EXPERIMENTAL TESTING AND NUMERICAL SIMULATIONS OF AN HELICOPTER FUEL TANK CRASH

Marco Anghileri
Aerospace Enginering Department. Politecnico di Milano. Italia
Lorenzo Notarnicola
CIRA (Centro Italiano Ricerche Aerospaziali). Capua. Italia

Abstract

Object of the present work is the study, by means of experimental testing and numerical simulations, of the crashworthiness characteristics of an helicopter fuel tank.

A good design of fuel tanks is essential in preventing dangerous injuries in crash landings; most of those injuries are in fact caused by fire generated by fuel leakage after the impact. While good results has been obtained in reducing accelerations expert by passengers during impacts improving seats and restraints systems, extensive effort are still required in order to reduce fire hazard in crash landings.

Existing regulations ask for fuel systems crash resistance to be verified with static tests and a final drop test. The prescribed static tests are of arduous realisation mainly due to the difficulty of representing fluid dynamic loads acting on to the tank structure. This work try to propose a new kind of testing for helicopter tanks by means of dynamic tests similar to those prescribed for other aircraft structure (i.e. seats). Besides the experimental tests a finite element numerical study has been conducted to better investigate the fluid-structure interaction and therefore detect the solutions necessary to make the structure able to pass the tests prescribed by the regulations.

Introduction

In the last years several attempts have been made to improve aircraft and helicopter passenger safety during crash landing. The introduction of shock absorber mounted on the seats and deformable subfloor have allowed to obtain a better safety than in the past. In this moment dangerous injuries are caused mainly by three causes: human body high accelerations, i.e. cerebral damages, impacts against cockpit surfaces and injuries caused by fire or suffocation. While a good safety can be achieved for the two first problems (accelerations and impacts), with already experimented solutions, for the third problem we are far from the solution. Numerous studies, conducted since the '40, have revealed the very severe hazard associated with postcrash fire. Table I (Ref. 1) show that approximately 15 percent of the injuries and fatalities in Army and civilian helicopter accidents in the '60 and '70 were caused by fire. At the end of the '60 U.S. Army issued the first regulations (MIL-T-27422A) with the objective of eliminate postcrash fire in survivable accidents. Crashworthy fuel systems were developed obtaining very encouraging results (see Tab.2).

Tab. 1 - Fire hazard in helicopter accidents

	Injuries		Fatalities	
	Thermal	Non-Thermal	Thermal	Non-Thermal
U.S. Army Helicopters 1967-1968 100 Accidents 133 Postcrash Fires	64	1.297	95	159
U.S. Civilian Helicopt. 1974-1978 86 Accidents	13	174	18	42

Tab. 2 Safety Improvements due to CrashWorthy Fuel System

	Survivable		Non survivable	
Classification	W/O CWFS	With CWFS	W/O CWFS	With CWFS
Thermal Injuries	20	5	5	0
Non-Ther. Injuries	529	386	13	28
Thermal Fatalities	34	0	31	1
Non-Ther. Fatalities	120	44	229	85
Accidents	1160	1258	61	32
Postcrash Fire	43	16	42	18

Civil regulations concerning postcrash fire hazard are been developed only in the 1993 and presently to avoid fire after an emergency landing two methods are considered: chemical products added to fuel to avoid inflammable vapour productions and new fuel structure design to limit the risk of fuel leakage after impact.

This work starts from these considerations concerning an existing fuel system (Agusta Helicopters A109) designed before the issue of actual regulations on fuel tank crash resistance. The first objective was to find the compliance of that fuel tank with regulations, the second being verify regulation applicability and coherence.

Regulation Requirements and Limits

Regulations for civil helicopter (JAR 27-29, ref 2) require the fuel tank crash resistance to be verify by test at the following ultimate inertial load factor (in the case of fuel tank located above or behind the crew or passenger compartment) :

(i) Upward - 1.5g
(ii) Forward - 8g
(iii) Sideward - 2g
(iv) Downward - 4g

and by means of a final drop test from the height of 15.2 m. In each case the structure must represent a fuel tank with water to the 80% of the normal full capacity and at the end of the tests must retain its contents and exhibit no leakage.

Clearly the first four tests are not of easy solution due to the loads that must be simulated (idrodynamic pressure on the tank walls). Considered as static tests they result inapplicable, while dynamic tests require information on acceleration pulses shape and duration. Besides, crash landings tests of other structural parts (i.e. seats) of the aircraft are already simulated by means of deceleration pulses obtained in especially designed crash test machines (Ref. 3).

Finally it seems then that the only way to find out the compliance with existing regulations is to setting up dynamic tests with specific deceleration pulses. At this point the problem is to find an appropriate pulse shape and to take in account for the shortness of such a dynamic test and for the strain rate sensitivity of the structural material.

Experimental Tests

Test Facility

The crash test facility in use by the Aerospace Department of the Politecnico of Milano belongs to the group of "deceleration sled facilities", that is to say that the sled after reaching a desired velocity, is decelerated according to a normalised pulse shape. The item is mounted on a sled running on 2 horizontal rails. The initial velocity is reached by means of a compressed air piston that launches the sled over a relatively long distance (4 meter). The compressed air system is capable to accelerate a 2000kg sled up to a velocity of 15 m/s. After the free run, the sled is decelerated by an oleo-pneumatic brake which provides the desired pulse shape and avoids the sled to move back. This facility is in use from several years mainly for seat tests according to TSO regulations.

Tank Dynamic Tests

With the purpose of maintain almost the same structural stress, as in static tests described in the regulations, appropriate deceleration pulses have been set up. In particular deceleration pulses with safety factors if compared with standard regulations have been developed. This to take in account the strain rate sensitivity of the structural materials behaviour and the shortness of the phenomenon.
The inertial load factors considered has been:

(i) Forward - 12g
(ii) Sideward - 4g

Owing to some difficulties due to leakage's from the tank locking cap in the vertical position, the tests with upward and downward inertial loads prescribed by regulation has not been carry out. While the upward test seems to be not significant (because of its low acceleration level), the downward one, with the forward test, is particularly crucial and will be performed in the future activities.

The fuel tank was installed onto the sled with a structure representing the fuselage section near the tank itself. In particular has been represented the landing gear and the fuselage connections (Fig. 1).

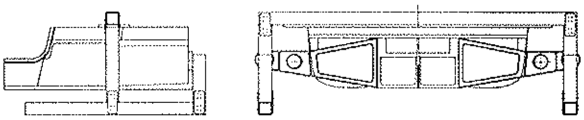

Fig. 1 - Fuel Tank

Even if is not required by the regulations the structure has been instrumented by means of 8 accelerometers to obtain information on the displacements of the walls of the structure to be compared with numerical simulations. The accelerometers has been set on that tank walls that are in contact with the fluid. The tests have been conducted filling the tank with water to the 80% of the normal full capacity.

Figures 2 and 3 depict the facility conditions related to the forward and sideward tests.

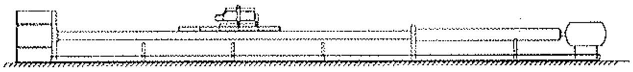

Fig. 2 - Foreward Test

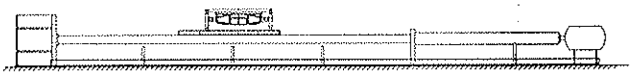

Fig. 3 - Sideward Test

The pulse shape adopted was the most rectangular the facility system could realise (see Fig. 4, 5).

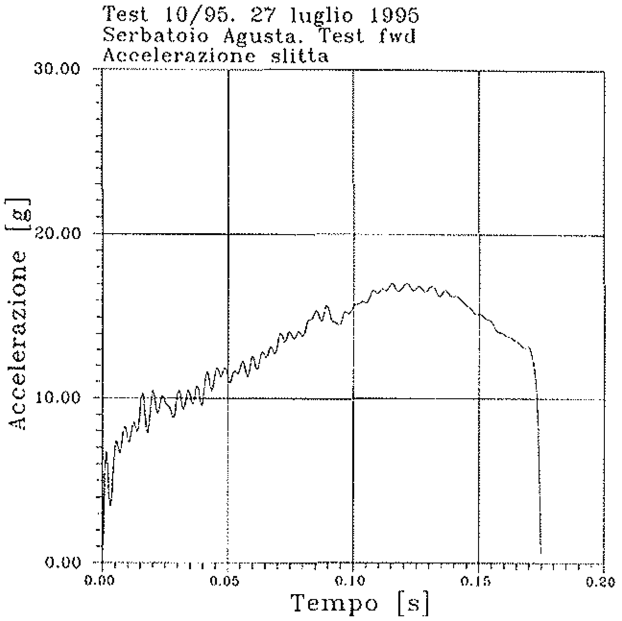

Fig. 4 - Foreward Test Acceleration Pulse

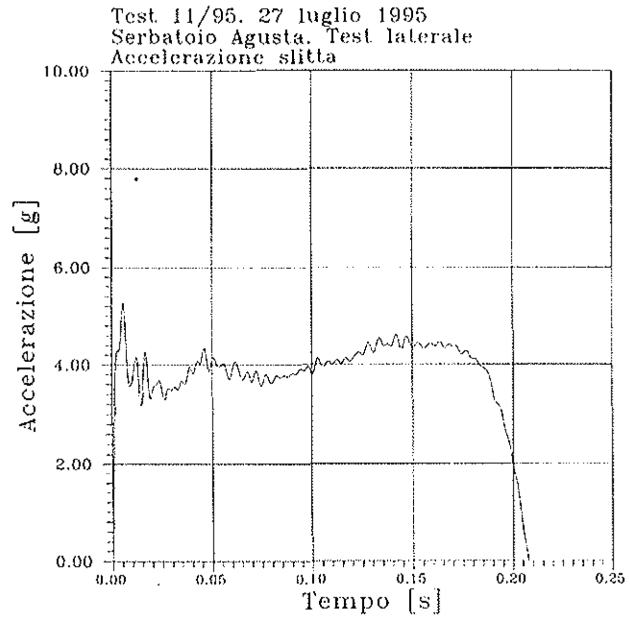

Fig. 5 - Sideward Test Acceleration Pulse

These dynamic tests have been followed by the final drop test from 15.2 m height. The tank has been winched with a jib crane by mean of a four point attachment and fast release hook (Fig. 6).

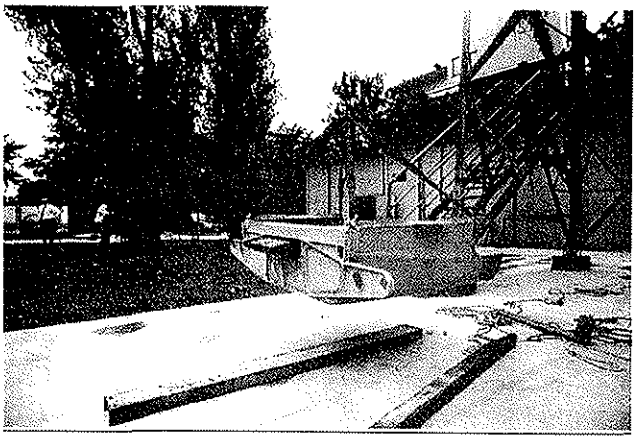

Fig. 6 - Fuel tank lifting

Results

Interesting results have been obtained from these tests conducted on a structure designed to not satisfy the Jar 29 regulations, and even if with minor modifications the structure will be able to pass the tests in the future.

In both dynamic tests there was no leakage's of water and no residual deformation of the structure was found. In particular a good behaviour has been verified for the connections of the fuel tank to the helicopter structure. Figures 7 and 8 show the displacement on the upper and frontal panel in the forward acceleration test. In the sideward loading test no significant data on the displacements has been possible to carry out (from the accelerometers signals) because of the position of the sensors and the low value of the acceleration.

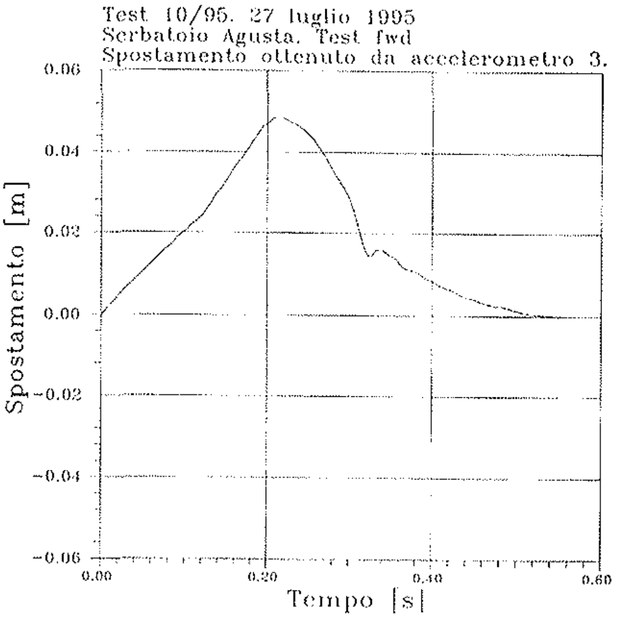

Fig. 7 - upper panel displacement

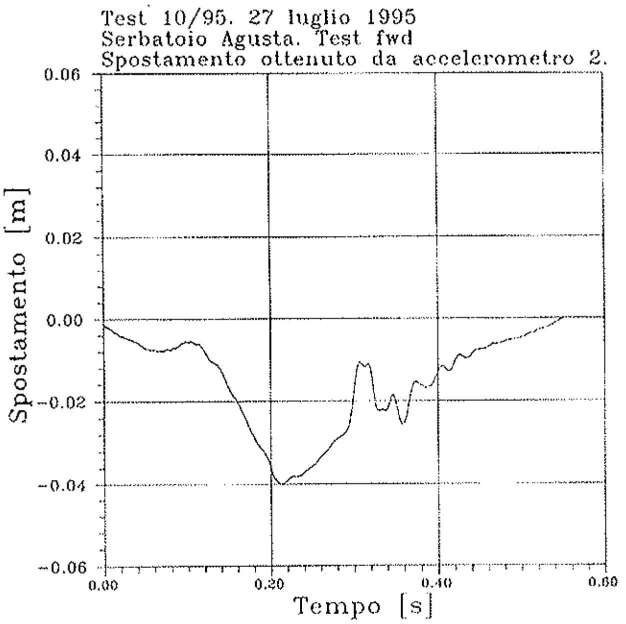

Fig. 8 - Frontal panel displacement

A less better behaviour was verified in the drop test. During the drop test the tank has lightly changed his attitude going to impact near the landing gear connection zone. The structure attitude, anyway, has remained within a tolerance of 10° as prescribed by the regulation.

Some leakage's had occurred due to the rupture of some valves in the lower part of the tank; anyway there was no tearing of the internal bladder.

In Fig. 9 are shown the fuel tank after the drop test. In this picture it could be seen that the main damage had occurred on the back of the tank, near the locking cap.

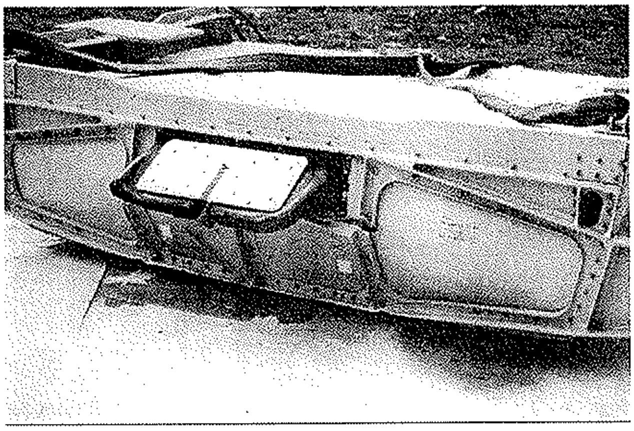

Fig. 9 - Fuel tank after the drop test

Numerical Simulation

Beside this experimental activity a finite element numerical study of the phenomenon has been conducted by means of special codes developed to study crash problems. In fact the numerical study of such a phenomena require the use of codes with good capabilities of representing transients with high non-linearities. Although the development of this type of code is relative new, some of them are extensively used and enough reliable.

The main difficulty for these simulations is the representation of the fluid inside the structure, this because the fluid does not fill the tank and therefore the movement of the water in the structure must be modelled.

This because the water during the crash exert dynamic pressure on the walls and his presence must be take into account to obtain reliable results (Ref. 4). The problem is the representation of two materials with behaviour and constitutive laws completely different. A solution consist on representing the structural part of the tank through a lagrangian description and the fluid using an Eulerian description of the continuum (Ref. 5). Beside common lagrangian finite element codes some special codes based on a combined lagrangian-eulerian formulation has been developed. With this kind of approach no approximation is made on the constitutive model of the fluid and there isn't any problem caused by highly deformed mesh.

In the present paper are reported only the results related to a numerical study conducted with the lagrangian code ESI-PAMCRASH. The analysis conducted with the code MSC-DYTRAN, based on a lagrangian-eulerian approach, is in progress.

Model characteristics

The A109 fuel tank is mainly made of a sandwich structures realised of textile composite and alloy honeycomb. The facing materials are woven fabric of glass and kevlar fibers. With the purpose of better represent the behaviour of such a material quite all the model was constructed by mean of solid elements covered by layered shell elements. The woven fabric has been represented by mean of a nonlinear bi-phase constitutive model with a damage fracturing law. The alloy honeycomb has been represented with a nonlinear bi-fase solid model; in such model the fiber fase is used to represent most of the axial cell elasticity and the highly non-linear cell crushing behaviour, while the matrix phase is used to represent mainly the in-plane behaviour.

The fluid inside the tank has been represented with solid elements characterised with a constitutive model based on the equation of state p=p(v).
The discretisation, shown in Fig. 10, consist of 1728 solid element, 2070 shell element and 159 beam element.

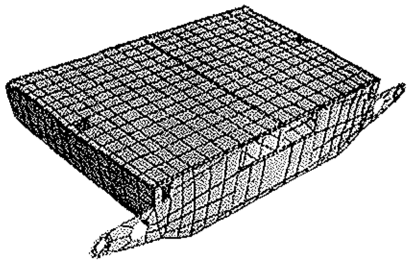

Fig. 10 - Fuel tank FE discretisation

The test considered for the numerical analysis has been the drop test; the model, with an initial velocity of 17.27 m/s, corresponding to the height of 15.2m, impact on a rigid wall. The simulation have required about 1 hour on a SGI-R8000.

Results

These simulations have given interesting information on the phenomenon and gave us a good referring point on the study of fluid-structure interactions, present also in other crash fields (example: ditching), by means of finite element simulations. The lagrangian model, even if less accurate than a lagrangian-eulerian model, has not presented numerical problems usually due to the high deformation of the elements representing the fluid. As could be seen from Fig. 12 the deformation of the fluid seems well simulated. Obviously with this kind of representation there's no possibility of simulate any leakage.
The stress distributions at the impact (Fig. 13) confirm that the back panel of the tank is the part of the structure where possible ruptures could occur.

Finally in Fig. 11 and 12 are shown, respectively, the rigid wall force magnitude and the kinetic and internal energy.

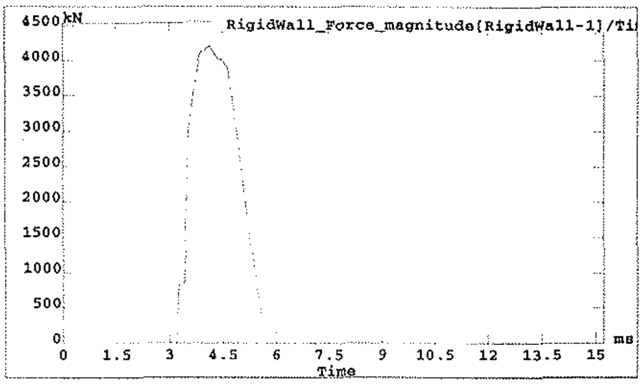

Fig 11

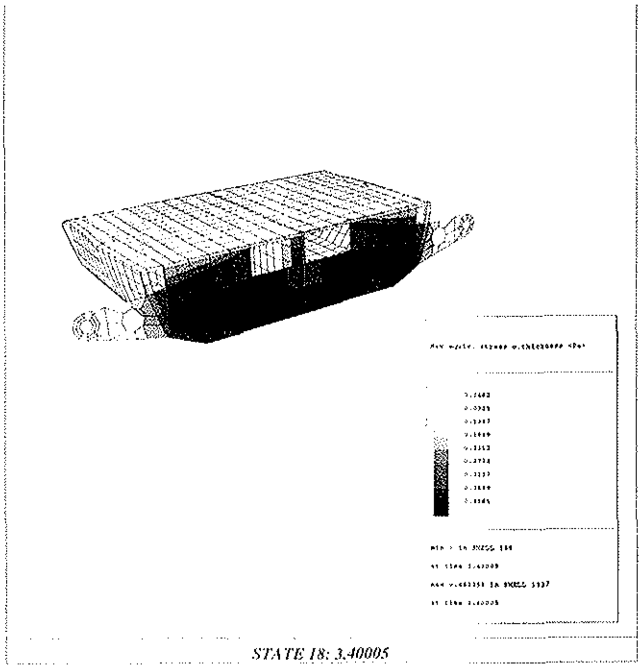

Fig 12 - Deformation contour

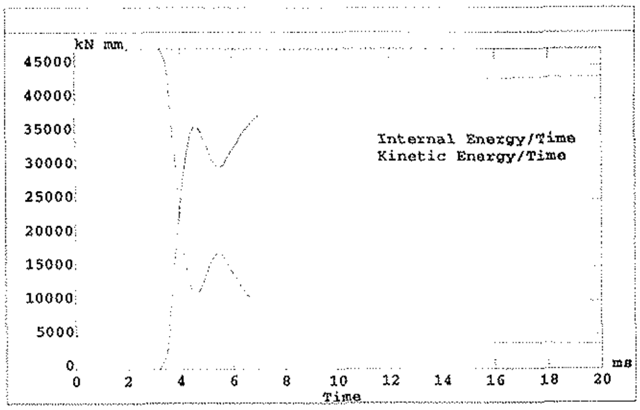

Fig 13 - Stress contour

Conclusion

- Part of the actual regulations are not suitable for crash test.
- Deceleration pulses (similar to those used in seat dynamic certification) should be used to verify structural integrity before droop test.
- In present work an alternative procedure has been proposed.
- Final drop test is mandatory to certify the structure.
- A fuel tank not developed to comply craswhorthiness requirements given good results.
- Numerical simulations give a good approximation of the real behaviour even if they cannot give indication concerning possible leakage.

Future activity

Two different solution for the same fuel tank are to be tested with the same procedure described including downward test. Numerical simulation using eulerian - lagrangian finite element code are in progressing.

References

[1] "Analysis of Rotocraft Crash Dynamics fo Development of Improved Crashworthiness design Criteria", J.W. Coltman, A.O.Bolukbasi, D.H.. FAA report, 1985

[2] Joint Aviation Requirements. 5 November 1993.

[3] Advisory Circular n° 25.562-1. "Dynamic Evaluation of Seat Restrain System & Occupant Protection on Transport Airplanes". June 1990

[4] "Unstructured grids and adaptive techniques applied to fluid structure interaction in industrial simulations". F.Garaud, P. de kernel, J.L. Matilla. Journees Numeriques, September 1992.

[5] "Numerical Simulation of a Ship Colliding Against a pier Structure". L.T. Kisielewicz, K. Ando , A. Petijean.. 3rd International Offshore and polar Engineering Conference- Singapore - 1993

-