Impact Simulations of a Composite Helicopter Structure with MSC.Dytran

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ABSTRACT:

For several years, Eurocopter Deutschland GmbH has been using MSC.Dytran to investigate the crashworthiness behavior of a composite helicopter fuselage and its components. This work, although started relatively late during the prototype development, has very rapidly been applied as the primary method to develop the optimized crashworthy structure in detail.

1 INTRODUCTION

The NH90 (see Figure 1), (**N**ATO **H**elicopter of the **90**'s) is a quattro-lateral program of France, Germany, Italy and the Netherlands. It will be built in two main variants as NFH (**N**ato **F**rigate **H**elicopter) and as TTH (**T**actical **T**ransport **H**elicopter).

Figure 1 NH90 German Prototype PT4 (TTH)

The industrial partners consist of Eurocopter France (EC), Eurocopter Germany (ECD), Agusta and Fokker Aircraft B.V. The preliminary design date back already to the early 1980's but the development phase was started September 1992. First flight was performed in December 1995. The series production was started May 2001.
The NH90 is a helicopter in 9000 kg class. It features a primary structure mainly of carbon fiber reinforced composite, dimensioned to fulfill crashworthiness requirements comparable to MIL-STD-1290A [1]. The main aspects of the crashworthiness requirements (applicable to TTH variant) are impact velocities of:

- V_x = 0 to 15 m/s
- V_z = 0 to 11 m/s

The preliminary crashworthiness investigations were started at the end of 1989. Back then and consequently for the following 9 years the main tool was KRASH85 and DRI/KRASH-PC. The responsibility for the global crashworthiness was given to Eurocopter [2].

In 1998 after the second drop-test of a main fuselage section it became obvious that a detailed crashworthiness design without advanced simulation tools, "virtual drop testing" is not possible. Eurocopter started to search for finite element method based codes able to perform non-linear explicit crash-simulation with composite materials.

At this time the message from institutes, such as DLR (**D**eutsche Forschungs- und Versuchsanstalt für **L**uft- und **R**aumfahrt Technik) was that commercial codes, used by automobile industry, such as PAM/CRASH are not able to handle a complex composite structure. However, as a result of a visit to a software release presentation in 1998 in MSC Munich and in following discussion it was brought to our knowledge that MSC.Dytran could be applied to our specific problems.

Eurocopter obtained a demo license at 1998 for a test period of 3 months and consequently purchased the program license. Currently, Eurocopter has four licenses of MSC.Dytran, the program is used to detail design of the composite structure, as the preparation work for the center fuselage drop test, scheduled to December 2001.

2 Approach to Crashworthiness

2.1 General Requirements

Of the design impact conditions the hardest requirements are for the vertical impact conditions. This is due to the fact that statistically the impact envelope of the helicopters, unlike the airplanes, fall within a small roll/pitch angles and small lateral velocities. It also makes it possible to design a localized crashworthy structure consisting of the landing gears and the crashworthy sub-floor structure. Due to this fact the crashworthiness is more and more a standard requirement of a military helicopter. The critical impact condition for the NH90 is a statistically representative vertical impact on the rigid ground.

The main components are qualified with separate tests. Such components are: the landing gear (Fokker), the cockpit structure (EC) and the center fuselage (ECD). This is partly due to the shared responsibility of the development; this way each nation is able to qualify its own component. The global crashworthiness is then qualified with simulations. A full-scale drop-test of the helicopter has not been foreseen.

2.2 ECD Part

For its own part ECD is required to demonstrate the crashworthiness of the center fuselage with a drop-test, scheduled to December 2001. The center fuselage drop test article (CTA, see Figure 2) will have a gross-weight of approximately 6 tons. It is to demonstrate that it can take a vertical impact on a rigid ground. At the moment the drop test features 14 troops on crashworthy seats, roughly 1370 kg of fuel (demonstrated with 80% volume of water in the fuel tanks).

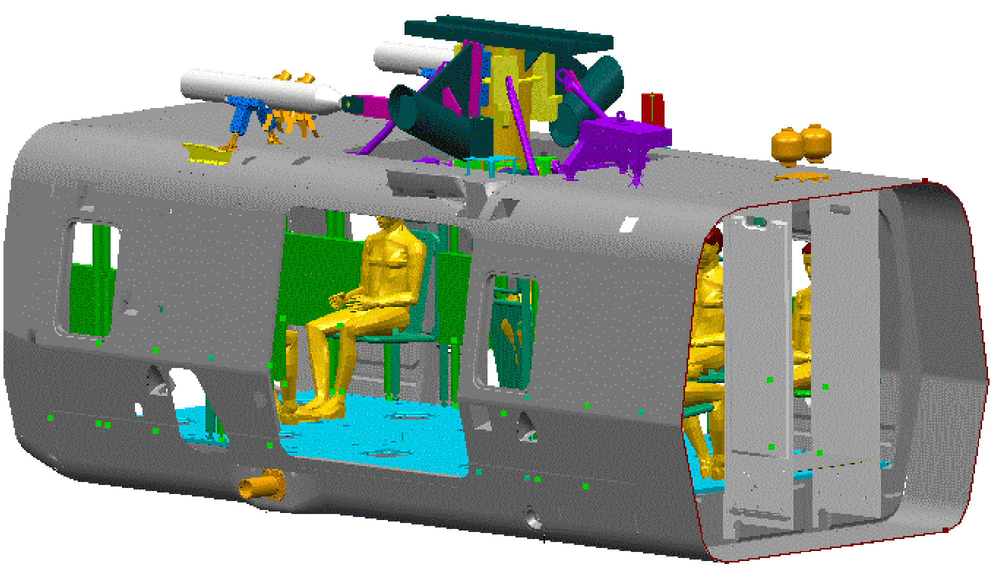

Figure 2 Center Fuselage Drop-Test Article (CTA)

The boundary conditions, such as eventual mass reduction of the rotor and the main gearbox, due to the rotor lift have been derived with series of simulations with DRI/KRASH-PC. The detail design task, dimensioning of the structure shall be done with MSC.Dytran.

2.3 Development in ECD

In the beginning of the development it was considered that a block-wise approach simulation-test-calibration-simulation-test would suffice. With simulation tools a considerable amount of testing can be saved.

The smallest block is a part of the crushable sub-floor structure. These blocks build a next larger component - a fuselage section. The fuselage sections then build the complete structure. The drop-tests/simulations proceed then from a smaller block to bigger (See Figure 3).

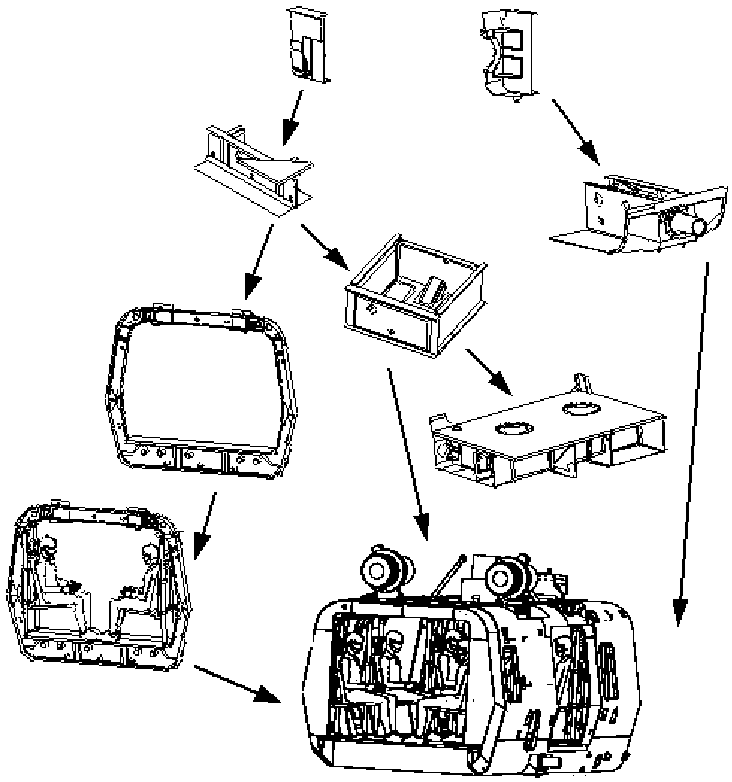

Figure 3 Building Block Approach to Crashworthy Structure

Today, the calibration work has been done with a limited series of tests. The largest of these tests was a fuselage section drop test in 1998.

3 Simulation Approach

In the early phase it was planned that the dimensioning work could be twofold. Dynamic simulation would be done with DRI/KRASH-PC and the resulting loads would be applied to static load cases in MSC.Nastran.

Along the years, it became more and more obvious that a certain link was, however, missing. The structure had its own mind to do things that were not obvious from the simulations. It was sometimes a mystery why a certain particular failure occurred. As the simulation tool was not able to predict a failure, but relied more on a hybrid approach, where failure characteristics have to be manually feed, it was obvious that a failure could not occur where it has not been programmed to occur. Unfortunately, in such non-linear short-period dynamic events, as impacts, an occurrence of a failure is not always very predictable. Moreover, a small event tends to lead to a major event. A softening of a certain part due to plasticity results in a “deformation route“ and all of a sudden the whole system may decide to follow it.

To fill this gap in simulation ECD decided to purchase MSC.Dytran. Today, the program has established itself more or less as a center point for the detailed definition of the structure. It has been used to simulate almost everything between a simple sub-floor crash structure and the whole center-fuselage.

The new modified approach is to use relatively cheap and fast DRI/KRASH-PC to define the envelope and its corner points, to define the boundary conditions (mass reductions etc.) and then to apply them to MSC.Dytran to get the detailed outcome. A further control is then done to boundary conditions (acceleration on the masses, forces etc.) to speculate whether a discrepancy between initial conditions and the simulated results exist.

Parallel to this, the structure is verified with static load-cases with MSC.Nastran, although it has been noted that transient type of analysis would be closer to realistic loading. The advantage of the static load-cases is, however, the simplicity.

4 MSC.Dytran in Praxis

4.1 History

During the three years of active usage MSC.Dytran has been used to investigate a variety of the problems. During the test period of three months it was used to simulate the drop test of the fuselage section (See Figure 4).

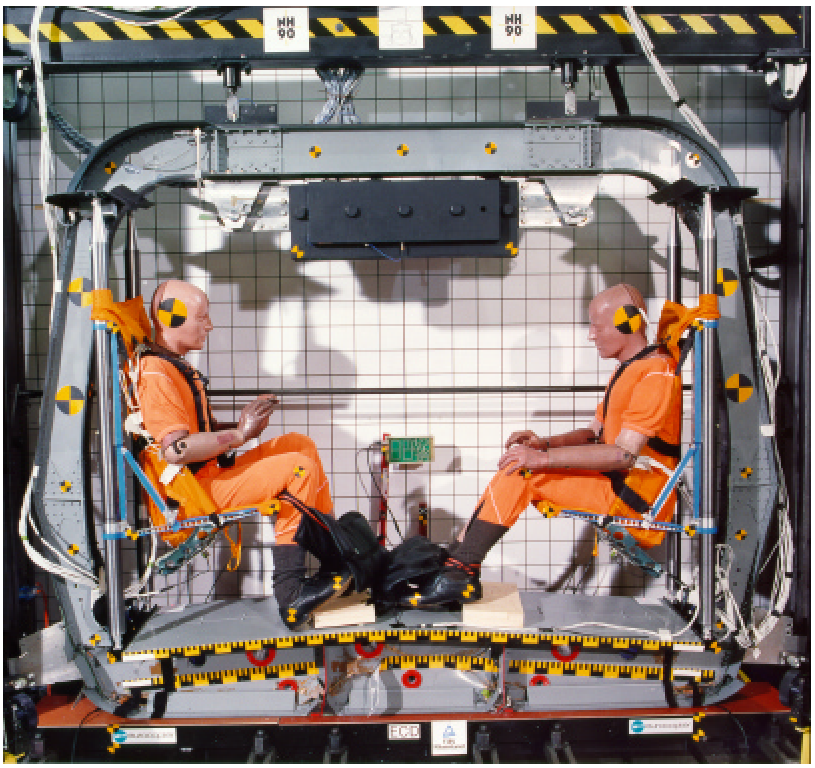

Figure 4 Drop-Test of NH90 frame #6 in 1998

It was noted that even with limited amount of expertise:

- It was easy to start using MSC.Dytran; its similarity with MSC.Nastran was of enormous advantage.
- A fear for a necessity to invest huge amount of time to define new material models/libraries for this purpose was unnecessary.
- Quality of the results was surprisingly good.
  - Program was able to show most of the times qualitatively good failure mechanism throughout the impact sequence.
  - The factual figures, measured parameters, compared reasonably well, if not in the actual values but in the tendency and characteristics.

Of course, the new approach required huge modifications/adaptations on the established way of working. It was noted that it is possible to generate and maintain different models to static and dynamic analysis. For this reason the complete static FE-model of the helicopter had to be regenerated to fulfill the different modeling requirements of MSC.Dytran. A blessing in this was the similarity of MSC.Dytran and MSC.Nastran input formats [4]-[5]. Later, it has been noted that the way more detailed model required in

MSC.Dytran analysis serve also as a better basis for normal static analysis with MSC.Nastran. It also enables largely new possibilities for static work, such as buckling investigations etc.

Following chapters will introduce simulation of three typical examples: a part of sub-floor structure, a fuselage section and the center-fuselage.

4.2 Sub-Floor Sandwich Panel

The smallest block of the crashworthy structure is a composite sandwich panel. The panel has been divided to crush zone and to a stable area above the crush zone. In the impact, the failure is “triggered“ directly in the foot of a panel. After the initial failure, the failure proceeds upwards breaking always in pieces as small as possible maximizing the energy-absorption. The ideal force-displacement law and a typical real-life curve from test are shown in Figure 5.

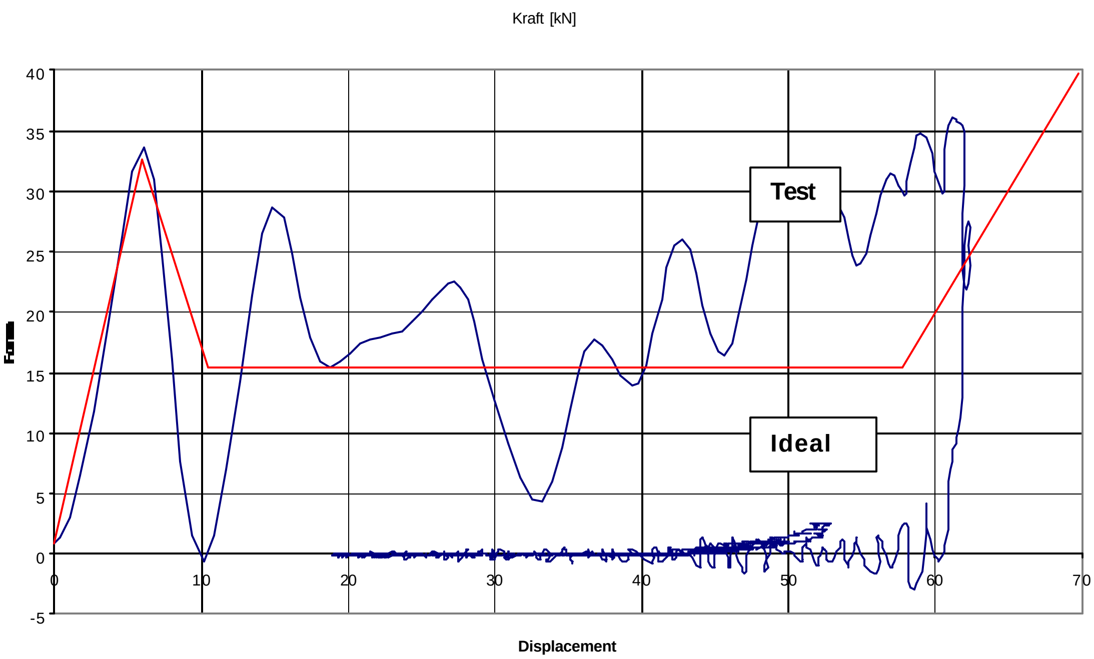

Figure 5 Force Displacement Curve from Test vs. Ideal Curve

A simulation model was created to calibrate the material libraries. Basically, it turned out that creation of the material in MSC.Dytran is relatively simple. In the simplest case a ply-material of composite needs only correct failure stresses. The ply-drop-off method in MSC.Dytran takes care of the progressive failure in the lamina. It must be said that the most unsatisfactory results come usually from the simulations of the smallest specimen. In a simulation of a larger structure as, for example a fuselage section, the micromechanical effects, such as delamination etc. loose relative importance. A model of sub-floor sandwich panel is shown in Figure 6. The model consisted of 8746 elements. 1360 elements were normal plate elements. 2606 were plate elements with laminate properties and the rest were solid elements to model a honeycomb core. The general element side on the laminate faces was 7x7 mm.

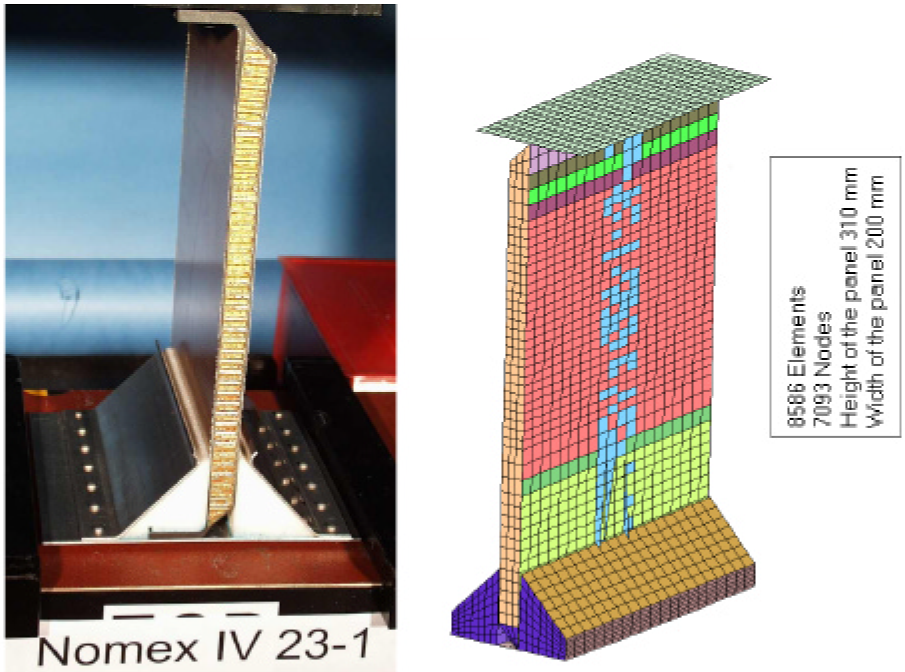

Figure 6 Sandwich Sub-Floor Panel, Test Specimen and MSC.Dytran Simulation Model

Important values for such a panel specimen are: the first peak of impact, the total energy absorption with 120 mm of stroke and the average force level. A comparison test vs. simulation is shown in Table 1. The drop test was performed with an impact velocity of 8.2 m/s.

	Test	Simulation with MSC.Dytran
Peak Force at Impact	33.6 kN	22 kN (with 300 Hz filter)
Absorbed Energy at 60 mm displacement	1.16 kJ	1.04 kJ
Average Crushing Force	20.9 kN	17 kN

Table 1 Comparison Test vs. Simulation from a Sandwich Panel Drop Test

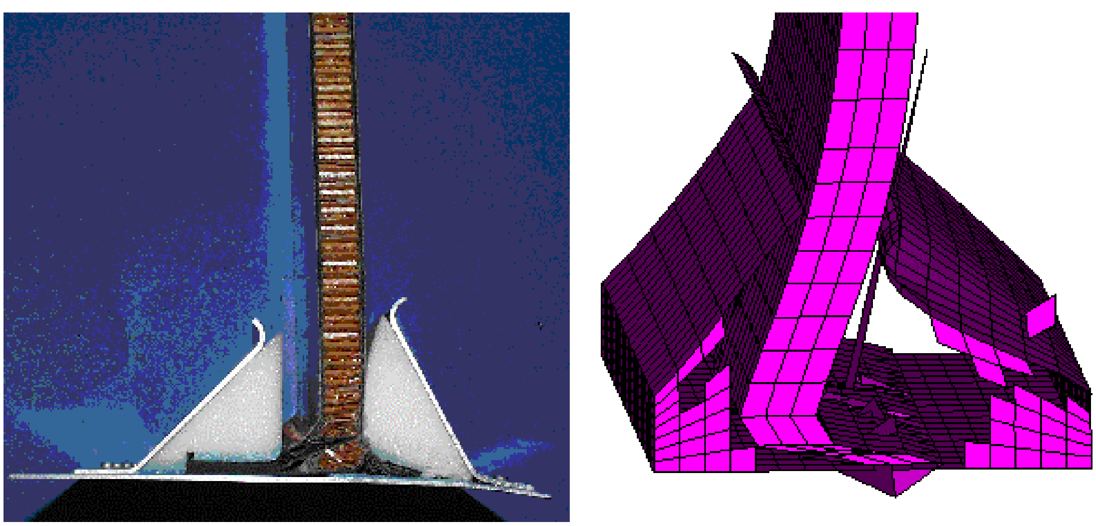

Figure 7 Deformed Results, Drop Test and the Simulation

Figure 8 shows a comparison of the impact force, from the drop test and from a simulation with MSC.Dytran.

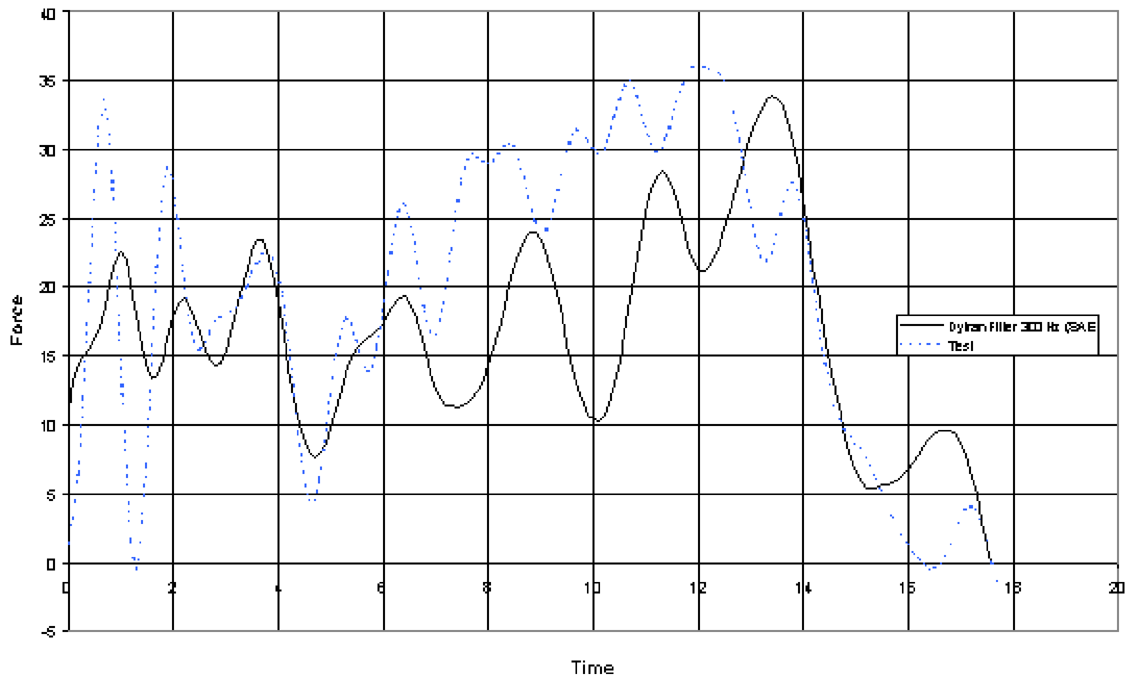

Figure 8 A Comparison of Impact Force, Test vs. Simulation

Up to certain reasonable limits the simulation provides a perfect match with the drop test. It must be noted that each repeated simulation run provides identical results; repeated real-life tests, however, will not.

4.3 Fuselage Section

A larger block is a fuselage section. The most interesting thing from the simulation point of view is the non-linear crushing behavior of the sub-floor structure, consisting of multiple coupled panels from the previous chapter. Another interesting result is the dynamic behavior of the structure above the floor level. Given that the crushing load and kinematic behavior of the sub-floor structure are correct, the behavior of the structure above the floor should remain stable and within a linear area. The strength of this area can be then verified with both static and transient analysis with MSC.Nastran. A simulation of a complete frame #6 was actually the first real-life application of MSC.Dytran in Eurocopter. After very positive experiences the simulation work got started on a larger scale. At this time it was not completely clear how far the simulation results can be trusted and the expectations were not very high. It was assumed that a simulation of the first 30 ms would be already out of a reliable range, whereas a normal impact takes approximately 45-60 ms. Later, it turned out that a simulation is relatively reliable from the beginning to the end. The result from the drop test is shown in Figure 4. A comparable picture from a simulation with MSC.Dytran is shown in Figure 9.

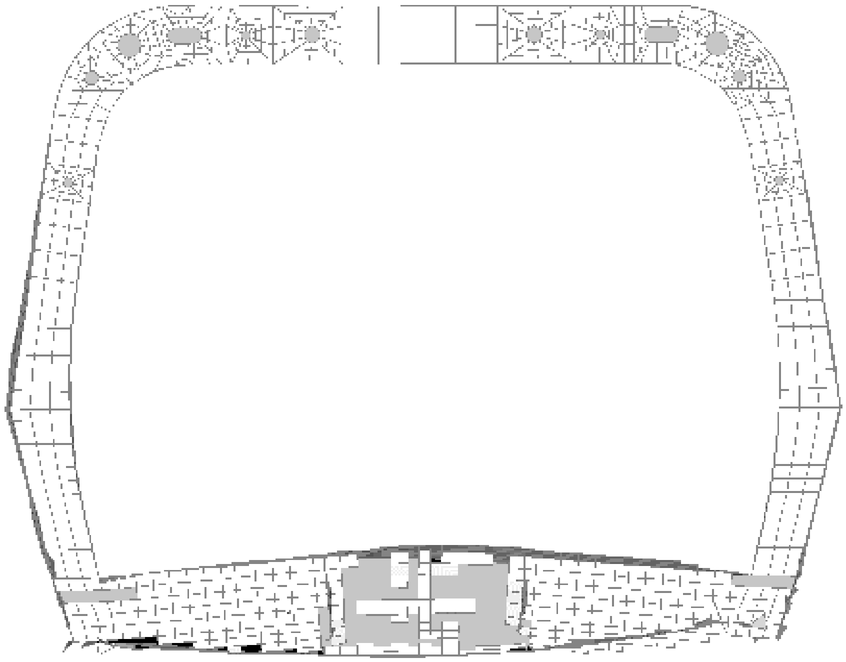

Figure 9 Deformation of the Frame #6 at the End of a Simulation with MSC.Dytran

The model consisted only of 2535 nodes, at this time approximately a detail level from the complete fe-model the helicopter. This fact was very important as it was vital to figure out how coarse an even larger model may be for still reliable results. This was due to intolerably long runtimes. Already to boost up the performance of a single frame simulation the laminate properties (sometimes consisting of 100 layers in PCOMP) had to be condensed. A special program had to be written to condense successive similar orientation layers into one layer. A coarse mesh on the upper parts of the frame was assumed to be acceptable. If non-linearities such as buckling should occur, it was assumed based on MSC.Nastran buckling investigations that a coarser mesh (stiffer representation) has actually a lower buckling value.

The displacements measured from the top of the frame were within an error level of 10-20%. The peak accelerations of the heavy weights on the upper structure were also reliable with an error of some 10%. The internal loads on the frame flanges, measured from strains were also within a similar error margin. The impact force of the frame provided the most impressive match, this is shown in Figure 11.

An important result from the simulation was that the shape of the damaged structure and locations of the fractures were in the correct places. This provides an extremely usable insight to the failure mechanism.. If a catastrophic failure of the area above floor level is predicted to occur before the whole stroke of the sub-floor is consumed, it is likely to occur in the real-life as well. Instabilities, such as buckling were shown correctly and usually at a right moment within few milliseconds from the real occurrence. For example, in reality the longerons in the sub-floor area buckled at t=4.0 ms [3], the simulation told exactly the same thing (See Figure 10)

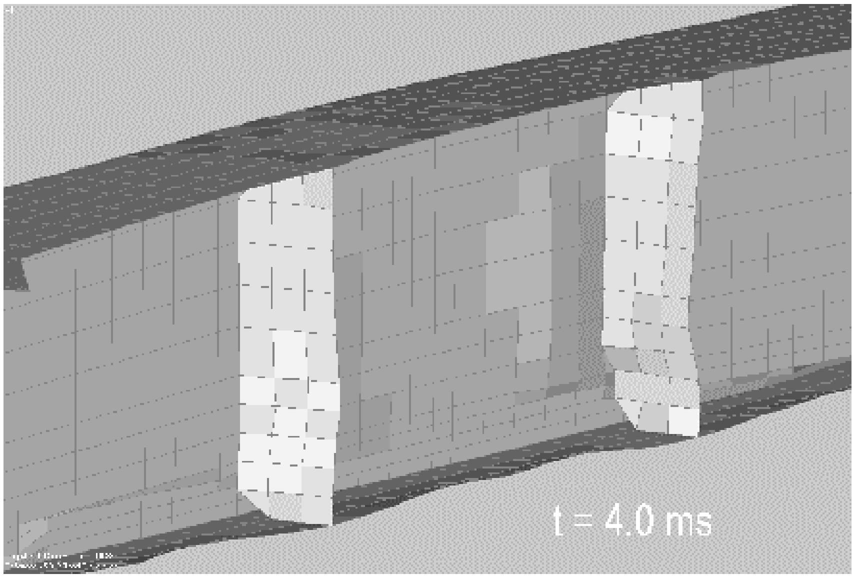

Figure 10 Buckling of the Sub-Floor Longerons in MSC.Dytran Simulation

One of the main tasks with MSC.Dytran simulations is to tune the kinematics of the structure during the impact. The rest of the work is then evaluating the results and establishing sufficient margins to cover possible quantitative errors.

It is obvious that one simulation is not enough. In the case of the simulation of frame #6 satisfactory results were not reached with the first trial. However, after series of trials a characteristic behavior appeared more often. Of course it is comparably easy to simulate a drop test afterwards, simulating something beforehand is hundred times more difficult. After a series of simulations and modification a pattern starts repeating itself and it can be assumed that this is the most likely outcome in the real-life.

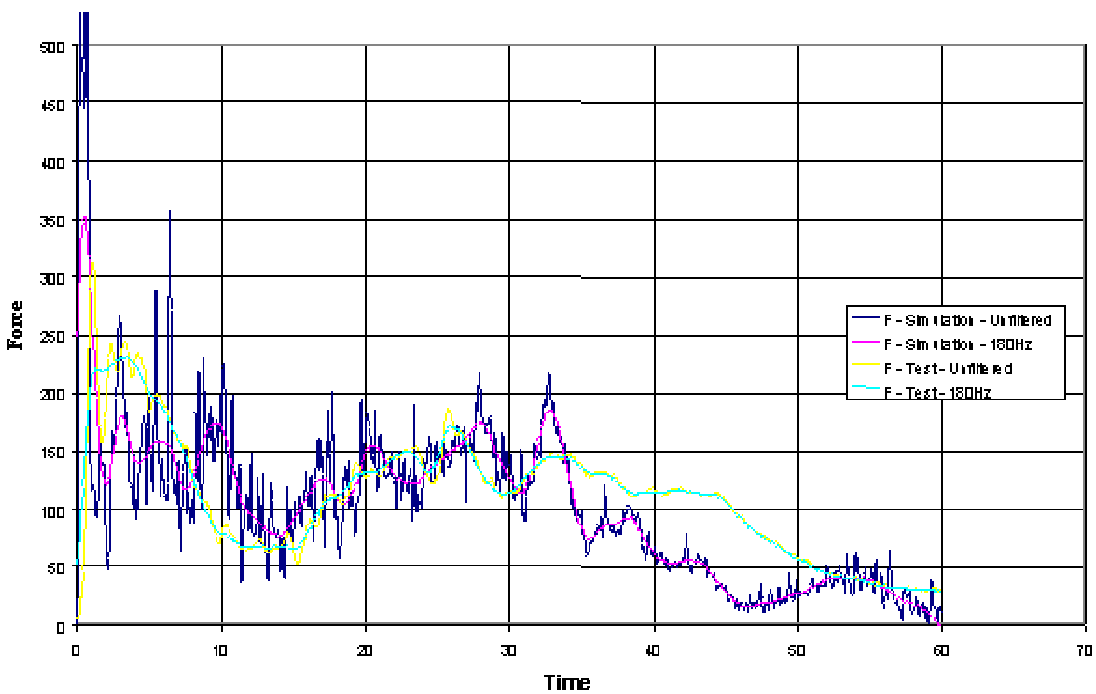

Figure 11 Comparison of Impact Force, Test vs. Simulation with MSC.Dytran

A frame is so far the largest tested block simulated with MSC.Dytran. As a preparation of the center fuselage drop test all of the frames have been simulated separately and compared with the typical behavior of frame #6. After the frames forming the center fuselage impact structure have been dimensioned, a simulation with complete center structure will be performed.

4.4 Center Fuselage

As the most ambitious step the final drop test of the helicopter center fuselage is simulated with MSC.Dytran as the preparation. The results from the global simulation are then compared with the single simulations of the frames and differences are investigated. The model of helicopter center fuselage consists of 66924 elements. The model has 498 properties from which 497 are laminate properties. Although the model is rather coarse compared with the crash models of automobile industry the composite materials make it extremely complex and a simulation of 30 ms of impact lasts roughly one week. The model, thus, is on the practical upper limit of the calculation performance. Simulation with the onboard fuel using MSC.Dytran Euler-Lagrange coupling has been made, the preliminary results support the assumption that fuel plays a passive part. The Euler-Lagrange approach, however, lengthens the runtime with a factor of 1.7.The runtime being already a week with a pure Lagrangian model, the coupled approach does not provide an option for parameter studies.

The MSC.Dytran model of the NH90 center fuselage is shown in Figure 12. The same model is used for both static analysis with MSC.Nastran and dynamic impact analysis with MSC.Dytran. A result from a simulation with 7.7 m/s impact speed is shown in Figure 13. The results show no radical failure of the fuselage frames. The cabin volume is maintained. The results some year ago did not give the same message, the structure starts being ready for the test.

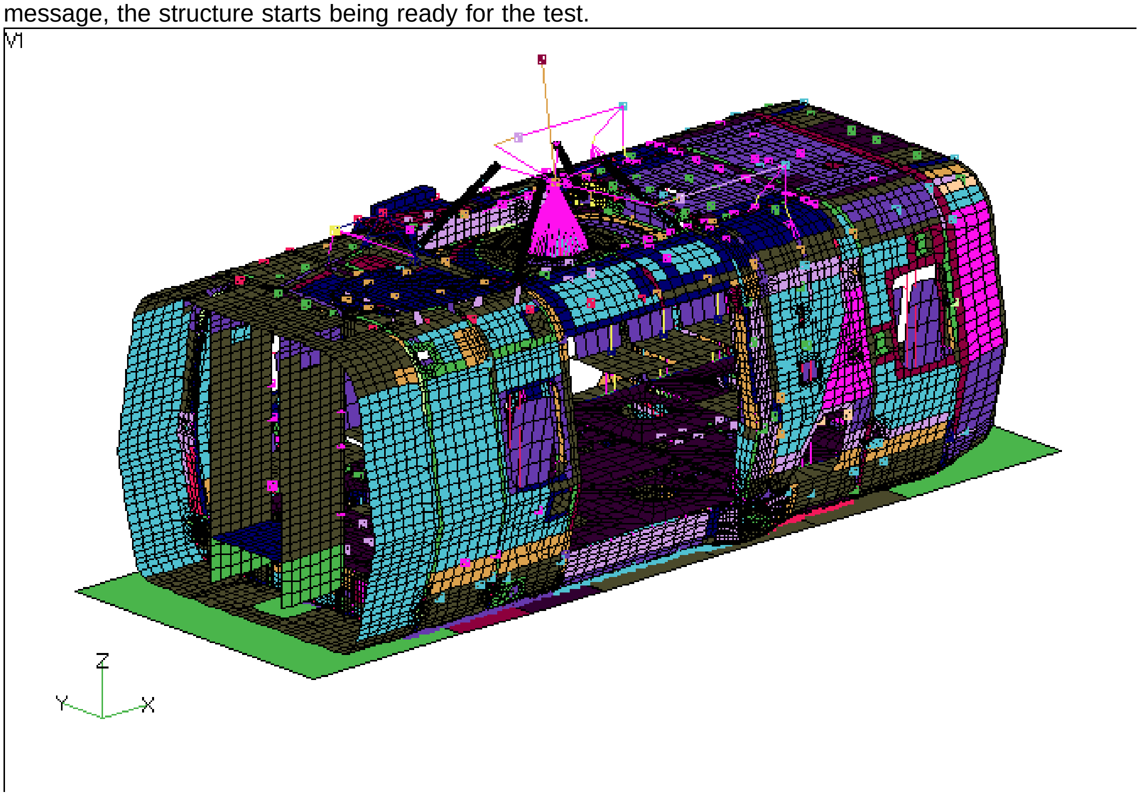

Figure 12 MSC.Dytran Model of NH90 Center Fuselage

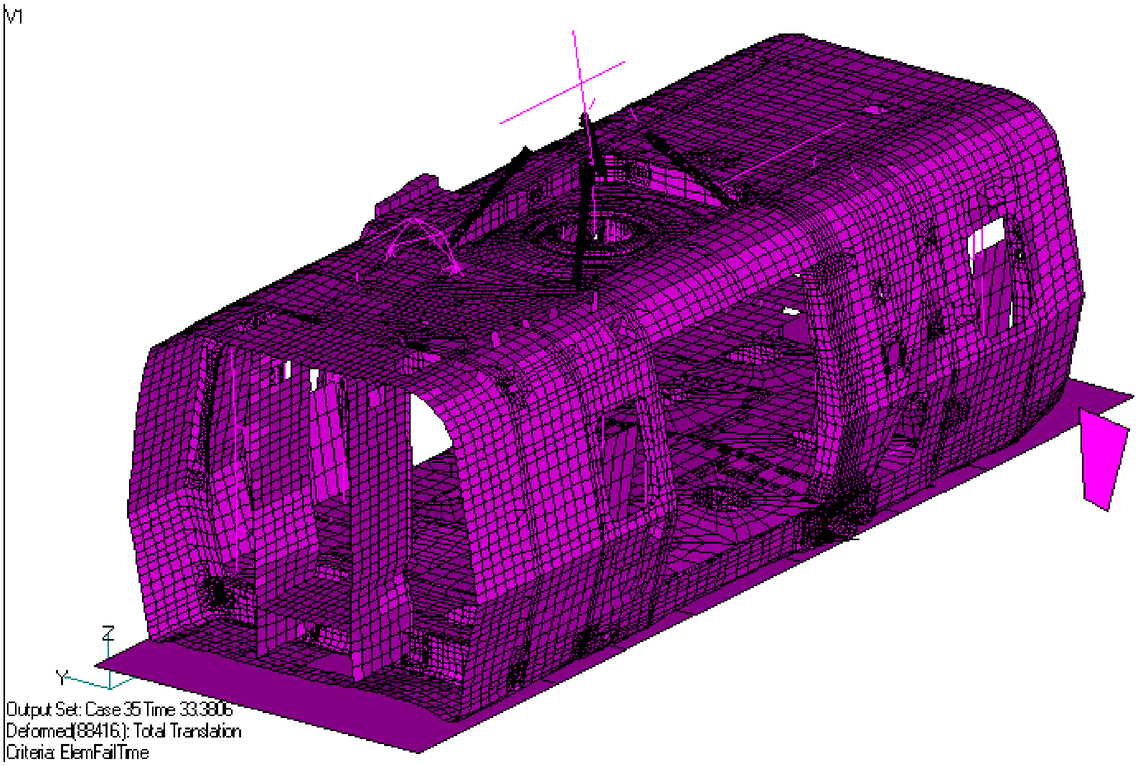

Figure 13 Deformed Structure at T=33 ms after Impact

5 CONCLUSIONS

After three years of active usage, MSC.Dytran has established itself as a solid part in the crashworthiness development of the helicopter structure in Eurocopter Deutschland. Looking back at the structure in the beginning of the design work and comparing it with the current modified structure a lot of crucial modifications can be detected. These modifications, largest of these being a completely new fuselage frame only for the crashworthiness purpose, if not carried out would have meant a lot of trouble. Although, the major drop test is still to be performed, it is certain that in risk reduction MSC.Dytran has more than fulfilled its expectations.

Simulation reduces radically the amount of testing but will not altogether replace it. As a development tool the simulation is in many ways better than test. A test is carried out in few seconds, requires months of preparation work and the only thing left after the test is the measurements and high-speed camera films. However, when testing something for the first time, it often happens that the most important measurement is lacking as something was not foreseen. A high-speed film is taken from predefined angle and cannot be rotated later on to have a more careful look at some details. Simulation can be always be repeated to get more information of some detail. It is even possible to plot the strains all over the structure, which is hardly feasible in real practice. The animations can be rotated, zoomed and panned. However, it has to be always remembered that simulation results depend first of all on the quality of the model and second of all on the structure. The test depends only on the structure itself and leaves little room for speculation.

6 REFERENCES

(1) U.S Army Aviation Systems Command, “Military Standard, Light Fixed and Rotary-Wing Aircraft, Crash Resistance“, MIL-STD-1290A(AV)

(2) Nitschke, D, “Systematic Development of Crashworthiness of the NH90“, 2nd International KRASH User‘s Seminar, Cranfield, U.K, June 1995

(3) Oster, R, “NH90 – Crashworthiness; Drop Test an Spant 6 mit Troop Seats und zwei Personal-Dummies (HII)“, Eurocopter Report PN D/GXP3-98/05, Eurocopter Ottobrunn, Germany, 1998

(4) MSC.Nastran User‘s Manual, Version 66, The MacNeal-Schwendler Corporation, Los Angeles, CA, November 1988

(5) MSC.Dytran User‘s Manual, Version 4, The MacNeal-Schwendler Corporation, Los Angeles, CA, November 1997