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Landing Gear, design and crash behaviour

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ABSTRACT

A crashworthy rotorcraft landing gear will weigh more than a landing gear designed for normal descent velocities. This extra weight is needed for increased energy absorption capacity and for the necessary reinforcements due to the higher loading occurring in a landing gear during a crash. A way how to estimate this extra weight is here presented.

INTRODUCTION

The landing gear of a modern helicopter has to fulfil a lot of requirements. Minimum stiffness is required to avoid ground resonance of the vehicle. Minimum strength is required to sustain all normal landing conditions without damage on the one hand and to survive crash on the other. Further minimum energy absorption is needed to make a successful hard landing or emergency landing (no ground contact) and to make a crash survivable.

In this paper the energy absorption capacity of the landing gear (=L.G.) will be considered and it will be explained why "moderate" crash requirements, as is the 85th percentile of the Mil. Std. 1290A, do ask for certain additional mass. This will be done by means of examples taken from NH90 activities.

The part of the total crash energy which must be absorbed by L.G. is estimated. A part of this energy can be stored in already existing energy absorbers used during normal landing. These absorbers must be suited for higher touch down speeds. The rest must be absorbed either by already existing equipment or by new elements which can absorb crash energy efficiently. The internal energy distribution in the L.G. can be estimated by analyses, here done by the KRASH programme. The needed additional mass to create a crashworthy L.G. is the sum of:

- adaptation of existing energy absorbers for higher touchdown speeds
- adaptation of other existing equipment for energy absorption
- additional structural parts for crash energy absorption
- reinforcement of some parts because internal loading occurring during crash is more than during normal landing cases.

CRASH ENERGY

Crash requirements for future helicopters are gathered from investigations of accidents/incidents with helicopters not specificly designed for surviving a crash. From these investigations survivability criteria have been derived (see Mil.Std. 1290 etc.). Knowing that a lot of crashes with those helicopters are declared as being survivable we were wondering about the extra weight crash requirement asks for.

For the NH90 the normal L.G. energy absorption capacity is more or less fixed by the following vertical speeds of the vehicle:

-hard landing case : 4 m/s (no damage)
-emergency landing case : 6 m/s
(repairable damage).

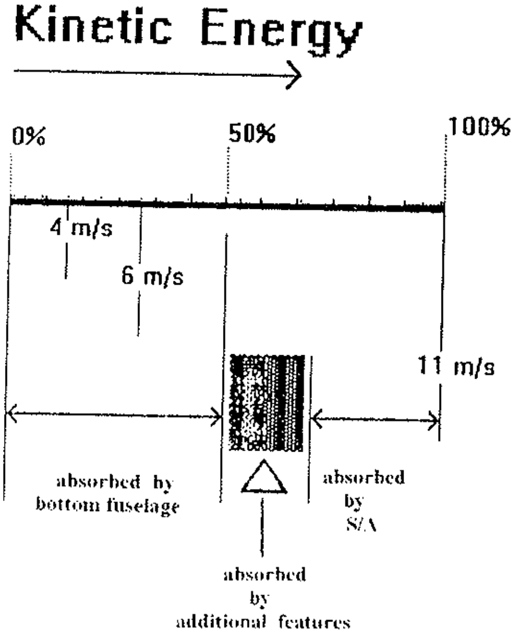
A rotorcraft is crashworthy if occupants survive a crash with a speed equal or less than:

- 11 m/s (85th percentile of Mil.Std. 1290 etc.).

The crash case contains an amount of energy which is too much to be absorbed by only the L.G. absorbers. Plastic deformation of L.G. parts and the bottom part of the fuselage contribute to the energy absorption . Sharing of this crash energy between L.G. and fuselage bottom is presented in figure 1.

About 50% of the crash energy will be absorbed by the landing gear (= L.G.). 30 % will be absorbed by the already existing L.G. shock absorbers and 20 % by additional crash features. The rest, 50%, has to be accepted by the fuselage bottom structure. These numbers have only a global character.

Figure 1 sharing of crash energy

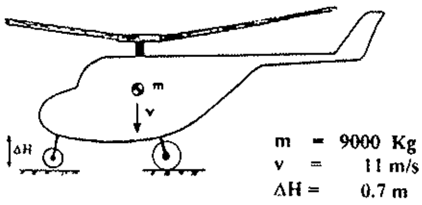


DESIGN

The designer is tasked to modify the "normal" L.G. energy absorption capacity into the same capacity for higher touch down speeds (upto 11 m/s in stead of 4 to 6 m/s). Further he is tasked to install an additional energy absorbing capacity which will be used only during a crash or if vertical speed is more than 4 m/s. Both capabilities are required with adding a minimum extra mass! For such a design activity it is necessary to know at least the internal loading and energy distribution in the L.G. during a crash. In figure 2 a first estimation of the mechanical behaviour of the vehicle during a crash is presented. Assumptions are made for: helicopter mass, impact distance of L.G., relative amount of energy absorbed by all gears and load versus deflection of the gear. These assumptions correspond with values obtained from the NH90 helicopter development program. By means of examples copied from the NH90 activities the questions related to energy absorption and belonging mass will be treated further. The NH90 helicopter will be provided with two main L.G.'s just behind Xcg and a nose L.G.. Design concepts of nose and main L.G. with their main energy absorption elements are presented in figures 3 and 4. In these concepts also additional energy absorbers are foreseen:

- crash tube in nose L.G.
- R/A in main L.G.

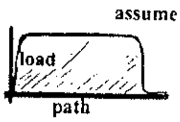
Figure 2
mechanical behaviour during crash



a. Total kinetic energy
0.5 * m * v * v = 0.5 * 9000 * 11 * 11 = 545 KJ

b. Assume 50% of total kinetic energy absorbed by landing gears and each gear 33% so nose gear absorbs about 90 KJ

c. Maximum load during crash
energy absorbed = load * path
so
load = 90 000 / 0.7 = 130 000 N



d. Deceleration [= a]
load = mass*deceleration so deceleration = load / mass = 130 000 / 3000 = 43 m/(s*s)

e. Duration [= t]
ΔH= v*t - 0.5*a*t*t ---> 21.5*t*t - 11*t + 0.7 = 0 --->
t = 0.07 s

Figure 3
design concept nose L.G.

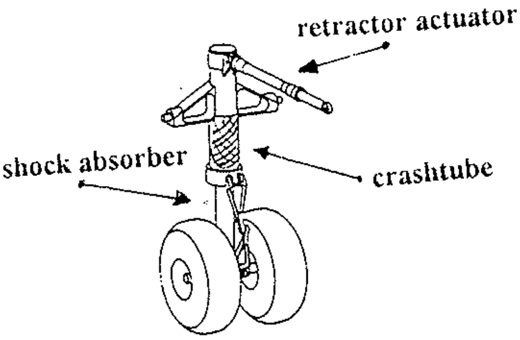
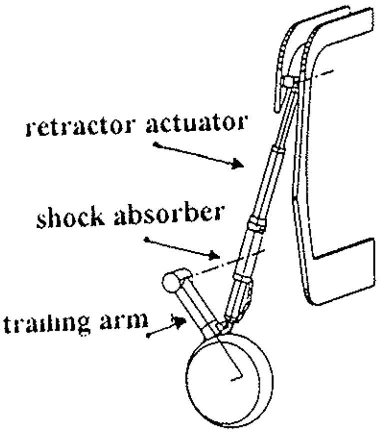


Figure 4
design concept main L.G.



NOSE L.G.

In figure 2 it is assumed that all gears absorb their part of the crash energy equally. That means that nose gear absorbs as well 90 KJ during a crash. The maximum amount of energy to be absorbed by all shock absorbers is assumed to be about:

(6x6) / (11x11) of total crash energy =
(36/121) x 544 = 162 KJ.

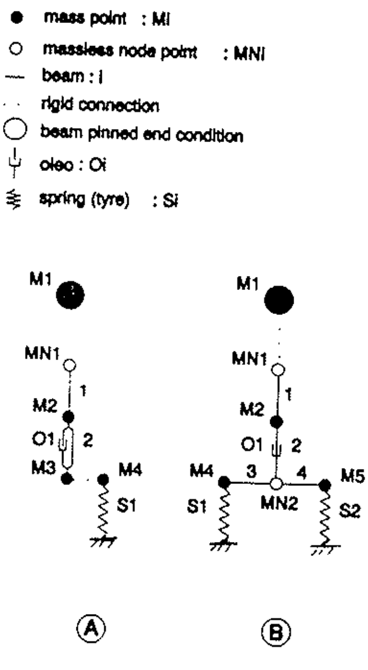
In this case each gear has to accept in its shock absorber about 54KJ. The rest, filling up to 90 KJ and mentioned here "the additional energy" , has to be absorbed by tires and "additional" structure. The nose gear has been designed with a crashtube as additional energy absorbing element. Further the shock absorber has been added with provisions keeping the internal pressure at an acceptable level during the high speed region of the crash. A KRASH93 simulation of the mechanical behaviour of the gear design has been performed and presented in figures 5 and 6. From figure 6 the amount of energy absorbed by the three elements are:

- both tyres	7%	[6,3 KJ]
- crash tube	31%	[27.9 KJ]
- shock absorber	62%	[55,8 KJ].

Estimation of needed mass for here above mentioned crash tube can be done by applying data from Farley/Bird/Modlin (ref.: 1). A specific energy absorption of 50 KJ/Kg seems to be realistic for such an item. So this will result in a pure crashtube mass of about:

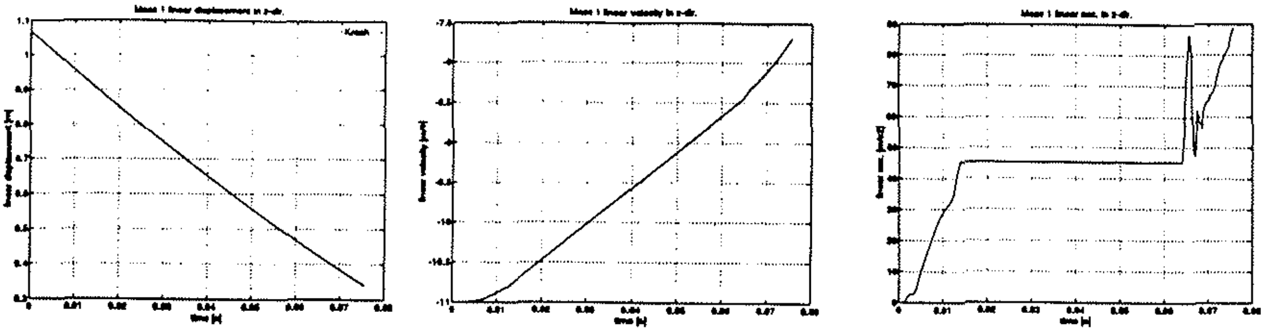
0,52 Kg.

Figure 5
single nose landing gear crash model



(A=side view; B=aft-fore)

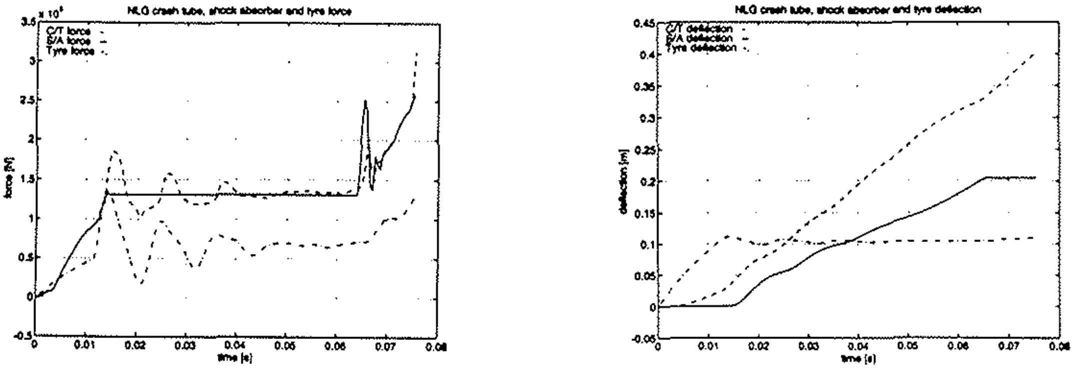
Figure 6
mechanical behaviour single nose L.G.



Mass 1 linear displacement in z-dir.

Mass 1 linear velocity in z-dir.

- Mass 1 linear acc. in z-dir.



[The mass needed in the bottom fuselage in order to absorb its part of the crash energy is at least 5,4 Kg] . Coherence between these KRASH results and what is determined by simple calculations (see Fig.:2) is rather well shown. It means that the energy absorbing properties for: tires, shock absorber and crash tube are choosen in an acceptable way. Compared with hard landing case or emergency landing case extra mass is needed for:

- crash tube + its load introducing structure
- "high speed" provisions in shock absorber

MAIN L.G.

For the main L.G. the same sort of activity has been performed. The KRASH93 model and its mechanical behaviour are presented respectively in figures 7 and 8. Comparison of these results with the preliminary estimations, presented in figure 2, shows here a stiffer and also a more energy absorbing L.G.. This is caused by model simplification. In the model wheel and shock absorber are placed in one line. In the real L.G. design these elements are not placed in one line. The difference between model and reality is about:

[A +B]/A =1,5 (see fig. 4 for A and B).

The crash energy in this simplified model of the main L.G. is absorbed by following three elements: tyre [0,15 m], shock absorber [0,25 m] and retraction actuator [0,30 m]. The deflection of these items are presented between brackets.

The amount of absorbed energy by these elements are:

- tyre	11 %	[13,2 KJ]
- shock absorber	40 %	[48,0 KJ]
- retraction actuator	49 %	[58,8 KJ].

The mechanical behaviour determined by this model shows a 25% higher deceleration and so internal load level (after taking into account 1,5 for the [A+B]/A factor). So stiffer elements are incorporated than foreseen by the simple calculation of fig. 2.

This stiffer behaviour is caused by main L.G. legs design philosophy. Design of this leg is the result of minimizing its mass. This is reached by :

- **minimizing length of R/A and shock absorber (=S/A)**
- **.providing just enough R/A stroke for wheel retraction**
- **keeping loading in leg at acceptable level (leg's location on trailing arm)**
- **not ground contact for vertical speeds (=Vz) less than 6 m/s.**

These considerations result into a main leg design with following qualities:

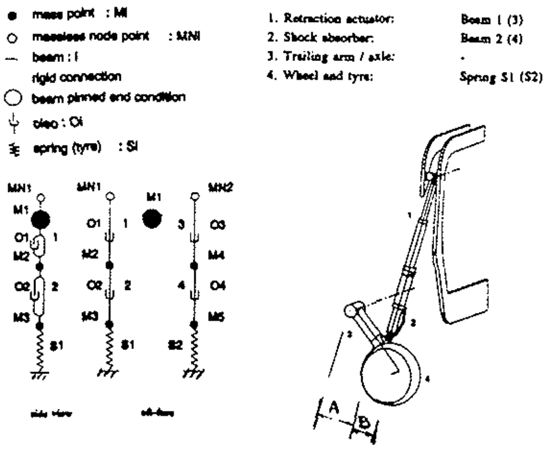
- **S/A accepts all energy up to Vz = 4 m/s**
- **R/A absorbs energy if Vz is equal or more than 4 m/s.**

Further its maximum stroke of 0,45 m gives the R/A a large energy capacity which will be consumed by crash conditions with "high" roll angles. The R/A is when normally operating secured by shear pins. If leg load surpasses the preset value these pins will be sheared off and R/A acts as an oleo. Surpassing this preset value means a stiffer mechanical behaviour than is foreseen by the simple calculations of Figure 2.

In order to make this gear crashworthy extra mass is needed for:

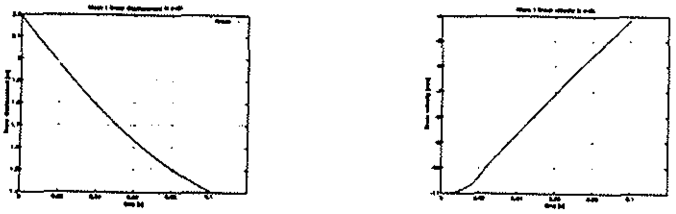
- **"high" speed provisions in R/A**
- **adaptation of R/A for its energy absorption function .**

Figure 7
simplified main L.G. Krash model



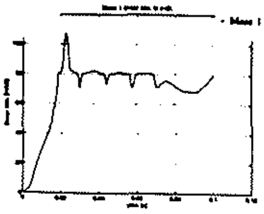
Simplified main landing gear model

Figure 8
mechanical behaviour simplified main L.G.

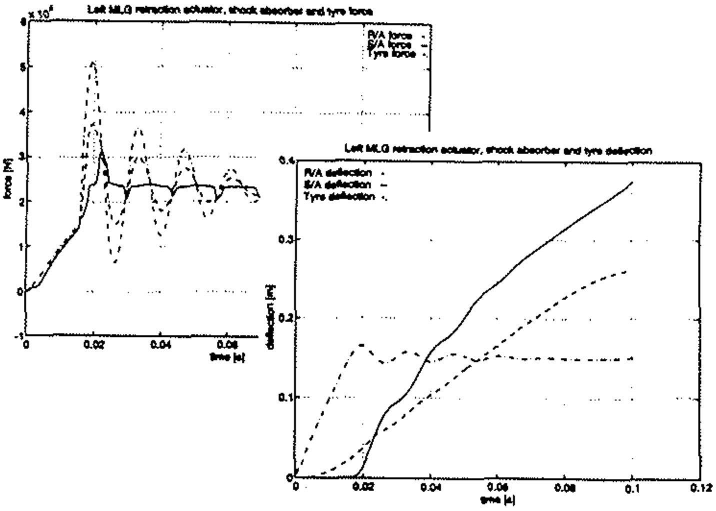


Mass 1 linear displacement in z-dir.

• Mass 1 linear velocity in z-dir.



• Mass 1 linear acc. in z-dir.



TOTAL HELICOPTER

The total helicopter KRASH93 model is presented in figure 9. The main landing gear model has been changed. The wheel is not more in line with shock absorber and retraction actuator. This change is conform the present design.

Following analyses have been performed yet (see Table 1).

Table 1
performed Krash93 analyses

No.	Loadcase	V impact
1	hard landing (level)	4 m/s
2	emergency landing (level)	6 m/s
3	crash (level)	11 m/s
4	crash (roll: 0' pitch: 10')	11 m/s

R/A loading of first three cases (fourth one does not differ much from third one) are presented in Figure 10. R/A influence on leveling the peak loading is well shown. If such a leveling device was not incorporated the peak loads could reach a much higher level. Due to this load leveling quality no extra reinforcement is needed.

Figure 10
R/A loading for 1st three loadcases

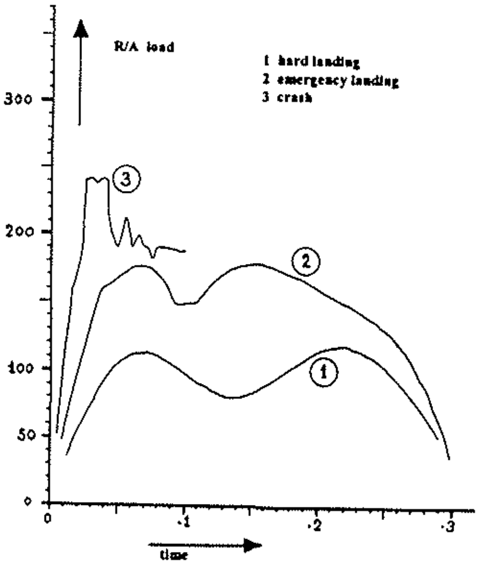
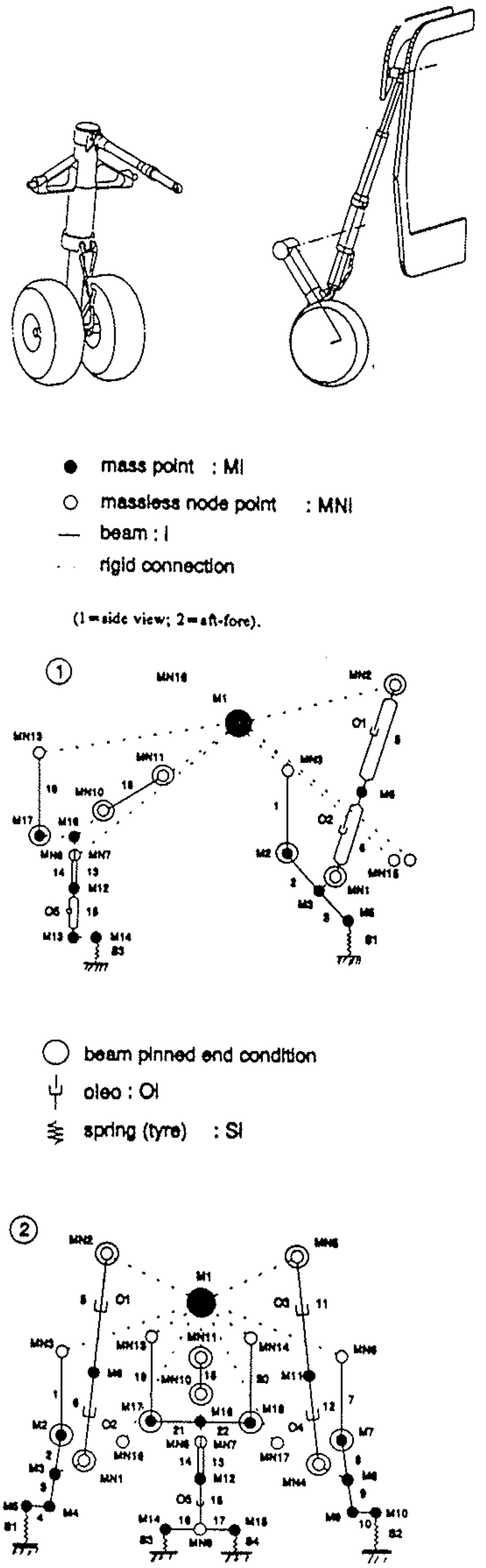


Figure 9
total helicopter KRASH93 model



CONCLUSION

Because specific energy absorption of oleos is about ten times less than that of structural items made of composites [50 KJ/Kg] only oleos should be applied if strictly needed [for touch down speeds up to 4 m/s].

Existing oleos, needed for normal operating, can be adapted for higher touch down speeds if its weight impact is acceptable. This is also applicable for items, already existing in the L.G., which can be suited as well for energy absorbtion.

Increasing the capacity of oleos in stead of adding composite crash absorbing structure should be avoided.

Decreasing of the 4 m/s boundary, hard landing case, causes a lower mass for the strictly needed normal shockabsorber. The rest of the energy caused by a crash can than be absorbed by material with a much higher specific energy absorption. This results in a lower total weight.

The maximum impact speed of 11 m/s can be increased by adding material with higher specific energy capability. To respect maximum deceleration levels additional stroking length must be provided, resulting in some additional weight increase.

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1. The role of fiber and matrix in crash energy absorption of composite materials

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[presented april 7-9 1986 / Georgia Tech / Crashworthy Design of Rotorcraft]