Flight Research Hangar in the east area, 1946, showing two Boeing B-29s and a Douglas DC-6 undergoing tests.

Recollections of the

LANGLEY MEMORIAL AERO LAB

in the Forties

by William H. Phillips

INTRODUCTION—This article is based on a talk that I gave to the staff of the Langley Research Center as part of a monthly Colloquium series. My qualifications for presenting the talk were that 1990 was my 50th year of continuous employment at the center (originally the Langley Memorial Aeronautical Laboratory of the NACA) located in Hampton, Virginia, and which in 1958 became the Langley Research Center at NASA. Because I have always enjoyed research work, my career has been very satisfying, and as a result my impressions may be somewhat more favorable than would be obtained from some other people. Nevertheless, I will try to give a fair evaluation of the work done at the laboratory in the 1940s.

The Langley Memorial Aeronautical Laboratory (LMAL) was the first research center established by the NACA (National Advisory Committee for Aeronautics). The first facilities were put in operation at Langley Field, Hampton, Virginia, in 1920, and this laboratory remained the only research center of the NACA until 1939, when personnel from Langley founded the Ames Research Center in Sunnyvale, California, to provide Aeronautical Research Facilities on the West Coast. Other Langley personnel in 1940 initiated the Lewis Research Center at Cleveland, Ohio, to do powerplant research. The early history of the LMAL as well as that of the decade of the forties covered in this talk are well documented in references 1 and 2. I hope that my personal account may add some insight into the accomplishments of the LMAL during the forties.

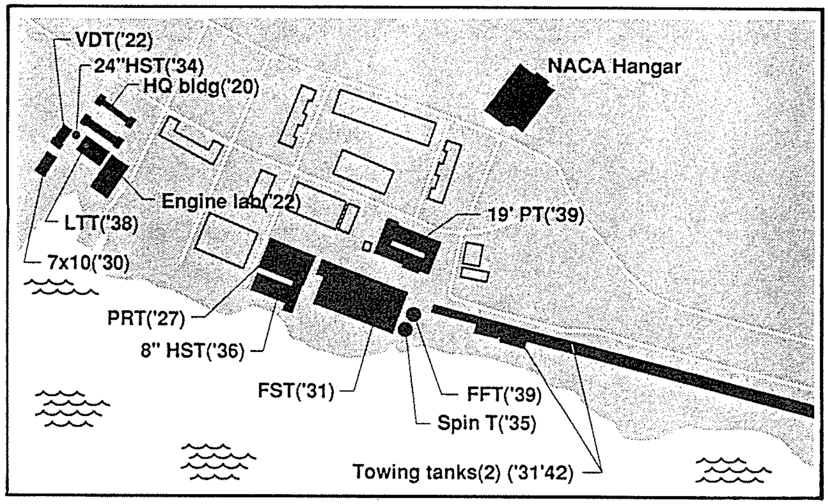
My decision to work at the Langley Memorial Aeronautical Laboratory (LMAL) was based on the good reputation that the NACA had enjoyed in the aeronautical industry, as shown by the favorable impressions given by some of my MIT professors who had either worked at the LMAL or had served on NACA committees. Also, a brief summer employment in industry convinced me that I was more suited to research work than to the more hectic pace of industry. As a result, I took the Civil Service exam, and after some delay was accepted for employment. I reported for work on July 1, 1940, and was assigned to the Flight Research Division.

The main topics that I will cover in this article are the social life and surroundings in Hampton, the Langley facilities and their growth in the forties, and the main technical developments and research contributions in this period. In presenting this material, I would like to acknowledge the assistance that I have received from the historical records given in references 1, 3 and 4. Discussing events that happened almost 50 years ago is almost like describing the activities of another person, and it is necessary to refer to recorded facts and written records to gain assurance that the material being presented is correct.

Social Life and Activities—In the early days of the LMAL, the small number of engineers assigned to work at the laboratory found that Hampton was a rather isolated and provincial place, with fishing and crabbing the main occupations of the local residents. The first few engineers met with considerable animosity from the local population, and the lack of any social and cultural activities made life difficult, particularly for the wives. In 1940, the center was still quite small, with less than 750 total employees. The problems of living with the local population, however, had largely, though not entirely, disappeared. The natives frequently referred to the center employees as "NACAnuts" or "Brainbusters," though these jibes were mainly expressions of humor rather than malice. I found life extremely happy and exciting, particularly since this was my first experience living away from home and without the routine of studying at MIT. The small size of the center allowed most of the employees to know a good number of the staff personally. The small social groups and organizations that had formed made for a pleasant social life as well as providing for a good interchange of research ideas.

Though there were no sophisticated cultural activities comparable to those in a large city, the employees made their own entertainment. Some of these social activities were the Engineers Club, Model Airplane Club, Tennis Club and Noble Order of the Green Cow. The only professional society, the Engineers Club, was founded in 1940 and put on excellent programs. There was a very active model airplane club, an item of importance to me, since this had been my main hobby before coming to Langley. NACA hired over 100 expert model airplane builders, starting about 1938, using a special Civil Service exam for which the only requirement was that the applicant should have won a model airplane contest. Edward R. Sharp, later director of the Lewis Research Center at Cleveland, felt that these people would make good technicians and model makers. After arriving here, these model builders kept up their interest in model airplanes, holding regular club meetings and large contests. Club meetings were held in the Syms Eaton Academy in downtown Hampton, a former school that was used as a community center. The faith that Mr. Sharp put in the model makers proved to be justified, as many of these employees improved their education in the NACA Apprentice School, and later rose to become branch heads, directors of facilities, and to hold other influential positions.

Among the recreational organizations was the NACA Tennis Club, which had probably been started in the late



NASA facilities in 1940—east area of Langley Field. Outlines show some present Air Force buildings.

'20s. The club had six clay courts made by rolling the existing soil, which proved quite satisfactory for the purpose. I remember often going out early in the morning to weed and roll the courts, and then play tennis the rest of the morning.

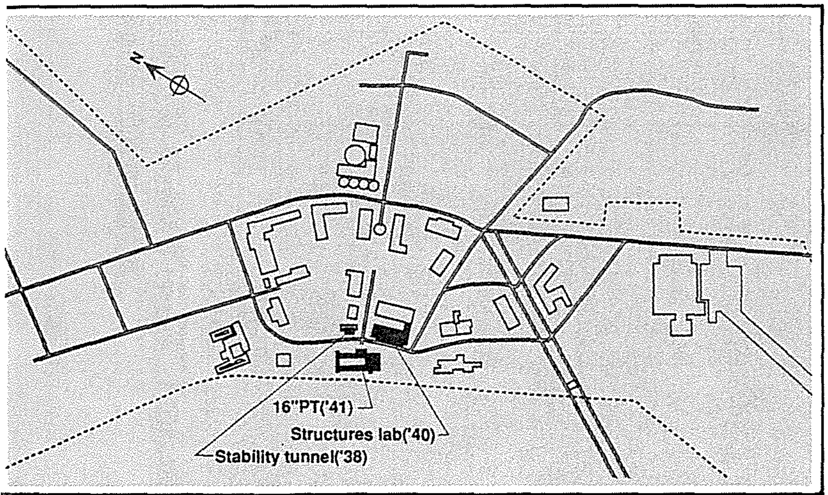
Finally, I should mention the "Noble Order of the Green Cow," a social club that put on dances for the employees. These dances were often held at the Hampton Armory and were very well attended.

Other activities available in the area were: beaches, movies, sailing, flying, golf, bowling, roller skating, riding, concerts and Little Theatre. Since there was no TV in pre-WWII days, movies were probably the main source of entertainment. There were three movie theatres in Newport News. There were also two in Hampton, one in Wythe, one in Phoebus, and one in Hilton. In those days, these theatres often presented live entertainment, such as big-name bands. I remember seeing such well-known bands as Jack Teagarden; Vincent Lopez, Eddie Duchin, and Russ Morgan.

During the '30s, quite a few engineers flew their own light planes, but this hobby, of course, ended with the start of the war, except for Civil Air Patrol activity. There were at least three private airports available on the Peninsula; namely, Morgan's Field between downtown Hampton and Langley Field, one on a site that is now Copeland Industrial Park in Newport News, and one remaining from the Curtiss Naval Flying School dating from before WWI, near the Small Boat Harbor in Newport News.

Golf was available at Langley, at the Hampton Country Club (then called the Chamberlain Country Club), and a very interesting course on the battlefield at Yorktown. Unfortunately, the clubhouse at Yorktown burned down about 1942, and Secretary of the Interior Ickes ruled that golf was not a suitable activity on a national historic site. I think I learned more American history, however, playing golf on the battlefield than modern tourists do when they go through the visitor center.

Cost of Living—Hampton in 1940 was a very economical place to live. Most engineers, when they first came to work, lived at communal apartment houses, or lived and boarded in houses in Hampton where they were taken in as members of the family. Later, as the number of new people increased,



NACA facilities in 1940—west area of Langley Field. Outlines show some present NASA structures.

FACILITIES OPENED IN THE FORTIES

Name	Date
Impact Basin	1942
9″ SST	1942
Low Speed and High Speed 7x10	1945
Gust Tunnel	1945
Flutter Tunnel	1945
Ind. Aero Lab	1946
Helicopter Tower	1946
Flight Res. Hangar (West Area)	1950
UNDER CONSTRUCTION 1950	
4 Ft Supersonic Tunnel	
Gas Dynamics Lab	

some landladies served meals to groups of 20 or 30 employees. At the boarding house I attended, the landlady served two meals a day, seven days a week, including a big Sunday dinner, for $10 a week. My salary as a junior engineer was $2,000 a year, but I was able to save at least half this amount.

Growth at Langley During the Forties—The '40s, of course, was the period of WWII and was a time of tremendous expansion at Langley. The number of professionals increased from 277 in 1940 to 1,158 in 1950, and the total number of employees increased from 739 to 3,388, larger than the present Civil Service complement. In those days, there were no contractor employees on site. Just about everything, including mowing the lawns, running the cafeteria, and building models for the tunnels, was done in-house. During this period, a number of employees were sent out on recruiting trips to various colleges to bring in new people to satisfy the demand. Many of these recruits were not familiar with the type of work done at Langley, so the University of Virginia and William and Mary extension courses were started to train the new employees. I taught several courses in flying qualities and stability and control during the period 1943 to 1947.

During a brief period for about a month after Pearl Harbor, engineers were assigned to guard duty in the facilities during the night. The buildings were blacked out, and about two engineers in each facility made periodic checks to guard against possible terrorist attacks. It would seem that this quiet period would be a good time to catch up on writing reports, but I found that reports I tried to write at night tended to be rather rambling and disjointed and usually had to be done over by the light of day.

Everyone at Langley felt a special urgency to work extra hard during the war. The main personal sacrifices, however, were those due to gas rationing and the imposition of a 48-hour work week. Practically everyone was in a riding combination or came to work by bus, and everyone worked on Saturday during the war years.

The number of facilities at Langley also expanded greatly during the '40s. Drawings show the facilities in the east and west areas, respectively, and the years when they were put into operation. By 1940, the facilities in the east area were just about the same as they are today. The latest facility was the 19-Foot Pressure Tunnel, now the Transonic Dynamics Tunnel, which occupied the last space available in the east area. After this, most further expansion had to be done in the west area. The Propeller Research Tunnel was torn down in 1950, making room for the new 8-Foot Transonic Pressure Tunnel.

When I came to work in 1940, the only major research facilities in the west area were the Stability Tunnel, the new 16-Foot Pressure Tunnel, and the Structures Lab, and even these last two had not yet been put into operation. The Stability Tunnel was a small wind tunnel for dynamic model tests and curved flow studies. It was later donated to the Virginia Polytechnic Institute and State University in Blacksburg, Virginia, and the office part of the building became the present Dispensary. There were some other buildings such as the wood shop and warehouse buildings not shown on the map.

The acquisition of new facilities in the '40s is shown below. Some of these are no longer in existence. The Impact Basin was used for studying loads on seaplane hulls during landing in waves. After serving its purpose, it was torn down to make room for the ACD parking lot. I think the office part of the building is the present Travel Office. The Gust Tunnel, in which models were catapulted into a vertical air current, is now used as Building 1218, the Executive Conference Center back of the Headquarters building. Other major facilities under construction in 1950 included the 4-Foot Supersonic Tunnel and the Gas Dynamics Lab. Many other facilities have been added since then.

RESEARCH PROGRAMS AND PROJECTS IN THE FORTIES

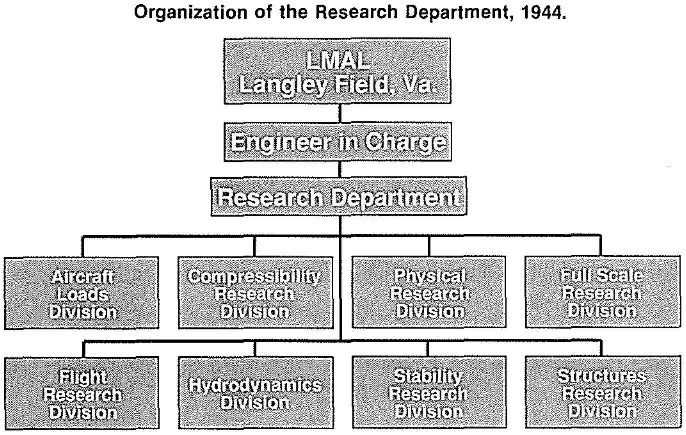
Types of Research—Now I would like to go to the main subject of this talk, the research programs and projects in the '40s. As I mentioned previously, I was working in the Flight Research Division. Flight testing of airplanes requires knowledge of such areas of work as performance, loads, structures, and stability and control. I was, therefore, in a better position than most young engineers to keep abreast of the work of different groups at the Center. At the same time, I was not always aware of the very latest development in specific fields, many of which were classified because of military applications.

The organization of the Research Department in 1944 is shown below. Though most of these groups worked in different locations, there was a program that assisted in keeping all workers informed of the work in other divisions. This program was a series of monthly meetings (first called Section Head Meetings, later Department Meetings), starting about 1942, in which a Section Head would have his engineers present some of the important projects that his group was working on. In most divisions, the section was directly below the division in the line of management. These meetings were held after working hours but the Associate Director, Floyd Thompson, strongly recommended that all Section Heads and higher-ranked supervisory employees in the Research Department should attend and most all of them did.

The Center, of course, was heavily involved in WWII, and the aircraft industry was in a period of tremendous development. Much of the work at the lab was concerned with the testing and improvement of military airplanes. The Flight Research Hangar in the east area about 1944 (see photo) housed a number of airplanes that were under test. These airplanes included most of the new fighter airplanes that were produced in that period. When I started work, I was located in the offices at the side of the hangar facing the field. I thought this was a fine location, because I could look out and watch all the military and research airplanes landing and taking off. Later, however, the second hangar was added and I was transferred to the new offices at the other side of the building. Another photo taken somewhat later shows the hangar with some of the larger airplanes. My own work was on the subject of flying qualities of airplanes. This work was very challenging and exciting, because in that period a new military airplane was brought out about every month, and most of these airplanes had stability and control problems.

By flying qualities are meant the stability and control characteristics of an airplane that have an important bearing on the safety of flight and the ease of control in straight flight and in maneuvers. In the years prior to WWII, flying qualities of airplanes were improved by a trial and error procedure, without the benefit of any fundamental knowledge or theoretical background. Efforts were started in 1937 to obtain more knowledge of this subject by making systematic flight tests of instrumented airplanes and by correlating the measured data with pilots' opinions. The first flight tests of this

Organization of the Research Department, 1944.



type were directed by Hartley A. Soule, and the work was continued by Robert R. Gilruth, whose later contributions will subsequently be described. I was assigned to work in Gilruth's branch and actively participated in the flying qualities research throughout the '40s. Gilruth published a report, based on the results obtained on the first 16 airplanes tested, entitled "Requirements for Satisfactory Flying Qualities of Airplanes" that became the basis for further research and that was also largely adopted by the military services for specifying the flying qualities of new military airplanes. During the war, airplanes were produced that had much higher power, weight, and wing loading than earlier airplanes. These changes resulted in many stability and control problems that were studied extensively both in the wind tunnels and in flight. Many tests were made with powered wind tunnel models, and methods were developed to predict flying qualities of airplanes from these results. An arrangement was made with the military services that the third production airplane of each new type would be sent to Langley for flying qualities studies. Flight tests to find cures for problems were particularly urgent, because in many cases crashes had occurred, the causes of which required analysis and correction. In other cases, the objective was to obtain an advantage in maneuverability over some enemy airplane. Several foreign fighters, including the *Spitfire, Hurricane,* and a captured Jap *Zero* were instrumented and tested at Langley. During this period, methods were developed to reduce control forces by use of the spring tab control, a kind of aeromechanical servomechanism, and later by use of hydraulic servomechanisms. I was heavily involved in analysis of these systems and in determining their effects on flying qualities.

The development of methods and devices to reduce control forces also required research on human pilot response characteristics and on requirements for the force characteristics produced by control feel devices. The results of this research were incorporated into the flying qualities requirements and contributed to the later development of supersonic airplanes which, because of their large and irregular control surface hinge moments, always use hydraulicaly actuated controls. A more complete historical summary of flying qualities research is given in reference 5.

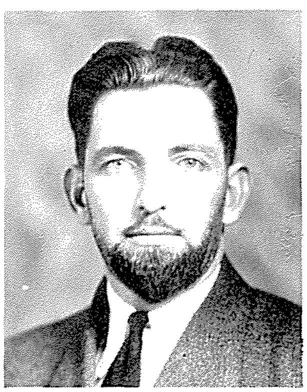
In addition to these problems associated with existing airplanes, however, the thoughts of the research leaders were on the problems of higher-speed flight. Undoubtedly, the main research projects of interest in this period were the study of compressibility effects, the problems of flight at transonic speed, and the development of airplanes capable of supersonic speed. I will, therefore, emphasize these developments in this talk.

It should be realized, of course, that many other research programs were going on in addition to those studying compressibility effects. Practically every phase of aeronautics was being studied. In addition, in discussing research on compressibility effects, I have to cover several programs one after the other. In practice, however, most of the work in different groups was going on simultaneously. The exact sequence of events is, therefore, difficult to present.

Research Leaders in the Forties—Much of the work on high-speed flight revolves around the ideas of several key research leaders. It, therefore, seems appropriate to develop

Flight Research Hangar in the east area, 1944, showing military airplanes under test.

this paper around the contributions of these leaders. I will present pictures of several of these people and tell you about their accomplishments. I guess it is not unusual to find that the more brilliant people are also somewhat eccentric. This was indeed true of these people.



Eastman N. Jacobs

Eastman Jacobs was a brilliant thinker and experimenter who is noted primarily for his development of the laminar-flow airfoil and of the low-turbulence wind tunnels required to demonstrate its advantages. Jacobs was heavily involved in all the aerodynamics work at the Center, and was responsible for planning the 24-Inch Supersonic Tunnel and the 8-Foot High-Speed Tunnel as well as the low-turbulence tunnels. I knew him because he often accompanied his teenage son who participated in model contests. To illustrate his broad interests, he once read a report I had written on the flying qualities of the *Spitfire* airplane. When he got a chance to talk to me about it, he said rather harshly, "If we are goi g to all the trouble to instrument these airplanes, we certainly ought to make tests at more than one center of gravity position." He went on to point out how this procedure would enable a better analysis of the static ability and the control surface hinge moments. Later, we studied this subject and used this method in all subsequent tests.

I think it would be considered rather unusual today for a division chief to give advice to a young engineer working in a different division and in a different field of research. I must admit that I was scared of Jacobs. After all, I was just a junior engineer, and he had an international reputation. Also, his piercing eyes and beard made him a formidable figure. Today, of course, a beard like this is common, but at that time he was probably the only person at the Center who had one. I later learned that Jacobs was one of the first people at Langley working seriously on jet propulsion. In 1940, he built an experimental apparatus called the "Jeep" consisting of an aircraft engine driving a compressor. The compressed air was then mixed with fuel and burned in a device that we would today call an afterburner. People who worked on this setup recall what a terrifying device it was. It was set up in a small metal shed in the west area, and burned one and a half gallons of gasoline per second, the flow of which was regulated manually. The noise and vibration were tremendous, and water had to be sprayed on the shed to keep it from getting red hot. Jacobs developed this equipment to the point of demonstrating that the fuel could be burned in a steady and stable manner without burning up the equipment. Unfortunately, the Air Force kept secret their knowledge of the Whittle turbojet motor, and when Jacobs learned about it in 1943, he immediately saw the advantages of this concept. I remember what a thrill it was to see the first U.S. jet airplane, the Bell YP-59, make a low pass over Langley Field about 1945.

In later years, I always had a great deal of admiration for

Eastman Jacobs. He came from a wealthy family and really did not have to work at all, yet for many years he was one of the hardest working and most productive engineers at Langley.

Dr. Theodore Theodorsen was a very capable mathematician and physicist who was born and educated in Norway, then got his Ph.D. at Johns Hopkins. He came to the NACA immediately after graduating in 1929. Unlike some other mathematicians, he applied his knowledge to solving some very practical problems of airplane design. At Langley, he ran the Physical Research Division and put out reports, now considered classics, on several important aeronautical problems. His paper on the flutter of airfoils with control surfaces provided the first fundamental understanding of wing flutter, a problem that had resulted in many airplane crashes since the early days of aviation. Next, he published a paper on calculation of pressure distribution on arbitrary airfoils, a real intellectual achievement that involved complicated mathematical analysis. Later, he developed an accurate theory of propellers. In the solution of this problem, he used an electric analog in which models of the propeller wake were inserted in a tank of electrolyte and voltage distribution was used to measure the flow potential distribution in the slipstream. In recent years, Dr. Herbert Ribner, who worked at Langley in the '40s and is now a Professor Emeritus at the University of Toronto and a Distinguished Research Associate at Langley, has had a student repeating some of Theodorsen's solutions using modern digital computation, but he found that the accuracy of the solutions was excellent and that it could not be improved without using excessive amounts of computer time.


Theodore Theodorsen

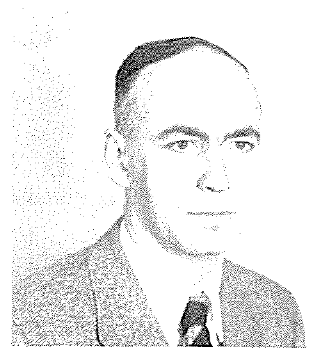
Theodorsen and Jacobs each had such a solid reputation at Langley that few people disputed their technical ideas, and if they did, they rarely prevailed. My only encounter with Theodorsen was when I ventured to design a device to prevent flutter of spring tabs. In those days, the so-called spring tab was often used in the primary control systems of airplanes to reduce the control forces. In order to prevent flutter, however, it was necessary to mass balance the tab. Then the mass balance weight on the main surface had to be increased to balance the tab balance weight. The result was an undesirable weight penalty. I devised a linkage that moved the tab balance weight forward so that it did not require an increase in the main surface balance weight. This device was built and installed in a spare vertical tail, I believe from a Lockheed 12 airplane. Before any flight tests, it was necessary for Theodorsen to come and approve it. When Theodorsen looked it over, he hauled back with his fist and blam! hit the tail a solid blow, causing it to shudder and shake. Then he said, "It will flooter" and walked off, thus ending the project. I thought his decision was rather arbitrary, but I guess he was right. He was pointing out that there were higher-frequency modes involved that my linkage would not take care of.

Theodorsen felt that he deserved special treatment at Langley and did not abide by some of the rules that applied to the rest of the staff. For example, my wife, who before we were married worked in the Editorial Office, tells me that Theodorsen would not come to the Editorial Office to have his reports reviewed. The editors had to come to his office. He was very cooperative when they did go over his reports, however. Despite his accent, he used excellent English in his technical reports. Theodorsen left Langley in 1946 to teach Aeronautics in Brazil. Later, he returned to this country and worked for the U.S. Air Force at Wright Field from 1950 to 1954 and later at the Republic Aircraft Corporation.

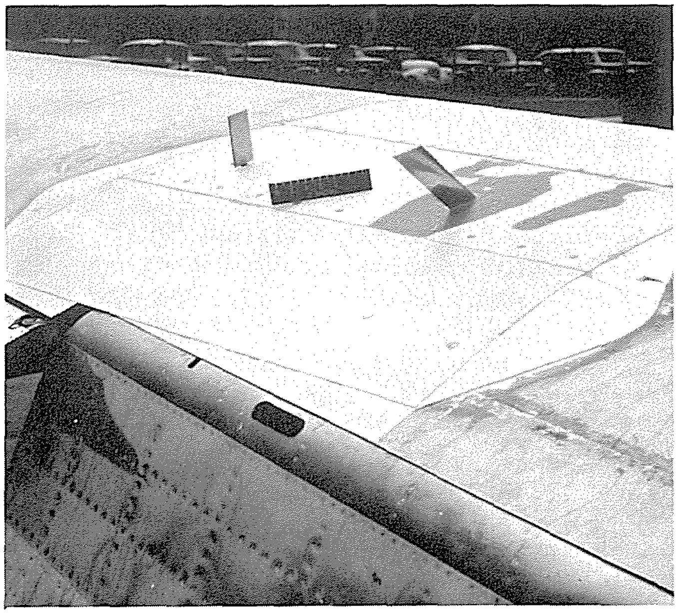
Research on Compressibility Effects—The first appearance of compressibility effects of importance to aeronautics was the effect of high Mach numbers on the tips of propellers. This problem resulted in some tests of airfoils in a supersonic jet by Dryden and Briggs as early as the '20s. Further studies of this type were conducted at Langley in some tunnels driven by blowdown from the Variable Density Tunnel, the most advanced being the 24-Inch High-Speed Tunnel that started operation in 1934. The first really serious occurrences of compressibility effects, however, were in high-speed dives by fighter airplanes of WWII. When the pilots put these airplanes in terminal velocity dives starting from about 30,000 feet altitude, they were frequently unable to recover. In some cases where the airplane did recover, it came back bent and wrinkled. Obviously, this was a problem of extreme importance to the designers. Unfortunately, wind tunnels were unable to investigate this problem because of the choking phenomenon. In a closed-throat tunnel, as the speed is increased to the point that shock waves start to form on the wing, further attempts to increase the speed result in shock waves spreading across the entire test section. After this point, increase in the tunnel fan speed simply results in a stronger shock wave.

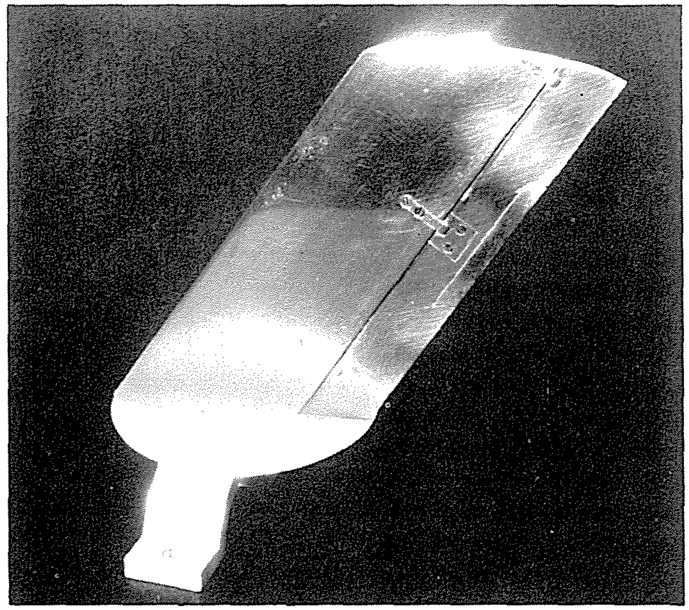
My boss in the Flight Research Division, Dr. Gilruth was, of course, very aware of this serious compressibility problem, because we operated the latest military fighter airplanes.

Dr. Robert R. Gilruth was a very capable engineer who also had the ability to inspire other people with enthusiasm for his ideas. He had up to that time been primarily engaged in studies of the flying qualities of airplanes. At this point, however, he began to consider how the airplanes that we operated might be used to study some of these compressibility problems. He devised two techniques, the wing-flow technique and the bomb-drop technique. Both of these methods were rapidly developed and put into operation.


Robert R. Gilruth

In the wing-flow method, a small model is mounted on the upper surface of the wing of a fighter airplane. When the airplane is dived from a high altitude and a pullout is made at a high but still safe Mach number, the flow on the upper surface of the wing smoothly increases from subsonic to supersonic. A region of reasonably uniform flow exists that may be used as the test region for a small model.





Wing-flow model on P-51 wing showing a 45° swept model, a flow direction vane, and between them a six-inch ruler to show the scale.

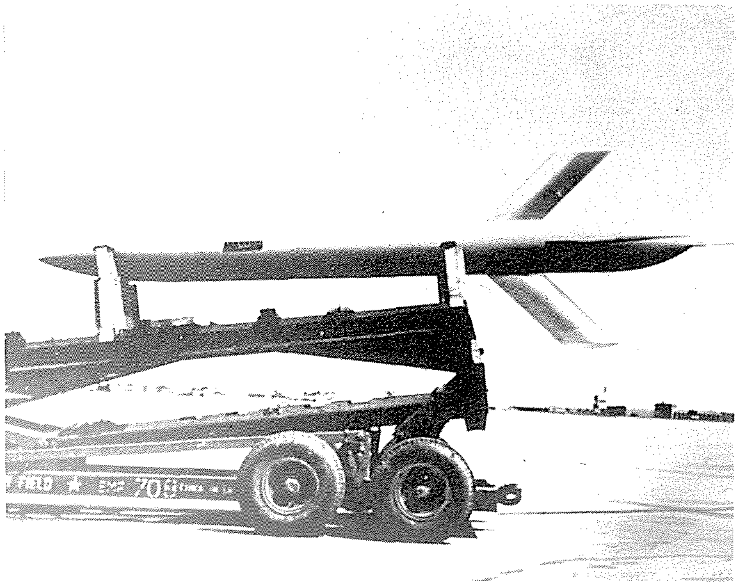
A typical wing-flow model of a 35° swept wing with the 25 percent chord flap. A circular end plate is at the base of the model.

Vought F7U-1 *Cutlass* Navy fighter at Langley.

The photo shows a model mounted on the wing of a P-51 airplane. A special glove is built on the wing to give a more uniform flow region. As the airplane goes through its dive and pullout, the model is oscillated back and forth at a frequency of about one cycle per second, to vary either the angle of attack or flap deflection. The forces on the model are continuously recorded with a strain gage balance and a recording oscillograph. The dive lasts about 30 seconds and in this period the Mach number at the model increases from about 0.7 to 1.2.

The balances and other equipment for these tests were all designed by engineers in the Flight Research Division. A vacuum-operated windshield wiper motor was usually used to oscillate the model. A single 30-second dive covered the whole range of angle of attack and Mach number, providing as much data as might normally be obtained in a couple of weeks of wind tunnel testing. As a result, the engineers were soon overwhelmed with data, but they worked hard to evaluate it and to put out reports.

As might be imagined, there was considerable criticism of the wing-flow method by some wind tunnel people because of the small size of the models and the non-uniformity of the flow field. Nevertheless, the data obtained provided the only source of information at transonic speeds. Later, a "transonic bump" using the same technique as the wing-flow method was installed in the floor of the 7 × 10 tunnel. Some of the airplane companies immediately used these data in the design of their airplanes, perhaps placing more reliance on it than we would have recommended. For example, the Chance Vought Company laid out the design of the F7U *Cutlass* Navy Fighter on the basis of the test of the wing-flow model shown here. The design was a tailless airplane with the same sweep, aspect ratio, and airfoil section as the model tested. The lack of adverse control characteristics shown in this test convinced the designers to proceed with this configuration. Later, a more accurate model of the airplane (a half model on an end



Typical bomb-drop model mounted on a dolly. This model has two sets of 45° swept wings in a cruciform arrangement but displaced horizontally from each other. Boom at rear is telemetering antenna.

plate) was tested. The completed airplane is shown in the third picture. This is probably the only case in history when the design of a new airplane was inspired by data taken in a 30-second test run.

The second method originated by Bob Gilruth for transonic testing was the so-called bomb-drop method. In this technique, a heavy aerodynamically shaped body was dropped from high altitude. The model was carried aloft by a B-29 and later an F-82 airplane. In a drop from 30,000 feet, a body about eight feet long and weighing about 1,500 pounds reaches a Mach number of about 1.2 before impacting the ground.

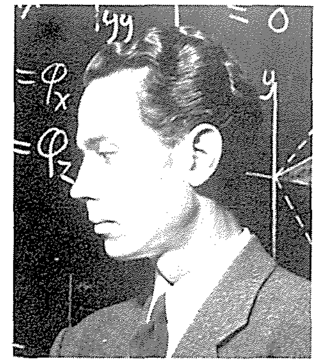
This program was actually a joint program with the British. The British agreed to develop a recovery technique so that the test models could be reused, but Gilruth decided to proceed with expendable models. After a couple of years, our tests had produced useful data from about 20 models, whereas the British had yet to make a successful drop and recovery. This experience shows the validity of Gilruth's direct approach.

The models were tracked by radar to determine their speed and trajectory. In addition, they were equipped with pitot heads and accelerometers, and wing and tail surfaces were mounted on balances to measure drag. These data were telemetered to the ground. The bomb-drop method, of course, had the advantage of providing data in free air on large-scale models. It was, therefore, particularly useful for checking theories or other experimental techniques.

Before long, it was desired to make tests at higher Mach numbers than could be reached in the drop tests, and it was realized that rocket launching could boost models to higher Mach numbers more economically than carrying them up to high altitude with a large airplane. As a result, the Rocket Launching Facility at Wallops Island was set up, and the Pilotless Aircraft Research Division was established, with Gilruth as chief. In the period 1946–1949, rocket models were launched at the rate of over 100 per year, all expendable.

The bomb-drop project was a really high-tech operation for its day, using a B-29, the best and largest bomber in the inventory. In addition, the FPS-16 tracking radar, used to determine the trajectories, had just been developed. The telemetering equipment was not even commercially available and was all designed and built in the NACA Instrument Research Division. The operation of all this equipment was coordinated and carried out by the Langley engineers and test pilots. In retrospect, this project provided an excellent training ground for the future manned space flight programs. Many of the engineers involved went on to become designers, computer specialists, flight directors, and administrators in these later programs.

While these initial efforts were going on to provide experimental transonic data, Robert T. Jones developed a theory that was to revolutionize the design of high-speed airplanes.

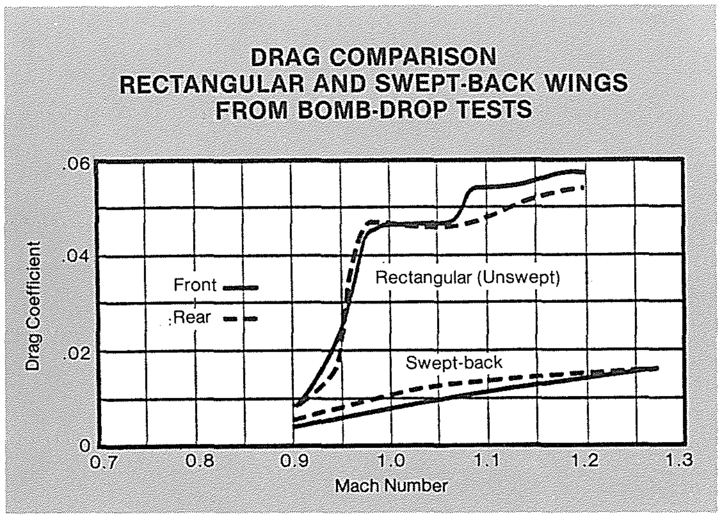


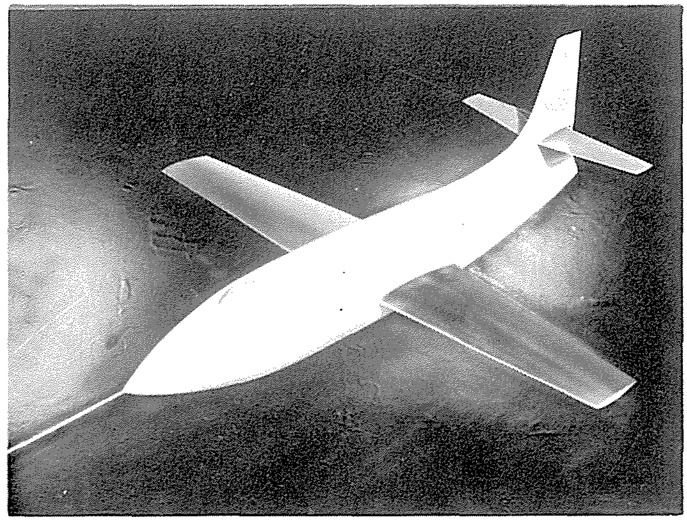
Robert T. Jones

Robert T. Jones worked at Langley from 1934 to 1946, and then transferred to Ames where he worked until he retired a few years ago. Jones probably is responsible for more useful ideas and analytical techniques than anyone else at Langley. Jones was a capable mathematician, but usually he was able, with ingenious thinking and a minimum of mathematics, to solve problems that baffled other engineers. Among his ideas that we flight-tested were all-moving tail surfaces (sometimes called stabilators) that allowed independent adjustment of hinge moments while producing maximum lift effectiveness. We also tested his beveled-trailing edge ailerons and a differential aileron linkage to reduce hinge moments. Jones' work is perhaps better known than that of some of the others I described because he gave a colloquiuum lecture here a few years ago, and because his collected works were published by the Ames Lab at the time of his retirement.

Jones' first contribution to transonic flow theory was the paper, "Properties of Low-Aspect-Ratio Pointed Wings at Speeds Below and Above the Speed of Sound." Jones had developed this theory about 1943, but the paper was immediately classified secret, so his theory was not immediately known to the industry. Soon after, Jones wrote the paper, "Wing Plan Forms for High-Speed Flight," which showed that highly swept wings would experience much less drag rise than unswept wings when going through the speed of sound. When people heard of these theories, their first reaction was usually one of disbelief. Dr. Floyd Thompson, the associate director, set up an editorial committee with Dr. Theodorsen as chairman. After due consideration, Theodorsen ruled that Jones' paper should not be published. He did not believe that supersonic flows could be analyzed by such a simple approach as Jones had used. Faced with this disagreement, Thompson ruled that Jones' paper should not be published until the results were confirmed experimentally.

By the time experimental confirmation was obtained, many other events had occurred that made the results anticlimactic. First, it was learned that a paper had been published in Germany in 1935 by Adolph Buseman, entitled "Infinitesmal Conical Supersonic Flows." This paper was





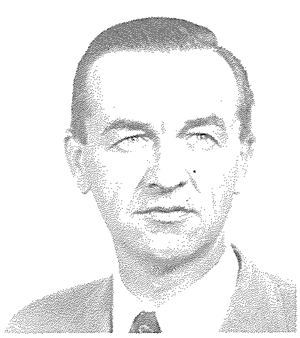
Photograph of one-quarter scale drop model of Bell XS-1 airplane.

highly mathemathical and the title was not such as to attract the attention of an airplane designer, but R.T. Jones immediately recognized that it confirmed his theory. Also, when the war ended in 1945, it was found that the Germans were using swept wings on airplanes such as the ME.163 and ME.162, and the industry rapidly became aware of their advantages.

The NACA received some criticism from the industry that they had delayed so long in publishing Jones' important result. Subsequently, confirmation of the theory was obtained by both the wing-flow and bomb-drop methods. The convincing comparison from bomb-drop tests of rectangular and 45° swept wings through the transonic range finally dispelled any doubt about the validity of Jones' theory.

The transonic problems were also being attacked by the wind tunnel people by two approaches, the Research Airplane Program and the solution of the wind tunnel choking problem. The leader of these efforts was John Stack.

John Stack worked at Langley from 1938 to 1968, and at the time was head of the Compressibility Research Division. He had a very dynamic personality, and if he believed in an idea, he would fight for it by every possible means. I recall one incident that illustrates Stack's dedication. Once about 1952, the 16-foot tunnel caught fire. The fire was in the cooling tower, up on top of the tunnel, that contained lots of oil-soaked wooden slats. It was a raging smoky fire visible from all over the Center. Stack ran up the ladders and catwalks and, standing on top of the burning tunnel, personally directed the firefighters.



John Stack

The research airplane program is too long a story for me to recount here. As early as 1938, a jet-propelled research airplane had been proposed by Eastman Jacobs. After many discussions with the Air Force and Navy, largely due to Stack's persistence, the contract for the Bell X-1 airplane (originally called the XS-1) was awarded to the Bell Aircraft Corporation. Gilruth and Stack disagreed on the fundamental reason for the tests. Stack wanted an airplane with a thick wing that would emphasize the transonic problems that he could not study in the wind tunnels. Gilruth wanted to use a thin wing to better represent future airplanes and to minimize stability and control problems that might endanger the pilot. Eventually, the Bell Corporation compromised by building two wings, one 10 percent thick and one eight percent thick.

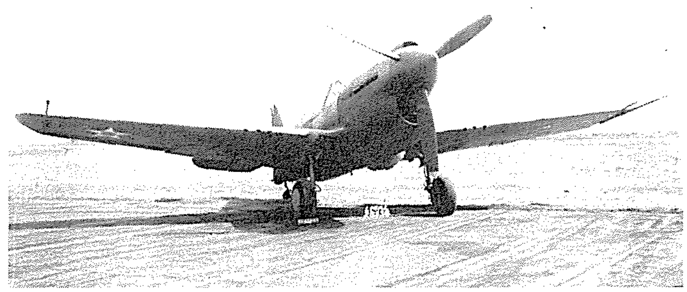
My main reason for introducing the XS-1 is to show my involvement with it. One of the unknown factors in the design of the XS-1 was the ability of the elevator to provide longitudinal control through the transonic speed range. The wind tunnels, of course, could not study the problem because of choking. It was decided to build a drop model to investigate the problem. This model also provided the opportunity to obtain some bomb-drop data under lifting conditions. Up to that time, all bomb-drop tests had been made on symmetrical models at zero lift.

The model, like other drop models, was of solid steel, had a seven-foot span, and weighed 1,350 pounds. It was equipped with a very simple type of automatic pilot. An accelerometer sensed when the acceleration went outside the range 0.4 to 0.8g. If the acceleration went outside these limits, the elevator was moved at a slow rate to bring the acceleration back into this range. The model was intended to roll slowly during the drop to maintain a predictable trajectory.

When I fly model airplanes, I customarily look at the model from the rear to check whether the wing is twisted. As a matter of habit, I did this on the XS-1 model. Though the wing was supposed to be machined to an accuracy of one-thousandth of an inch, I could readily see that the wing was twisted enough to deflect the trailing edge on each wing by about one-eighth of an inch. (This defect is something like the error in the mirror of the Hubble telescope, which was supposed to be accurate to a millionth of an inch but was actually off by about one-sixteenth inch.) Calculations showed that the wing twist was enough to cause the model to roll at an excessive rate. Therefore, two small wedges, like ailerons, were placed on the trailing edge to oppose the built-in twist.

The model reached a Mach number close to 1.0, and the longitudinal control worked as intended. At low Mach num-

North American F-86 *Sabre,* a typical Air Force fighter in service in 1950.
Curtiss P-40 *Warhawk,* a typical Air Force fighter in service in 1940.



bers, in low-density air at high altitude, the full-up deflection of the elevator of 10° was not enough to maintain 0.4g. As the speed increased, the model was held in the desired limits except for a period of rather wild oscillations at a Mach number around 0.75. At the highest Mach number, full down deflection of the elevator of 4° was not enough to hold 0.8g, and the acceleration built up to about 2g.

When the model was dropped, it was observed in the optical tracker to be rolling, as shown by flashing of light from the wings. Near the end of the flight, however, the model stopped rolling and performed a pullout. It flew far from the designated drop area on Plum Tree Island and crashed about a mile away in the swamps around Poquoson.

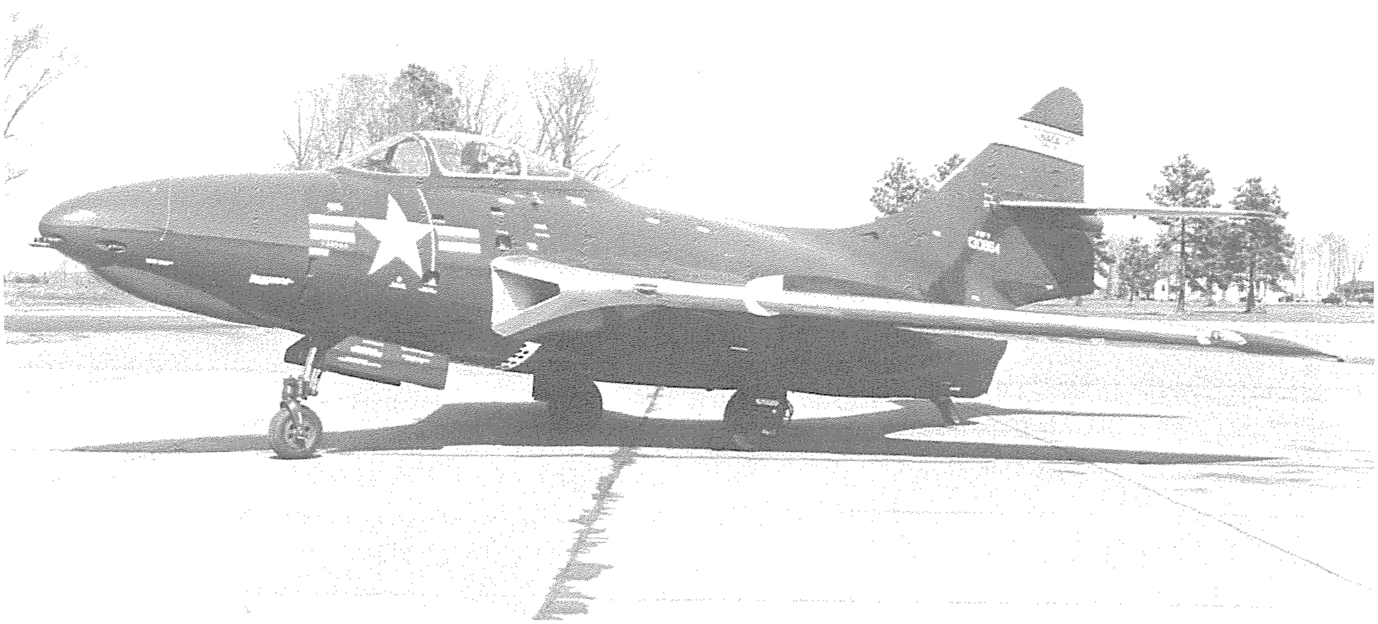
Of course, dropping a heavy bomb in a populated area is not considered very good practice, but evidently no one was aware of the incident. As a result, nothing was ever said about it, and the model, to this day, is probably buried 15 feet deep in the mud somewhere around Poquoson.

In examining the records further, the oscillation mentioned previously was found to represent a violent pitching in angle of attack from the positive to the negative stall. At this point, the model was well below the Mach number for any serious transonic effects. Knowing the heavy weight of the model and its observed rolling motion, I was led to analyze the problem as some kind of gyroscopic effect. Analysis of this type of instability was published in a report entitled "Effect of Steady Rolling on Longitudinal and Directional Stability." The report showed the possibility of this type of instability occurring on fighter airplanes then in the design stage. The problem became known as the "roll coupling phenomenon" and the report received quite a lot of attention when the problem actually was encountered on airplanes like the X-3 and the F-100. This experience shows that the important research results from a test are often quite different from those intended when the tests are planned.

The final important development in transonic testing was the slotted throat for transonic tunnels. The closed-throat tunnels, as mentioned previously, encountered choking. It was known that open-throat tunnels would go through the transonic range, but the power required for large continuous flow tunnels was excessive. Ray Wright, who worked under John Stack, reasoned that the wall corrections for closed- and open-throat tunnels were of opposite sign. A partially open test section, therefore, might be found that would reduce the wall corrections to zero. I remember attending a department meeting at which Ray Wright presented his mathematical analysis of this problem. He found that only about 12 percent open area would reduce the wall corrections to zero.

No one at this point really knew whether the slotted throat would give realistic flow conditions at transonic speeds, but the reduced wall corrections were considered attractive enough to make a small-scale test. A small jet attached as a blowdown tunnel to the 16-Foot Pressure Tunnel was installed, and rather accidentally it was found that this jet went smoothly through transonic speeds.

John Stack immediately proposed, in 1948, that the main



Grumman F9F-7 *Cougar,* a typical Navy fighter in service in 1950.

Brewster XF2A-1 *Buffalo,* a typical Navy fighter in service in 1940.

test section of the 16-Foot Tunnel be equipped with a slotted throat, and this change was approved despite opposition from some of the prominent transonic flow experts at Langley. Stack then ordered a slotted throat be placed in the 8-Foot Transonic Tunnel. This job could be completed more quickly. The slotted throat at first gave excessive drag, preventing tunnel operation at supersonic speeds. The engineers at the 8-Foot Tunnel, including Dick Whitcomb, tailored the slot shapes and in about seven months had developed a slotted throat with smooth transonic flow and no choking. By 1950, both the 8-Foot Tunnel and the 16-Foot Tunnel went into operation as transonic tunnels. These tunnels provided the facilities for Dick Whitcomb to develop the Area Rule and later the Supercritical Airfoil, making possible airplanes capable of more efficient operation at transonic and supersonic speeds.

CONCLUDING REMARKS

The research conducted at Langley in the '40s had developed the knowledge of compressibility effects from a minor problem occurring on the tips of propeller blades to a broad base of knowledge that made possible the design of airplanes capable of safe flight in the transonic speed range. The progress in Air Force and Navy fighter airplanes were made possible by this knowledge, together with the use of the jet engine. The Air Force Curtiss P-40 *Warhawk* is compared with the North American F-86 *Sabre,* and the Navy Brewster XF2A-1 *Buffalo* is compared with the Grumman F9F-7 *Cougar.* The two later airplanes, both in service by 1950, were capable of much higher performance and of dives to transonic and supersonic speeds with no adverse stability and control effects. In addition, the test facilities had been developed that made possible, in the following decade, the development of the first service airplanes capable of supersonic speeds in level flight, such as the Century Series fighters. Finally, the rocket model facility at Wallops Island had developed the engineering techniques and trained personnel that in the '50s would be able to take the lead in the Manned Space Program. □

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