EIGHTEENTH EUROPEAN ROTORCRAFT FORUM

E - 17

PAPER NO. 148

PROPOSED REVISIONS TO MIL-STD-1290

ROTARY WING AIRCRAFT CRASH RESISTANCE

L. BURROWS

U.S. ARMY

AVIATION SYSTEMS COMMAND

SEPTEMBER 15-18, 1992

AVIGNON, FRANCE

ASSOCIATION AERONAUTIQUE ET ASTRONAUTIQUE DE FRANCE

PROPOSED REVISIONS TO MIL-STD-1290 ROTARY WING AIRCRAFT CRASH RESISTANCE

by
LeRoy T. Burrows
Aerospace Engineer, Safety and Survivability Division
Aviation Applied Technology Directorate
U.S. Army Aviation Systems Command
Fort Eustis, Virginia 23604-5577

ABSTRACT

The current MIL-STD-1290 provides one set of crash resistance design criteria for military helicopters. It is recognized that for small helicopters it is more difficult to meet the seat stroke and high mass component retention than for a medium and large size helicopter and to meet current design criteria, the percentage of weight empty dedicated to crashworthiness becomes unacceptable. In addition, how a helicopter crashes must be taken into account. Accident data shows that low inertia rotor blade helicopters with high disc loadings crash at higher impact velocities than the same weight aircraft with high inertia rotor blade systems and lower disc loadings. In addition, indications are that the helicopter type (i.e., attack, air assault, utility, cargo) also affects aircraft crash modes. Suggested different levels of design criteria for crash resistance are presented with rationale to support the need for variable design criteria.

1. INTRODUCTION

Modern-day training and tactical employment requirements for the U.S. Army helicopter dictate that a large percentage of operations occur in the low-speed, low altitude flight regime, with reduced margins of safety normally associated with higher airspeed and higher altitude operations in case of emergency. This increased probability of accident occurrence, coupled with the lack of an in-flight egress capability, makes design for crash resistance essential for Army helicopters.

Research investigations directed toward improving occupant survival and reducing materiel losses in aircraft crashes have been conducted by the Army for more than 30 years. However, up until approximately 15 years ago the principal emphasis within the Army aviation survivability was placed on accident prevention. Although this is indeed the ultimate objective deserving priority effort, past experience clearly shows that an accident prevention program alone simply is not sufficient. Mishaps of all natures involving Army aircraft have been, are, and continue to be a major, expensive problem. Research has been accomplished on accidents worldwide involving Army aviation, and accident histories are routinely disseminated throughout the Army. Unfortunately, too many lessons learned from these accident histories are not applied and hazardous design features, human errors, and operational errors are repeated year after year. Too many Army aircrewmen are still being fatally injured in potentially survivable accidents, and the percentage of major injuries and rate of materiel losses are still unacceptably high. There is no easy solution to the problem. Significant gains can be made, however, toward reducing these unacceptable accident losses, but to do so requires aggressively pursuing programs that addresses key issues of both accident prevention and crash resistance design. Since the helicopter's potential for accident is great due to its mission and the environment in which it must accomplish that mission, it is imperative that it be engineered to minimize damage and enhance occupant survival in crashes. In designing helicopters to be more crash survivable, two subissues then become paramount: establishing viable crash resistance criteria, and the more difficult task, applying these crash resistance criteria to Army aircraft design without unacceptably affecting its performance and cost. An unacceptable effect is a source of constant debate among performance and survivability specialists in any new helicopter system formulation and development. The performance specialist considers the weight devoted to crash resistance as a penalty while the survivability specialist looks at this weight as necessary to save personnel and materiel and as being cost effective over the fleet life cycle. The design criteria presented and discussed herein is for military helicopters. Civil helicopters should be designed for crash resistance but accident data indicates this level should be significantly less than that of a military aircraft. Military aircraft train as they must fly to survive in combat. This dictates nap-of-the-earth, contour and low level flights at velocities that are within the height-velocity limitations of the aircraft thus preventing full autorations. The potential for mishaps in these flight modes is compounded by the emphasis on night operations using night vision aids.

2. CURRENT CRASH RESISTANCE DESIGN CRITERIA

2.1 General

In-depth assessment of available crash data was first accomplished in the mid-60's by a joint guide for light fixed- and rotary-wing aircraft, published in 1967. Revisions to this guide were made in 1969, 1971, 1980, and 1989 (Reference 1). This design guide was subsequently converted into a military standard (MIL-STD-1290) in 1974 which was revised in March 1986 (Reference 2).

MIL-STD-1290A addresses five key areas that must be considered in designing a helicopter to conserve materiel and provide the necessary occupant protection in a crash:

- Crashworthiness of the structure--assuring that the structure has the proper strength and stiffness to maintain a livable volume for the occupants and prevent the seat attachments from breaking free

- Retention strength--assuring that the high mass items such as the transmission and engine do not break free from their mounts and penetrate occupied areas

- Occupant acceleration environment--providing the necessary crash load absorption by using crushable structures, load limiting landing gears, energy-absorbing seats, etc., to keep the loads on the occupants within human tolerance levels

- Occupants environment hazards--providing the necessary restraint systems, padding, etc., to prevent injury caused by occupant flailing

- Postcrash hazards--after the crash sequence has ended, providing protection against flammable fluid systems and permitting egress under all conditions

2.2 Systems Approach

For maximum effectiveness, design for crash resistance dictates that a total systems approach be used and that the designer consider survivability issues in the same light as other key design considerations such as weight, load factor, and fatigue life during the initial design phase of the helicopter. Figure 1 depicts the system's approach required relative to management of the crash energy for occupant survival for the vertical crash design condition. The crash G loads must be brought to within human tolerance limits in a controlled manner to prevent injury to the occupants. This can be accomplished by using the landing gear, floor structure, and seat to progressively absorb most of the crash energy during the crash sequence. Thus, the occupant is slowed down in a controlled manner by stroking/failing the landing gear, crushing the floor structure, and stroking the seat at a predetermined load before being subjected to the crash pulse which by then has been reduced to within human tolerance limits. In addition, the large mass items such as the overhead gearbox are arrested by stroking/failing of the landing gear or fuselage structure, and in some cases, by stroking of the gearbox within its mounts. In this example, assuming that the landing gear has been designed to meet the minimum requirements of MIL-STD-1290A, i.e., 20 FT/SEC, the fuselage would be decelerated to approximately 37 FT/SEC at the time of contact with surface. The Army's most recent helicopters, the UH-60 BLACK HAWK and AH-64 Apache, are both designed generally in accordance with the requirements of MIL-STD-1290A.

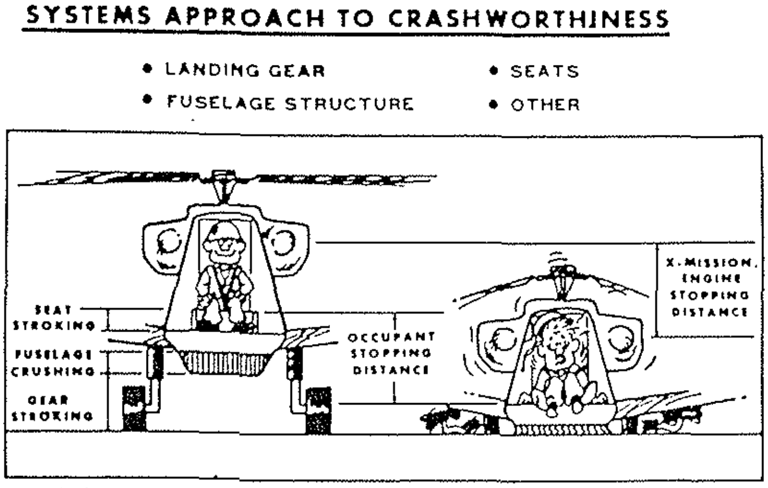

Figure 1. Energy Management System

2.3 Crash Impact Design Conditions

A survivable crash is one wherein the impact conditions inclusive of pulse rate onset, magnitude, direction and duration of the acceleration forces that are transmitted to the occupant do not exceed the limits of human tolerance for survival, and in which the surrounding structure remains sufficiently intact during and after impact to permit survival. Thus, helicopters designed to meet MIL-STD-1290A shall be designed to prevent occupant fatalities and minimize the number and severity of injuries while minimizing aircraft damage to the maximum extent practical. Table 1 presents the current MIL-STD-1290A crash design conditions for helicopters expressed in terms of impact velocity change with associated minimum attitude requirements.

Table 1. Summary of Crash Impact Design Conditions for Helicopters and Light Fixed-Wing Aircraft with Landing Gear Extended

CONDITIONS	IMPACT DIRECTION (AIRCRAFT AXES)	OBJECT IMPACTED	VELOCITY CHANGE, ΔV (FT/SEC)	ROLL	PITCH
1	Longitudinal (Cockpit)	Rigid Vertical Barriers	20		
2	Longitudinal (Cabin)	Rigid Vertical Barriers	40		
3	Vertical*	Rigid Horizontal Surface	42	$\pm 10°$	$+15°$ to $-5°$
4	Lateral, Type I	Rigid Horizontal Surface	25		
5	Lateral, Type II	Rigid Horizontal Surface	30		
6	Combined High Angle Vertical Longitudinal	Rigid Horizontal Surface	 42 27		
7	Combined Low Angle Vertical Longitudinal	Plowed Soil	 14 100		

*For the case of retracted landing gear the seat/airframe/landing gear pod combination shall have a vertical crash impact design velocity change capability of at least 26 FT/SEC at an attitude of $+15°$ to $-5°$ level pitch and $\pm 10°$ roll.

Perhaps the most critical MIL-STD-1290A factor in designing the helicopter for crash survivability is the vertical design impact velocity change requirement. Since the helicopter spends a large percentage of its operational life in the low-speed, low altitude flight regime there is no opportunity for autoration and accidents predominantly occur with high vertical descent rates and with the aircraft in a near normal attitude. Thus, the aircraft must withstand vertical impacts of 42 FT/SEC, within the aircraft attitude limits of ± 10 degrees roll and +15 degrees (nose-up) to -5 degrees pitch, (1) with no more than 15-percent reduction in the height of the cockpit and passenger/troop compartments and (2) without causing the occupants to experience injurious accelerative loadings.

2.4 Landing Gear

The landing gear shall provide energy absorption capability to reduce the vertical velocity of the fuselage as much as possible under the crash conditions. MIL-STD-1290A requires as a minimum, the landing gear shall be capable of decelerating the aircraft at normal gross weight from an impact velocity of 20 FT/SEC onto a level rigid surface within an attitude envelope of ± 10 degrees roll and +15 degrees to -5 degrees pitch without allowing the fuselage to contact the ground and without gear penetration into an occupied area. Plastic deformation of the landing gear and its mounting system is acceptable in meeting this requirement; however, with the possible exception of the rotor blades, the remainder of the aircraft structure shall be flightworthy after impact. The standard landing gear design criteria is wholly inadequate for a crash resistant aircraft. Therefore MIL-STD-1290 includes additional landing gear requirements which are key to establishing the very positive cost effectiveness of design for crash resistance, as hard landings result from touchdown sink rates that in the past would be Class A mishaps. On the other hand, it is a very difficult design requirement for an attack helicopter with a turret mounted on the underside of the fuselage. Also, high energy attenuating retractable landing gear may require some innovative design.

3. FACTORS AFFECTING CRASH RESISTANCE DESIGN CRITERIA

3.1 Accident Data

Figure 2 (Reference 3) presents a history of U.S. Army helicopter survivable accidents in terms of vertical impact velocity versus cumulative frequency. In the early versions of the Crash Survival Design Guide and MIL-STD-1290 the design criteria was based upon the 95th percentile potentially survivable accident vertical velocity impact, which at that time was about 42 FT/SEC. Now with a greater data base one can see that that is too high of an impact velocity for the older, single engine, two bladed high inertia rotor system helicopters (30 to 35 FT/SEC). On the other hand, the high performance, twin engine, low inertia rotor system, high disk loading UH-60 would have a much higher impact velocity (45 to 50 FT/SEC). The AH-64 will probably go this direction as the data base expands since it is close to the UH-60 in rotor disk loading as is the RAH-66 Comanche. It is a fact of life that for small or medium size helicopters (4,000 to 18,000 lb DGW) a vertical crash impact design condition of 45 to 50 FT/SEC would be unaffordable from a weight and cost standpoint. Therefore the 95th percentile potentially survivable accident is no longer the basis for defining design criteria.

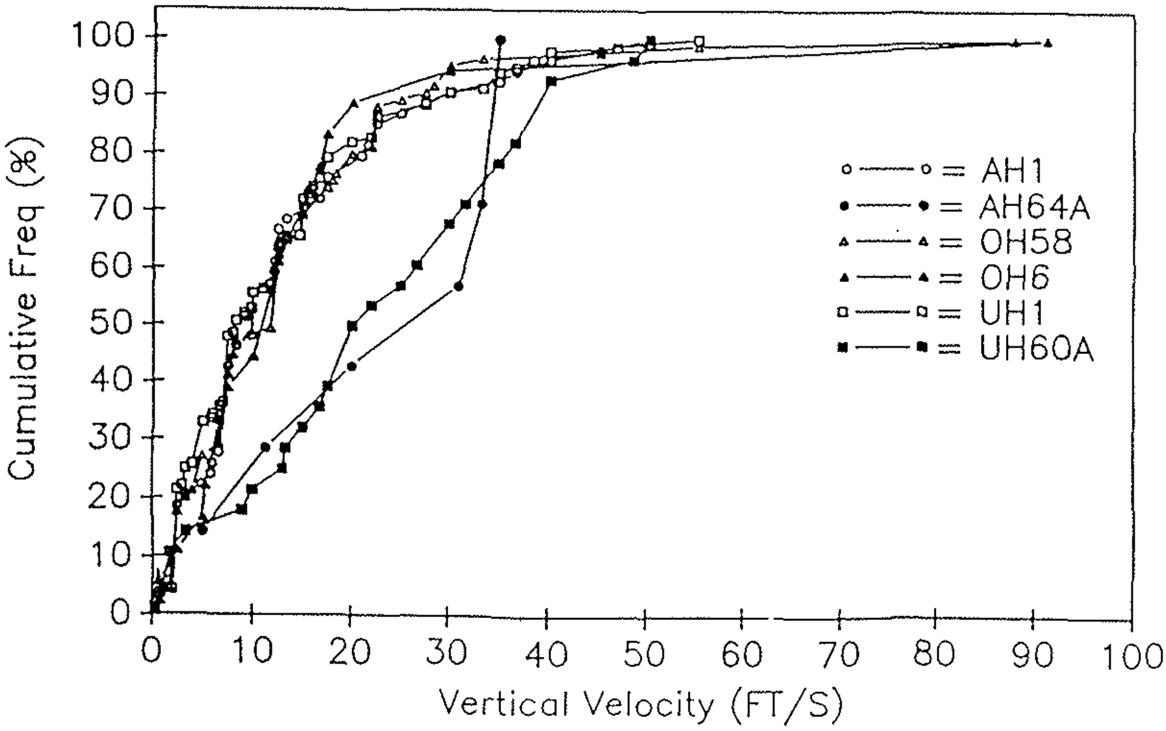

Figure 2. Army Helicopter Vertical Impact Velocity

3.2 <u>Autorotational Sink Rate</u>

The much higher autorotational sink rates of the AH-64, UH-60 and RAH-66 (proposed) than the older two bladed helicopters is based on the fact that they have similar disk loadings, all significantly higher than the two bladed older aircraft. Though it is difficult to correlate this, Table 2 (Reference 4) appears to offer an interesting relationship between maximum glide descent rate and the 95th percentile potentially survivable accident vertical crash velocity for each helicopter. The omissions are due to lack of adequate accident data base for the AH-64, OH-58D and RAH-66. There is no mistake that the newer higher performance helicopters crash harder than the older helicopters and that there is a correlation with the all engines inoperable autorational descent rate.

TABLE 2. HELICOPTER AUTOROTATIONAL PERFORMANCE

	MAXIMUM GLIDE PERFORMANCE A/S (KTS)	DESCENT RATE (FT/SEC)	VERTICAL CRASH VELOCITY (FT/SEC)
AH-1S	100	38.3	39.4
AH-64A	98	46.7	
OH-58A/C	71	29.6	29.5
OH-58D	80	40.7	
OH-6A	88	27.5	30.1
UH-1H	100	35.0	33.5
UH-60A	110	45.0	46.0
RAH-66	112	46.1	

3.3 Composite Structures

Future helicopter airframes will be constructed primarily from composite materials. Composite structures, when configured properly, have been demonstrated to efficiently attenuate crash energy not only in the specially designed crushable subfloor but in a multitude of failure modes which defy calculation. This was evident from the two full scale crash tests of composite aircraft by the U.S. Army. Also with the low elongation characteristics of composite materials, mass shedding in a severe crash can reduce the airframe and landing gear energy absorption (EA) requirement as long as the mass being shed does not pose a hazard to occupants. An example of this is a breakaway tailboom. Another example is a break away engine which would not be good for a troop carrying assault helicopter but may work for an attack helicopter. Of course the post crash fire hazard potential would have to be considered. Mass shedding has the affect of decreasing the loads in a severe crash and making it easier for the primary structure to retain the high mass components. With composite structures one must also consider load limiting concepts in joints where high stresses occur during a crash such as the main transmission mounts and the landing gear-airframe attachment.

3.4 Helicopter Type

The type or mission of the helicopter will dictate its usage, which in turn may affect the approach to crash resistance design. An assault or medivac helicopter like the UH-60 BLACK HAWK has a record of very hard landings on a frequent basis. The ability of the landing gear to withstand these hard landings without damage to the landing gear or aircraft structure has reduced maintenance costs and loss of aircraft. Here again, the disk loading is a factor. On the other hand, the AH-64 Apache usually takes off and lands from prepared, secure sites and records indicate an average landing descent rate significantly less than the BLACK HAWK. This would support a lower no-fuselage-contact design criteria for an attack helicopter landing gear which is significant in that gun turret impact is the critical factor in attack helicopter landing gear design. This same philosophy can be applied to other helicopter types. This does not change the overall system requirement for crash resistance.

3.5 Helicopter Size

As the aircraft decreases in size it becomes more difficult to obtain the desired length of seat stroke, depth of floor crush and length of landing gear stroke especially when an air transportability requirement limits the vehicle height. Also as the aircraft gets smaller, design for crashworthiness becomes a larger percent of the weight empty to the point where it cannot be justified. Therefore variable crash resistance design criteria is required. Today MIL-STD-1290A requires compliance with MIL-STD-58095 which dictates a minimum seat stroke of 12 inches. To truly allow the designer to employ the total systems approach to crash resistance he must have flexibility in defining seat stroke capability. This can become critical in a small attack helicopter where the front seat stroke may be restricted by ammunition or the ammunition feed mechanism.

3.6 Life Cycle Cost

Past crash resistance cost effectiveness analyses have shown that design for crash resistance is cost effective and pays for itself primarily through the reduction in mishaps afforded by a high performance landing gear. This will be especially true in the future where the mission equipment package may exceed the cost of the basic aircraft. Weight assigned to crash resistance will affect aircraft performance which affects fuel usage and operational costs. A careful analysis is necessary to obtain the best and most cost effective trade between design for performance and crash resistance.

4. SUGGESTED VARIABLE DESIGN CRITERIA

4.1 Vertical Crash Impact Design Conditions

Figure 3 is very much like one in Reference 5 except in that report the abscissa is Design Gross Weight (lb). Here it is suggested that the abscissa should be Weight Empty (lb) since for the smaller helicopters there is a tendency to assess the weight impact of crash resistance design as percentage of Weight Empty. Furthermore, it is suggested that this design point be for a combined impact attitude of 5° roll and 10° pitch onto a rigid surface. A recent analysis of AH-64 and UH-60 mishap data for the period 1 January 1982 through 1 January 1992 revealed that a 5° roll or less impact was experienced in 53% of all class A and B mishaps and a zero to + 10° pitch or less impact was experienced in 46% of all Class A and B mishaps. For this reason the 5° roll and 10° pitch impact appears to be a reasonable design condition. Helicopters do not usually crash on a rigid surface so a slight relaxation of the impact conditions is in order. The rigid impact surface is designated to facilitate crash dynamics calculations. The roll and pitch conditions do represent the majority of survivable crash impacts historically, but should not be a point design. The landing gear and crushable subfloor have to perform their energy attenuating (EA) functions over a wide range of crash impact attitudes. This suggested value is based upon existing crashworthy helicopter design capabilities and trade-off analyses to obtain an achievable level. It should not be taken as being critical of Reference 5 which provides values derived from sound analysis. These vertical crash impact conditions apply only to high performance, low inertia rotor blade helicopter systems with autorational descents in the order of 41 to 47 FT/SEC with disc loadings around 8 lb/ft^2. In helicopters with a lower autorotational descent rate and disk loading the crash vertical impact velocity design conditions should be lower.

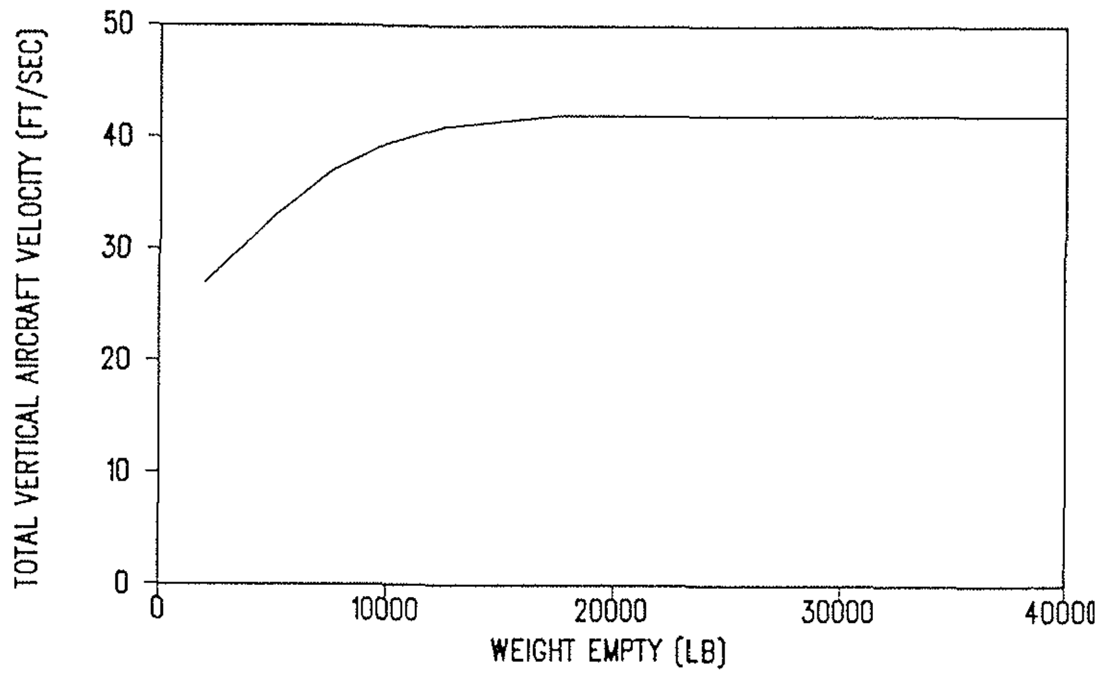

Figure 3. Suggested Vertical Crash Impact Design Condition for Total Aircraft

4.2 Landing Gear

For assault or medivac helicopters the landing gear shall be capable of delerating the aircraft with a 1 SDWG rotor wing lift and from an impact velocity of 20 FT/SEC onto a level, rigid surface without allowing the fuselage to contact the ground. Plastic deformation and damage of the landing gear is acceptable, however the remainder of aircraft structure should remain flightworthy. This should apply for Design Gross Weight (DGW) assault and medivac helicopters of 10,000 lbs and above with reduction to 17 FT/SEC for aircraft of 5,000 lb DGW. For observation and cargo helicopters a capability of 15 FT/SEC is suggested at 10,000 lb DGW and above and 13 FT/SEC for a 5,000 lb DGW. For an attack helicopter a value of 15 FT/SEC is suggested to include no gun turret housing contact for a 14,000 lb DGW and above and 12 FT/SEC for a 5,000 lb DGW. All these conditions should be met for a combined impact attitude of 5° roll and 10° pitch onto a rigid surface. In an attack helicopter the gun turret attachment should be designed to breakaway before damaging primary structure. Figure 4 depicts the suggested design criteria. For the reasons stated above, the suggested values slightly differ from Reference 5. Reference 5 is recommended to the reader for a broader treatment of categorizing crash resistance design criteria. This paper only address several key parameters.

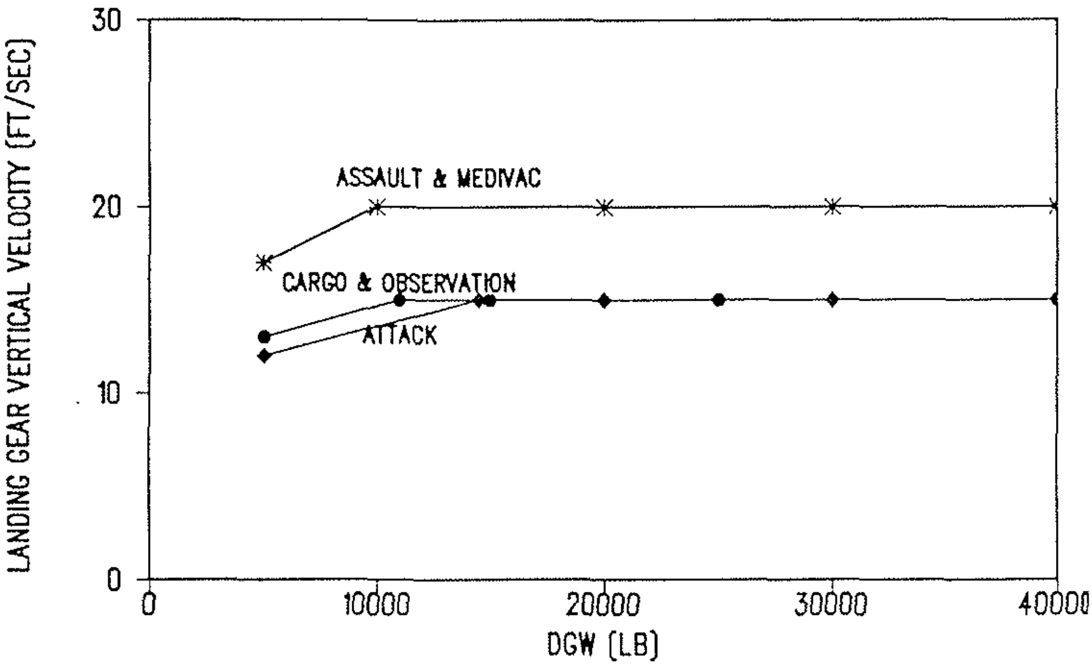

Figure 4. Suggested Vertical Crash Impact Design Condition for Landing Gear

4.3 Airframe

To offer protection for a landing gear up impact the fuselage shall be able to absorb the energy of 26 FT/SEC impact for a 12,000 lb DGW and above and 20 FT/SEC for a 5,000 lb DGW.

4.4 General

It should be noted that the crash resistance design criteria suggested herein are not official changes to MIL-STD-1290A but rather are based upon design studies and field data. This standard will be revised sometime in the near future and it is intended, at that time, that variable design criteria as discussed in this paper will be considered for inclusion. Input from the European rotorcraft industry will be sought during the revision process.

References

1. S. Desjardins, et. al. Aircraft Crash Survival Design Guide, USAAVSCOM TR 89-D-22A through E, 5 volumes, December 1989.

2. Military Standard 1290(AV), Light Fixed and Rotary-Wing Crash Resistance, March 1986.

3. From U.S. Army Aircraft Accident Data 1980 to 1990 and Communications with LTC(P) D. Shanahan, June 1992.

4. From U.S. Army Aircraft Operation Test Reports and Communication with LTC(P) D. Shanahan, June 1992.

5. J. Coltman, Development of Categorized Crashworthiness Design Criteria for U.S. Army Aircraft, USAAVSCOM TR 90-D-16, May 1990.