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Development and Use of Computational Techniques in Army Aviation R&D Programs for Crash Resistant Helicopter Technology

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INTRODUCTION

During the 1960's over 30 full-scale aircraft crash tests were conducted by the Flight Safety Foundation under contract to the Aviation Applied Technology Directorate (AATD) of the U.S. Army Aviation Systems Command (AVSCOM). The purpose of these tests were to conduct crash injury investigations that would provide a basis for the formulation of sound crash resistance design criteria for light fixed-wing and rotary wing aircraft. This resulted in the Crash Survival Design Criteria Designer's Guide which was first published in 1967 and has been revised numerous times, the last being in 1989 (Ref. 1). Full-scale aircraft crash testing is an expensive way to investigate structural deformations of occupied spaces and to determine the decelerative loadings experienced by occupants in a crash. This gave initial impetus to the U.S. Army to develop analytical methods to predict the dynamic response of aircraft structures in a crash. It was believed that such analytical tools could be very useful in the preliminary design stage of a new helicopter system which is required to demonstrate a level of crash resistance and had to be more cost effective than full-scale crash tests or numerous component design support tests. From an economic point of view, it is more efficient to optimize for the incorporation of crash resistance features early in the design stage. However, during preliminary design it is doubtful if sufficient design details, which influence the exact plastic deformation shape of structural elements, will be available. The availability of simple procedures to predict energy absorption and load-deformation characteristics will allow the designer to initiate valuable cost, weight and geometry tradeoff studies. The development of these procedures will require some testing of typical specimens. This testing should, as a minimum, verify the validity of proposed procedures for providing pertinent nonlinear load-deformation data. It was hoped that through the use of these analytical models, the designer could optimize aircraft design for crash resistance from both a weight and cost increment standpoint, thus enhancing the acceptance of the design criteria for crash resistance.

SYSTEMS APPROACH TO CRASH RESISTANCE

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 the 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.

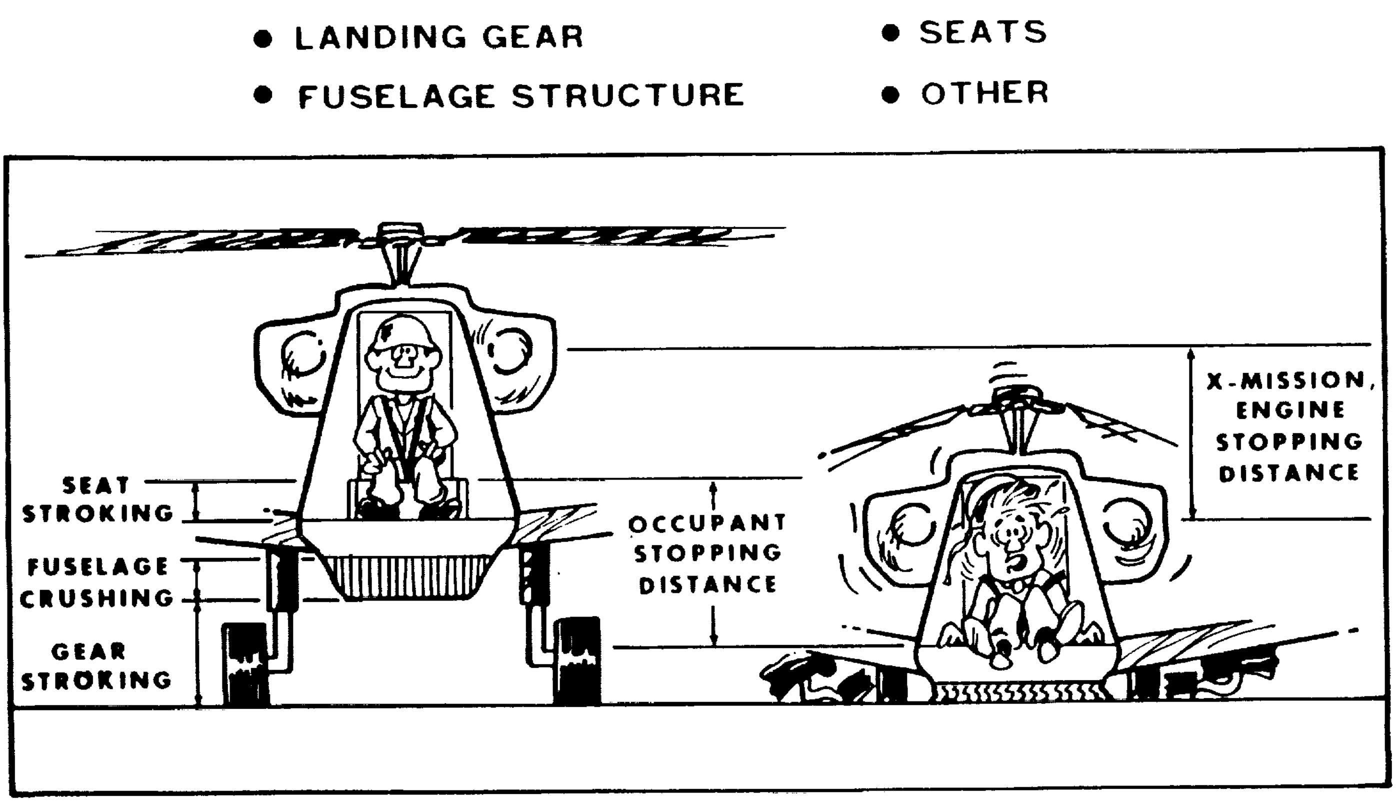

Figure 1 - Energy Management System

MODEL KRASH DEVELOPMENT

Figure 2 depicts the chronology of the development of model KRASH which is the most commonly used computer analysis of the dynamic response of aircraft structure during a crash impact. Model KRASH represents the structure with beam elements, crushable springs and lumped masses. It is intended to provide designers with simplified techniques with which to perform crashworthiness studies during the aircraft preliminary design phase.

In any crash resistant aircraft design a total systems approach must be employed to determine the most effective mix of energy attenuation from the landing gear, airframe structure and stroking seat. This is where program KRASH can allow you to quickly assess the relative effects of different energy attenuating component mixes, thus pointing the way to an optimized system design for crash resistance.

• **DYNAMIC SCIENCE/US ARMY**	**1969-1971**
• **LOCKHEED/US ARMY**	**1972-1974**
• **LOCKHEED/FAA**	**1975-1990**
• **DRI/FAA/NAVY**	**1990-1991**
• **US ARMY R&D PROGRAMS**	**1975-1992**
• **IR&D EFFORTS**	**1980-1992**

Figure 2 - Model KRASH Development

KRASH MODEL CORRELATION

As part of the development of KRASH, full-scale UH-1 cabin floor sections were crash tested to determine the load-deflection characteristics of the subfloor springs. In addition, a full-scale UH-1 was crash tested to help develop and validate the KRASH model (Fig. 3). Later, each time an aircraft was to be crash tested by the U.S. Army, whatever the reason, the aircraft would be modeled for the planned impact conditions using KRASH before the test and then the results would be compared to the test data and post test structure deformation. Using the actual impact conditions, if different, along with test results, the KRASH program would be exercised to fit the actual test and result. This empirical approach to improving the model or to just better understand influences of various structural concepts was used in full-scale testing of both the Bell and Sikorsky Advanced Composite Aircraft Program (ACAP) helicopters. The latter two tests were unique in that they provided the utility of model KRASH for composite structures.

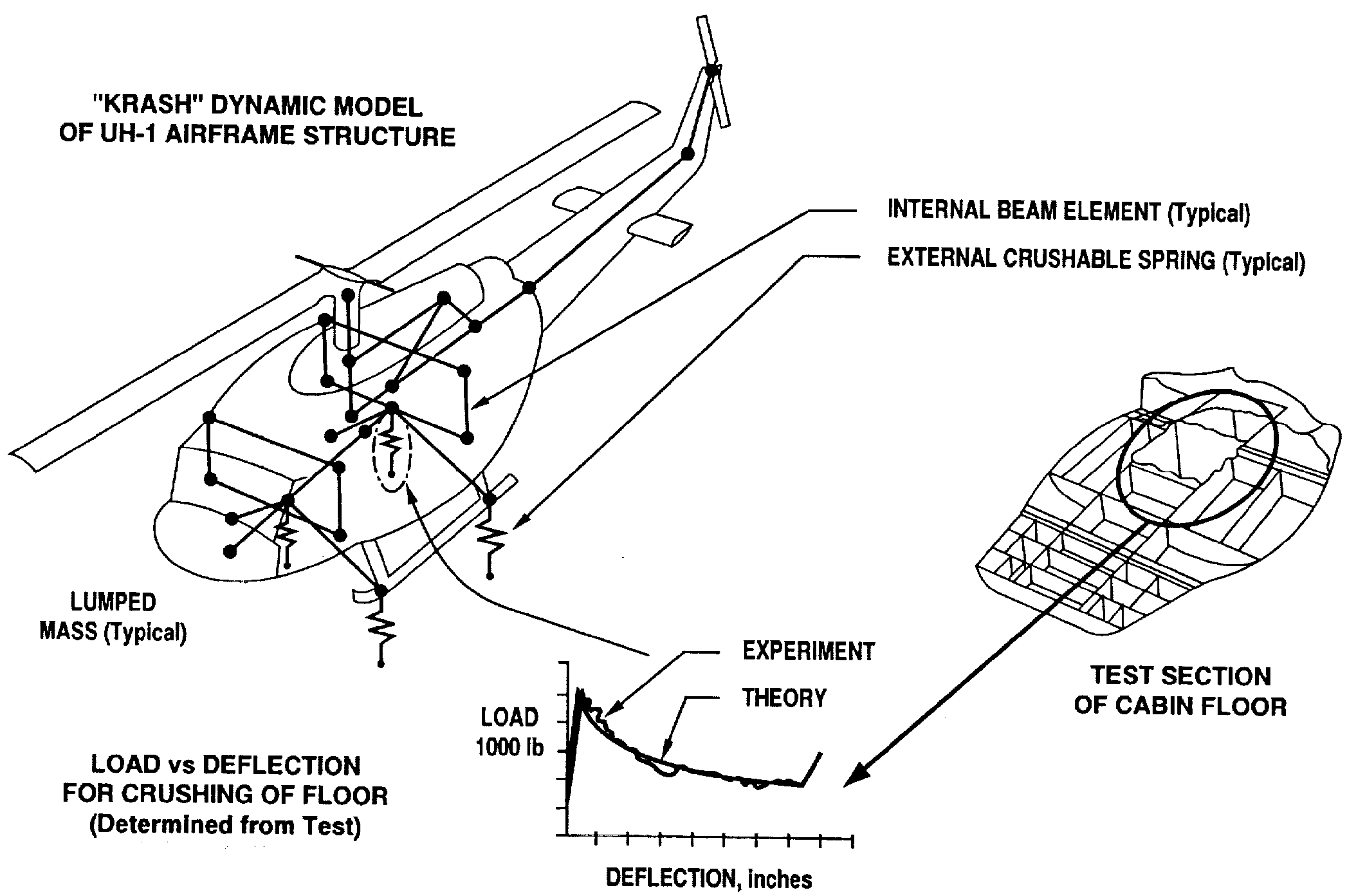

Figure 3 - KRASH Model Correlation

DESIGN SUPPORT TESTING TO SUPPORT ANALYSIS

KRASH is being used worldwide and has proven to be a useful tool in the preliminary design process for crash resistance in new rotorcraft. However, in preliminary design, energy absorbing subfloor spring constants are assumed based upon elemental structural test data, sometimes not much more than coupon specimen data. All too often, once the preliminary design advances into detail design and some elemental design support testing is conducted, it is found that the structural concept does not perform correctly and that the spring constants used initially are very difficult if not impossible to obtain within the structure weight allocated. This leads the designer into a trial and error design support test effort (see Fig. 4) with associated high costs, to obtain the elusive good crush initiators, good energy attenuation and a nice rectangular load-deflection relationship. Since this seems to be the case almost all the time, especially with composite structures, it seems that if we could develop a database from all this trial and error testing and make it available to all designers, we could significantly reduce the duplication of test effort that is currently going on with all kinds of test specimens. Furthermore, the analyst could use these test data as an empirical base to develop finite element models of the structural elements, thus reducing design support testing, though ultimately the final design would still have to be tested under realistic impact conditions. The sharing of data and increased use of analytical models will permit crash resistance component design formulation in less time at far less cost.

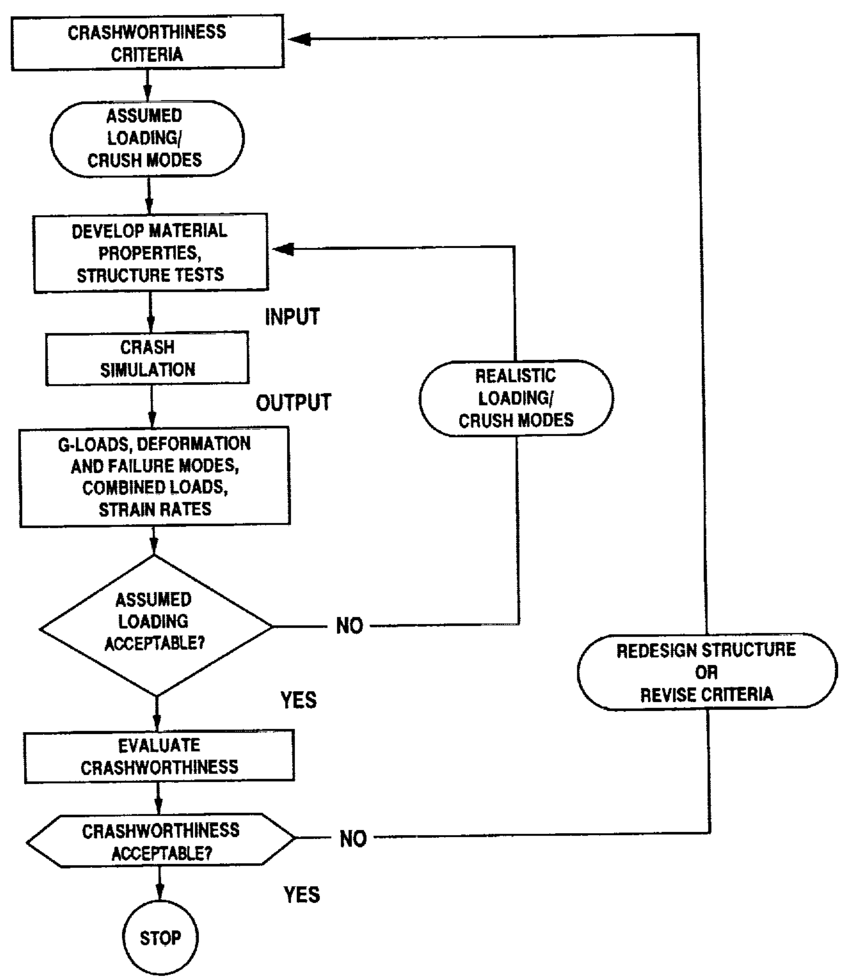

Figure 4 - Analysis/Test Logic Path

SOM-LA

Program SOM-LA (Seat/Occupant Model-Light Aircraft) has been developed for use in evaluating the crashworthiness of aircraft seats and restraint systems. It combines a three-dimensional dynamic model of the human body with a finite element model of the seat structure. It is intended to provide the design engineer a tool with which he can analyze the structural elements of the seat as well as evaluate the dynamic response of the occupant during a crash.

The occupant model consists of 12 masses that represent the upper and lower torso, neck, head, and two segments for each of the arms and legs. An optional model of the human body includes beam elements in the spine and neck, but is restricted to two-dimensional motion.

External forces are applied to the occupant by the cushions, floor and restraint system. Interface between the occupant and seat is provided by the seat bottom cushion, back cushion, and an optional headrest. The restraint system can consist of a lap belt alone or combined with a single shoulder belt, over either shoulder, or a double-strap shoulder harness. A lap belt tiedown strap, or negative G strap, can also be included. Each component of the restraint system can be attached to either the seat or the aircraft structure. SOM-LA is summarized in Fig. 5.

- **FINITE ELEMENT MODEL OF SEAT**
- **DYNAMIC MODEL OF 50TH PERCENTILE HUMAN MODEL AND ANTHROPOMORPHIC DUMMY**
- **GIVES STRUCTURAL BEHAVIOR OF SEATING AND RESTRAINT SYSTEMS UNDER TRANSIENT DYNAMIC LOADING CONDITIONS**
- **CAPABLE OF PREDICTING SEAT STROKE, OCCUPANT MOTIONS, OCCUPANT-FLOOR, OCCUPANT-CUSHION, AND OCCUPANT-RESTRAINT FORCES**
- **CAN ACCEPT ANTHROPOMETRY INPUT**
- **CANNOT ACCEPT FORCES OF OCCUPANT CONTACT WITH SURROUNDING STRUCTURE**

Figure 5 - Seat Occupant Model/Light Aircraft (SOM-LA)

ARTICULATED TOTAL BODY MODEL

The Articulated Total Body (ATB) Model is primarily designed to evaluate the three-dimensional dynamic response of a system of rigid bodies when subjected to a dynamic environment consisting of applied forces and interactive contact forces. Although the ATB Model was originally developed to model the dynamic response of crash dummies and, with later modifications, the response of the human, the ATB Model is quite general in nature and can be used to simulate a wide range of physical problems that can be approximated as a system of connected or free rigid bodies.

The approach used in the ATB Model to model the human or manikin body (the "body" in the ATB Model simulation) is to consider the body as being segmented into individual rigid bodies (the "segments" in the ATB Model) each having the mass of the body between body joints or, in the case of single-jointed segments, such as the foot, distal to the joint. An example would be the left upper arm segment, which represents the mass of the body between the shoulder joint and elbow joint. Segments are assigned mass and moments-of-inertia and joined at locations representing the physical joints of the human body, such as the shoulder joint or the knee joint. For the ATB Model the Generator of Body Data (GEBOD) is a source of anthropomorphic data for the zero to 100th percentile male, female, infant, child and dummy. These data include body masses, moment-of-inertia, and c.g.'s.

A personal computer version of ATB is named DYNAMAN which along with the ATB model has been useful in R&D programs to delethalize the helicopter cockpit. The ATB model is summarized in Fig. 6.

- **PREDICTS GROSS HUMAN BODY RESPONSE TO VARIOUS DYNAMIC ENVIRONMENTS**
- **CAN ACCEPT INPUT OF STROKING SEATS AND RESTRAINTS**
- **GEOMETRIC BODY MODELER (GEBOD) IS A SOURCE OF A WIDE RANGE OF ANTHROPOMORPHIC DATA INPUT**
- **CAN PREDICT CONTACT FORCES ON OCCUPANT**

Figure 6 - Articulated Total Body Model

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