Full scale crash test for cabin safety research

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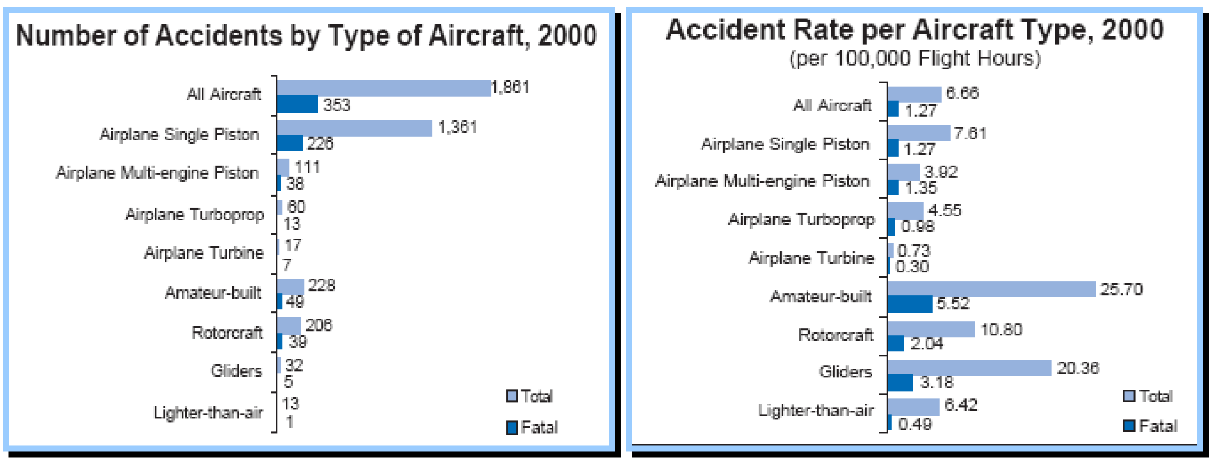
Abstract
The paper describes the Italian Aerospace Research Center Laboratory for Impact Test on Aerospace Structures (LISA), as an investigation tool for cabin safety aspects. Therefore, a short description of the facility, and its applicability to crashworthiness researches and investigation are given. Nevertheless, LISA present contribution to the study of cabin safety, through the prosecution of a previously successfully developed European project involving European Universities, manufacturers of safety devices and research centers, and focusing on improving occupant protection in case of accident is shown.

Introduction
Several studies of rotorcraft accidents have been conducted to identify safety issues and research areas that might lead to a reduction in rotorcraft accidents and fatalities. From 1990 to 1996, the NTSB (www.ntsb.gov) documented 1396 civil rotorcraft accidents in the United States in which 491 people were killed. A total of 1,837 accidents occurred during calendar year 2000, involving 1,861 aircraft. The total number of general aviation accidents in 2000 was higher than in 1999, with a 4% increase of 69 accidents. Of the total number of accidents, 345 were fatal, resulting in a total of 596 fatalities. The number of fatal general aviation accidents in 2000 increased 1,5% over calendar year 1999, but the total number of fatalities that resulted decreased by 4%.
The following graphs summarize the total number of general aviation accidents and the number of fatal accidents occurring in 2000 by type of aircraft. Most notable is the large number of accidents involving single-engine piston airplanes, which accounted for 73% of all accident aircraft and 64% of all fatal accident aircraft.



Number of accidents and accident rate per aircraft type

Amateur-built aircraft had the highest accident rate in 2000 with 25,70 accidents and 5,52 fatal accidents per 100,000 flight hours. Rotorcraft had the second highest rate among powered aircraft, with 10,80 accidents and 2,04 fatal accidents per 100,000 hours flown.

The CAA (www.caa.co.uk) documented between 1992 and 2001, 22 civil rotorcraft accidents in the United Kingdom, in which 16 people were killed.
Between 1990 and 2003 there have been 272 civil rotorcraft accidents in Germany (www.bfu-web.de) in which 81 people were killed. The rotorcraft data were compared to airline and general aviation data to determine the relative safety of rotorcraft compared to other segments of the aviation industry. In depth analysis of the rotorcraft data addressed demographics, mission, and operational factors. Rotorcrafts were found to have an accident rate about ten times higher to that of commercial airliners and about the same as that of general aviation. Partly this is due to the inherent risky operation of helicopters close to ground and due to the high complexity of the aircraft.

Studies and investigations have shown that even using state-of-the-art safety equipment, fatal or severe injuries still occur in helicopter crashes.
The idea suggests itself that existing safety requirement specifications are not sufficient to cover real world crash kinematics. Research has shown just how vulnerable the human body is to the severe trauma found in many helicopter accidents. That susceptibility is leading towards some remarkable new restraint technology for helicopter occupants and, perhaps later, for airplane occupants.

Although the simulation accuracy of the existing numerical codes is increasing steadily, crash tests on ground testing facilities are still considered the only reliable simulation mean.
The results of these tests are used to validate the models, to widen the knowledge on the crash behavior of air vehicles and their components, and the most important of all, to demonstrate compliance with the passive safety regulations in a certification process.
In addition, the tests provide an opportunity to observe the sequence of events during the crash in great detail due to the availability of extensive instrumentation and a controlled environment. Real accidents obviously provide limited opportunities in this regard because the exact sequence of events can only be deduced from the resulting wreckage after the accident. The efficiency of this source of data is limited because much of the tell-tale evidence may be altered by secondary crash effects or consumed by fire, and also because the accident investigation is primarily aimed at finding the causes of the accident. The investigators are usually not crashworthiness experts and the experts are not often part of an investigation team. Finally, many accidents do not get investigated in any great detail and reports are often not widely available.

Definitions

Highest Level of Injury:

Fatal – Any injury that results in death within 30 days of the accident.

Serious – Any injury that (1) requires the individual to be hospitalized for more than 48 hours, commencing within 7 days from the date the injury was received; (2) results in a fracture of any bone (except simple fractures of fingers, toes, or nose); (3) causes severe hemorrhages, nerve, muscle, or tendon damage; (4) involves any internal organ; or (5) involves second- or third degree burns, or any burns affecting more than 5% of the body surface.

Minor – Any injury that is neither fatal nor serious.

Flight safety and crashworthiness

The idea that aircraft accidents may have and should have survivors is a relatively recent concept. The old concept was just that accidents should not happen to aircrafts. The pursuit of safety, indeed started from the beginning of flight, but at that time was only aiming at the very essential target of preventing accidents, by means of better stability and flight qualities, safer structures, more reliable engines, better flight and navigation instruments, improved flight traffic control, etc. By the prevention of flight accidents Air transportation is the safest way to travel, exceeding by far the safety level of ground and sea transportation. Unfortunately, even if very low, the probability of a crash is not null, and the consequences of such a rare event can be very severe. But some times there are survivors, and even uninjured. So why not study the conditions that made these survival possible and try to improve such conditions to make survival more likely? This observation brought on the idea that safety can be substantially improved by protecting the occupants in a crash, when it could not be prevented. Prevention and protection became then the two big issues of safety.

Until now, typical full scale crash tests have been performed using either a remotely piloted full scale vehicle or a pendulum-like cable facility or vertical drop test.
The most accurate simulation of impact parameters during a crash is achieved in the new CIRA ground testing facility named LISA

The Italian Laboratory for Impact Tests on Aerospace Structures (LISA)

LISA mission

Inaugurated in April 2002, the laboratory main activities are deeply connected with experimental and numerical researches in crashworthiness of aerospace structures subjected to high energy impact. Applications are both in the aeronautical field, as passive safety, included ditching and/or emergency landing, showing the capability of an air vehicle (aircraft/helicopter) to protect the occupants from serious or fatal injury during an accident, and in the space field, where the main objective is to protect payload during the recovery phase (on ground or in the water), of space vehicles.
For the development of experimental activities, LISA facility is equipped with 3 test machines:

- The Large Structure Crash Testing Equipment

Full scale crash test facility frontal view

- The Ditching/Emergency Landing Facility

The sled and the horizontal track

- The Drop Test Tower

The guided drop tower at one corner of the pool (11,5 m high)

The Laboratory global view

LISA experimental capabilities

The LISA facility is rendered unique by its characteristics, result of the most sophisticated data logging systems. Impact is a very complex phenomenon to analyse, and for this reason requires very sophisticated instrumentation. A similar facility to LISA exists at in the United States (NASA Langley), working on the so-called pendulum operating principle. Originally used for the Apollo program, it was later converted into a crash test facility.
LISA, on the other hand, guarantees a guided trajectory for the test article (impact angle, speed, etc.) that permits verification of the numerical data obtained in the theoretical phase.

It is well known that a crash test article, like airplane or helicopter fuselage is not only very expensive but also unique, so that the failure of the test involving destruction of test article without acquisition of data, is a very economical danger for the client. At today state of art data acquisition system and the technique of its remotely control is not a problem anymore. Critical point, instead, is to actually assure test article impact parameters. For that reason CIRA, after the delivering of the Facility for Impact Test on Large Aerospace Structures by FERRARI "Ente Spazio", at the end of 2001, has decided to set up, testing and demonstrate rigorous test procedures of impact test on large structures and to submit the method, process and procedures to approval of ENAC, Italian Aeronautical Regulator Authority, thus gaining certification for the execution of full scale crash tests.

The Large Structure Crash Testing Equipment is the largest one and the sole existing in the world, with its dimensions and features, allowing the execution of high energy impact tests on full scale aerospace structures. It's around 36 meters high and more than 41 meters wide, it weighs over 400 tons and is capable of carrying out crash testing on real aircraft and/or spacecraft weighing up to 20 tons.
The test articles may be dropped onto three different types of impact surface: concrete, soft soil, and water. Trajectory angle may be varied from 5° to 90° (vertical).
The test article may be launched at speed necessary to achieve impact velocities of up to 20 meters per second at each angle, and may assume any attitude with respect to the trajectory.

TEST ARTICLE WEIGHT	Up to 20 tons
Impact Angle	From 5° to 90°
Impact Velocity	Up to 20 m/s , at any angle
TA Attitude	Potentially no limits
Accuracy	Velocity ± 5%
	Impact angle ± 1°
Impact Surface	Hard smooth concrete
	Soft soil (grass or ploughed)
	Water (100 m x 22 m x 5 m)

Basic operational envelop of the Large Structure Crash Testing Equipment

How LISA works

The test article is connected to the steel truss which is then lifted to the top of the main steel structure. Once on the top, the truss slides along the beams of the main steel

structures over 16 rubber wheels. In proximity of the ground, the test article is released free to impact with the specified surfaces, while the sliding truss is gradually braked before stopping. The large truss, which weighs 30 tons, is slowed to a stop in only 2 meters after the

test article has been detached to continue its fall towards the impact surface. The release system is purely mechanical.
While gravity is used as the only driving force for the accelerated downslide at high angle of trajectory, to accelerate the test article in case of low trajectory angles, additional driving propulsion is provided by a pneumatic system using air pressure up to 30 bars.

On October the 17th 2001, the first crash test on a large- scale aeronautical structure was carried out at CIRA. The test involved a free-fall drop into water of a Westland WG30 helicopter which has a maximum takeoff weight of 5,600 Kilograms and seating capacity for 12 passengers. The destructive type test was perfectly successful , and all necessary information was gathered for successive analyses thanks to the excellent functioning of the instrumentation prepared by the LISA team: 22 accelerometers, 12 pressure transducers, 1 anthropomorphic dummy equipped with lumbar load-cell and accelerometers, and 4 high - speed video cameras. This experiment terminated CIRA' s first test campaign within the European CAST program, aimed at investigating crashworthiness of helicopters on water, included design of structures using advanced simulation tools.
In the same campaign, 5 substructures were subjected to guided free-fall tests into water: a traditional sub floor and four external skin panels designed to be crash resistant.

WG30 impact on water   WG30 after impact

Since then, CIRA/LISA numerical and experimental experiences have been performed in cooperation with the most important aeronautical manufacturers like AGUSTA, PIAGGIO, ALENIA and AERMACCHI.
Vertical drop tests of full scale Agusta helicopters (A109, A139) and cabin mock-ups have been performed starting from 1994 at Agusta company, to get knowledge and experience of crashworthiness aspects and crash test set-up.
A full scale crash test of an Agusta AB204 has been successfully performed on September the 18th 2002 at CIRA, thus obtaining the Italian Civil Aviation Authority (ENAC) Certification.

As Alenia subcontractor (CRASURF European Research Project), a crash behavior numerical analysis of an ATR fuselage section has been performed in 2000.
Finally, a bird impact analysis of an AGUSTA AB612 wing (November 2001) and AGUSTA AB139 windshield (August 2000) have been performed, so as a bird impact numerical simulation of an Aermacchi – YAK AM46 windshields, in the period between 2001 and 2002.

In the last years LISA has been deeply involved in many European research projects with the objective to improve survivability of occupants in both cockpit and cabin in helicopter crashes, and minimize the risk of injuries. Among them:

- The Helisafe® project (2000 ÷ 2003), in cooperation with Autoflug, Siemens, DLR, Eurocopter, TNO, Politecnico di Milano and Martin Baker, has developed and validated a numerical simulation tool concept to reliably predict typical crash scenarios and simulate interaction between safety features and occupants.

- Helisafe TA, the prosecution of the previously mentioned project, actually on progress, will assess and validate the achieved improvement of the advanced safety systems developed in Helisafe®. The project main objective is to improve survivability of occupants in both cockpit and cabin in helicopter crashes and to minimise the risk of injuries.

HELISAFE TA project

Partners involved in the project are:

- AUTOFLUG
- EUROCOPTER
- CIDAUT
- TNO
- TU DELFT
- COVENTRY UNIVERSITY
- SIEMENS
- POLITECNICO DI MILANO
- PZL

CIRA contribution to project will be to perform two full-scale crash tests:

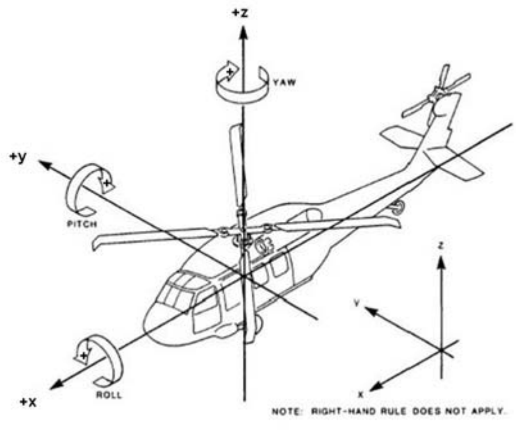
- the 1st without advanced safety systems developed in previous Helisafe® (only standard), as basis for the research work within Helisafe TA

- the 2nd integrating safety features, furtherly developed during the project, to assess and validate the achieved improvement of the safety equipment.

A Bell UH-1D has been chosen as test article, having the following characteristics:

Manufacturer: Bell Helicopters TEXTRON
Crewmembers: 1 – 2 pilots plus 1 flight mechanics
Passengers: Crew chief and 14 troops
Engine: 1 Avco-Lycoming, T53L-13 Turbo-Shaft
Engine: Power 1 044 kW (1400 SHP)
Max velocity: 220 km/h
Cruising speed: 200 km/h
Cruising range: appr. 500 km
Absolute ceiling: 4150 m
Overall length incl. main rotor: 16,43 m
Fuselage length over tail boom: 12,69 m
Overall height: 4,41 m
Fuselage height incl. landing gear: 2,37 m
Overall width: 2,54 m
Basic weight: 2315 kg
Take-off weight: 4315 kg

Up to now, crash data and associated impact conditions have been collected, analysed and evaluated with respect to the most severe injury patterns. The intention was to condense information on crash data into the reference scenario that have a high probability of occurrence and significance with respect to real world accidents to enable an assessment of the crash kinematics and in order to facilitate the definition of safety equipment and crashworthy design.
Impact path has been defined, combining horizontal and vertical velocity components.
The following scenario, and associated impact parameters, has been chosen:



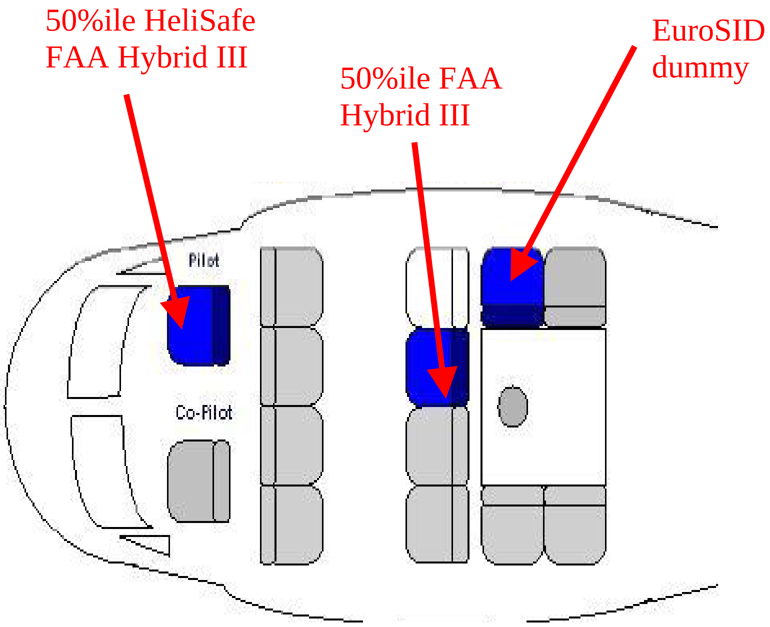
Horizontal velocity (vx)	+12,8 m/s (42 ft/s)
Lateral velocity (vy)	0 m/s
Vertical velocity (vz)	- 7,9 m/s (- 26 ft/s)
Pitch angle (Phi)	+5°
Roll angle (Theta)	0°
Yaw angle (Psi)	0°

As regards impact surface, concrete has been preferred for the following reasons:

1. Vertical impacts are most severe on hard surfaces where is no energy absorption provided by ground deformation. Whereas longitudinal impacts tend to be most severe on soft soil when ploughing is likely to occur
2. The test is easily reproducible (a 2nd test needs to be performed at the same conditions)

The test will be performed including three occupants: one pilotin the cockpit and two passengers in the 3rd and 4th row. Three Anthropomorphic Test Dummies will be then used:

- ✓ One 50%ile HeliSafe FAA Hybrid III, an upgrade of FAA version, developed in the first Helisafe project
- ✓ One 50%ile FAA Hybrid III
- ✓ One Eurosid dummy



and the following channels will be used for measurements:

Instrumentation for	N° of channels
Pilot (Helisafe FAA HIII-dummy)	27
Passenger (FAA HIII-dummy)	25
Passenger (EuroSID1-dummy)	28
Helicopter structure	48

For data acquisition, instrumentation actually available at LISA facility will be used for the test, consisting in:

- **One crash resistant Data Acquisition System,** able to measure up to 96 channels for acquisition from accelerometers, strain gauges, pressure transducers, etc.

- **Four crash resistant high speed video cameras**

  ❑ N° 2 digital cameras Phantom, up to 4000 fps frame speed, resolution up to 512x512 pxl
  ❑ N°2 Kodak Ekta RO Imager cameras, up to 1000 fps frame speed, resolution up to 512x512 pxl

Other than improving survivability of helicopter occupants, the full scale test is important also to:

- Establish injury levels with standard safety equipment to get realistic accident data and realistic crash pulses

- Improve understanding of the overall crash behavior of the helicopter structure with regard to the occupant (cockpit and cabin)

- Improve protection devices for helicopter occupants that allow increasing the rate of survival and reduce severe injuries, independent of their weight, size and seat position

- Improve knowledge of helicopter accidents, by the motion analysis of occupants and resulting contacts with the cabin structure

- Define and prototype a crash sensor system including Electronic Control Unit

- Develop supplemental realistic aviation related injury criteria with focus more on the whole occupant

- Make airworthiness recommendations for certification requirements in the future

Conclusions

It's firmly believed that future aviation safety systems have to fulfil a big number of requirements to **protect** occupants from multiple forms of injuries, and the combined application of a restraint systems with an energy absorbing seat and airbags guarantee optimal protection in case of crash.

Therefore improved restraint systems, lateral protection and corresponding design of cockpit and cabin have to be created.

LISA facility is now available to perform full scale crash test reproducing a big variety of different scenarios, giving the aeronautical community a powerful tool to investigate passive safety.