REPORT OF PROCEEDINGS

of

EIGHTH ANNUAL AIRCRAFT ENGINEERING RESEARCH CONFERENCE

Under auspices of the National Advisory Committee for Aeronautics

Langley Field, Virginia

May 4, 1933.

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The Eighth Annual Aircraft Engineering Research Conference between representatives of aircraft manufacturers and Government organizations and of the National Advisory Committee for Aeronautics was held on Thursday, May 4, 1933, at the Committee's laboratory, known as the Langley Memorial Aeronautical Laboratory, located at Langley Field, Virginia.

The National Advisory Committee for Aeronautics was represented by its officers and members and also by its Committee on Aerodynamics and Subcommittee on Aircraft Structures of the Committee on Materials for Aircraft, and members of its laboratory staff.

Most of those attending the conference went by boat from Washington to Old Point Comfort and were conveyed to Langley Field by automobiles. Others went by train, and some flew direct to Langley Field.

The Washington steamer arrived at Old Point at 6:45. After breakfast on the boat the party proceeded to Langley Field, arriving there about 8:00 a.m.
MORNING SESSION.

The opening session was held at 8:15 a.m., in the Officers' Club at Langley Field, which was made available through the courtesy of the Commanding Officer of the Field: Dr. Joseph S. Ames, Chairman of the National Advisory Committee for Aeronautics, presided as Chairman of the conference.

The Chairman stated that it was with a great deal of pleasure that he welcomed those attending the Eighth Annual Aircraft Engineering Research Conference. He explained that this conference was held each year at the Committee's laboratories, which are located on an Army field, and that the members of the party were therefore guests of the Army at this time. The Chairman said that unfortunately the Commanding Officer of Langley Field, Colonel C. C. Culver, was absent from the field but that he would ask Lieutenant Colonel A. L. Sneed, Acting Commanding Officer, to say a few words before the meeting began.

Lieutenant Colonel A. L. Sneed,
Acting Commanding Officer.

Colonel Sneed said that he wished to extend to the entire party the welcome of Langley Field and that he hoped this welcome could be repeated for years to come.

Purpose of Conference.

The Chairman stated that the purpose of the National Advisory Committee for Aeronautics in calling its Annual Aircraft Engineering Research Conference was to afford an opportunity for the representatives of the Army Air Corps, the Bureau of Aeronautics of the Navy, and other Government agencies, and of the aircraft manufacturers, to review the results of the research carried out during the past year at the Committee's laboratories, and also to afford them an opportunity to witness timely and interesting demonstrations of the research facilities and activities. He said the conference also afforded
an opportunity for the Committee to receive the comments and suggestions of the technical personnel of the military and other Government services and of the aircraft manufacturers as to the Committee's research program, and that such comments and suggestions were most appreciated by the Committee. The Chairman stated that the suggestions made by the members of the conference last year had been carefully considered by the Subcommittees on Aerodynamics and Power Plants for Aircraft, and that a number of the investigations suggested had been completed and some were under way. He said that at the morning session the results of the investigations would be shown in chart form by the members of the Committee's technical staff and he requested that the information given be considered confidential and that no attempt be made to copy the charts. The Chairman said the Committee had arranged for the release of advance copies of four reports following the afternoon session, which would contain some of the information shown in chart form at the conference and in the various laboratories. He then introduced Mr. H. J. E. Reid, Engineer-in-Charge of the Langley Memorial Aeronautical Laboratory.

Mr. H. J. E. Reid, Engineer-in-Charge.

Mr. Reid stated that on behalf of the Committee's laboratory, he was very glad to welcome those attending the conference. He said that the laboratory staff felt that these annual conferences were most helpful, inasmuch as they enabled the Committee to make contacts with the industry and to obtain from the representatives present ideas and suggestions as to further research. Mr. Reid said that the morning session would be devoted to a general presentation of the results of some of the more important investigations conducted by the Committee during the past year, and this would be followed by an inspection of the various laboratories, where the results of the Committee's work would be presented in greater detail. He explained that the laboratory was divided into four divisions, the aerodynamics division, the power plants division, the hydrodynamics division, and the physical research division. He then called upon Mr. Elton W. Miller, chief of the aerodynamics division, to tell something of the work that was being done in the various wind tunnels of the Committee.
Mr. Elton W. Miller, Chief of the Aerodynamics Division.

Mr. Miller stated that it had been realized for years that high-speed flight could only be attained by better streamlining, and that Professor Melvill Jones, of England, had pointed out about four years ago that if the airplane were perfectly streamlined only about one-third as much power would be required. Mr. Miller said that considerable progress in streamlining had been made since that time but that it still had to be admitted that even in the best airplanes of to-day about half the power was used in creating a turbulent wake. He said the reduction of drag and interference was of great interest therefore in connection with the demand for higher cruising speeds and that much of the work of the aerodynamics division was directed to that end.

With the aid of charts, Mr. Miller described the investigations being conducted by the aerodynamics division. His report was as follows:

Variable-Density Wind Tunnel. The principal project of the variable-density wind tunnel during the past year has been an investigation of wing-fuselage interference. The fuselage is represented by a streamline body of revolution and the program includes rectangular and tapered wings located in various positions with reference to the fuselage. The effects of cowling and filleting and of wing incidence, as well as biplane effects, are also included. (Mr. Miller exhibited charts giving the results for a nonfilleted wing at various positions and also showing how the characteristics of a typical combination, with the wing in an unfavorable position, could be improved by the use of suitable fillets.)

At last year's conference the preliminary results were given of an investigation in the variable-density wind tunnel of a large family of airfoils. One part of that investigation included the effect of modifying the leading-edge radius of the airfoil. The work was done at the request of the Navy Department, with a view to improving the characteristics of the N.A.C.A. 2412 section in the neighborhood of the stall. (Mr. Miller presented a chart giving the results of this particular investigation.)
It is generally recognized that there is a definite loss of efficiency in propellers if the tip speed is allowed to approach the velocity of sound, and the question naturally arises: "What are the possibilities of developing a propeller section more suitable for high-speed conditions?" The high-speed tunnel has been in service throughout the year and the characteristics of a family of airfoils have been measured for speeds up to about 85 per cent of the velocity of sound. The best section resulting thus far from this investigation is called the N.A.C.A. 216. The superiority of the section is shown by the lower drag and the higher lift. The reduction in drag is most marked for the higher speed. (Mr. Miller exhibited a chart showing the characteristics of this airfoil in comparison with those of a Clark Y airfoil of 9 per cent thickness.)

Atmospheric Wind Tunnel. The atmospheric tunnel section has been engaged on two very important projects during the past year: An investigation of high-lift devices, of especial interest in connection with reducing landing speeds; and an investigation of control at low speeds, particularly in connection with the high-lift devices. Mr. Weick will discuss this work this afternoon. I wish to speak briefly, however, of another investigation being carried out by this section - an investigation of cowlings. The Committee has had many requests for information on the design of N.A.C.A. cowlings for specific applications, and to supply such information a joint investigation has been undertaken by the power plants and the aerodynamics divisions. The power plants division is finding the quantity of air required for cooling the engine with any particular internal cowl ing arrangement, and the pressure difference through the cowl ing necessary to induce this flow of air. The aerodynamics division is now making a wind-tunnel investigation to find the pressure difference and quantity of air available for cooling with each of a large number of cowl ing forms.

It is planned that the results obtained on cooling by the power plants division and the aerodynamic results from the 7 by 10 foot tunnel will be made the basis of a final program in one of the large tunnels, using actual engines, with the more promising cowl ing forms. The final data should enable the designer to select the optimum cowl ing form and dimensions to meet his particular engine requirements.
Propeller-Research Tunnel. During the past year the investigation of wing-nacelle-propeller interference has been continued in the propeller-research tunnel and has now been practically completed, including results on tractor, pusher, and tandem arrangements for air-cooled engines, and some results with water-cooled engines. The factors for the tractor-propeller nacelle on both the monoplane and biplane are considerably superior to the pusher and tandem arrangements. This is undoubtedly due to the high drag of the rear engine in the tandem arrangement and the engine ahead of the propeller in the pusher arrangement. No cowling has so far been developed which reduces the drag of these types of nacelles to a value comparable with a carefully cowled arrangement. Other results of this investigation will be presented by Mr. Wood, in the propeller-research tunnel. (Mr. Miller presented a chart giving a comparison of the best pusher, biplane, and tandem arrangements for the air-cooled engine with cowling.)

The Committee has received a number of requests for information regarding the drag of the propellers on multiengine airplanes flying with one or more engines cut out. To supply this information, tests have been made of the drag of propellers under various operating conditions simulating idling, stopped, free-running, and feathered propellers. (Mr. Miller exhibited a chart giving the corresponding drags for a 9-foot propeller operating under the conditions named.) It is to be noted that the relative drag of idling, stopped, and free-wheeling propellers at ordinary pitch settings is greatly dependent on the pitch, and the results given cannot therefore be taken as representative of all conditions. The large reduction in drag with the blades feathered, or turned to nearly 90 degrees, shows the advantage of the controllable-pitch propeller which would make possible this large saving when any particular engine is cut out.

Full-Scale Wind Tunnel. A number of investigations have been carried out in the full-scale wind tunnel during the year. I shall only mention one of them - an investigation of buffeting on the tail of the McDonnell airplane. It has been pointed out before that the use of cowling and fillets has much to do with the smoothness of flow about the fuselage.
It was desired to find out in the case of the McDonnell airplane how the characteristics of the airplane, and particularly the buffeting on the tail, would be affected by the use of cowling and fillets. (Mr. Miller exhibited charts showing the polars for the different conditions mentioned and the effect of a fillet between the wing and the fuselage.) Installation of cowling and fillet together gave the largest reduction in drag and the greatest increase in lift.

Measurements were made of the amplitude of oscillation of the tail surfaces with the various alterations mentioned. (Mr. Miller exhibited a chart showing the per cent reduction in amplitude at 2 degrees below the stall.) The effects of the N.A.C.A. cowling, of a short auxiliary airfoil mounted in front of the main airfoil, of a fillet and the N.A.C.A. cowling in combination, and of a fillet alone were investigated. The fillet alone apparently reduced the buffeting to the greatest extent.

There has been considerable interest in recent years in the comparison of maximum lifts of airfoils as measured in different wind tunnels and of airplanes as determined in flight. As was stated last year, it has been possible to obtain excellent agreement between the results of tests of airplanes in our full-scale wind tunnel and in flight. The possession of the full-scale wind tunnel and the variable-density wind tunnel places the Committee in an especially favorable position to make a somewhat careful investigation of the subject of maximum lift coefficients.

It should be stated that the full-scale maximum lift coefficient of a particular wing is not a definite value, as might be supposed, but extends over a considerable range of Reynolds Numbers, depending on the size and landing speed of the airplane in question. (Mr. Miller exhibited a chart showing the results of tests on a series of Clark Y airfoils in the full-scale wind tunnel, all of the same aspect ratio but of different dimensions.)

Mr. Reid then called upon Mr. J. W. Crowley, Jr., who is in charge of the flight research section, to tell something about the work being done in that section.
Mr. J. W. Crowley, Jr., Flight Research Section.

Mr. Crowley presented various charts and described the investigations being made by the flight research section. His statement was as follows:

Because of the possibility of obtaining sustentation with little or no forward velocity, and the consequent possibility of safe flight at slow speeds, considerable attention has been given during the year to various types of rotating-wing systems. For the most part, the investigations made so far have consisted of studies of the theory of operation of the different types of systems, and have resulted in the formulation of a research program covering those types which showed promise.

Cyclogiro - Performance Prediction. One of the types studied is the cyclogiro. This machine derives its lift and thrust from two reaper-like rotors, one on each side of the fuselage, and has very interesting possibilities, particularly as regards flight in the very low speed range. The rotors are driven at a constant speed, and the desired amounts of lift and thrust are obtained by varying the angle of attack of the blades, which is accomplished by cams on the axis of rotation. As a consequence of the constant engine speed, the power available at all air speeds is constant. It has been taken at 270 horsepower, 20 horsepower being assumed to be lost in overcoming gear friction. (Mr. Crowley exhibited a chart giving the predicted performance curves for a 3,000 pound machine with 300 horsepower.) It is particularly interesting to note that there is an excess of power available at zero forward speed, which enables the machine to hover and climb vertically at 780 feet per minute. The maximum rate of climb is 1800 feet per minute. The top speed is about 90 miles an hour, considerably less than a clean airplane of the same weight and power. The rotors are capable of autorotating in the case of engine failure, and landings can be made satisfactorily.

Our studies show the desirability of further research and development of this type of aircraft, and model tests have been included in our research program.
Fixed Elevator - Landing Approach in Rough Air. Last year we discussed to some extent the possibility of obtaining a simplified landing procedure and shorter landings with conventional airplanes by the so-called "glide landing," in which the airplane is landed from a glide with a fixed stick position without the usual leveling-out procedure. We have demonstrated, by actual landings, that such a type of landing is advantageous and is perfectly feasible in smooth air, providing only that the airplane is equipped with a long-stroke shock absorber. We have questioned, however, the feasibility of this type of landing in rough air, and to obtain information on this subject, have measured the motion of an airplane making simulated glide landings in gusty air. (Mr. Crowley exhibited a chart showing how the motion of the airplane is affected by gusty air.) The results of this investigation indicate that, as far as landings in rough air are concerned, fixed-stick landings are of limited use and that in general during a landing, additional control should be in reserve to immediately counteract the effect of gusts.

Spinning Investigation. Spinning investigations have been continued during the year in flight and in the spinning tunnel which now is in regular operation. Our work to date indicates rather definitely that the most effective method of eliminating bad spinning characteristics is to provide sufficient damping yawing moment. Last year we showed, by means of motion pictures of the smoke flow over tail surfaces in flight, that conventional vertical tail surfaces could not be very effective in providing damping moment in yaw because of being blanketed by the horizontal tail surfaces. This year we will show the results of modification to the tail surfaces to improve their effectiveness.

Effect of Position of Horizontal Surfaces. An investigation was conducted in the spinning tunnel of the effect of the position of the horizontal tail surfaces on the yawing moment developed in a spin. Tests were made with the horizontal tail surfaces in three vertical positions and three fore-and-aft positions, and the yawing moment measured for various angles of attack while the model was spinning. (Mr. Crowley exhibited a chart showing the results of this investigation for an angle of attack of 50 degrees.)
general, these results indicate that it is possible to obtain increase in yawing moment, which we know is desirable from the standpoint of the spin, by a high or rearward position of the horizontal surfaces, or probably both.

**Effect of Fins on Spin.** In flight, the most interesting spinning investigation made during the year was for the purpose of improving the spin of a fighter airplane. Although from past experience we appreciated that fins located above the stabilizer and elevator are inefficient in producing yawing moment, practical features of the particular problem prevented the employment of any other measures, and consequently the effect of different size fins was investigated. (Mr. Crowley exhibited a chart illustrating the sizes of fins investigated.) As far as the spin itself was concerned, it was noted that there was a progressive improvement with the increase in size of the fin. The primary purpose of this investigation, however, was to improve the recovery characteristics. With the small fin the turns required for recovery were indefinite. In some cases, with the normal operation of the controls, recovery could be effected in four or five turns. In other flights, under apparently identical conditions, recovery could not be effected at all by usual control manipulation, but required a special handling of the controls, including full aileron with the spin. With increased size of fin, recovery became definite and could be accomplished with few turns, the large fin making it possible to recover in 1-3/8 turns.

Research on the aerodynamic loads experienced on airplanes in flight has, as in the past, been a major part of the flight research work. During the past two years the Committee has concentrated on that part of the load problem concerned with determination of the maximum total loads or accelerations, or load factors, that an airplane will experience under normal operating conditions. In general, it has been found that the loads experienced are a function of the use of the airplane which may be roughly distinguished as acrobatic and non-acrobatic, and that in the acrobatic category, the loads are largely dependent upon piloting technique, while in the non-acrobatic group, they depend primarily on the effect of atmospheric gusts.
Influence of Control Heaviness on Probable Load Factors. From the results of tests involving a number of pilots, it has been established that the average pilot will see "black" at an applied acceleration of about 5.5 or 6, and that in general, if allowed to use his own discretion, he will limit the severity of the maneuver to the acceleration at which he sees "black." We had thought that heaviness of the control would be the most important factor in connection with accelerations obtained on different airplanes in maneuvers, but results are now available that indicate that the control heaviness is of secondary importance except when it is abnormally high or low. (Mr. Crowley exhibited a chart showing the influence of control heaviness on probable applied loads.)

Load Factors in Inverted Maneuvers. Last year charts were shown representing the probable applied total load experienced by airplanes in maneuvers which, for the most part, were carried out in the positive angle of attack range. During the past year, from a number of different sources, similar information has been assembled for a variety of inverted maneuvers, that is to say, maneuvers performed in the negative angle of attack range. (Mr. Crowley exhibited a chart showing the results of this study.) From the results obtained, in combination with the pilots' remarks as to the effect of accelerations in the inverted direction, it has been concluded that the principal limitation to the severity of the inverted maneuver is the physiological resistance of the pilot to the acceleration. It is probable that a negative acceleration of 5g is a reasonable maximum to which pilots will care to subject themselves or can withstand repeatedly without harmful effects.

Gust Probability Curve. During the past two years the Committee has been collecting accelerometer measurements on a number of transport airplanes over several routes covering, broadly speaking, the whole United States. From the accelerations measured and certain characteristics of the airplane, it is possible to calculate the magnitude of the vertical components of the gusts that are responsible for the accelerations. For accelerometer measurements obtained in approximately 1,300 hours of flying time, calculations of the magnitude of the gusts encountered have
been made and a gust probability curve has been derived. (Mr. Crowley exhibited a chart showing the results of this study.) It was noted from the results of this study that the speed at which any gust is encountered has a very appreciable effect on the acceleration or load experienced, and therefore with the advent of increasing cruising speeds in transport airplanes, the question of loads caused by "bumps" becomes increasingly important.

Mr. Reid said that quite often in connection with the study of research problems, difficulties were encountered, but that with the assistance of the physical research division these small troubles were soon straightened out. He stated that one of the recent investigations which was of interest was the study of boundary-layer corrections in wind tunnels, and that Dr. Theodore Theodorsen, who is in charge of the physical research division, would tell something about this work.

Dr. Theodore Theodorsen, Chief of the Physical Research Division.

Dr. Theodorsen said that there had been in the past considerable uncertainty as to the proper value of the wind-tunnel boundary correction factor, in particular with respect to the applicability of the purely theoretical results. He said the laboratory had just completed an extensive experimental investigation on the boundary correction factor and that because of the unusual opportunity afforded by the full-scale tunnel, it had been possible to obtain a precise experimental verification of the theory. Dr. Theodorsen said that the results of this investigation would be published shortly in a Technical Report entitled "Experimental Verification of the Theory of Wind-Tunnel Interference."

Dr. Theodorsen said that throughout the past year a remarkable activity had taken place in the theoretical study of the problem of wall interference and that the effect of a finite span had been taken into account. He said that Glauert was responsible for the first result, which referred to a closed rectangular section, that a very excellent paper by two Japanese scientists, Sanuki and Tani, produced the correction factor for elliptical cross sections, both open and closed, also for airfoils
of finite span, and that a curve for the open rectangular section had been developed by the National Advisory Committee for Aeronautics. Dr. Theodorsen exhibited a chart showing these curves and stated that they would be contained in the Technical Report referred to.

Dr. Theodorsen said that the National Advisory Committee for Aeronautics was alone in the field of experimental studies on the boundary correction factor, no others having made any attempts to verify the theory, and that Technical Report No. 361, repeatedly quoted as the only reference, indicated a certain contradiction to the extent that there seemed to be a different correction for the angle and for the drag. He said the preliminary results of the present study also showed the same duplexity and that the correction factor was also seen to exceed the predicted value. Dr. Theodorsen said the tests were carried out on a series of standard Clark Y airfoils in both the model of the full-scale tunnel and the full-scale tunnel itself.

He said it was also shown that the maximum lift decreased with an increase in size of the airfoil and that it was also affected by the location of the airfoil in the test section. Dr. Theodorsen exhibited a chart showing the results obtained in the full-scale wind tunnel and in the model tunnel.

Dr. Theodorsen said that after numerous attempts to explain the contradictory results on the correction factor, it was realized that the decrease in maximum lift referred to tended to show that something was wrong with the velocity head, and to investigate this possibility an airplane was installed in the full-scale wind tunnel and the velocity measured immediately in front of it. He said the velocity head was found to be about 7 per cent below the estimated theoretical value, and that an airplane was next calibrated in flight with Pitot tubes at various locations and then installed in the full-scale wind tunnel. Dr. Theodorsen said that a difference of about 6 per cent in the velocity head was found, and as no apparent reason existed for this peculiar velocity drop, the phenomenon was investigated with great care. He presented a chart showing how the velocity error varied along the span of the airplane. Dr. Theodorsen said that the error became greater with an increase in the size of the object and that it was also found to increase until the angle of maximum lift was reached. He said the effect was restricted
to the immediate vicinity of the object, gradually diminishing towards the edges of the jet, but that it extended far in a forward direction and to a certain extent all around the tunnel and therefore was not related to the ordinary displacement blocking, which was negligible. Dr. Theodorsen said that with the establishment and isolation of this effect as the correction for the velocity head in the tunnel, the difficulties in the way of checking the boundary correction factor were cleared up. He exhibited a chart showing the final corrected results of the boundary correction factor.

Dr. Theodorsen said that the National Advisory Committee for Aeronautics had the unique opportunity of being able to compare flight results directly against the results obtained on the same airplane in the full-scale wind tunnel. He exhibited a chart showing the comparison, from the application of the boundary correction factor to the full-scale tunnel results on a full-scale airplane. Dr. Theodorsen said it was interesting to note that the maximum lifts compared very well, indicating that the turbulence in the full-scale wind tunnel apparently compared with that of the normal atmosphere.

In connection with the activities of the power plants division, Mr. Reid stated that during the past year some very interesting results had been obtained from investigations of safety fuel and of compression-ignition and two-stroke cycle engines. He said that a number of suggestions were made at the conference last year which the power plants division had had an opportunity of considering, and that Mr. Kemper would tell something about the results of these investigations.

Mr. Carlton Kemper, Chief of the Power Plants Division.

Mr. Kemper described the work being done by the power plants division, and presented various charts illustrating the results in detail. His statement was as follows:

At no other time in the history of the development of power plants for aircraft have the purchasers of airplanes been so overwhelmingly in favor of air-cooled engines as at present. The two factors which have greatly increased the performance obtained with radial
air-cooled engines have been the reduced drag of this type engine when fitted with the N.A.C.A. cowling or ring cowlings, and the improvement in specific power and weight obtained with new designs of cylinder finning. The demand for more powerful air-cooled engines is being supplied by increasing the number of engine cylinders and the engine speed. The large number of cylinders, usually fourteen, arranged in two banks, increases the difficulty of obtaining satisfactory cooling of all engine cylinders.

A considerable part of the aircraft engine research undertaken by the Committee during the past year has been directed toward a study of the fundamental factors influencing the cooling of air-cooled cylinders. The research program includes first, a study of the effect of fin pitch, fin width, and average fin thickness on the temperature distribution in and the quantity of heat dissipated from finned cylinders to an air stream; second, the determination of the quantity of air and pressure differences required to cool satisfactorily a given design of engine cylinder; and third, a study of the factors affecting the cooling of two-row radial engines.

The effect of fin pitch, fin width, and average fin thickness on the temperature distribution in and the heat dissipated from a steel cylinder having tapered fins has been investigated, using an electrically heated finned cylinder mounted in a wind tunnel. The range of fin pitch investigated was from 0.1 to 0.6 inch, the range of fin widths from 0.37 to 1.47 inch, and the range of average fin thickness from 0.04 to 0.27 inch. The cylinder diameter has been maintained constant at 4.5 inches. The temperature distribution and heat transfer coefficients for a given design of fin have been determined for air speeds from 30 to 150 miles per hour.

In order to present the data in a form which could be readily used by aircraft engine designers the actual geometrical area of the fin cooling surface, which is not uniform in temperature, is reduced to equivalent cooling area at a definite temperature. The temperature used is that of the fin base which makes it possible to treat all the cooling surface as if it were part of the cylinder wall. The results of tests made to determine the effect of fin pitch have indicated that
there is no appreciable reduction in the heat transfer if the fin pitch is maintained in excess of 0.1 inch. (Mr. Kemper presented a chart showing the effect of dimensions of steel fins on the heat transfer of air-cooled cylinders at an air speed of 80 miles per hour.)

All cowled radial engines require some form of intercylinder baffle or cylinder shrouds to obtain satisfactory engine cooling. The general use of the N.A.C.A. cowling and the advent of the two-row radial engine have necessitated a study of the cylinder baffles in order to obtain satisfactory engine cooling with the small frontal openings in the cowlings. The quantity of air available for cooling the engine is being reduced and effective cooling is being obtained by insuring that all the air taken into the cowling is brought in contact with the cooling fins on the cylinders. One of the questions which must be answered when using cylinder baffles is "How close should the baffles be placed to the cylinder without reducing the efficiency of the cooling fins?"

Tests were conducted to determine the effect of distance from fin tip to baffle on the temperature distribution of a finned steel cylinder mounted in a wind tunnel, and the results indicated that the closer the baffle to the fins the greater the cooling.

The study of the cooling of the two-row radial engine is being conducted in the full-scale wind tunnel at the request of the Bureau of Aeronautics, Navy Department. The object of this investigation is to obtain design information regarding the effect of wind speed, engine power, and engine speed on the cooling of two-row radial engines. The engine is mounted in a Navy service airplane. The equipment is unique in that the engine is fitted with a controllable-pitch propeller and a geared blower so that it is possible to develop constant engine power over a wide range of engine speeds and manifold pressures. The effect of wind speed on the cooling can be determined by varying the tunnel air speed. The temperature distribution over the engine is being investigated with 47 small-diameter wire thermocouples and two recording pyrometers. Thirty of these thermocouples are being used to determine the temperature distribution over two representative cylinders, one in the front row and one in the rear row of the engine. The velocity of the
cooling air flowing through the cowling is being studied with a large number of small-diameter impact tubes. (Mr. Kemper exhibited a chart showing the effect of wind speed on cylinder temperatures for a constant power output of 560 brake horsepower and an engine speed of 2,100 r.p.m.)

Recent aircraft accidents have forcibly brought to the attention of the transport operators the need for reducing the fire hazard in aircraft. The investigations conducted by the Committee have shown that the best way to materially decrease the fire hazard in aircraft is to use fuels having flash points considerably higher than that of the present gasolines. The Bureau of Aeronautics, Navy Department, has been sponsoring the research work undertaken by the Committee to determine the performance of aircraft engines operating with the new hydrogenated safety fuels developed by the Standard Oil Company of New Jersey. The flash point of the hydrogenated safety fuel tested by the Committee, determined by the open-cup method, was 125°F. Because of the low volatility of these safety fuels it is necessary to inject the fuel into the engine cylinder with a fuel injection system. A unique characteristic of these hydrogenated safety fuels is their high octane number. The hydrogenated safety fuel used in this investigation could be operated at a compression ratio of 8.0 without detonation.

The performance of a particular design of liquid-cooled engine cylinder operating with safety fuel has been studied during the past year at the request of the Bureau of Aeronautics of the Navy Department. The research has included a study of the effect of injection valve location, rate of fuel injection, and fuel distribution on the performance of a single-cylinder test engine when operating at compression ratios of 5.85 and 7.0. The range of engine speeds investigated was from 1,200 to 2,200 r.p.m. The effect of valve overlap and boost pressure on the performance of the engine has also been determined. (Mr. Kemper presented a chart showing the engine performance with hydrogenated safety fuel obtained when operating at a speed of 1,750 r.p.m. and a compression ratio of 7.0.)

Starting a cold engine with the safety fuel cannot be accomplished because of the low volatility of the fuel. Starting can be readily obtained by heating
the inlet air or the fuel in the injection lines. The best method of starting was found to be the injection of a small amount of gasoline into the inlet air by using the conventional engine priming system. Once the engine was fired on the gasoline-air mixture the safety fuel could be injected and the engine would continue to run on the safety fuel. The amount of gasoline required for starting a cold engine would be small and could be carried in a separate container connected to the engine priming system.

The designers of airships are of the opinion that the successful commercial airship must be powered with compression-ignition engines. The use of compression-ignition engines reduces the fire hazard and permits operating over a wide range of engine speeds with low specific fuel consumptions. To obtain additional lift and to eliminate the present heavy water recoveries when helium is used, the commercial airships would obtain the greater part of their lift from hydrogen stored in gas cells within the helium cells. Since the hydrogen required to lift a given weight of fuel contains a quantity of heat energy equal to 20 per cent of the heat energy of the fuel it would be desirable to utilize this energy in driving the airship by burning the hydrogen in the compression-ignition engines. If sufficient hydrogen could be burned efficiently in the compression-ignition engines to maintain constant lift, the use of water recovery apparatus would not be necessary. The recommendation was made at the last research conference that the Committee determine possible means of efficiently burning hydrogen in high-speed compression-ignition engines.

The investigations made by the Committee on a single-cylinder test engine showed that it was possible to burn sufficient hydrogen mixed with the inlet air to maintain constant lift for a full range of engine loads. The combustion of the hydrogen in the engine gave increased engine power and decreased fuel consumption.

The results of this investigation have been applied in comparing the performance obtained with an airship inflated with helium and using water recovery apparatus, and an airship of the same displacement having one-fourth the displacement filled with helium and the remainder filled with hydrogen.
The calculations show that for the same distance the pay load of a 6,500,000-cubic-foot airship could be increased 62 per cent by using hydrogen and helium instead of helium alone. For the same fuel load an increase in the cruising radius of 35 per cent could be obtained by burning the hydrogen in the compression-ignition engines.

A saving in aircraft power plant weight or increase in the power output per cubic inch of displacement may be utilized to give increased pay load or increased cruising speed. The two principal methods of increasing the power output of conventional engines operating on the four-stroke cycle are to increase the brake mean effective pressure and the engine speed. By placing the air charge under pressure and using a portion of the air charge to push the exhaust gases out of the engine cylinder it is possible to eliminate the exhaust and inlet strokes of the four-stroke cycle and operate upon the two-stroke cycle. To prevent the loss of fuel with the scavenging air it is necessary to inject the fuel into the engine cylinder and to time the injection to occur after the exhaust ports are closed. The Committee has continued its investigation of the factors influencing the performance of spark-ignition and compression-ignition engines operating on the two-stroke cycle. (Mr. Kemper exhibited a chart showing the performance of the two-stroke-cycle compression-ignition engine for a constant engine speed of 1,330 r.p.m.) Research now in progress to determine the optimum timing of the inlet ports and the exhaust valves should result in further improvement in the engine performance.

Mr. Reid said that during the past year a number of investigations had been conducted in the N.A.C.A. Tank. He said several requests had been received from members of the industry to have special work done in this tank at their expense and that this had necessarily delayed the Committee's research program for this piece of equipment. Mr. Reid said that Mr. Starr Truscott, who was in charge of the N.A.C.A. Tank, had a number of projects under way and had some very interesting results to present. Mr. Reid then called upon Mr. Truscott.
Mr. Starr Truscott, Chief of the Hydrodynamics Division.

Mr. Truscott referred to the work done by the Committee for outside parties mentioned by Mr. Reid, which included tests for the Edo Aircraft Corporation and the Glenn L. Martin Company, and certain specific work on hulls which was requested by governmental agencies. He said that the time necessary to complete these various tests seemed rather long, but that this was due to the fact that the time required for the tank to become quiescent after each run was so great that it had only been possible to make about fifteen runs a day. Mr. Truscott said that the problem of shortening the time between runs was recently solved by placing damping plates in the tank, and that it was now possible to make fifty runs a day.

He stated that during the past year the Committee had endeavored to carry out the tests requested at the last conference, which included a study of the fundamental factors connected with the friction of flying boat hulls, similar factors connected with the friction of seaplane floats, and some fundamental studies on planing surfaces.

Mr. Truscott said that an attempt had been made to determine the manner in which the performance of flying boat hulls on the water was affected by systematic changes in the dimensions and that about 1,000 different readings had been taken during the first series of tests. He said that they selected a float of good form and changed it by increasing the length and keeping the beam the same and then by increasing the beam and keeping the length the same, and that it had been found that the resistance at the hump speed decreased as the length and beam were increased, but that at high speed the resistance was increased in both cases. (Mr. Truscott exhibited charts showing the results of these tests.)

Mr. Truscott said that some of the data from this original series of investigations had been applied in the testing of a Macchi racing seaplane float of the 1926 type, and that for all speeds this float showed an improvement in performance.

Mr. Truscott said that the program covering the investigation of planing surfaces was now under way and that there would be a demonstration in the N.A.C.A. Tank in the afternoon which would illustrate some of the results
of this investigation. He said that a planing plate would be attached to the carriage and towed at an incline along the surface of the water and the pressures over the plane measured.

With reference to the work on the resistance of rivet heads on the outside of floats, Mr. Truscott said that equipment was now on hand for this investigation and that it would be undertaken in the near future.

**INFORMATION OF LABORATORY.**

The Chairman stated that Mr. Truscott's report concluded the morning program and that after lunch the guests would again assemble in the Officers' Club for the afternoon session, at which time Mr. Fred E. Weick would present some of the results of investigations conducted by the Committee during the past year on certain high-lift devices. The Chairman requested the guests to assemble in front of the Officers' Club in four groups, for a tour of inspection of the laboratory. The groups were composed of those with red tags, those with white, those with blue, and those with brown. The tags had been handed to the guests as they boarded the boat in Washington, and to others as they registered upon arrival. The Chairman stated that the blue group would be under the direction of Mr. Lewis, the brown group under Mr. Victory, the white group under Mr. Truscott, and that he would be in charge of the red group. He requested each group to keep together as much as possible in order to avoid confusion and delay. The Chairman said that the tour of inspection would end at the full-scale wind tunnel, where lunch would be served at 12:10 p.m. He stated that at the full-scale wind tunnel there would be on display most of the Committee's exhibits which had been prepared for the Century of Progress Exposition in Chicago.

The members of the conference then proceeded on a tour of inspection of the laboratory in accordance with the following program:

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At 12:10 p.m. all groups reassembled for lunch at the full-scale wind tunnel, after which they inspected the exhibition models prepared for the Committee's exhibit at the Century of Progress Exposition.

At 1:30 p.m. the entire party assembled in the test chamber of the full-scale wind tunnel, where a group photograph was taken. A Navy scouting airplane, the X04U-2, equipped with a two-row radial engine and a controllable pitch propeller, was in position for testing. Mr. DeFrance stated that at the request of the Bureau of Aeronautics of the Navy, the Committee was making a study of the cowling and cooling of this engine.

At 2:05 p.m. the party proceeded to the N.A.C.A. Tank, where Mr. Truscott gave a more detailed description of the program of tests for this equipment. He also called attention to models of various floats and hulls which were on display. Following this, a demonstration was made in the tank of a planing surface being towed through the water. At the rear of the carriage a board carrying several manometers to record the pressures was attached. The manometer board was so displayed that it could be viewed by the guests and the different levels in the tubes noted as the model was towed. The running of the model in the tank also demonstrated the effectiveness of the wave suppressors.

**AFTERNOON SESSION FOR DISCUSSION OF HIGH-LIFT AND LATERAL CONTROL PROBLEMS.**

At 3:30 p.m. the members of the conference interested in aerodynamic problems reconvened in the Officers' Club, with Dr. Ames presiding, a special conference for those interested in engine problems being held simultaneously in the power plants laboratory.

Mr. Victory announced that the guests who were leaving Old Point Comfort by train or by any other means of travel than the boat to Washington might nevertheless board the Washington boat at Old Point Comfort at 4:45 p.m., and in company with the majority bound for Washington, proceed to Norfolk without additional charge, have dinner on the boat, and return to Old Point on the Washington boat in time to catch evening trains. He said that this arrangement had been made because of the fact that the Chamberlin Hôtel at Old Point was closed.
The Chairman asked Mr. Reid to explain the principal subject of discussion at this session.

Mr. Reid stated that during the past year probably more interest had been shown in high-lift devices and various means for control of airplanes than in any other subject which had been investigated in the various researches at the Committee's laboratory, and that owing to this unusual interest the Committee had changed its program somewhat from that followed in previous years, and would devote this session particularly to the discussion of this problem. He said that Mr. Fred E. Weick, who was in charge of this work, would describe briefly the work done by the Committee during the past year on high-lift and lateral-control devices.

Mr. Fred E. Weick, Assistant Chief of the Aerodynamics Division.

Mr. Weick presented a statement and exhibited a number of charts of the results of the Committee's investigation of high-lift and lateral-control devices for airplanes, as follows:

The marked increase during the past year or two in the speed of military and commercial airplanes has been accomplished partly by increase of engine power, but principally by reduction of drag. This low drag brings with it the disadvantage of limiting the gliding angle that can be obtained at low speed and makes necessary a very long, flat approach to a landing. The higher maximum speeds have also been accompanied by a tendency to use heavier wing loadings, and the landing speeds have increased to about 70 miles per hour in many cases. Under these adverse landing conditions devices for increasing the maximum lift coefficient and also the drag at the high angles of attack are of the greatest interest.

Last year at this time the highest lift coefficient which the Committee had obtained was 3.17, which was obtained with the Fowler wing, as shown by the first figure on the chart. Since then the Committee has continued the investigation in an attempt to obtain still higher lift coefficients. The arrangements studied, as shown on the chart, include a
conventional Handley Page slot added to the leading edge of the Fowler wing; a special slot having a slat of good airfoil section combined with the Fowler flap; and this same arrangement with the addition of a fixed slot, in accordance with a suggestion of Mr. Fowler. This last combination gave the highest lift coefficient yet obtained, 3.76.

The next chart shows a flap consisting of an auxiliary airfoil pivoted at the rear of the main wing, as developed by Wragg and used on recent Junkers airplanes. The auxiliary is so located that a slot is formed between the two wings, but the auxiliary is not retracted into the main wing. With this arrangement and with an auxiliary airfoil of 15 per cent, the maximum lift coefficient was 1.81.

In this connection it should be explained that two different areas are used by the laboratory in the computation of maximum lift coefficient. With retractable devices the lift coefficient is based on the original wing area regardless of whether the flap is extended or retracted, for then the coefficient correctly shows the difference in lift with the device extended and retracted, but with devices which are not retracted into the wing the total area is used. The lift coefficient of 1.81, which is based on the total area, would be 2.08 if based on the area of the main wing only.

The fixed auxiliary airfoil, which was demonstrated at last year's conference on an F-22 monoplane, has been investigated further. Tests have been made on several sizes of auxiliary wing with three different airfoil sections each, in various positions with respect to the main wing. None of these has been found to be definitely superior in all respects to the original, although a symmetrical section gives a lower minimum drag. The chart shows four sizes, all having the original section, each being shown in its optimum position.

The next chart shows a combination of the fixed auxiliary airfoil ahead of the wing and a split trailing-edge flap at the rear. The maximum lift coefficient, based on the basic area of the main wing, was increased from 1.25 for the plain wing and 1.99 for the fixed auxiliary airfoil alone, to 2.54 with a
simple 20-per-cent split flap and to 2.91 with a 30-per-cent flap of the Zap type, in this case moved to the rear as well as deflected downward. In view of the active interest shown in the split flap, the tests have been extended to include the effect of variations in location of the flap and also the hinge moments. The next chart shows the maximum lift coefficients obtained with simple flaps of different chords. It is apparent that there is no advantage in increasing the flap chord to greater than about 20 per cent of the wing chord.

The next chart shows the effect on the maximum lift coefficient of cutting away the flap from the tips, and also from the center. As the flap is cut away from the tip, the loss of lift is small at first, but becomes substantial if sufficient flap is removed to allow room for ordinary ailerons. If the flap is cut away from the center, the loss starts more rapidly, being in the neighborhood of 8 or 10 per cent for the cut-out usually found necessary for structural reasons.

The Committee's investigation of lateral control has been continued, with a view to finding at least one means of lateral control which is satisfactory from all standpoints throughout the entire range of angle of attack used. Some of the devices which appeared promising from the wind-tunnel investigations have been tried during the past year on an airplane in flight, and as a result information has been obtained regarding the requirements of good lateral control, and it has also been found that each of the devices tested has one or more undesirable characteristics.

One interesting feature brought to light by the comparison of the flight and wind-tunnel tests is that the yawing effect of ailerons as observed by the pilots corresponds to the yawing moments as measured in the wind tunnel about wind axes, not body axes as had previously been thought. As an example of the effect of adverse yawing moments, consider an airplane (demonstrating with small airplane model) gliding to a landing, which suddenly encounters a gust of wind causing the left wing to drop. The pilot, moving the stick to the right, turns the left aileron down and the right one up. When the left aileron is deflected
downward it causes an increase in drag on the left wing which tends to retard the left wing and causes the airplane to turn or yaw to the left. This adverse yawing effect, due to the fact that the upper, or right, wing is traveling more rapidly than the left wing and therefore has higher lift, induces a rolling moment in the opposite sense to the primary rolling moment of the ailerons. If the angle of attack is sufficiently high, with ordinary conventional ailerons this yawing effect will be sufficient to keep the left wing from rising, and the airplane is likely to go into a spin to the left. The yawing moments caused by the ailerons are unimportant in cruising and in high-speed flight, but are of great importance at the high angles of attack near and above the stall.

The wind-tunnel tests had showed that all of the conventional aileron arrangements, regardless of differential motion or of such balancing arrangements as the Frise type, gave adverse yawing moments with respect to the wind axes at high angles of attack. After further examination of these wind-tunnel results in the light of the flight results, it is not surprising that control above the stall was not obtained in flight with conventional ailerons of either the long narrow or the short wide form, regardless of differential motion. Lateral control above the stall was obtained with spoilers, but these had the defect of a lag or delayed action. It appears at the present time as if a lateral control arrangement which would be satisfactory in every respect, except possibly for increased complication of structure, both above and below the stall would be the proper combination of ailerons and spoilers.

The next chart shows computed rolling moment coefficients from the results of flight tests on the McDonnell low-wing monoplane equipped with both slots and flaps, the flaps being cut off to allow room for conventional slotted ailerons. These curves show that the rolling moment coefficients obtained were about the same regardless of whether the slots were open or closed or the flaps up or down, which is in accordance with what would be expected from the wind-tunnel tests.

There is not time to mention all the work done during the past year on lateral control, and most of the remainder of the discussion will be confined to lateral control devices suitable for wings with flaps or other
high-lift devices which extend over the entire span. The next chart shows the various devices of this nature now being studied. These include two types of spoiler, one retractable, sliding in and out of the slot, and the other of the hinged-flap type, which fits along the upper surface when closed; an upper-surface aileron, which may be considered as a flap-type spoiler in the rearmost possible position; an external aileron consisting of a separate airfoil supported near the wing, which, when deflected downward, becomes in effect a spoiler; another external aileron just above the trailing edge of the wing, in the position used in the Zap arrangement; an auxiliary airfoil forward of the wing, usually considered fixed but here deflected differentially for lateral control; and finally an auxiliary flap which is deflected downward for high lift and also differentially for lateral control, as in the Junkers designs.

The next chart shows the results of wind-tunnel tests on spoilers of the retractable type as compared with the results for conventional ailerons. The rolling moment coefficients of the spoilers are low compared with those of the ailerons at low angles of attack in the high-speed range, but increase to a slightly greater maximum value than is obtained with the ailerons. Whereas the yawing moments with the conventional ailerons are adverse and have reasonably high values at the stall and above, with the spoilers large positive yawing moments are obtained.

The results of flight tests on the F-22 high-wing monoplane of this same type of spoiler, of the hinged-flap type of spoiler, and of conventional ailerons of long narrow form are shown on the next chart. The curves show the control deflection against time in seconds, and indicate that all three controls reached their maximum deflections in approximately the same time. With the ailerons the rolling velocities started in the right direction as soon as the stick was deflected, but with both types of spoilers there was a slight rolling in the wrong direction first, followed by a rolling in the right direction, which built up to a much higher rate of rotation than with the ailerons. This start in the wrong direction gives the effect of a delayed action or lag of about 0.5 second, which makes these spoilers unsatisfactory as lateral-control devices when used by themselves.
The next chart shows the results of wind-tunnel tests on upper-surface ailerons. The rolling moments are about the same as those obtained with the standard conventional ailerons, but the yawing moments are positive for the angles of attack below the stall and do not become adverse even above the stall.

The results of wind-tunnel tests on the same upper-surface ailerons mounted on a wing with a split flap deflected downward for increased lift are shown on the next chart. The rolling moment coefficients are slightly higher for this condition, but the yawing moments reach small adverse values at the stall, although they are much better than those given by the conventional ailerons. This type of control appears to be fairly promising, and will be tested in flight on the F-22 monoplane.

The next chart shows the external aileron in a forward location just above the nose of the airfoil. The curves of rolling and yawing moments are similar to those for the spoilers, with positive yawing moments and high rolling moments above the stall. This type of control is also to be tested in flight on the F-22 wing with split flaps.

Wind-tunnel results on the external aileron in the location used by Zap in combination with the Zap flap are shown on the next chart. For this location the rolling moment coefficients are nearly the same as for ordinary ailerons except that they decrease somewhat more rapidly above the stall, and the yawing moments are superior to those of ordinary ailerons.

The next chart shows the wind-tunnel results obtained with an auxiliary airfoil of the type which is usually fixed ahead of the wing for improvement in speed range, but of which the right and left portions are in this case deflected for lateral control. The rolling moments at low angles of attack are at first small, but they increase rapidly with increase in angle of attack, and the yawing moments are positive. The rolling moment coefficient decreases somewhat just below the angle of attack for maximum lift, but reasonably high values are maintained well above the stall. This device shows possibilities of giving satisfactory lateral control, and will also be tried in flight.
The next chart shows the rolling and yawing moment coefficients obtained with the auxiliary airfoil flap used as a lateral control, as in recent Junkers designs. The rolling moment coefficients are similar to those obtained with ordinary ailerons, although somewhat higher with the particular size tested in this case, but the yawing moments are adverse and are greater than the adverse moments given by ordinary ailerons. From all indications this device would not give lateral control at or above the stall.

Another control project which the Committee has under way is the study of tabs, or auxiliary flaps attached to ailerons, rudders, and elevators for the purpose of balancing the control forces or of trimming the airplane, or of both. Measurements are being made of the hinge moments obtained with various sizes and forms of tabs on aileron, elevator, and rudder models in the wind tunnel, with check tests in flight to take account of the motion of the airplane. The work on ailerons is practically completed, but results are not yet available from the tests of tabs on elevators and rudders. The chart gives the results obtained with an aileron tab which is 10 per cent of the aileron chord and covers the entire aileron span. The hinge moment coefficient with zero tab deflection corresponds to the condition of the aileron without the tab, and is shown for both ailerons with equal up-and-down deflection of various amounts. If a flap linkage is used which gives the flap the same movement as the aileron, the flap remaining parallel to itself, the hinge moments are reduced. If the tab is deflected beyond a certain point there is overbalance at the low aileron deflections. For this reason ailerons with tabs should have hinge moments which do not fall below this certain point. This particular feature has been substantiated in flight tests.

As previously stated the investigation of tabs on tail surfaces is now under way, and information on these devices will be available at a later date.

The Chairman inquired whether any of the members of the conference desired to ask any questions regarding the investigations which had been described.

Announcements. Mr. Reid announced that at the close of the session advance copies of the following papers, which would later be issued as Technical Notes of the
National Advisory Committee for Aeronautics, would be available at the rear of the hall for those who desired them.


"Wind-Tunnel Tests on Model Wing with Fowler Flap and Specially Developed Leading-Edge Slot," by Fred E. Weick and Robert C. Platt.

"Full-Scale Wind-Tunnel Research on Tail Buffeting and Wing-Fuselage Interference of a Low-Wing Monoplane," by Manley J. Hood and James A. White.

"The Effect of Rivet Heads on the Characteristics of a 6 by 36 Foot Clark Y Metal Airfoil," by Clinton H. Dearborn.

The Chairman stated that the various laboratories which had been inspected that morning would be open and might be revisited by the members of the conference for further inspection or for the discussion of particular problems with members of the Committee's staff. He said that at 4:00 p.m. automobiles would be ready to take the members of the conference back to Old Point Comfort.

Thereupon, at 3:40 p.m., the conference adjourned.

SPECIAL SESSION FOR CONSIDERATION OF AIRCRAFT ENGINE PROBLEMS.

A small group of the members of the conference met in the power plants laboratory at 2:30 p.m. for the purpose of discussing research problems relating to aircraft engines. Mr. G. W. Lewis, Director of Aeronautical Research of the National Advisory Committee for Aeronautics, presided as Chairman of the meeting.

Mr. Lewis stated that at the session now being held in the Officers' Club there was to be a discussion of high-lift devices and new types of lateral control, and as there were a number of the members of the conference particularly interested in aircraft power plants, it
seemed desirable to hold a separate session in order to give them an opportunity to ask questions and express opinions on this subject. He said that the suggestions made at this meeting would be referred for consideration to the Committee on Power Plants for Aircraft of the National Advisory Committee, and as many as seemed desirable would be included in the research program.

Mr. Lewis stated that, in response to inquiries regarding the efficiency factor obtained in the investigation of the resistance of a cowled air-cooled engine when the nacelle was located in the leading edge of the wing, he had asked Mr. Donald H. Wood, in charge of the propeller research tunnel, to explain how this factor was derived.

Mr. Wood said that this factor was determined for an actual case, tests being made on a $\frac{4}{9}$-scale model representing a full-size nacelle 45 inches in diameter with a 300-horsepower air-cooled engine. He stated, however, that the efficiency factor thus determined applied only to the relative conditions assumed, and that it would change under other conditions, such as increased engine power, which would result in increased drag and higher speed, increased diameter of the propeller, and increased lift over the wing due to the slipstream. Mr. Wood explained in detail how these various influences affected the efficiency factor.

Air-Cooled Engines.

Comments on Research Program. Mr. Lewis stated that it was proposed to discuss at this session air-cooled engines, hydrogenated safety fuels, two-stroke-cycle engines, and compression-ignition engines, including maximum cylinder pressures, fuel-injection systems, fuels for compression-ignition engines, spray photography, and spray combustion. He requested Mr. Carlton Kemper, chief of the power plants division, to outline the Committee's program of research on the cowling and cooling of air-cooled engines, and invited comments and suggestions.

Mr. Kemper stated that the present program consisted of three principal lines of attack: (1) A study of the actual finning of the cylinder; (2) the measurement of the quantity of air and the pressure difference required
to cool satisfactorily a given design of cylinder when mounted within an N.A.C.A. cowling; and (3) a study in the full-scale wind tunnel of the cooling of the two-row radial engine under actual flying conditions. He said it was felt that this program would give considerable information on the design and cowling of air-cooled engine cylinders, and that the purpose of the work being conducted in connection with the aerodynamics division was to place the design of the cowling on a rational basis so as to obtain minimum drag and at the same time satisfactory cooling of the engine. Mr. Kemper stated that the experimental work on finned cylinders was about completed and a report was being prepared; that work had just been started on a given cylinder design; and that part of the experimental work on the two-row radial engine had been completed.

Mr. Roland Chilton, of the Wright Aeronautical Corporation, inquired what the conclusions were as a result of the Committee's research as to the optimum fin, with respect to its height, thickness, and spacing.

Mr. Kemper replied that the results of the tests showed that the fin pitch should not be less than 0.1 inch. He said that as regards fin height and fin thickness the results indicated that the more fins it was possible to place on the cylinder barrel the greater the cooling, and that at the present time the amount of fin area which could be placed on the barrel was limited only by machining conditions. He asked Mr. Oscar W. Schey, of the power plants division, to give further details of this study.

Mr. Schey stated that computations had been made on a steel fin of infinite length and the indications were that the fin could be cut down to 2 inches in height and still have a cooling efficiency of 90 per cent of that of a fin of infinite length, that is, it would carry off 90 per cent of the heat. He said that an aluminum fin could probably be 3 or 3.5 inches in height and operate at that efficiency.

Mr. Chilton asked if any indications were obtained as to the relative value of the turbulent flow from the baffle.

Mr. Kemper stated that the heat transfer coefficient was greater with a turbulent than with a smooth flow;
that anything which set up turbulence would increase the cooling.

Mr. Schey added that a short investigation had been made in which the fins were bent slightly in front, which apparently changed the streamline flow greatly and reduced the temperature considerably in the rear of the cylinder by creating turbulence in front.

Mr. R. F. Gagg, of the Wright Aeronautical Corporation, asked if comparable experiments had been made with low air velocity and high static pressure across the baffle, and inquired as to the effect on the leading side of the cylinder.

Mr. Kemper stated that a series of tests had been made in which the effect of various openings in the baffle around the cylinder had been investigated, beginning with a very narrow opening, the optimum condition with the opening in the front of the cylinder being determined and also with the opening in the rear, and it was found that the best condition was with the baffle starting about 90 degrees from the front of the cylinder.

In response to inquiry of Mr. Chilton regarding the effect of the air velocity through a cowled engine, Mr. Kemper stated that tests had been conducted in the full-scale wind tunnel on the two-row radial engine, in which a survey had been made of the velocity through the cowling by using a large number of small impact tubes. He said the results had not yet been analyzed, but should give an indication of the quantity of air flowing through the cowling and around the baffles required for satisfactory cooling.

Mr. Val Cronstedt, of the Lycoming Manufacturing Company, suggested the possibility of increasing the speed of the cooling air during the tests when the atmospheric temperature was high, so as to maintain constant cooling.

Mr. Kemper said that the question of making corrections for the change in atmospheric temperature by a change in the velocity of the cooling air stream was under consideration at the present time, and that opinion was divided as to whether there was any rational way in which this correction could be made for the full-throttle condition, although it might be possible to do so if it was desired to operate the engine at part throttle.
Mr. Gagg suggested the use of a hot-wire anemometer for determining the velocity of flow past the cylinders.

Mr. Lewis inquired if there were any further comments or suggestions with reference to the investigation of the fundamental factors in the design of single and two-row radial engines.

Mr. P. B. Taylor, of the Wright Aeronautical Corporation, said that from the research conducted by his company on the cooling of air-cooled engines it was found that there was a great difference between the results of tests made on the dynamometer torque stand and in flight. He suggested that the Committee include in its program an investigation to determine why there was such a tremendous difference in the effectiveness of baffles and fins in different types of testing.

Mr. Lewis stated that the Committee could make wind-tunnel tests which were comparable to flight tests, but did not have a dynamometer testing equipment for a complete engine.

Hydrogenated Safety Fuels.

Problems Involved in Use of Safety Fuels. Mr. Lewis stated that the Bendix Research Corporation had conducted some investigations of hydrogenated safety fuels for the Navy, and asked Mr. F. C. Mock to say a few words on this subject.

Mr. Mock stated that there were a number of people working on safety fuels and the injection of gasoline, and that there were a number of different ways of looking at the problem. He suggested that in the course of the work conducted by the Committee the proper way to consider the fundamentals could be determined without much difficulty; for instance, the question of penetration in Diesel engines and the difference in volatility between aviation gasoline and safety fuels. Mr. Mock said that it made quite a difference in the application of injection to an engine whether the injected fuel was expected to strike the cylinder wall. He stated that another problem of interest was the determination of the leanest air-gas ratio which would burn in a cylinder; that it had been suggested that by injecting the fuel in the vicinity of the spark plug,
ignition could be insured with very lean mixtures, and possibly the efficiency of the engine cycle increased and the fuel consumption reduced. He inquired if in the Committee's work the air-gas ratio had been measured and the limits of ignitability determined with fuel injections in different combinations, and comparison made with what could be achieved in regular ignition with carburetors. He also stated that he was particularly interested in knowing whether a certain degree of stratification had any effect on the detonation characteristics of a given fuel.

Mr. Kemper replied that in the Committee's work on hydrogenated safety fuels compression ratios at which the fuel would detonate had not been reached. He stated that so far no attempt had been made to obtain a stratified charge. With reference to the fuel striking the cylinder wall, Mr. Kemper said that from the results of spray photographs under certain conditions the sprays did impinge against the wall, but so far no serious results had been experienced.

When called on by Mr. Lewis, Mr. W. W. White, of the Standard Oil Company of New Jersey, said that the future of hydrogenated fuels rested entirely with people such as those attending this conference. He stated that there was nothing in the process of manufacture or in the crude source which would make the fuel more expensive to produce than the present-day gasoline; that so far the production had been entirely in the laboratory, involving laboratory personnel, overhead, and cost; and that the next step would be to increase the production about one thousand per cent and the commercial cost would then go down proportionately.

Use of Large Valve Overlap. Mr. Lewis stated that in the injection investigations conducted by the Committee the results of tests with ordinary valve timing and with valve overlap indicated that valve overlap offered a great advantage. He asked Mr. Arthur Nutt, of the Wright Aeronautical Corporation, to comment on this feature.

Mr. Nutt said that the Committee's experiments with valve overlap had been very interesting to his company, particularly with reference to its application to supercharged engines. He stated, however, that large valve overlap was regarded with some fear as regards idling, as it naturally increased the difficulty in idling, but said that one way in which this trouble might be overcome was
by the injection of safety fuel, gasoline, or heavy oil directly into the cylinder. He expressed the opinion that it was impossible to determine conclusively from the tests on the single-cylinder engine whether large valve overlap would be useful in the future, and that this could be determined only by its application to multicylinder engines by the industry. He suggested that, along the line proposed by Mr. Taylor, it would be desirable if the Committee could have a dynamometer equipment with sufficient capacity to complete those experiments.

Mr. Lewis stated that this had not been done because it was desired to avoid duplication. He said it was expected that the results obtained by the Committee on the single-cylinder unit would be applied by other laboratories and the industry.

Mr. Nutt said that his company had checked the valve overlap experiments on the Conqueror engine at its plant and also at Wright Field, and it was found that increased overlap with the supercharged engine was decidedly beneficial. He stated that around 30 or 40 degrees overlap had been used without encountering any difficulty in idling, but how far this could be carried with a carbureted engine had not been determined.

On inquiry of Mr. Lewis, Mr. E. A. Ryder, of the Pratt and Whitney Aircraft Company, stated that valve overlap was being used on the United Aircraft and Transport Corporation lines.

Two-Stroke-Cycle Research.

Mr. Lewis stated that it was felt by many engineers that future engines for commercial air transports, as a result of the increasing length of flights and the need for reduced fuel consumption, would be the straight compression-ignition two-cycle type or at least a modification of that type, and that the Committee was testing a single-cylinder engine in connection with this problem. He asked Mr. Chilton to express his ideas as to the extent and character of the work on the two-stroke-cycle engine.

Mr. Chilton said that if the two-stroke-cycle research was intended to cover spark-ignition as well as
compression-ignition engines, there was not much he could suggest that had not already been included in the Committee's program. He inquired as to the benefits of tangential inlet on the swirl.

Mr. Kemper stated that the investigation on the two-stroke cycle engine would be conducted both with compression ignition and spark ignition. With reference to Mr. Chilton's question, Mr. Kemper said that tests had been conducted with guide vanes in the inlet, arranged so that the angle of the vanes could be varied, and it was found that by shifting the vanes it was possible to eliminate detonation.

In response to inquiry as to whether there had been any difficulty with piston lubrication, Mr. J. A. Spanogle, of the power plants division, said that the lubrication at first provided was entirely too great and had been reduced all through the tests. He stated that there had been some difficulty with the top rings being gummed, but it was felt that this was a matter of piston design rather than lubrication.

Compression-Ignition Engines.

Maximum Cylinder Pressures. Mr. Lewis stated that one problem in connection with compression-ignition engines was what should be accepted as the maximum cylinder pressure. He said that in the Packard radial engine, for instance, the maximum cylinder pressure was very high, being 1200 pounds per square inch, while in the tests conducted by the Committee this pressure had been kept to about 800 or 900 pounds per square inch. He asked for expressions of opinion as to the maximum cylinder pressure for four and two-stroke-cycle engines for aircraft use, and also as to the methods used to measure the pressure.

Mr. Chilton said that if such an engine were to be as light as those built at present, the Committee was to be commended for setting a pressure limit of 800 pounds per square inch. He stated that in his tests he had used the balanced pressure diaphragm indicator and the Prescott sampling valve to measure the maximum cylinder pressure.

Mr. Nutt said that almost all compression-ignition engines for aircraft purposes developed about the same
horsepower as gasoline engines, but weighed more and gave more trouble. He remarked that the tendency seemed to be to attack the problem of fuel consumption from the standpoint of using safety fuels, rather than to go to the high pressures and the troubles which would be encountered in the compression-ignition engine, but that after all it seemed it should be possible to obtain the same fuel economy with gasoline.

Mr. Lewis said that there were a number of steps to be taken in this problem, and that probably the first would be the use of hydrogenated fuel. He stated that in Europe during the past year there had been great activity in designing and building engines of the compression-ignition type, because of the need for engines suitable for use in the long flights made by their transport lines.

Mr. Taylor inquired as to the opinion of the Committee with regard to increasing the economy of the engine by utilizing the energy in the exhaust to drive a turbine directly, or carrying it a little further and using a steam installation to drive a turbine which would be geared to the propeller shaft.

Mr. Lewis replied that there was a great deal of interest in this problem, and that many engineers obtained maximum horsepower with an engine by boosting, but expressed the opinion that development along that particular line would parallel the development in metallurgy and strength of structures. He stated that Mr. Taylor's suggestions were interesting in connection with engine development.

Fuels and Fuel-Injection Systems. Mr. Kemper stated that the Committee had not made very exhaustive tests on fuels for compression-ignition engines, but had endeavored to keep abreast of the productions of the oil refiners, consulting with them as to the best fuel available and changing the type of fuel used in tests to take advantage of the results of their research.

At Mr. Kemper's request, Mr. Spanogle stated that from simple tests devised for the comparison of fuels it was concluded that the range of injection advance angle over which the fuel could be used in any given engine was a measure of the suitability of the fuel for that engine, and that the ignitability of the fuel was of course a
measure of its usefulness in compression-ignition engines; and also that if the injection was advanced until the power reached a maximum without encountering what would be considered destructive pressures, the fuel was suitable to the engine. Mr. Spanogle said that injection pressures up to 6,000 pounds per square inch were commonly used in the injection system.

On inquiry of Mr. Lewis, Mr. Schey stated that there had been no noticeable trouble with leakage around lapped surfaces with hydrogenated fuels.

There was discussion of the susceptibility of compression-ignition engines to changes in fuel oil.

Mr. White remarked that the fuel specifications were too broad, and that either the specifications would have to be more rigid or the engine would have to be less susceptible to changes in fuel.

There was also discussion of various types of fuel-injection nozzles. Mr. Mack said he had followed with considerable interest all the information published by the Committee and that it had been helpful. He emphasized the point that consistency of operation was one important consideration in a nozzle. He said practically every one described by the Committee was fairly consistent, though some required extreme accuracy in manufacture to insure that they would operate correctly, but that in a few widely used types of nozzles the spray discharge was not symmetrical.

Mr. Kemper said that in his opinion the original single round-hole orifice was the most desirable, the next best being a series of round-hole orifices so proportioned as to give good distribution of the fuel throughout the combustion chamber. He said two important factors to be taken into consideration in the design of a fuel-injection system were the form of the combustion chamber and the amount of air flow, and that he would hesitate to recommend any general form of nozzle to fit any type of combustion chamber, since each combustion chamber was a problem in itself.

N.A.C.A. Spray Photography Apparatus and Spray Combustion Apparatus. Mr. Lewis stated that the Committee's fuel spray photography apparatus and fuel spray combustion chamber were available for a general research program on
the injection problem, including the use of gasoline, hydrogenated fuel, or Diesel oil, and that the Committee would like to receive suggestions as to any problems the solution of which would be of value to the industry.

It was also mentioned that the Committee had available an apparatus not shown in the exhibit, for investigating the operation of fuel pumps.

Mr. Lewis said that in the few minutes of time remaining it was proposed to run the two-cycle compression-ignition engine, showing the idling characteristics, and the conference adjourned at 3:50 p.m. to witness this demonstration.

The following were present at the conference:

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Dr. Charles G. Abbot, Smithsonian Institution,
Rear Admiral Ernest J. King, U.S.N.,
Dr. Charles F. Marvin, U. S. Weather Bureau,
Honorable Edward P. Warner,

Mr. G. W. Lewis, Director of Aeronautical Research,
Mr. John F. Victory, Secretary,
Mr. E. H. Chamberlin, Assistant Secretary.

Members of Committee on Aerodynamics:

Dr. L. J. Briggs, Bureau of Standards,
Lieutenant Commander W. S. Diehl (C.O.), U.S.N.,
Dr. H. L. Dryden, Bureau of Standards,
Mr. Richard C. Gazley, Aeronautics Branch, Department of Commerce,
Major C. W. Howard, U.S.A.,
Mr. G. W. Lewis,

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Dr. Charles F. Marvin, U. S. Weather Bureau,
Honorable Edward P. Warner,
Commander W. W. Webster (C.C.), U.S.N.,
Dr. A. F. Zahm, Division of Aeronautics, Library of Congress,

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Captain Howard Z. Bogert, U.S.A.,
Mr. C. P. Burgess, Bureau of Aeronautics, Navy Department,
Mr. Richard C. Gazley, Aeronautics Branch, Department of Commerce,
Mr. Charles Ward Hall, Hall-Aluminum Aircraft Corporation,
Lieutenant Lloyd Harrison (C.C.), U.S.N.,
Mr. G. W. Lewis,
Lieutenant Commander R. D. MacCart (C.C.), U.S.N.,
Professor J. S. Newell, Massachusetts Institute of Technology,
Mr. J. A. Roche, Materiel Division, Army Air Corps,
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