INSPECTION–1953

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116.2-64

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WELCOME . . . .

The National Advisory Committee for Aeronautics welcomes you to the 1953 Inspection of the Langley Aeronautical Laboratory.

As a nation we are engaged in the extraordinarily difficult task of developing practical military airplanes capable of operating at supersonic speeds. Working as partners in this effort are the military services, the aircraft industry, and the NACA. The aerodynamic, structural and other problems requiring solution to enable this achievement are increasingly acute, and it is becoming apparent that the innovations in design which will be necessary must be supported by adequate research.

In order that the work of the staff and facilities of the NACA laboratories may be most useful, continual cooperation and interchange of ideas with the industry and the military services are essential. We value this opportunity to note trends and new techniques in aeronautical research. We trust your visit will be both profitable and enjoyable.

J C Hunsaker

Chairman
National Advisory Committee for Aeronautics

Tactical Sonic Aircraft Pose Difficult Problems

Supersonic flight by operational military aircraft is not only a necessity; it is an attainable certainty. But as the day draws near when prototype models of tactical airplanes will take to the air, it is becoming increasingly apparent that the task of America's aircraft industry to create designs which will meet the operational and performance requirements of the military services is indeed gigantic.

In addition to the higher flight speeds implicit in future performance goals, our aircraft must afford the necessary range to enable accomplishment of their fighter or bomber missions. They must be maneuverable; their qualities of stability and control must be sufficiently manageable to permit satisfactory operation by their pilots. By their design and construction, they must be capable of avoiding, or withstanding, the perils of flutter, buffeting, and aerodynamic heating which become more serious and complex as speeds increase.

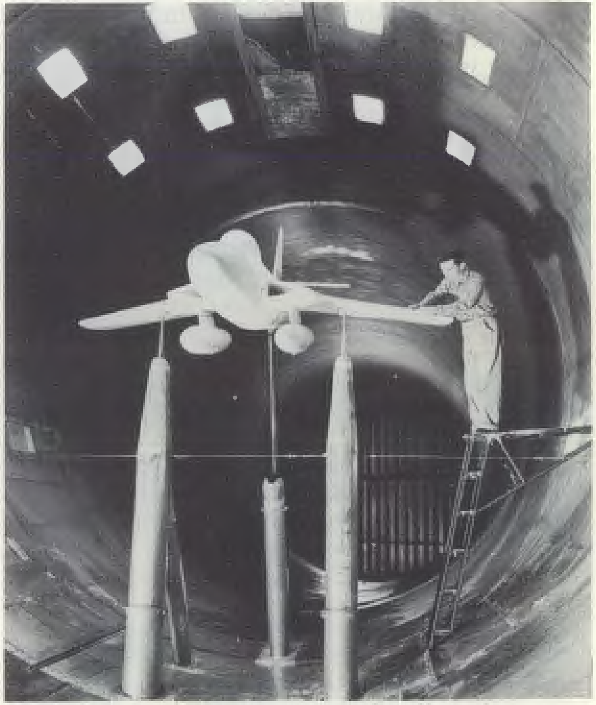
Since the first faster-than-sound flight by the Bell X-1 in 1947, much scientific information has been gathered in the laboratory and with special research airplanes about the aerodynamics of the transonic and supersonic speed ranges, enough in fact to warrant attempts to design tactical aircraft capable of such speeds. This intense research effort has resulted in something else of at least equal importance; it has provided a better understanding of the magnitude and the nature of the problems demanding solutions.

No less, what has been learned about transonic and supersonic aerodynamics has resulted in the sobering realization that success or failure of a new airplane may be dependent upon design differences which can be deceptively subtle.

Problems of flight, although they are magnified as speed increases, do not necessarily grow in orderly manner. In the transonic range where there is a mixture of subsonic and supersonic flows, the problems pile up and interlock. The laws that govern these flows come into conflict and confusion, eluding mathematical treatment.

The lack of mathematical means for predicting aerodynamic behavior in the transonic range can be compensated only by providing adequate experimental data. We have yet to learn the extent to which detailed information about one specific design can be successfully applied to other designs.

One of the greatest difficulties in providing such information has been the development of the research tools with which to provide it. Over a period of years the NACA has been successful in contriving various means for conducting aerodynamic research in the transonic speed range. The technique of using rocket-powered models has been and continues to be most useful. Specially designed research airplanes also have provided valuable information. A recent achievement was the successful development of truly transonic wind tunnels. The Langley Laboratory now has three large transonic wind tunnels that are providing the type of detailed aerodynamic information so vital to the successful design of supersonic aircraft. The fact remains that these tunnels, even if staff and funds were available to permit their full use, lack the capacity to satisfy the demand from the aircraft industry for a seemingly limitless amount of experimental data. And so



Stability research in 19-foot Pressure Tunnel

long as the industry is engaged in the design of new aircraft of improved performance, the need for such information may be expected to continue.

One of the major problems confronting the designers of tomorrow's airplanes is to learn how to keep drag as low as possible, thus to obtain maximum speed with the power plants available. This, of course, is a problem that has been basic since the advent of the airplane, but today the possible gains, or losses, can be multiplied many times.

In the past, the difference between an optimum design and one second best, assuming the same power, might at most be only a few miles an hour. Today, the difference may be measured, literally, in hundreds of miles an hour. The state of the art is being expanded so rapidly that no longer is there a time margin between the acquisition of research data and the application to aircraft design.

The aircraft designer of today is faced with a most difficult challenge, how to make effective use of new aerodynamic knowledge, almost as rapidly as it is provided, without compromising the almost equally difficult structural and weight requirements.

Because of the costs involved in time and money, it is imperative that the "right" design be determined in advance of prototype construction. With the research equipment now available, we are beginning to understand more about the differences in design which can produce such drastic differences in performance. As rapidly as such information is acquired, it is made available to the industry.

To obtain the high speed capabilities desired, airplanes designed for operation in and beyond the transonic range generally utilize sweptback wings of low aspect ratio. From the drag standpoint, such an arrangement may be necessary, but it is likely to result in serious control problems. One of the most violent of these is called pitch-up, which can result in destructive air loads being imposed on the structure.

Here is a complex problem of great concern which is being studied intensively at all speeds. At high speeds it is particularly vicious, and in the rare atmosphere found at the altitudes where such high-speed airplanes may be operating, it may be necessary even in level flight to maintain an attitude close to that where stalling pitch-up occurs.

Another major problem which has been greatly aggravated by higher operating speeds and the designs by which these speeds are obtained, is flutter. Basically, flutter is vibration of some part of the airplane, excited by the imposition of air loads. In World War II and before, flutter often involved a coupled bending torsion action of the wing. This type of flutter could be effectively restrained or avoided at the relatively low speeds of the day. It is still with us, but in addition, numerous other types of flutter are causing great concern.

Today, when flutter is mentioned, it is necessary to specify what type. It may be bending-torsion, bending-pitching, stall, one-degree-of-freedom-control, skin or panel, or chordwise. All types of flutter may become rapidly destructive. In the past it often was possible to design an airplane so its flutter speed - the lowest speed at which flutter occurs - was well beyond its top operational speed. With the high operational

Instrumenting dynamic model for flutter study

speeds now contemplated for the types now being designed, there may be little if any margin between the predicted flutter speed and the expected operational speed.

Aircraft designed for transonic or supersonic operation usually have wings so thin and fuselages so small that it is necessary to modify them for their tactical missions by addition of "external stores," such as rocket pods or fuel tip tanks. Recent experience has been that nearly every airplane acquires external stores sooner or later, some of them so large as to constitute effectively a major modification of the airplane's characteristics, particularly respecting flutter. When the external store is a fuel tank, its flutter-inciting potential may vary widely depending upon whether it is fully filled, partially full, or empty.

One aeronautical problem where the severity is related directly to the speed involved is the effect of aerodynamic heating upon the structure. Already it is a problem of real severity respecting missiles; hardly less so, it is a matter of concern to the designers of tomorrow's airplanes. If the missiles or airplanes were to fly indefinitely at steady speeds where aerodynamic heating became serious, the problem would be difficult enough requiring measures necessary to take care of expansion and weakening of the structural materials.

The problems actually encountered, however, are much more complex because the missile or airplane may be expected to accelerate and decelerate as well as maintain steady speeds. As a result, the affected structures much of the time will be becoming hotter or cooler with speed change, and a multitude of problems develop due to inequalities of thermal expansion of the various elements of the structure.

Problems such as those mentioned briefly above are not ones which can be studied in leisurely fashion, with resulting answers stored against the day when they will be needed. Instead, because the performance characteristics of currently programed aircraft and missiles may be dangerously compromised if solutions are not obtained quickly, research is channeled narrowly to insure the maximum gain in terms of immediately useful information. Under such "hand to mouth" conditions it is extremely difficult to provide the broad basis of knowledge for a sound technology.

New Tools for Research

One of the essentials for effective research attacks on the many complex problems of high-speed flight is the development of useful tools with which to conduct these investigations. In the transonic range, where there is an interplay of subsonic and transonic flows, the urgent need for great quantities of experimental information justified the very large effort resulting in development of wind tunnels where these aerodynamic problems could be accurately observed. These transonic tunnels supplement rather than replace such other research equipment as rocket-propelled models which telemeter required information to ground stations, and full-scale research airplanes.

Similarly, in order to study problems of flight at supersonic speeds, the NACA has had to develop varied and complicated research equipment. These include continuous-operation type tunnels, with test sections ranging in size up to 8 by 6 feet and with speeds extending to Mach numbers of 2 or more; free-flight rocket-powered models capable of speeds up to Mach numbers of 4, and various intermittent wind tunnels and air-jets which extend the Mach number range to 9. Special ballistic techniques have been used to study problems at Mach numbers as high as 20, equivalent to more than 15,000 miles an hour at sea level.

Two research facilities at the Langley Laboratory which went into initial operation in 1953 are the 8-foot transonic pressure tunnel, and the gas dynamics laboratory. During the design and construction of each, problems as difficult as those associated with the high-speed goals themselves, had to be overcome.

The new transonic facility is the third large wind tunnel at Langley used in the study of problems in this speed range. Compared to the other 8-foot tunnel at Langley, which can operate only at atmospheric pressure and in which only the speed can be varied, the new tunnel with its completely closed circuit is much more flexible in operation. Not only can speed be varied while the tunnel is operating, but also pressure and temperature. Here, investigations can be conducted under controlled tunnel air conditions to study independently the effects of compressibility and scale effect through the transonic speed range.

Such operation is made possible by auxiliary equipment which pumps, cools, and dries the tunnel air. A compressor with 10,000 cu ft/min capacity is used to vary tunnel pressure from 1/4 atmosphere to 2 atmospheres. Air drying equipment, used in conjunction with an 80 ice-ton refrigeration system, assures that air in the tunnel itself will be properly conditioned. Power for the tunnel is supplied by a 25,000-hp induction motor. New types of control systems make possible regulating tunnel speed to within 1/4 of 1 percent, and temperature to within 2°.

The gas dynamics laboratory is used in studying fundamental aspects of the problems of flight at very high speeds and altitudes. Because much of the work here is exploratory in nature, it was decided that test runs measured in minutes or even seconds would suffice. This permitted use of intermittent blowdown tunnels and air-jets which could be operated from a stored-air supply, rather than continuous-operation tunnels requiring as much as 200,000 hp to attain the desired Mach numbers, which would be enormously expensive.

Air at high pressures and high temperatures is needed for the work conducted. The high pressures are necessary to achieve large-scale effects, and the high temperatures to avoid air liquefaction at the high Mach numbers, and also so that heat-transfer problems can be investigated.

Clean, dry air is stored under compression in a tank farm consisting of a large number of specially-built steel bottles manifolded together. The capacity is 20,000 cubic feet, and at the 5,000 psi storage pressure, the air weighs about 250 tons, and has a density of about 1/3 that of water. Heating devices can bring the air to a maximum temperature of 1040° F before use.

The facilities of the gas dynamics laboratory have been so designed as to provide the necessary versatility to permit study of many fundamental problems related to very high-speed flight. These include flow around wings and bodies, stability of various body shapes, air inlets for supersonic aircraft, characteristics of air at very high temperatures, and effects of unsteady air flows on aerodynamic shapes. Altitudes up to 200,000 feet may be simulated, and speeds up to $M = 9$ attained.

Tank farm at Gas Dynamics Laboratory stores 20,000 cubic feet of air under 5,000 psi

Rocket Models to Mach = 4 . . . .

One of the first of the research techniques developed to enable exploration of aerodynamic problems in the transonic speed range utilized rocket-powered models equipped with telemetering devices which sent the required information back to ground stations. Even with the present availability of large transonic wind tunnels, this technique continues to be used intensively in the procurement of data in the transonic area.

At the same time, its use has been extended to investigation of problems at supersonic speeds, up to Mach numbers of 4, thus to provide large amounts of data urgently needed in the design of supersonic aircraft and missiles.

Work by the Pilotless Aircraft Research Division, using free-flight models, is grouped under the headings of performance, stability and control, and flutter and buffeting. Under performance are included lift and drag investigations, boundary-layer studies, and inlet performance. In order to fly at supersonic speeds, ways must be found to decrease drag and increase engine power. Increasing power in turn requires more efficient air inlets. The boundary-layer studies are especially important with respect to aerodynamic heating, because this problem is already serious with respect to missiles and only slightly less so respecting the airplanes of tomorrow.

Under stability and control are listed such problems as control effectiveness, control hinge moments, aerodynamic damping in pitch, roll, and yaw, flying qualities, automatic stabilization, and dynamic behavior. The design requirements which permit flight at supersonic speeds and high altitudes have resulted in seriously inadequate dynamic stability, so serious in many cases that pilots are unable to control the airplane, in other cases, serious enough so that the airplane is neither a good gun or bombing platform. Finding ways to solve these problems is imperative, and by use of rocket-powered models it is possible to study the behavior of new designs without endangering the life of a pilot or spending the large sums required to finance a prototype based on inadequate information.

The very thin, low aspect ratio wings which will be required for tomorrow's extremely high-speed fighters are showing increased susceptability to flutter. Similarly the thin, swept wings of bombers, with higher aspect ratio, and their externally mounted engines and other "stores," develop flutter conditions extremely difficult to predict by theory, and rocket-powered models are being used intensively to supply a basis for extending present methods of predicting flutter dangers, as well as to confirm the flutter safety of new airplane designs.

Again, buffeting is an old problem which has assumed new seriousness. At sonic speeds, buffeting can no longer be always cured by addition of fillets and fairings. Indeed, buffeting now can occur on the wing itself as a result of shock-induced separated flow. The pilot, as a result, gets a ride similar to that if he drove his car at high speeds along a railroad track, bumping over the cross ties. As speeds are increased, buffeting may be encountered at all airplane lift coefficients, not just at the stall. Thin wings have helped in reducing the severity of this buffeting problem, but it has not been eliminated. The rocket-powered model technique has been used to obtain considerable basic information for the evaluation and prediction of buffeting characteristics.

Preparing rocket model of F4D for launching

Research Aircraft Mission Expanded

The specially designed research airplanes are being assigned an expanding mission. In addition to continuing their fundamental role of exploring in flight problems in the transonic and supersonic speed ranges, they are now being used for flight testing of design features suggested by research to solve or soften some of the troubles which aircraft experience at these speeds.

Since the historic first supersonic flight by the Bell X-1, the research airplanes have had a vital function in the coordinated research effort to attain the basic knowledge leading to practical faster-than-sound speed. Because of the complexity of some of the anticipated high-speed problems, it was realized they could be properly assessed only by actual flight. For example, when the Douglas D-558-II became longitudinally unstable at high speeds (it was flown 1238 mph), it was experiencing a difficulty which had been anticipated from theoretical and wind-tunnel studies. Such instability, which would impair seriously the effectiveness of a combat airplane, could be thoroughly evaluated in flight by the D-558-II because of its capability of attaining the speeds at which it was expected to develop.

Wind-tunnel research has indicated that several devices might be helpful in alleviating stability troubles, and these are being flight-proven. One such modification is the "fence." When installed on the wings of the D-558-II, fences serve to retard the tendency of air moving close to the wing surface to flow outward, and thus improve stability. The tests made with wing fences installed have shed considerable light on how similar investigations, in the wind tunnels, should be evaluated in the light of flight experience.

Another such design modification, based on a different aerodynamic principle, is the leading-edge chord extension of the wings. These extensions also have been flight tested on the D-558-II, and their effectiveness in improving stability is currently being analyzed and compared with predictions based on wind-tunnel data.

The third device is perhaps the oldest and best known, because it has been used in improving the stability of swept wing airplanes at low speeds.

Leading-edge slats are installed on the wings, permitting the air to flow freely in the slot between the wing and the slat. This modification now is being investigated on the D-558-II in the transonic and supersonic ranges to determine whether it will be similarly effective at the higher speeds.

The capabilities of such devices with respect to other wing shapes also are under study, and the Bell X-5, equipped with wings whose sweep can be altered from 20° to 60° in flight, is being used in this work. The sweep range of the X-5 brackets the wing angles currently of interest for transonic and supersonic flight.

Over-all, the research airplane program is a three-way partnership of the aircraft industry, the military services, and the NACA. Two new airplanes have recently been added to the group of high-speed airplanes. One is the Douglas X-3, turbojet-powered airplane designed for supersonic flight investigations. The other is a Boeing B-47 Stratojet bomber, which has been specially instrumented for flight research of the interrelated aerodynamic and structural problems which are associated with the high-speed flight of large aircraft.

The Quality of Research . . . .

The quality of aeronautical research is dependent upon the integrity of the measurements, the fact finding, upon which final conclusions are based. Adequate instrumentation of the highest quality, and models which reproduce most faithfully the airplane or missile under study, are therefore essential, and the instrument research laboratories and model shops of the NACA have been made as efficient as possible with this in mind.

It is an exception, rather than the rule, that the instruments with which to record needed data are commercially available. Consequently, the work of the instrument specialist often begins with a study of how to devise the record-taking equipment which will enable learning new facts about an aerodynamic, thermodynamic or structural problem. Then may come difficult development and design effort before the new instrument can be constructed and installed in the research facility. Finally, and of paramount importance, there remains the responsibility for insuring that the measurements gathered by the new instrument

Checking instrumentation in rocket model

which of course must be in usable form, are correct.

Such techniques as mechanical, electronic, optical, pneumatic, and hydraulic devices from the NACA's instrument research laboratories now are being used to measure more than a hundred variables including pressure, force, temperature, velocity, angular accelerations, and altitude. At the Langley Laboratory alone, on any workday, instruments will be at work measuring pressures at some 10,000 "stations" on aircraft being flown or models being studied in the wind tunnels.

Formerly, many of the records were taken under static or uniform conditions. Now, research investigations are concentrating upon phenomena involving change, and the instrumentation required must be capable of recording the desired information. Further, the information obtained in such situations often is not in its raw form, and must be passed through filters and analyzers to become readily useful.

Demands upon the modelmakers frequently go beyond the stipulation that the product be an accurate scale copy of the object under study. Only by devising new fabricating procedures is it possible for them to keep pace with the demand from the research scientists for more and better models. Man-hour saving methods are constantly being sought at the same time that the models are required to meet more stringent requirements respecting complexity, precision, strength, and, in many cases, relatively light weight.

In some instances, it is necessary that the model be constructed to scale dynamically as well as dimensionally. Such models may be used to investigate spin characteristics. Still other models must be scaled down - structural representations of airplane studies for study of ditching. Missile and airplane models, to be rocket-fired, must be light and have enough room internally for the instrumentation, telemetering equipment, and controls.

The modelmakers work with many materials, including magnesium, aluminum alloy, steel, titanium, plastics and wood. Both conventional and special shop practices are used in the construction of the research models, and tolerances of vertical, longitudinal and transverse dimensions may be kept to within two ten-thousandths of an inch.

Fitting plastic models with varying wings

Heat Problems Become Urgent

With missiles being flown at Mach numbers of 4 or higher, and with airplane speeds constantly being projected farther into the supersonic range, the problems of aerodynamic heating have become among the most important and urgent in aerodynamics. At sustained flight at a Mach number of 4 at 40,000 feet, the skin temperatures of a missile can rise to 900° F.

The problem can be divided into two parts: (1) the determination of the dependence of the heat inflow or rate of heating on the factors that govern it, and (2) the effect heating has on the structure, particularly when subjected to high aerodynamic forces. Progress has been made on both phases of this problem.

In studying the rates and manner in which aerodynamic heat flows into the skin of missiles and aircraft structures at various speeds, it has been necessary to devise new research techniques which would enable precise reproduction, on the ground, of the manner in which this takes place at speeds up to a Mach number of 4, and other investigations are being conducted on aerodynamic heating up to Mach numbers of 10, or 6600 mph at altitude. If such speeds were maintained, the temperature rise would approach 7000° F.

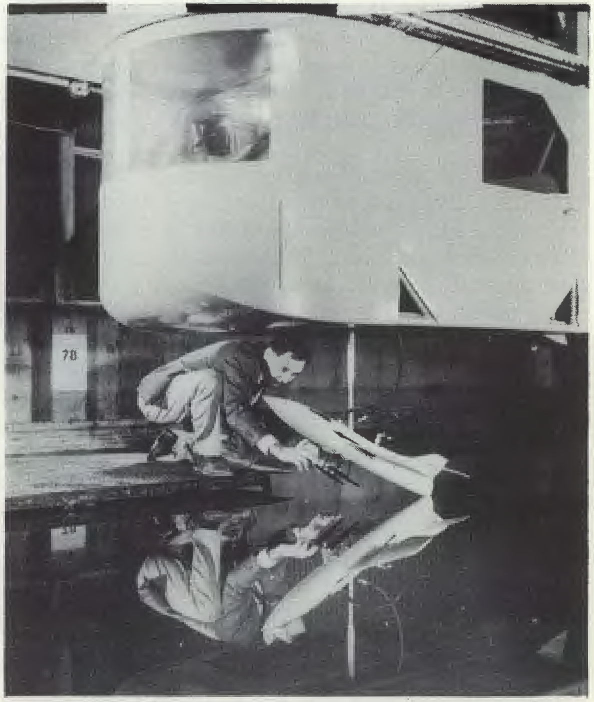
Perhaps the most obvious effect of aerodynamic heating is the reduction in basic strength of the materials used in aircraft and missile construction. This in itself is serious enough, but other problems arise which appear even more complex. One such problem stems from the fact that at high temperatures, materials tend to creep; that is, under the action of an unchanging load, the material stretches. In an airplane structure, for example, its useful lifetime might be limited by excessive distortion of the wings after continued flight at high temperatures. Depending on the temperature and load, the creep lifetime of a structure can vary between thousands of hours and a few seconds.

An entirely different structural effect of aerodynamic heating occurs when an aircraft or missile structure is subjected to very rapid heating and portions of the structure undergo rapid changes in temperature. What happens, of course, is that the temperature distributions in the structure become uneven, causing thermal stresses and buckling, which can change its effective stiffness and tendency to flutter. Whether an airplane will flutter or not depends, in addition to aerodynamic considerations, upon its vibration characteristics which in turn depend on the stiffness properties of the structure. With stiffness lowered by aerodynamic heating, an airplane which otherwise was flutter free might suddenly develop flutter and be destroyed.

Hydro-skis and Ditching

Research by the NACA leading to successful development of hydro-skis, which enable high-speed water-based aircraft also to land and take off from snow or sod, was begun in 1947. More recently, this research effort has produced basic information to permit the designer to select the type of hydro-ski best suited to his specific needs.

Earlier flat-plate hydro-skis were found to have good lift characteristics and acceptable resistance characteristics, but they were not easily retractable into the curved fuselage of an airplane. Curved ones, however, were found to



Hydro-ski model in Towing Tank

be less efficient than flat plates. Since then, information has been obtained about hydro-ski shapes which are not only suitable for retraction into curved fuselages, but have as good lift and resistance characteristics as the flat-plate type.

Among other research effort by the Hydrodynamics Division of the Langley Laboratory is the continuing investigation of ditching characteristics of new aircraft. If the new designs studied are unusual, investigations of ditching are made using models which are scaled to strength as well as dimension. If the new design is similar to models for which tests have already been made, it is possible to predict its ditching characteristics analytically as was the case with the Boeing B-52.

Considerable work has been done on swept-wing designs, and it has been determined that wing sweep has little effect on ditching behavior other than aerodynamic influence on handling and landing characteristics. In instances where engine nacelles are hung below the wing, the possibility exists they could "dig in" on ditching with harmful effect if they were so strongly attached to the wings as to withstand the heavy loads experienced during a water landing.

Strength, Fatigue Problems Grow

Sharp increases in aircraft performance, resulting from advances in aerodynamic design and more powerful engines, have imposed more and more severe requirements upon the aircraft structure. Higher speeds, higher wing loadings, thinner wings, and sweptback designs all have made more difficult the task of providing a structure which is adequate without excessive weight penalties.

The problems faced include developing the new types of structure which will meet the changed requirements, and also learning how to predict the useful life of a complicated structure subject to the repeated application of loads which ultimately result in failure - fatigue failure. At the same time, research is being pressed to prolong the fatigue life of structures.

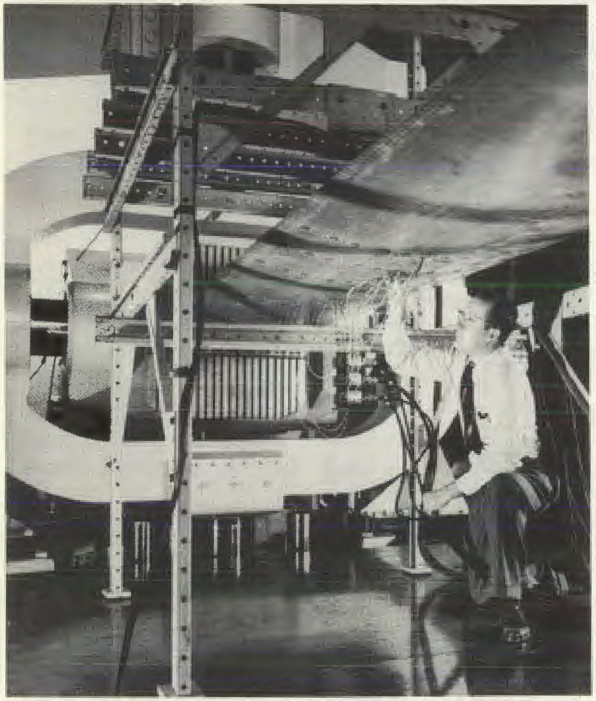
For thin wings, respecting structural efficiency, it has been found that stressed skin construction with multiple spars or webs becomes more suitable than the older, two-spar, skin-stringer type of construction. The NACA's research on the strength of multiweb wings has included testing more than a hundred multiweb beams, covering the range of proportions of interest for thin wing design, in the combined load testing machine. This equipment, believed to be the only one of its kind, can apply and weigh bending and twisting moments up to 3,000,000 inch-pounds, and forces up to 250,000 pounds. In this manner, the loading combinations experienced in various flight conditions can be readily simulated.

In addition to the design data resulting from the studies of multiweb construction, experience gained in the testing and analysis of the specimens has pointed the way toward improvements in detail design which can result in substantial increases in strength without increasing the weight. The ultimate strength of the beams, for example, was found to vary appreciably with small changes in the details of attachment of the skins to the webs.

The NACA also is studying the use of integrally stiffened construction in conjunction with multiweb, post-stiffened, or delta-wing designs. Also, for use in delta-wing designs, sandwich construction is being investigated. The work described here has been concerned with conventional aluminum-alloy construction. Structural research also is being focused on problems arising from the use of materials capable of maintaining strength at the higher temperatures resulting from aerodynamic heating.

Long-range fatigue research by the NACA may be classed under four headings: (1) comparison of materials from the standpoint of fatigue properties, (2) investigation of the effects of detail shapes on the fatigue properties of the structures, (3) analysis of the cumulative effects of load cycle variation and the amplitude of load which is typical of the actual loading of aircraft structures, and (4) study of the fundamental nature of fatigue.

Because adequate information about the first of these problems generally can be obtained from other sources, the NACA is limiting its work in this area to the extent needed to form a good background for other phases of the fatigue problem. More extensive research is being conducted on the effects of detail shapes, and considerable information has been collected to show how the



Thin wing tested under combined loads

strength of a structural member may be weakened by seemingly minor discontinuities like machining grooves, rivet holes, and small changes in cross-sectional dimension.

Full-scale fatigue tests are being made on wings of transport-type aircraft. By use of special equipment, the wings are made to vibrate at their natural frequency by motor-driven cranks attached to the wing-tips through a connecting rod and spring system. Instrumentation provides data about the start of cracks, as well as the measurement of strains at various locations on the wings. Attention is also being focused on the relatively unexplored problems of low-cycle, high-stress fatigue. The basic nature of the mechanism of fatigue is being studied using X-ray diffraction equipment, electron microscope, and standard metallurgical apparatus.

Helicopter Research Intensified

With the helicopter continuing to be more useful for military and civil purposes, increased emphasis has been given to research which will provide answers to many detail problems. Current helicopter research by the NACA includes studies of aerodynamic efficiency, flying and handling qualities, loads and stresses, and vibration and flutter.

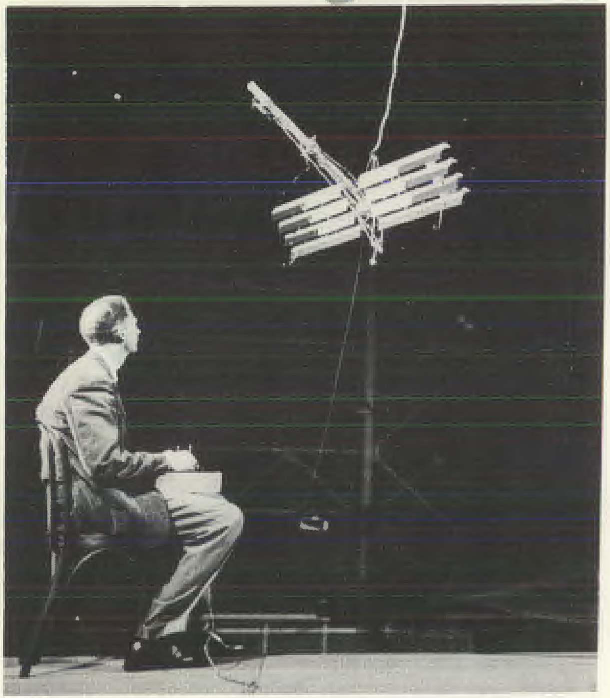
The work is being carried forward at several of the Langley facilities. Typical of these projects are the propulsion tests conducted on the helicopter tower, configuration studies in wind tunnels, flying qualities evaluations by the Flight Research Division, and dynamic model testing by the vibration and flutter group. Because of the need for a light, efficient structure which will have a long service life, it is becoming increasingly important to know the magnitude and frequency of the loads to which the helicopter will be subjected, from which the design stresses and the fatigue life of the machine can be determined.

Another aspect of the problem of developing lightweight, long-life helicopters is flutter. In the past, mass balancing has been used to bring the center of gravity of blades sufficiently forward to avoid flutter problems, and also to eliminate twisting moments resulting in undesirable stick forces. With the advent of larger helicopters, irreversible controls have been adopted, eliminating the excessive stick force problem, and consequently the designer wishes to eliminate the weight of mass balancing.

"Vertical Riser" Problems Noted

Recent development of turboprop and turbojet engines which have a very high power to weight ratio has quickened interest in the possibilities of designing aircraft which will possess both the vertical rising capabilities of the helicopter and the high speeds of conventional airplanes. One of the most serious problems inherent in the concept of a vertically rising airplane is how to provide adequate stability and control during hovering and transition flight.

To produce direct lift for hovering flight, it is necessary to accelerate air straight downward. This can be accomplished either by rotating the propellers through 90^{o} as the airplane goes from normal forward flight to hovering, or it can be accomplished by deflecting the wings and flaps, by a sort of Venetian-blind arrangement, so that the slipstream is turned straight downward while the propellers remain in their normal attitude.



Stability and control of "vertical riser" studied

It is this latter well-known concept for obtaining direct lift which the Laboratory has been using to simplify the study of stability and control problems.

By use of the Venetian-blind vertical-rising model, both pitch, roll, and yaw control problems can be studied effectively. Yaw control is obtained by moving the flaps so the slipstream is deflected slightly backward from the vertical on one side and forward on the other side. Roll control is obtained by varying the pitch of the outward propellers differentially to increase the velocity of the downward-deflected slipstream on one side, and reduce it on the other. A rate-sensitive artificial stabilizing device, to provide additional damping in pitch, has been installed in the model to overcome unstable pitching oscillation characteristics.

Landing Gear "Too Heavy"

With the size and speed of airplanes increasing steadily, the weight of the landing gear has similarly been increased to withstand the heavier loads experienced. Although the landing gear performs no useful function in flight, it can constitute as much as 24 percent of the structural weight of the entire airplane.

In the past, landing gear design procedures have been based largely on cut-and-try experience, and the economic pressure toward weight reduction has made necessary studying the problem anew, to establish up-to-date design requirements and procedures that will insure safety with the least possible cost in weight. Many research techniques are being used in attacking the problem.

A first step in developing more precise landing-loads requirements is to obtain statistical information about the severity and frequency of the load-producing conditions likely to be encountered by an airplane in landing. Measurements are now being made of landings of transport airplanes in routine daytime operations. These include data covering sinking speeds, forward speed, angle of bank, and rate of bank. From this information it is expected the conditions resulting in loads in the landing gear and airplane structure can be better understood.

A second phase of the studies is directed at determining the manner in which the forces in the landing gear and airplane develop in arresting the motion of the airplane at impact. This is being studied both in the Laboratory, where techniques have been developed to permit simulating such conditions, and also by use of specially instrumented aircraft.

In the Laboratory, both analytical and experimental studies are being made of the complicated physical process which occurs at the moment of initial landing impact. This process, which lasts for only a fraction of a second, involves the interaction of friction, tire springing, oleo shock strut springing and damping, and landing gear support structural elasticity. The build-up of load is very rapid, being reached in about 1/20 second, but it is so great as to raise the question how either gear or the tires can withstand the tortures imposed.

Already an understanding is being obtained of the dependence of the coefficient of friction on other factors which must be considered. From this type of data, it is becoming possible to explain, on the basis of the varying conditions under which the experiments were made, such as tire and surface heating, relative skidding velocity, etc., the wide variation in experimentally gathered measurements of the friction coefficient.

Because it is not feasible to simulate exactly in the Laboratory all the conditions existing during a landing, the problems are being studied during actual landings. A B-29 Superfortress has been equipped with instrumentation to provide the following information: vertical, drag, and side forces in the axles; ground reaction forces; determination of dynamic effects; sinking speed; forward speed; drift angle; bank and pitch angles; angular velocities and angular accelerations; and tire and shock-strut action.

Crash-fire Reduction Possible

In its long range studies of the crash-fire problem, the Lewis Laboratory has obtained a much clearer understanding of the mechanism of an aircraft crash fire - why and how a fire starts and spreads - thus enabling a better appreciation of important factors in the problem heretofore not fully recognized. At the same time, the actions of fire-extinguishing agents have been studied more fully.

By the use of an experimental inerting system, which did not take account of the weight and bulk problems which would require solution in developing a similar equipment for commercial or military aircraft use, the Lewis Laboratory has succeeded in blanketing the more common ignition sources of crash fires. The system includes a spray rig which cools the hot exhaust collector ring below the temperature where fires may start, and also suitable inerting materials.

At the same time, previously hidden ignition sources have been disclosed. One of these is the high charge of static electricity which may build up as the crashed airplane slides along the ground; another is the hot friction sparks which may be generated as the metal fuselage skids along a concrete runway.

With the research program now expanded to include studies of aircraft powered by turbojet engines, results of the work already accomplished point to the possible realization of significant reductions in the crash-fire hazard.

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