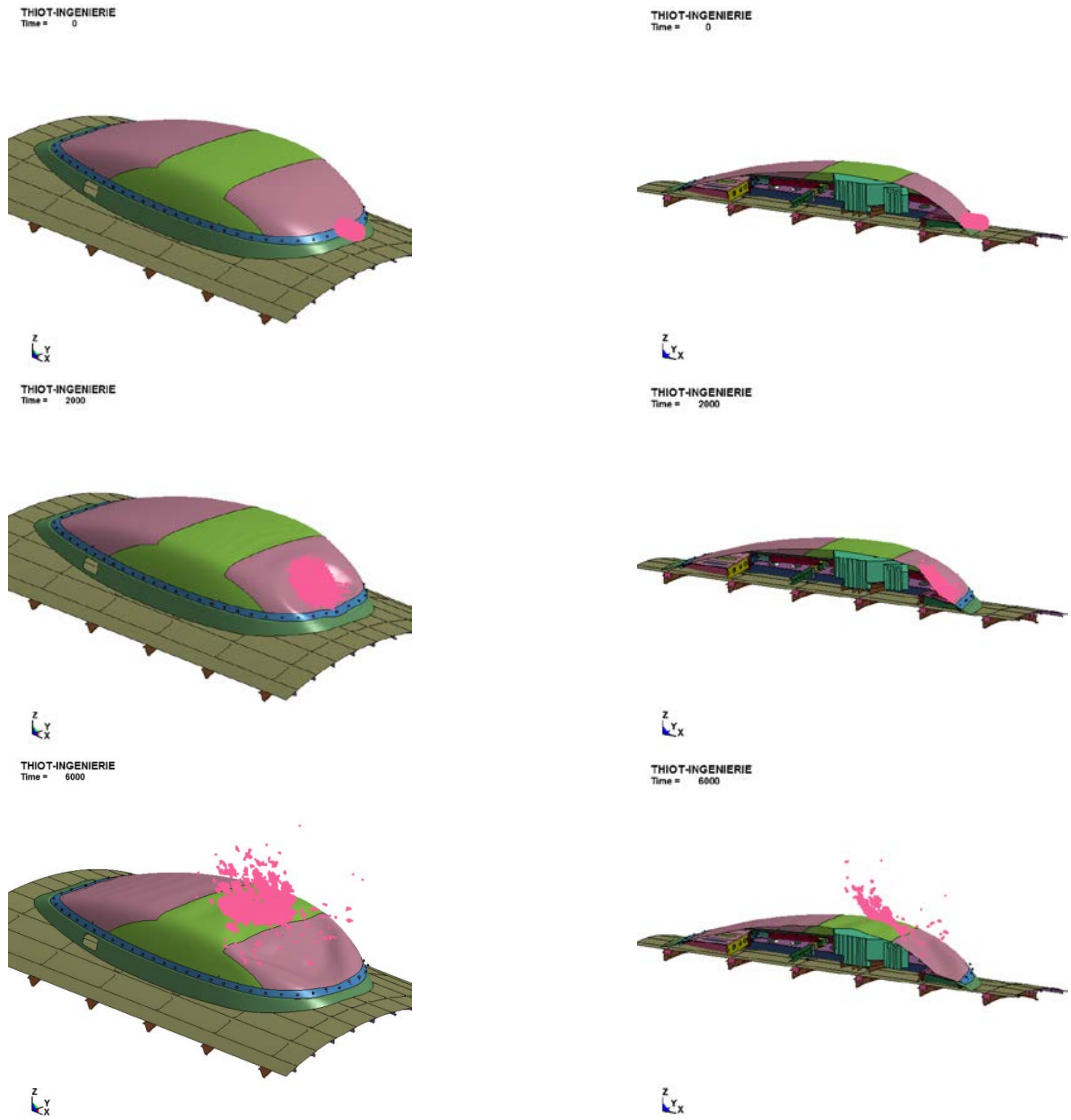


Fig.40: Comparison of strain for A8

6 Calculation of radome and interface structure

After validation of the composite material behavior, calculations of the interface structure on fuselage have been performed. These calculations have allowed us to improve the front part of the interface structure. The last design is the one tested during the bird strike certification test.
Pictures of this section show the calculation of the last design.
Fig.41: shows the deformation shape of the projectile and the radome. During the first moments, the projectile spreads over the surface of the radome. Then, it is deflected and ejected to the top side of the radome. The radome undergoes large deformation and hits the antenna.
Fig.42: shows the Von Mises stresses on the structure.

Fig.41: Deformation of the radome



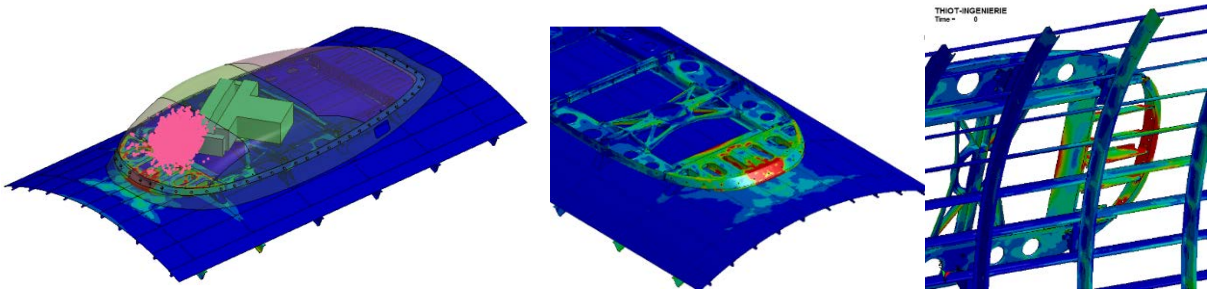


Fig.42: Maximum Von Mises stressesCertification test and correlation

7 Certification test

7.1 Test rig and measurements

Fig.43: to Fig.44: show the setup configuration. The whole structure (Radome+interface sructure+piece of fuselage) is screwed on steel frame.

Measurements have been performed to be able to do some correlations with calculations and to improve knowledge of the structure and material.

<u>Metrology systems</u>:
- Projectile velocity measurement,
- One deflection measurements: one rear side of the radome,
- One high speed camera,
  Four strain gauges (Bi-directional).

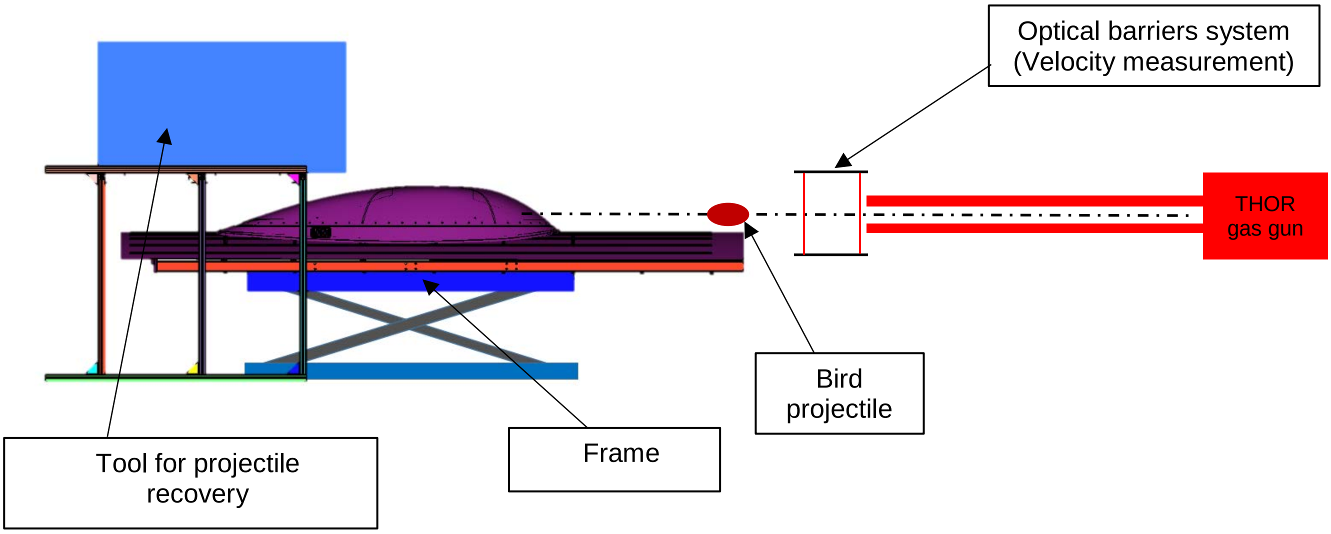


Fig.43: Test rig configuration

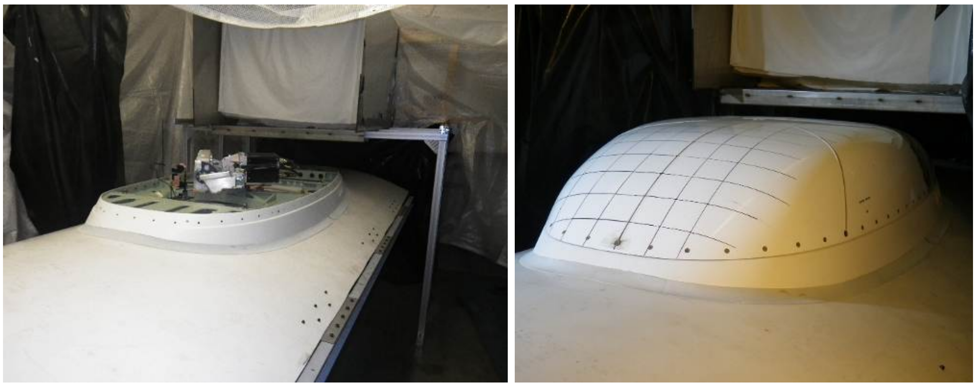


Fig.44: Radome view

The certification test is performed by a gas gun of the Thiot-Ingenierie shock physics laboratory. (Fig.45:)
THOR Light Gas Gun (LGG) is a single stage launcher (see Figure below) which can be configured using different barrel diameters: Ø100 mm, Ø140 mm, Ø 220 mm and Ø 350 mm. Thank to this particularity, the LGG allows to obtain several impact velocities with various types of projectiles or targets. This gas gun allows getting higher energies that TITAN.

Fig.45: THOR LGG (220 mm version).

7.1 Test Parameters

The following table shows the main parameters of test.

Table 2 : Summary of the shot parameters

Thiot test number THOXXX	**Bird mass (g)**	**Impact velocity ($m.s^{-1}$)**
TH0006	1842	191.7

7.2 Measurement results

The following pictures are taken from high speed camera video. (Fig.46:)

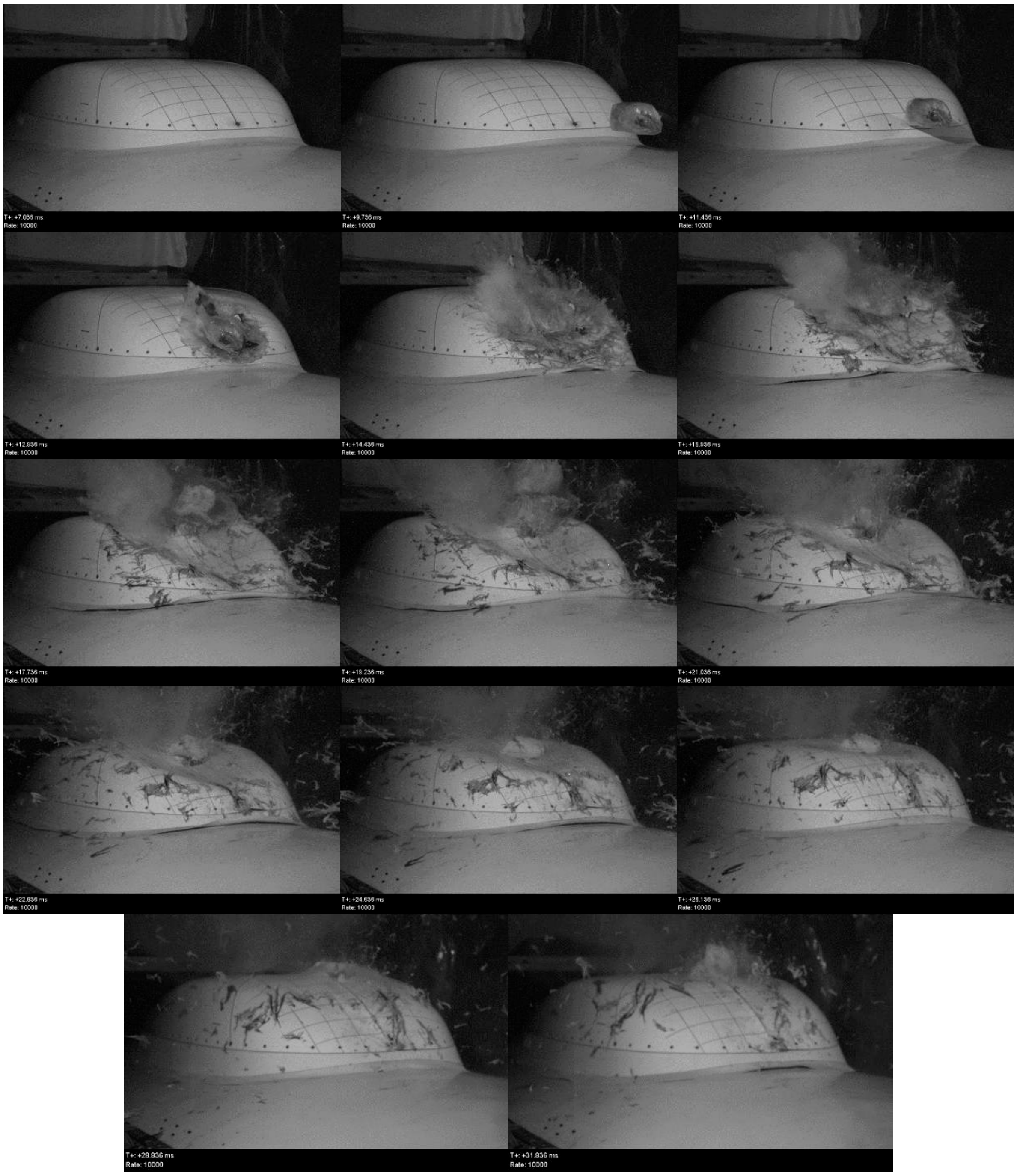


Fig.46: Pictures extracted from high speed camera

7.3 Test and calculation correlation

On following sections, velocities and strain measurements from sensors are plotted. Velocity signal is integrated to get displacement of measured points and it is derivated to get accelerations. (Fig.47: to Fig.52:)
The velocity measurements signal is lost before the end of the test due to the impact of the radome on the sensors.
A strain gauge is placed on the interface structure between the radome and the fuselage.
The correlations show that global behaviors are well predicted by calculations.

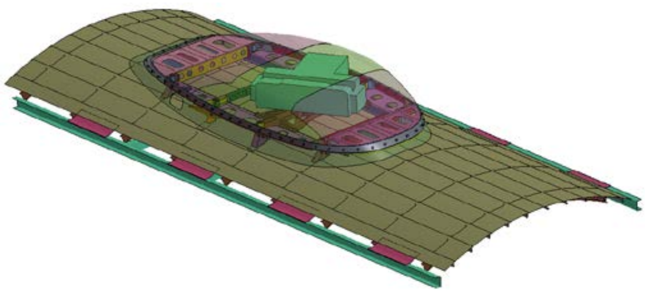


Fig.47: Global structure vizualisation

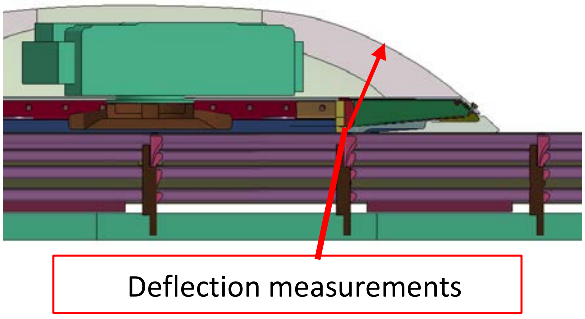


Fig.48: Deflection measurement location

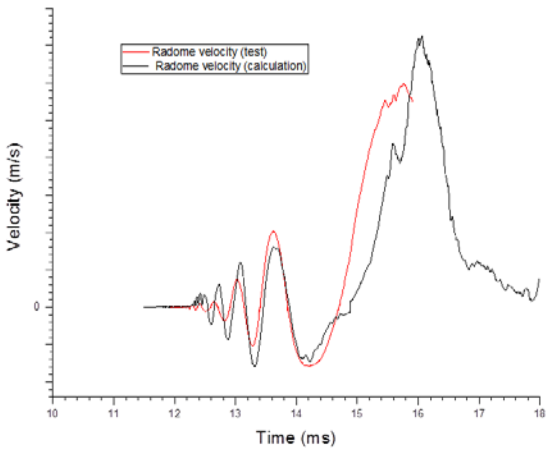


Fig.49: Comparison of velocity

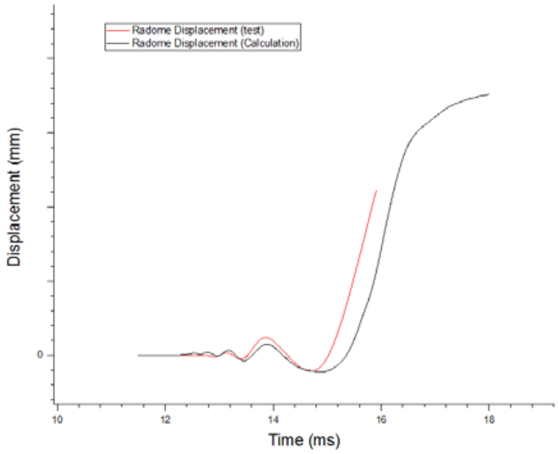


Fig.50: Comparison of displacement

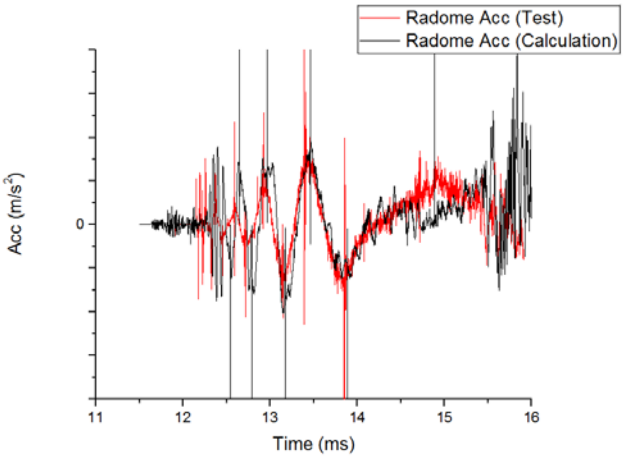


Fig.51: Comparison of acceleration

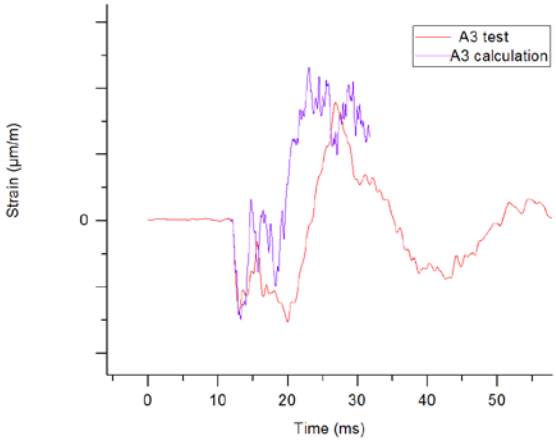


Fig.52: Comparison of stain

8 Summary

This paper presented the development of an aircraft structure subjected to bird strike. The structure is an additional radome used to add some connectivity means on current commercial planes.
The challenge of this development was to certify the radome and the interface structure in less than 8 months. Due to this short delay and uncertainty of composite materials, a strategy mixing calculations and tests has been performed to obtain a strong development efficiency.

After preliminary calculations on the radome, some gelatin tests with metrology means have been performed at Thiot-Ingenierie shock physics laboratory to study the behavior of composite materials.

Correlations are used to perform calculation on the radome to improve the interface structure before the certification test.

The final design has been validated with a bird strike certification test at Thiot-Ingenierie shock physics laboratory. Measurements have been set on this test in order to improve knowledge and to conduct a final correlation between test and calculations.

Thanks to this study, the certified interface structure has been improved to obtain certification for other aircrafts.

This method can be applied to various aircraft structure. Moreover, it is a way of and improved and robust methodology for aircraft structure certifications.

9 Literature

[1] F. Plassard, P.L. Hereil, P. Joseph, J. Mespoulet. *Experimental and numerical study of a bird strike against a windshield*. Thiot-Ingenierie – DYMAT 2015.

[2] J. Thorpe: *International bird strike committee: "Fatalities and destroyed civil aircraft due to bird strike*, 1912-2002 (2003)

[3] Report of Associate Administrator of Airports, Office of Airport Safety and Standards, Airport Safety & Certification "*Wildlife strikes to civil aircraft in the United States 1990-2013*", Washington (2014)

[4] J. R. Allan, *The costs of bird strikes and bird strike prevention* (2000)

[5] S.C. McCallum, C. Constantinou, *The Influence of Bird Strike Analysis*, (2005)

[6] L. Jun, L. Yulong, G. Xiaosheng, *The Influence of bird-strike on sidewall structure on an aircraft nose*, Chin. Soc. Of Aero. & Astro., Beihang University

[7] L. S. Nizampatnam, *Models and methods for bird strike load prediction*, Aero. Eng. Wikita State University (2009)

[8] J.P. Barber, H.R. Taylor, J.S. Wilbeck, *Characterization of bird Impacts on a rigid Plate* (1975)

[9] P. Thiot, *Description of a new 220 mm gas launcher at THIOT INGENIERIE's plant and first results*, Proceeding of the 61st ARA meeting, Thun (2010)