GPO PRICE $ ____

CFSTI PRICE(S) $ ____

Hard copy (HC) 1.00

Microfiche (MF) .50

ff 653 July 65

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Presented at the International Committee on Aeronautical Fatigue

[redacted]

Munich, Germany
June 21-22, 1965

N66-18359
(ACCESSION NUMBER) (THRU)
25 1
(PAGES) (CODE)
TMX 56562 17
(NASA CR OR TMX OR AD NUMBER) (CATEGORY)
FACILITY FORM 602

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Research on fatigue continues to occupy the interest and attention of a large number of investigators in the United States. The work to be reported here will be limited to that conducted in Government Laboratories or under Government sponsorship and to studies that may have reasonably direct application to aircraft structures. The review is organized according to the agency that sponsors the investigations.

References to tests of components or structures of particular aircraft are generally omitted because of the tremendous volume of such information being gathered and because results of such tests are not readily generalized.

I. NASA RESEARCH

A. Supersonic Transport Materials

A large share of the work done at the Langley Research Center during the past 2 years has been devoted to the behavior of materials suitable for use in the proposed U.S. supersonic transport. The studies were largely experimental and treated a variety of titanium alloy and steel sheet materials in a temperature range from -110° F (195° K) to 550° F (561° K).

Crack propagation and residual static strength tests were conducted on 8-inch (20.3-cm) wide specimens. The overall conclusions reached were: when compared by strength-to-density ratios, the more favored materials in the series were more resistant to crack growth and static failure than were the currently used aluminum alloys. The temperatures used in the tests had only a minor effect on the behaviors of the better materials. In these tests, the titanium alloy Ti-8Al-1Mo-1V in the duplex annealed condition generally had very desirable properties (refs. 1 to 4). This material is also readily weldable, but is susceptible to salt stress corrosion. Other intensive studies are being conducted to evaluate this latter phenomenon in more detail.

The effects of prolonged exposure to elevated temperatures on the fatigue behavior of simple joints and notched and unnotched specimens have also been studied. Exposures exceeding 24,000 hours have not produced significant deleterious effects (ref. 5).

A brief review of these and other related results is presented in reference 6.

Under contracts with Battelle Memorial Institute and Ling-Temco-Vought Corporation, additional data were obtained on the fatigue behavior of Ti-8Al-1Mo-1V titanium alloy and AM 350 CRT alloy steel (refs. 7 and 8).

[redacted]

Two new projects have been initiated to study further the long-time exposure effects on fatigue behavior. In one series, several dozen cantilever specimens are mounted in an outdoor device (ref. 9) and heated to 550° F. Fatigue cycles are applied in appropriate numbers to produce failure in 1 to 2 years if the outdoor exposure had no effect. The specimens will be allowed to cool before they are subjected to fatigue loads in order to allow dew to form on them and will also be cool during rain and snow storms.

In the second project, a number of sheet specimens are subjected to axial loads and temperatures programed to simulate supersonic flights. Means for compressing the time required to conduct such tests without compromising reliability will be sought. Ten testing machines with servo-controlled hydraulic loading devices apply the required loads to long strip specimens with central notches at six different cross sections. Programing of load and temperature is accomplished by a curve-following sensor. Emphasis will center on titanium alloys in the initial series.

B. Cumulative Damage

Studies of fatigue behavior under complex time histories of stress are continuing. A servo-controlled hydraulic testing machine programed by punched cards has been constructed. This unit can schedule 55 discrete, individually adjustable load levels in any desired sequence. With a new memory device that is being installed, the device is expected to operate at rates up to at least 30 cycles per second. The nominal load capacity is 20,000 pounds (8.9 kilonewtons).

Recent results of tests conducted in this device have shown that the ground-air-ground cycle and other negative loadings can produce reductions in life that are much greater than would be expected from current theories of cumulative damage. The effect is more severe when the negative load cycles are applied in flight-by-flight sequence rather than in blocks (ref. 10).

In another investigation, tests have been conducted with four different random time histories of stress and with "equivalent" stress schedules based on various counting procedures (refs. 11 and 12). Most of the counting procedures were described by Schijve. Some of the companion tests were conducted with the significant stress peaks applied in the same sequence as was used in the random time histories. These tests showed that the stress fluctuations eliminated by counting only the maximum peaks between zero crossings or by ignoring fluctuations smaller than 8 percent of the maximum alternating stress applied had little or no effect on total life. Similarly, results of block tests conducted with schedules based on analysis by other counting procedures produced only minor effects on life with one exception. Tests conducted with statistics based upon amplitudes only, but with all means reduced to the common overall mean required a somewhat larger number of cycles to failure. This result agrees with Kowalewski's data. Surprisingly, results of block tests conducted with more elaborate programs involving some 30 combinations of mean and alternating stresses did not correlate well with the results of the random load tests. No systematic trend was evident.

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A high-speed hydraulic fatigue test device has been installed recently at the Langley Research Center. Its important features follow:

Maximum frequency	400 cps
Maximum force	15,000 lb (67 kilonewtons)
Maximum displacement	±1 in. (2.54 cm)
Maximum rate of head motion	50 inches per second (1.27 m per sec)
Response to random input flat to	250 cps
Range of specimen stiffnesses for optimum response	2×10^5 to 7×10^5 lb/in. (350 to 1230 kilonewtons/cm)

The unit is programed from a random noise generator with seven sets of peak-notch filters to shape the power spectrum of loads applied, or a tape record may be used. The programer also has constant-frequency and automatically controlled frequency-sweep oscillators.

C. Plastic Stresses at Notches

A fundamental study is under way of local plastic action at notches in aluminum-alloy specimens subjected to repeated loads. The specimens are subjected to constant-amplitude axial loads. Both repeated tension (R = 0) and completely reversed (R = -1) loadings have been used. Load cycling is continued until local stress conditions stabilized, usually in 30 to 50 cycles. Local stress histories were determined by recording local strain histories during cycling and reproducing these histories in simple unnotched specimens. The fatigue lives for the notched specimens were estimated from stabilized local stresses and an alternating-versus-mean-stress diagram for unnotched specimens of the same material. These predictions compared favorably with lives from S-N data for the notch configuration tested.

In addition, an expression was developed for calculating local plastic stresses. An acceptable correlation was obtained between predicted stresses and stresses observed during the first cycle of loading (ref. 13). (Copies of this paper have been sent to the ICAF Executive Secretary for distribution as ICAF documents.)

D. Acoustic Fatigue Studies

NASA research on acoustic fatigue is conducted in a group that also has responsibility for studying structural response to acoustic and vibration environments and the reliability of equipment exposed to such environments. The programs are in support of both the space and advanced aircraft development programs. Current emphasis is placed on defining the acoustic environments generated by large booster engines and by supersonic flight in the atmosphere (refs. 14 to 17). Special attention has been directed toward the effects of intense noise at frequencies below 50 cps including subaudible frequencies.

A new facility designed for testing at low frequencies has been placed into operation at the Langley Research Center (ref. 18). This facility consists of a 24-foot-diameter by 20-foot-long test chamber equipped with a 14-foot-diameter hydraulically actuated loudspeaker and a movable wall for tuning purposes. The facility is man-rated and is of sufficient size to test manned spacecraft.

Studies associated with structural response and fatigue have dealt with structures ranging from simple panels to complex spacecraft packages in an operational condition (refs. 19 and 20). Response and fatigue studies have been made of simple aluminum panels and of advanced structures fabricated by techniques specially intended for the high-speed flight conditions. Attention has been directed toward development of facilities for simulating acoustic input environments combined with elevated temperature of supersonic atmospheric flight. The combined acoustic and vibration environments of a missile guidance computer during launch liftoff have been successfully simulated in the laboratory with the use of an air jet to generate the environments (ref. 21).

The Langley facilities are also used to study behavior of building-type structures and physiological and psychological studies of man in intense noise (refs. 22 and 23). In addition to studies in discrete-frequency noise and in random noise, there are also studies dealing with effects of acoustic loading of the impulse type such as results from the sonic boom (refs. 24 and 25). Other papers written by the group or under their sponsorship are listed as references 26 to 28.

E. Definition of Load Environment

Since the Symposium 2 years ago, research has continued in the area of repeated loads on aircraft. The results of some of this research are given in references 29 to 37. References 29 and 30 present results on the turbulence environment in severe storms and at high altitude. References 31 and 32 provide summaries of repeated loads measured on commercial transport airplanes during routine operations. Experimental and analytical results pertaining to repeated loads caused by runway roughness are given in references 33 and 34. References 35 to 37 contain results having a bearing on the repeated loadings of helicopters.

F. Construction of New Fatigue Research Laboratory

A new fatigue testing laboratory building is being constructed at Langley Research Center. The building covers 24,000 square ft (2500 sq m), most of which will be air conditioned. A 50- by 100-foot non-air-conditioned (16×30 meters) bay will be equipped to handle fatigue tests of structural specimens at elevated temperatures. Electrical power for heating the specimens will be taken from an existing 10-megawatt power supply which is part of the present Structures Research Laboratory. The air-conditioned laboratory space will house existing and planned testing devices for fatigue and static tests. Trenches in the floor will facilitate distribution of power, cooling water, air, and hydraulic pressure from a central pumping station. The building should be ready for occupancy by the Fall of 1966.

II. U.S. AIR FORCE RESEARCH

The fatigue program of the U.S. Air Force encompasses a broad range of topics including some mechanism work at one end of the scale to the refinement of fatigue analyses at the other. The primary goal of the program as a whole has been and is to bring about an improvement in the prediction of structural fatigue performance and systems operational life.

A. Air Force Materials Laboratory

Several individual projects are under way to produce analytical procedures for predicting mechanical behavior (fatigue) of structural materials by relating metallurgical and/or physical factors. The role of interstitial solute elements in strain aging phenomena, for example, is being clarified for titanium, tantalum, and iron (ref. 38). Several aspects of elevated temperature behavior are also under study, including strain rate effects in aluminum and the superalloys L-605 and René 41 (refs. 39 and 40), effect of low pressures (partial vacuum) on the crack propagation and stress-accelerated oxidation of molybdenum, and the effect of loading curve shape on crack propagation rate and fatigue life (ref. 41).

It has been shown that below 25 percent of the melting temperature of some metals, the effect of a combined creep-fatigue loading is controlled by the fatigue component, above about 75 percent, the creep component predominates, and between these limits, the failure mechanism involves a combination of the two (refs. 42, 43, and 44). Study of the mechanisms is continuing. Recent results of thermal fatigue research indicate that thermal fatigue life (of Nimonic 80A and PH 15-7 Mo stainless steel in this case) is a function of the width of the first hysteresis loop regardless of specific test conditions (ref. 45). Current work is also under way on the development and modification of certain constitutive equations governing nonlinear cyclic stress-strain laws (ref. 46). Studies are being conducted of the dislocation density, dynamics, and type associated with the immediate vicinity of an advancing crack in relation to areas some distance removed. Electron fractographic and transmission techniques are employed (ref. 47). A study of proton irradiation of metals has revealed that work hardening rate is affected somewhat; however, total fatigue life remains essentially unchanged. Finally, a program is just getting under way to develop a micromechanical theory to represent the fatigue and fracture behavior of metal-matrix composite materials systems. Extensive effort is being expended on the development of techniques for fatigue (as well as creep) reliability estimation (ref. 48). Professor A. M. Freudenthal, Columbia University, New York, has developed a theory (refs. 45 and 50) and is currently analyzing flight loads data, structural component static and fatigue data, and full-scale structural test information in a program designed to verify his theoretical procedures and indicate where modifications will be necessary (ref. 51). The search for appropriate data from both foreign and domestic sources is continuing.

The Materials Laboratory is continuing a research program on several aspects of vibration and damping in materials and structural composites related to the acoustical fatigue problem in high-speed turbojet and rocket vehicles.

Included in the studies are investigations of statistical properties of the acoustic excitation, response of structural elements, damping behavior, and new and special concepts and techniques for increasing damping (refs. 52 to 64). At present, acoustical fatigue evaluation is being made of the performance of structural elements containing highly damped joints at elevated temperatures. These elements have been built from design procedures optimized with respect to damping capacity and fatigue strength. Further modification in design will be dictated by results. Work is continuing on the development of new concepts and working constructions for increasing the damping properties of structures.

The Second International Conference on Acoustical Fatigue was sponsored and conducted by the AFML in April 1964. The conference proceedings will be available in June 1965 (ref. 65).

B. Flight Dynamics Laboratory

The construction of the RTD Sonic Fatigue Facility at Wright-Patterson Air Force Base is nearing completion. This facility is expected, first, to contribute to the prevention of sonic fatigue by enabling the accumulation of knowledge of the fragility levels of structure and, second, by enabling the proof testing of the final design.

The RTD Sonic Fatigue Facility consists of two test chambers into which high-intensity sound is introduced by sirens. An air supply system is provided for each test chamber. Data recording and data analysis equipment is provided to service either test chamber.

The most important technical characteristics of the test chambers and associated equipment are now described with the large chamber being discussed first.

The large chamber air supply system provides a high volume flow of air (300,000 cfm, 29.3 psia pressure) for actuating the sound generation system. The compressor which supplies the foregoing airflow is powered by a 40,000 hp motor and its associated electrical system. The air supply system also includes means for controlling the humidity and temperature of the air in order to provide air within the limits required for maximum generation of sound and the operating limits of the testing device.

The main test chamber has interior dimensions of 70 feet by 56 feet by 42 feet. This is a double shell chamber especially designed to withstand the acoustic environment. There are two modes of operation, reverberant and anechoic. A maximum sound pressure level of 160 dB re 0.0002 dyne/cm^2 will be obtained throughout the chamber in the reverberant mode of operation.

There are 25 two-foot-diameter low-frequency sirens installed in a 14-foot by $12\frac{1}{2}$- foot bank in the large test chamber wall. Nine 1-foot-diameter high-frequency sirens are installed in a movable bank. Each low-frequency siren covers a frequency range of 50 to 2400 cps with maximum power output of 40,000 watts. Each high-frequency siren has a frequency range of 500 to 10,000 cps with maximum power output of 10,000 watts.

The instrumentation system provides the capability to record 72 channels of microphone, strain gage, or accelerometer data simultaneously. By the use of time-sharing on 30 channels, 342 separate transducer outputs may be recorded. Data obtained from tests are recorded on analog tape and held for analysis in the facility data analysis system.

The data analysis system provides the capability to analyze the experimental data directly into forms suitable for use in theoretical analysis and establishment of criteria. These analyses include: amplitude probability density, cross correlation, auto correlation, power spectral density, and one-third octave band spectra. An analog to digital conversion system can prepare the data for further analysis on an IBM 7094 digital computer.

The small test chamber is located within the facility complex and provides capabilities similar to the large chamber but greatly reduced in size.

The small test chamber air is supplied by a compressor capable of providing 10,700 cfm of air at 45.7 psia. Humidity and temperature are controlled similarly to the large test chamber air system.

The small test chamber provides a 1-foot by 1-foot test section for progressive wave tests. A 15-foot by 8-foot by $7\frac{1}{2}$- foot termination room can be used for reverberant tests. A sound pressure level of 174-dB re 0.0002 dyne/cm^2 can be obtained in the progressive wave test section.

One high-frequency siren and one low-frequency siren provide the acoustic input for the small test chamber.

Twelve channels of the large chamber instrumentation system can be used, or the special small chamber instrumentation system can be used for a test. This system provides a wave analyzer, spectrum analyzer, phase meter, counter, filters, RMS meters, oscilloscopes, one-third octave band analyzer, and a direct reading strain indicator.

The existence of these two test chambers provides the capability to conduct many different types of high-intensity noise tests. Small research tests involving electronic components, mechanical systems, or human beings can be conducted at the same time as fully instrumented full-scale tests of complete missiles or major structural sections of large aircraft. This flexibility is proving to be of great value in solving high-intensity noise problems encountered by the Air Force.

Recent publications regarding sonic fatigue are listed as references 66 to 75.

General Dynamics/Convair, under contract AF 33(615)-2116, has been conducting tests to determine the effects of high loading on the subsequent fatigue life of axially loaded aluminum-alloy specimens prepared with Chromeite finish. Preliminary tests had shown that the fatigue life of 7075-T6 can be improved more than 10 times in the maximum stress range 27,000 to 40,000 psi by the application of this very thin (0.0002 in.) surface finish which is a proprietary process of the Chrome-ite Co. of Gardena, California. Early results of the Convair effort have verified that fatigue life is about ten (10) times that of uncoated specimens for 2024-T3 axially loaded unnotched specimens. The 2024-T3 data had an unusually small spread of results at a maximum stress of 40,000 psi (R = 0) where all four (4) results were between 2.7×10^6 and 3.4×10^6 cycles. The 7075-T6 results were not as good, however, due possibly to insufficient control on coating uniformity. The 2024-T3 specimens were also tested with various preloads ranging from 45,000 to 65,000 psi. As anticipated, certain preloads remove benefits due to Chrome-ite plating; however, in no case does the life appear less than for specimens without Chrome-ite. Subsequent testing will finish the unnotched studies and evaluate the behavior of Chrome-ite on notched specimens. The final report will be ready for distribution by August of 1965.

In the area of full-scale testing, the results of three efforts have been published since the last meeting (refs. 76 to 78).

III. U.S. NAVY AERONAUTICAL STRUCTURES LABORATORY

A. Structural Fatigue Research

The laboratory and theoretical fatigue investigations conducted by the Naval Air Engineering Center, Aeronautical Structures Laboratory (ASL) are concerned primarily with the development and verification of (1) fatigue life prediction methods and (2) statistical reliability methods as applied to structures. Emergency laboratory structural fatigue investigations and development work in connection with specific structural problems arising in fleet aircraft are also performed.

Full-Scale Structures

A summary of recent data from tests of full-scale structures is included in reference 79. More recent full-scale data are contained in reference 80. Data for both constant amplitude and spectrum loading are included; however, the spectrum loading data, except for that in reference 80, are all for one direction of loading. Analysis of the data led to the following conclusions:

1. For full-scale structures the scatter in lifetime was small for lives less than 10^6 cycles; the ratio of maximum-to-minimum lives was less than 2:1. The scatter almost approaches that obtained for laboratory riveted-joint specimens.

2. The Corten-Dolan cumulative damage hypothesis predicted lives for unidirectional loading that agree favorably with actual test results. The Miner-Palmgren linear rule was generally very conservative for unidirectional loading and did not predict the effect of spectrum changes on life.

Currently tests are under way to determine the effect of including load reversals in the spectrum. Limited results to date indicate that the inclusion of a small number of reversals increased the life appreciably; using a fighter spectrum the median life increased from 760 hours to 3530 hours, and using the spectrum for attack-type aircraft the life increased from a median of 7820 hours to more than 40,000 hours (test still running). These results are contrary to what one would expect based upon results of simple specimen tests. Similar additional tests will be performed using a number of specimens of a different structure. Although the actual reason for the peculiarities of these results is unknown, it is conjectured that the cause may be found by a study of the local strain history in a joint.

During the investigation of a service problem disclosed by a part failure, 12 identical parts with approximately 1500 flight hours of service were tested using spectrum loading. The total lives to initial visible crack of these used parts were compared with the test lives of eight virgin parts. The combined failure rate plot for initial visible cracking shows the life variation possible for a number of identical parts.

An experimental program, reported in references 81 and 82, has recently been completed to determine the comparative structural characteristics of a glass fiber reinforced plastic structure and its metal prototype. The results demonstrated a large (>8x) increase in fatigue life of the glass fiber reinforced plastic structure over the metal prototype; however, this was obtained with an early development glass fiber reinforced plastic structure, which was heavier than its metal counterpart. Further development is needed to reduce the weight of the glass fiber reinforced plastic structure to be competitive on a strength/weight basis with conventional construction.

Simulated Structures

Constant- and variable-amplitude fatigue tests are being performed on 7075-T6 aluminum-alloy box-beam specimens. The objective of this program is to determine the effects on fatigue life of type of spectrum, limit load stress level, block size, sequence of loading, and the inclusion of stress reversals. The results of the Phase I tests led to the conclusion that block size and static margin of safety (or limit load stress level) have a significant effect on life for load spectra having only positive loadings and with fixed sequence lo-hi loading. The effect of block size is not predictable by currently used cumulative damage hypotheses since these hypotheses ignore sequence of loading and block size as parameters.

Basic Research

The increase in life of a full-scale structure resulting from the addition of negative loading to the flight loads spectrum and the effect of block size noted in the box-beam tests cannot be substantiated by existing knowledge. In the hope that these results might be explained by consideration of the local strain history two programs have been undertaken to measure local behaviors.

One is a theoretical and experimental investigation to determine the cyclic stress-strain behavior and fatigue properties of aircraft metals being performed under contract by the University of Illinois with Prof. Jo Dean Morrow as the principal investigator. Both constant-strain and constant-stress behavior will be investigated in the plastic range for both unidirectional and reversed stressing. The study of cycle-dependent stress relaxation is of particular importance since it is related to the relaxation of residual stresses in a structure as a result of repeated loading.

The second is an in-house experimental investigation of the cycle-dependence of the strain field around open and filled, but unloaded, holes in a quasi-infinite plate under plane stress.

Test Methods

Under contract with the Hughes Tool Company, Aircraft Division, a method was developed for performing rotor blade fatigue tests during whirl tests by installation of rotor excitation panels underneath the rotor disc. The results of the initial investigations are contained in references 83 and 84. Present work is to generalize the results to rotors with any number of blades and solidity.

Crack Detection

Various crack detection methods and equipment are evaluated during fatigue test programs for the purpose of obtaining simple and reliable methods for detection of cracks in major structure. The greatest difficulty encountered is the extremely rapid crack propagation rate for current materials and methods of construction, which necessitates detection of cracks as small as 1/32 inch in length. Investigations of the feasibility of using infrared and radioactive tracer methods (refs. 85 and 86) have been conducted but the results of these investigations indicate that for the current state of the art, these methods would be no more successful in detecting small cracks in metal structures than currently used dye-penetrant and electromagnetic methods.

Special Publications

A review of laboratory structural fatigue test data and service experience with actual structures indicates that the majority of failures are caused by the lack of appreciation of the importance of the fatigue problem on the part of detail designers, production personnel, and inspectors. The Navy had two publications prepared for educational purposes. One (ref. 87) was prepared primarily for production, inspection, and maintenance personnel. (Copies of this publication have been submitted for use as an ICAF document.) The second, a technical book prepared by Dr. H. J. Grover of Battelle Memorial Institute, is an engineering review of fatigue and contains an extensive bibliography. The book is being reviewed and should be available later this year.

Reference 88 covers the problems concerning attainment of reliability in airframe structures and delineates methods whereby this goal may be achieved.

B. Environments Research

A fleet-wide statistical survey of aircraft structural fatigue based on flight VGH recorder load history data from operational aircraft is being conducted by the Naval Air Engineering Center, Aeronautical Structures Laboratory. Approximately 3000 flight hours of oscillograph maneuver history from jet attack and fighter aircraft have been analyzed and reported. Results of these surveys are published in references 89 and 90.

A study of helicopter flight-loads environment based on an 8-channel recorder is also being conducted. Since fatigue-sensitive components of helicopter structures are not always a function of maneuver loads a search is being made to establish which flight parameters are most useful in fatigue surveys. Reference 91 covers a preliminary study in this area.

A second survey is carried out by a counting accelerometer mounted at the center of gravity and an indicator which is read on a monthly basis. All first-line service aircraft will soon have a counting accelerometer as a permanent part of the aircraft equipment. As of January 1, 1965, 1800 aircraft were equipped with counter systems. Approximately 300,000 hours of counting accelerometer data from 20 models of naval aircraft have been reported and analyzed to date (refs. 92 to 94). Statistical analysis of service aircraft load histories reveals a wide difference in the individual histories of such aircraft. Seasonal load-rate changes also have been observed. Changes in weapon system mission assignments of a given model aircraft often result in significantly different load histories. Knowledge of these changes in the flight-loads environment is an important consideration in the assignment and use of service aircraft.

It is expected that the VGH recorder data and counting accelerometer data combined with service experience and structural fatigue test results can be combined to establish the criteria for extending the useful life of an aircraft and to better predict airframe structural reliability.

The laboratory collects approach and landing data of naval aircraft during field and carrier operations in order to obtain statistical data on the parameters that define the environment. The data are obtained through use of a specially designed 70-mm camera system. The major parameters are: sinking speed for each gear, horizontal speed at touchdown, wing lift factor, airplane pitch and roll angles, off-center distance, glide-path angle, touchdown distance from ramp, and flight-path, sideslip, and engagement angles.

These environmental data are used for both the solution of structural landing problems on operational aircraft and the formulation of requirements for the structural design and testing of new aircraft. In addition, these data have been used to evaluate various landing-aid systems and to develop improved carrier pilot techniques.

The photographic records are obtained without interference to field or carrier operations, and no installation of equipment on the observed aircraft is required. The photo measurements do not affect the landing process because pilots are usually unaware of the presence of survey equipment. Results of these surveys are published in references 95 through 99.

Because of the increased hazards of night operations, the laboratory is presently conducting research and development in an attempt to film night landings, and to compile statistical night approach and landing data.

IV. INSTITUTE FOR THE STUDY OF FATIGUE AND RELIABILITY

This Institute was established in the Department of Civil Engineering at Columbia University and is sponsored jointly by the U.S. Navy and the U.S. Air Force. Professor A. M. Freudenthal is its Director. The Institute engages the services of a variety of investigators, both U.S. and foreign, for various periods of time. A summary of their current projects follows.

The principal emphasis of the metal physics studies has been on investigations of the basic mechanism of fatigue of pure metals in torsion at various temperatures as well as a study of the interaction of fatigue in creep and basic mechanisms of cumulative damage. This study confirmed the concepts developed by Professor W. A. Wood over the last few years concerning the initiation and the propagation of fatigue. The new development is the observation of significant fatigue damage along grain boundaries at room temperature as well as the interrelation between fatigue damage and surface rumpling under large strain amplitudes.

A new development is the discovery of the accumulation of second-order strain under repeated cycling and the correlation of such strain accumulation with fatigue. The second-order strain accumulation, as a result of which a specimen cyclically strained in torsion shows considerable elongation is very significant in the interpretation of various types of instability phenomena arising in fatigue as well as in the interpretation of the interaction between fatigue and creep.

Redundant mechanical systems subject to random fatigue loading are investigated theoretically as well as with the aid of a simple model consisting of 10 parallel bars subject to building fatigue. The results, which are being evaluated, are supposed to throw some light on the significance of redundancy in "Fail-Safe" design under conditions of fatigue as a function of the anticipated operational life of the structure. Also, an extensive study has been completed in which the reliability of several aircraft structures for which service records could be reconstructed has been numerically evaluated.

The publications of this Institute are listed as references 100 to 115.

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NASA-Langley, 1965