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REFERENCE : 1) Report Agusta 129-01-22, "Criteri di progetto a crash dell'elicottero A129"
2) Rel. Martin Baker MBA/QTP/128, "Dynamic, static and enviromental test plan for the energy absorbing helicopter seat used in the Agusta A129", Iss. 5
3) SAE J211, "Instrumentation for Impact Test, SAE Recommended Practice, October 1988.
4) A. Gamon, "General aviation airplane structural crashworthiness user's manual", Volume I, Program Krash Theory
5) A. Gamon, G. Wittlin, General aviation airplane structural crashworthiness user's manual", Volume II, Techniques and Applications

TITLE : A129 CRASH TEST AND SIMULATION

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Agusta, the Department of Aerospace Engineering of the Politecnico of Milano and CIRA (Centro Italiano Ricerche Aerospaziali) in the last four years have carried out a crashworthiness research program. The main goal was to improve the partners capabilities in crash testing, test data analysis and numerical simulation in order to achieve deeper understandings in rotorcraft crashworthy design. The program included four full scale helicopter drop test beside an extensive theoretical and numerical simulation activity. The submitted paper included the last executed crash test in July 1997. The experimental data have been utilized to developed a Krash matemathical model able to understand the crashworthy behavior of an helicopter fuselage in several impacts conditions during the preliminary design phase.

1. INTRODUCTION

The objective of the program was to obtain experimental data from the a full scale crash test in order to build a mathematical model that will be used to understand the crashworthy behavior of an helicopter fuselage in several impacts conditions during the preliminary design phase. The test article is an A129 rotorcraft fuselage in project condition phase (Ref 1).and the mathematical model and simulation have been performed using the Krash code.

2. FULL SCALE TEST

2.1 Fuselage Setup

All parts of the actual fuselage not needed for the test objectives have been substituted in the test article with dummies having the same inertial properties.
The table 1 lists the elements, and their weights, that have been taken away and substituted with dummies consisting in lead blocks attached to the fuselage in such a way to not detach at the impact.

Item	weight
Shaft bendix	21 Kg
Sight unit	91 Kg
Battery unit	37 Kg
Copilot instrument	30 Kg
Pilot instrument	35 Kg
Bay 1 apparatus	80 Kg
Bay 2 apparatus	30 Kg
Bay 3 apparatus	30 Kg

Table 1

The parts that have been replaced with analogous components not able to fly are listed in the table 2.

The components not listed in the table (i.e. tail rotor, seats etc.) were already installed in the fuselage and did not need to be removed. The fuel tanks were been filled with water, respectively 350 Lt for the front tank and 360 Lt for the rear tank.

The pilot behavior has been simulated using two 55th percentile Anthropomorphic Test Dummies (Ref.2).
The weight and the the c.g. position of the fuselage has been verified at setup termination.
The Data Acquisition System (DAS) has been installed in the baggage dept because no dangerous yielding or leakage from the tanks was foreseen in that area. The DAS has been mounted on shock absorbing supports in order to reduce the G level at which it was exposed. The cables running from the transducers to the DAS were placed outside the fuselage on the left side in order to minimize the risk of cable strapping and to not interfere with the cameras field of view.
A white background has been placed behind the test article to provide a better contrast for hi speed cameras movie. A grid was drawn on the fuselage surface to help in identifying fuselage deformations and panels buckling, the grid size was 20 cm.

Item	Weight
Transmission	225 Kg
Main Rotor Head	161 Kg
4 Main Rotor Blade	149 Kg
Engine DX	181 Kg
Engine SX	181 Kg
HIRNS (mock up)	14 Kg
Conditioning	23 Kg
Launchers n.2 (mock up)	114 Kg
Missile TOW n.8 (mock up)	198 Kg

Table 2

2.2 Impact condition

The test has been executed dropping the fuselage from 6 meter with null attitude and straight trajectory the corresponding impact velocity was 10.8 m/s.
The fuselage has been lift by the mean of the rotor shaft, a crane has been used to lift the fuselage as shown in figure 1.

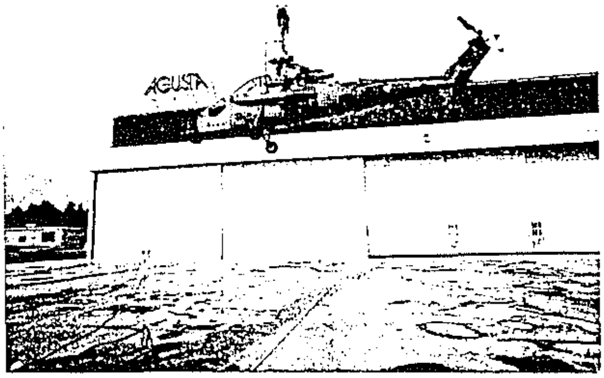


Figure 1

The test situ was chosen basing upon the following requirement.
- rigid impacts surface
- provide a wide enough area for the test article, the operators and crane
- availability of a white background for the telecast

The test has been performed at the Agusta company hangar.

2.3 Test instrumentation

Piezoresistive accelerometers have been used to measure the accelerations at the impact, the full range for the accelerometers was 250 G, table 3 lists the location and the orientation of the accelerometers.
The anthropomorphic test dummy mounted lumbar load cell. Strain gages have been mounted on the transmission support and the gear box to measure the dynamic load they were subjected to.
LVDTs have been mounted on the seats and on the bumpers to measure the displacement during the impact. The foreseen displacement were 300 mm for the seat and 600 mm for the bumper.
The DAS is able to withstand shocks up to 70G, the sampling frequency for each channel 10 kHz and the acquisition time is 6 sec.
The data were both stored in the on-board memory and transmitted to a ground unit for redundancy.
In order to minimize the risk of malfunctioning of any component and data loss, an automated control system based on a Programmable Logic Computer (PLC) drove the article release. The PLC released the test

article upon receipt of a ready signal from the DAS and from the hi-speed cameras system. For the hi-speed movie three hi-speed camera and an ordinary digital camera have been used, in particular the cameras was:
- a Bolex Paillard, 64 fps for the global test scene;
- a Nac-E10, 250 fps for the fuselage side shot;
- a Locam, 250 fps, for the front shot;
- an ordinary digital camera for global test scene.

Before the test execution and after the test took place the same photograph have been taken of the same parts in order evaluate the damage level.

Before the test execution photograph have also been taken of:
- the test article while on the ground and before the drop;
- inner cabin, sets and mannequins;
- main and tail landing gear;
- tail;
- all sensors (accelerometers, strain gages, LVDT);
- on board data acquisition system;
- test field.

Sensor	Axis	Location
1	Z	Forward frame
2	Z	Pilot panel
3	Z	Copilot seat
4	Z	Copilot head
5	Z	Copilot bottom seat joint
6	Z	Copilot top seat joint
7	Z	Pilot seat
8	Z	Pilot bottom seat joint
9	Z	Pilot top seat joint
10	Z	Landing strut mount
11	Z	Forward mount gear box
12	Z	Rear mount gear box
13	XYZ	Gear box
14	Z	Engine mount
15	XYZ	Engine
16	Z	Tail rotor
17	Z	I.G.B.
18	Z	Machine gun frame

Table3

2.4 Test Execution

The task list before drop was the following:
- test area cleaning;
- release system verification;
- check for extraneous objects on the test article;
- test article hooking;
- data acquisition system check;
- hi-seed camera check;
- release system check;
- 10cm test article lift for attitude control;
- count down;
- drop;
- data acquisition and storage.

The acquired data have been processed according to the SAE J211 specifications. This standard gives recommendation on environmental immunity, transducers mounting, measurement methods, data acquisition system performance and data filtering.

2.5 Result analysis

The overall behavior of the test article was acceptable. In fact the structure maintained its global integrity, no external object (engine, gear box, landing gear support) penetrated the cabin, beside the cabin kept a surviving volume

Figure 2 shows the fuselage after the impact.

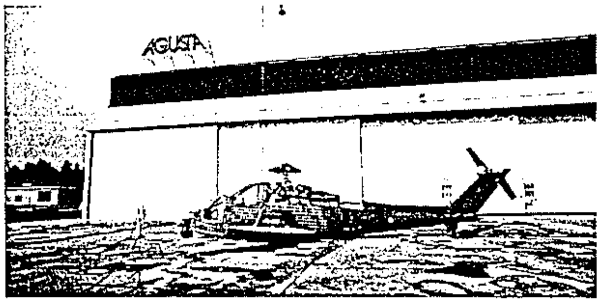
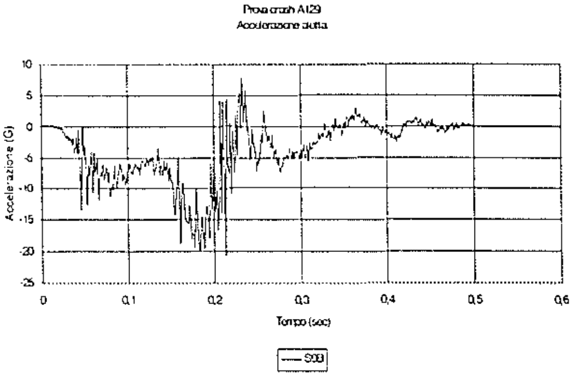


Figure 2

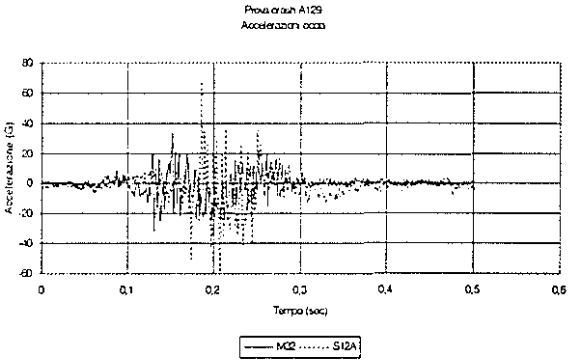
It can be noticed that:
-the main and the rear landing gear failed
the copilot windshield detached

At this stage only the accelerations have been analyzed. The following figures show some of the acceleration time histories.



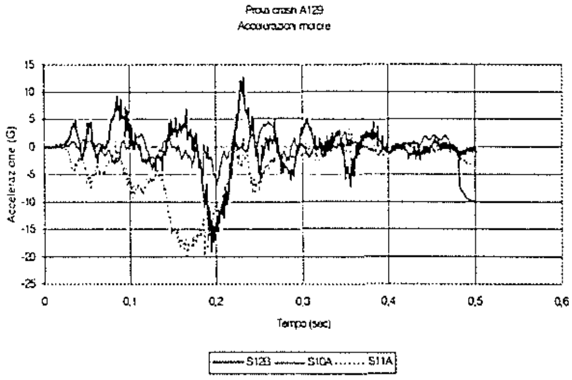
S8B: wing acceleration

Graph 1



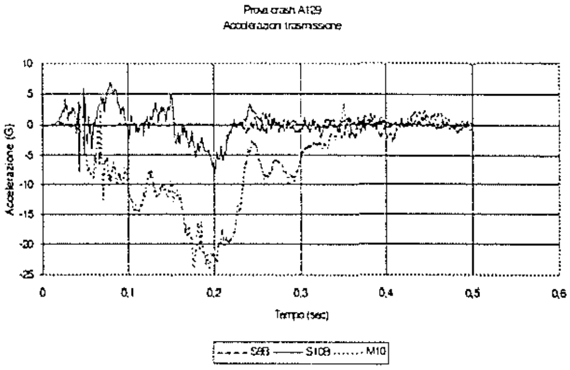
M32: tail acceleration
S12A: IGB tail rotor

Graph 2



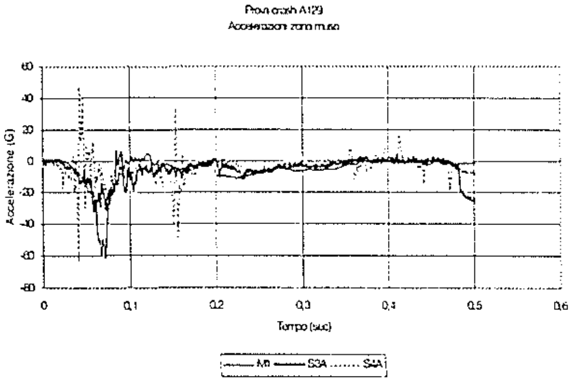
S12B: engine acceleration in the x direction
S10A: engine acceleration in the y direction
S11A: engine acceleration in the z direction

Graph 3



S8B: gearbox accelerations in the x direction
S10B: gearbox accelerations in the y direction
M10B: gearbox accelerations in the z direction

Graph 4



M1: machine gun acceleration
S3A: copilot command panel acceleration
S4A: landing strut mounting acceleration

Graph 5

These experimental data will be compared to the numerical model results.

3."LOAD-DEFLECTION"CURVE EXPERIMENTAL EVALUATION

A fundamental element for the krash code to work properly is the knowledge of the load-deflection characteristics of the structural element that during the crash interacts with the impact surface, these elements are called contact elements.

In order to define the behavior of the contact elements and of the elements subject to large deformations some load-deflection curves have been measured using an horizontal sled facility, at the Department of Aerospace Engineering of Politecnico di Milano.

The test articles have been obtained extracting 11 parts from another A129 available from the manufacturer Augusta.

The following component tests were considered meaningful:

- copilot seat frame
- landing strut mount
- pilot seat frame
- fuel tank mountings
- tail bottom box
- tail box frame
- tail bottom frame
- upper deck, this particular item has been cut in two parts in order to be properly mounted on the testing machine.

Figure 3 shows these components.

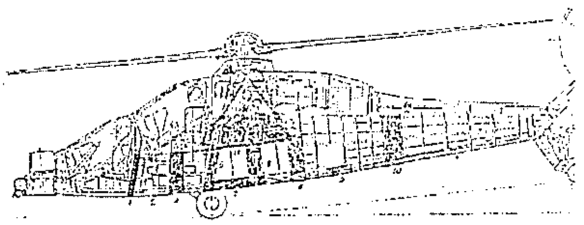


Figure 3

The test article was clamped on the vertical side of the incus, the sled was then accelerated to the required velocity thanks to an hi pressure air system.
Because of the test article's size the impact surface have been extended using a vertical steel plate on the front section.
During the test displacements and accelerations have been recorded in order to obtain the load deflection curve for the sub-component. Data have been sampled at 8 kHz. The raw data have been subsequently digitally filtered using a CFC180 filter, a CFC60 filter showed to be not adequate as it took off too much energy from the pulses.
Some shots have been taken using a NAC E-10 camera, 16mm 1500 fps.

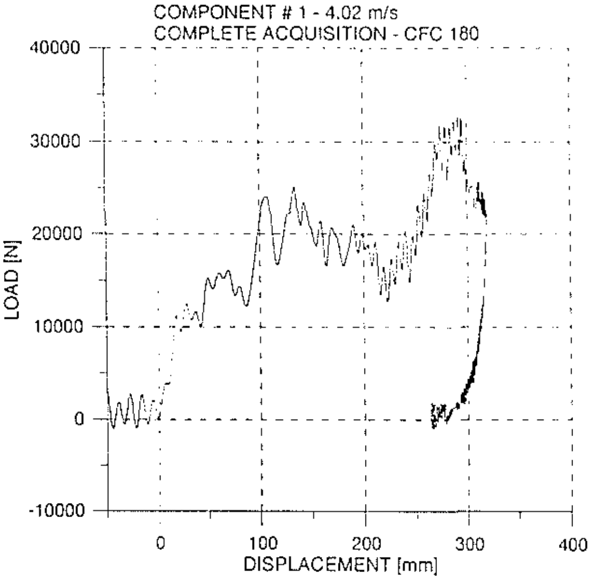
3.1 Impact Condition

The sled-test condition have been set considering that the drop-test article weight is about 3700 kg, the impact velocity will be 10.8 m/s it follows that the kinetic energy was 215kJ.
If we suppose that the landing gear will dissipate the 60% of the energy (129kJ) the remaining part of the structure will absorb the 40% corresponding to 86kJ. The main absorbing elements will be:
- machine gun mounting frame;
-copilot seat support frame;
- main landing strut mounting frame;
- pilot seat support frame;
-fuel tank forward frame;
- fuel tank rear frame;

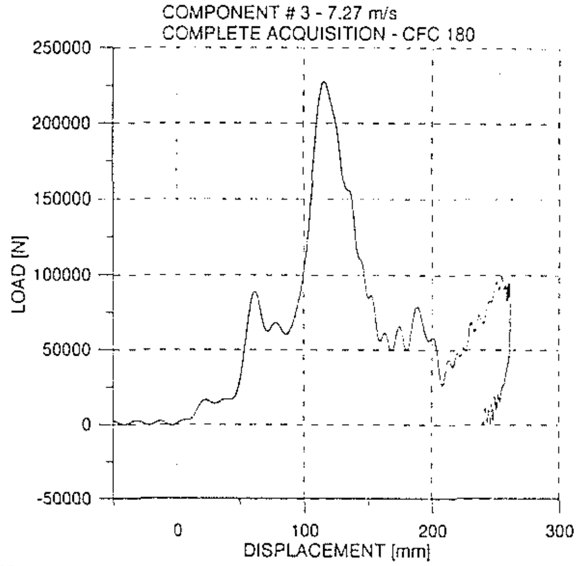
Assuming that all the parts will share the same portion of energy, each one will absorb approximately 14.3 kJ.
Now as the impact mass of the sled is about 714 Kg the velocity at the impact, in order to have the same energy level of the drop test, has to be 6.3 m/s.
The real impact velocity ranged from 4 to 9 m/s basing because of the different strength of the elements tested.

3.2 Results

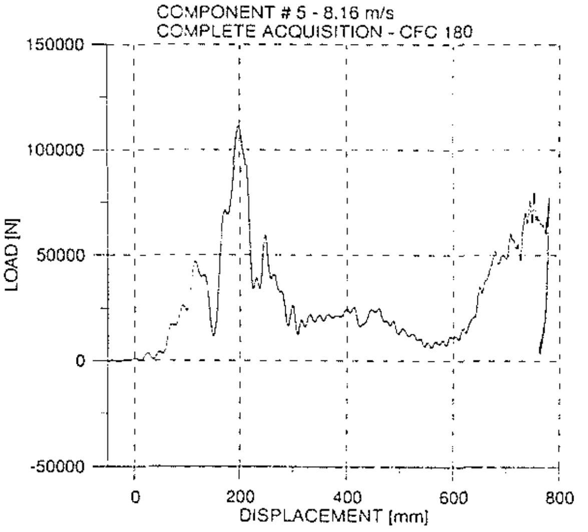
The results for each component are shown below, particularly the load-deflection curve are shown.



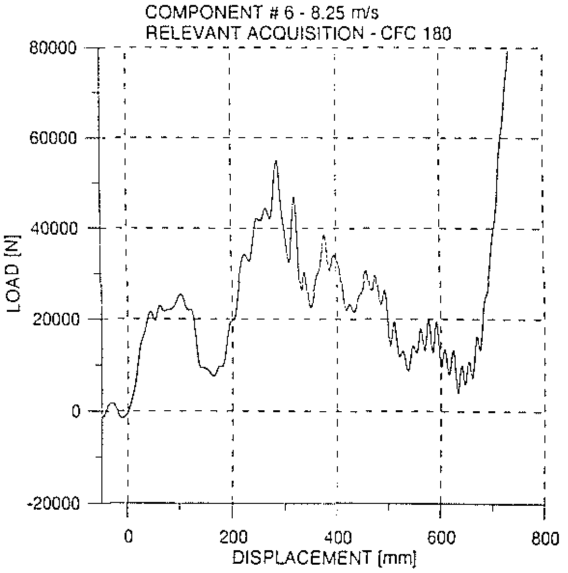
Copilot seat frame (component 1), impact velocity.4.02 m/s.



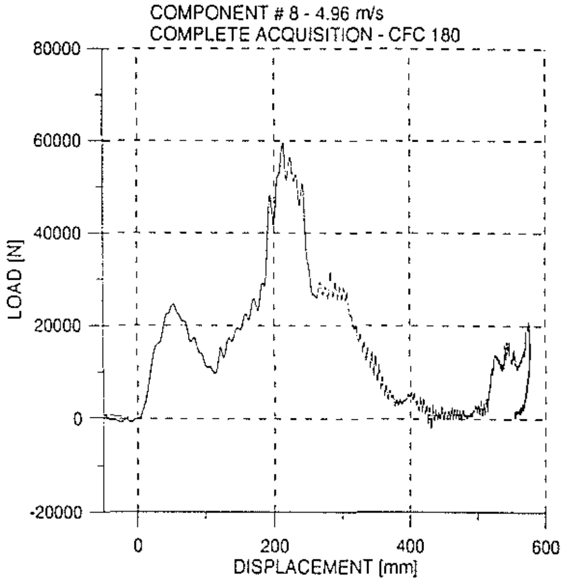
The landing gear strut mount section (component 3), impact velocity: 7.27m/s.



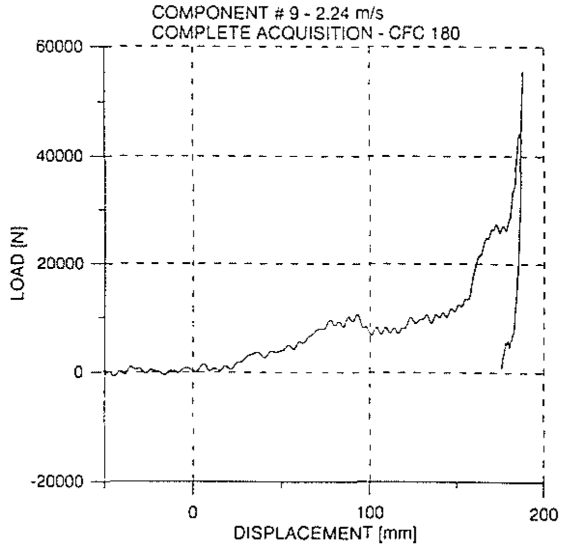
The pilot seat section (component 5), impact velocity: 8.16m/s.



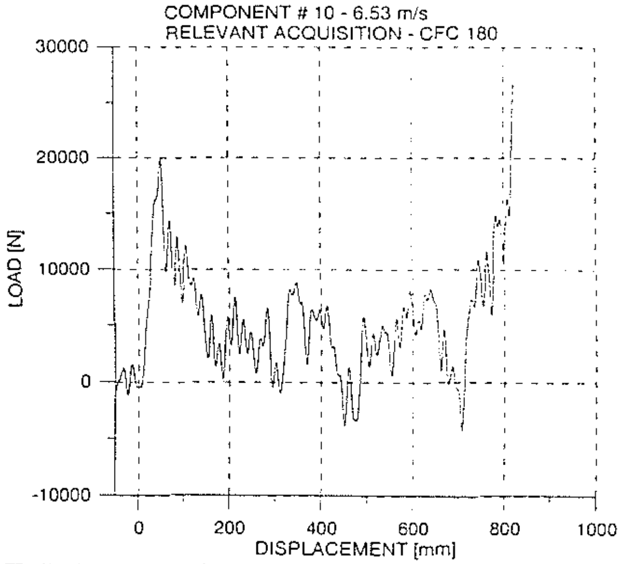
The middle fuel tank frame (component 6), the impact velocity: 8.25m/s.



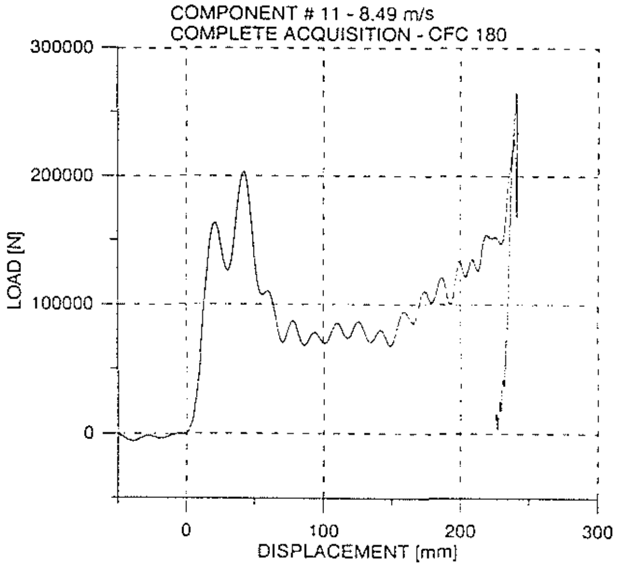
Rear fuel tank frame (component 8), impact velocity 4.96 m/s.



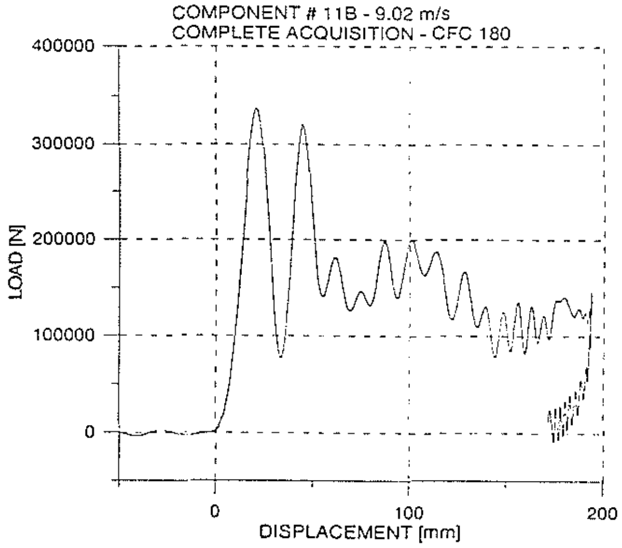
tail bottom box (component 9), impact velocity: 2.24 m/s.



Tail box section (component 10), impact velocity: 6.53m/s.



Upper deck (component 11), impact velocity: 8.49 m/s.



Upper deck (component 11B), impact velocity: 9.02m/s

In some cases the impact energy was too high and it could not be completely converted in deformation of the test article, instead in some cases the test article deformed in a not controlled way and the impact mass hit against the incus, for these cases the data obtained are not meaningful as they don't represent any possible behavior of the sub component under testing.

4. KRASH SIMULATION

The Krash code is able to predict the dynamic response of vehicles during crash scenarios. A Krash numerical model consist in masses connected by internal beams and non linear external spring element to simulate the contact at the impact location (Ref. 4).

4.1 Krash model description

For the numerical simulation a 3D matemathical model, as shown in figure 4, has developed consisting in 30 masses, 28 springs, 64 internal beams, 9 non linear beam. The main landing gear behavior has been simulated using shock strut element.

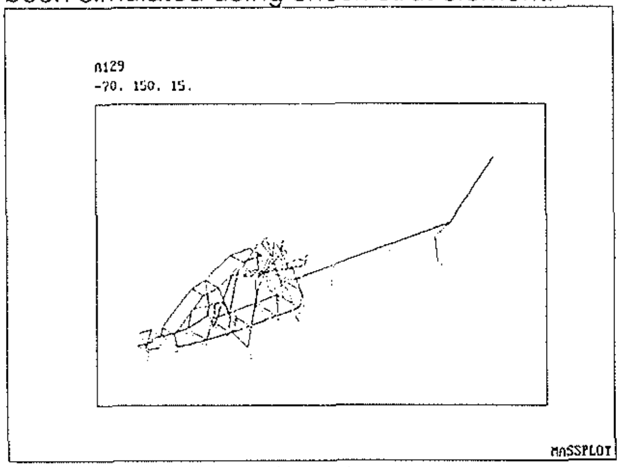
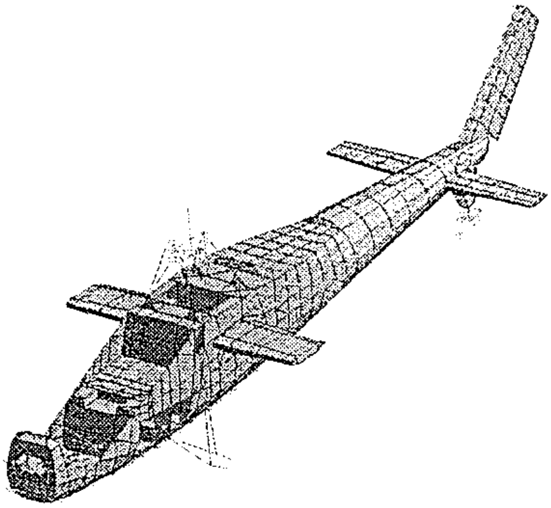


Figure 4

4.2 Mass distribution

The mass distribution for the Krash model, representing the inertia properties of the model, has been obtained using a Finite Element Model of the structure under examination. This model was built during the project phase, the effective position of the c.g. of each mass has been taken in account of. When the c.g. position of the mass was not coincident with the position of any node, nodal points were rigidly connect the mass, while the beams and the springs were connected only by the means of nodal points.



4.3 Internal beams

The connection elements were considered massless and represents the stiffness properties of the structure to be analyzed.
Each internal beam have been characterized with the cross section inertial properties. Most of the elements have linear behavior, and just 9 beams are modeled as non linear.

4.4 External Spring

External springs are non linear contact element simulating the crushable portion of structure interfering with the impact surface.
In order to find out the load deflection curve for this elements a several tests have been conducted on full size components.
Figure 5 shows the external springs distribution for the subfloor and the landing gear wheels.

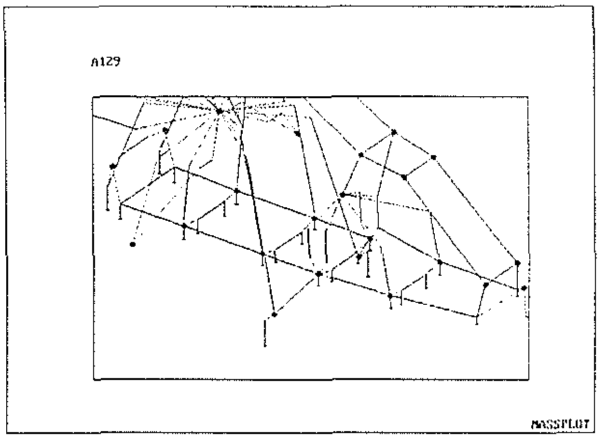


Figure 5

4.5 Impact Condition

The simulation impact condition was 10m/s impact velocity corresponding to a 6 meter fall. The impact surface was supposed as rigid and the object had zero attitude.
In order to reduce the computational time the beginning of the simulation was the impact time.

4.6 Sequence of meaningful events during Krash simulation

t = 0.000:
- beginning of main landing gear wheel impact.

t = 0.019:
- main landing gear compression;
- beginning of machine gun impact.

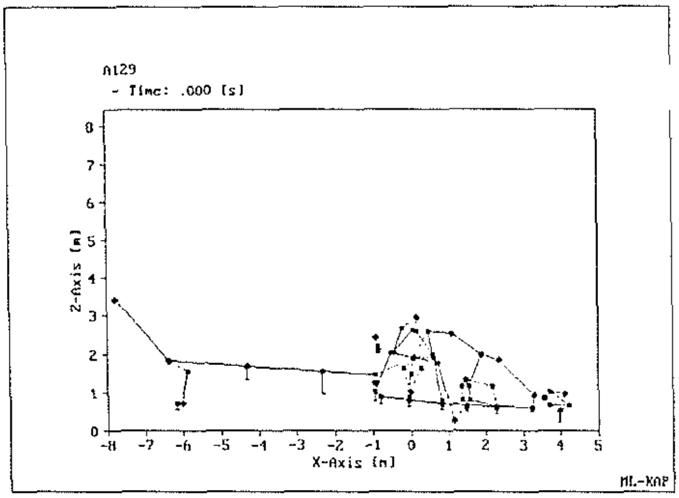
t = 0.051:
- beginning of front subfloor crushing;
- main landing gear compression;
- beginning of tail landing gear wheel impact

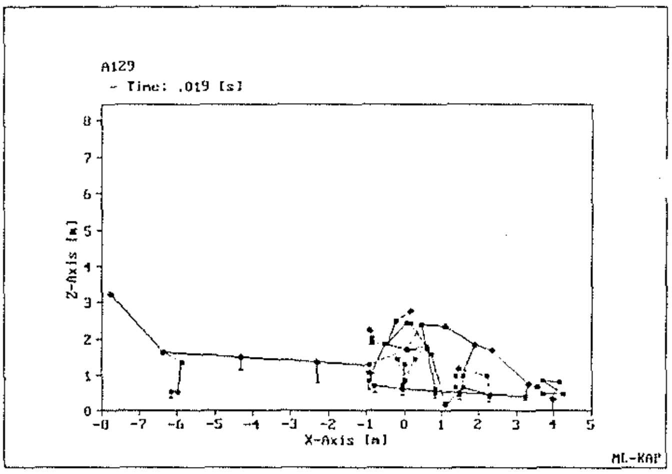
t = 0.096:
- beginning of nose rebound
- beginning of rear subfloor crushing
- highest compression of main landing gear
- beginning of first tail section impact
- tail bending

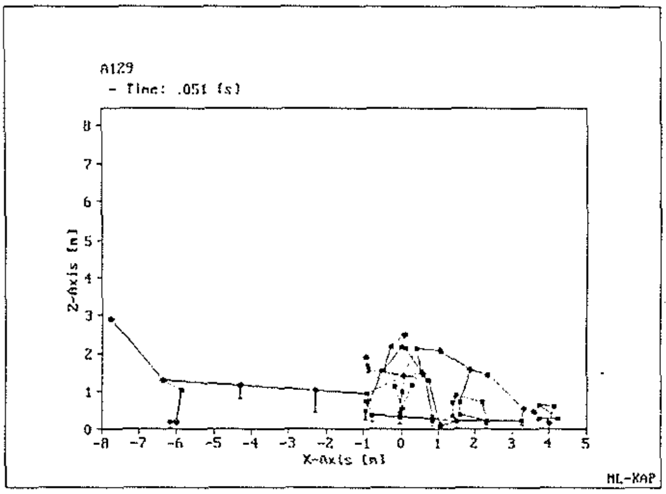
t = 0.122:
- nose detachment from the ground
- beginning of maim landing gear elongation
- rear subfloor crushing
- tail section impact
- tail bending
- tail landing gear compression

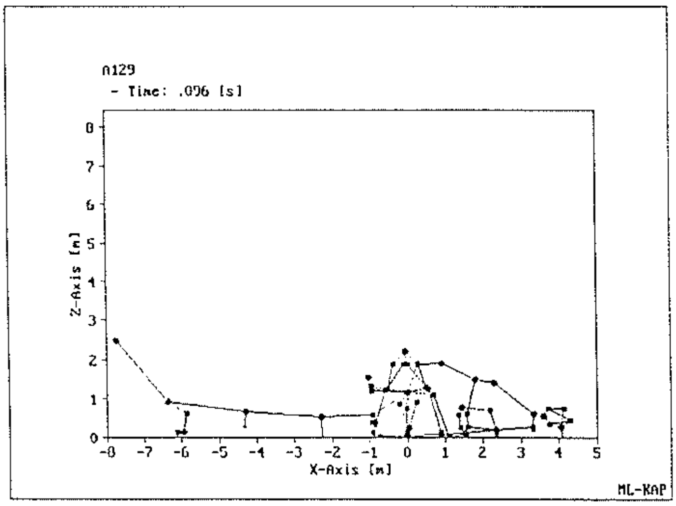
t = 0.320:
- fuselage detachment from the ground
- total tail impact on the ground
- tail landing gear failure

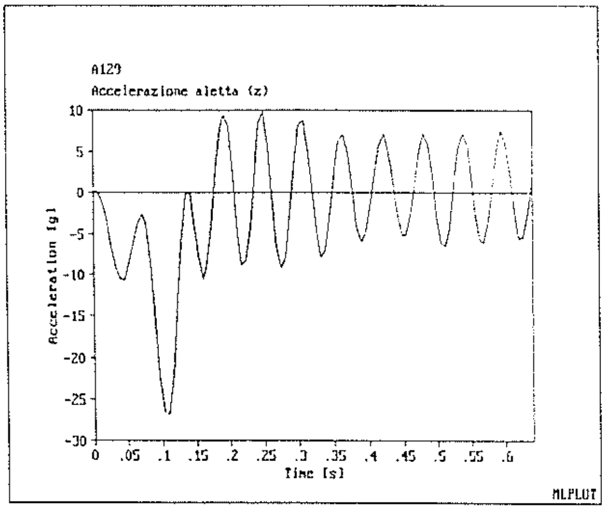
The subsequent simulation time show the rebound of the whole structure and the second impact on the ground



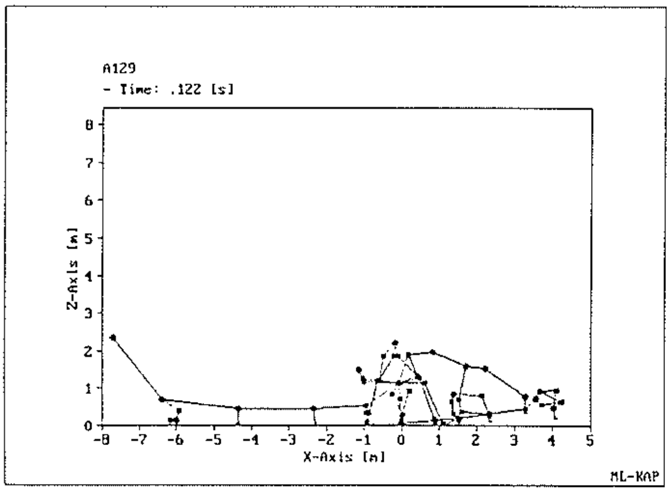


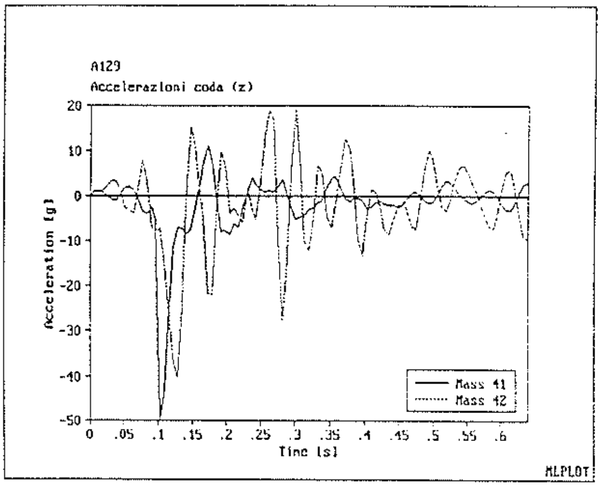




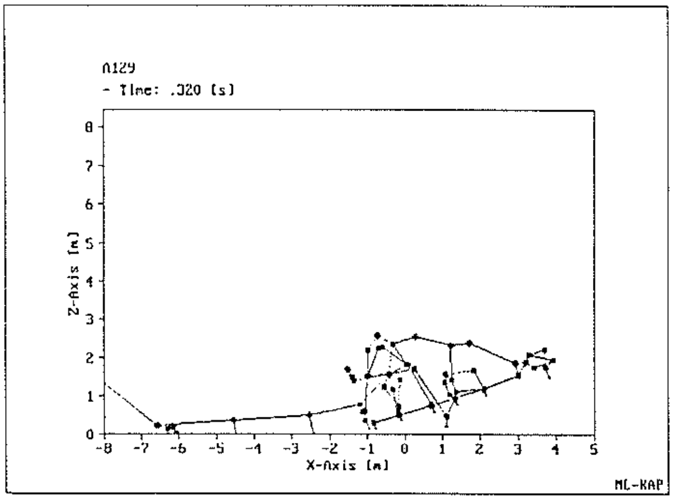


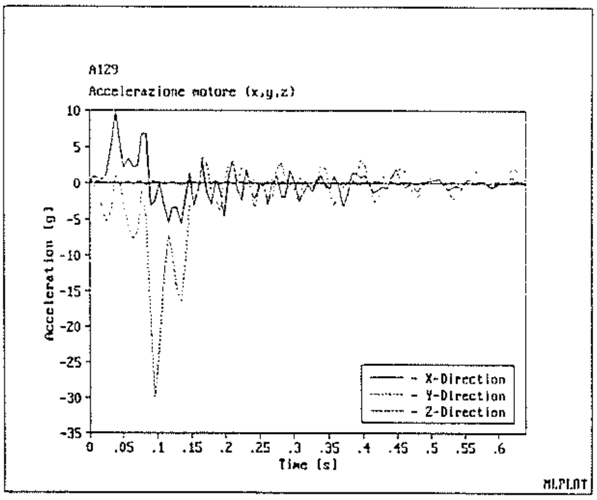
wing acceleration
Graph 1





M41: tail acceleration
M42: IGB tail rotor
Graph 2

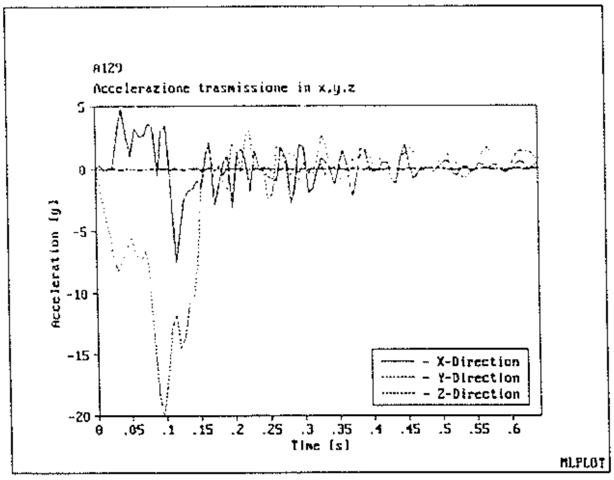




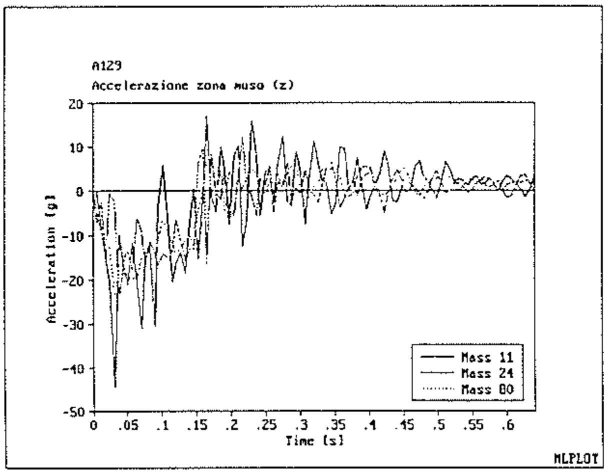
engine acceleration in the x direction
engine acceleration in the y direction
engine acceleration in the z direction
Graph 3

4.7 Results

Following are shown the acceleration time history obtained from the Krash numerical simulation that are compared with the data test.



gearbox accelerations in the x direction
gearbox accelerations in the y direction
gearbox accelerations in the z direction
Graph 4



M11: machine gun acceleration
M80: copilot command panel acceleration
M24: landing strut mounting acceleration
Graph 5

5. Experimental and numerical data comparison

The acceleration level obtained with the Krash numerical simulation are quite close to the experimental data.

The observed differences between the Krash output and the test data are due to the different locations of accelerometers in the test article and of the masses in the Krash model, in fact it was not feasible to mount the accelerometer in the exact location of the c.g. of the mass, moreover the accelerometer measure is strongly influenced by the stiffness properties of the structure section it was mounted on.

It can be noticed a delay factor between the dynamic response of the real structure and the Krash model response. In particular some of the experimental peaks occur before than the predicted time and the numerical outcome shows a narrower pulse than the test result.

It has to be taken account of the approximation undertaken in modeling the load-deflection curve for the contact elements. Krash, in fact, just allows to assign two load levels (Ref. 5) as shown in figure 6

This can be glanced as a consequence of having modeled a stiffer structure than the real one.

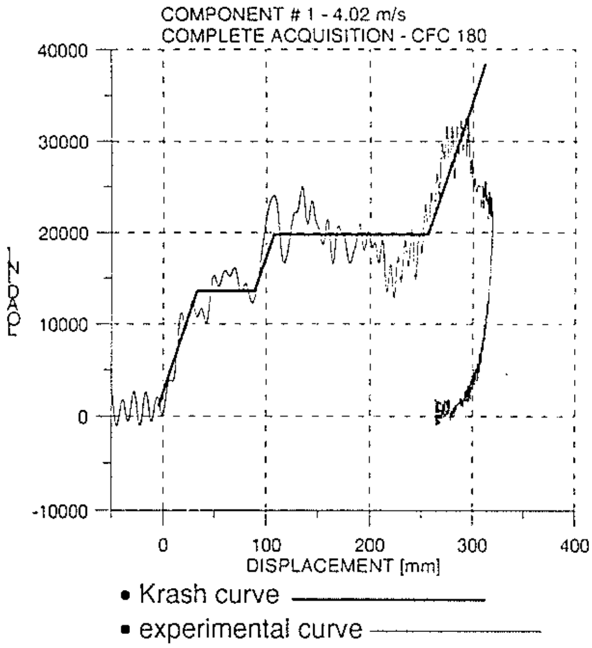


Figure 6

Beside the testing velocity for the sub-components load-deflection characterization was for sure different from de impact velocity at the full article drop-test.

6. Conclusions

From the results provided by the Krash model it can be acknowledge that the numerical model is suitable for rotorcraft crashworthy behavior analysis in the preliminary design phase. We are confident that if more detailed information's are available, in particular for the shock strut elements, which models the main landing gear, it will be possible to obtain a Krash numerical model also able to provide useful analysis during a developing project phase.