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HELICOPTER OPERATIONAL LOADS SPECTRUM AND DESIGN CRITERIA

A. J. Gustafson, Jr.

Advisory Group for Aerospace Research and Development

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on

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by

A.J.Gustafson, Jr

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PREFACE

Realistic helicopter design criteria benefits the operational capability of helicopters by reducing the possibility of over or under design. Better performance and reliability are possible while achieving increased operational availability and reduced maintenance requirements when design criteria reflects more truly the actual operational conditions of significance in establishing design criteria in a realistic mission load spectra. In the Fall of 1973, the Structures and Materials Panel of Advisory Group for Aerospace Research and Development established a working group to review and assess the Helicopter Design Mission Load Spectra Data within the NATO Nations.

The means considered by the Working Group to fulfill this general aim were to establish improved design criteria through a better definition of the loads spectra. The loads spectra would be developed through analysis of the available operational loads measurement data and a comparison to design loads requirements. It was proposed that a review of the operational loads measurement programs recently completed and in progress, along with an analysis of this data as related to mission spectra for the US Army be presented. This presentation was made by Arthur J.Gustafson at the 38th Meeting of the Structures and Materials Panel in April 1974.

The Working Group suggested publication of this paper as a valuable contribution to the continued effort to increase the reliability of future helicopters through improved design criteria.

RICHARD L.BALLARD
Chairman of the Working Group
on Helicopter Design
Mission Load Spectra

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SUMMARY

The USAAMRDL helicopter loads programs have proceeded along three complementary lines: loads prediction techniques, mission spectrum development, and loads measurement. The loads measurement programs involved the measurement of several flight parameters on helicopters performing actual missions in SEA and CONUS. The flight parameters were: airspeed; altitude; vertical, lateral, and longitudinal acceleration at the helicopter's center of gravity; outside air temperature; main rotor speed; engine torque; and longitudinal, lateral, and collective stick positions versus time. Five basic types of aircraft were instrumented: cargo, crane, utility, observation, and gunship. The operational profiles deduced from the field data were compared to the profiles used in the design of the aircraft. The results of this effort are currently being used to construct mission profiles for the next generation designs for these types of aircraft.

The UH-1H helicopters have been instrumented in Alaska to acquire usage data as related to Arctic operations. Currently, a single UH-1H is undergoing flight tests in sub-zero temperatures in Alaska. Both main and tail rotors and other critical components have been strain gaged to determine whether operations in the cold, dense atmosphere affect the load levels and hence the life of these components.

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A knowledge of flight loads is necessary for the design of new helicopters. The primary sources of these loads are aerodynamic forces acting on the rotors and the fuselage, and they vary with the helicopter flight configuration: hover, forward flight, turns, pull-ups, and other combinations of maneuvers.

The USAAMRDL helicopter loads programs have proceeded along three complementary lines: mission prediction, loads calculation, and loads measurement. The loads calculation program has centered about the various analytical models, most of which were discussed during the AGARD Specialists Meeting in March 1973 and will not be discussed here. The loads measurement and mission prediction efforts are interrelated and are discussed as they collectively relate to design criteria.

Army helicopters have traditionally been designed to meet FAA type specifications. One of our early concerns was with the adequacy of CAM 6, civil aircraft type mission spectra, for designing aircraft that were flying combat missions in Vietnam. During the Vietnam conflict, four types of Army helicopters were instrumented to determine their combat usage.

Flight loads are not measured in a direct manner, but are calculated from knowledge of the effects of these loads, such as accelerations at the center of gravity or strain measurements on critical components. A number of flight parameters must be measured to put together a useful spectrum of aircraft loads. In our operational use surveys taken in Vietnam, the following flight parameters were measured: airspeed, altitude; vertical, lateral, and longitudinal acceleration at the helicopter's center of gravity; outside air temperature; main rotor speed; and longitudinal, lateral, and collective stick positions. These data were processed and analyzed according to four flight phases, called mission segments: (1) ascent, (2) maneuver, (3) descent, and (4) steady state. Data are presented in the form of time and occurrence tables, cumulative frequency distribution curves, and exceedance curves. These data show the time spent in the mission segments and the parameter ranges; the number of peak parameter values occurring in each range of each of the mission segments, and in the ranges of one or more related parameters; and the time to reach or exceed given maneuver or gust normal load factors.

An analysis and correlation was made of the mission profile derived from the foregoing operational data and the mission profiles used in the engineering development of these helicopters. An attempt was made to resubstantiate the original fatigue predictions from the loads derived from operational data and to assess the usefulness of the operational data for constructing mission profiles.

It was generally concluded that the mission segment breakdown of the loads data was insufficient for direct correlation with the engineering development criteria. Further breakdown was necessary, as illustrated in Figures 1 and 2. Due to the limited instrumentation installed and the selection of parameters to measure, it was not possible to use actual measured data to achieve the breakdown. A great deal of this reallocation of flight parameters is arbitrary, and there is the possibility that each designer made his allocations to show maximum agreement with his original design. Even so, some

differences in helicopter use, as opposed to design, were noted. In general, operating conditions in a combat environment were less severe than predicted, although, for the CH-54, for example, gross weight was frequently exceeded, as shown in Figure 3. These high gross weights are allowable on a static strength basis, but probably produce damaging loads in fatigue related components.

Considerable historical information on the OH-6A helicopter shows that the main and tail rotor drive systems encountered a more severe load (torque) spectrum in service than was predicted during engineering development. This condition was not fully identified by the operational use survey, probably due to inadequate data on sideward and yawed flight conditions.

The manner in which the operational data was reduced was not always advantageous. Presentation of flight parameters independently rather than simultaneously prevented study of unfavorable combinations of these parameters. High speed and high gross weight, high speed and maneuvers, hover with large C.G. offset, and the several factors affecting blade stall could not be easily deduced from the final data as presented, although they were recorded during the field survey.

We have concluded from these reviews that operational data collection and editing can be improved. Better definition of discrete ground and flight regimes is required to develop accurate mission profiles. Measurement of peak loads and specific load paramters, such as main rotor head moment or main and tail rotor flapping angles, would yield more accurate fatigue load prediction. It was also concluded that the means for developing mission spectra for new aircraft should be examined. The reports on this work are now being published, but to speed the flow of information to industry and other Government agencies, a conference was held in June 1973 to present the major conclusions of this work.

We have discussed some shortcomings in our operational use surveys, but even if they had been without fault, some caution must be exercised when interpreting this data. During engineering development, the mission profile is used to calculate both ultimate and fatigue loads for determining "life" of structural components. The mission profile is usually developed from consideration of all probable uses of the helicopter, historical data, and the helicopter's characteristics. Operational data is basically incomplete because of operational restrictions in the field or psychological factors that limited how the aircraft was flown. Some restrictions are due to excessive vibration, power limits, or tactical procedures; some others are due to training. For example, the CH-54 was rarely flown above 90 knots with an external load, even though this is well below the speed permissible by any structural or flight limitations. Presumably this was a psychological limitation associated with what the pilots considered to be a safe speed when carrying external cargo.

Currently, effort is under way to improve our understanding of such factors and to start development of criteria for constructing mission profiles. This work includes development of mission profiles for observation, utility, utility tactical assault, attack, crane, and transport helicopters for the next-generation requirements for such helicopters. These helicopters will have increased power, less vibration, and greater agility and can, in general, be flown to and beyond structural limits easier than present-day helicopters. The impact of such factors on design loads and criteria may be significant.

Flight parameter measurements made by different operational organizations on their helicopters would be extremely useful data for new helicopter design. Such data should highlight those flight parameters that are insensitive to mission, type of training, or operational constraints. These factors probably vary widely with different operational organizations; therefore, common aspects of the flight loads are likely to represent common characteristics of the type of rotor system (teetering, articulated, or "rigid"). For example, on a rigid rotor system, hovering with a large C.G. offset may be as damaging in fatigue as maneuvering flight; in an articulated rotor this may not be true. Thus, in specifying fatigue design criteria, gross weight and C.G. distributions may be as important as maneuver conditions and duration, depending upon helicopter type. The continuing design spectrum effort and loads measurement programs are directed at further understanding in this area.

Two measurement programs now being conducted are cold-weather operations with a utility helicopter and a strain survey of a gunship. The effects that flying in cold, dense air have on loads are being studied in Alaska. Data that define the effect of extreme cold-weather operations on rotor systems loads and the resulting influence on the fatigue life of critical components are needed for criteria in the design of future helicopters whose primary military operations may be performed in arctic weather. This effort is based on the consideration that the reliability (fatigue) of critical helicopter dynamic components may be adversely affected by operational flight usage in a sub-zero temperature environment. Flight and engine torque operational redlines are easily exceeded because of the greater horsepower-producing capability of the engines in the denser atmosphere. At normal design conditions and a forward speed of 121 knots, for example, the UH-1H rotor operates at a tip Mach number of 0.91, but at -50 degrees Fahrenheit the tip Mach number increases to 1.04 with an accompanying increase in vibratory loads. Also, since flight and stress data for the UH-1H operating in Vietnam is available, an evaluation of cold- and warm-weather operational characteristics will be made to assess the impact of these different environmental conditions on helicopter operations. The second program is a strain survey of the AH-1G gunship. The AH-1G rotor will be extensively instrumented to obtain detailed loads data on the teetering rotor. This data will improve our understanding of the teetering rotor as related to fatigue of critical components and, in particular, will provide data to verify analysis methods for predicting helicopter maneuver boundaries.

Another reason for investigating the AH-1G rotor/airframe loads and responses is the need for a comprehensive understanding of the operational characteristics of a teetering rotor to permit further development of this type of rotor system. The development of realistic design criteria and analytical prediction tools that accurately account for the basic fatigue mechanisms can, through the resulting improved design, be efficient in curbing structural failure of aircraft components due to fatigue.

The AH-1G program, in particular, will provide data to verify analysis methods for predicting helicopter maneuver boundaries (blade stress, pitch link loads, stall, etc.). The data acquired from tests of the AH-1G, of course, will provide insight into the phenomena associated with teetering rotor operations and will provide support to the AAH program. Anticipated future studies would be similar for hingeless and articulated rotors. In conclusion, we find that there are difficulties in measuring operational use parameters and some further difficulties in interpreting the measured data. Also, field measurement programs are usually very short, 200 flight hours or so, and high load factors that are very damaging to fatigue-sensitive components are seldom measured at all because of their infrequent occurrence.

It is these very high, infrequent loads which are also the most difficult to predict analytically, as was noted in the March 1973 meeting. The case for full-time loads monitoring on all aircraft is very strong; however, this too is fraught with practical field problems.

The manner in which the helicopters are used and an unusually high attrition rate, such as recently experienced in Vietnam, can hide fatigue problems which may take some time to develop. For example, we are currently experiencing a latent fretting fatigue problem with the AH-1 rotor blades which has surfaced since the Vietnam conflict. The attrition rate of these helicopters and rotor blades has been drastically reduced, and the accumulated flying time has reached the point that long-term fatigue problems are developing.

The many difficulties associated with collecting, interpreting, and calculating flight loads coupled with the importance of accurately predicting loads for new aircraft warrant a high degree of cooperation among all users of helicopters. Notwithstanding the many differences in operational use, training, and theater of operations, it is felt that much useful information can be gained by an interchange of data. As a minimum, the peculiarities of the major types of rotor systems may become better understood.

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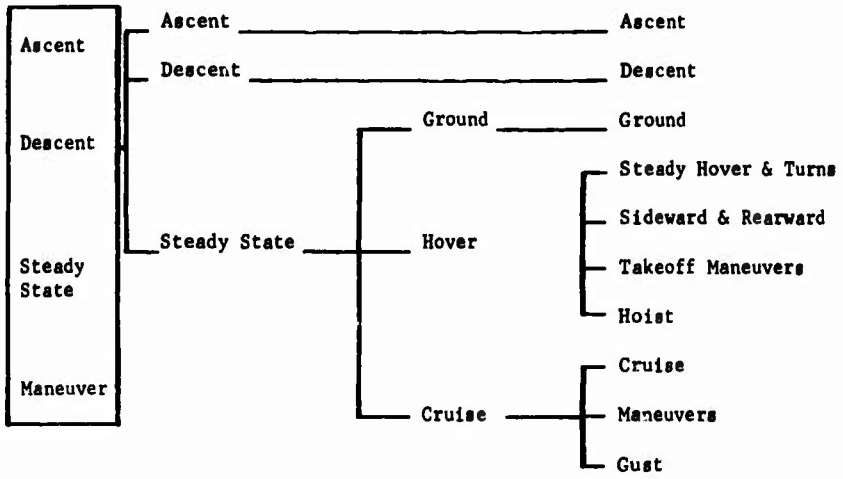

FIGURE 1. FURTHER SPLITS FOR FLIGHT DATA

Basic Condition Detailed Condition	Airspeed	RPM	Remarks	Percentage of Occurrence	
I a. Maximum performance takeoff					0.50
1.	0	Maximum		0.500	
b. Climb (takeoff power)					2.00
1.	Best rate of climb	Maximum		2.000	
2.	Best rate of climb	Minimum			
Climb (maximum continuous power)					4.00
3.	Best rate of climb	Maximum		4.000	
4.	Best rate of climb	Minimum			
II a. Longitudinal, lateral and pedal reversal, hover			Control Motion		1.50
1. Longitudinal reversal, hover, rapid	0	Maximum	±25%	0.150	
2. Longitudinal reversal, hover, rapid	0	Minimum	±25%		
3. Longitudinal reversal, hover, slow	0	Maximum	±25%	0.350	
4. Longitudinal reversal, hover, slow	0	Minimum	±25%		
5. Lateral reversal, hover, rapid	0	Maximum	±25%	0.150	
6. Lateral reversal, hover, rapid	0	Minimum	±25%		
7. Lateral reversal, hover, slow	0	Maximum	±25%	0.350	
8. Lateral reversal, hover, slow	0	Minimum	±25%		
⋮	⋮	⋮	⋮	⋮	⋮

FIGURE 2. INCOMPLETE LISTING, OH-6A MISSION PROFILES - DETAILED CONDITIONS

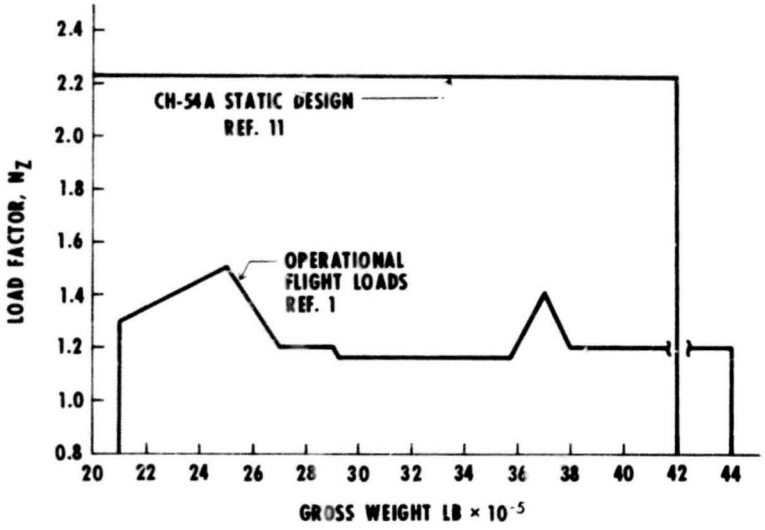

FIGURE 3. LOAD FACTOR VS. GROSS WEIGHT ENVELOPE