CRASH ANALYSIS OF THE "HIGH CABIN"-VERSION OF THE NH90 TRANSPORT HELICOPTER FUSELAGE

J.Majamäki
Eurocopter Germany
81663 Munich
Germany

OVERVIEW

For Scandinavian countries a special NH90 version with a higher cabin has been developed. Like for the original "standard" cabin version, the contract between the industry organisation NHI and the customer organisation requires crashworthiness, based on MIL-STD 1290 and the Weapon System Requirements. The previous experience of the development of the Tiger helicopter resulted in a better understanding of helicopter crashworthiness and led to more efficient verification methods, for example: advanced simulations. Early in the pre-development and development phase of the NH90 in the late 1980s simulations and parametric studies with the code KRASH concerning the global crash behaviour of the helicopter were performed. Principal load distributions and load factors over the crash duration were calculated. The results were taken into account in the further design. With the NH90 test-building block approach, the necessity for expensive testing was largely reduced. On the other side, the development on the analysis area was improved remarkably. The simulation effort benefits from the drop test in form of verification results. Based on the performed tests, practical experience and knowledge about interpretation of results were gained. The simulation with the help of the code RADIOSS has improved the capability to extrapolate the result of component tests outcome. The experience and the joint test and analysis approach, which was applied to the standard cabin development of the NH90, have allowed a rapid development of the "High Cabin"-variant of the NH90. Experiences from the development are shortly summarized in this paper.

1. INTRODUCTION

The NH90 (see Figure 1), (Nato **H**elicopter of the **90**'s) is a program of five nations: Germany, Italy, France, the Netherlands and Portugal. The Helicopter exist in two main variants NFH (**N**ato **F**rigate **H**elicopter) and TTH (**T**actical **T**ransport **H**elicopter). The preliminary design dates back to the early 1980's, whereas the actual development phase was started September 1992. The serial production was started May 2001.

Figure 1: NH90 TTH Prototype PT4

Currently NH90 has been sold to a variety of customers all over the world – totalling in app. 500 orders. The NH90 is a medium size transport helicopter with next generation concept. It features primary structure completely out of carbon fibre reinforced composites. As a novelty for helicopters NH90 features modern avionics with glass cockpit and fly-by-wire. Structurally, as an addition to the composite structure NH90 features crashworthiness according to MIL-STD-1290(AV). The main aspect of NH90 crashworthiness requirements (applicable to TTH variants) are impact velocities of:

Forward speed 0 m/s to 14.4 m/s combined with vertical speed from 10.6 m/s to 0 m/s, impact on rigid ground with extended landing gear.

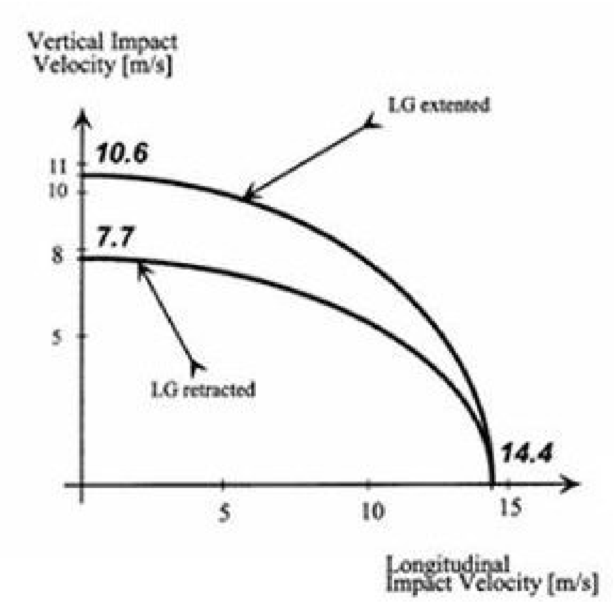

Figure 2: Combination of Vertical Impact Velocity and Forward Velocity (NH90 Crash Specification)

The impact attitude can vary between ±5° roll and up to 15° pitch.

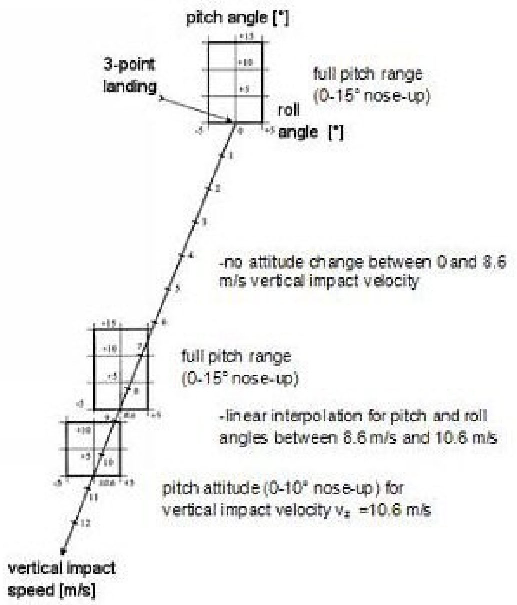

Figure 3: Pitch and Roll Attitudes in Combination with Vertical Impact Speed (NH90 Crash Specification)

First background studies for crashworthy structure (mainly on energy absorbing impact zone) were already performed late 1989. Analyses were largely performed with KRASH-85 computer code – originally developed for the aircraft impact analysis with support of US Army. Whereas KRASH provides useful basis with modest financial investment, the rapid development in the software and computing technology has brought out a range of computer codes with capabilities that possibly could not be foreseen earlier in 90's. The modern explicit finite element calculation codes that run in computer clusters are mainly developed for the needs of automotive industry, however, rapidly gaining popularity in aerospace industry. Although aerospace needs are somewhat different from automotive needs, due to longer development process, physical size of the vehicle and mostly due to the different priorities, the explicit simulations are applied to increasing number of most imaginative problems. One such an everyday application is, for example, a simulation of a bird impact, which has become almost an irreplaceable substantiation method.

Still, relatively rare application area is the simulation of the complete aircraft crash. The lack of application is a sum of several factors. Firstly, in a conventional fixed wing aircraft the impact conditions may largely vary over a range of velocities and attitudes, not to mention impact surfaces. Secondly, since no strict concrete requirements (where the definition is already difficult due to the first point) exist, such a development would be done on manufacturer's own initiative. Thirdly, the aircraft are developed over a long period of time and built in relatively small numbers, a demonstration test of already one specimen is significantly more expensive in relation than a test of an auto mobile. Fourthly, a simulation of an aircraft impact is a very complex matter, due to the size and complexity of an aircraft, modest computing resources (comparing with automotive industry) and long impact sequences, which make the analysis very time consuming. However, these factors primarily concern the fixed wing aircraft. In the helicopter, an integration of crashworthiness features makes much more sense and is becoming more a reality. The helicopters, typically, have a smaller velocity range, are more often subjected to crashes and statistically majority of accidents fall into a limited attitude and velocity envelope. This allows a dedicated and pointed design of a structure, with only small weight penalty, as long as the requirements are kept on reasonable level. The requirement definition is also one step ahead of fixed wing department. For military customers helicopter crashworthiness is much higher on the list of priorities.

2. HISTORY OF ANALYSIS ON NH90

NH90 development has largely benefited from the development of the computing technology. Initial idea for simulation approach was to apply the established code KRASH for the development task. Necessary testing is done to support the analysis approach. KRASH is based on “hybrid” approach. In this context it means that a simplified structural model with beams and mass points is completed with non-linear characteristics, featuring, for example, the crushing behaviour of the impact zone. Derivation of such non-linear characteristics is then traditionally done with component-tests. Whereas the models are simple and the runtime is very short, the problem with the approach is that non-linear: damage/failure relies completely on user fed characteristics. The drawback from this is that the program is not able to do autonomous damage prediction – the damage, if not explicitly modelled, will not take place. Due to this fact the user has to exercise a lot of judgement, which in turn requires experience. In the early 90s – KRASH was practically the only solution that could be applied on complete aircraft level. In the case of NH90 the issue was further complicated by the composite material. Although, the first explicit codes were already actively applied by the automotive industry in 90's, the approach seemed impractical for helicopters.

At 1998 a test license of MSC.Dytran was obtained and as Eurocopter had just performed a complex fuselage section drop-test the tool was applied for a case study. The results seemed promising, particularly considering the modest experience with the tool. A great plus was a great degree of similarity between the input data format of MSC.Nastran and MSC.Dytran, which spared great deal of modelling effort, as the FE-calculation model could be directly taken from static stress analysis and used for impact simulations. Of course, the required discretion of the modelling level was somewhat higher for explicit simulations, but a suitable balance was quickly established, after refining the static stress model. This also benefited the every day stress analysis, as the old model was already becoming outdated. It was envisioned that a more detailed explicit simulations could be used, for example, in the design of components, such as fuselage sections (See Figure 2). The information could be then integrated into KRASH-code for global simulations. This way, already some sparing in the actual testing could be achieved.

Figure 4: NH90 Fuselage Section, Drop-Test and Simulation

Initially, this worked as planned, however, as the time closed in 2002 for centre fuselage drop-test (CTA), both the computer hardware and the used finite element code had matured in parallel processing to a level which made simulation of the complete centre fuselage impact possible. Whereas a simulation still required 8 days in 2xCPU pentium IV hardware, it was app. 24 times faster than on the original UNIX-server, where it all started.

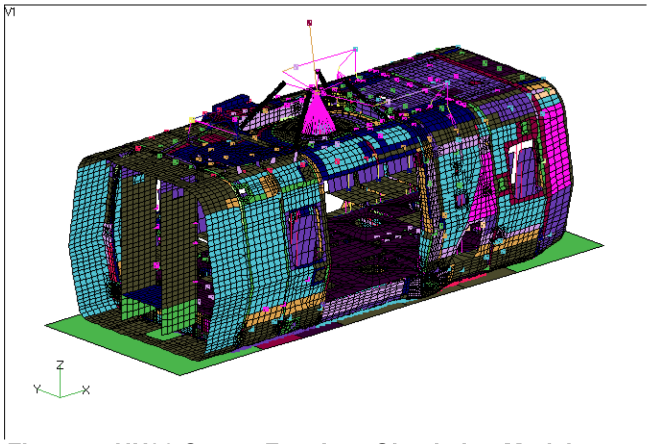

Figure 5: NH90 Centre Fuselage Simulation Model

After centre fuselage drop it was relatively easy to project the development of computing speed as the speed increase was linearly related to CPU speed, therefore later 3 Ghz PC-hardware again brought 50% more performance. This increase came just right in time for complete helicopter simulations. The centre fuselage model was equipped with tail, cockpit and landing gear and analysis with complete helicopter model were started.

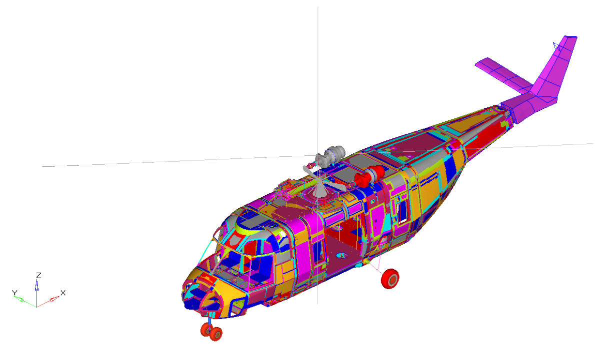

Figure 6: NH90 Complete Helicopter Simulation Model

At this point the explicit simulation was already used for a definitive substantiation of the most critical impact cases. The original tool KRASH was now adapted to the parametric work of filtering and selecting the critical impact cases for detail study. In the end, it was possible to select approximately 8 dominant impact cases from the NH90 crash envelope that covered the others. In this sense the demonstration with analysis provide a better coverage as conventional drop-test, which is often executed for one selected case. Such a singular selected case is often not the definitive most critical one (if such a single case can be named), but rather an impact scenario that can be executed on the test set-up accounting for real-life constrains.

3. ANALYTICAL APPROACH

Today KRASH is still extensively used for the parametric studies, although, it would be just as possible to work with explicit codes using significantly coarser discretion in models and essentially achieve the same benefits. KRASH is, however, still inexpensive and perhaps due to the personal preferences such a step has not been taken. Meanwhile, MSC.Dytran has been replaced by Mecalog Radioss - or Altair Hypercrash as the product is known since the beginning of the year. However, the analytical approach has remained unchanged.

KRASH-approach is not that dependant on the detail level of the model, indeed the helicopter, for impact analysis, could be even realized with one mass point and a spring featuring the crushing behaviour of the impact zone. For this reason the program is extremely suited for preliminary design phase, where the design does not take concrete forms yet. The preliminary design leads to first estimates of the required characteristics – in the case of crashworthiness these characteristics could be, for example, required energy absorption over available stroke, of a certain area. This in turn results in first preliminary loads. A balance between available stroke , required energy absorption of the structure and the loads, so that the crash is in line with other load requirements, has to be established. In the case of helicopter, such other load requirements are the conventional flight loads, which is still the primary purpose of the whole design. Only then it is possible to form the idea of the required characteristics in to a concrete design. First at this point it, consequently, starts making sense to apply more complex finite element analysis for design verification.

Testing is typically started much earlier in the development, in form of design studies, on a small component level. Energy absorbing sub-floor structure, which ideally crushes on a constant force level, providing a high specific energy absorption over weight is a complex development task, which often requires systematic testing of several specimens. At this point computations are of not notable use. However, as the development progresses and reaches a state where first structural components are constructed and first larger scale drop tests are performed, application of analysis and in particular finite element analysis can be considered.

The role of the simulation at this point is verification of the design in the first place, but with approaching test, the boundary conditions for a test have to be established. Test is always an extreme simplification of reality – the purpose of the analysis is to see that the boundary conditions are derived so that a reasonable link to the real conditions can be achieved. At this point it is also necessary to start qualifying the analysis tools and start generating trust at means and methods. In order to obtain trust at analytical approach, a test needs to be simulated beforehand and a concrete prediction of the outcome, preferably, of some meaningful physical parameters need to be performed, and the results need to be documented. Ideally, a good test would happen exactly as predicted, however, seldom does. Therefore, third stage of a drop test is comparison of results and improvement of the analysis (remodelling, correction of errors, adjustments). By systematically following prediction, test, comparison cycle, preferably showing convergence between the three along the years, a sufficient trust is gained for final qualification of the structure.

At the same time, as components evolve into assemblies and finally to complete aircraft, the testing can be reduced and analysis shoulder more responsibility in the development. The tests are now required more as an evidence for analysis and not necessarily as a demonstration of the concrete capabilities of the design.

With NH90 small component tests of the sub-floor required several dozen, if not hundred component tests. Larger assemblies of the sub-floor area were tested approximately 10 times. Fuselage sections were tested in three occasions. The complete centre fuselage was successfully tested once. This reduced testing, where numerical majority of tests is performed on inexpensive small component level, is known as a building block approach (See Figure 7)

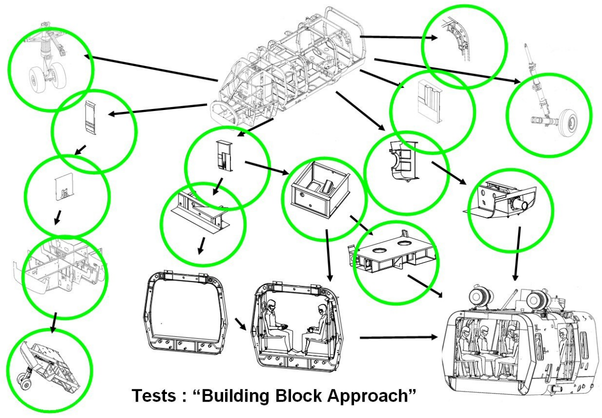

Figure 7: NH90 Building Block

4. DEVELOPMENT OF NH90 HIGH CABIN VARIANT

As the design&development of the “standard”-version of NH90 was coming to the end and serial production was started, new customers started showing interest. One such an interest group was the Scandinavian countries that needed all simultaneously upgrade of the old equipment. Due to the largely similar but yet at times different common requirements and priorities it turned out difficult to find a helicopter that could satisfy everybody's needs. Whereas one country wanted to have bigger transport helicopter, the other needed to have a moderate sized helicopter that would better fit on ones ship deck . As an attempt to please everyone, a modification of NH90 with an elevated cabin was proposed. The proposal found positive resonance from Swedish defence forces, which initially ordered 15 high cabin helicopters. The purpose of the modification was to allow sufficient cabin height, to allow people standing straight up in the cabin. This was of particular interest for SAR-operations. Although 25 cm elevation of the fuselage may sound a drastic modification (over 10% of height increase)– it was projected that a modified helicopter essentially stays the same. This was due to the fact that the modification was based on same rotor system and many of the original solutions were kept – for example high cabin overhead structure is identical to the standard low cabin solution.

Particularly challenging aspect of the modification was to try and preserve the original crashworthiness capability of the airframe. It was carefully analysed what kind of influence the elevated fuselage dimensions might have on impact behaviour. Essentially, only a fraction of the helicopter weight is due to the airframe. For this reason, elevated cabin variant is not strturally heavier than the low cabin variant. The mass distribution and inertia, which is all mainly due to the mass items (equipment, troops, engines, rotor, gearbox) is comparable. One relatively easy comparison for the global behaviour of the variants can be done with eigenfrequency analysis. As Figure 8 shows, for example, the first bending mode of the fuselage, which is the most important mode influencing the landings and crash shows only minor difference, which falls within the error margin of the calculation themselves.

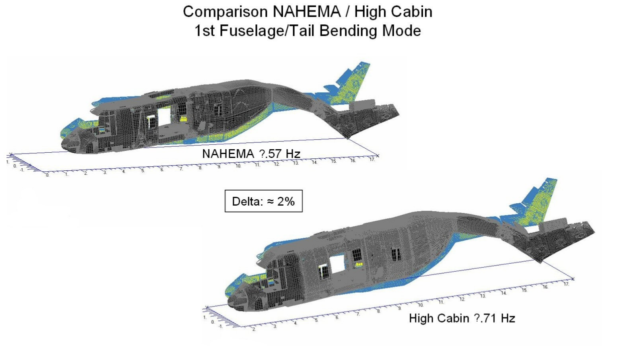

Figure 8: Comparison of First Fuselage Bending Mode - Standard Cabin vs. High Cabin

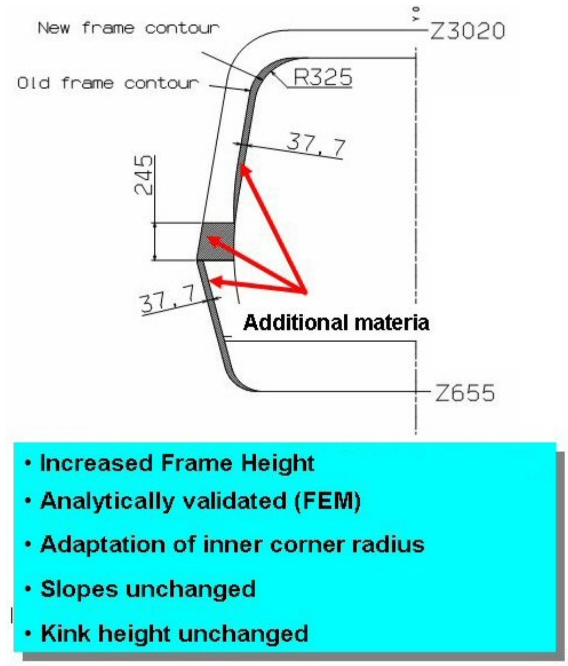

Figure 9: Modification of Original NH90 Low Cabin Geometry to High Cabin Geometry

The elevation of the cabin height was achieved by preserving significant portions of the old design. Important factor for crashworthiness was preserving the original landing gear, the upper deck design and heavy mass support, such as main gear box and engines. Another significant factor was preserving the original sub-floor design with the energy absorbing construction. Although, high cabin sub-floor area is few centimetres wider than on the low cabin, the difference is minor. Due to these two factors the whole development could be concentrated on the area between the sub-floor and the roof. Having comparable mass and having comparable crushing zone, the structure in between is subjected to a similar loading. Since, this loading is well understood from the standard cabin development, numerous simulations and drop tests – it was possible to take several short cuts when developing high cabin.

Knowing that typically the fuselage sections failure mode in crash is due to the stability and knowing that the topology modification has an influence on this, a special attention was paid to preserve the integrity of the sections. As a design measure the vertical parts of the sections were broadened in order to increase the cross-section.

First estimate in the relationship between the old design and new design can be assessed even simply with Euler's buckling formula. Whereas the absolute value provided by the calculation is not very accurate, a relationship between the two designs can be established. In second verification loop FE-methods were applied but still in the static analysis. The explicit method, as the most time consuming approach was used on the final investigation.

Since the differences in design could be localized so pointedly it was also relatively easy to apply engineering judgement to assess the possible influence. With parametric studies it was quickly concluded that the differences can be only most pronounced in impact cases where the fuselage sections see highest vertical loads. The highest vertical loading in turn occurs in almost pure vertical impacts. Therefore it was not necessary to perform the analysis broadly over the complete domain as it was done for standard cabin, instead the information about critical cases was already known and could be concentrated further to the particular loading. The remaining cases could be investigated more with “expectation, assumption and confirmation”-approach.

5. QUALIFICATION OF HIGH CABIN

During the short development phase of high cabin it was possible to perform limited amount of simulations. At this stage analysis were mainly limited to linear transient analysis with MSC.Nastran and simulations with KRASH. Additional problem with the intensive analysis during the development phase, was lack of resources, as the standard cabin variant was simultaneously going through the crashworthiness qualification phase. It was, however, possible to pay enough attention to the development in the critcal areas that radical setbacks could be avoided.

During the development, it was possible to apply many improvements to the design and way of working that was not possible in the tight schedule of the standard cabin serialization. With the involvement of the advanced composite design tools in larger scale it was possible to generate a second generation FE-model for stress calculations in a relatively short time. Special attention was paid during the modelling that the model could be used in the explicit simulations. The task of converting the MSC.Nastran model to simulation model, required still some 6 months of work. The process was somewhat complicated by the introduction of Mecalog Radioss as the simulation code. It was, however, too good a chance to pass for switching the analysis code. Such a change was impractical for existing standard cabin – since it would have cause much of double work. Instead, High Cabin provided a nice controlled environment where it was possible to introduce limited number of changes. As Mecalog has been working years with Eurocopter France, the cooperation was on very good foundations, and the software was further adapted to the special needs of Eurocopter Germany. Although, from engineering point of view, Radioss has been a clear choice for a longer time, as a common tool for Eurocopter Group, such a switch is very difficult in aeronautic branch. This is usually possible only with a new project. High Cabin project, provided a suitable break and the change could be carried out without too much negative impact on time schedule.

Already from the beginning, the high cabin modification was treated as minor. No dedicated structure tests were foreseen in the contract. Along with the change of analysis code, the lack of tests caused certain concerns during the qualification. It was, however, possible to argue that large amount of component tests from the "building block" would have been 100% identical to High Cabin. The transferable tests that would have been identical for High Cabin are circled green in Figure 7. These tests would have been performed in identical form - even if there had been no standard cabin. Many of the performed tests were simulated once more with structure models extracted from the global High Cabin simulation model. So in this sense still a limited amount of double work was required. After the results from benchmarking, comparing the analysis codes, were presented, the analysis approach was accepted. Even, in spite of the invested time for the dedicated benchmarking and programming of suited conversion tools, the gain in the actual work due to the more effective parallel processing and robustness, an overall gain in time was achieved.

From engineering point of view, in the end, the fact that the analysis results have a high degree of comparability between the two variants, in spite of the different analysis models, in spite of the differences in the real hardware and in spite of the different analysis codes, is an ultimate proof for a real comparability of the two variant. In the reality any of the mentioned differences can only cause an increasing divergence, the fact that the results do not diverge is therefore supporting the probability of the results. One typical comparison, between the variants, for main gear box accelerations in one typical impact case from explicit FE-analysis is shown in Figure 10.

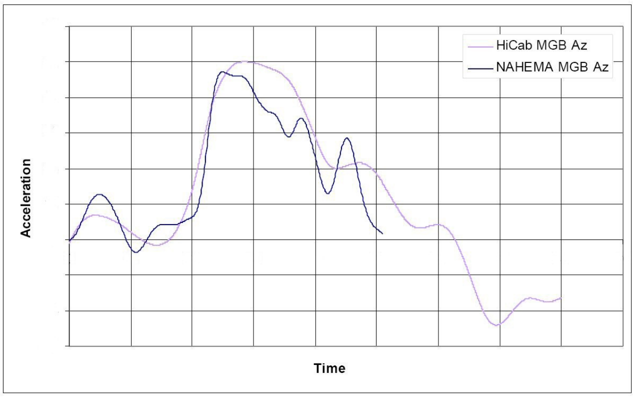

Figure 10: Comparison of MGB Accelerations in a Typical Impact Case - High Cabin vs. Standard Cabin

Simulateneously, the results from FE-simulations were supported independently by analysis with KRASH, another typical example is shown below in Figure 11, featuring vertical loading of a fuselage section supporting main gear box.

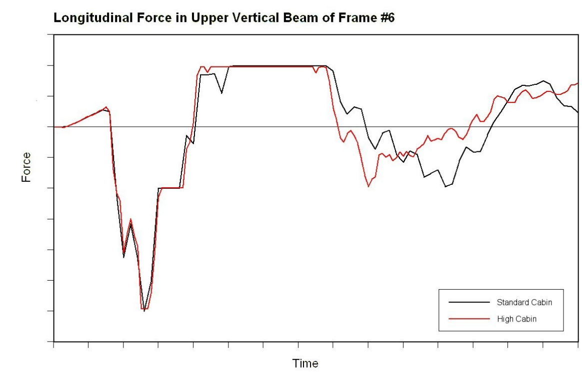

Figure 11: Comparison of Vertical Load on a Fuselage Section in a Typical Impact Case - High Cabin vs. Standard Cabin

With several such comparisons it was possible to gather sufficient amount of evidence for the similarity between the variants, High Cabin and Standard Cabin. In the end treating the modification about the cabin height as minor was shown justified.