EXPERIENCE OF VIRTUAL SIMULATION OF AIRCRAFT ACCIDENCES RELATED TO STRENGTH PROBLEMS

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Abstract

This paper summarizes some experience of numerical modeling, concerning the strength of aircraft structures during flight accidences (FA) investigation. Several cases were analyzed, including earth collision crashes, lightning strikes on aircraft, rollover impacts. Virtual simulations were performed via Finite Element Analysis using explicit and implicit codes. These results showed that approach of using numerical simulations of this kind is acceptable and efficient in discovering of flight accidences.

1. Introduction

Among tasks, related to the strength of aircrafts and arisen during flight accidences (FA) investigation, these can be pointed out:

- Analysis of FA reasons, discovering probability of that the accidence was consequence of design errors related to lack of strength properties of aircrafts structure (static strength, durability and so on);
- Investigation of FA conditions – identifying of flight condition during FA using FCR (flight condition recorders), analysis of aircraft parts state, crew and witnesses testimonies;
- Analysis of residual strength of the aircraft, damaged during FA, determination of possibility to safe exploit of the aircraft structure after FA, specification of investigation area for NDI procedure to find out of hidden defects, estimation of proposed repair adequacy and, in some cases, developing a decision about possibility to make a safe flight this damaged aircraft, or to forbid it if flight without repairing is too dangerous.
- Improving the knowledge level about strength of the aircraft structures: making safety margin adjustment, using FA load conditions. There is great difference between fixed wing aircrafts and rotary wing ones – helicopters have more possibility to safe crew and structure during FA. So analyst has more opportunity to estimate a behavior of structure under action of real extreme load condition.

These tasks listed above not exhaust whole list of strength issues, but they are these, there virtual simulation using FEA can be efficiently applied.

However these tasks bring some requirements regarded to the numerical models, and these demands as a rule more stringent, then those required during aircraft design process. It stems in particularly from special features of FA, considering these as physical processes. As a rule FA processes are dynamic and nonlinear, the aircraft structure can lose integrity, changing his stiffness and mass properties during FA event. As result, virtual models should be multidisciplinary.

It means what it should be possible to solve static, dynamic, fracture mechanic, post-buckling tasks, to analyze fluid-structure interaction. Frequently situations occur, when analysis of complex systems such as "flexible structure - control – external aerodynamic" or "flexible structure - control – actuating mechanisms" is required.

A meeting of these requirements can be done either using a common multidisciplinary virtual model, or developing a set of different models, interacted by means of some interface program.

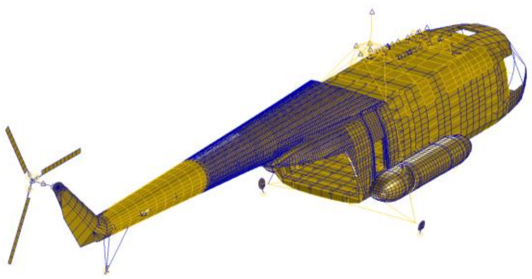
At present there are several programs, that are satisfied the requirements listed above, for example:

- Integrated set of MSC.Software codes (Nastran + Dytran + Marc + EASY5 + ADAMS);
- ANSYS codes;
- Integrated set of LMS International codes (LMS.Virtual Lab, LMS AMESIM);

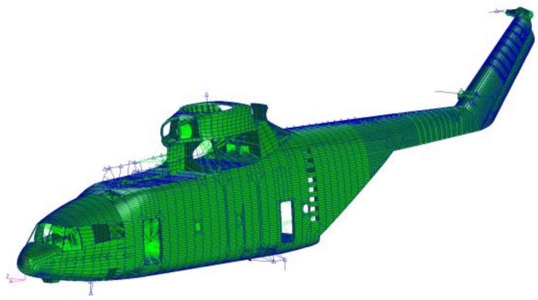
Currently stress analysts of Mil Moscow Helicopter Plant are using commercial codes of MSC.Software.

2. Examples of virtual simulations in tasks of flight accidences investigation

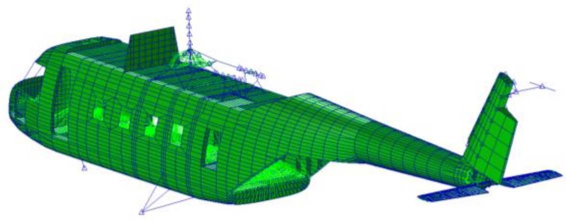
A reliable performing of virtual simulation of FA can be done only in case of having proven finite element model (FEM). This FEM should be validated using ground and flight tests results. Mil Moscow Helicopter Design Bureau has developed a set of universal models, meeting these requirements. The models present all helicopter structures, developed and operated this time. Some of these models are shown in Figure 1.



Mi-8, Mi-17



Mi-26



Mi-38

Figure1. Strength analysis FE-models of helicopter strictures

Of course, these models are developed and used not only for FA investigations, but they are tools, required for design and to resolve the problems, arising during life cycle.

However, our experience shows what high-level models evidenced their applicability and efficiency for FA problems investigations.

2.1 Analysis of in-service damage impact on the residual strength of Mi-26 fuselage.

A task of residual strength investigation of heavy Mi-26 helicopter was performed. The structure got an in-service damage of one of main frames (Figure 2 - 3). The stress state changing due to this damage and load paths redistributions were analyzed. The conclusion was given about possibility of single safe flight of the aircraft to a place of repairing; requirements to flight condition (weather, aircraft configuration, maneuvers limitation) were developed.

Commercial code Msc.NASTRAN was used, linear static solution was performed.

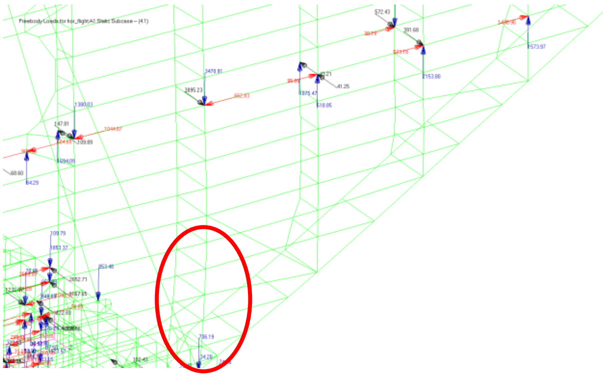


Figure 2. Load distribution in damaged area.

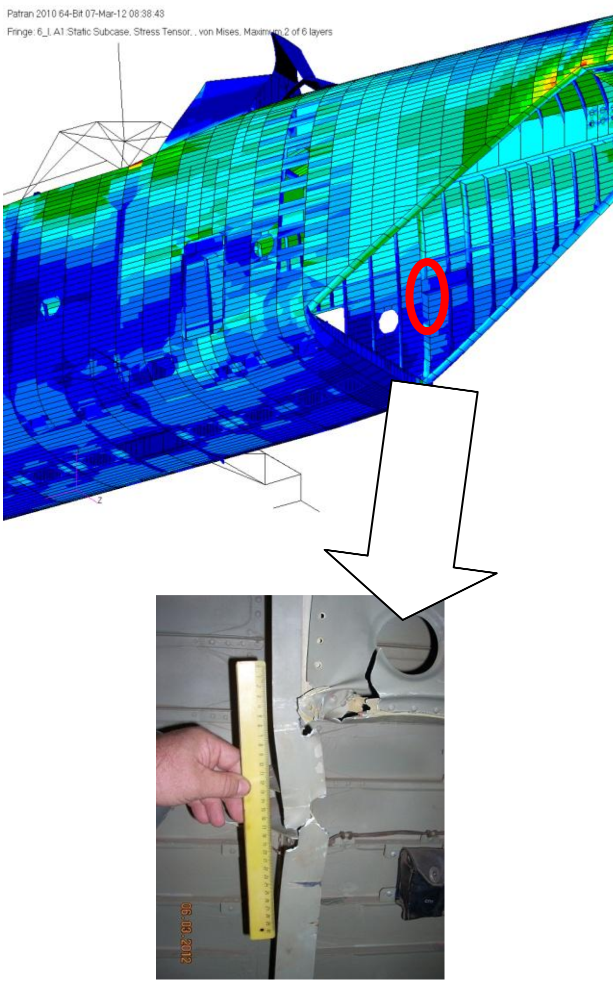


Figure 3. Stress-strain state of structure received in-service damage

2.2 Crash landing analysis and residual strength estimation of Mi-8 fuselage structure.

Flight accidence at Vorkuta, (19.12.2009) was investigated. Residual strength and damage dimension estimations were performed; loading during the crush landing was simulated. Pictures of destroyed structure are given in Figure 4.

Flight recorder data, structure review reports, crew testimonies and official report of investigation commission were used as analysis initial data. During analysis performing explicit commercial code Msc.DYTRAN was used.

A final phase of crush of FA was simulated – namely – collision of aircraft with earth and partially destroying of the structure (tail beam detachment). Predicted load factor (Figure 5) in area of mounted flight recorder sensor and pictures of destroyed structure were quite close to reality.

The main goal of the work was estimation of possibility of structure repairing for returning to service. Analysis results showed what such repair is possible under conditions when NDI results in areas, localized by means of simulation (Figure 6), are positive, and leveling results are positive too.

Figure 4. Views of aircraft structure at site of FA.

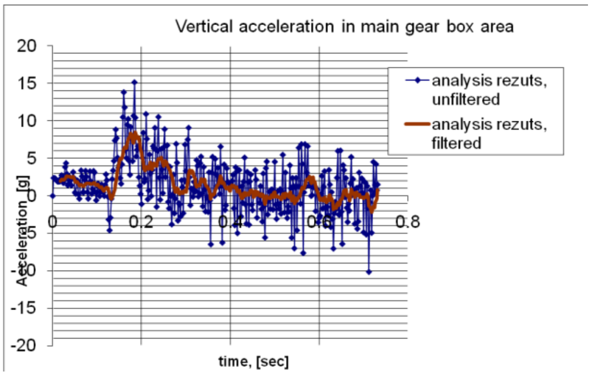
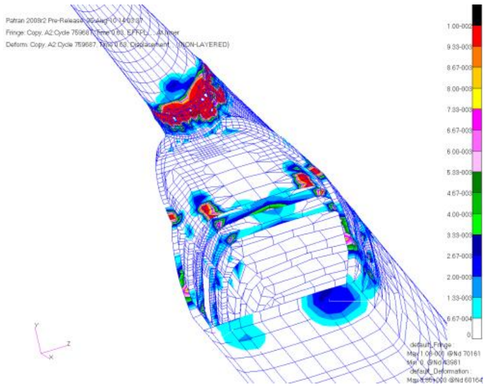
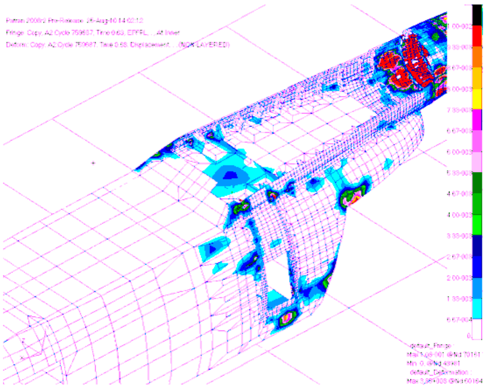


Figure 5. Vertical acceleration of main gear box, [g]



Back view of middle part of fuselage



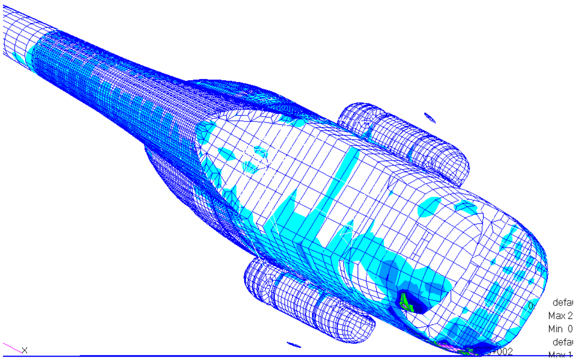
Side view of fuselage (part of structure hidden for clarity)

Figure 6. Plastic strain distribution

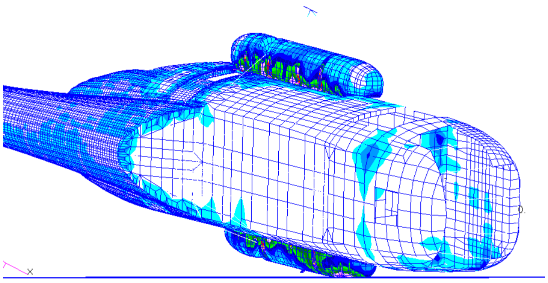
2.3 Rollover impact investigation, analysis of fuel tank strength and integrity.

Some situations can occur during FA, when rollovers take place after rough landing. In case of Mi-8, fuel tanks have side position; it leads to necessity to substantiate safety of such design. Namely – it need to prove by means of analysis strength sufficiency of these tanks, in other words, to show what tanks remain these integrity and thread of post crash fire is minimal.

Using Msc.DYTRAN (and Msc.Patran – pre-post tools), such crash situation was simulated, when aircraft slides in side direction and then rollover to main gear box took place. Two phase fluid behavior was simulated inside fuel tanks, physical, geometry and structure (contact) kinds of nonlinearity were taken into account. It was shown by analysis, what plastic deformation during such rollover does not lead to damages with spillage remarkable amount of fuel.



τ = 0.05 sec



τ = 1.0 sec

Figure 7. Mi-8 rollover stages

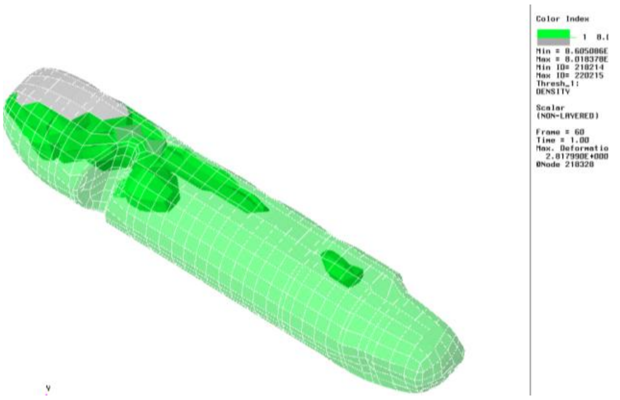


Figure 8. Fuel position in tank
τ = 1. sec

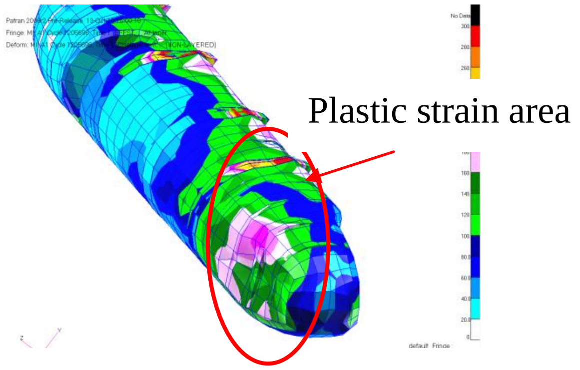


Figure 9. Deformed state and plasic strains of tank structure

Photographs of real structures after rollovers are shown in Figures 10, 11.

It can be see very close agreement between simulations and real FA pictures.

Figure 10. Photograph of helicopter structure after rollover

Figure 11. Deformed state of tank structures after real rollovers

2.4 Estimation of impact of lightning strikes a tail rotor blade of Mi- 26T.

When investigation this FA (took place at 11.05.2011) next goals were defined:

- To reveal a physics of the phenomena, that caused the structure damages funded after safe landing;
- To give estimation of hidden damages, obtained during the FA;
- To develop conditions of safe flight to repairing plant.

Simulation was performed using a set of models of this aircraft structure and related commercial codes - Msc.Nastran (Sol. 129), Msc.DYTRAN, Msc.ADAMS.


Figure 12. Damaged tail rotor blade and fin.

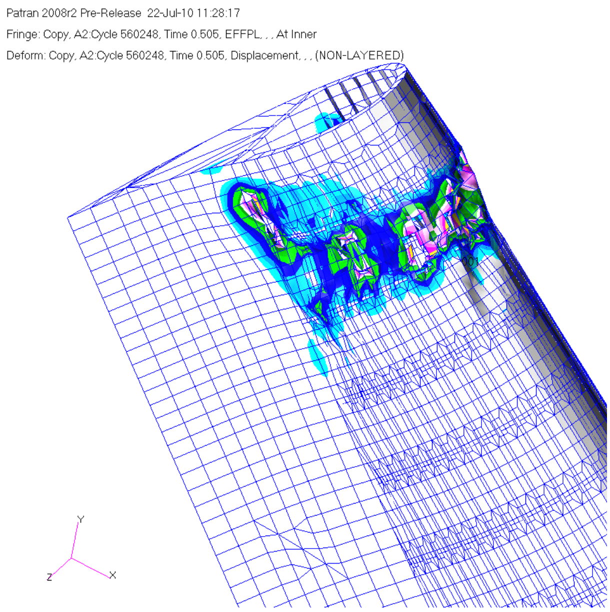


Figure 13. Deformed state and plastic strain of fin skin
(τ = 0.67 sec)

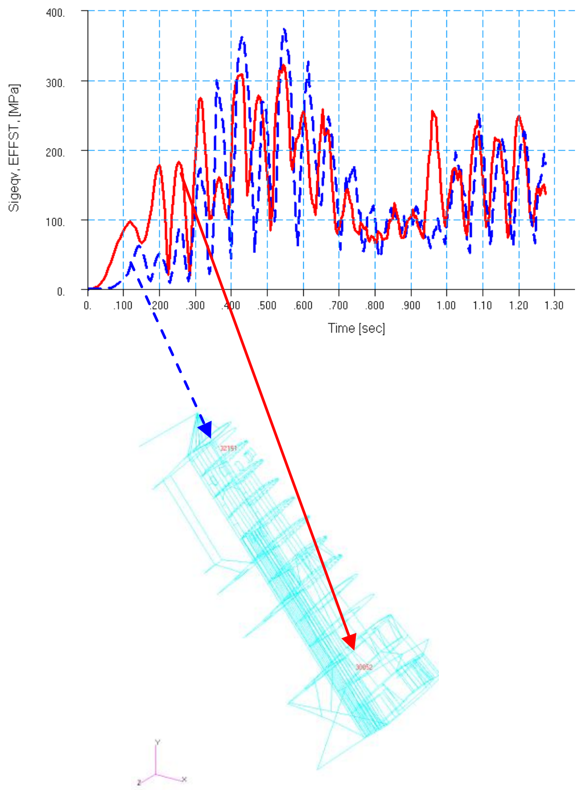


Figure 14. Time history of equivalent stresses in fin spar caps (sections rib3 – rib4, rib13 – rib14).

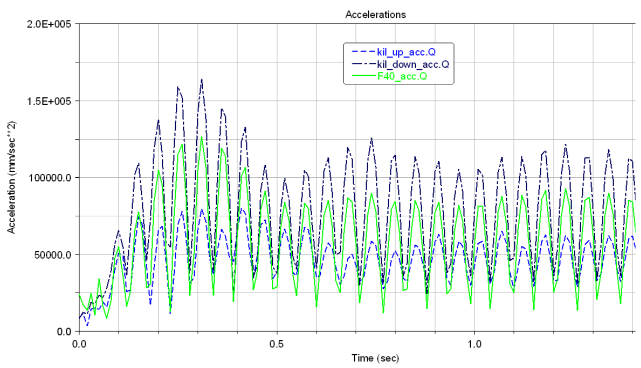


Figure 15. Accelerations in tail and boom structure of aircraft (kil_up_acc – tail gear box, kil_down_acc – intermediate gear box, F40_acc – flight recorder mount in boom)

It was discovered what main cause of structure damage was tail rotor disbalance, forced with detachment of part of tail rotor blade. The followed process can be characterized as having short overload (release of elastic energy), excitation of oscillations simultaneously with progressive damaging and structure stiffness changing. Finally the process had become stabile on definite level of damage and oscillation amplitude.

These analysis results were quite close to those recorded in the real structure, both in magnitude of accelerations and damage pattern.

2.5 FA investigation and strength analysis of Mi-26T damaged structure

In the case a main goal of investigation consists was discovering of FA cause. At moment of FA (at 20.12.2011) the helicopter has carrying load externally, suspended from cables. During approaching with low velocity to landing site partial destroying of aircraft structure with detachment of tail boom had took place. Then emergency landing had proceeded.

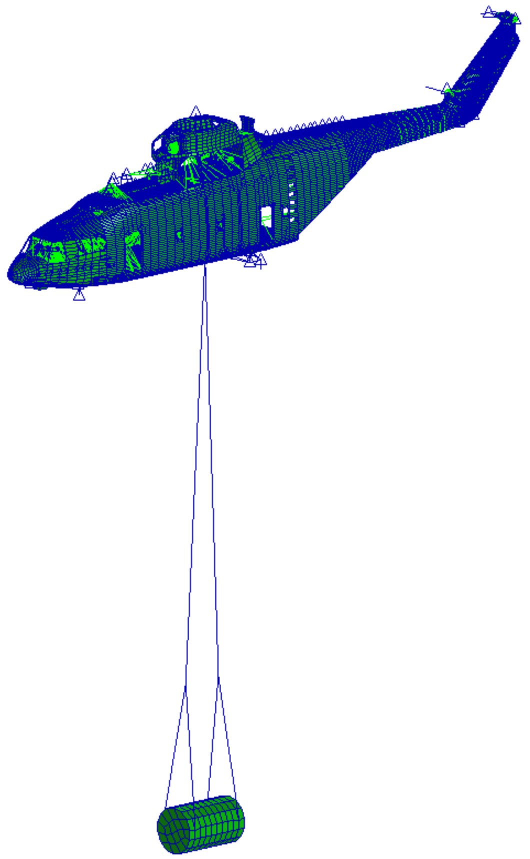


Figure 16. Analysis FE-model of Mi-26 structure with slung load.

Fractography analysis shows, what fatigue damages were present in the skin at the area of frame #33. Fatigue crack growth to a state of critical length was taken place due to coincidence the number of adverse factors:

- Bad quality of repairing
- Insufficient material properties of structure skin (skin material - Al-Li allow 01420);
- Unacceptable quality of structure inspection in service. The crack, having length about critical, should be once and again detected during walk-around inspections.

Performing numerical analysis, FE-model of aircraft structure in configuration of carrying slung loads was used. Next results were obtained:

- Dynamic loads of aircraft were identified;
- Critical length of the fatigue crack was calculated;
- Estimation of vibration loads changing during the crack grown was performed.

For critical crack length determination a special singular finite elements were included into whole structure model. It allowed calculating of K_I (stress intensity factor) with adequate accuracy.

It was pointed out, what during regular inspection (in on-ground position) the crack has open state; it should alleviate crack detection.

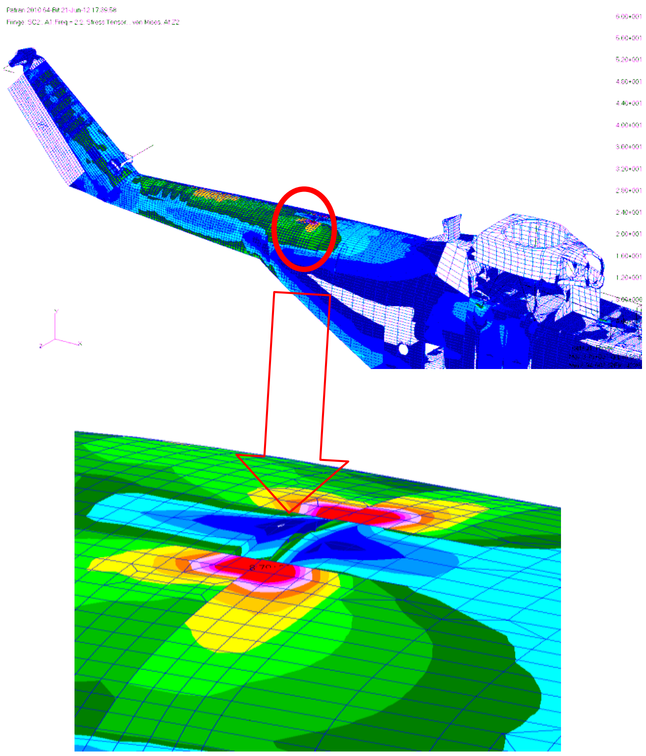


Figure 17. Stress and deformed state of cracked structure.

Analysis showed, what having load factor sensor near GC of aircraft, data received had not enough sufficiency for estimation of vibration state changing. It was due to sensor position nearly in vibration mode shape zeroes, with excitation on main rotor rotation frequency.

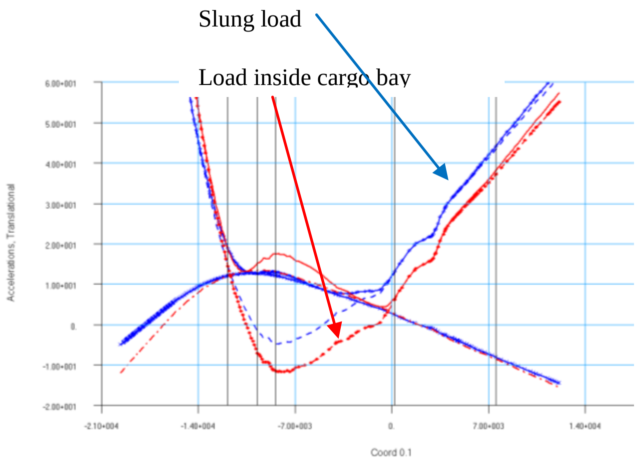


Figure 18. Vertical acceleration distribution along length of fuselage, in case of slung load configuration, and in load inside. Excitation frequency – 2.2 Hz.

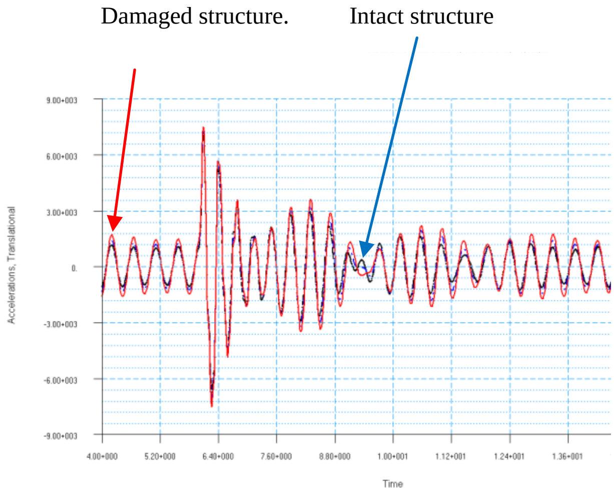


Figure 19. Vertical acceleration time history during maneuver performing. Intact and damaged structure, near #33 frame, [mm/сек^2].

It was pointed out, what in case, when several acceleration sensors were disposed in critical points of aircraft structure (for example near crosswise skin joints), it become possible to predict arising of dangerous fatigue cracks (Figure18, 19).

Investigation of influence of “aircraft-slung load” system parameters upon dynamic stress state of helicopter structure was performed. It was shown, what there were adverse combination of loads weight and cable lengths. Flight test data confirmed this conclusion.

Conclusion

Gained experience of FA investigations using multidisciplinary FE-model proved acceptability and efficiency such approach. In several cases using of this methodology is the only way to discover accidence reasons.

The simulation results allowed developing acceptable technical solution in the every case examined. Recommendations for the future updating aircraft structures, and improving service procedures were prepared.

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