CRASHWORTHINESS INVESTIGATIONS IN THE PRELIMINARY DESIGN PHASE OF THE NH90[I]

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Abstract

After the introduction of MIL-STD-1290 several helicopters like the AH64 Apache and the UH60 Black Hawk were built in accordance respectively nearly in accordance with the whole range of requirements of that standard. The primary structure of this first generation of crashworthy helicopters consisted more or less completely of metal.
In the meantime more experience has been gathered which led to a reduction of crash requirements as well as to the application of new structural materials. Therefore new helicopters like the Tiger (PAH2/HAP/HAC) and the NH90 are designed to a 90% and 85% fulfilment of MIL-STD-1290 respectively. Furthermore after some technology programs (ACAP, BK 117 composite airframe) they are the first helicopters whose primary fuselage structure consists nearly completely of composites (like carbon fibre reinforced plastic - CFRP or aramid fibre reinforced plastic - AFRP).
To identify problem areas and to verify the present design concept, simulations with KRASH85 have been performed at MBB for the NH90. Due to the early state of the program a simplified two-dimensional model was judged to be the best compromise between effort and accuracy of results. After some iterations a quite good representation of the structure was found and parametric studies could be performed under consideration of the main crash features of composites like high specific energy absorption, lack of ductility and higher susceptibility to the loss of structural integrity in areas of energy absorption.
After all, the high potential crashworthiness of the NH90 could be confirmed and the main crash design parameters were determined.

1. Introduction

The establishment of MIL-STD-1290 (AV) in 1974 and its application in the following years indicated the introduction of a new design philosophy. From that time on an improved crashworthiness became a major design requirement. This led to a number of different technology programs which resulted together with the outcome of full scale crash tests (like BO 105 or BK 117) and the experience from real accidents in a quite big data base about the crash response of lightweight metal structures.
For the present development of the Tiger and the NH90 which feature a more or less complete composite fuselage this experience is only of limited value. But some technology programs like the BK 117 composite fuselage program in Germany at MBB and the ACAP in the US served already to fill this gap. Furthermore the German Ministry of Defence sponsored a more detailed research program with respect to the NH90 (Fig. 1-1). Although

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Fig. 1-1: Full Scale Mock-Up of NH90

further investigations are highly desirable, presently the following conclusions can be drawn:

- The specific (per unit mass) energy absorption of composites is significantly higher than that of traditional metal structures if suitable configurations (e.g. sine waves), material combinations and lay-ups are selected.
- The lack of ductility of composites necessitates to design for progressive failure (instead of yielding) of energy absorbing members and to consider that structural integrity is mostly lost during energy absorption of CFRP. This can be improved by the use of aramid.

Besides the selected material, the design of a H/C is of course also defined by its intended purpose. The NH90 is a joint venture of France, the Netherlands, Italy and West Germany. It is a transport and utility helicopter in the 8-9 t class. The NH90 will operate land based (TTH) as well as ship based (NFH). For the NFH deck handling quality is of great importance. Therefore the NH90 is equiped with a nose type landing gear. Furthermore this configuration provides the desired rear loading capability (ramp). Despite the different requirements which exist for both variants a high degree of commonality of parts was specified too.

To assess the crashworthiness of the NH90 simulations were conducted. The objective of them was mainly:

- to investigate configuration related impact behaviour
- to investigate composite related behaviour
- to determine the necessary ratio of sine wave members to sandwich in the subfloor structure
- to investigate the influence and the consequences of the stiff composite fuselage
- to investigate the interaction of landing gear and structure

2. Review of KRASH85

KRASH85 is an advanced version of KRASH79. Both programs were developed by the Lockheed-California Company under a sponsorship of the FAA and the US Army. They predict the response of vehicles subjected to multidirectional crash environments. For that purpose these vehicles are represented by models which consist primarily of lumped masses and interconnecting massless beams. Further necessary elements are springs which provide contact to impact surfaces. Optional massless node points which are rigidly connected to their respective mass points are used to specify a more detailed geometry. Also an injury criterion for occupants the dynamic response index (DRI) is incorporated in KRASH. Other capabilities that are available but not used up to now include for example volume penetration calculations, occupiable volume change calculations and oleo shock strut specification (only single stage). As KRASH is a so called hybrid program especially the plastic behaviour of the elements has to be provided as input. Possible initial conditions are e.g. linear and angular velocities, attitudes, slopes and flexibilities of crash surfaces.

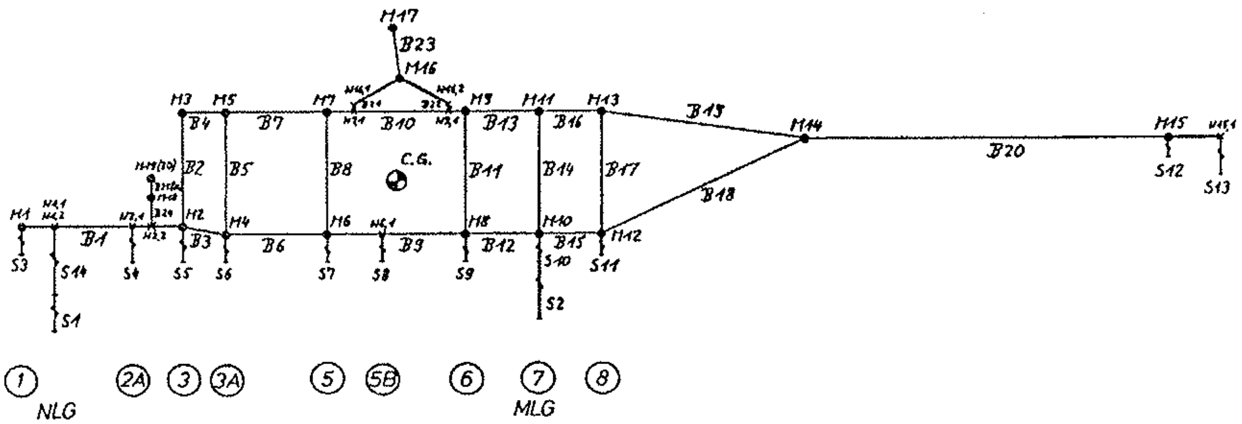

Fig. 3-1: NH90 KRASH-Model

A detailed description of the programs and their capabilities is compiled in [1] - [4]. For the investigation of the NH90 only KRASH85 was employed.

3. Description of Model

Due to the already mentioned early stage of design it was decided to specify only a two-dimensional (2D) model where the structure is condensed on the x-z-plane (plane of symmetry). Although this simplification limits the simulation to combinations of longitudinal and vertical velocities with pitch

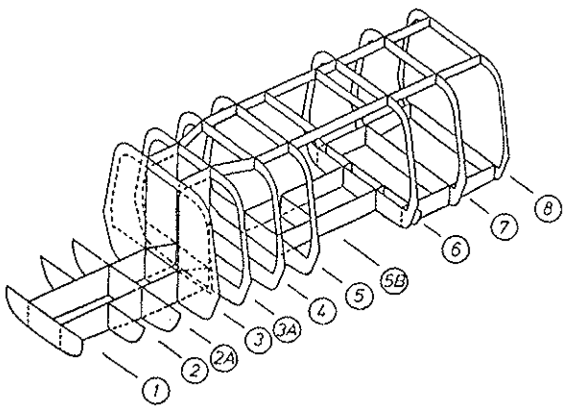

Fig. 3-2: Structural Concept of NH90

angles (initial angular velocities were not investigated) it was judged that these restrictions are tolerable for a preliminary investigation. The limitation to a 2D-model reduces the effort considerably and it was estimated that this compromise yields the best relation of expense to benefits. The complete model is depicted on Fig. 3-1 with important details like element identifications and frame numbers. It is based on the structural concept of the main crash relevant part of the H/C as shown on Fig. 3-2 and consists altogether of

20 mass points
11 massless node points
14 external springs
26 internal beams
1 DRI

The KRASH-elements that were used for the NH90-model will be described in the following subchapters in the same sequence as they appear in the KRASH-input.

3.1 Mass Distribution

In principle in KRASH there are two possibilities to represent a given mass distribution which was performed in this case in accordance with specified c.g.-envelopes. The first one is to specify individual masses e.g. fuel or cargo at their real locations and to represent prominent structural coordinates like intersections of frames and keel beams by massless node points. Although this method perhaps requires less preparation it is believed that the second method yields a more distinct model which is probably also easier to interpret. As it can be seen again from Fig. 3-1 in most cases mass points (solid circles) were located at intersections of structural members. Except the mass points of the pilot/seat model (M18 - M20) only M16 and M17 represent individual masses - main gear box and main rotor, respectively. Among those predefined "structural" mass points a typical NH90 mass of 8500 kg (less the effective mass of pilot and seat, see chapter 3.4 and M16, M17) was distributed in such a way that a c.g.-location was achieved that corresponded with the above mentioned c.g.-envelopes. Also the resulting mass moments of inertia were accurate enough. Other loading conditions e.g. empty weight could be simulated by variation of only a few distinct mass points. The massless node points (crosses in Fig. 3-1) are used to specify a more detailed geometry without increasing the number of beams.

<u>3.2 Representation of Impacting Members</u>

As already mentioned in KRASH only springs can provide contact with impact surfaces by definition. Mass points without a spring will penetrate such surfaces without resistance. Therefore, if longitudinal or lateral impacts shall be simulated (against obstacles) also longitudinal and lateral springs have to be specified. As these preliminary investigations of the NH90 included only crashes on level ground the model is equiped only with vertical springs.

In the NH90-model these springs represent (see Fig. 3-1) landing gears (S1, S2, S14), bottom structure (S3 - S11), tail boom (S12) and tail skid (S13). The general shape of a load-deflection-curve of a spring is depicted on Fig. 3-3 [1].

The springs S1 and S2 were specified according to the present landing gear configuration (for S14 see chapter 4.2). The bottoming of them was shifted in the first instance to high deflections to avoid the disturbance of the deformation of the bottom structure.

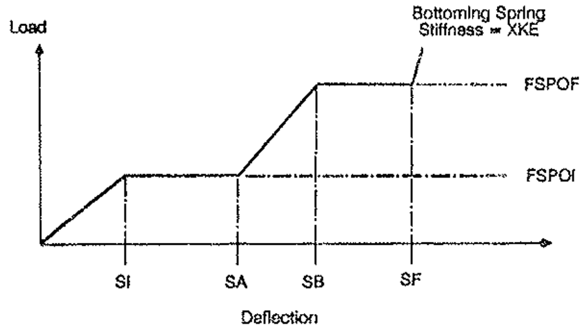

Fig. 3-3: General Shape of Load-Deflection-Curve

To determine the characteristics of the bottom structure springs the actual design concept with longitudinal members (keel beams) as sine wave structures and lateral members (frames) as sandwich (see Fig. 3-2) was taken as a basis. This concept combines the advantages of good specific energy absorption of sine waves with the simplicity of sandwich. The crash response of both components was already investigated by static

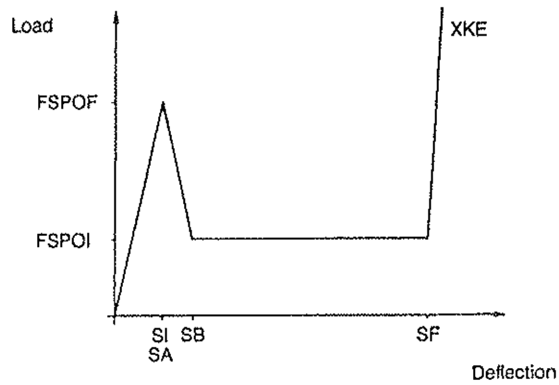

Fig. 3-4: Typical Shape of Structural Load-Deflection-Curves

and dynamic tests. From this experience, confirmed by literature, it was known that sandwich is less efficient than sine waves. Finally it was regarded as a rational assumption (which was also confirmed by tests) that intersections of keel beams and frames generate additional stiffness but by proper triggering (i.e. initiation of controled failure) an additional energy absorption can be achieved. The typical shape of the load-deflection-curves of the structural springs is shown on Fig. 3-4. The characteristic values were determined considering the following aspects:

- running length of represented structure
- ratio of sine wave to sandwich
- number of intersections

The tail boom spring (S12) and the tail skid spring (S13) were specified under rough assumptions. The main purpose was to avoid the penetration of M15 into the ground. Especially the tail boom turned out to be an area of possible optimization.

3.3 Specification of Structural Fuselage Members

A fracture or a deformation of structural members which form the protective shell was to be excluded due to the fact that structural deformation of CFRP-structure could result in a loss of structural integrity. Thus the occuring loads under the specified impact conditions have to be resisted and only the elastic behaviour including the failure load of those members has to be provided as an input. In this respect the predominant use of composite simplifies the development of a KRASH-model considerably.
The cross sectional properties of the beams were determined in accordance with an existing NASTRAN-model of the NH90. Of course several NASTRAN-elements had to be combined to form a KRASH-element. For example beam B9 of Fig. 3-1 has the complete cross-sectional area and moments of inertia of the corresponding structure of the NH90 which consists on the whole of floor panel, keel beams, lower shell, and lower door rails. To represent the elastic behaviour of the fuselage under essentially vertical crash loads as precise as possible the cross-sectional areas of the frame beams B2, B5, B8, B11, B14 and B17 were reduced according to the ratio of the longitudinal stiffness of the initial beams to the vertical stiffness of two-dimensional frame models.
The tail boom properties are based on rational assumptions as a detailed lay-out is not yet available. Finally the main rotor mast and the main gear box were represented in a rational manner too.

3.4 Description of Pilot/Seat-Model

As the crashworthy crew seat is an integrated part of the whole crashworthy system of a H/C its proper representation in a simulation is of great importance. It allows the assessment of different hazards as well as the establishment of requirements for the real seat.
The specification of the complete model concerning coordinates and masses was performed under consideration of [9]. Therefore M18 (see Fig. 3-1) which combines the lower body and the seat was located on the neutral seat reference point and M19 which represents the upper body was located 10 inches higher. Furthermore both mass points comprise only 80% of the specified masses of pilot and seat as this effective mass has to be decelerated by the crashworthy seat. This effective mass was distributed among the two mass points in a ratio which is also confirmed by [10].
To deserve the designation "crashworthy" a seat has above all to attenuate high vertical input accelerations at floor level to tolerable values for the human body. According to [9] again a limit of 23g can be considered as reasonable. Experience has shown however that due to internal vibrations in the body accelerations may be amplified. Therefore the static limit of the beam that represents the energy absorbing seat (B24) was put to 17g.

4. Crash Simulation

4.1 Crash Envelope

The procuring agencies of the four-national NH90 program specified a 85% fulfilment of MIL-STD-1290 [5] which is the best compromise with respect to weight/cost and survivability for the European usage (see also [6]). Furthermore a study which has been performed in 1982 in the

USA [7] has shown that the requirements of MIL-STD-1290 are too conservative.
In accordance with the above mentioned crash envelope, the KRASH-simulations were performed with a longitudinal velocity v_x of 15 m/s and a vertical impact velocity v_z of 11 m/s. As for the NH90 only a 2D-model was established, the specified lateral velocities ($v_y = \pm 8$ m/s) as well as roll angles were neglected. The specified pitch attitude range of 0 to 15° nose up was slightly exceeded in the simulations as also a -5° (nose down) case was investigated. During all simulations a rotor-lift to weight ratio equal unity was applied.
For the KRASH-investigation the following procedure was defined:

1) level impacts without longitudinal velocity to develop iteratively the basic model
2) investigations at the boundaries of the crash envelope with different pitch attitudes and longitudinal velocity to identify problem areas

It should be noted that "level" impact was understood as 1.5° nose-up (NU) attitude due to the difference in the maximum extensions of nose landing gear and main landing gears.

4.2 Simulation Results

A number of iterativ simulations were necessary for the development of the NH90 KRASH-model. These parametric variations although performed partly with assumptions or preliminary data can significantly improve the understanding of the general crash dynamics and the relationship between the individual components.

a) Subfloor Structure: The design goal of a clear separation of sine wave structure to longitudinal members and sandwich structure to frame members has been confirmed basically as feasible with respect to the energy to be absorbed, g-load limits and crushable height.
But the simulation results revealed a too stiff front fuselage area compared to the related masses. Therefore the energy absorption capability of the sine wave contributions of frame 1, 2A, 3 and 3A (S3 - S6) were reduced by one third corresponding to the same reduction in ply numbers in that area. This reduction of the specific energy absorption capacity improved the situation significantly but the vertical accelerations in the cockpit area are still high although the duration is very short. In the cabin area the limit of about 50g is not exceeded (Fig. 4-1). Besides the accelerations also the deformation-time-histories (Fig. 4-2) show that a

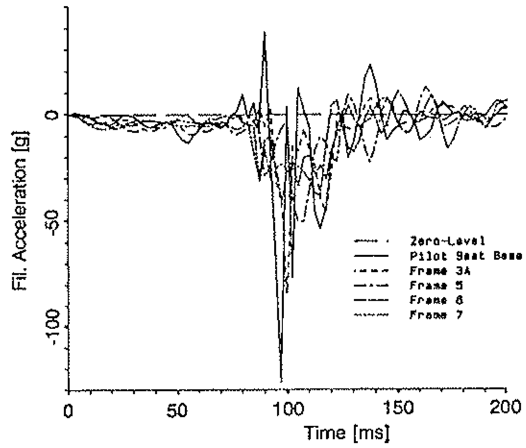

Fig. 4-1: Vertical Accelerations at Floor Level

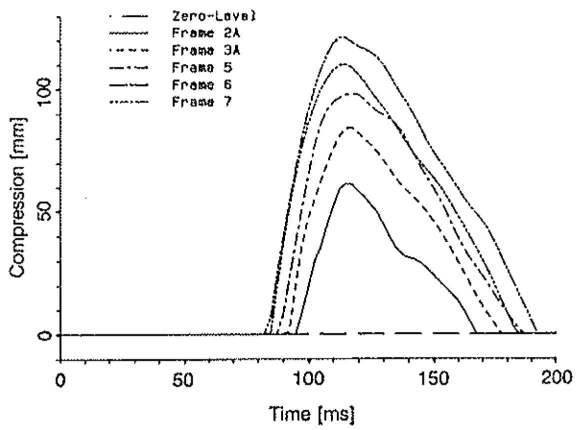

Fig. 4-2: Vertical Deformation of Subfloor Structure

further reduction of stiffness of the forward subfloor structure is possible. It is a matter of the later detail design to investigate if a reduced sine wave thickness or a redistribution of sine wave and sandwich structure is the suitable way under the structural strength requirements of this area.

b) Landing Gear: As already mentioned the LG-springs had initially a more or less perfect behaviour as the bottoming of them was shifted to deflections that couldn't occur during the simulations. But this characteristic represented only the main landing gear (MLG) correctly enough. To provide the single stage nose landing gear (NLG) with additional stroke it is equiped with a so called crash tube which is realized as a sleeve around the damper. This crash tube was considered in the KRASH-model by the introduction of a spring (S14) which has the same geometric origin as the NLG (S1) but a reduced length. After the combined stroking of both members a simultaneous drop of the force level to a residual value was specified to represent the assumed controllled fracture of the NLG-support-structure.

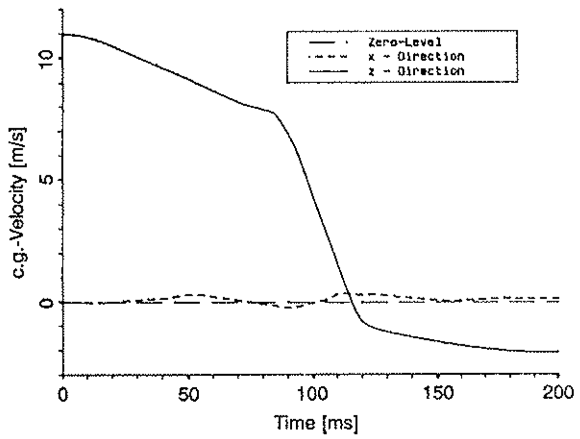

Fig. 4-3: c.g.-Velocity of Helicopter

The main influence of this modification on the "level" simulation is depicted on Fig. 4-3. The fracture of the NLG can be recognized from the slight smoothing of the z-velocity-time-history at about 70 ms. Nevertheless energy management of LG and subfloor structure is good. At impact of the bottom structure (bend of the z-velocity-time-history at 85 ms) the LG had attenuated approximately 48% of the kinetic energy of the helicopter.

c) Main Gear Box Mounts: Due to the already mentioned lack of ductility of a CFRP fuselage and the necessity to avoid fracture the accelerations at floor level are transfered more or less undiminished to the roof level (Fig. 4-4). This behaviour is also

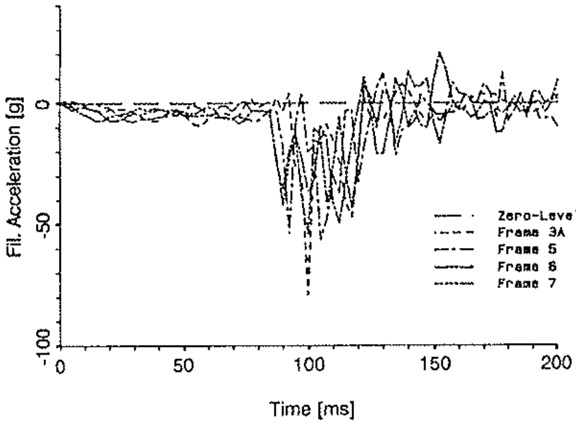

Fig. 4-4: Vertical Accelerations at Roof Level

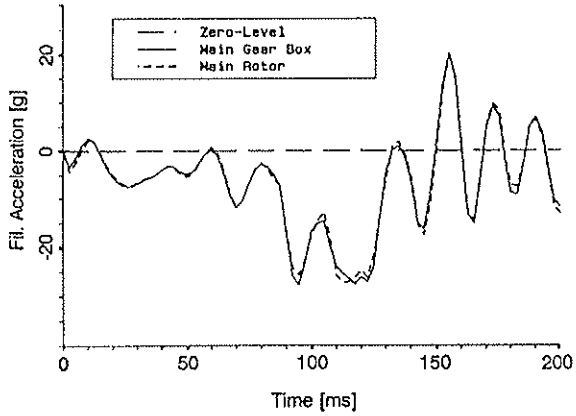

Fig. 4-5: Vertical Accelerations of Heavy Masses

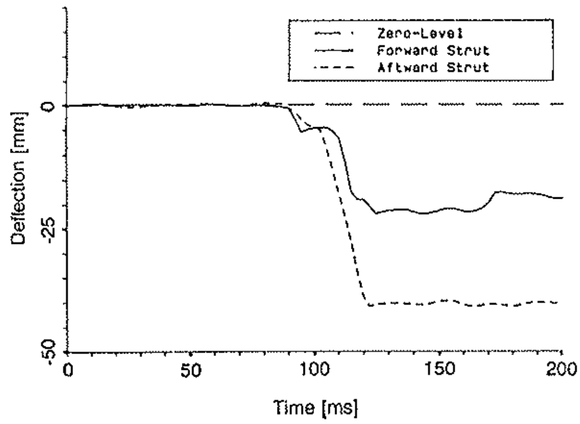

Fig. 4-6: Vertical Deformations of Main Gear Box Mounts

described in [8]. Therefore the application of local energy absorbing members was investigated to attenuate the accelerations at heavy masses (e.g. lifting system). The advantage of this procedure is the avoidance of very heavy gear box mounts which could sustain those high inertia loads as penetration of the cabin has to be positively excluded. These energy absorbing members were specified to a static load factor of 20g. The result of this modification is shown on Fig. 4-5 and Fig. 4-6. The dynamic overshoot of the accelerations is remarkable but as the strokes of the absorbers are very moderate a further reduction of the load level is possible.

d) Seat: Finally Fig. 4-7 and Fig. 4-8 illustrate that the crashworthy crew seat fulfils its duty.

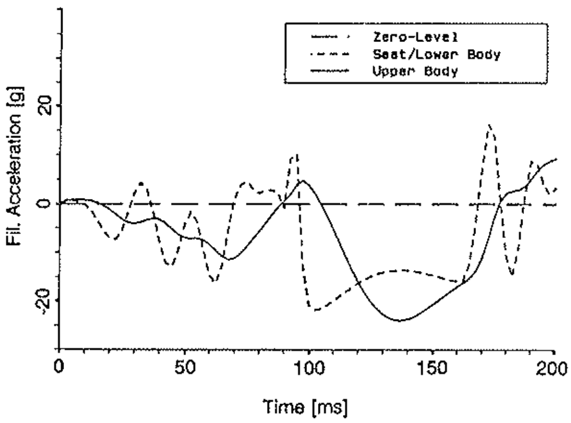

Fig. 4-7: Vertical Accelerations of Pilot and Crew Seat

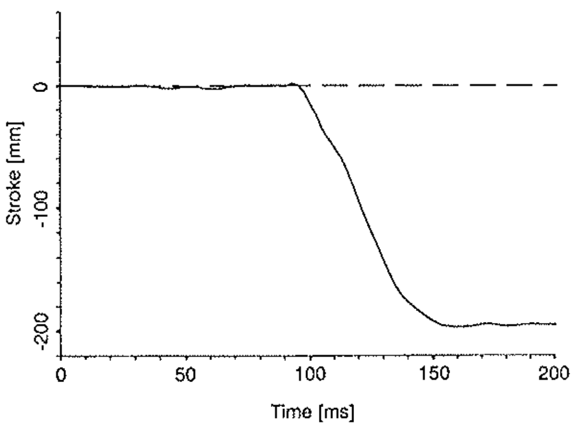

Fig. 4-8: Vertical Stroke of Crashworthy Crew Seat

Despite the high accelerations at the seat base the load factor for the pilot is reduced to a survivable level without utilizing extreme strokes. Two opposite influences may be investigated in the future. The further decreased stiffness of the forward subfloor structure will yield a reduced input acceleration for the seat but unsymetrical and inclined attitudes of the helicopter have to be considered too.

e) Different Attitudes: The simulations with different pitch angles revealed some more knowledge about the behaviour of the NH90 as expected. Fig. 4-9 gives an impression of the motion of the crashing H/C from the 15° nose up (NU) position. The obvious rotational movement is initiated by the first

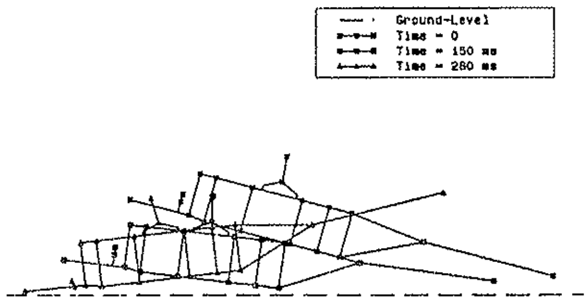

Fig. 4-9: Behaviour of Helicopter during 15° NU Impact

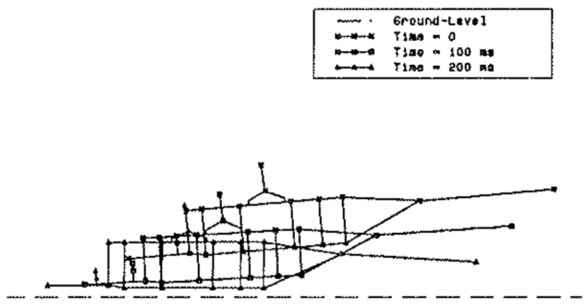

Fig. 4-10: Behaviour of Helicopter during 5° ND Impact

impacting tail skid and further amplified by the MLG and the tail boom structure. Due to this additional rotational velocity this crash case turned out to be the most critical. Future investigations will show if a predetermined breaking of the tail boom or a better energy absorption at the end of the tail boom (which was based up to now on assumptions) can improve the situation. The last simulation with a 5° nose down (ND) attitude generated results which were comparable to the level impact. This moderate behaviour is depicted on Fig. 4-10.

5. Conclusions and Recommendations

The preliminary investigation of the NH90 with program KRASH85 has demonstrated again the benefit to perform crashworthiness examinations at an early time in the development of a H/C.
Firstly the basic lay-out can be checked and problem areas be identified leaving enough time for corrections.
Secondly, parametric variations may be performed and their influence be studied.
For both purposes KRASH85 has proven its maturity. Although only a two-dimensional model was set up to represent the NH90 several simulations yielded already decisive conclusions. Considering the following areas of possible optimization, the results basically show that the NH90 can fulfil the ambitious crashworthiness requirements defined by the procuring agencies.

- A combination of sandwich (easy to manufacture) and sine wave members (better energy absorption) proved to be adequate for the subfloor structure.
- Stiffness of the subfloor structure has to be adjusted carefully along the fuselage to reflect the different portions of energy which have to be attenuated under different impact conditions.
- The nose LG configuration with crash tube and subsequent controlled breaking showed no negative influence on the crash performance.
- The nose down acceleration due to the stiff tail boom on a 15° NU impact was discovered, but this behaviour can be improved by a predetermined breaking of the tail boom.
- The amount of local energy absorption capacity to reduce the g-loads of the heavy masses has been evaluated.

This well functioning KRASH-model gives the possibility for the following additional investigations:

- Influence of predetermined breaking of the tail boom on the 15° NU crash.
- Influence of an energy absorbing NLG-actuator on a crash with longitudinal velocity.
- Further adjustment of stiffness of energy absorbing members in the subfloor structure.
- Crashworthiness of H/C with empty weight.

More detailed simulations covering also yaw and roll angles, lateral velocities, et cetera are restricted to a 3D-model.

6. References

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