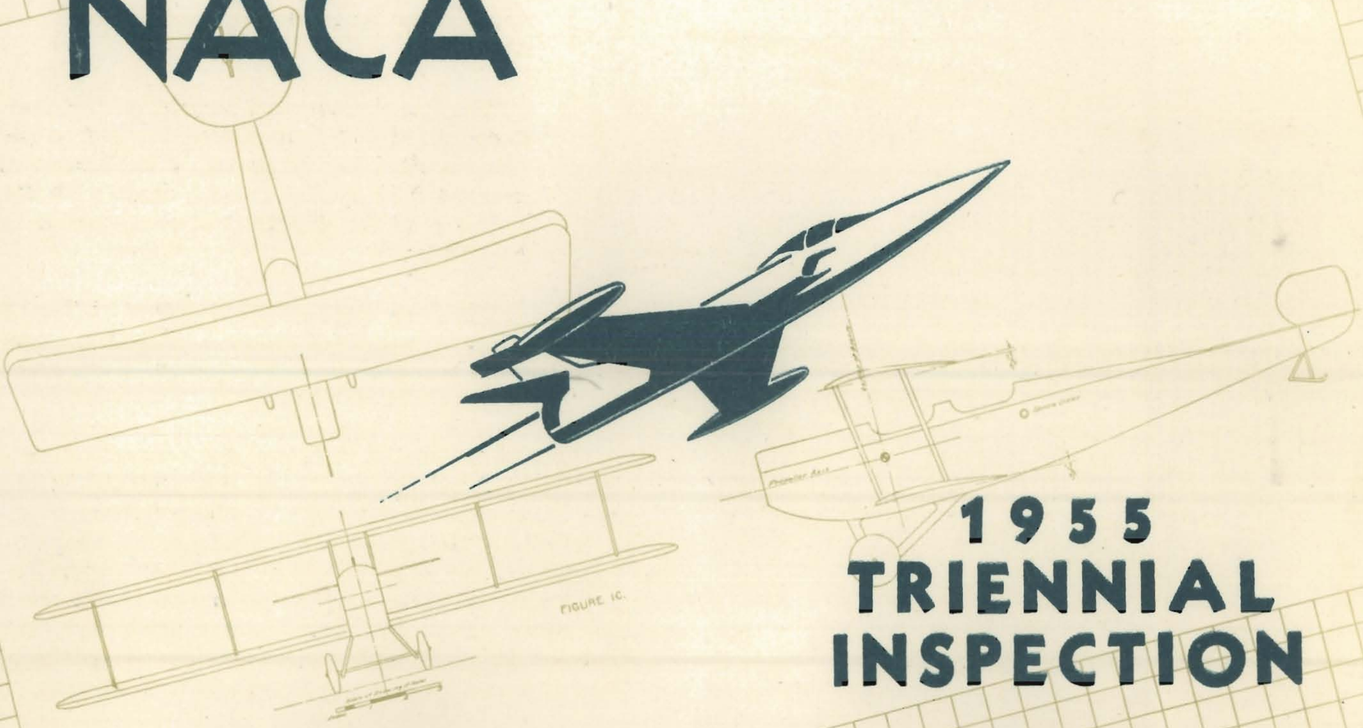
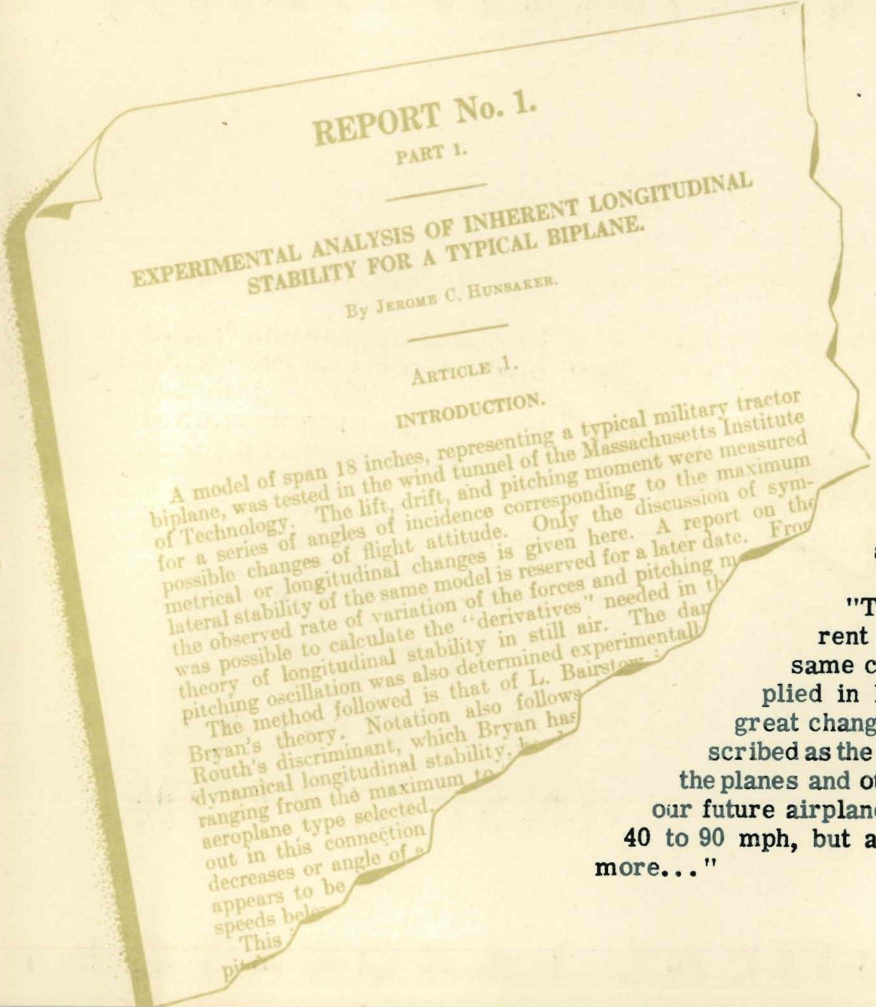
1915 ▪ ▪ ▪ 40th ANNIVERSARY ▪ ▪ ▪ 1955

NACA



1955
TRIENNIAL INSPECTION

AMES AERONAUTICAL LABORATORY



REPORT No. 1.

PART 1.

EXPERIMENTAL ANALYSIS OF INHERENT LONGITUDINAL STABILITY FOR A TYPICAL BIPLANE.

By JEROME C. HUNSAKER.

ARTICLE 1.

INTRODUCTION.

A model of span 18 inches, representing a typical military tractor
biplane, was tested in the wind tunnel of the Massachusetts Institute
of Technology. The lift, drift, and pitching moment were measured
for a series of angles of incidence corresponding to the maximum
possible changes of flight attitude. Only the discussion of sym-
metrical or longitudinal changes is given here. A report on the
lateral stability of the same model is reserved for a later date. Fro
the observed rate of variation of the forces and pitching m
was possible to calculate the "derivatives" needed in th
theory of longitudinal stability in still air. The da
pitching oscillation was also determined experimentall
The method followed is that of L. Bairst
Bryan's theory. Notation also follows
Routh's discriminant, which Bryan has
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THE COVER

"Many of the major problems of the aircraft of the future are old problems in new dress.

"The first technical report of the National Advisory Committee for Aeronautics, written in 1915 by Dr. J. C. Hunsaker, present NACA Chairman, dealt with the problem of the stability of an airplane in free flight.

"The then current high-speed military airplane was the Curtiss J N2 with a maximum speed of about 85 mph and a minimum speed of about 43 mph.

"The problems of stability and control of current and future aircraft are describable in the same conceptual framework... which Hunsaker applied in NACA Report No. 1. There are, however, great changes in the superstructure, in what Bryan described as the approximations to the air pressures to which the planes and other parts of the machine are subjected. For our future airplanes we must assure stability not at speeds of 40 to 90 mph, but at speeds extending from 100 to 1000 mph or more..."

H. L. Dryden, January 7, 1955

WELCOME...

The National Advisory Committee for Aeronautics welcomes you to its 1955 Triennial Inspection of the Ames Aeronautical Laboratory.

As a nation, we are in a race to acquire the scientific knowledge necessary to create airplanes and missiles with the capabilities that permit military use at extreme altitudes across intercontinental distances, and with supersonic swiftness to penetrate enemy defenses. This is a race that starts in the research laboratories. It may be decided there. The technical problems involved are complex, interrelated, and difficult. How rapidly we solve them will be determined mainly by the effort applied.

In order that the researches of the NACA laboratories may be most fruitful, continual cooperation and interchange of ideas with the industry and with the military services are essential. We value this opportunity to discuss trends and new techniques in aeronautical research. We enjoy greeting again old friends and meeting with those who visit us for the first time. We hope your stay at the Ames Laboratory will be both profitable and enjoyable.

J C Hunsaker

Chairman
National Advisory Committee for Aeronautics

Achieving the potentials of flight

In many ways, the situation today in aeronautics parallels that of 40 years ago when the NACA was established "to supervise and direct the scientific study of the problems of flight, with a view to their practical solution..."

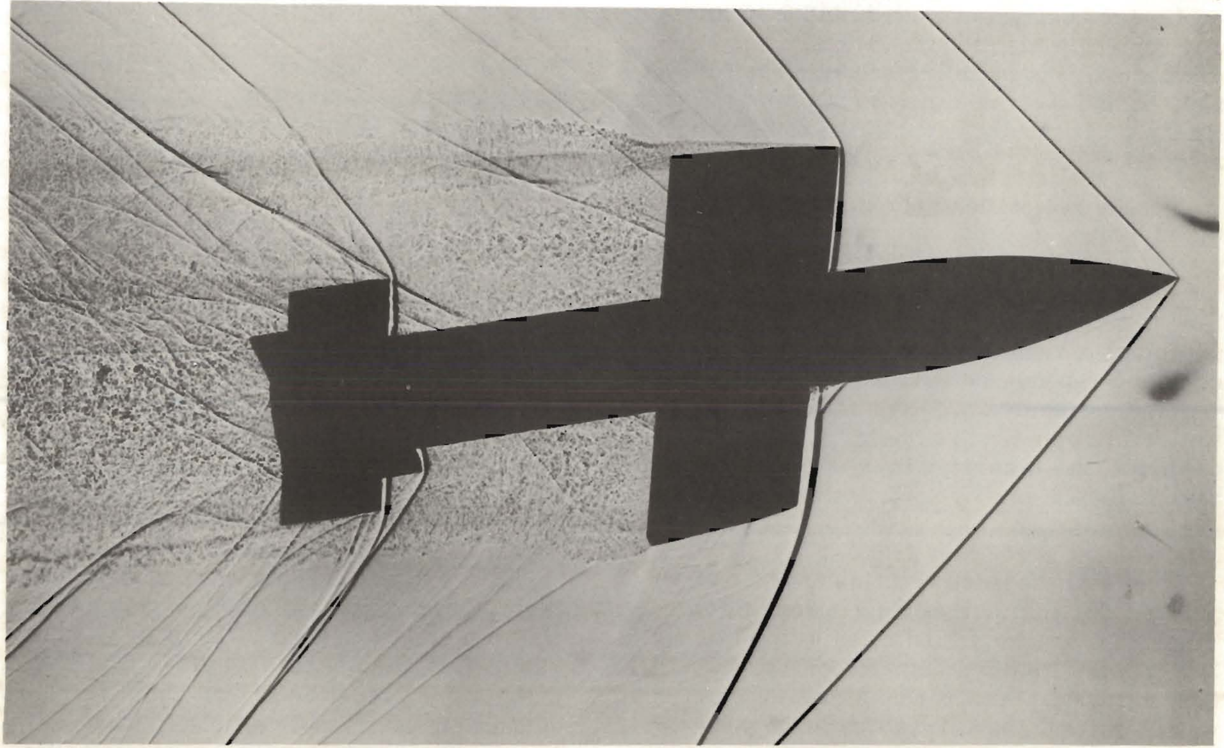
In 1915 much remained to be done before the airplane could demonstrate its great potential as a vehicle of commerce and a weapon of war. Twelve years had passed since Kitty Hawk, but the airplane was still a fledgling beset by many troubles.

The NACA in its first report observed that "although an aeroplane is designed so that statically it is stable to a satisfactory degree, it does not necessarily follow that the machine is dynamically stable... such instability has probably been the cause of a large number of accidents." In the same report, the NACA called for "development of high powered aeronautic motors of the lightest possible construction consistent with reliable operation and the maximum economy of fuel and oil consumption."

In 1955 much remains to be done before the airplane can demonstrate its great potential as a supersonic vehicle of commerce and a supersonic weapon of war. Eight years have passed since the first flight at a speed faster than that of sound, but the supersonic airplane is still beset by many troubles.

Stability and control remain problems; the extension of speed from less than 100 mph to 1000 mph and more has served only to increase their complexity and severity. Respecting engines, "lightest possible construction with reliable operation and the maximum economy of fuel and oil consumption" continues to be an essential element in the unending drive for more power.

Forty years ago, a compelling reason for creation of the NACA was the fact that in the United States, the birthplace of the airplane, aeronautical progress had been so tentative and so slow that other nations, willing to make the necessary effort, had long since taken the lead. In the years that followed, qualitative leadership in aeronautics was returned to the United States on a permanent basis. This



Shock waves and vortexes mark free flight of stability research model at Mach number 1.6.

continuing achievement has been the result of a partnership in which the military services, the aircraft manufacturers, and the NACA have pooled their energies to improve steadily the performance capabilities of American aircraft.

Today, the nuclear bomb carried now by the airplane, and ultimately by its unmanned counterpart, the guided missile, has become the most powerful military weapon of all time. How to intercept the delivery systems which an enemy might employ if he elected to use nuclear weapons against the United States has become a massive problem demanding solution with compelling urgency. A corollary problem, no less urgent, is for the United States to learn how to deliver retaliatory nuclear weapons.

More than 10 years ago, in 1944, Germany put the V-2 into use against Great Britain. The range of this guided missile was hardly 200 miles. Its maximum velocity was about 3600 mph, and the maximum altitude it reached was 60 miles. The V-2 was far from perfect--its accuracy was poor even though its range was short, and 15-20 percent of the missiles fired exploded during flight, probably because of aerodynamic heating. The grim fact remains that this instrument of destruction flew so high and so fast that the British were unable to make a single interception in the months it was used.

The problems demanding solution if an intercontinental ballistic missile is to be developed are close to those attacked in the design of the V-2. The differences are largely those of degree.

The gap between initial achievement of supersonic performance by a prototype or experimental airplane and day-to-day accomplishment of such performance under the rigors of service operation and maneuver can be very great. In the area of supersonic flight, in addition to problems arising from the demands for faster flight over longer ranges, it has become obvious that more, much more, must be known about the laws of nature to enable more efficient, more satisfactory flight at faster than sound velocities.

Today, as always in the history of aeronautics, the magnitude of the problems faced is surpassed only by the immensity of the future possibilities. Those possibilities can and must be transformed to actualities. This can come about in any nation willing to make the effort in manpower and equipment.

Stability at supersonic speeds

At the supersonic speeds of today's tactical airplanes and missiles, stability and control have a crucial bearing on the ability of an aircraft to accomplish its task. Stability is the quality which causes an aircraft to return to steady flight after it has been disturbed by a gust or some control change. Without this automatic, built-in tendency to seek equilibrium, the difficulties of accurate control are greatly multiplied -- can become insurmountable.

The aircraft designer tries to achieve stability by carefully placing lifting and control surfaces in such a way that any disturbance creates an opposite aerodynamic response, tending to restore the aircraft to balanced

F-102 model tested for dynamic stability.

flight. During its entire history the NACA has sought to arm the designer with all possible information to help him attain the required stability characteristics, and for subsonic airplanes practical solutions have been generally available.

While the principles of stability have been understood for many years, new problems and complexities appear when they are applied to transonic and supersonic aircraft. Mathematical formulas used in stability analysis remain the same but the values to be applied have changed so extensively that the designer must have a large amount of new and detailed information to guide his work.

Interference between wing, body and tail surfaces exists at subsonic speeds but in the supersonic range it appears in new forms and with different emphasis.

Much research is being done on interference caused by vortexes. Every lifting surface produces a vortex, which is simply a swirling column of air extending rearward. Large amounts of energy may be packed into these rotating columns of air. If an airplane's tail moves into the path of a vortex, its ability to produce an aerodynamically stabilizing force may be seriously reduced or even reversed so that the tail aggravates any disturbance.

Modern airplane design employing short stubby wings and lengthened fuselages adds complications because a share of the total

Wing vortexes visualized by vapor screen method.

lift is carried by the fuselage which in turn creates additional vortexes with whose effects the designer must reckon. Progress is being made in providing the designer with information on this type of interference over a wide range of airplane attitudes and speeds.

Shock waves, always present at supersonic speeds, are another source of difficulty. These concentrated pressure disturbances originate at points where there are sudden changes in an aircraft's contours. The shock waves change their position as speed increases, bending closer to the body of the airplane or missile. Jet engines mounted at some outboard point along the wing set up shock waves which can seriously interfere with the vertical tail and with its job of providing directional or "weathercock" stability. In a side slip, the shock waves can strike unevenly on the tail, altering its aerodynamic behavior and causing severe stability changes. Wind tunnel information on shock wave effects is becoming available to guide the designer in minimizing interference from this source.

Dynamic stability problems grow

Dynamic stability is closely linked with static stability, although in the laboratory it is often studied separately to reduce the formidable complications involved. Dynamic stability studies seek to understand the motions an airplane makes as it responds to a disturbance. These motions usually consist of one or more oscillations as the aircraft seeks its steady flight position. The persistence, time and size of oscillations are quite important.

Precise knowledge of dynamic stability is necessary to design satisfactory maneuvering performance into new aircraft types. Without acceptable dynamic characteristics, an airplane may be unsuitable as a gun or bombing platform or unmanageable by the pilot under some flight conditions. Usually the problem must be solved afresh for every new design because considerable changes in dynamic stability arise from every change in airplane geometry.

The lengthened fuselages and thin stubby wings favorable for supersonic speeds frequently

Leading edge extensions mounted for flight testing.

cut down on damping, the tendency to develop forces which quickly wipe out an oscillation when it occurs. Subsonic designs usually have high damping but a new series of difficulties is encountered as designs to achieve supersonic speeds sacrifice damping for performance. Oscillations caused by low damping can take place so quickly and violently that a human pilot cannot control them and special corrective devices such as the yaw damper have been used to cope with the problem.

Recently a new form of dynamic instability, traceable to the spreading of the modern airplane's weight along its lengthened fuselage, has given difficulties. When an airplane of this type rolls, centrifugal forces tend to swing the nose and tail outward and the airplane begins to yaw. If it completes a full roll revolution in less time than a single yaw oscillation, centrifugal forces outweigh the stabilizing influences and a violent yawing and pitching motion uncontrollable by the pilot is liable to occur. This complicated and dangerous reaction may strain the airplane beyond safe structural limits.

This form of instability is called roll-yaw coupling and although ways have been found to alleviate it, intensive research in wind tunnels, in flight and by theoretical study often employing analog computers, is required for a fuller understanding of the problem.

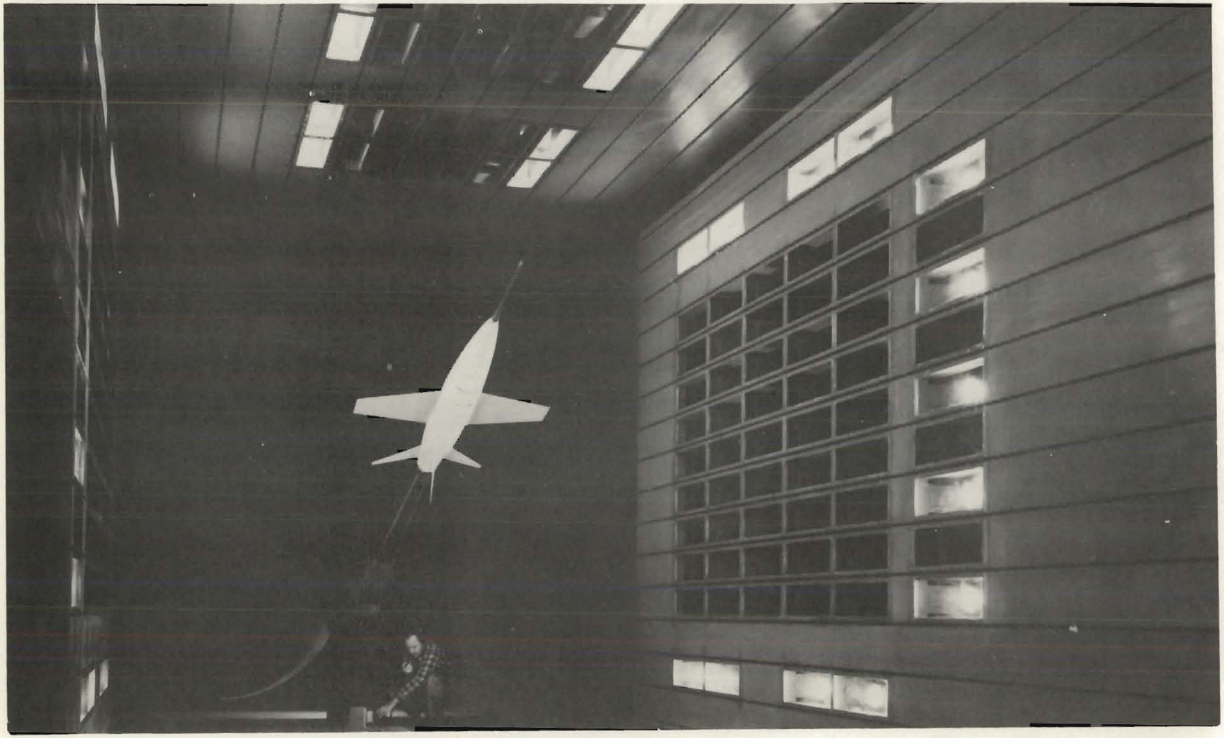
Transonic tunnels get results

The most valuable additions to the tools of aeronautical research in recent years are the truly transonic wind tunnels. In them precise and efficient methods of wind-tunnel experiment are being applied to the critically important range of speeds near the speed of sound. Difficult questions which defied mathematical treatment or solution by other experimental methods are being answered in these tunnels and they are giving the designer data of vital importance to all new transonic and supersonic aircraft.

When John Stack and his associates of the NACA's Langley Aeronautical Laboratory were honored by the Collier Trophy Award for 1951 for their work in devising a successful transonic wind tunnel, little could be said of the nature of its mechanism or the results being produced. This year for the first time the NACA is showing the slotted working section of the Ames 14-foot Transonic Wind Tunnel, one of the largest and newest of its kind to enter service.

Wind tunnels are useful in proportion to their ability to reproduce under controlled laboratory conditions the same type of air flow found in free flight. The transonic tunnel can do this smoothly with precise speed variation from subsonic through the speed of sound to low supersonic values.

Conventional subsonic and supersonic tunnels do not produce accurate results close to the speed of sound because of a phenomenon called "choking" which occurs when shock waves forming near the speed of sound block the air passage between a model and the solid tunnel walls. When choking exists, adding power merely intensifies the blockage without increasing the tunnel speed. A choked tunnel cannot give reliable results since in free flight shock waves extend unhindered by the confining walls of a wind tunnel.



Perforated test section of the Ames 14-foot Transonic Wind Tunnel

The NACA transonic tunnels achieve a close approximation to free-air conditions by providing slotted walls which permit flow disturbances to pass through the open parts while retaining sufficient solid area to guide the air uniformly past the model.

It would be difficult to overestimate the contributions which transonic tunnels have made toward solving the complicated stability and control problems encountered as an airplane passes through the region of mixed subsonic and supersonic flow near the speed of sound. In the tunnels, detailed force, flow and pressure studies can be undertaken with a degree of accuracy and economy hitherto impossible, and the tactical transonic and supersonic airplanes now flying reflect the value of such tunnel work.

Detailed pressure studies, for example, led to several possible solutions to the pitch-up problem which can be troublesome for airplanes with swept-back wings at transonic speeds. Pitch-up may occur abruptly in flight as a pilot attempts a sharp turn or pull-up maneuver, and it can happen so violently that structural damage or loss of control may take place.

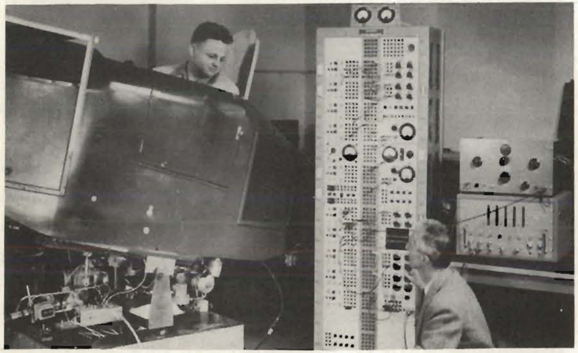
When swept-back wing models were tested through the speed of sound in transonic tunnels, it was discovered that rather large variations existed in the way in which lift was distributed over the wings. When angle of attack was increased to supply the additional lift needed for a pull-up or tight turn, most of the extra lift was found to come from the inner portion of the wing, away from the wing tip. The center of lift thus moves forward and inward so rapidly that it can overcome the forces tending to keep the airplane stable.

Further tunnel research led to devices which can maintain the wing-tip area as an effective lift producer. Chord extensions are one way of keeping the wing tip uniformly at work through a wider range of angles of attack. Wind-tunnel experiments show that swept-back wings with chord extensions have a nearly stationary center of lift and this device is now appearing on several production airplanes.

Computers aid flight research

The airplane itself has long been one of the most useful tools available for the study of aeronautical problems. From the days when its pilots flew World War I biplanes to the present research airplane fleet operated by the High-Speed Flight Station, the NACA has made extensive use of this technique.

Recently the development of analog computers and simulators has added a new dimension to flight research. These devices yield rapid and continuous solutions to the complex mathematical equations the scientist uses to express the dynamic performance of an airplane or missile. As an adjunct to indispensable research in actual flight, computers broaden the scope of investigations and greatly reduce hazards to personnel.

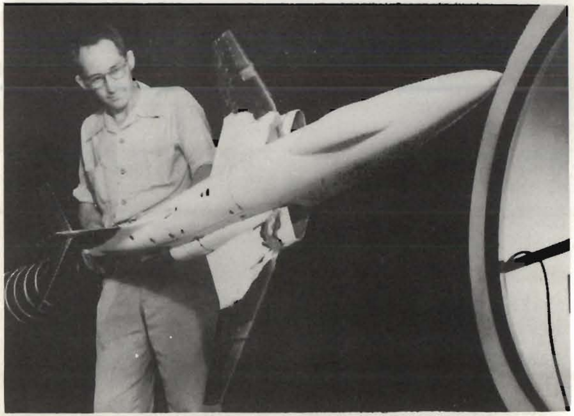


Computer simulates flight reactions.

Most significantly, computers permit assessing the flying qualities of aircraft yet unbuilt. With wind tunnel information as a foundation and flight results as a check on accuracy, the computer solves equations representing the performance of hypothetical future aircraft. The results are of great value to the design engineer.

Computer analysis provided the key to understanding a difficulty found in some modern fighter airplanes with power controls. Pilots reported experiencing violent oscillations which in a few cases caused the loss of prototype airplanes in flight when structures were stressed beyond their limits. Pilots found they could stop the oscillations by removing their hands from the cockpit control stick. This suggested that the airplane was probably throwing the pilot around to such an extent that he inadvertently moved the stick so as to aggravate the oscillation.

Obviously such a problem would be difficult and dangerous to explore in flight but it can be tackled on the ground by electronic simulation. To do this an actual airplane with powered controls is linked to an analog computer. The pilot moves the stick and rudder pedals as he would in a flight maneuver and the airplane's control system responds accordingly. From the control system movements the computer calculates how the airplane would react if actually flying, and its answers are made visible to the pilot by a moving dot of light on a viewing screen. By changing the simulator settings a wide range of variables can be easily checked.


Interceptor model in Supersonic Tunnel

Simulator studies proved that inadvertent control-stick changes could sustain an oscillation once started. To cure the difficulty, it is possible to put into the system a device which permits control changes only if the pilot moves the stick with a preset amount of force. This prevents inadvertent control changes if oscillations occur.

Working from a foundation of wind-tunnel data gathered during tests of models, computers have also been of great help in assuring satisfactory flight characteristics for new airplanes. To the basic data provided by the wind tunnels, the computer adds a simulation of the mass, inertia, and dynamic response of a new airplane. The results tell whether the airplane will be satisfactory in flight, or, if unsatisfactory, what changes are required.

In a typical case, the computer disclosed the effects in flight of aerodynamic irregularities found during wind-tunnel tests of a particular model. The irregularities showed up in the way in which the model's nose-up or nose-down tendency varied as the angle of attack was changed. When these irregularities were checked by the computer for an elevator-controlled airplane it appeared that in flight they could cause abrupt pitch-up to high angles of attack followed by oscillations that a pilot could not control.

Since it has been found that the violence of pitch-up may be lessened by increasing inertia and control effectiveness, the computer was used to test the same irregularities applied to an airplane with greater inertia and a more effective all-movable horizontal tail. Here the pitch-up was markedly less severe and within the pilot's ability to control.

Flight tests have proved the accuracy of the simulator's results and it is now enlarging the usefulness of the wind tunnels and aircraft which are the primary tools of aeronautical research.

Wings that flex and twist

Long slender fuselages and thin swept-back wings mark the design of modern jet transports and bombers for efficient high-speed flight over intercontinental distances. Like a finely tempered blade, these thin narrow shapes are very strong and at the same time quite flexible. This flexibility and its effects during flight are called aeroelasticity and are the focus of intensive current research interest.

The flexible airplane responds in a far different way to the air loads and stresses of flight than its more rigid predecessors. Important changes in lift distribution occur as the flexible wing twists and bends in flight, presenting a variety of angles of attack along its length. Slim fuselages and tail surfaces also deflect, altering both the loads on, and the stability contributions of, the horizontal and vertical tail.

Ailerons can cause sizeable distortions of a flexible wing when the pilot moves them to roll the airplane. At high speeds wing twist can greatly reduce and even reverse the effec-

Optigraph measures wing flex.

tiveness of an aileron so that the airplane rolls in an opposite direction from that called for by the pilot.

Excellent possibilities exist for improving the efficiency and performance of large airplanes if the designer can be given more knowledge to guide his work. To this end the NACA is pursuing an extensive flight program with a Boeing B-47 jet bomber to complement wind-tunnel results. The airplane was made available by the U. S. Air Force. It is being flown from the NACA's High-Speed Flight Station at Edwards, California. Scientific teams from that Station and from the Ames and Langley Laboratories cooperate in analyzing and interpreting the data gathered.

Seldom has a more thoroughly instrumented research airplane taken to the air. Precision devices measure and record every motion the pilot applies to the controls and the airplane's response to his commands. Nearly 500 electric strain gages measure and record stresses throughout the structure and a specially designed optigraph records flex and twist in the wing and tail surfaces. Numerous accelerometers detect and measure vibrations and a continuous record of speed, altitude and flight angles is made.

One immediate benefit from this research has been the verification in flight of theoretical methods for predicting wing bending and twist. The program is being pushed forward to obtain data for speeds at which present theory is inadequate.

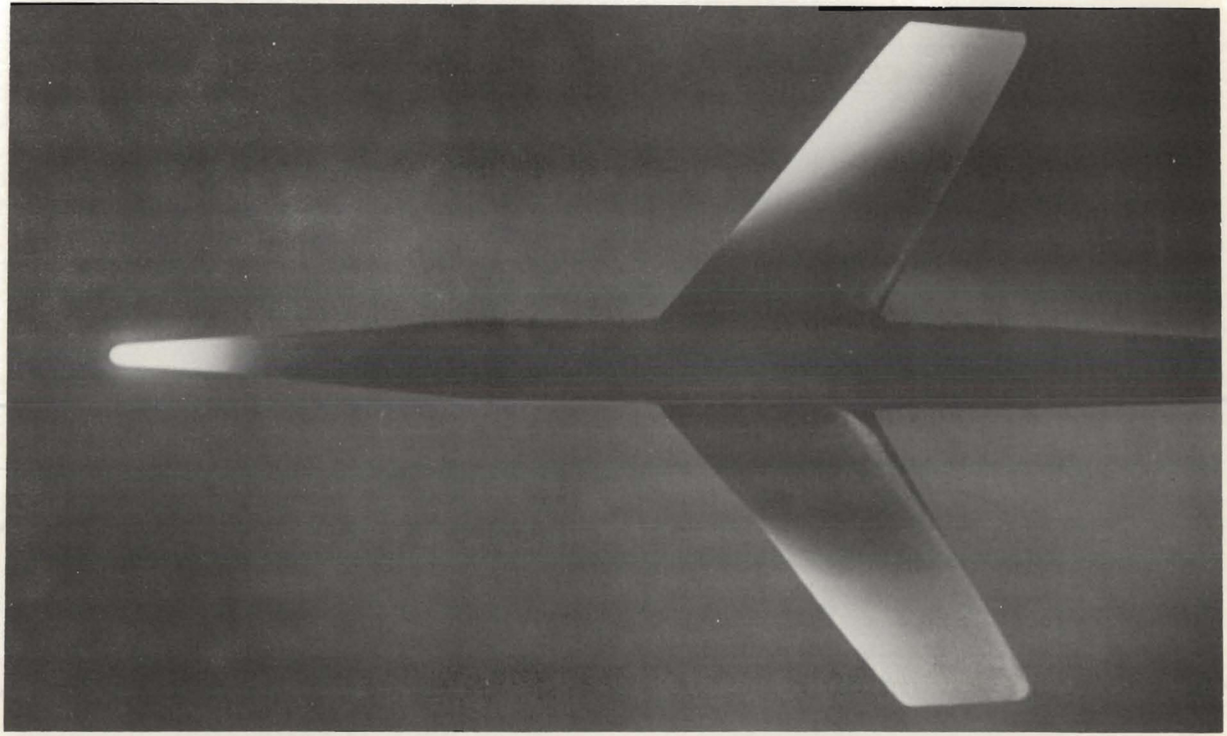
Additional benefits are expected to accrue in structural design. In the absence of precise information on the lift loads that a wing must carry or the stresses it must endure, prudent design practice insists on adding strength in doubtful cases to assure safety. If research can define more sharply the limits within which a structure must perform satisfactorily, the weight penalty that goes with unneeded extra strength can be avoided. In a modern jet transport a weight saving of 10 percent could add perhaps 10 or 20 passengers to the payload.

Hypersonic flight and heat

Intensive research on the difficult problems posed by flight at extremely high speeds is being pursued energetically to exploit the potential advantages of intercontinental missiles traveling between 10 and 15,000 miles per hour.

The most significant advantage of this type of missile is its relative invulnerability. Even with an aircraft equally fast, the problem of intercepting an object moving at 20 times the speed of sound would be extremely difficult. Only seconds would elapse between the time such a missile could be detected and the time it impacts at destination.

The true ballistic missile is accelerated to hypersonic speeds in the first 15 or 20 miles of its flight and this initial push carries it to altitudes well beyond the earth's thin mantle of atmosphere. Its flight path under the influence of gravity resembles the trajectory of an artillery shell. As it re-enters the atmosphere,



Infrared photograph shows effects of simulated aerodynamic heating.

resistance of the air reduces its speed to about 5,000 miles per hour at the end of the flight. Tail fins may be needed for control during this final phase.

A second type of hypersonic aircraft of interest is the glide missile, intended to operate within the atmosphere and hence equipped with wings to produce aerodynamic lift. Like a ballistic missile, it reaches very high speeds during the opening phase of its flight and then glides to its destination along a flat trajectory. Lift provided by the wings gives the glide aircraft long range and presents the interesting possibility of landing it under control at the end of flight. Thus it may well have commercial as well as military applications.

Much valuable information on hypersonic flight has already been accumulated, but it is clear that enormous amounts of additional knowledge are required for designing successful missiles to attain these performance goals. Among the many difficulties of hypersonic flight, the aerodynamic heating problem appears to be the most troublesome at the present time, although progress is being made.

Temperatures high enough to melt or even vaporize most metals quickly develop in the air next to the skin of a hypersonic aircraft. Even at only half the speeds envisioned, or about 7,000 miles per hour, sustained flight would produce temperatures up to 8,000° F. Very high rates of heat transfer exist at such elevated temperatures which means that heat will flow rapidly into the aircraft's skin and structure.

Pointed bodies and sharp leading edges are at a disadvantage under such conditions for while they have low aerodynamic drag they tend to absorb heat more readily than blunt shapes and have less material in which to store it.

Despite the magnitude of the temperatures to be dealt with, a number of promising techniques are under investigation as solutions to the problem. One of these, transpiration cooling, requires a porous skin through which a liquid may be evaporated. The human body is cooled in this way and a similar system may be the answer to the temperatures of hypersonic flight.

Accurate information on the heat effects on structure is essential to safe and efficient design since it is not expected that cooling will take care of all the heat generated. Studies are therefore being made on how heat flows through a skin and its supporting structure. Mathematical procedures are used to analyze the flow of heat and an electric analog computer has been built to obtain rapid solutions. The computer is especially useful in obtaining an understanding of non-uniform heating and the unequal thermal stresses to which a structure is subjected.

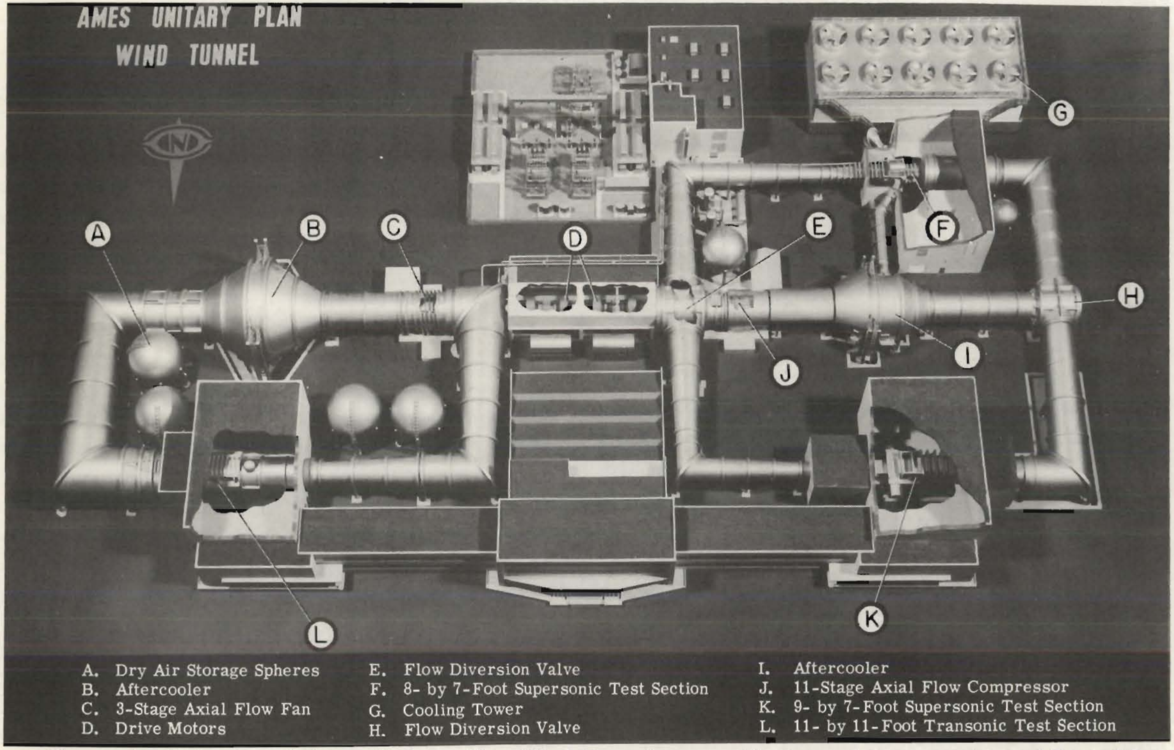
New facilities at the Ames Laboratory are engaged with some of the perplexing problems of flight at extremely high speeds and altitudes. A 10- by 12-inch Heat Transfer Tunnel has been added to existing equipment for work on aerodynamic heating and an 8-inch Low Density Tunnel simulates conditions at altitudes near the upper limits of the earth's atmosphere.

Unitary wind tunnels in action

A properly balanced program of aeronautical development is built upon a foundation of fundamental scientific research vigorously and imaginatively applied to attain practical ends. The Congress endorsed this principle in 1915 when it established the NACA to be responsible for the "scientific study of the problems of flight with a view to their practical solution."

In its early years the NACA concentrated on fundamental research and the acquisition of a growing store of basic information from which progressively more advanced aircraft evolved. At the same time, its scientific talent and laboratory facilities were always available when the need arose to help in applied or development testing projects of the aircraft industry or the military services.

During World War II military needs laid heavy emphasis on development work and nearly all of the NACA's facilities put aside fundamental investigations to supply the more



A. Dry Air Storage Spheres
B. Aftercooler
C. 3-Stage Axial Flow Fan
D. Drive Motors
E. Flow Diversion Valve
F. 8- by 7-Foot Supersonic Test Section
G. Cooling Tower
H. Flow Diversion Valve
I. Aftercooler
J. 11-Stage Axial Flow Compressor
K. 9- by 7-Foot Supersonic Test Section
L. 11- by 11-Foot Transonic Test Section

Three-circuit layout of Ames Unitary Plan Wind Tunnel covers Mach number range from 0.7. to 3.5.

urgent demand. The inevitable result, a serious lack of new basic information, was apparent shortly after the war ended. The ability to do both jobs at the same time was plainly beyond the capacity of the size of the staff and research tools available.

Mature and informed assessment of the nation's needs by Congressional and scientific leaders led to the adoption of the Unitary Wind Tunnel Plan Act of 1949. In essence, the Act provided for a series of large, powerful new wind tunnels in which development testing can be done without interrupting the vital business of fundamental research.

The three new facilities built by the NACA under the Unitary Plan begin work this year. As they move toward full-capacity operation, other NACA facilities will be released for basic investigations and a more favorable balance between research and development will be achieved.

Each major NACA Laboratory is the site of a Unitary Plan Wind Tunnel. At the Langley Laboratory, a 4- by 4-foot tunnel working in the range of Mach numbers between 1.2 and 5.0 is now being calibrated. It will concentrate on aerodynamic studies of missiles and airplanes.

The Lewis Unitary Plan Wind Tunnel is designed for testing aircraft propulsion systems and their components. Its 10- by 10-foot test section will work in the Mach number range of 2.0 to 3.5.

The Ames Unitary Plan Wind Tunnel operates at Mach numbers between 0.7 and 3.5, a range made possible by the unique design of three testing circuits driven from a single power supply. Most efficient use is thus made of the 180,000 horsepower electric drive motors.

A slotted 11- by 11-foot transonic test section permits work between Mach 0.7 and 1.5. In this branch of the tunnel a three-stage axial flow fan circulates the air.

For supersonic tests, the facility has two circuits, each driven by an 11-stage axial flow compressor placed in a common air passage. Huge flow-diversion valves direct the compressor output through the circuit required. In one branch, a 9- by 7-foot test section operates between Mach 1.4 and 2.6; in the other, speeds between Mach 2.4 and 3.5 are attained in an 8- by 7-foot test section. While one test section is in use, the two remaining ones are available for model instrumentation or maintenance.

High speed electronic computing equipment reduces test data and plots the results on graphs while the run is in progress.

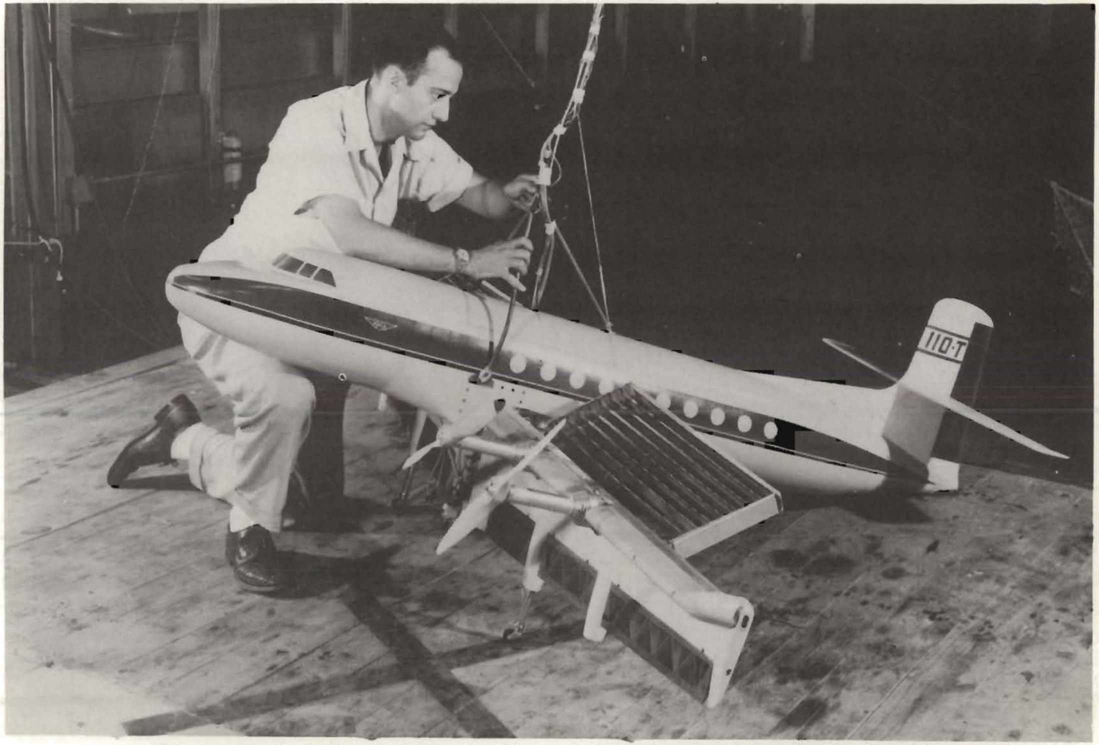
The Unitary Tunnels will enable designers to obtain comprehensive measurements on large scale models of transonic and supersonic airplanes and missiles. Models large enough to include movable control surfaces permit stability studies at high speed. Detailed pressure surveys can be accomplished accurately and efficiently. Internal air duct investigations can be made to guide design. Working in close partnership with the aircraft industry and the military services, the new facilities will be used to improve the performance and reliability of the aircraft of today and tomorrow.

Lower landing and take-off speeds

The successful drive of recent years for higher speeds has been marked by a rise in speed of other types of airplanes besides the more dramatic supersonic research aircraft. But science meanwhile has not neglected the problem at the lower end of the speed scale, that of holding down landing and take-off speeds. This effort may be summed up as a "drive for less concrete" in modern airports.

Any means to slow down landing and take-off speeds, to permit operations from unprepared places, or ultimately toward vertical flight itself, is of immense value to civil and military aviation. Some research answers are evident in the helicopter, boundary-layer control, the vertical take-off airplane, the seaplane hydro-ski and the thrust vector.

Though control of boundary-layer air is one of the oldest problems of aeronautical research, it appears ever more promising in the current trend toward turbojet power and extremely thin wings. The gas turbine



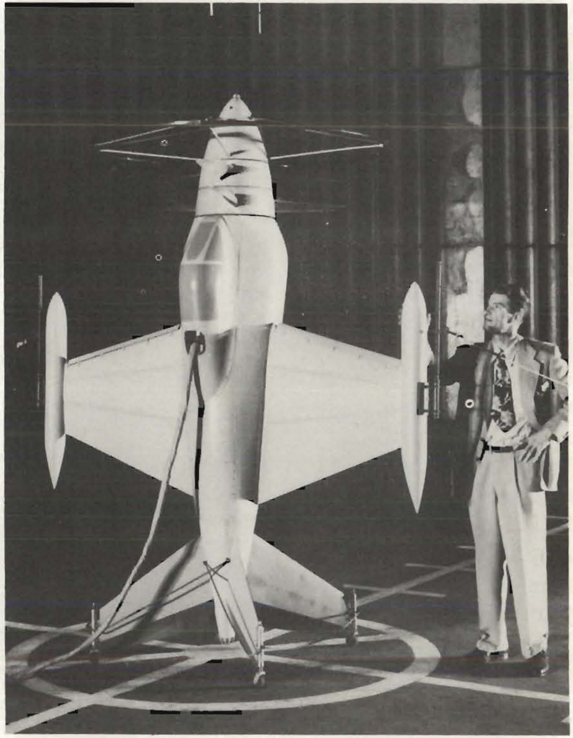
Vertical take-off transport model studied in Langley Free-flight Tunnel.

is a convenient means either to blow or draw off the boundary-layer; furthermore, the design of flaps as a speed reduction device has become comparatively more difficult with modern wing configuration.

Boundary-layer control offers much promise for naval aircraft, where a few knots reduction in stalling speed can mean proportionately more to the capabilities of carrier-borne planes. To the Air Force and civil aviation it promises a landing aid for jet aircraft better than the flaps in general use.

The idea of reducing launch-and-landing speeds is, in the extreme, vertical take-off, which the familiar helicopter performs well. But the helicopter has a limited top speed and is not therefore useful for some purposes. Research, however, is continuing upon problems of rotary-wing aircraft and their application.

One type of vertical take-off or VTO aircraft capable of a wide speed range is the one which rests on its tail. Provided with enough thrust to exceed its own weight, this VTO



Wind tunnel test of VTO scale model.

takes off vertically, then tips over to climb and cruise in the normal attitude. It backs down tail-first to land.

Research with VTO reveals that once enough thrust is provided, its chief problems are stability and control in hovering and in transition to forward flight. Turboprop and turbojet VTO both have been under extensive research and development.

Research has continued upon another type of VTO, the principle of deflecting propeller slipstream downward through sets of large wings or turning vanes. The objective is a system which can produce vertical lift while the airplane remains in the horizontal attitude or nearly so, but which is readily retractable to form a clean monoplane wing for forward flight. NACA scientists are studying various flap and slot combinations with models of transport and smaller planes, and with thrust provided by both propellers and turbojets.

Other tests are being conducted with models whose wings and propellers are turned upward 90 degrees from the horizontal. This principle permits hovering and landing and take-off in small space, plus reasonably high performance in cruising flight.

The thrust vector or "flying platform" principle investigated by the NACA Langley Laboratory is still another VTO concept. This grew from the idea that a man can fly naturally and control his movements without complex machinery or training. First studied with jets of air attached to a man's feet, the principle has been extended to the teetering rotor platform design now being developed by industry.

The "drive for less concrete" must not overlook the possibilities of water-based aircraft. Since the war hydrodynamic research has attacked the problems of cumbersome seaplane floats and hulls to find solutions without compromising performance either in flight or on water. Out of this work has come the hydro-ski, a flotation device which is retracted into the airplane body like a set of wheels. The hydro-ski has been proved capable of attractive performance, has reduced landing loads by three-fourths, and has the possible added advantage of practical use on such surfaces as snow and ice.

Hydroplane research, in addition, has evolved greatly improved hull shapes. The new narrow hulls of flying boats can reduce aerodynamic drag simultaneously with lighter landing loads and much better hydrodynamic performance.

Reducing crash hazards

Continued NACA research on aircraft crashes has produced two results of significance in the field of safety. The results are a clearer understanding of the hazards of fire and injury due to impact. This knowledge has led to the concepts of an inerting system for turbojet engines and of a passenger seat of new type.

Research by the Lewis Laboratory utilized data from many sources and included the controlled crash, over a period of six years, of 37 service-worn airplanes.

Previous study of the fire problem revealed the engine as the chief source of ignition, seconded by the widespread electrical system of the airplane. The inerter for turbojets is basically like that conceived earlier for piston engines. In all full-scale crash tests which incorporated the inerting system there was no fire.

Worst fire prevention problem of the gas turbine is its lingering appetite for air, i.e., its fast-spinning compressor continues for some time after a crash to force large amounts of air through its heated interior. In the circumstances of crash damage, spilled fuel and other combustibles are thus sucked into the engine, or otherwise contact the hot surfaces. Some engine parts, notably the heavy turbine wheel, may remain hot enough to start a fire many minutes after a crash.

The inerting system consists mainly of plumbing positioned to spray critical points of the engine with coolant. Best coolant proved to be water, which not only cools effectively and is readily available but quickly converts

Dummy "pilots" jet fighter through severe crash in research on impact survival problem.

to steam. The resulting blanket of steam excludes oxygen. The jet requires more than twice as much coolant as the piston engine.

Like the reciprocating engine system, the inerter for jets is triggered by a crash-sensitive switch which releases the coolant and "kills" the plane's electrical circuits. The experimental system is believed possible of development at suitably low weight for practical use.

View inside plane before test of crash-resistant seat.

Simulated load studies in the laboratory and in staged crashes in the field were set up to investigate the problem of survival from other than fire hazards, especially the limits of human endurance, and problems of seat structure, location and position. These led to the search for solution in passenger seating built to resist crash impact hazards.

Research with the crash-resistant seat, now in the final stages, indicates the soundness of this approach. The experimental article combines elasticity, strength and ability to withstand shock from all directions. It has no sharp parts dangerous to the occupant. In addition, the principles of impact survival are aimed to reduce or eliminate injury by missiles produced by damage to the aircraft structure.

The seat makes extensive use of rubber to absorb loads of shock and recoil. The structure provides enough strength to sustain large loads of impact without collapsing or permitting the seat to break free from its fastenings.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