NASA Contractor Report 3882

Propeller Propulsion System Integration

State of Technology Survey

S. J. Miley and E. von Lavante

GRANT NAG1-214
MARCH 1985

NASA

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S. J. Miley and E. von Lavante
Texas A&M University
College Station, Texas

Prepared for
Langley Research Center
under Grant NAG1-214

National Aeronautics
and Space Administration
Scientific and Technical
Information Branch
1985

SUMMARY

A literature survey was performed to identify and review technical material applicable to the problem area of propeller propulsion system integration. The survey covered only aerodynamic interference aspects of the problem, and was restricted primarily to propeller effects on the airframe. The subject of airframe aerodynamic interference on the propeller was limited to the problem of vibration due to nonuniform inflow. The problem of airframe effects on propeller performance was not included.

A total of 121 references are given. The references are grouped into the subject areas of Aircraft Stability, Propulsive Efficiency, Aerodynamic Interference, Aerodynamic Interference - Propeller Vibration, and Miscellaneous.

INTRODUCTION

An extensive literature survey was performed to identify and review technical material applicable to the problem area of propeller propulsion system integration. The survey covered only the aerodynamic interference aspects of the problem, and was restricted primarily to propulsion system effects on the airframe. The subject of airframe aerodynamic interference on the propeller was limited to the problem of vibration due to nonuniform inflow. The problem of airframe effects on propeller performance was not included.

The survey effort utilized libraries of government, industry and universities. The majority of the effort was directed to the time period prior to 1964. The period from 1964 to present is well covered by computer data bases, and a minimal effort was required to assemble a survey for this period. Indicies compiled and published by National Technical Information Service (NTIS), National Aeronautics and Space Administration (NASA STAR), Engineering Index, United States Government Research and Development Reports (USGRDR), British Aeronautical Research Council, and American Institute of Aeronautics and Astronautics (AIAA IAA) were used. In addition, the aeronautical bibliography produced by the WPA in 1940, from the holdings of the Institute of the Aeronautical Sciences was also used.

The results of the survey showed that there are few remaining collections of aeronautical technical material preceding 1960. The NASA Langley Research Center Technical Library has the most extensive collection and includes industry and foreign material.. Two other important sources are the National Air and Space Museum, which contains a set of the "Operation Paperclip" captured German and Japanese technical documents, and the Library of Congress, which provides copies of NTIS PB number documents dating back to 1942. The once important collections of the Institute of the Aeronautical Sciences and of the Wright Aeronautical Development Center no longer exist. The value of this old aeronautical material is recognized by only a few, and there is continuous pressure to destroy what remains in the interest of economy. Surveys of the technical libraries of the major airframe companies showed only recent technology. Material from the propeller aircraft era was either inaccessible or destroyed.

In terms of foreign material, there is much more available on German work during World War II, than on British work. The reason for this is that there is no effective means of applying British report declassification to the holdings of american government technical libraries.

AVAILABILITY OF THE CITED REFERENCES

All cited references are available to the public. In most cases, the source(s) where copies of a reference can be obtained, are evident. In general, all government reports (NACA, NASA, US Army, etc.) can be obtained from the National Technical Information Service (NTIS). When known, the ordering accession numbers (AD numbers or PB numbers) are given. The reports which have a NTIS PB number can be obtained from the Photo Duplication Service of the Library of Congress. Copies of technical journal articles, domestic and foreign, are best obtained through an inter-library loan.

ORGANIZATION OF THE REPORT

The report contains 111 references with abstracts. The references are organized into five categories, and are listed in chronological order within each category. A separate reference section is provided where the cited authors are listed in alphabetical order with cross-referencing of reference number and page number.

The five categories and the respective number of references are: Aircraft Stability (26), Propulsive Efficiency (15), Aerodynamic Interference (63), Aerodynamic Interference - Propeller Vibration (13), and Miscelaneous (4). The scope of the survey was limited to the aerodynamic effects of the propeller propulsion system on the airframe. Two other integration areas of concern, aerodynamic effects of the airframe on propeller performance, and propeller noise, were not covered. There are major research programs under way for these areas, where extensive reference material is already available.

Aircraft Stability

The material in this section concerns the effects of the propeller slipstream on aircraft stability. Most of the references deal with longitudinal stability as influenced by slipstream effects on downwash and dynamic pressure at the tail. The reference material shows that there were two important research activities in this area, one in Germany during the period 1935-1945, and one in the United States during the 1960°s. The german effort was directed towards conventional single- and multi-engine aircraft, while the american effort was directed toward V/STOL aircraft. There has been no recent activity in this area as far as published literature is concerned.

The existing reference material is primarily experimental, and being generated by different uncoordinated research activities, is not presently in a useful form to be applied to current needs in this problem area. No reliable analytical methods have emerged from the various attempts reported in the references.

Propulsive Efficiency

Propulsive efficiency is concerned with the net propulsive force delivered to the airframe. A central question of this problem area is the accounting of the parts of the airframe which are credited to the propulsion system in the determination of the net force. A prime example is the comparison of two different twin-engine aircraft configurations; one with a tractor-pusher installation in the fuselage, the other with the engines mounted on the wing. In the case of the wing mounted configuration, the total drag of the engine nacelles are credited to the propulsion system. For the fuselage installation, the drag increments associated with the change in the fuselage shape to house the engines and the increase in friction drag due to the slipstream are credited to the propulsion system. How then, can the two configurations be compared in terms of propulsive efficiency?

The reference material in this section is essentially all experimental, and involves tests of systematic variations in configuration. Most of the references concern the size and geometry of the nacelle on propulsive efficiency, or the question of pusher versus tractor configuration. The nacelle studies concern primarily radial engine configurations, although there are some "wing-buried" engine configurations which may be applicable to turboprop installations.

The results from the various configuration studies indicate that a finite nacelle size is required for good propulsive efficiency. The nacelle size is dictated by the amount of high drag shank area on the propeller. The question of tractor versus pusher configuration is not resolved by the present data. The tractor configuration has the positive attribute of the presence of the airframe improving the performance of the isolated propeller and the negative attribute of increased friction drag due to the slipstream. The these attributes tend to reverse for the pusher configuration. The presence of the airframe reduces the performance of the isolated propeller, however, the induced flow of the propeller tends to "clean up" the boundary layer flow on the upstream parts of the airframe, reducing friction drag.

Aerodynamic Interference

This problem area represents the majority of the cited references. The concern here is with the effects of the propeller slipstream on the aerodynamic behavior of the wing. A significant part of the effort in this area has been directed towards the development of reliable analytical models. Model development started initially with a lifting line representation for the wing, and a weak jet representation for the slipstream. The model was subsequently improved to include slipstream swirl, higher axial velocities and a lifting surface representation for the wing. Recently, three-dimensional body panel methods are being employed to provide a better representation of the airframe configuration. The remaining problem for model development is to allow for the deformation and displacement of the slipstream as it encounters the airframe.

Aerodynamic Interference - Propeller Vibration

The operation of a propeller in a nonuniform flow causes periodic variation in the blade loading which leads to vibration. For tractor configurations, this is primarily a problem for wing mount installations. The nonuniformity is due to the wing upwash, and results in a vibration at the blade passage frequency. The fuselage also supplies a component to the nonuniform flow. For pusher configurations, the vibration is due to both airframe component induced nonuniform flow, and cutting of viscous wakes by the propeller blades. For wake cutting, the vibratory frequency may be a multiple of the blade passage rate.

Miscellaneous

This section contains references which may be of interest, but due not fall within the other categories.

AIRCRAFT STABILITY

1

Propeller Slipstream and Longitudinal Stability. (Luftschraubenstrahl und Langsstabilitat.)

H. Blenk

Luftfahrtforschung, Vol. 11, No. 7, January 1935, pp. 202-206.

The results of several investigations are reported here. Sufficient detail is lacking for most of the results. Reductions in stability for full throttle operation are reported, and the dependency of stability on the propeller advance ratio is noted.

Measurements of the Influence of the Propeller Slipstream on Stability about Pitch Axis. (Messungen uber den Einfluss des Schraubenstrahls auf die Stabilitat um die Querachse.)

E. Eujen and W. Drude

Deutsche Versuchsanstalt fur Luftfahrt, E.V., Forschungsbericht FB 369, June 1935.

NTIS PB 38390

A flight test program was performed with a Junkers W 33d aircraft. The aircraft is shown in Figure 2-1. A control surface effectiveness was defined as

$\underline{(dC_m/d\delta)/(dC_m/d\delta)^*}$

where ( )* denotes undisturbed flow and ( ) denotes presence of the slipstream. For the particular aircraft tested, this factor increases linearly with lift for full throttle operation. This is caused in part by the increase in total pressure at the elevator due to the slipstream. The measured increase in total pressure at the elevator was less then the theoretically determined value. The control surface effectiveness was also found to be dependent on advance ratio.

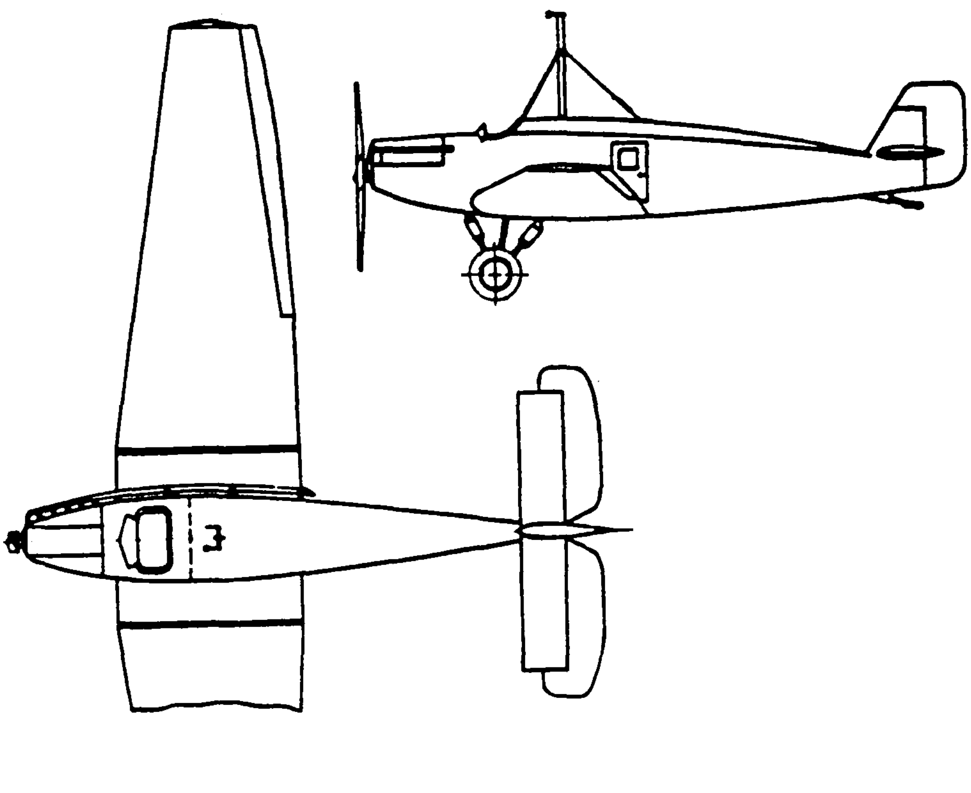

Figure 2-1. Test model used.

Flight Measurements of the Influence of Propeller Slipstream and Position of Landing Flap on the Flow and Total Pressure at the Tail. (Flugmessungen uber den Einfluss von Schraubenstrahl und Landeklappenanstellung auf Abwind und Straudruck am Hohenleitwerk.)

E. Eujen

Deutsch Luftfahrtforschung, Forschungsbericht FB 832, May 1937.

NTIS PB 31708

A flight test program was performed using a Kl 36A aircraft. Test conditions included different flap settings, propeller running and propeller stopped. The effects of the downwash and slipstream were measured by a total pressure probe, and by elevator deflection for stick-free flight. Aircraft trim for each flight condition was obtained by changing the c.g. position through an adjustable weight.

The results showed that the downwash factor due to the flap was significantly reduced by the propeller slipstream. This destabilizing effect was partially compensated for by the increase in total pressure at the tail due to the slipstream.

Effect of Slipstream on the Longitudinal Stability of a Low Wing Monoplane.

C.M. Bolster

Journal of the Aeronautical Sciences, Vol. 4, No. 10, May 1937, pp. 411-416.

A one-sixth scale powered model was tested in a wind tunnel to measure the effects of the slipstream on longitudinal. The model is shown in Figure 4-1.

Comparisons with theory show good agreement for the power-on lift coefficient, but poor agreement with the power-on pitching moment coefficient. The slipstream was found to increase the longitudinal stability of the aircraft, and to also increase the elevator control power. At stall, the vertical location of the horizontal stabilizer was shown to be important.

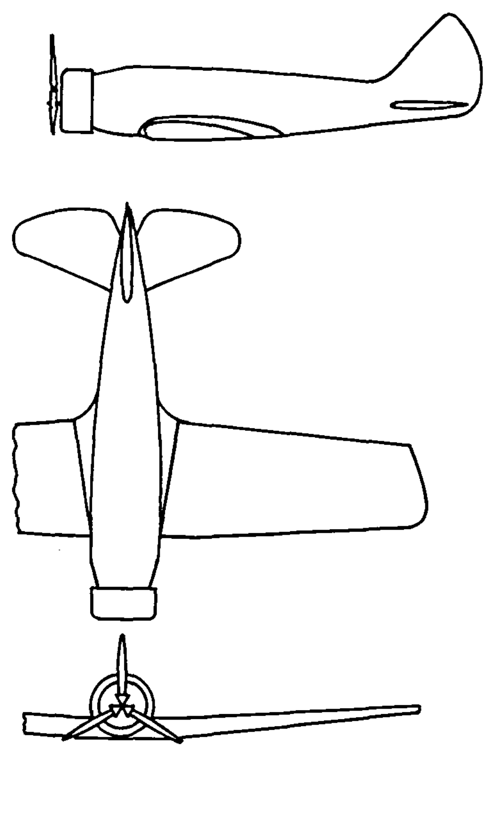

Figure 4-1. Test model used.

Experimental Contribution to the Problem "Downwash and Slipstream". (Experimenteller Betrag zum Problem "Abwind und Schraubenstrahl".)

R. Schmidt

Jahrbuch 1937 der deutschan Luftfahrforschung, pp. 139-153.

NTIS PB 24697

Extensive flow measurements were made in flight at the empennage for two different aircraft. The measurements included total pressure and flow direction. The first aircraft was a Do 11, a conventional twin engine configuration with tractor propellers mounted on the wing. Both propellers rotated in the same direction. The second aircraft was a Do J, a tandom twin engine configuration with the engines mounted above the fuselage. The propellers were attached at opposite ends of the nacelle in a tractor-pusher arrangement. The propellers were counter-rotating. The measurements were made over a range of angles of attack and thrust levels. Contour plots are given for the conditions in terms of total pressure and flow direction.

It was found that the presence of the slipstream reduced the stability of the conventional twin engine Do 11 significantly. It was recommended that counter-rotating propellers be used on the aircraft. The results are analyzed in terms of a stability efficiency defined as

$$(dC_m/dC_n)/(dC_m/dC_n)^*$$

where $(\ )^*$ denotes undisturbed flow and ( ) denotes the presence of the slipstream.

6

Effect of Propeller Slipstream on Wing and Tail.

J. Stuper

NACA Technical Memorandum TM 874, August 1938.

A wind tunnel test to measure the effect of a slipstream on a wing was performed. In the first part of the test, the slipstream was created by an axial flow fan, with the swirl component removed. In the second part of the test, a conventional propeller was used. Measurements of the slipstream velocity distribution, slipstream flow angle distribution and wing pressure distribution were made and are given in the report.

Results for the pure jet flow slipstream case showed that wing lift increase with jet velocity, and that the downwash angle at the tail also increase with jet velocity. For the propeller slipstream case, the wing lift distribution varied in a nonsymmetrical manner across the slipstream region. The slipstream splits into two halves above and below the wing which shift spanwise in opposite directions due to the swirl velocity component. These halves do not recombine, but are displaced laterally at the tail. The measured distributions are presented in graphical form. No tabular data is given.

7

Investigations on the Downwash Behind a Tapered Wing with Fuselage and Propeller.

H. Muttray

NACA Technical Memorandum, TM No. 876, September 1938.

An experimental program was performed to measure the downwash behind a tapered wing. The test models are shown in Figure 7-1.

The measurements were in good agreement with theoretical calculations based upon a non-rolled-up vortex sheet. Allowances were made for lowering of the sheet. For the case without propeller running, the "angular" fuselage showed a marked improvement in longitudinal stability over the "conventional" fuselage. Downwash measurements with the propeller running showed a very strong swirl in the vicinity of the tail. For the full-throttle condition, the model with the "angular" fuselage showed superior stability over the "conventional" fuselage model.

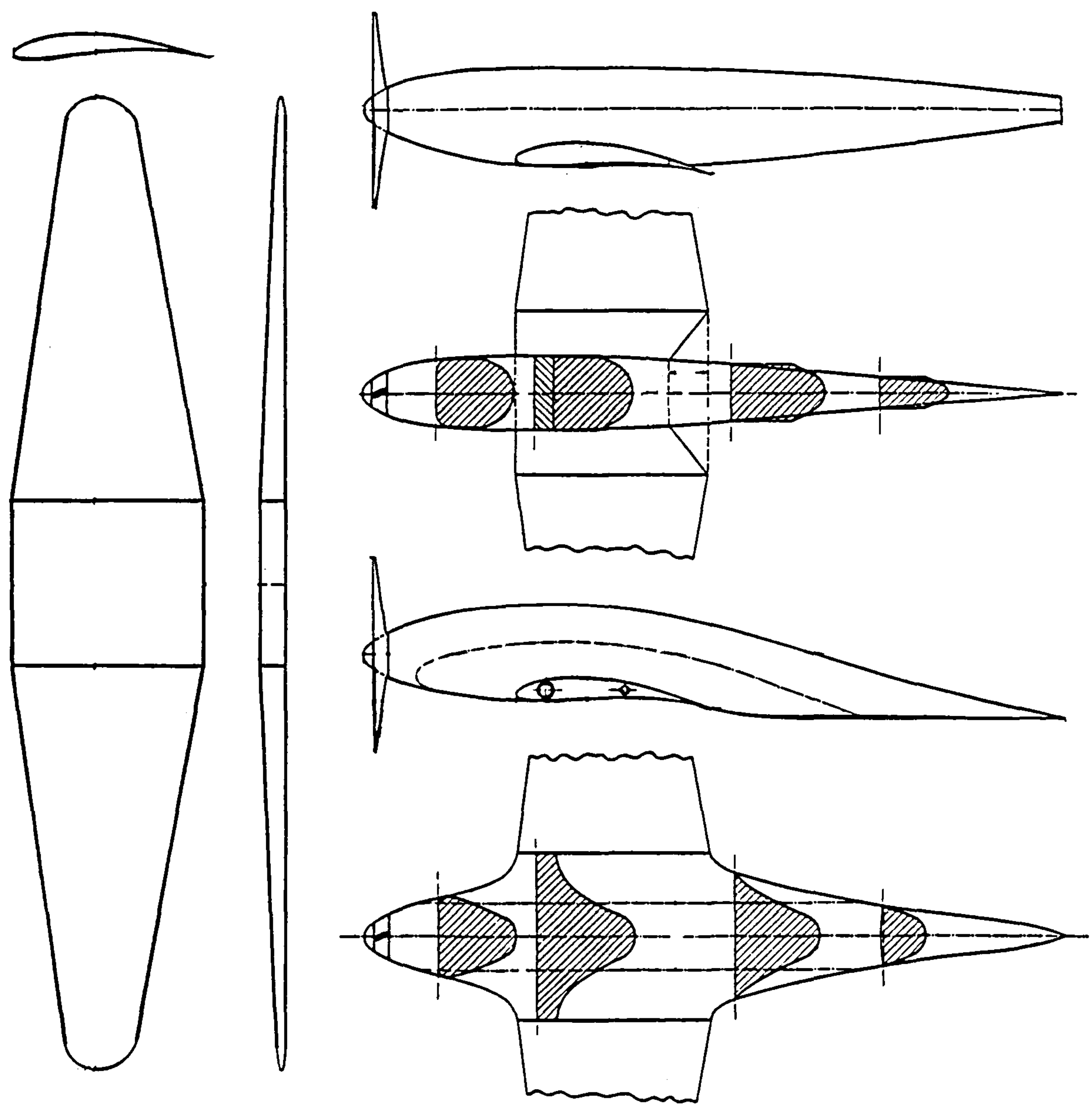

Figure 7-1. Test models used.

8

Summary Report on Downwash Measurements with and without Propeller Slipstream. (Zusammenfassender Bericht uber Abwindmessungen ohne und mit Schraubenstrahl.)

I. Flugge-Lotz and D. Kuchemann

Jahrbuch 1938 der deutschen Luftfahrtforschung, 1938, pp. 172-193.

NTIS PB 24546

The results and analyses of previous investigations are reported. Over 100 references are given including both American and European.

The Mutual Influence of Individual Parts of the Aircraft with Rotating Propellers. (Die gegenseitige Beeinflussung der Einzelteile am Flugzeug mit laufender Scgraube.)

J. Stuper

Ringbuch der Luftfahrttechnik, March 1939.

NTIS PB 20309

A general survey of the state of the art as of 1939 is given. Results from american and european research programs are summarized and presented in graphical form. Many of the references cited by Stuper are included in this report.

The Influence of Running Propellers on Airplane Characteristics.

C.B. Millikan

Journal of the Aeronautical Sciences, Vol. 7, No. 3, January 1940, pp. 85-106.

A review of the experimental program at the California Institute of Technology investigating the effects of the propeller slipstream on airplane characteristcs is presented. The experiments were carried out with small powered models in various wind tunnels. Most of the tests were funded by private companys and specific data about the models is held confidential.

Results of the experiments are presented concerning the slipstream effects on both aircraft stability and performance.

11

Flight Measurement on the Problem of the Propeller Slipstream Influence on the Aircraft. (Flugmessungen zur Frage des Luftschraubenstrahleinflusses auf das Flugzeug.)

E. Eujen

Aerodynamische Versuchsanstalt, Gottingen, Bericht B 42/15/1, March 1942.

NTIS PB 36461

In-flight measurements of the influence of the propeller slipstream on aircraft stability were performed using the Messerschmitt Bf 108. The aircraft is shown in Figure 11-1. The stability was determined by measuring the change in lift for a constant elevator position. The C.G. position was changed by use a moveable weight. Propeller operating conditions, from idle to full throttle were covered in equal steps.

The method of using the tail as an integrated probe proved to be efficient and reliable. The method used for calculation of the pitch stability gave useable results, however, there are certain changes necessary. The results are presented in graphical form.

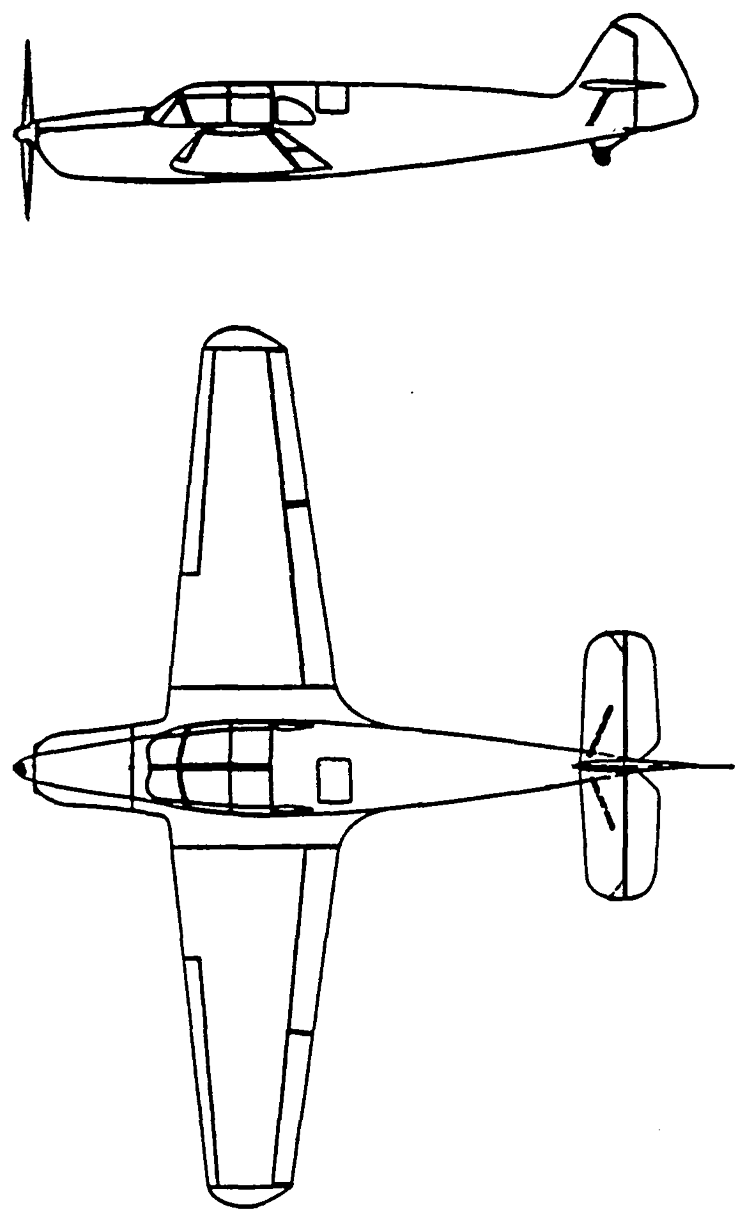

Figure 11-1. Test model used.

The Effect of Propeller Operation on the Air Flow in the Region of the Tail Plane for a Twin-Engine Tractor Monoplane.

H.H. Sweberg

NACA Wartime Report WR L-381, August 1942.

Extensive flow surveys were made in the region of the tail plane of a twin-engine tractor monoplane model. The model is shown in Figure 12-1. The surveys were made with and without propellers, and with flaps retracted and deployed.

The presence of wing caused the slipstream to split into two parts, one above and one below the wing. These parts separated laterally in the direction of the slipstream rotation and did not recombine. Large variations in total pressure with vertical location were found at the tail. The downwash angle at the tail was independent of vertical location. Total pressure variation and downwash angle were found to depend strongly on flap deflection and direction of propeller rotation. The results of the flow surveys are given in the form of combined contour and flow vector plots.

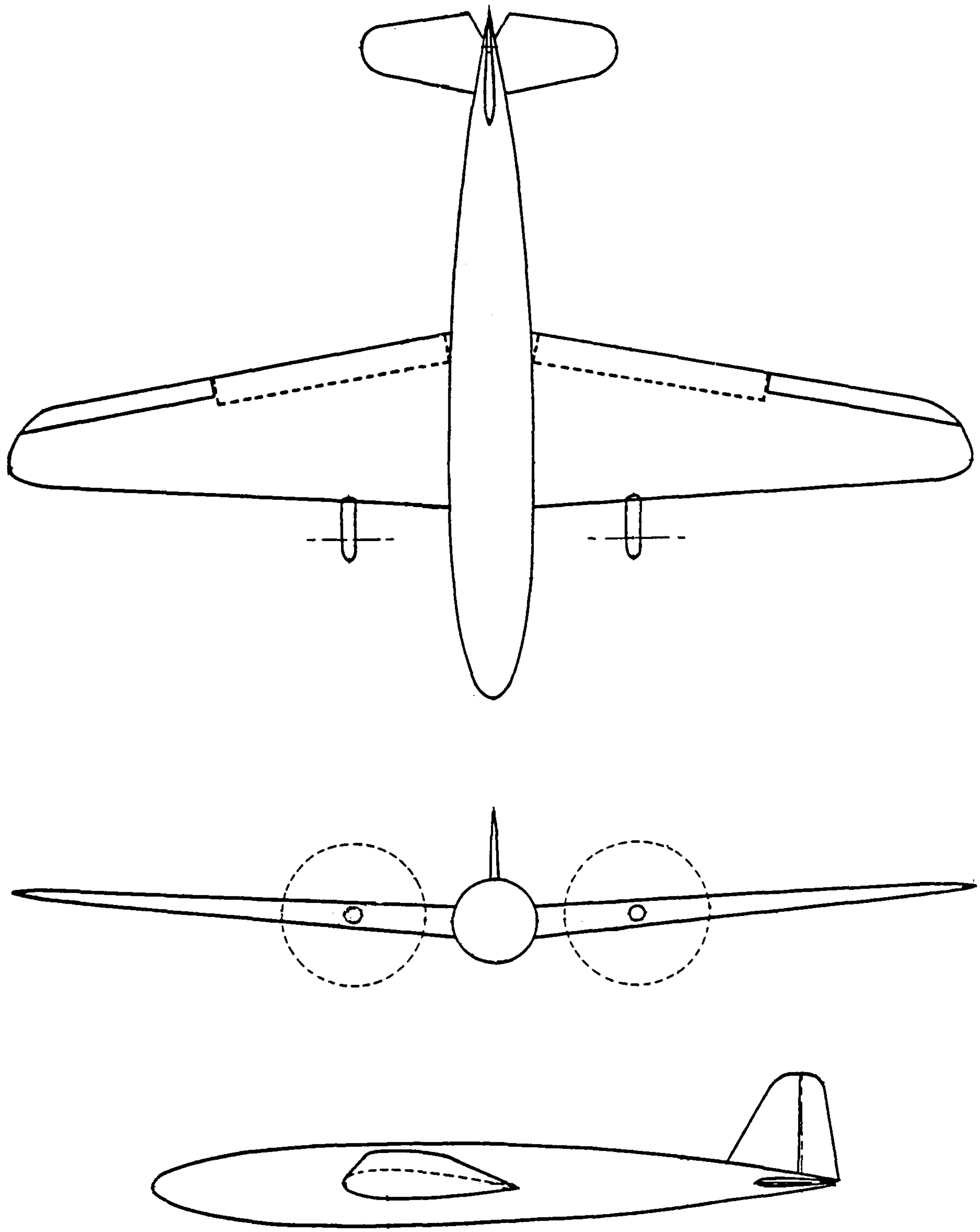

Figure 12-1. Test model used.

13

Drag Analysis of Performance Obtained at Aircraft and Armament Experimental Establishment on Various Aircraft, with Particular Reference to Slipstream Corrections.

W.D.J. Annand and A.K. Weaver

British Aeronautical Council, Reports and Memoranda R&M No. 2168, March 1943.

NTIS PB 92556

Drag analyses from carefully controlled flight tests of a Hurricane II aircraft show discrepancies between the results for cruise and the results for climb. Flight test results from four different aircraft were subsequently analyzed to investigate this discrepancy. The aircraft are unidentified by model, but include a four-engine model, a two-engine model, and two single-engine models.

The discrepancies were traced to slipstream effects at the tail, and to the unknown pitching moment contribution of the propeller/nacelle combination. Reference was made to the German work in this area, but no experimental data was given to substantiate the conclusions.

14

On the Influence of the Propeller Slipstream on the Yaw Damping. (Zum Influss des Schraubenstrahles auf die Wendedumfung.)

Author Unknownn

Luftfahrtforschungsanstalt Hermann Goring Institute fur Aerodynamik, August 1944.

NTIS PB 39142

A wind tunnel test was performed to determine the effects of the propeller slipstream on yaw damping. A low-wing single engine model was used. Model test configurations included with- and without-tail, and with- and without- propeller. A range of advance ratios, angles of attack and Reynolds numbers were run. Damping characteristics were measured by oscillating the model. Measurements were also made of the total pressure at the tail.

A theoretical analysis to predict turn damping was developed and was found to be in reasonable agreement with the experimental results. The experimental results showed that 90 percent of the yaw damping was due to the vertical tail. This was increased by a factor of three due to the slipstream, for low advance ratios. Results are given in graphical form showing the effect of the different configurations and test conditions on yaw damping.

15

Notes on the Propeller and Slipstream in Relation to Stability.

H.S. Ribner

NACA Wartime Report, WR L-25, October 1944.

Charts and formulas are presented in convenient form for use in the computation of the effects of propellers on stability. Formulas and curves are given for:

(a) The propeller "fin effect" in terms of the thrust coefficient.

(b) The effect of the wing on the propeller normal force in pitch.

(c) The propeller yawing moment due to pitch.

(d) The sidewash induced by the propeller in yaw.

Formulas are given for the contributions of the direct propeller forces to the airplane pitching moment, wing moment, and shift in neutral point due to power.

16

An Investigation of the Mutual Interference Effects of a Tail-Surface - Stern Propeller Installation on a Model Simulating the Douglas XB-42 Empennage.

W.A. Bartlett, Jr. and A.A. Marino

NACA Wartime Report, WR L-625, November 1944.

The mutual interference effects of tail surfaces and a stern propeller were investigated on a model representative of the empennage and propeller installation of the XB-42 airplane. The test model is shown in Figure 16-1. The tests were conducted primarily to determine the effect of tail-surface - propeller spacing upon the periodic tail-surface loading coincident with propeller blade passage.

The pressure impulses on the control surfaces due to propeller blade passage were found to increase with propeller rotational speed or blade angle, or with decreased tail-surface - propeller spacing in both static and positive dynamic thrust. Average pressure distributions obtained at two chordwise stations on the left elevator indicated that the control-surface effectiveness increased with increasing thrust coefficient and decreased with increasing negative-thrust coefficient. An elevator deflection of 20 degrees decreased the envelope efficiency of the six-blade dual-rotating propeller in the low advance ratio range and increased the envelope in the high advance ratio range.

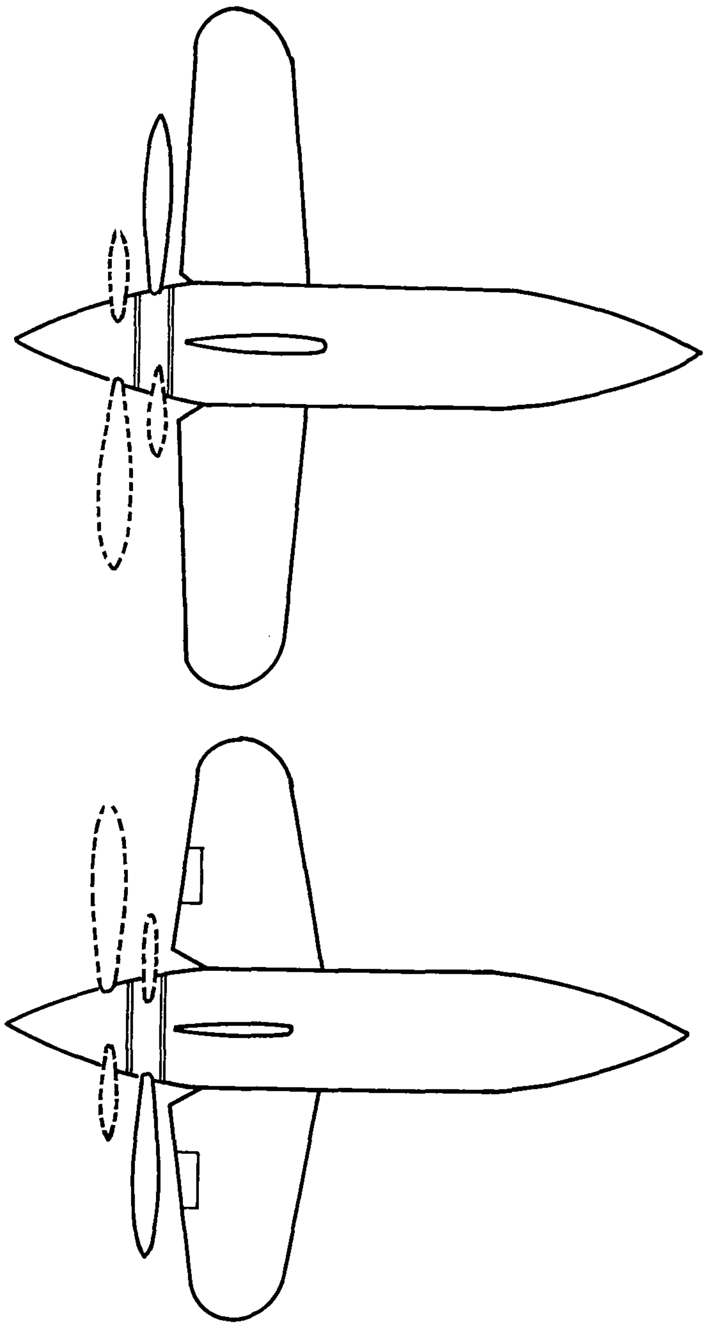

Figure 16-1. Test model used.

17

Wind-Tunnel Investigation of Alternative Propellers Operating behind Deflected Wing Flaps for the XB-36 Airplane.

E. Boxer

NACA Wartime Report, WR L-533, December 1945.

Tests have been conducted in the NACA Langley propeller-research tunnel to determine the aerodynamic characteristics of two pusher propellers of identical plan form, but different airfoil sections operating behind a slotted flap. The tests were made upon a wing-flap-nacelle combination simulating the arrangement at the center nacelle of the XB-36 airplane. The test model is shown in Figure 17-1. Tests were made over a range of blade angles and flap deflections necessary to cover all flight conditions of the subject airplane.

The peak efficiency of both propellers was reduced 2.5 and 6 percent for 20 degrees and 40 degrees flap angles, respectively. Extension of the landing gear decreased the maximum and take-off efficiencies only slightly for most conditions.

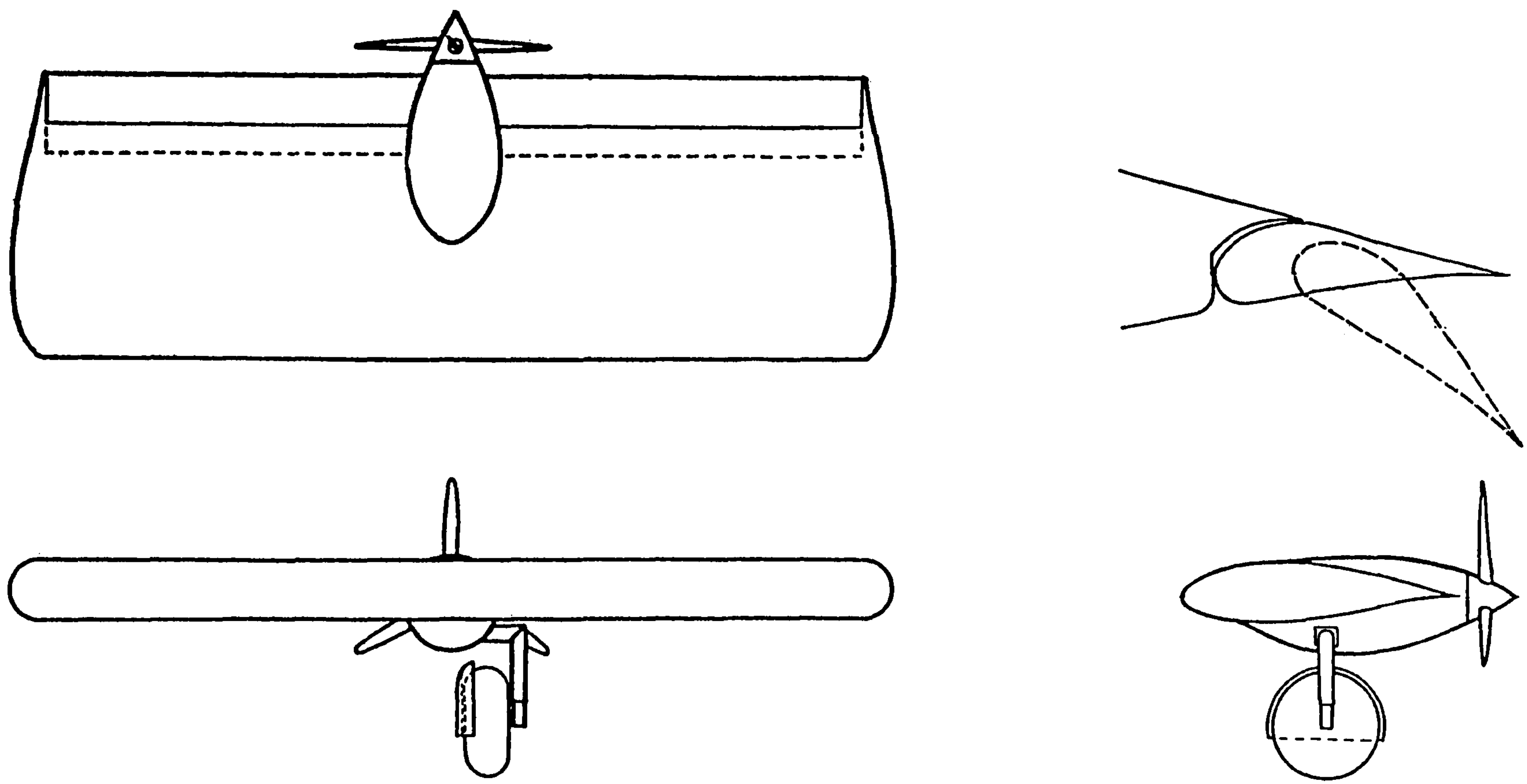

Figure 17-1. Test model used.

18

Effect of Slipstream Rotation in Producing Asymmetric Forces on a Fuselage.

H.S. Ribner and R. MacLachlan

NACA Technical Note, NACA TN 1210, March 1947.

An approximate theory of the effect of slipstream rotation on the forces on a fuselage without a wing was developed. The slipstream is modeled by a vortex aligned with the longitudinal axis. This configuration gives rise to a lateral force and yawing moment in pitch or a normal force and pitching moment in yaw. The forces are proportional to the angle of inclination and to slipstream rotation as measured by the ratio of propeller torque to the square of the diameter.

A wind tunnel investigation was performed to check the predictions for the lateral force on a fuselage shaped as a body of revolution. The results were in general agreement with the theoretical value.

Effect of Propeller Thrust on Downwash and Velocity at Tailplane - A Collection of Data from Low Speed Wind Tunnel Tests.

A.W. Spence

British Aeronautical Research Council, Current Papers CP No. 21, August 1947.

NTIS PB 101947

Results from wind tunnel tests of single- and multi-engine aircraft models are presented. The models are shown in Figures 19-1 to 19-4. Both single and counter-rotating propeller systems are included. The direction of propeller rotation for the multi-engine models is also varied.

No attempt to generalize the results was made. Results from particular configurations is discussed. The need for a systematic research program in this area is described.

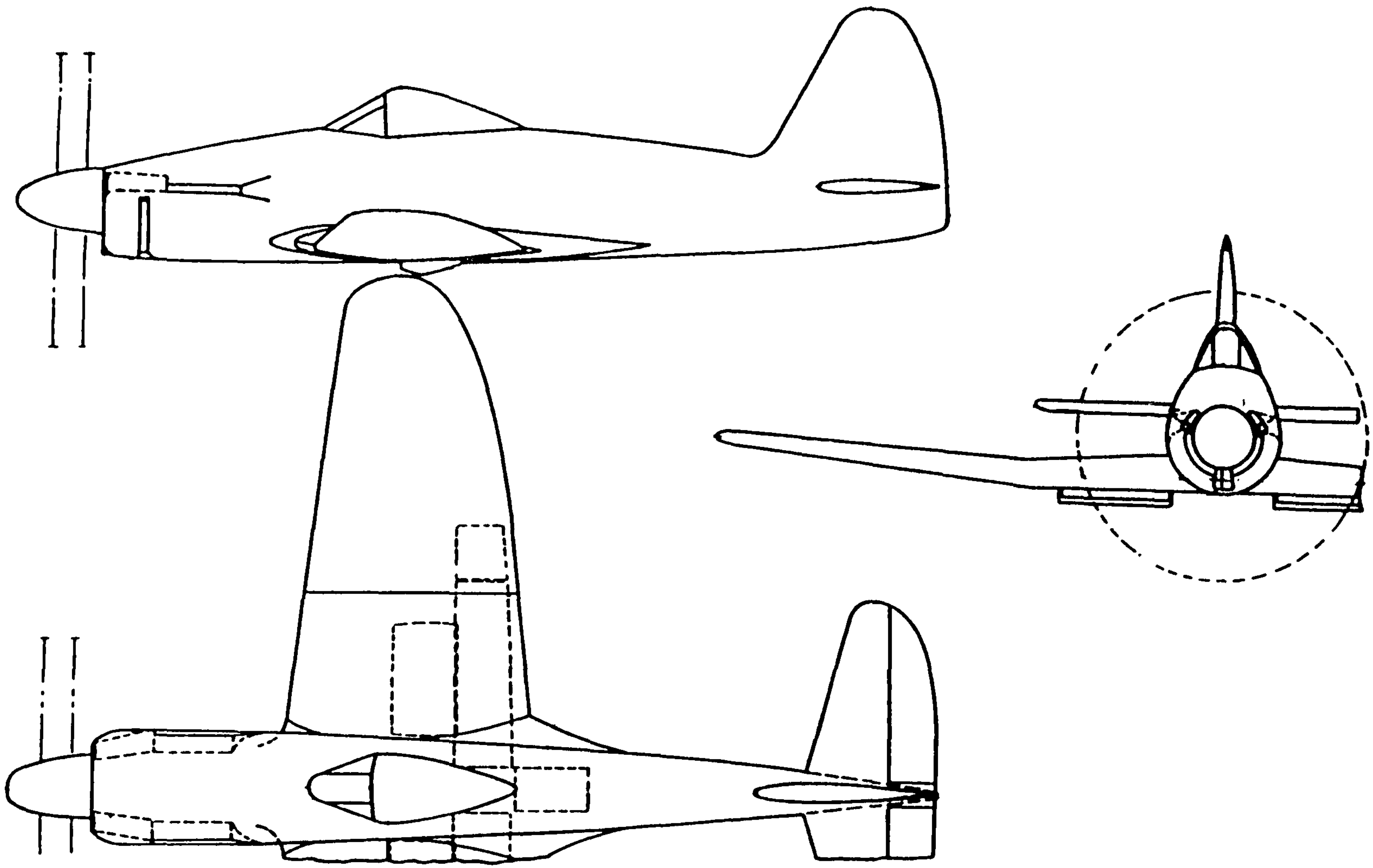

Figure 19-1. Test models used, model (a).

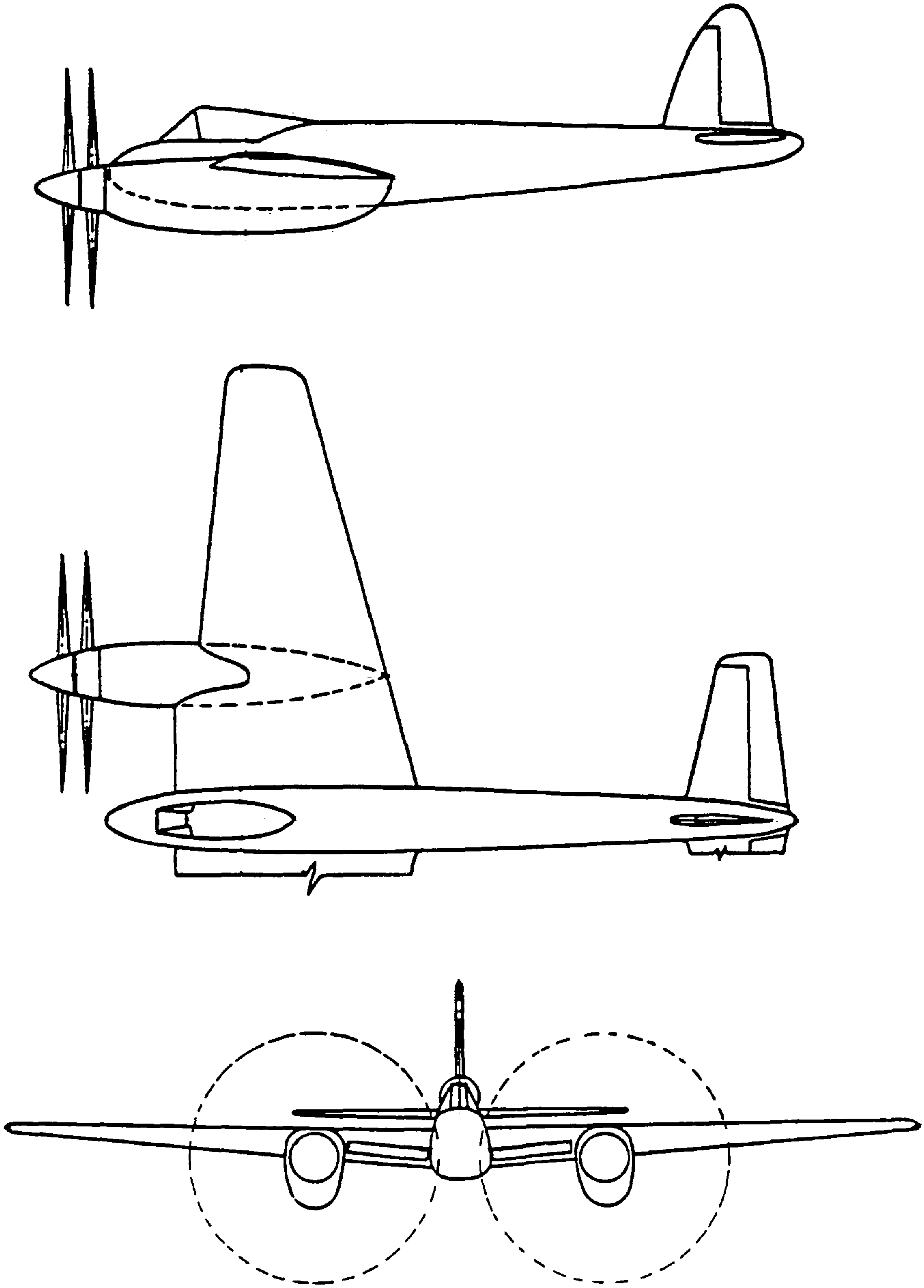

Figure 19-2. Test models used, model (b).

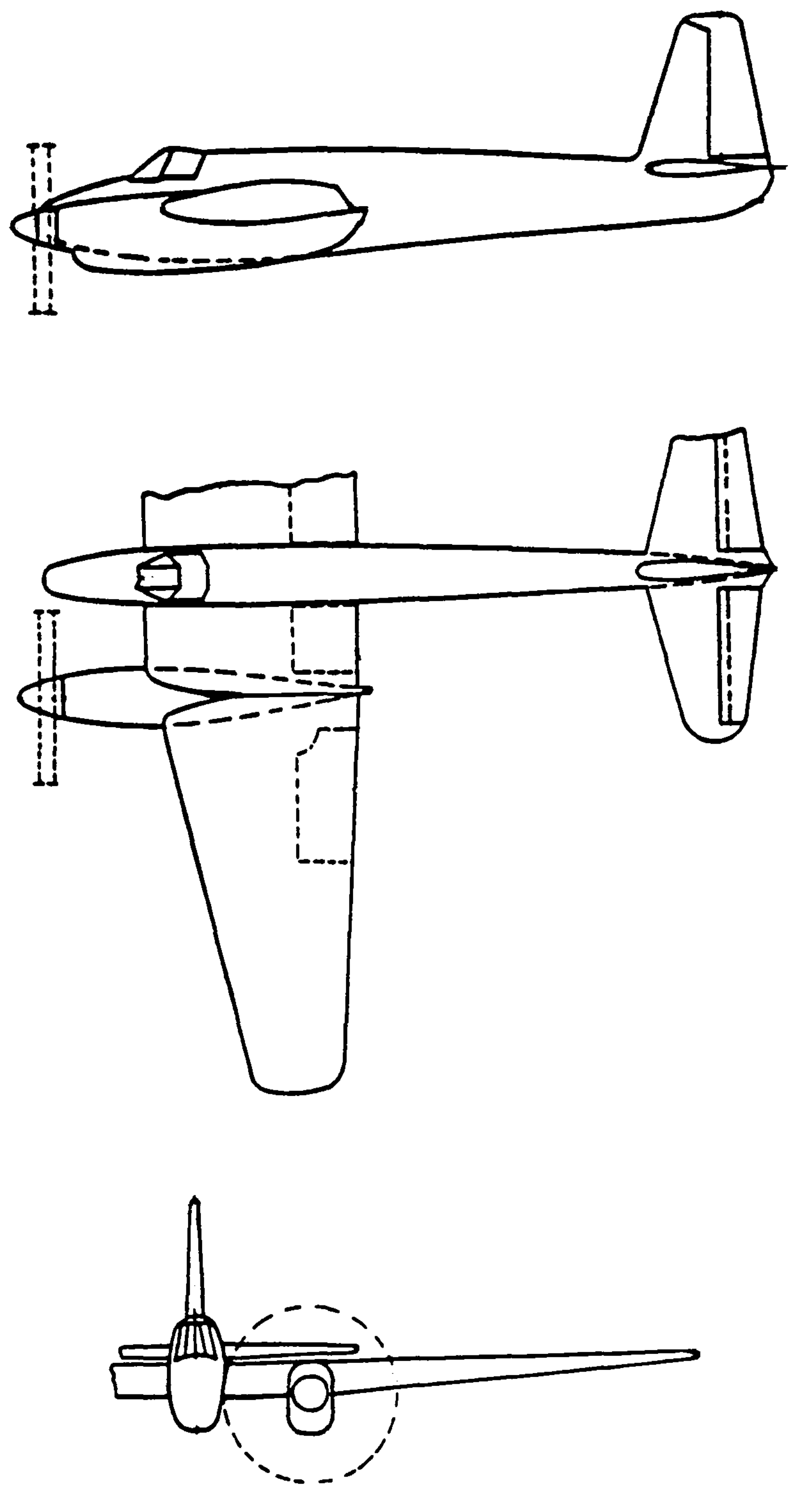

Figure 19-3. Test models used, model (c).

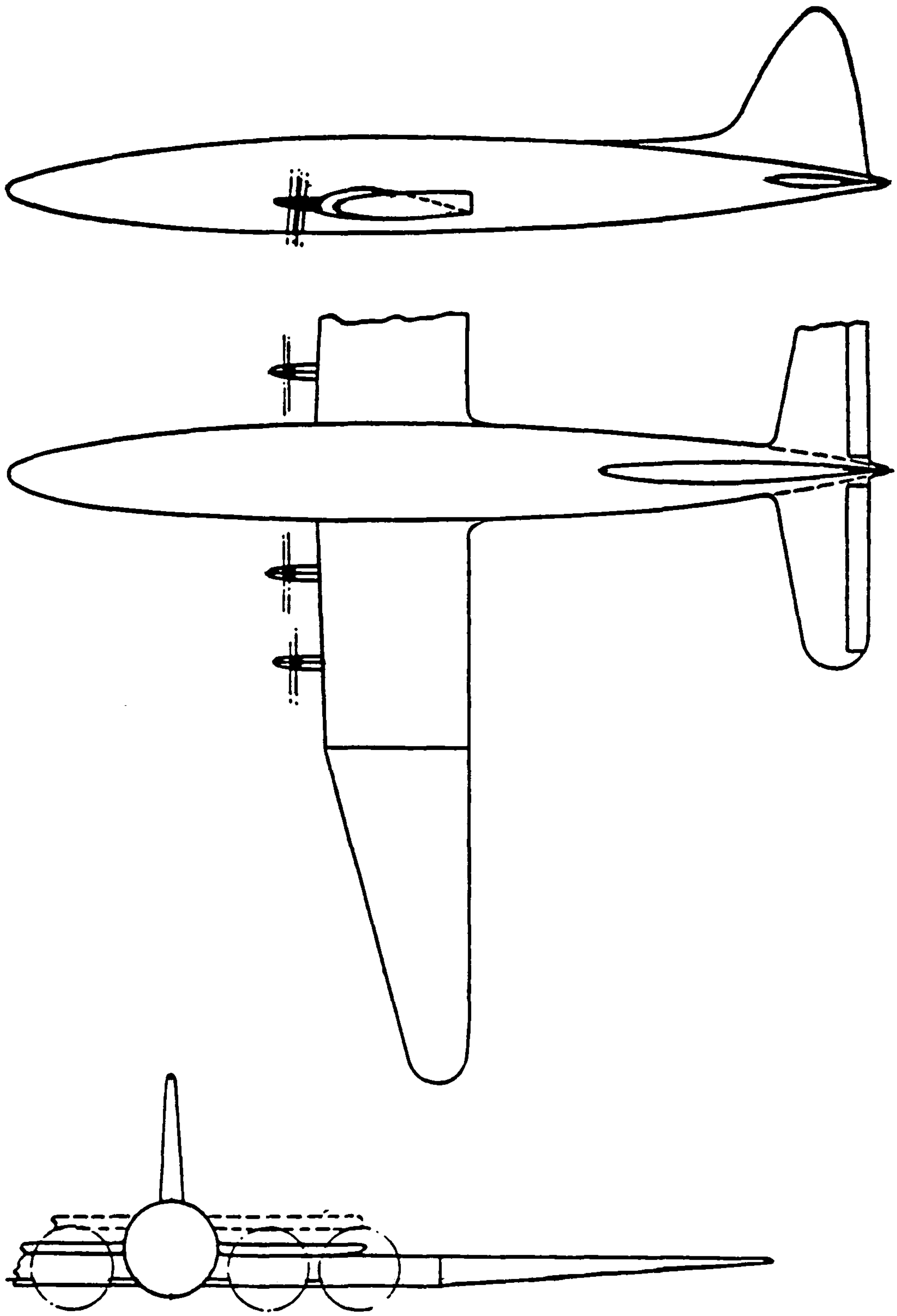

Figure 19-4. Test models used, model (d).

Downwash and Dynamic Pressure at the Horizontal Tail of a Six-Engine Pusher-Propelled Airplane.

G.C. Furlong

NACA Research Memorandum, RM L8F21, July 1948.

Air-flow surveys have been made in the vertical plane of the elevator hinge line of a powered model of a high-wing, six-engine, heavy, pusher-propelled bomber. The test model is shown in Figure 20-1. The values of downwash and dynamic pressure ratio obtained from the surveys are presented in the form of contour charts.

The results of the tests indicated that the average values of downwash obtained from the surveys were approximately 1 - 2 degrees greater than the effective values obtained from force and moment data. The nacelle-wing juncture, the fuselage-wing juncture, and the nacelle had a pronounced effect on the flow at the tail.

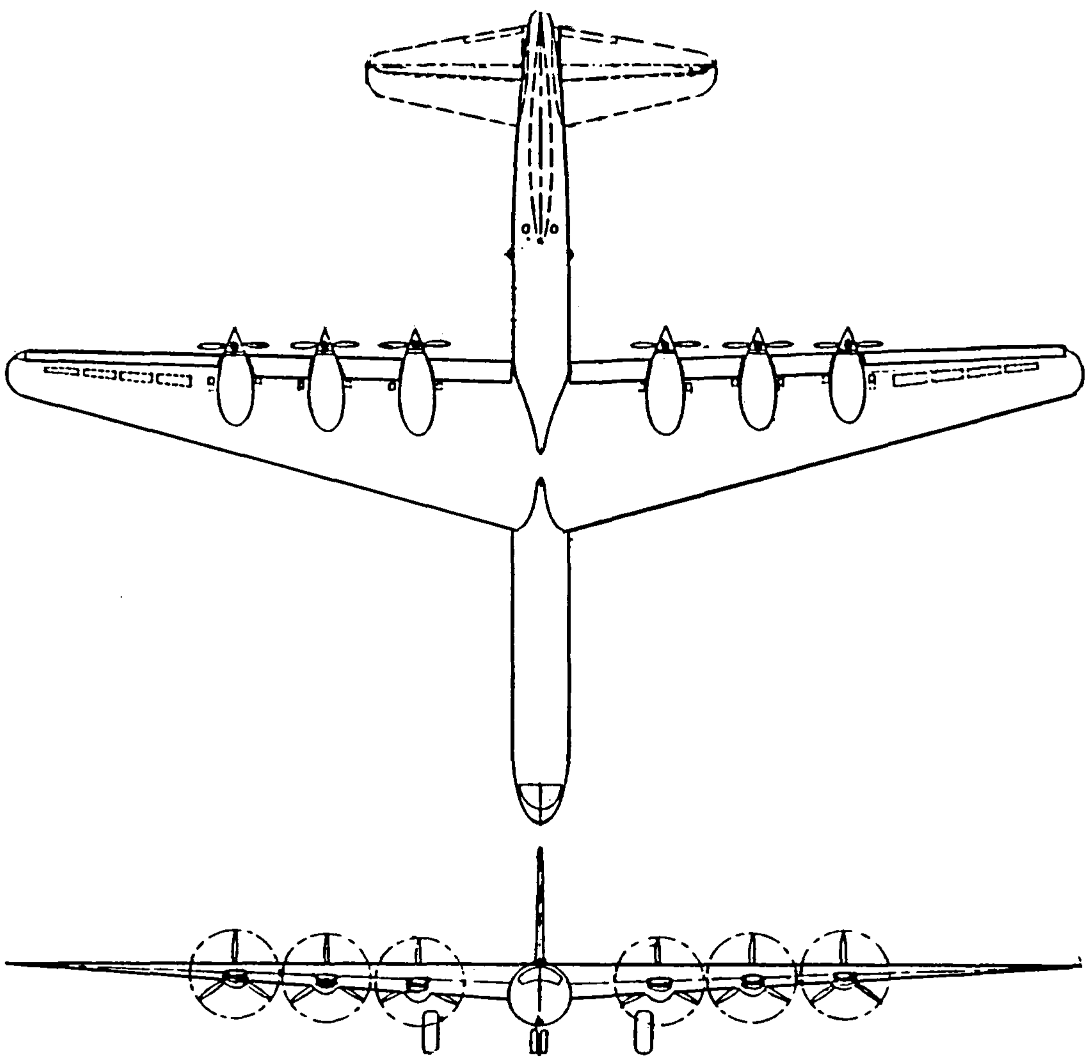

Figure 20-1. Test model used.

21

Low-Speed Wind-Tunnel Investigation of the Effects of Propeller Operation at High Thrust on the Longitudinal Stability and Trim of a Twin-Engine Airplane Configuration.

W.C. Sleeman, Jr. and E.L. Linsley

NACA Research Memorandum, RM L52D04, 1952.

An investigation was made to determine the effects of dual-rotation propeller operation at high thrust on the static longitudinal stability characteristics of a semispan powered model representing a twin-engine airplane configuration. The test model is shown in Figure 21-1. The flow field behind the model was studied extensively by several techniques which provided information relating the tail contribution to over-all stability characteristics.

Stability and trim changes associated with an extreme constant power condition were found to be greatly dependent upon both tail height and vertical location of the center of gravity. Large adverse effects of power were obtained for a configuration having the center of gravity located on the thrust line and the tail in a high position. It was found the adverse power effects could be essentially eliminated either by moving the tail down in the slipstream or by utilization of the direct-propeller-thrust moment associated with a vertical displacement of the center of gravity to provide stability.

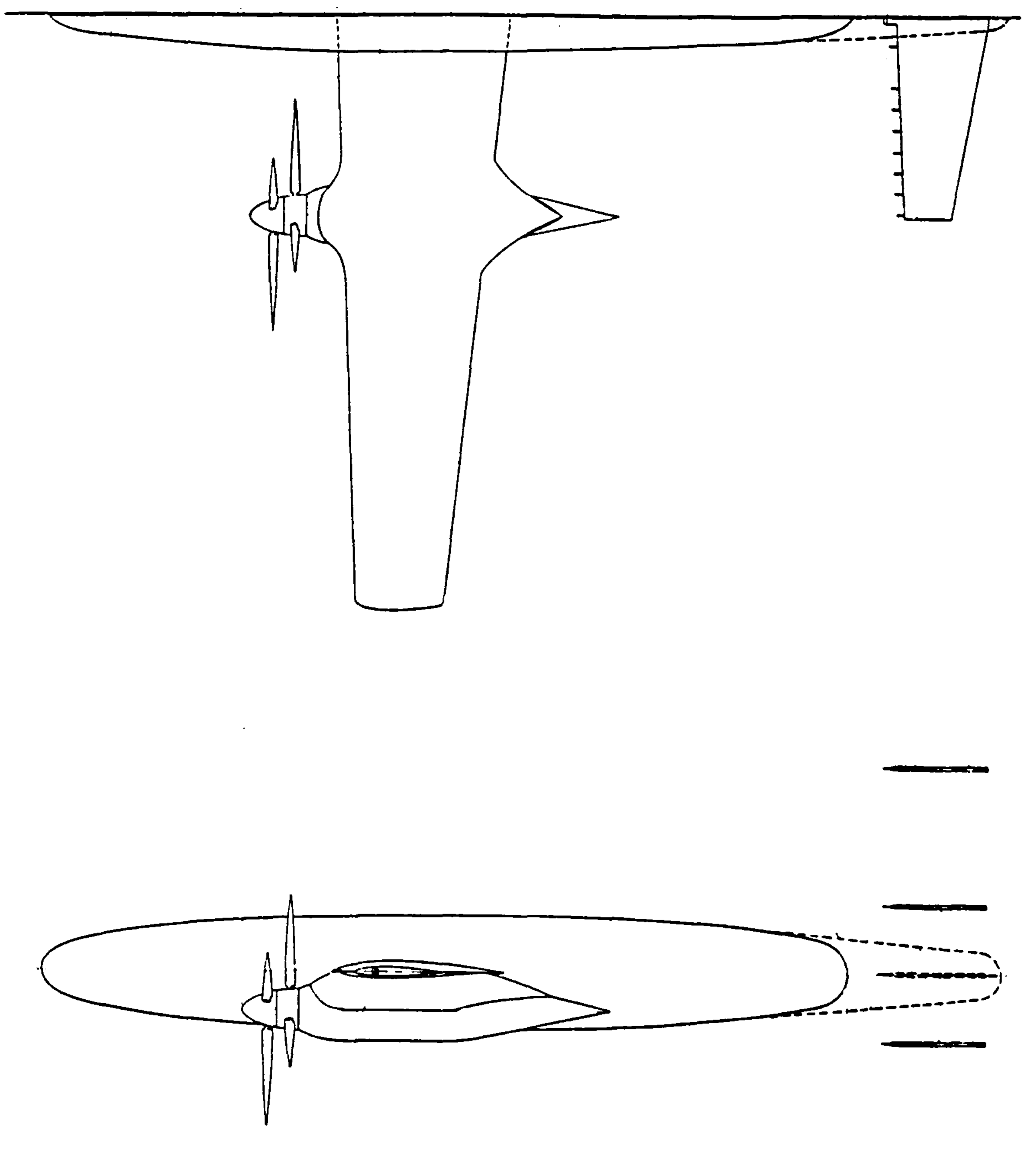

Figure 21-1. Test model used.

22

Flow Conditions in a Slipstream.

F. Weinig

Mississippi State University, Department of Aerospace Engineering, Translation by Georg Timm, August 1956.

This is a translation of an article published in 1936 which summarizes the available information concerning the behavior of the slipstream. Flow visualization and experimental data are included.

23

Effects of Propeller Slipstream on V/STOL Aircraft Performance and Stability.

L. Goland, N. Miller and L. Butler

U.S. Army Transportation Research Command, TRECOM Technical Report 64-47, August 1964.

NTIS AD 608186

A method is developed to predict the aerodynamic forces and moments of a wing immersed in a slipstream. The basic approach of Koning is used with modifications applied from low aspect ratio wing theory. The method is used to investigate two-and-four propeller VTOL and STOL wing configurations. Comparisons with existing data are performed and the satisfactory correlations are obtained.

24

Charts for Estimating Aerodynamic Forces on STOL Aircraft Wings Immersed in Propeller Slipstreams.

K.P. Huang, L. Goland and I. Balin

Dynasciences Corp., Report No. DCR-161, November 1965.

NTIS AD 634722

Equations and charts are presented for estimating the lift and longitudinal force coefficients of STOL aircraft wings immersed in propeller slipstreams. The method of Goland et al (reference 23) is used. The effect of many design parameters is analyzed.

25

Lifting Surface Theory and Tail Downwash Calculations for V/STOL Aircraft in Transition and Cruise.

E.S. Levinsky, H.U. Thommen, P.M. Yager and C.H. Holland

USAAVLABS Technical Report TR 68-67, October 1968.

NTIS AD 680969

A large-tilt-angle lifting-surface theory for tilt-wing and tilt-rotor V/STOL aircraft is given. The wing/propeller configuration is represented by a discrete-vortex Weissinger-type lifting surface theory in combination with a inclined actuator disk model. Wing-induced modifications to the slipstream boundary conditions are included.

Comparisons with experimental data show satisfactory agreement for small inclination angles. However, for large tilt angles, the theory predicts significantly lower downwash angles at the tail then available experimental data indicate. Design charts are provided for two- and four-propeller (rotor) configurations, for flight conditions ranging from hover to cruise.

26

Stability and Control Characteristics of a Large-Scale Deflected Slipstream STOL Model with a Wing of 5.7 Aspect Ratio.

V.R. Page and T.N. Aiken

NASA Technical Note, TN D-6393, October 1971.

A wind-tunnel investigation was conducted to determine the stability and control characteristics of a large-scale model representative of a propeller-driven STOL transport. The test model is shown in Figure 26-1. Longitudinal and lateral-directional characteristics were obtained for a four-engine configuration having a wing of 5.7 aspect ratio fully immersed in the propeller slipstream. Configuration variables included an aileron, a spoiler, a slot-lip aileron, a spanwise variation of propeller thrust and two vertical heights of the horizontal tail.

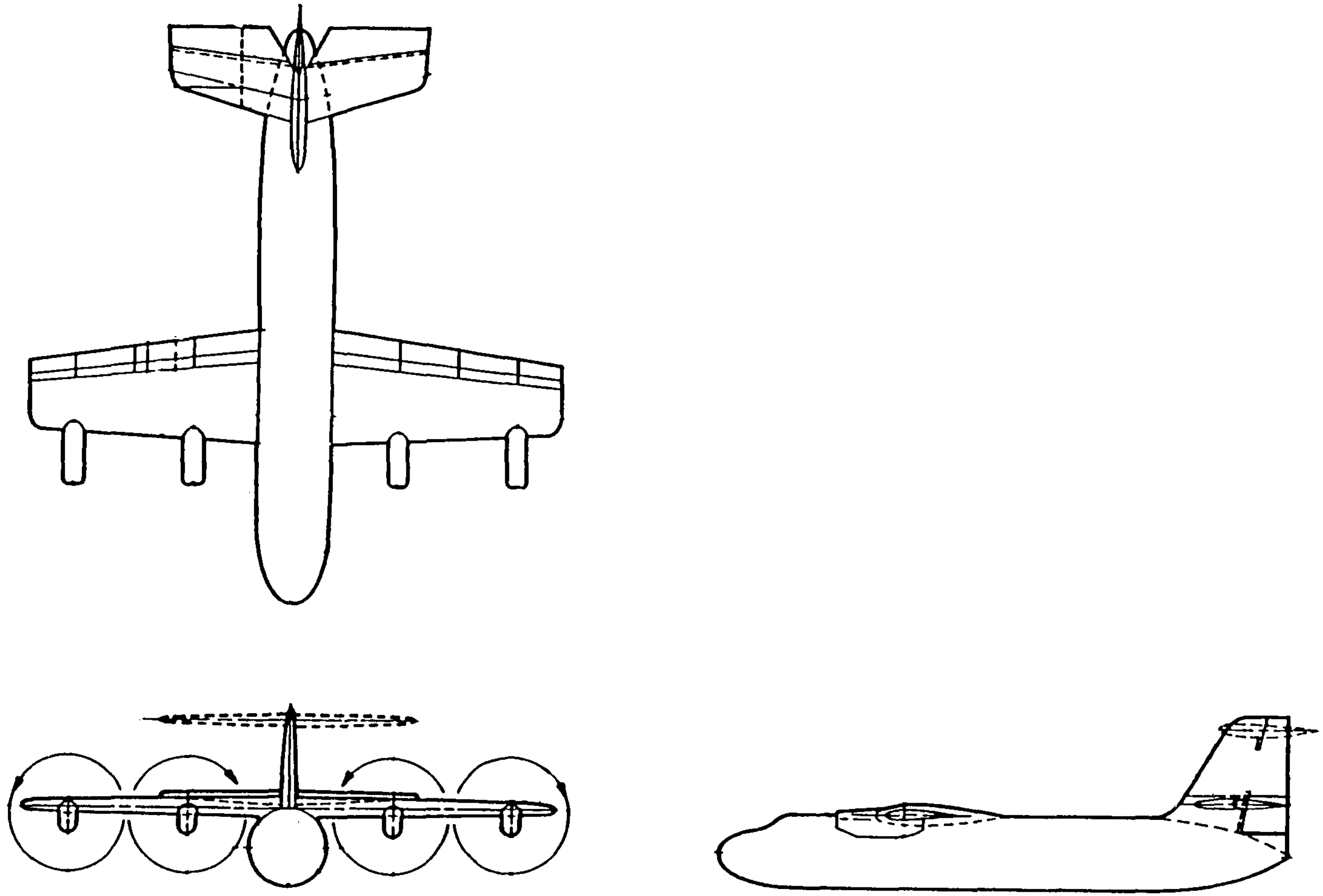

Figure 26-1. Test model used.

27

The Effect of a Tractor Airscrew on Body-Wing Interference.

E. Ower, R. Warden and L.J. Jones

British Aeronautical Research Council, Reports and Memoranda R&M No. 1512, November 1932.

The lift, drag and propulsive efficiency characteristics of a wing-nacelle-propeller combination were measured over a range of angle of attack, propeller operating condition and vertical position of the wing. The test model is shown in Figure 27-1. Force measurements were made over the range of test conditions, with and without the propeller.

For the no-propeller case, locating the wing slightly above the nacelle centerline produced the least interference drag. The worst location was the lowest position. The presence of the slipstream did not alter this. The slipstream tended to improve conditions where the interference drag was high, but not to the extent required to surpass the other wing locations. Generally, the best wing-nacelle configurations without the slipstream were also the best with the slipstream.

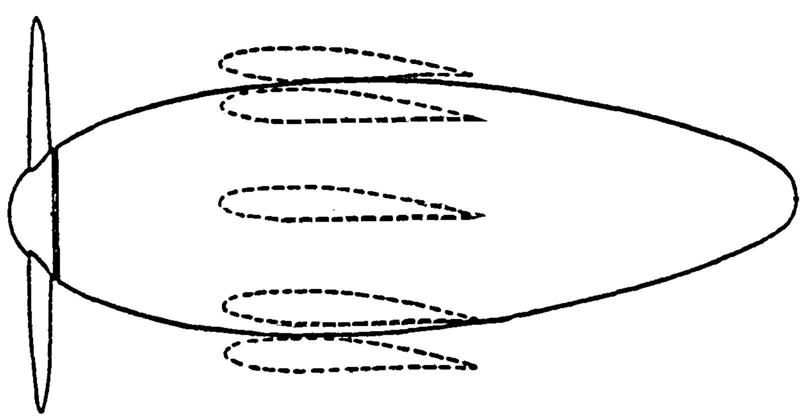

Figure 27-1. Test model used, and configurations.

Comparative Measurements of Propulsive Efficiency of Pusher and Tractor Propellers Installed in Single Engine High Performance Aircraft. (Vergleichmessung uber den Vortriebswirkungsgrad von Zug- und Druckschraubenantrieb bei einmotorigen Hochleistungsflugseugen.)

M. Kramer and T. Zobel

Deutsch Versuchsanstalt fur Luftfahrt, Forschungsbericht FB 492, November,1935.

NTIS PB 38458

Two powered single engine 1/5 scale models were tested in the DVL 1.2 meter wind tunnel. The model configurations were different; one being a tractor installation, the other being a pusher. The models are shown in Figures 28-1 and 28-2. Elliptic shaped endplates were used on the model wing to increase the effective aspect ratio above that indicated in the figures. The model propellers were scaled from Junkers type P 19. Power was supplied by electric motor. Model force data was obtained from a six-component balance. No individual propeller force measurements were made. Propeller torque was measured from the motor current. Model data were taken for conditions corresponding to low- and high-speed flight. Data included propeller-off and propeller-running.

The results showed that the pusher configuration had lower drag (although induced drag was higher) and higher propulsive efficiency. The increase in propulsive efficiency of the pusher configuration relative to the tractor configuration was 4.5 percent in high-speed flight and 3.5 percent in low-speed flight. Results are given in graphical form for the two configurations and the two flight conditions.

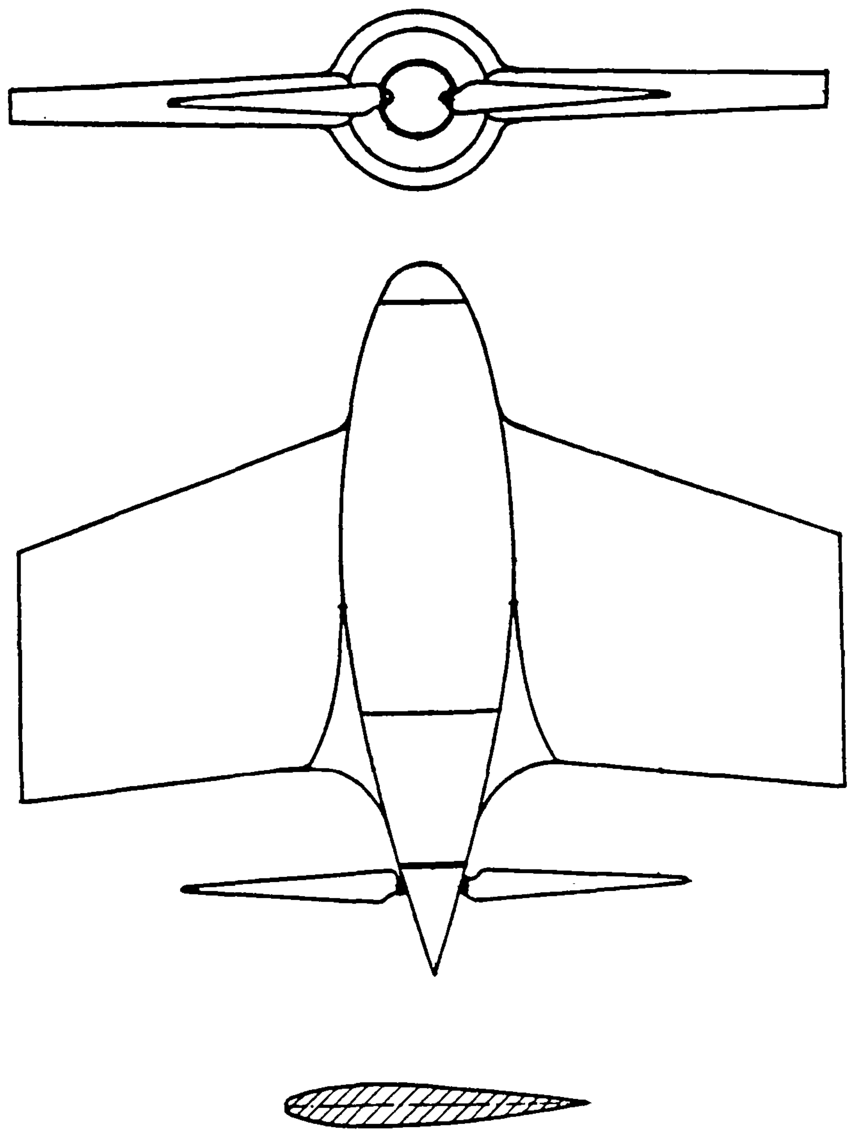

Figure 28-1. Test models used, pusher configuration.

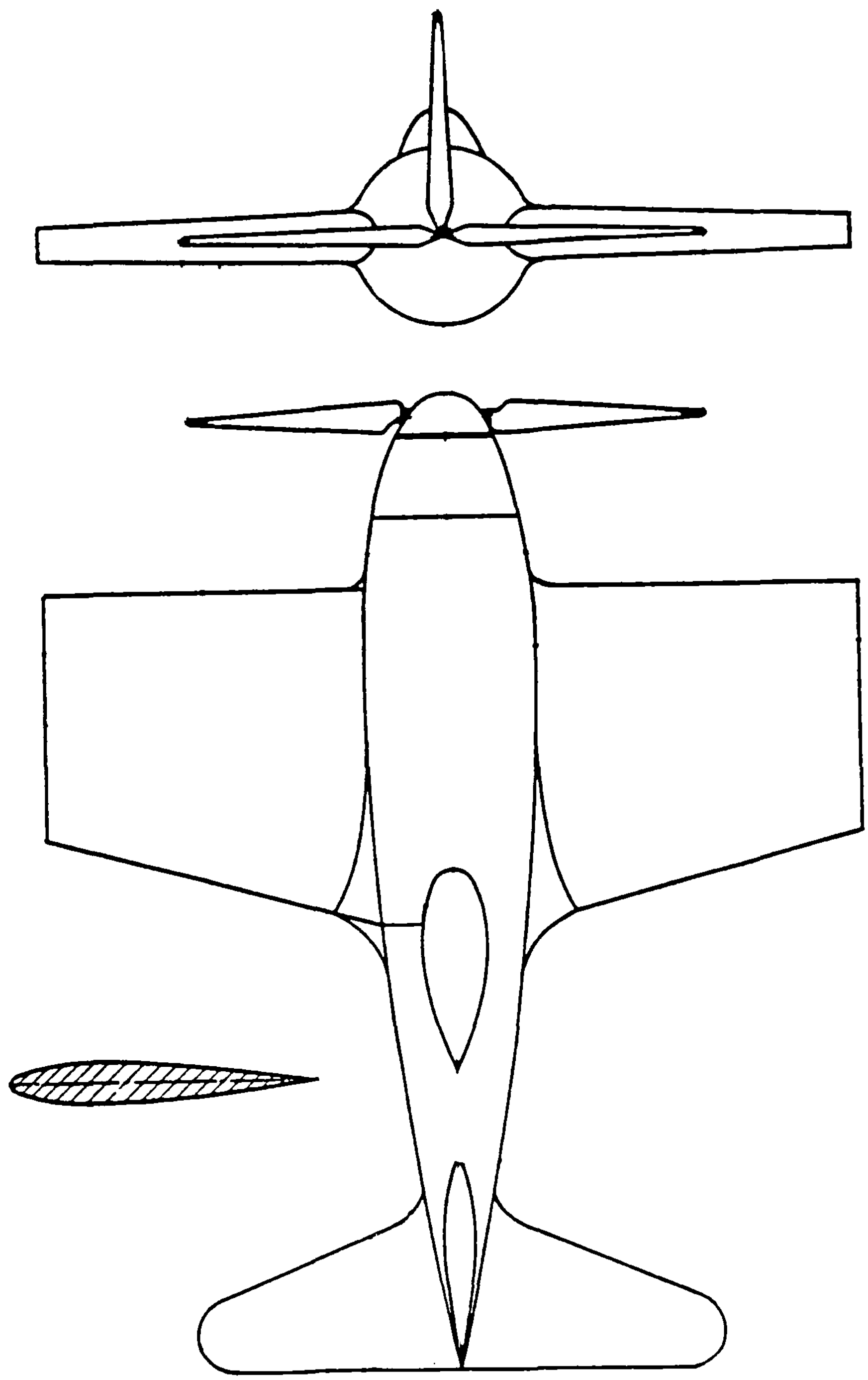

Figure 28-2. Test models used, tractor configuration.

Engine Nacelles and Propellers and Airplane Performance.

D.H. Wood

S.A.E Journal (Transactions), Vol. 38, No. 4, April 1936, pp. 148-160.

The extensive experimental study of engine-nacelle location and cowling made by the N.A.C.A. is reviewed. The factors contributing to the efficiency of the engine-nacelle and propeller group are discussed. Several examples are given showing how the results of experiments are applied, and how the use of improved cowlings and nacelle locations increases the high-speed performance of airplanes.

The effect of engine size on the nacelle drag is discussed, and charts are given from which values may be used in calculating the nacelle drag in preliminary performance estimates. Consideration is given to the influences of cooling drag and the relative merits of liquid versus air cooled engines.

Drag and Propulsive Characteristics of Air-Cooled Engine-Nacelle Installations for Two-Engine Airplanes.

A. Silverstein and H.A. Wilson, Jr.

NACA Wartime Report WR L-456, April 1938.

A four-engine model was tested in the NACA Langley Full Scale Wind Tunnel to determine the efficiency of wing-nacelle-engine installations as compared to engines installed within the wing. Different radiator installations were also tested. The test model is shown in Figure 30-1.

The results indicated that the aerodynamic characteristics of the model with the enclosed engines are superior to those for the conventional nacelle installations. The conventional nacelles increase the drag coefficient by 9 percent. The maximum propulsive efficiency for the enclosed engine installation was 80 percent for the pusher configuration and 76 percent for the tractor configuration.

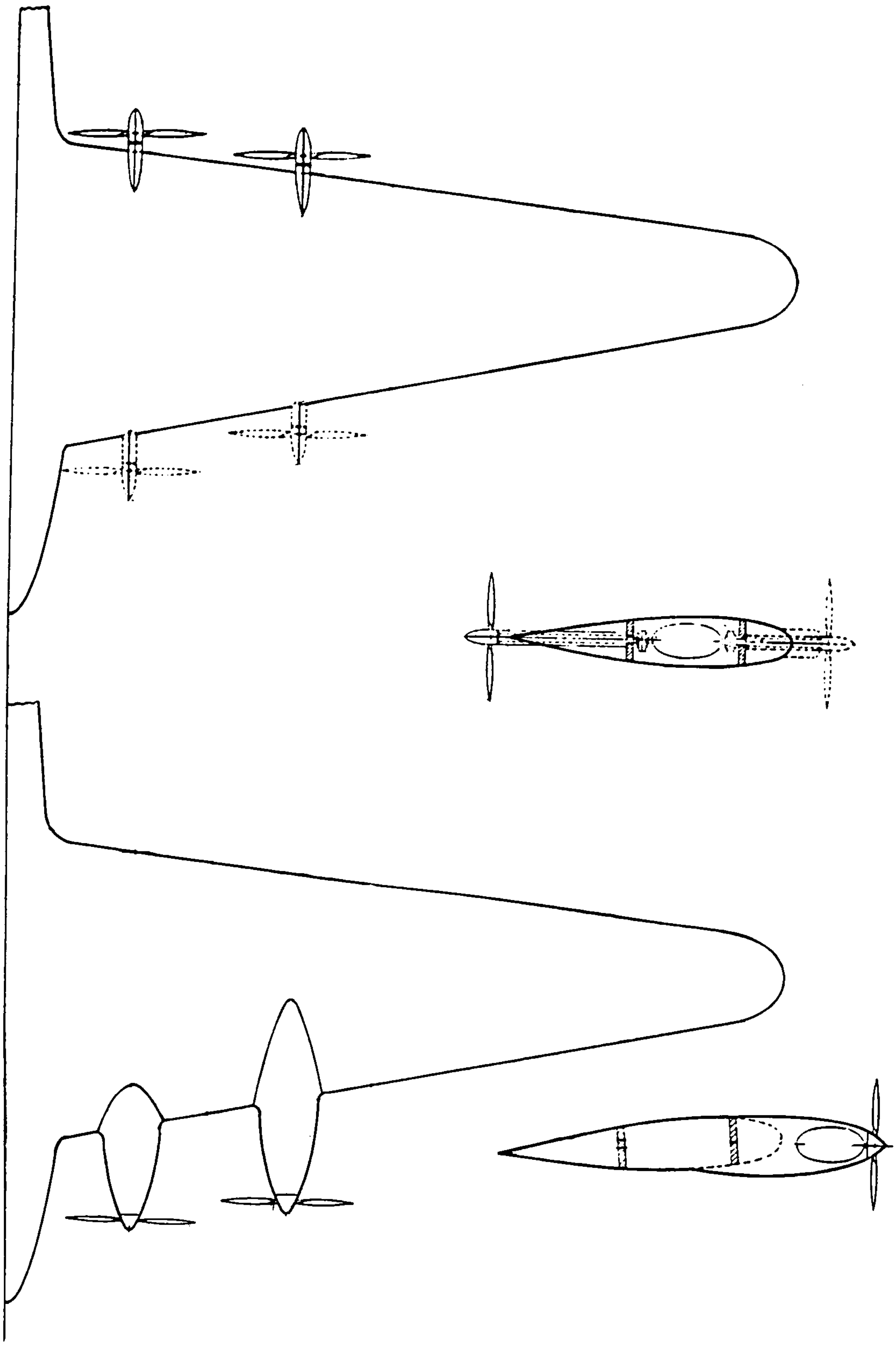

Figure 30-1. Test model used, and configurations.

31

Tests of Several Model Nacelle-Propeller Arrangements in Front of a Wing.

J.G. McHugh

NACA Wartime Report WR L-510, September 1939.

A wind tunnel test program was run to determine the effects of the nacelle location on propulsive efficiency. The test model configurations are shown in Figure 31-1. The nacelle shapes are representative of radial engines where propeller blockage interference is of importance.

The results showed that the effect of propeller-nacelle diameter ratio on propulsive efficiency was dependent on the vertical position of the nacelle. Minimal effects ocurred for the center position and increased as the nacelle was lowered. The propeller slipstream had little effect on wing lift and moment coefficients in the cruising range.

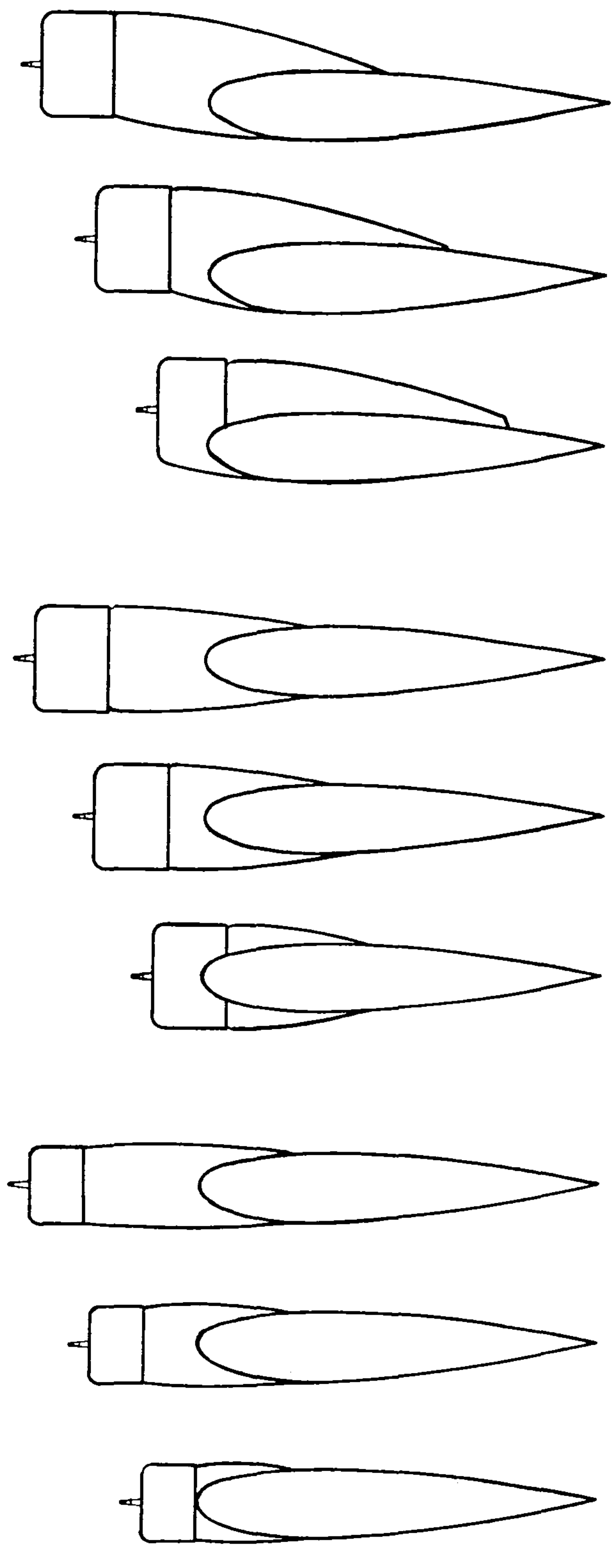

Figure 31-1. Test model used, and configurations.

The Effect of Nacelle-Propeller Diameter Ratio on Body Interference and on Propeller and Cooling Characteristics.

J.G. McHugh and E.H. Derring

NACA Report 680, 1939.

An investigation was conducted in the N.A.C.A. 20-foot tunnel to determine the slipstream drag, the body interference, and the cooling characteristics of nacelle-propeller combinations with different ratios of nacelle diameter to propeller diameter. Four combinations of geometrically similar propellers and nacelles, mounted on standard wing supports, were tested with values of the ratio of nacelle diameter to propeller diameter of 0.25, 0.33, and 0.44.

The results show that the effect of variation in the ratio of nacelle diameter to propeller diameter on propulsive efficiency is not important until the nacelle becomes approximately one-third of the propeller diameter. Beyond the one-third ratio point, the propulsive efficiency decreases rapidly with further increase in relative body size. The presence of a spinner over the propeller hub increases the propulsive efficiency by an amount varying from 1.5 to 4 percent.

Note on Wing-Nacelle-Airscrew Interference.

E. Ower, R. Warden and R.C. Pankhurst

British Aeronautical Research Council Reports and Memoranda R&M No. 2439, June 1940.

A wind tunnel test was performed to determine the behavior of the maximum propulsive efficiency of a wing-nacelle-propeller combination over a range of blade pitch angles. The test model is shown in Figure 33-1.

Results of the measurements are presented in graphical form. No general conclusions are available because only one combined configuration was tested.

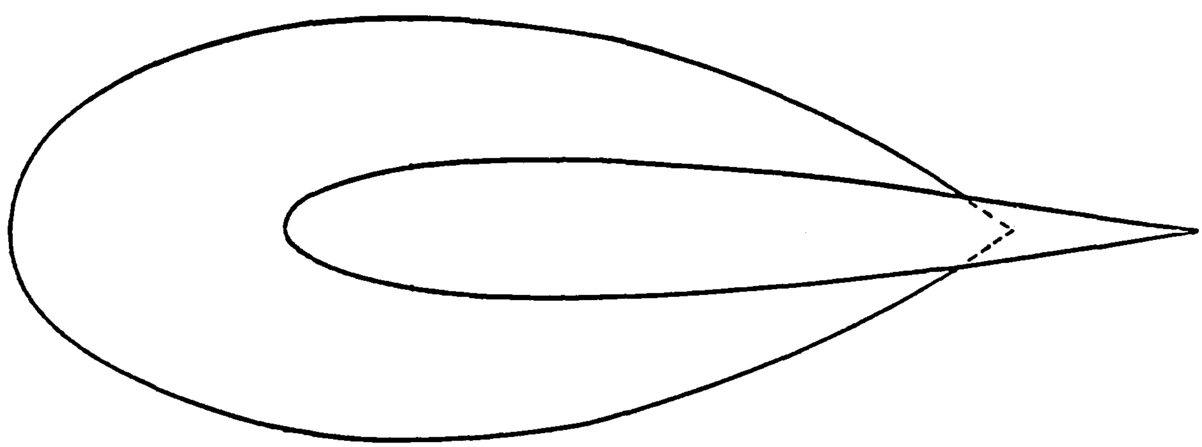

Figure 33-1. Test model used.

Comparison of Pusher and Tractor Propellers Mounted on a Wing.

J.S. Thompson, R. Smelt, B. Davison and F. Smith

British Aeronautical Research Council, Reports and Memoranda No. 2516, June 1940.

A wind tunnel test was performed to investigate the relative propulsive efficiencies of tractor versus pusher propeller installations. The test models are shown in Figure 34-1. Model thrust and torque measurements were made with the propeller and nacelle only, and then with the wing added.

The pusher installation had a higher efficiency then the tractor for the nacelle only configuration. The presence of the wing reversed this relationship, ie. the tractor nacelle/wing had a higher efficiency than the pusher nacelle/wing. The increase in the tractor nacelle/wing efficiency also includes the effect of higher friction drag of the wing due to movement of the laminar transition point forward. If this is accounted fore in determining the propeller efficiency, the tractor installation is even more favorable.

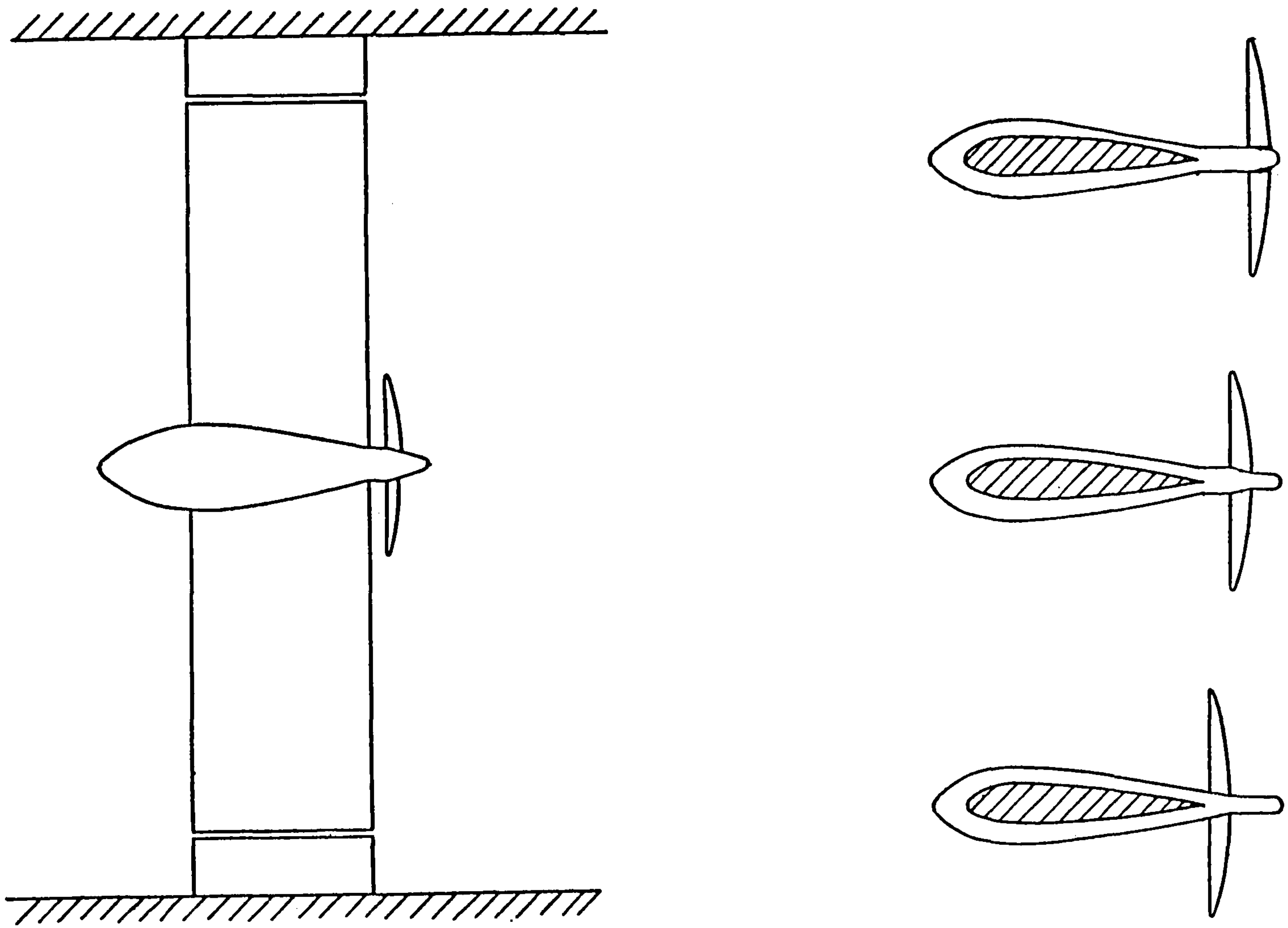

Figure 34-1. Test model used, and configurations.

Drag and Propulsive Characteristics of Air-Cooled Engine-Nacelle Installations for Two-Engine Airplanes.

H.A. Wilson, Jr. and R.R. Lehr

NACA Wartime Report, WR L-428, December 1940.

Research on wing-nacelle-propeller arrangements has been conducted in the NACA full-scale wind tunnel with tests on a model of a two-engine airplane provided with nacelles varying in diameter from 1.5 to 2.6 times the local wing thickness. The test model is shown in Figure 35-1.

The results show the variation of the nacelle drag with the ratio of the nacelle diameter to the wing thickness, the effects of the nacelles on the aerodynamic characteristics of the airplane, and the propulsive and the over-all efficiencies for all the arrangements.

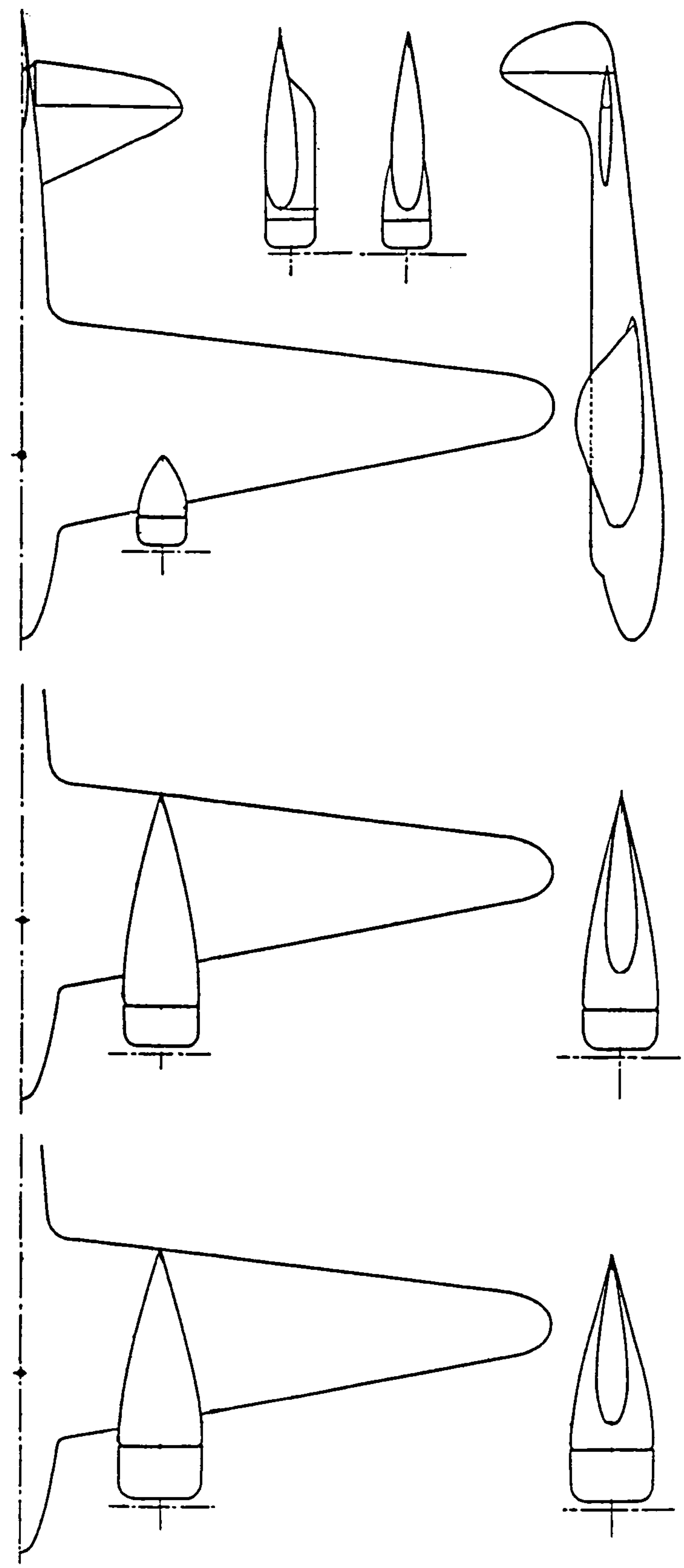

Figure 35-1. Test model used, and configurations.

Wind-Tunnel Tests of Several Model Tractor-Propeller and Pusher-Propeller Wing Extension-Shaft Arrangements.

H.N. Harmon

NACA Advanced Confidential Report, June 1941.

Tests were performed in the 20-foot propeller-research tunnel to investigate the possibility of obtaining increased net efficiencies of propeller-nacelle units by enclosing the engines in the wings and by using extension shafts. The test models are shown in Figures 36-1 and 36-2.

It was found that the net efficiency of a conventional round-shank propeller mounted on an extension shaft in front of or behind a wing increased with an increase in the diameter of the spinner and the shaft housing. The efficiencies of the pusher position appeared to be more critically affected by spinner size than those for the tractor position. The spinners with large diameters for the pusher position resulted in a higher efficiency than those for the tractor arrangements. The reverse was true for the small spinners. The use of propeller cuffs in combination with a small diameter spinner generally resulted in net efficiencies that were comparable with those found for the large-spinner combinations.

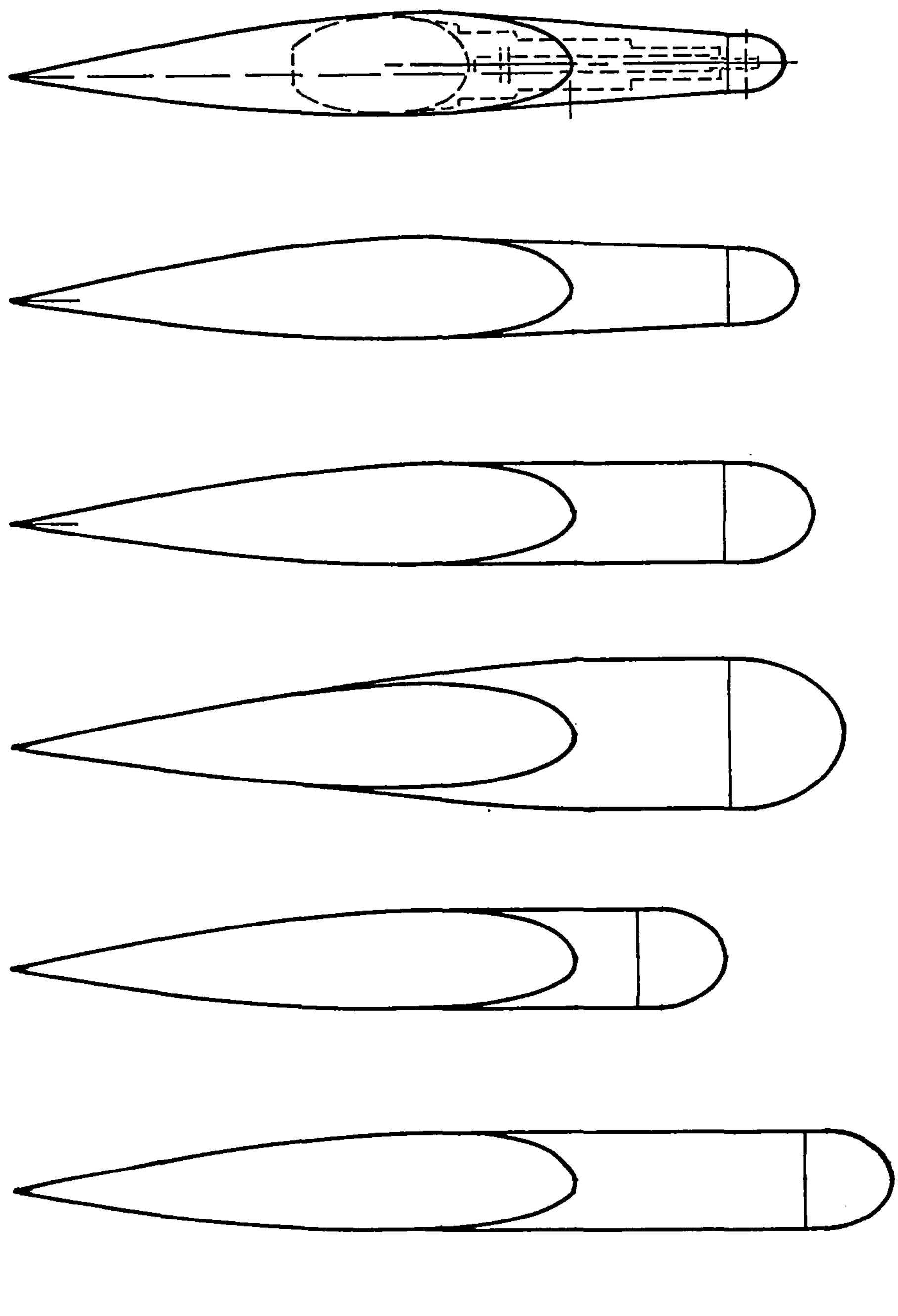

Figure 36-1. Test models used, tractor configurations.

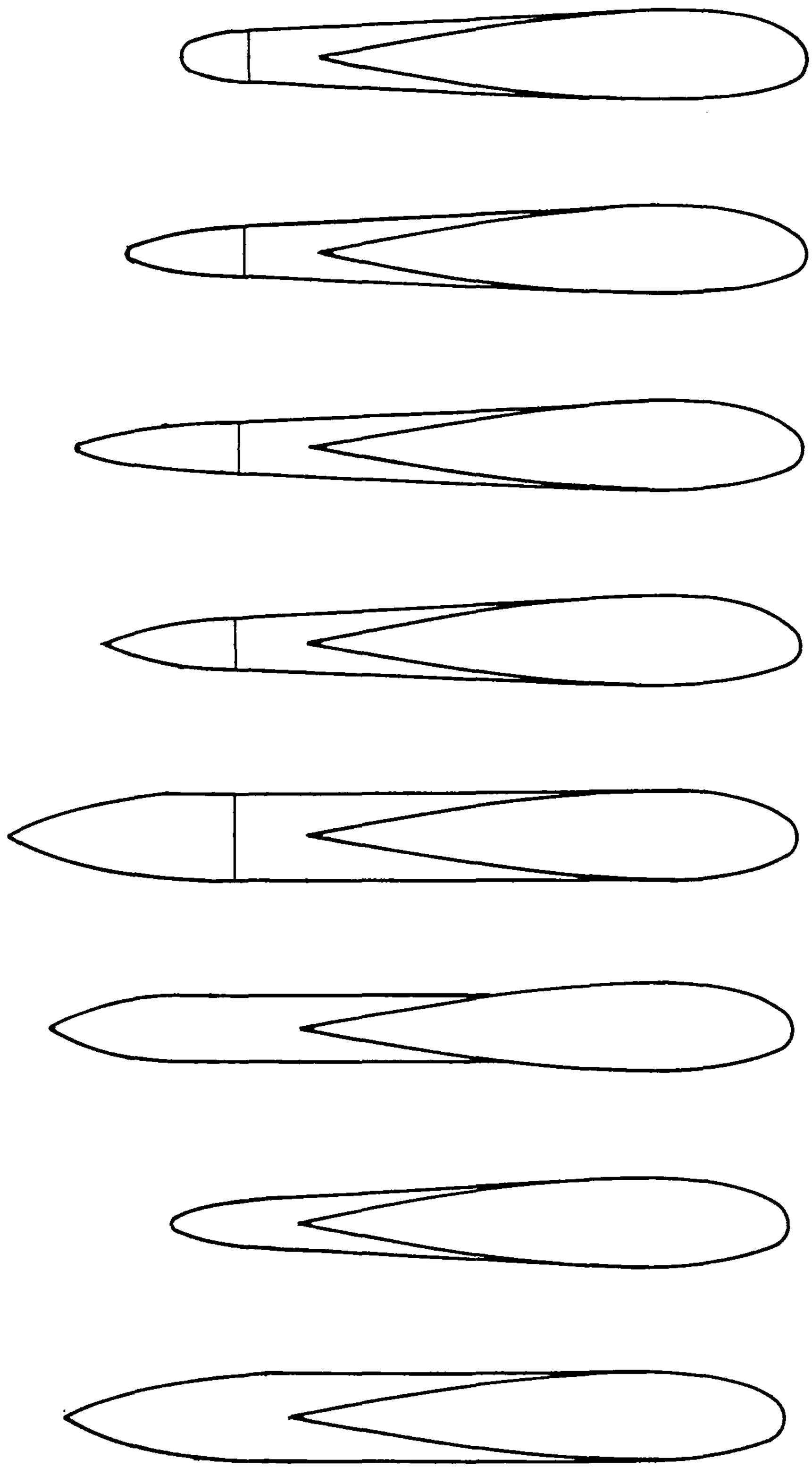

Figure 36-2. Test models used, pusher configurations.

37

Full-Scale-Tunnel Investigation of a Multiengine Pusher-Propeller Installation.

H.A. Wilson, Jr.

NACA Wartime Report WR L-246, November 1942.

A large-scale model of a four-engine pusher-propeller configuration was tested in the NACA Langley Full Scale Wind Tunnel. Trailing edge extensions (contravanes) deflected to provide rotating flow to the propellers were also tested. Measurements of the net model forces were made.

The use of contravanes increased the propulsive efficiency by 3.5 percent. The pusher configuration with the contravanes had the same propulsive efficiency as a previously tested tractor configuration of the same model.

Drag and Propulsive Characteristics of Air-Cooled Engine-Nacelle Installations for Large Airplanes.

A. Silverstein and H.A. Wilson, Jr.

NACA Technical Report No. 746, 1942.

A four-engine tractor propeller model was tested in the NACA Langley Full Scale Wind Tunnel. The diameter and longitudinal location of the nacelles were varied systematically. Representative model configurations are shown in Figure 38-1. Model force measurements were made with and without propellers.

Propulsive efficiency decreased linearly from 77 percent to 67 percent as the nacelle diameter was increased. Propulsive efficiency was also sensitive to longitudinal location, being higher for the location farthest from the wing. The maximum lift-drag ratio of the model was substantially reduced by the addition of the nacelles to the model.

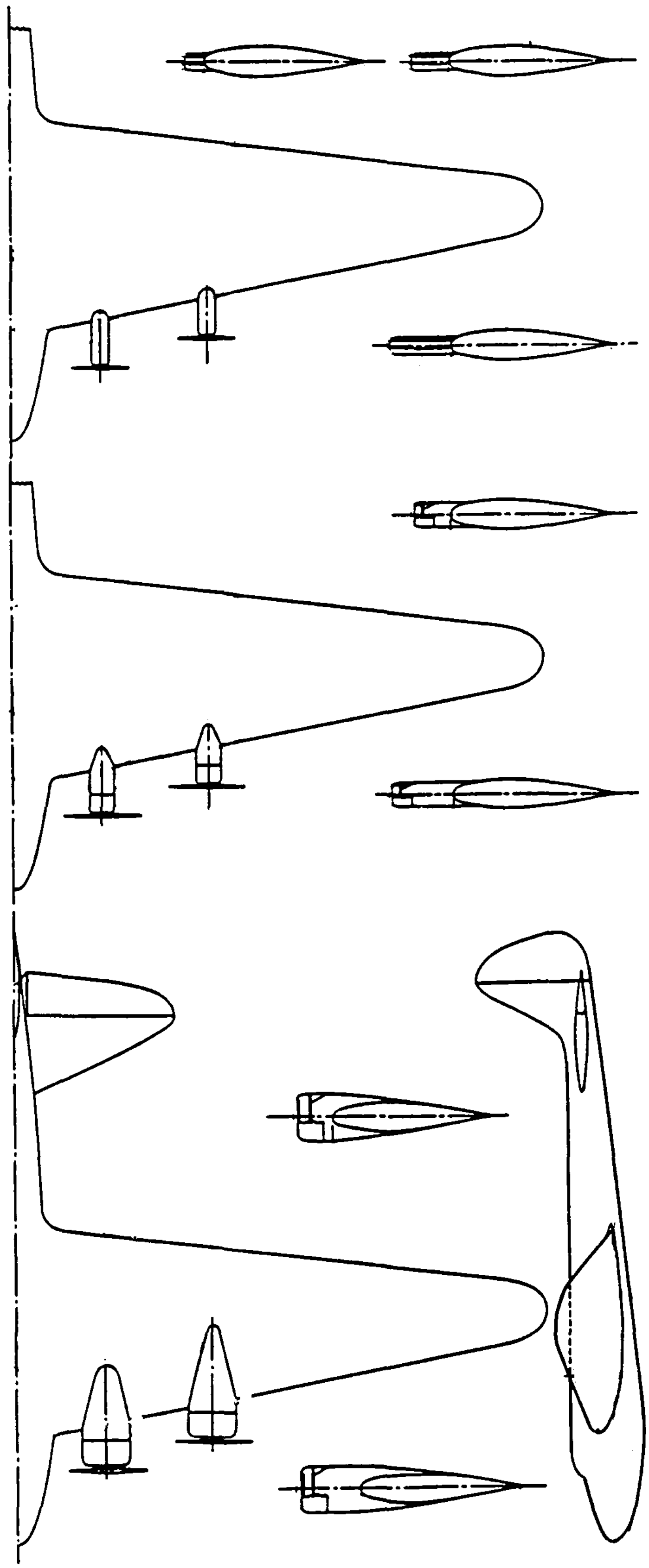

Figure 38-1. Test model used, and configurations.

39

Wind-Tunnel Investigation of Alternative Propellers Operating behind Deflected Wing Flaps for the XB-36 Airplane.

E. Boxer

NACA Wartime Report, WR L-533, December 1945.

Tests have been conducted in the NACA Langley propeller-research tunnel to determine the aerodynamic characteristics of two pusher propellers of identical plan form, but different airfoil sections operating behind a slotted flap. The tests were made upon a wing-flap-nacelle combination simulating the arrangement at the center nacelle of the XB-36 airplane. The test model is shown in Figure 39-1. Tests were made over a range of blade angles and flap deflections necessary to cover all flight conditions of the subject airplane.

The peak efficiency of both propellers was reduced 2.5 and 6 percent for 20 degrees and 40 degrees flap angles, respectively. Extension of the landing gear decreased the maximum and take-off efficiencies only slightly for most conditions.

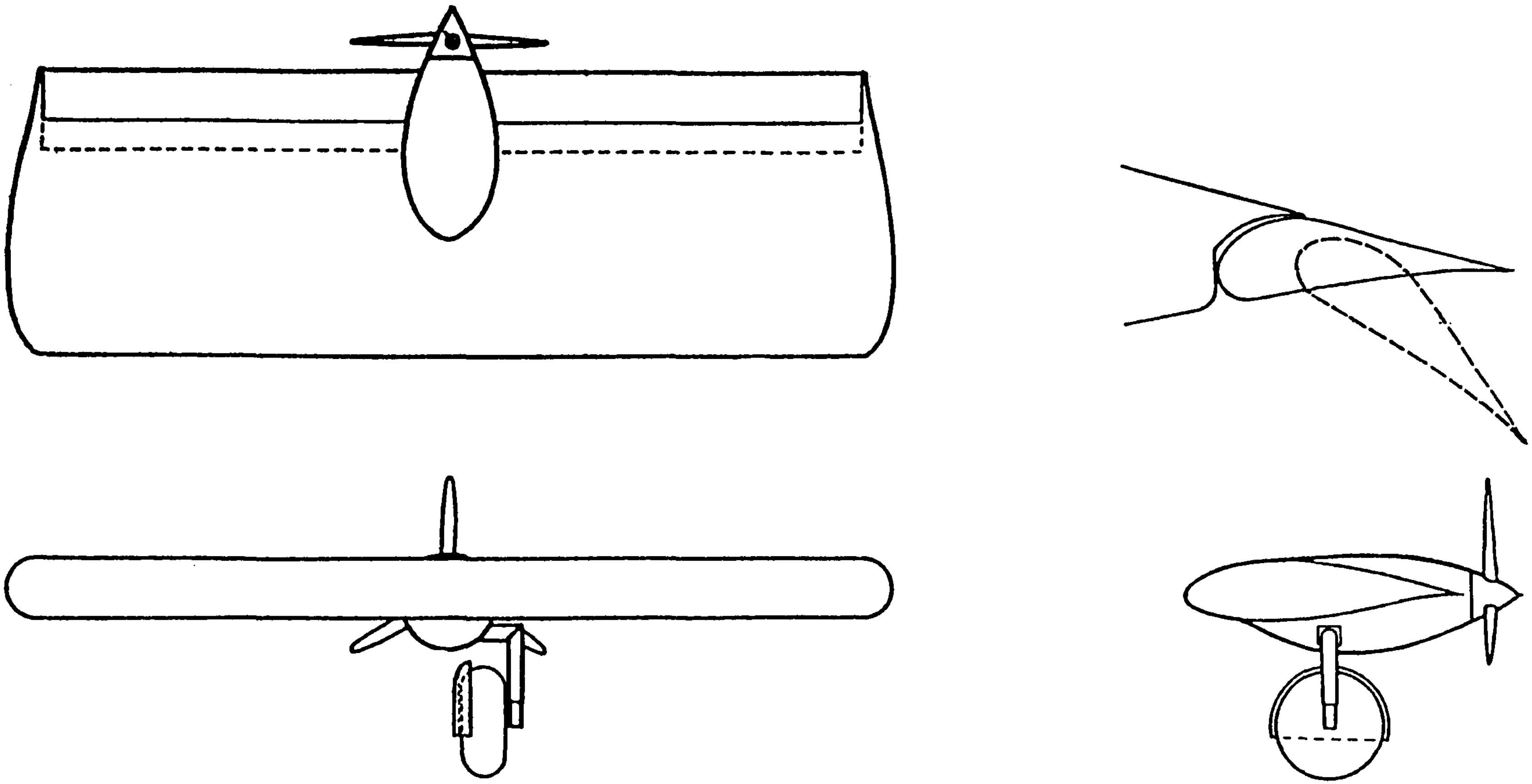

Figure 39-1. Test model used.

40

An Analysis of Prop-Fan/Airframe Aerodynamic Integration.

M.L. Boctor, C.W. Clay and C.F. Watson

NASA Contractor Report CR-152186, October 1978.

Aerodynamic design studies of different prop-fan installations were performed using proprietary computer codes. Aft fuselage and empennage mounts, as well as conventional wing mounts were considered. Summaries of each of the configuration studies are provided.

41

Prop-Fan Integration at Cruise Speeds.

H.R. Welge

AGARD Symposium on Aerodynamics of Power Plant Installation, AGARD Paper 33, May 1981.

The aerodynamic installation features of a highly loaded turboprop (prop-fan) on an aircraft for flight at Mach 0.8 are discussed. The aerodynamic flow envrionment in which the prop-fan must operate is shown for both wing and aft-fuselage installations based on analytical studies using advanced surface panel methods. The effects of various prop-fan slipstream parameters on the drag of a supercritical wing are presented.

The results indicate that only small drag penalties occur. Drag reductions are possible by tailoring the local wing section to account for the rotor-induced flow. Using these inputs, an integrated wing/nacelle is shown.

42

Influence of the Propeller on other Parts of the Airplane Structure.

C. Koning

Aerodynamic Theory, Volume IV, W.F. Durand ed., 1935.

The first in-depth development of the influence of the propeller slipstream on the aerodynamics of the wing. The slipstream is represented as a uniform jet without the tangential swirl component. The jet velocity is restricted to be only slightly larger than the free stream velocity, limiting the analysis to only high advance ratios. The jet is of circular shape extending downstream parallel to the flow. The wing is represented by a lifting line with trailing vorticies. The lifting line model restricts the analysis to wings of high aspect ratio.

Wing-Nacelle-Propeller Interference for Wings of Various Spans - Force and Pressure-Distribution Tests.

R.G. Robinson and W.H. Herrnstein, Jr.

NACA Report No. 569, 1936.

An experimental investigation was made in the N.A.C.A. full-scale tunnel to determine the effect of wing span on nacelle-propeller characteristics, and the lateral extent of nacelle and propeller influence on the wing. The test model is shown in Figure 43-1. Both force measurements and surface pressure distribution measurements were made.

Force and pressure-distribution results indicate that the influence of a nacelle and a propeller may be considered to extend laterally on the wing the same maximum distance, or about five nacelle diameters and two propeller diameters outboard of their common axis. Additional results are presented showing the net and propulsive efficiencies, and polar curves of the wing-nacelle-propeller model.

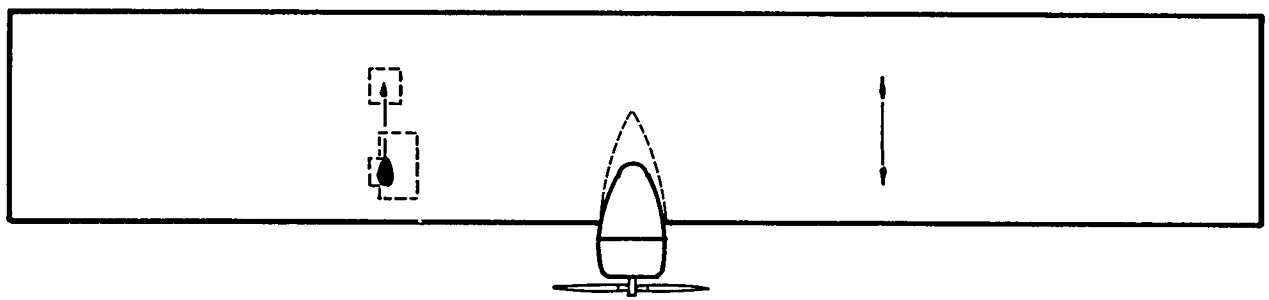

Figure 43-1. Test model used.

Pictures of Flow in a Propeller Slipstream Disturbed by a Wing. (Stromungsaufnahmen eines durch einen Tragflugel gestorten Propellerstrahls.)

J. Lotz

Aerodynamische Versuchsanstalt, Goettingen E.V., FB 899, December 1937.

NTIS PB 36561

Various configurations of a propeller and wing were studied in a water tunnel. Air bubbles were injected as the visualization medium. Pictures were taken from the side, from below, and at an angle from above. The configurations included propeller only and propeller with wing. Three different wing chords were used. The test conditions were for an advance ratio of 0.14, and a Reynolds number range of 2.8×10^4 - 7×10^4.

The pictures show that the slipstream adapts to the wing flow; the swirl is reduced significantly; and that the slipstream halves, split off by the wing, move spanwise in the direction of the swirl.

45

Effect of Propeller Slipstream on Wing and Tail.

J. Stuper

NACA Technical Memorandum TM 874, August 1938.

A wind tunnel test to measure the effect of a slipstream on a wing was performed. In the first part of the test, the slipstream was created by an axial flow fan, with the swirl component removed. In the second part of the test, a conventional propeller was used. Measurements of the slipstream velocity distribution, slipstream flow angle distribution and wing pressure distribution were made and are given in the report.

Results for the pure jet flow slipstream case showed that wing lift increase with jet velocity, and that the downwash angle at the tail also increase with jet velocity. For the propeller slipstream case, the wing lift distribution varied in a nonsymmetrical manner across the slipstream region. The slipstream splits into two halves above and below the wing which shift spanwise in opposite directions due to the swirl velocity component. These halves due not recombine, but are displaced laterally at the tail. The measured distributions are presented in graphical form. No tabular data is given.

46

The Mutual Influence of Individual Parts of the Aircraft with Rotating Propellers. (Die gegenseitige Beeinflussung der Einzelteile am Flugzeug mit laufender Scgraube.)

J. Stuper

Ringbuch der Luftfahrttechnik, March 1939.

NTIS PB 20309

A general survey of the state of the art as of 1939 is given. Results from american and european research programs are summarized and presented in graphical form. Many of the references cited by Stuper are included in this report.

The Effect of the Slipstream on an Airplane Wing.

A. Franke and F. Weinig

NACA Technical Memorandum, TM 920, November 1939.

The work of Koning (reference 42) is applied to the case of a wing spanning a slipstream and extended to include slipstream rotation and propeller in yaw. The conditions which must be met at the slipstream boundary are developed. With the aid of the image method, it is shown how these boundary conditions may be complied with for the case of an airfoil in a propeller slipstream in horizontal flow as well as for the propeller in yaw and with allowance for the slipstream rotation.

It is shown how the effective angle of attack and the circulation distribution with due regard to slipstream effect can be predicted. This leads to the determination of the lift, drag and pitching moment distribution across the wing.

48

Wing in a Slipstream. (Tragflugel im Schraubenstrahl.)

A. von Baranoff

Jahrbuch 1939 der deutschen Luftfahrtforschung, 1939, pp. 222-230.

NTIS PB 24399

A theoretical model of a wing in a slipstream is described. The slipstream model is restricted to one with no contraction, no deformation behind the wing, and constant axial velocities. The slipstream model includes a constant rotational velocity component. The wing is represented by a lifting line and is restricted to infinite aspect ratio. Comparisons between the theoretical model and experimental results are included.

Pressure Distribution Measurements of a Wing Model with Engine Nacelle and Rotating Propeller. (Druckverteilungsmessungen an einem Tragflugelmodell mit Motorgondel und laufendem Propeller.)

W. Albring

Deutsche Luftfahrtforschung, Forschungsbericht FB 1908, May 1942.

NTIS PB 37676

A 1:16 scale reflection plane model of the FW 200 Condor wing and inboard engine nacelle was tested in a 1.5 meter wind tunnel. The test model configuration is shown in Figure 49-1. The test Reynolds number based on the model wing chord was 6.5×10^5. The wing section airfoil was a NACA 2318. The test conditions included cruising flight, climbing flight and descending flight with the propeller operating as a brake. Both the nacelle and the wing were extensively instrumented with surface pressure taps.

The measured pressure distributions are presented in axonometric form. The effects of the presence of the nacelle on the wing pressure distribution are detailed. The nacelle results in a decrease in wing lift compared to the wing only case. For the configuration of the wing and nacelle without propeller, there was a constant decrease of lift coefficient for all angles of attack. There was also a decrease in pitching moment coefficient. With the propeller running, the decrease in lift is reduced for cruising flight, and an increase in lift is experienced for climbing flight. The measured pressure distributions are given in tabular form.

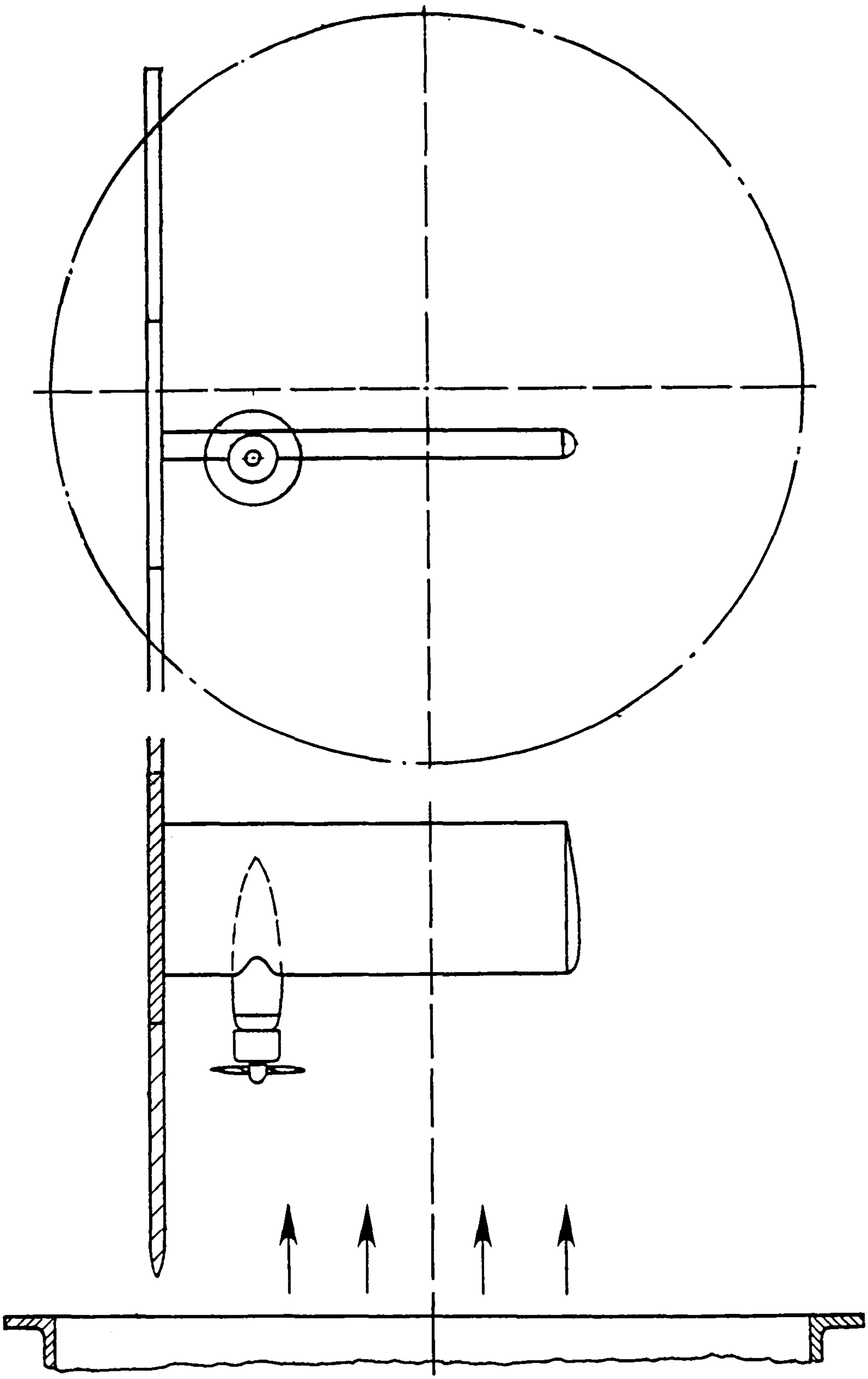

Figure 49-1. Test model used.

50

Calculation of the Effect of Slipstream on Lift and Induced Drag.

H.B. Squire and W. Chester

British Aeronautical Research Council, Reports and Memoranda R&M 2368, October 1945.

A lifting line theory is developed for a wing immersed in a jet of higher velocity. An additional analysis is included to account for the effects of slipstream swirl. The method is applied to determine the conditions for minimum induced drag.

51

Non-Uniform Flow and Its Influence on an Aerofoil.

F.W. Riegels

British Ministry of Aircraft Production, Volkenrode, Reports and Translations No. 931, March 1947.

A summary of the available information concerning the behavior of the slipstream and its effects on the wing and tail is presented. The influence of the fuselage and nacelles is included. Experimental results from many German research programs is discussed.

The Effect of a Simulated Propeller Slipstream on the Aerodynamic Characteristics of an Unswept Wing Panel with and without Nacelles at Mach Numbers from 0.30 to 0.86.

G.H. Jordan and R.I. Cole

NACA Technical Note, TN 2776, September 1952.

Force tests were made in the N.A.C.A. Langley 24-inch high-speed tunnel in order to determine the effect of a simulated propeller slipstream on the aerodynamic characteristics of an unswept wing panel with and without nacelles. The lift, drag and pitching moment were measured at angles of attack of 0 degrees and 3 degrees through a range of Mach numbers from approximately 0.30 to 0.86.

The test results obtained for Mach numbers of the simulated propeller slipstream equal to and 10 percent greater than free stream indicated no significant changers in lift and pitching-moment coefficients for the configurations investigated. The Mach number for drag rise near zero lift was decreased approximately 0.02 as a result of the increase in propeller-slipstream velocity.

A Preliminary Theoretical Investigation of the Effects of Propeller Slipstream on Wing Lift.

E.W. Graham, P.A. Lagerstrom, R.M. Licher and B.J. Beane

Douglas Aircraft Co., Report No. SM-14991, November 1953.

A theoretical method for the calculation of the lift of a wing in a slipstream is presented. The method is based upon slender body theory. Comparisons of the developed method with a lifting line method and Weissinger°s method are given. Propeller effects are representated by actuator disk theory. Comparisons of the three methods with experimental data are included, and the requirements for future experimental research are discussed.

Effects of Operating Propellers on the Wing-Surface Pressures of a Four-Engine Tractor Airplane Configuration Having a Wing with 40 degrees of Sweepback.

C.D. Kolbe and F.W. Boltz

NACA Research Memorandum, RM A53I29, April 1954.

An investigation was performed to evaluate the effects of operating propellers and of nacelles on the wing-surface pressures on a semispan model of a four-engine tractor airplane configuration. The test model is shown in Figure 54-1.

At high thrust coefficients, the propeller slipstream caused large changes in the spanwise distribution of loading over the region of the wing immersed in the propeller slipstream. The strong rotational components within the slipstream were responsible for large inflections in the spanwise distribution of loading behind the up-going propeller blades. Relative small changes were seen behind the down-going propeller blades. At high subsonic Mach numbers, the over-all effects of operating propellers were not large when compared with the low-speed case.

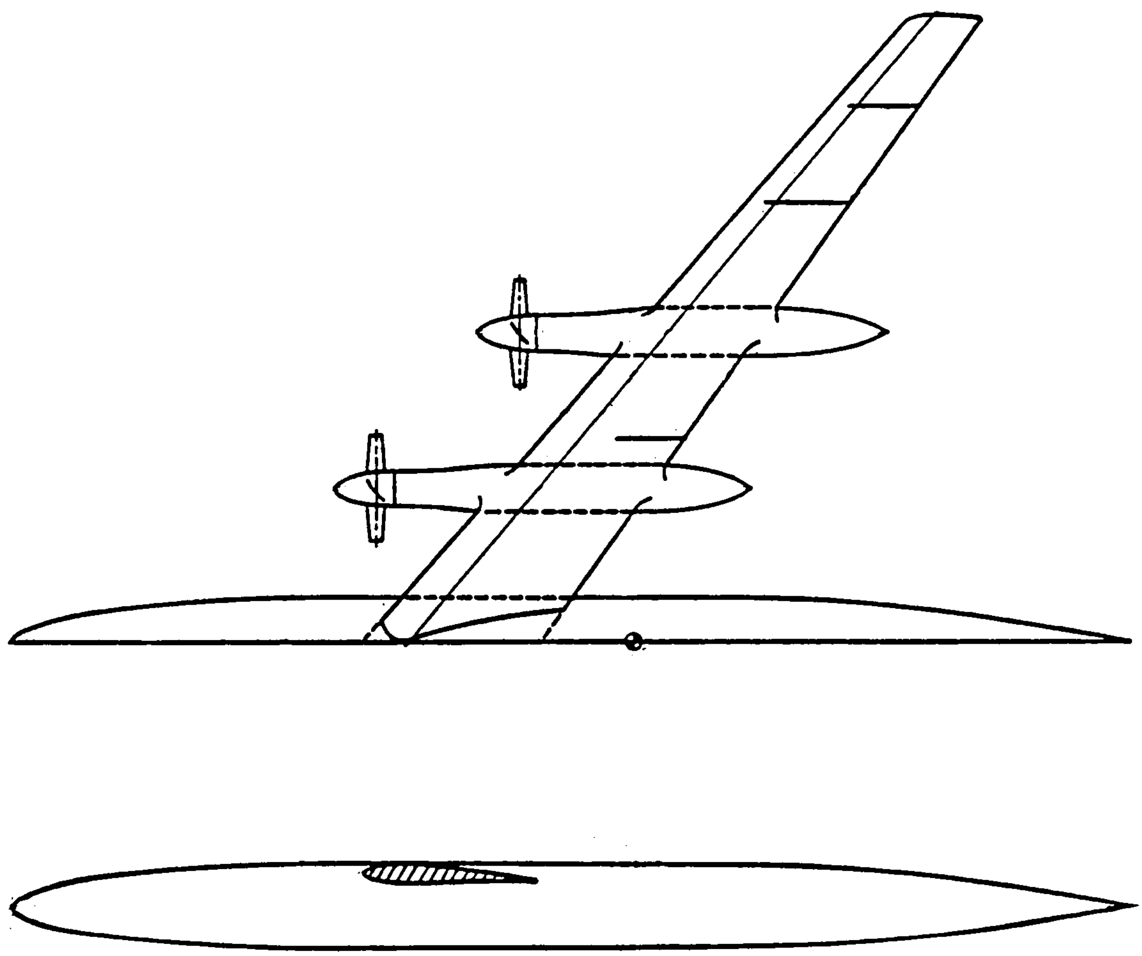

Figure 54-1. Test model used.

55

An Investigation of a Wing-Propeller Configuration Employing Large-Chord Plain Flaps and Large-Diameter Propellers for Low-Speed Flight and Vertical Take-Off.

R.E. Kuhn and J.W. Draper

NACA Technical Note, TN 3307, December 1954.

An investigation was conducted of a wing with large-chord plain flaps and auxiliary vanes. The purpose of the vanes was to rotate the thrust vector of two large-diameter propellers through large angles required for vertical take-off and low-speed flight. The test model is shown in Figure 55-1.

Under static thrust conditions, a maximum upward rotation of the effective thrust vector of 45 degrees was obtained. This was increased to 67 degrees with the addition of two auxiliary.

A method is presented for calculating the lift due to flap deflection and slipstream for small flap deflections. The lift due to flap deflection at zero thrust and the lift due to flap deflection at zero forward speed are known.

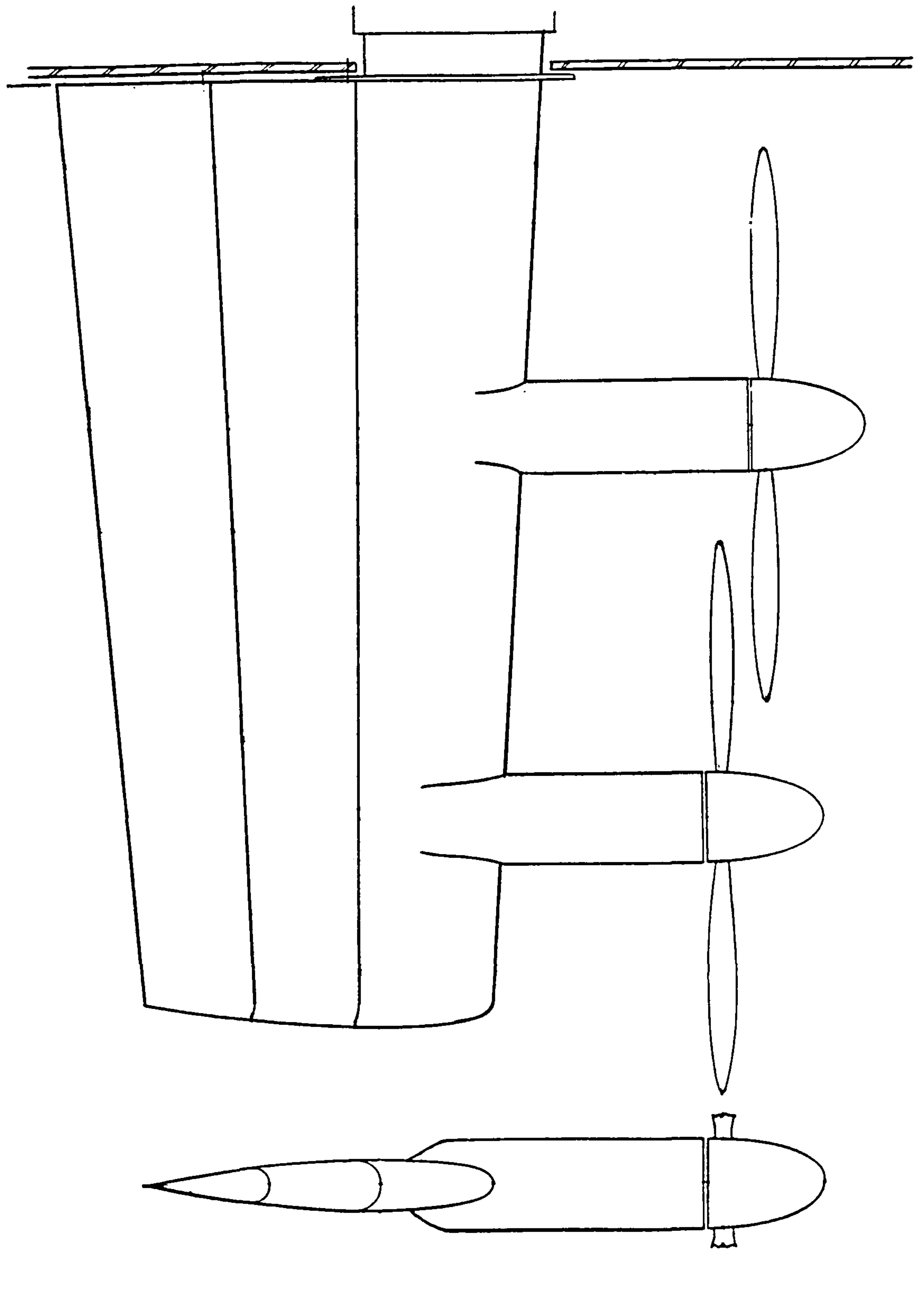

Figure 55-1. Test model used.

Analysis of Wind-Tunnel Tests to a Mach Number of 0.90 of a Four-Engine Propeller-Driven Airplane Configuration having a Wing with 40° of Sweepback and an Aspect Ratio of 10.

G.C. Edwards, D.A. Buell, F.A. Demele and F.B. Sutton

NACA Technical Note, TN 3790, September 1956.

An investigation has been conducted at speeds up to a Mach number of 0.90 to determine the effects of operating propellers on the longitudinal characteristics of a four-engine tractor airplane configuration having a 40 degree swept wing with an aspect ratio of 10. The test model is shown in Figure 56-1. Results from previous wind tunnel tests show that these effects are of most concern in the low-speed high-thrust flight regime.

The analysis of the low-speed data indicates that the large variations of longitudinal stability with angle of attack resulted primarily from passage of the tail into and out of the slipstream. The slipstreams also created large lift increments on the wing, particularly with flaps deflected, which resulted in increases in stability (with increasing thrust coefficient) from the outboard propeller and decreases in stability from the inboard propeller. It was concluded that the longitudinal stability characteristics of the model could be improved by moving the nacelles outward, increasing the tail height, and reducing the tail span.

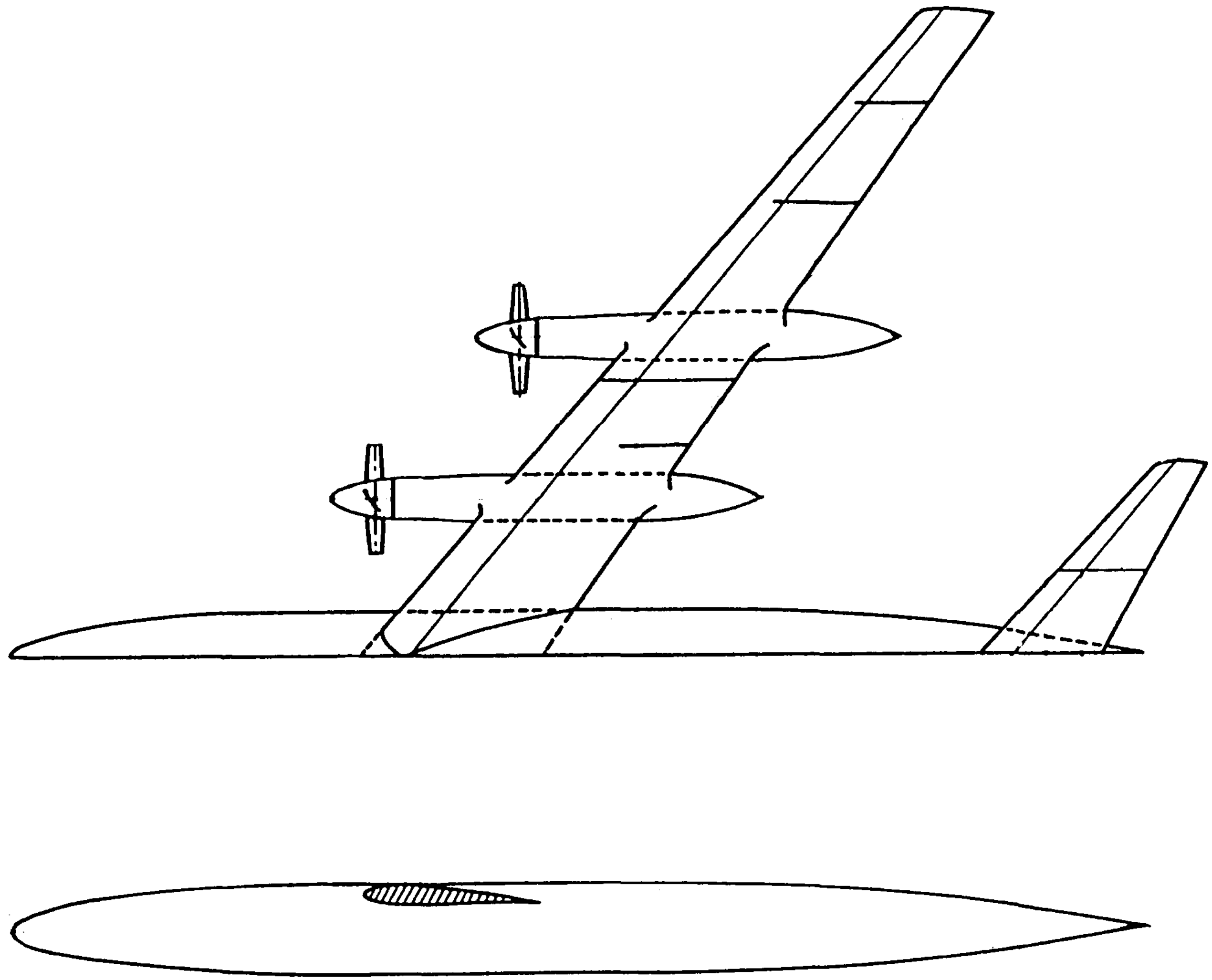

Figure 56-1. Test model used.

Investigation of the Aerodynamic Characteristics of a Model Wing-Propeller Combination and of the Wing and Propeller Separately at Angles of Attack up to 90 Degrees.

R.E. Kuhn and J.W. Draper

NACA Report 1263, 1956.

An investigation of the aerodynamic characteristics of a model wing-propeller combination, and of the wing and propeller separately at angles up to 90 degrees has been conducted. The test model is shown in Figure 57-1. The tests covered thrust coefficients corresponding to free-stream velocities from zero forward speed to the normal range of cruising speeds.

The results indicate that increasing the thrust coefficient increases the angle of attack for maximum lift and greatly diminishes the usual reduction in lift above the angle of attack for maximum lift. An appreciable direct pitching moment was found to exist on the propeller itself at high angles of attack. The pitching moment was approximately doubled when the propeller was operated in the presence of the wing and corresponded to a downward moment of the effective center of thrust of about 20 percent of the propeller radius.

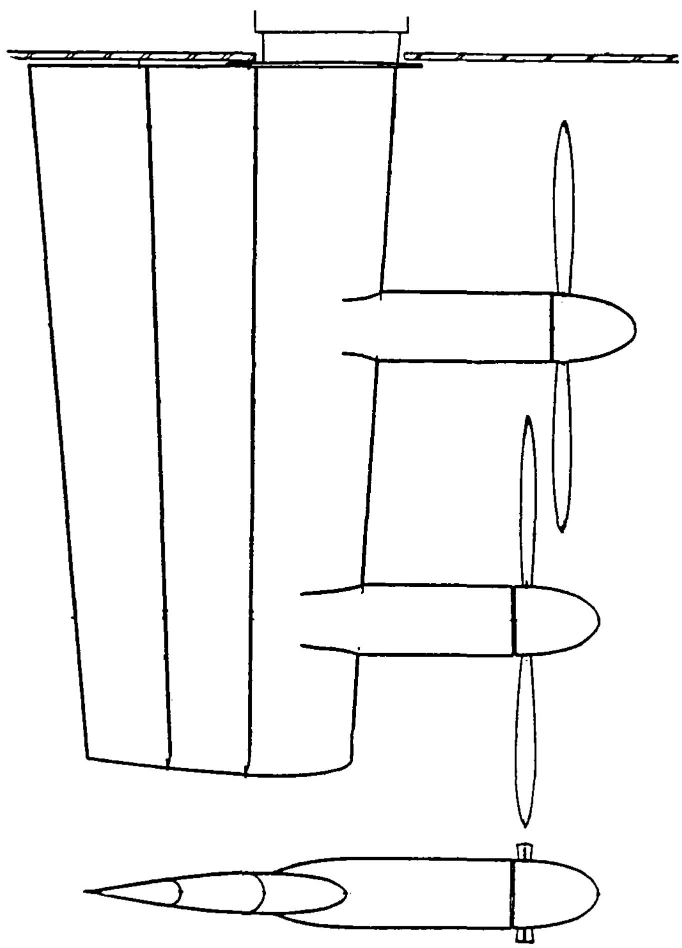

Figure 57-1. Test model used.

Experimental Investigation of the Aerodynamics of a Wing in a Slipstream.

M. Brenckmann

University of Toronto, Institute of Aerophysics, UTIA Technical Note No. 11, April 1957.

A experimental study of a wing in a slipstream was performed to determine the lift distribution due to the slipstream at different angles of attack. The test model is shown in Figure 58-1. The lift distribution was measured by the use of a segmented wing. Each segment had its individual force measurement system. Velocity and flow direction surveys were also made in the slipstream for the different operating conditions of the test.

The results showed that potential flow models tended to underpredict the lift at high angles of attack. This was attributed to the ability of the slipstream to retard flow separation. Potential flow models are valid for low to moderate angles of attack when the slipstream rotation is included in the solution. A closed form solution, obtained from slender body theory, showed good agreement with the experimental data when destalling effects were accounted for.

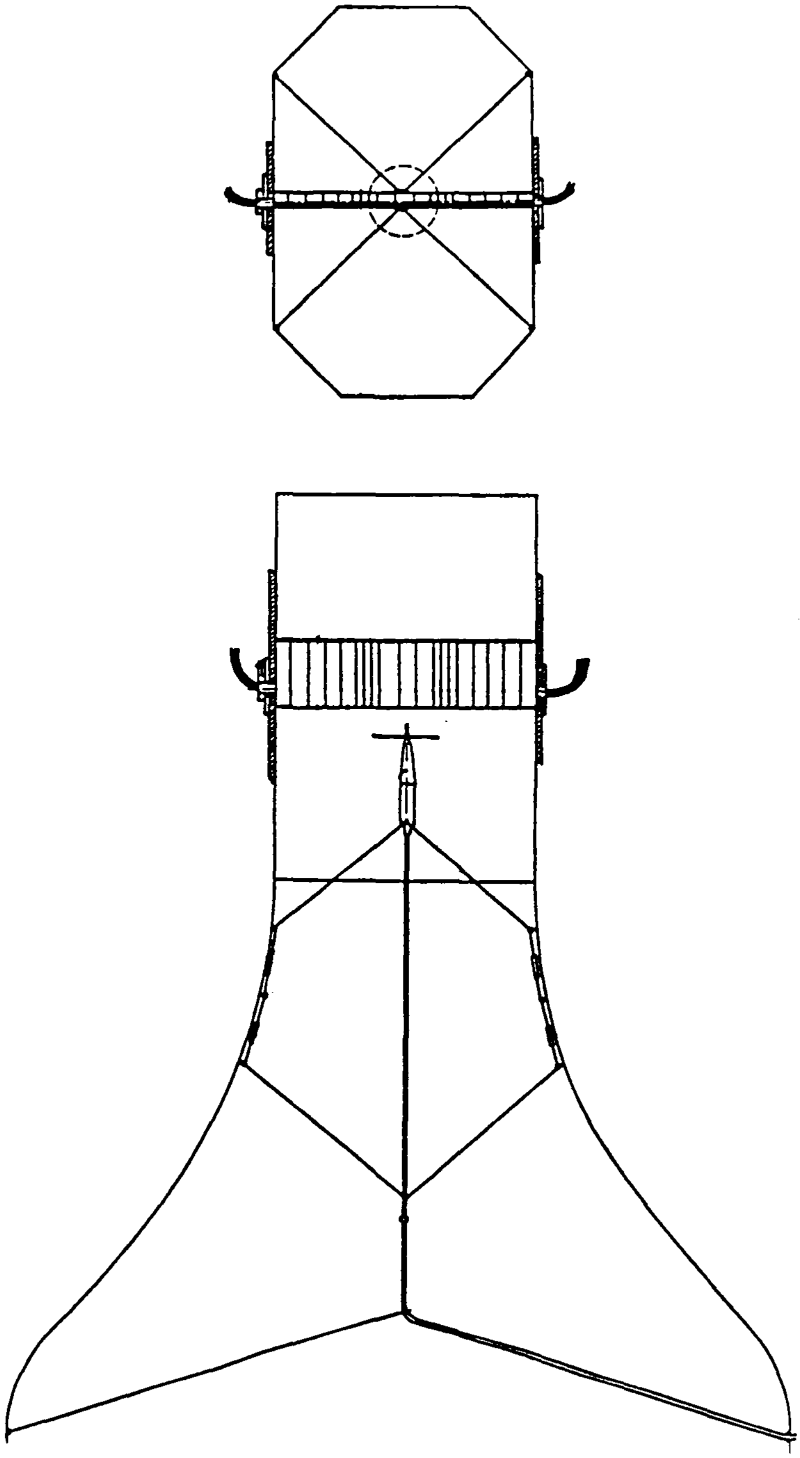

Figure 58-1. Test model and installation in test section.

Figure 58-1. Test model and installation in test section.

A Review and Summary of the Available Aerodynamic Data on Deflected Slipstream Arrangements Suitable for VTOL Applications.

J.A. Dunsby

Canadian National Research Council, Aeronautical Report LR-205, September 1957.

A review is made of the existing experimental and theoretical aerodynamic data on wing-propeller combinations intended for vertical take-off utilizing the deflected slipstream principle. While a considerable volume of data is available indicating the trends of many important characteristics, it is clear that much theoretical and experimental work remains to be done.

60

Propeller and Wing Interactions at Subsonic Speeds.

C. Ferrari

High Speed Aerodynamics and Jet Propulsion, Volume VII, Princeton University Press, 1957.

The work of Koning is extended to include the effects of compressibility, tangential flow in the slipstream (swirl), and slipstream at an angle of attack relative to the free stream. Little in the way of numerical examples are included.

61

Large-Scale Wind-Tunnel Tests of an Airplane Model with an Unswept, Aspect-Ratio-10 Wing, Two Propellers, and Area-Suction Flaps.

J.A. Weiberg, R.N. Griffin, Jr. and G.L. Florman

NACA Technical Note 4365, September 1958.

An investigation was made to determine the effects of a propeller slipstream on the lift obtainable and the flow requirements for suction applied to the porous area of a trailing-edge flap on a model of a twin-engine airplane. The test model is shown in Figure 61-1.

The lift increment produced by the propeller slipstream increased approximately in proportion to the slipstream velocity. The propeller slipstream had no effect on the suction flow requirements. The suction pressures required increased with thrust coefficient approximately in proportion to the slipstream velocity.

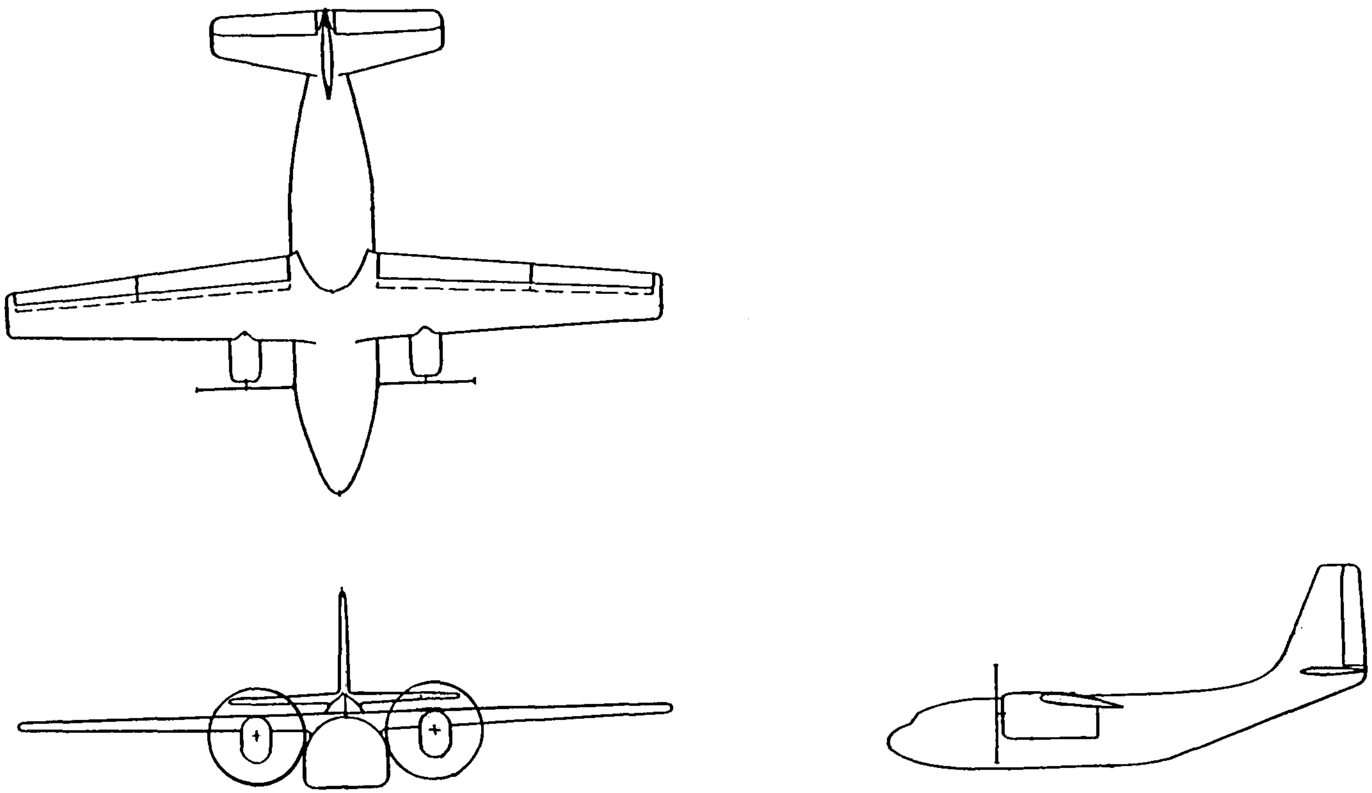

Figure 61-1. Test model used.

Lift Characteristics of Wings Extending through Propeller Slipstreams.

S. Rethorst, W. Royce and Y.T. Wu

Vehicle Research Corporation, VRC Report No. 1, September 1958.

The characteristics of wings extending through slipstreams are examined. The effects of wing plan form are of primary interest. The Rethorst analysis of nonuniform flow is used as a basis.

The study shows that the lift generating capabilities of wings extending through a jet varies greatly with the wing plan form. The existence of optimum plan forms for various combinations of wing areas and jet velocity ratios is shown.

The results suggest that programmed sectional wing twist, provided for example by flaps, would permit that attainment of high stalling lift coefficient with a gradual stall pattern progressing inboard to the root.

An Investigation of the Fundamental Parameters which Govern the Aerodynamics of Various Wing-Propeller Combinations as Related to Vectored Slipstream Aircraft.

N.R. Augustine

Princeton University, Aeronautical Engineering Department, Report No. 437, October 1958.

An experimental investigation of the basic aerodynamics of wing-propeller combinations is presented. The wing was fitted with large-chord slotted flaps which would be suitable for VTOL/STOL aircraft. The significant parameters necessary to define the aerodynamics of this type configuration are established, and the trends produced by variations of the parameters are discussed. The validity of using the slipstream dynamic pressure as a fundamental variable is considered in some detail.

Based on the experimental investigation, a theoretical model is developed to predict the lift produced by large flap deflections on a wing immersed in a slipstream. A comparison of this theory with experimentally determined data is included.

Large-Scale Wind-Tunnel Tests of an Airplane Model with an Unswept, Aspect-Ratio-10, Wing, Two Propellers, and Blowing Flaps.

R.N. Griffin, Jr., C.A. Holzhauser and J.A. Weiberg

NASA Memorandum, MEMO 12-3-58A, December 1958.

An investigation was made to determine the lifting effectiveness and flow requirements of blowing over the trailing-edge flaps and ailerons on a large-scale model of a twin-engine, propeller-driven airplane having a high-aspect-ratio, thick, straight wing.

With sufficient blowing jet momentum to prevent flow separation on the flap, the lift increment increased for flap deflections up to 80 degrees. This lift coefficient also increased with increasing propeller thrust coefficient. The blowing jet momentum coefficient required for attached flow on the flaps was not significantly affected by thrust coefficient, angle of attack, or blowing nozzle height.

65

Theory of Wings in Slipstreams.

H.S. Ribner

University of Toronto, Institute of Aeronautics, UTIA Report No. 60, May 1959.

A general potential theory has been developed for determining the lift distribution of a wing in one or more slipstreams of arbitrary shape or position. The method is based on the use of a reduced potential within the slipstream, and the representation of the slipstream effects by means of a distribution of vorticies (or doublets) along the slipstream boundary. In addition, the wing-plus-wake is represented by a sheet of vorticies (or doublets).

The resulting integral equations are reduced to a set of linear algebraic equations by segmenting the wing into spanwise strips.

66

Pressure Distribution and Force Measurements on a VTOL Tilting Wing-Propeller Model.

Part I: Description and Tabulated Results.

J.A. Dunsby, M.M. Currie and R.L. Wardlaw

Canadian National Research Council, Aeronautical Report LR-252, June 1959.

Part II: Analysis of Results.

M.M. Currie and J.A. Dunsby

Canadian National Research Council, Aeronautical Report LR-284, June 1960.

A reflection plane model of a twin-engine tilt-wing VTOL configuration was tested over a range of thrust coefficient at different incidence angles. The test model is shown in Figure 66-1. The wing was extensively instrumented with surface pressure taps, providing chordwise pressure distributions at several spanwise locations. The measurement results are presented in tabular form in Part I, and in graphical form in Part II.

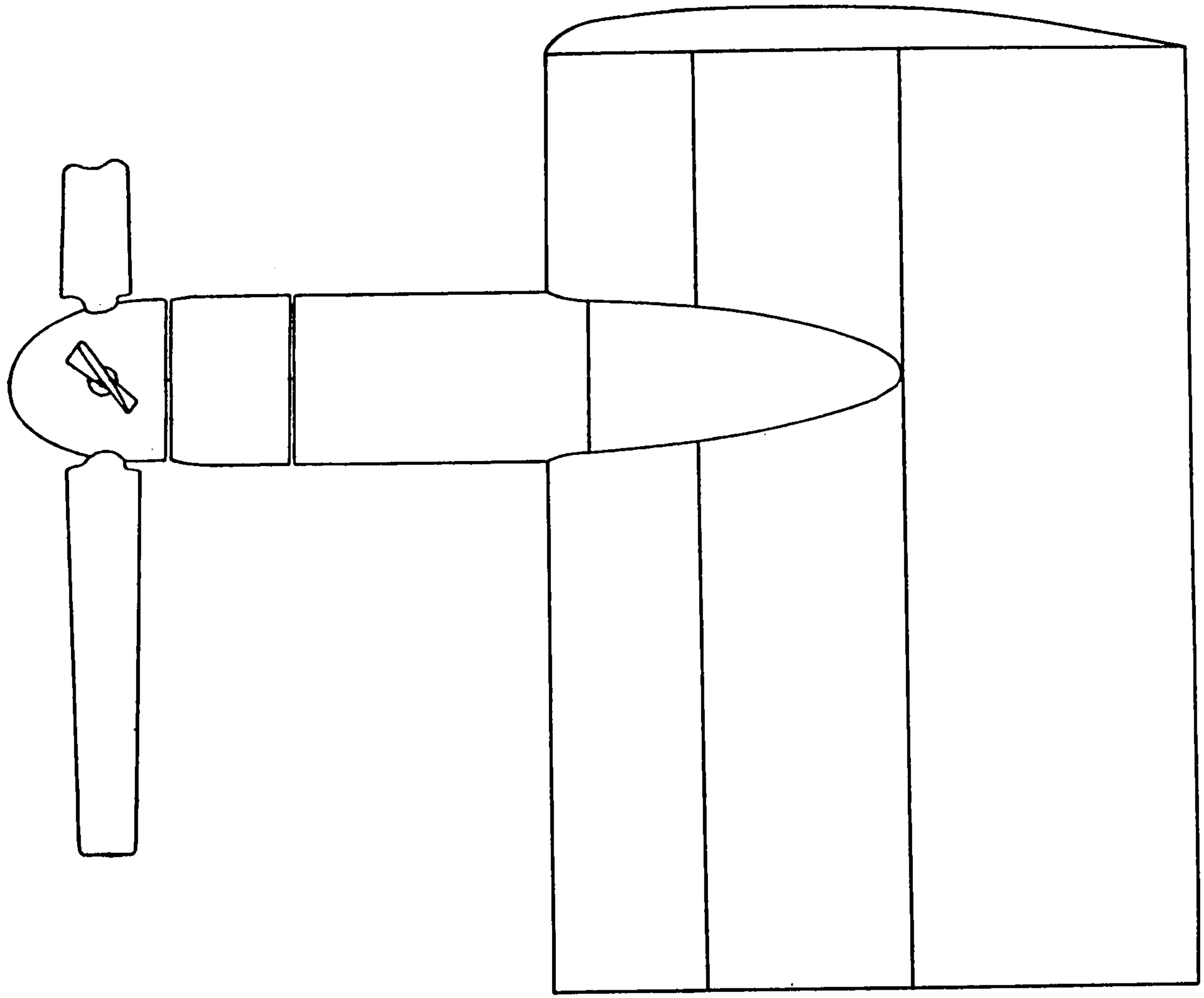

Figure 66-1. Test model used.

67

A Theory of Wing-Propulsion Combinations in Slow Flight.

R.J. Vidal

Cornell Aeronautical Laboratory, Report No. A1-1190-A-1, September 1959.

NTIS AD 216171

A theoretical model is described which will calculate the performance of wing-propulsion systems over a range of flight speeds from hover to high subsonic speed. The model combines Prandtl wing theory with Rankine-Froude actuator disk theory. The formulation is based on the assumption of a uniform propulsive jet encompassing the wing, which after being deflected by the wing, remaines straight and does not roll up.

The results have been compared with helicopter data and good agreement was obtained at all forward speeds. The model is useful for evaluating different STOL configurations consistent with the model.

68

A Review of the Wing-Slipstream Problem with Experiments on a Wing Spanning a Circular Jet.

F.W. Gobetz

Princeton University, Department of Aeronautical Engineering, Report No. 489, January 1960.

A review of the theories of Koning (reference 42); Franke and Weinig (reference 47); Graham et al (reference 53); Squire and Chester (reference 50); Ferrari (reference 60); and Rethorst et al (reference 62) is given. An experiemntal program was performed with a pressure instrumented wing spanning a jet created by an axial blower. The wing pressures were connected to an integrating manometer which gave a single reading for each spanwise station.

The experimental results supported Rethorst°s theory in relation to the other theories. The presence of the blower shroud alters the jet velocity distribution from the theoretical models so that direct comparisons are difficult.

69

The Two-Dimensional Effects of Slipstream Shear on Airfoil Characteristics.

R.J. Vidal, J.H. Hilton and J.T. Curtis

Cornell Aeronautical Laboratory, Report No. AI-1190-A-5, September 1960.

The current theories for two-dimensional airfoils in uniform and nonuniform shear flows of infinite extent normal to the chord are reviewed. A new method, based on the use of images, is presented which allows the shear flow to be of finite extent as is the case with a slipstream. Experiments with a symmetrical Joukowsky airfoil in a uniform shear flow and a two-dimensional simulated slipstream are reported. Good agreement between theory and experiment were found for the airfoil section characteristics.

Experimental Determination of Spanwise Lift Effects on a Wing of Infinite Aspect Ratio Spanning a Circular Jet.

R.S. Snedeker

Princeton University, Department of Aeronautical Engineering, Report No. 525, February 1961.

A wind tunnel test program was performed of a infinite aspect ratio wing with its center immersed in a jet. The test setup is shown in Figure 70-1. The wing was instrumented with chordwise rows of surface pressure taps at several spanwise locations. The spanwise rows were concentrated in the region of the jet. A test matrix of different angles of attack, and of different ratios of jet velocity to free stream velocity were run.

Chordwise pressure distributions at different spanwise locations are given for different jet velocity ratios. Spanwise variations in lift coefficient and lift slope are also given. All results are presented in graphical form.

71

A Lifting Surface Theory for Wings Extending through Multiple Jets.

T.Y. Wu and R.B. Talmadge

Vehicle Research Corporation, VRC Report No. 8, August 1961.

The basic Rethorst lifting surface theory for a wing extending through a single jet is generalized to enhance its applicability to the solution of many general and secondary problems concerned with the non-uniform aerodynamics of wing-propeller interaction. The generalization is first developed in detail for the single jet model, then extended to multi-jet arrangements.

The spanwise lift distribution of an example multi-jet arrangement was determined. Large increases in lift inboard and within the jet were obtained when the free stream velocity was small compared to the jet velocity. A lesser but significant increase occurred outboard of the jets.

72

Aerodynamics of Deflected Slipstreams: Part I - Formulation of the Integral Equations.

A. Sowyrda

Cornell Aeronautical Laboratory, Report No. A1-1190-A-6, October 1961.

The lifting surface equations for a wing-jet combination are derived for small flow deflections. In the present formulation both the jet and the wing, together with its wake, are represented by vortex sheets as the limit of a thin layer of rotational flow. The vorticity distributions are accordingly subject to the dynamical equations governing rotational flow. A treatment of the lifting surface equations for the case of a jet in combination with a high-aspect ratio wing is included.

An Investigation of the Induced Velocity in the Vicinity of a Propeller and its Influence on Wing Lift.

L. Goland

University of Pennsylvania, Ph. D. Dissertation, 1962.

Two theoretical procedures are discussed; one which determines the velocity induced in the near wake of a propeller, and one which determines the spanwise lift distribution of a wing immersed in the propeller slipstream. The first procedure is applicable for helicopter rotors in hovering, climbing or forward flight; V/STOL configurations and propellers with nonuniform disk loading.

Little is provided in the way of comparisons with experimental data or other theoretical methods.

74

A Lifting Surface Theory for Wings at High Angles of Attack Extending through Multiple Jets

E. Cumberbatch

Vehicle Research Corporation, VRC Report No. 9, July 1963

A lifting surface theory has been developed for wings located at arbitrary heights and high angles of attack in a stream cotaining an arbitrary number of multiple jets. The analysis is systematically presented in the order of; wing at arbitrary height in a single jet, wing at high angle of attack in a single jet, and wing at arbitrary height and high angle of attack extending through multiple jets.

75

Lifting Surface Theory for Wings at High Angles of Attack Extending through Inclined Jets.

T.Y. Wu

Vehicle Research Corporation, VRC Report No. 9a, October 1963.

Lifting surface theory for wings extending through propeller slipstreams based on the Rethorst solution has been extended to include the effect of jets inclined to the free stream flow. This extension permits the prediction of spanwise lift distribution and induced drag of tilt-wing and deflected slipstream and V/STOL aircraft over the entire flight spectrum, from hovering to cruise.

It is demonstrated that the effect of inclined jets on wing characteristics may be determined by applying appropriate boundary conditions to formulations developed in previous reports (references 62 and 71).

76

A Lifting Surface Theory for Wings Extending through Multiple Jets in Separated Flow Conditions.

E. Cumberbatch and T.Y. Wu

Vehicle Research Corporation, VRC Report No. 10, October 1963.

A lifting surface theory for wing-propeller slipstream interactions in separated flow conditions has been developed. The case where the flow over wing portions immersed in the propeller slipstreams (jets) is attached while the flow over the wing outside the jets is separated is treated in detail. The case where flow is separated both inside and outside the jets may be analyzed in a similar manner.

The theory is based on the Rethorst lifting surface solution with cavitation (separated flow) theory developed by Wu and Wang. A lifting surface representation based on a generalization of Weissinger°s approximation was developed. In the separated flow regions, the location of the lifting line and the station where downwash boundary conditions must be satisfied are determined from cavitation theory and/or experimental results.

Wing Pressure Measurements within the Propeller Slipstream for a Large-Scale V/STOL Wind-Tunnel Model Simulating Transition.

M.M. Winston and R.J. Huston

NASA Technical Note, TN D-2014, October 1963.

Pressure data are presented in tabular form for a wide range of flight conditions of vertical or short take-off and landing (V/STOL) configurations from measurements on a wing segment in the propeller slipstream of a large-scale model in the NASA Langley full-scale tunnel. The test model is shown in Figure 77-1. These data provide information on the type of flow and load distribution to be considered in the design of V/STOL configurations ranging from unflapped tilt-wing types to highly flapped deflected-slipstream.

The results indicate that the extent to which the relative intensities of the free-stream and slipstream velocity components affect the spanwise wing loading was dependent upon the wing-flap configuration. Also, the results of tuft observations and pressure measurements indicate that significant flow improvements (including stall delay, more uniform spanwise loading, and more desirable spanwise stall progression) were obtained by addition of a leading-edge slat to the wing behind the upward-turning propeller blade.

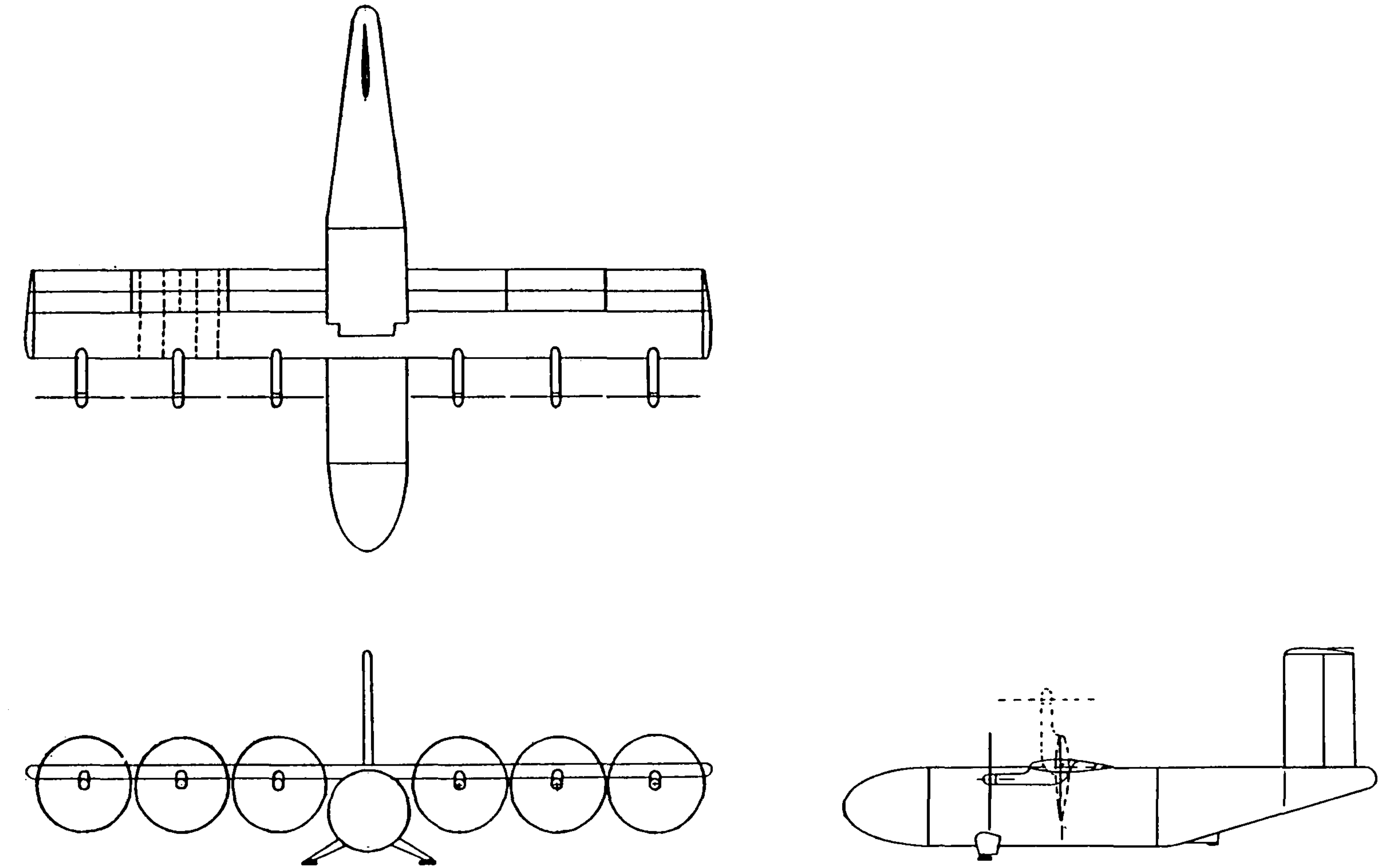

Figure 77-1. Test model used.

Effects of Propeller Slipstream on V/STOL Aircraft Performance and Stability.

L. Goland, N. Miller and L. Butler

U.S. Army Transportation Research Command, TRECOM Technical Report 64-47,
August 1964.

A method is developed to predict the aerodynamic forces and moments of a wing immersed in a slipstream. The basic approach of Koning is used with modifications applied from low aspect ratio wing theory. The method is used to investigate two-and-four propeller VTOL and STOL wing configurations. Comparisons with existing data are performed and the satisfactory correlations are obtained.

The Lift of a Propeller-Wing Combination due to the Slip-Stream.

D.H. Chester

Israel Journal of Technology, Vol. 3, No. 1, February 1965, pp. 102-119.

The problem of obtaining the power-on increment of lift of a practical propeller-wing combination in flight is described. The various parts of the problem are explained and it is shown that some of the previous attempts to obtain a solution were too limited to be of real practical use. A solution is found for each part of the problem, and is fully explained in the paper. Synthesis of the various parts produces a general solution. The program of operations required to supply a numerical answer is laid out.

Theoretical and Experimental Studies of Airfoil Characteristics in Nonuniform Sheared Flow.

W.G. Brady

USAAML Technical Report TR 65-17, May 1965.

The report discusses results from a continuing research program studying the behavior of airfoils in slipstream flow. The development of theoretical models for a two-dimensional airfoil in inviscid nonuniform shear flow is described. A computer program is being assembled, but is not yet operational. A experimental program was performed using a infinite aspect ratio wing spanning an axisymmetric nonuniform sheared flow jet. The wing was segmented in the spanwise direction, with one segment being instrumented to give lift, drag and pitching moment force measurements. The spanwise distribution of these force components was obtained by repeating test conditions and moving the instrumented segment to a new location.

The experimental results showed that significant differences in airfoil behavior existed between the inside-jet section and the outside-jet section. Separation was delayed to higher angles of attack and higher lift coefficients were obtained for the inside-jet section. The inside-jet section behaved in a two-dimensional manner, while the outside-jet section was decidedly three-dimensional in behavior. Vertical position of the wing in the jet had little effect.

A Computer Study of a Wing in a Slipstream.

H.S. Ribner and N.D. Ellis

AIAA Paper No. 66-466, AIAA 4th Aerospace Sciences Meeting, Los Angeles, California, June 27-29, 1966.

University of Toronto, Institute for Aerospace Studies, UTIAS Technical Note No. 101, February 1967.

A Fortran IV program has been formulated based on a theory of wing-slipstream interference by Ribner which accounts for the slipstream effects by means of a vortex sheath. This sheath together with the wing vorticity lead to a pair of simultaneous integral equations for the unknown circulations. A stepwise approximation to the circulations reduces the pair to a system of linear algebraic equations.

The program has been restricted for simplicity to the case of a slipstream centered on a rectangular wing. The results show a progression from approximately °slender body theory° for very narrow slipstreams to °strip theory° for very broad slipstreams and compare well with experimental data.

Theoretical and Experimental Investigation of the Aerodynamic Properties of Airfoils Near Stall in a Two-Dimensional Nonuniformly Sheared Flow.

W.G. Brady and G.R. Ludwig

USAAVLABS Technical Report TR 66-35, June 1966.

AD 638361

The results of a combined theoretical and experimental program are reported. A digital computer code was developed to calculate airfoil pressure distributions in a particular type of two-dimensional, inviscid, nonuniform shear flow. A wind tunnel test was performed to develop experimental data for an airfoil in the same shear flow as was used in the theoretical model. Chordwise pressure distributions were obtained with the airfoil at several locations within the shear flow, and over a range of angles of attack.

Airfoil separation characteristics were found to be dependent on the location within the shear flow. This effect was related to changes in the adverse pressure gradient resulting from the local shear flow. It was also found that by referencing the lift coefficient to the stagnation streamline dynamic pressure and correlating with the angle of attack measured from zero- lift, the experimental data collapsed to almost a single lift curve. The computed pressure distributions were in good agreement with the measured data.

83

Investigation of Propeller Slipstream Effects on Wing Performance.

M. George and E. Kisielowski

USAAVLABS Technical Report TR 67-67, November 1967.

A theoretical and experimental investigation was performed to determine the effects of propeller slipstreams on wing performance. A reflection plane model of a fuselage-wing-nacelle-propeller was tested in a wind tunnel. The spanwise distributions of lift, drag and pitching moment were measured by use a segmented wing. Each segment had its individual three-component force measurement system. The net model forces were also measured. The test model is shown in Figures 83-1 and 83-2.

Comparisons between the theoretical model and the experimental data were in general agreement. The use of a segmented wing to measure spanwise distributions was validated. Results of the spanwise distribution measurements are presented in graphical form.

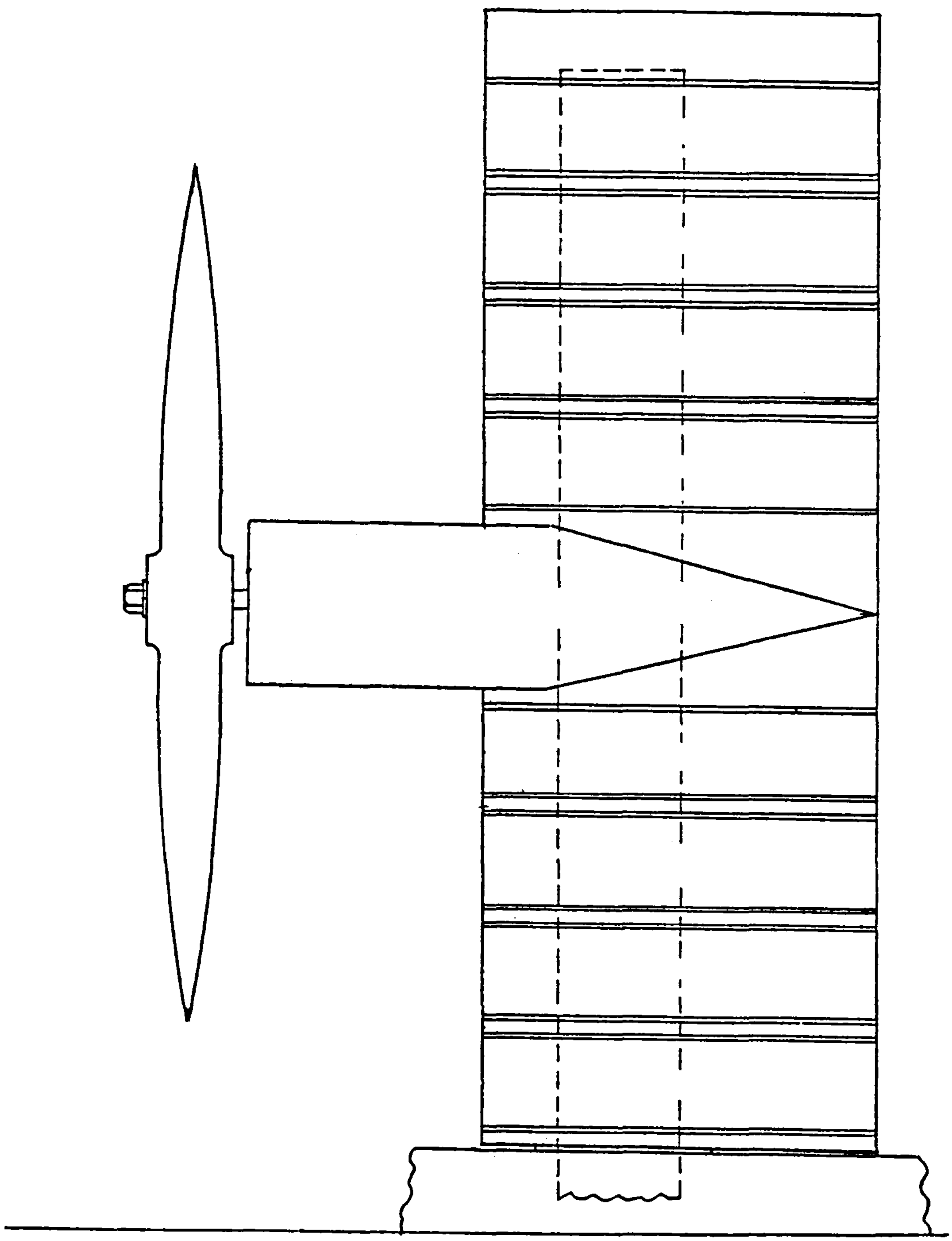

Figure 83-1. Test model used.

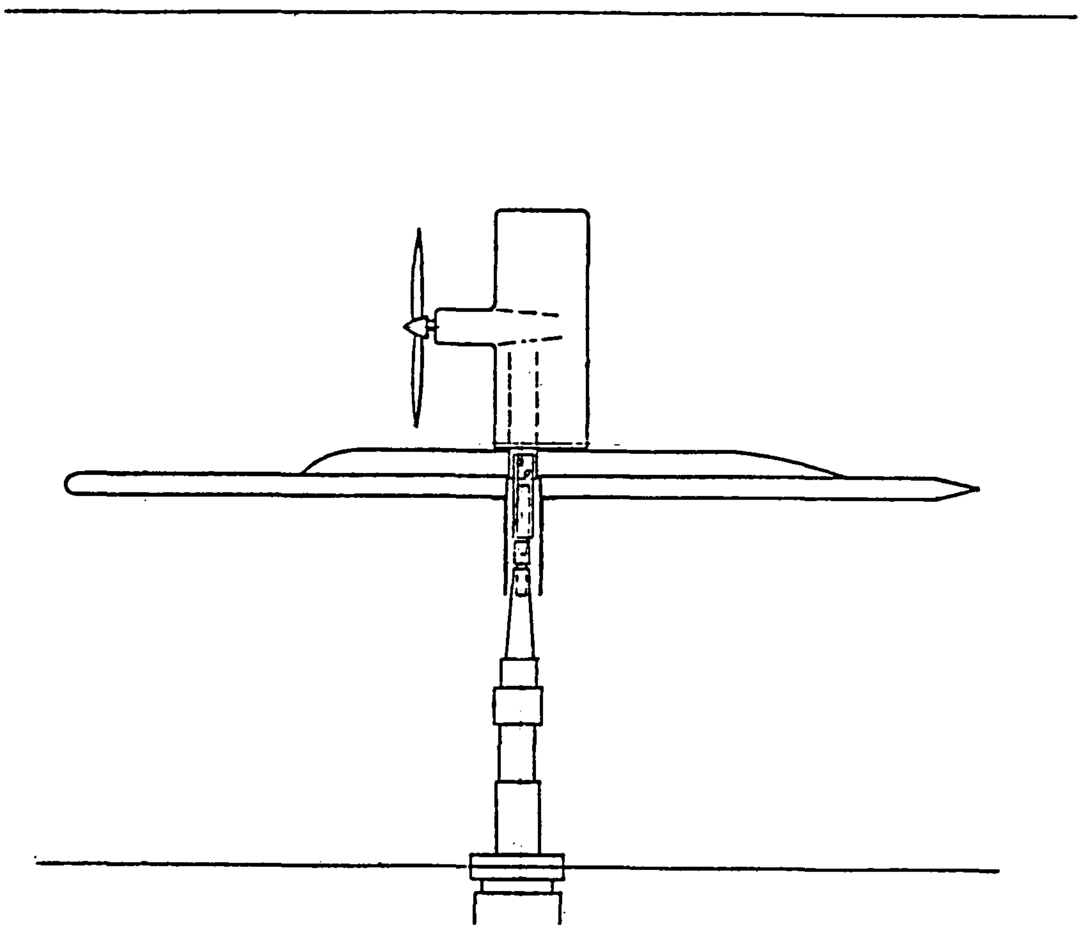

Figure 83-2. Test model installation in test section.

84

An Experimental Investigation By Force and Surface Pressure Measurements of a Wing Immersed in a Propeller Slipstream:

Part I - Force and Moment Measurements.

Canadian National Research Council, NAE Aeronautical Report LR-501, March 1968.

Part II - Surface Pressure Measurements.

Canadian National Research Council, NAE Aeronautical Report LR-525, June 1969.

Y. Nishimura

A reflection plane model of a wing/propeller configuration was tested in the NAE 6° x 9° low speed wind tunnel. The model is shown in Figure 84-1. Wing angles of attack from 0 degrees to 90 degrees were run. Different spanwise locations of the propeller, and a range of flap settings and propeller operating conditions were run.

Spanwise distributions of lift, drag and pitching moment coefficients are given for the test conditions. The integrated pressure results agreed with the force measurement results. No major conclusions are given. The major concern of the report is to publish the data.

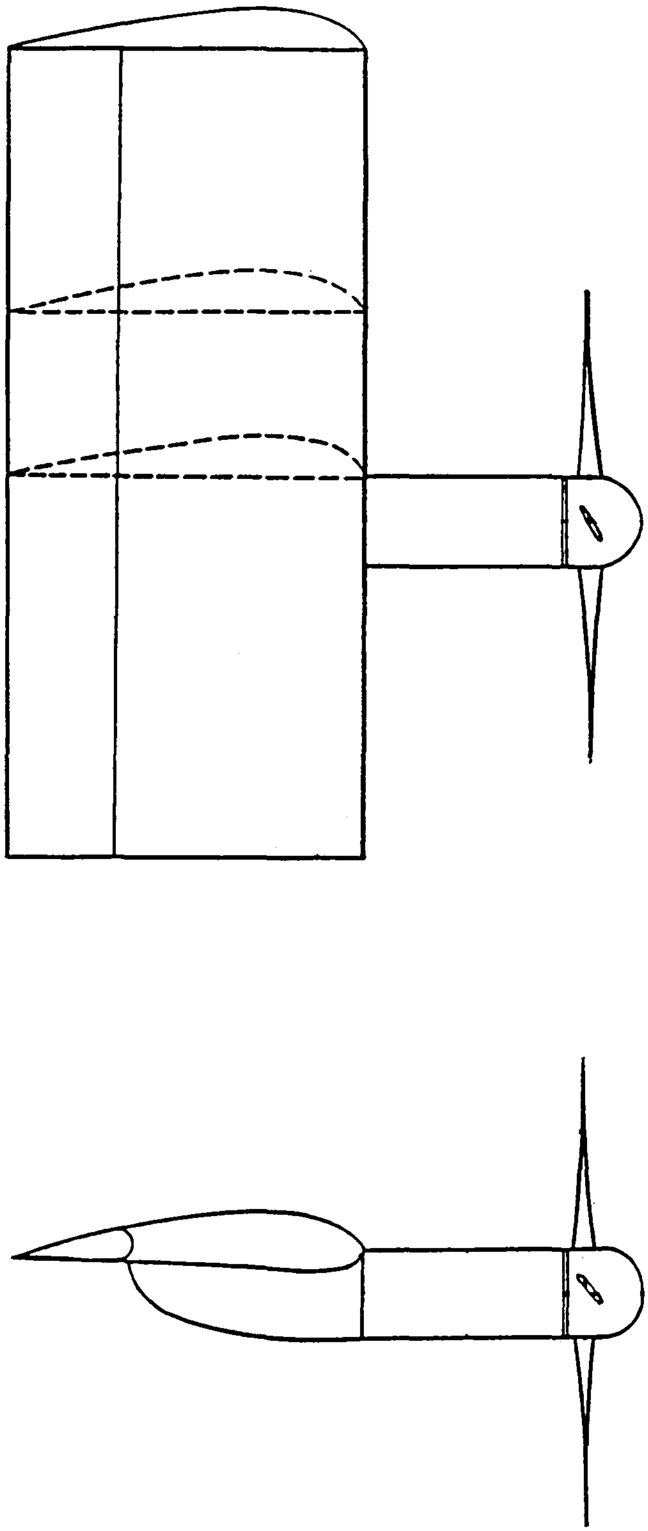

Figure 84-1. Test model used, and configurations.

Lifting Surface Theory and Tail Downwash Calculations for V/STOL Aircraft in Transition and Cruise.

E.S. Levinsky, H.U. Thommen, P.M. Yager and C.H. Holland

USAAVLABS Technical Report TR 68-67, October 1968.

AD 680969

A large-tilt-angle lifting-surface theory for tilt-wing and tilt-rotor V/STOL aircraft is given. The wing/propeller configuration is represented by a discrete-vortex Weissinger-type lifting surface theory in combination with a inclined actuator disk model. Wing-induced modifications to the slipstream boundary conditions are included.

Comparisons with experimental data show satisfactory agreement for small inclination angles. However, for large tilt angles, the theory predicts significantly lower downwash angles at the tail then available experimental data indicate. Design charts are provided for two- and four-propeller (rotor) configurations, for flight conditions ranging from hover to cruise.

86

Wing Surface Pressure Data from Large-Scale Wind Tunnel Tests of a Propeller-Driven STOL Model.

V.R. Page and P.T. Soderman

NASA Technical Memorandum TM X-1527, 1968.

N68 19065

Wing surface pressure data in tabulated form are given for a four-engine STOL transport configuration. The test model is shown in Figure 86-1. The data is provided for a matrix of angles of attack, propeller operating conditions and Reynolds numbers.

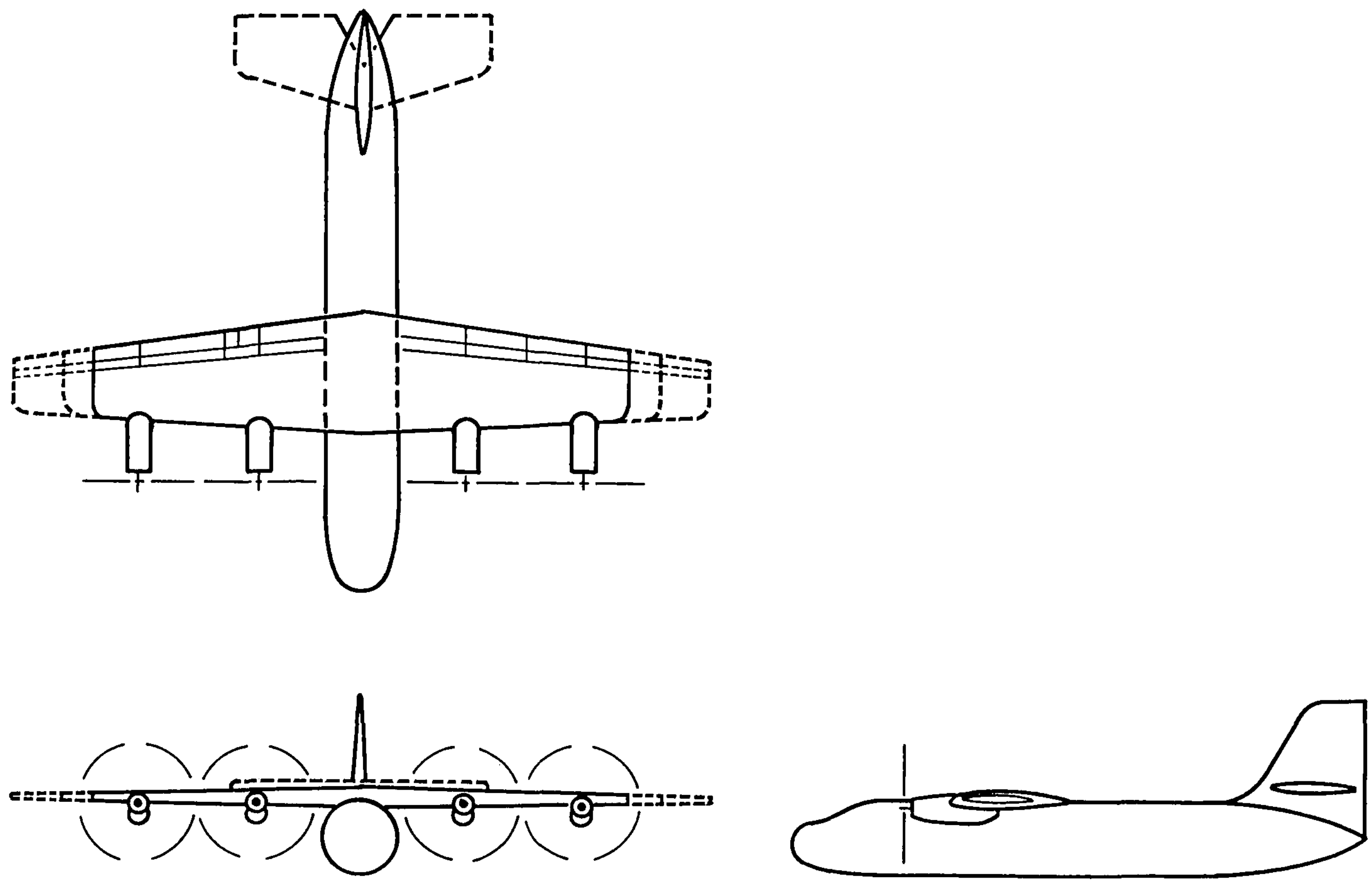

Figure 86-1. Test model used.

Lifting-Surface Theory for V/STOL Aircraft in Transition and Cruise.

E.S. Levinsky, H.U. Thommen, P.M. Yager and C.H. Holland

Journal of Aircraft, Vol. 6, No. 6, November-December 1969, pp. 488-495.
Journal of Aircraft, Vol. 7, No. 1, January-February 1970, pp. 58-65.

A large-tilt-angle lifting-surface theory is developed for tilt-wing and tilt-propeller (or rotor) type V/STOL aircraft. The basis of the method is the development of an inclined actuator disk analysis. Closed form solutions are obtained for the velocity potential at large distances behind the actuator surface. Both the normal velocity and the nonlinear pressure boundary conditions are satisfied across the slipstream interface. Effects of slipstream rotation are also evaluated. The actuator disk analysis is combined with a discrete-vortex Weissinger-type lifting-surface theory for application to wing-propeller combinations at arbitrary tilt angle and forward speed.

Airfoils in Two-Dimensional Nonuniformly Sheared Slipstreams.

G.R. Ludwig and J.C. Erickson, Jr.

Cornell Aeronautical Laboratory, Report No. AC-2489-S-1, July 1970.

AD 709696

AIAA Paper No. 71-84, AIAA 9th Aerospace Sciences Meeting, New York, New York, January 25-27, 1971.

A theoretical and experimental research program was performed to investigate the aerodynamic behavior of an airfoil in a two-dimensionally nonuniform sheared slipstream. A theoretical model was developed to calculate the airfoil pressure distribution, and has been used successfully for slipstreams with moderate shear.

Study of the experimental data show large effects on the stalling characteristics due to changes in the upper surface pressure distributions as a result of the shear flow. Differences in lift appear to depend on the stagnation pressure of the streamline intersecting the airfoil.

Analysis of Wing Slipstream Flow Interaction.

A. Jameson

NASA Contractor Report CR-1632, August 1970.

Theoretical methods are developed for calculating the interaction of a wing with a circular slipstream, and with a spanwise extended slipstream representative of multiple propeller arrangements. The methods are based upon the use of image techniques. Additional, more simplified methods for performing these calculations are also described and compared with the more detailed methods. Comparisons of the developed methods with existing experimental data are given. Computer codes were developed and are available from the COSMIC Computer Library, University of Georgia.

90

Aerodynamic Calculations for the Interference of Several Propeller-Jets with an Airfoil. (Berechnung der Aerodynamik des von merreren Strahlen Beaufschlagten Tragfluegels).

B. Lobert

3. Jahrestagung der Deutschen Gesellschaft fur Luft- und Raumfahrt e.V., December 1970, DGLR Paper No. 70-057.

After a brief description of the theory of Levinsky, Thommen, Yager and Holland (reference 85), the suitability of this method of calculating the aerodynamics of a wing immersed in one or more slipstreams is investigated by a comparison with experimental results. The comparison is conducted on the basis of lift, drag, pitching moment, normal-force distribution and wake characteristics. The results of an investigation of the influence of the main propeller-wing-characteristics on the descent capability of propeller-driven V/STOL aircraft is also given.

Interference of Wing and Multi-Propellers.

L. Ting, C.H. Liu and G. Kleinstein

AIAA 4th Fluid and Plasma Dynamics Conference, AIAA Paper No. 71-614, June 1971.

A systematic procedure is presented for the analysis of the interference of wing with multi-propellers. The theory is based on the assumption that the radius of the propeller and the chord are of the same order and both are much smaller than the span. With the inverse of the aspect ratio as the small expansion parameter, the local two-dimensional solution for the sectional lift to angle of attack relationships uncouple from the outer three-dimensional solution in the spirit of Prandtl lifting line theory. As the plan form of the wing reduces to the lifting line, the stream behind the propellers reduces to a thin sheet of a jet carrying the sectional momentum gained by the propellers and supporting a pressure difference across the sheet. By representing the thin sheet of a jet as a vortex sheet, an integral equation is obtained.

Several numerical examples are presented to demonstrate the versatility of the analysis. As a means of comparison, a modified classical analysis is presented for the special case that the multi-propellers are overlapping and the stream behind them is of uniform velocity and is confined inside a cylinder of elliptical cross section. The results show that the classical analysis overestimated the effect of the propellers.

92

Interference for Wing with Single and with Multi-Propellers.

C. Liu

New York University, School of Engineering, Ph. D. Dissertation, June 1971.

The development of theoretical procedures for the calculation of the spanwise lift distribution for wings with single and multi-propellers is described. Comparisons with other theoretical models are provided.

Aerodynamics of Wing-Slipstream Interaction: A Numerical Study

N.D. Ellis

University of Toronto, Institute for Aerospace Studies, UTIAS Technical Report No. 169, October 1971.

University of Toronto, Ph. D. Dissertation, January 1972.

A theory of wing-slipstream interaction has been developed which accounts for slipstreams of arbitrary cross-section by means of vortex sheaths. These sheaths together with the wing circulation pattern are dictated by the boundary conditions. The analysis leads to simultaneous integral equations. A multiple lifting line approximation is used to reduce the integral equations to a set of simultaneous linear algebraic equations. Fortran programs have been developed for the case of round slipstreams distributed with lateral symmetry on a rectangular wing.

The computed span loading have the shape expected from experimental. A sequence of curves of added lift show a progression from °slender body theory° for very narrow slipstreams to °strip theory° for very broad slipstreams. Excellent agreement is seen with the experimental results of Brenckmann (reference 58), both for span loadings and integrated lift. Calculated flow fields downstream of the wing were qualitatively as expected, displaying interesting effects of slipstream rotation.

Interference between a Wing and a Surface of Velocity Discontinuity.

N. Inumaru

Aeronautical Quartarly, August 1973.

A study is made of the aerodynamic interference between a wing and a surface of velocity discontinuity in a non-uniform potential flow field. The surface of discontinuity is deformed around the wing, which penetrates the surface. In this paper, a deformation of the surface is theoretically predicted, which leads to the conclusion that a "sectorial region" will be formed on the wing. Formation of the sectorial region is shown to exist in previous experimental results.

The Aerodynamic Characteristics and Trailing Vortex Wake of Propeller V/STOL Configurations.

R.H. Wickens

Canadian Aeronautics and Space Journal, Vol. 21, No. 3, March 1975.

The paper describes the aerodynamic characteristics of lifting propellers and wing-propeller configurations, with particular reference to the concept of a powered-lift system, and its complex flows downstream in the wake.

The propeller, when inclined to large angles, and high advance ratios, is a singular example of a powered lift system in which the lift is derived partly by deflecting and energizing a stream tube of air, and, in part, by a wing-like vortex flow in which the propeller disc can be thought of as a low aspect ratio wing of circular plan form.

The trailing wake is characterized by mixed regions of propulsive and vortex flow in which concentrations of vorticity may induce downwash and sidewash velocities of considerable magnitude in the surrounding fluid. The propulsive stream tube, or slipstream, is an integral part of this wake, and deforms with it, ultimately rolling up with the trailing vorticies.

96

Experimental and Theoretical Investigations on the Problem of Propeller/Wing Interference up to High Angles of Attack.

B. Strater

NASA Technical Translation TT F-16490, August 1975.

A wind tunnel test program was performed to measure force and flow characteristics for various combinations of a wing and propeller. The model is shown in Figures 96-1 and 96-2. The model is representative of tilt rotor aircraft, and the results may not be immediately applicable to more conventional multi-engine aircraft. Force data were acquired for the propeller and wing individually. Surface pressure distributions of the wing were also measured. Slipstream velocity and flow angularity data are provided for the isolated propeller case. The angle of attack range extended to 90 degrees. A range of spacing distances between the propeller disk and the wing was included in the test matrix.

A review of previous research of the wing/slipstream problem is given. Theoretical procedures for the calculation of propeller performance with inclined airflow and following wing, and the performance of the propeller/wing combination are given.

The results show that the presence of the wing gives a thrust augmentation over that of the isolated propeller. The augmentation increases as the distance between the propeller and the wing is reduced. The wing lift coefficient and lift slope increase as the propeller advance ratio is reduced. Comparisons with the developed theoretical procedures show good agreement up to medium angles of attack. There were large differences at the high angles of attack, particularly in the prediction of drag. All results are given in graphical form.

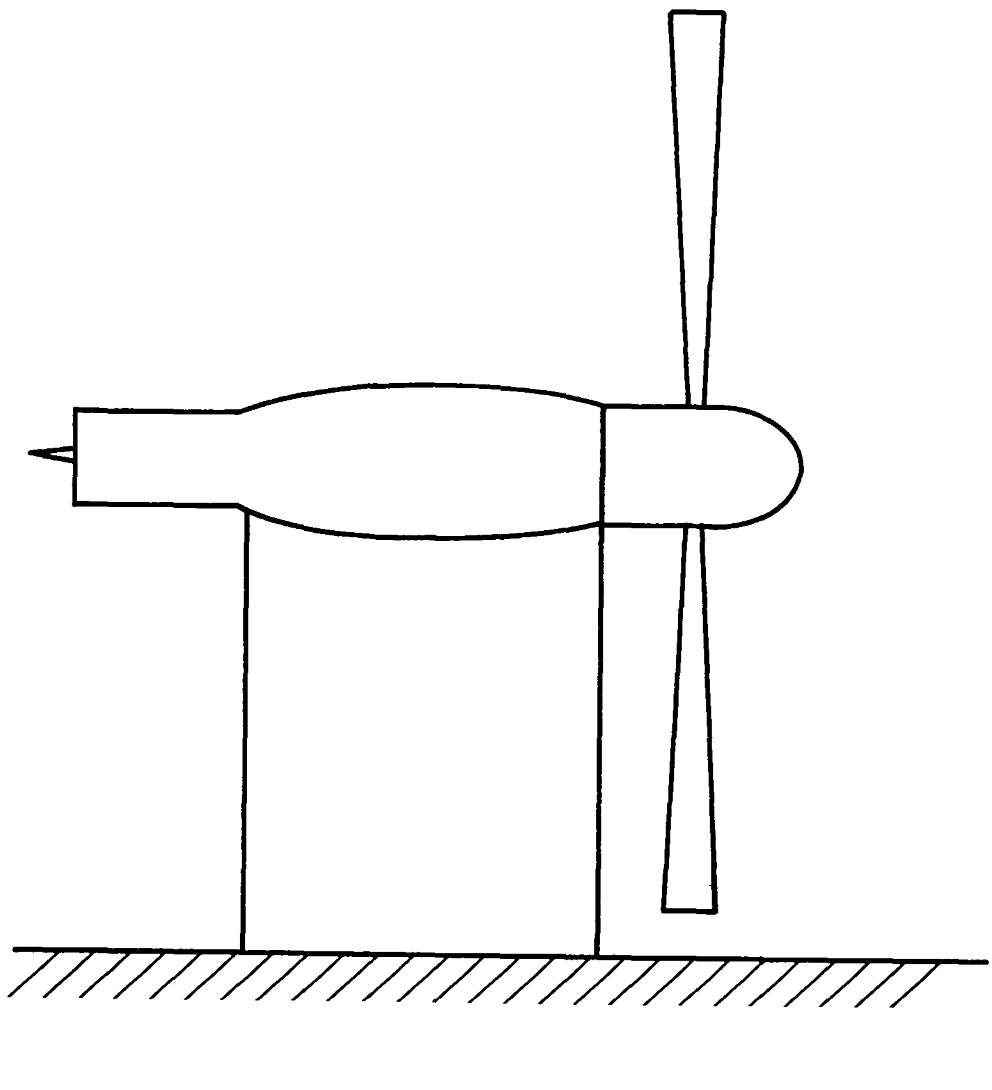

Figure 96-1. Test model used.

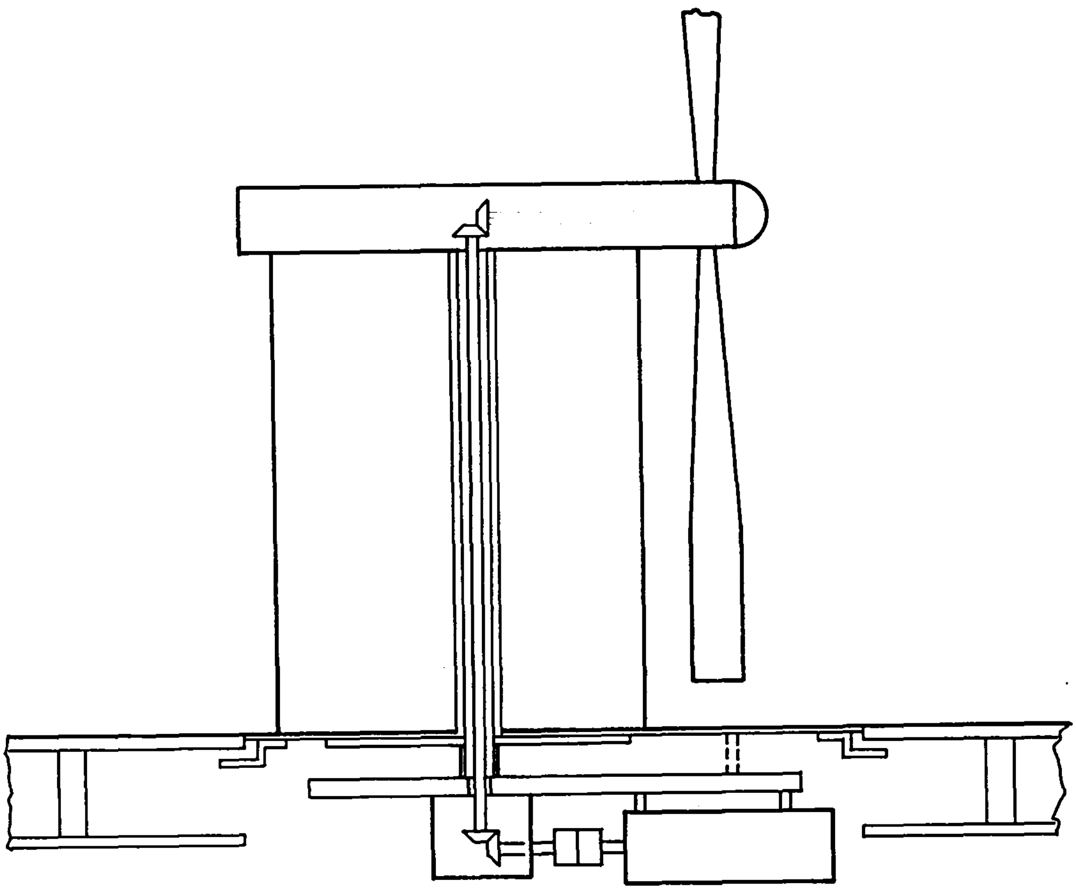

Figure 96-2. Test model installation.

Wing-Slipstream Interaction with Mach Number Nonuniformity.

C.E. Lan

Journal of Aircraft, Vol. 12, No. 10, October 1975, pp. 759-760.

A numerical method for obtaining the wing aerodynamic characteristics with slipstream interaction and Mach number nonuniformity is presented. The method is based on a quasi vortex-lattice procedure and a two- vortex-sheet representation of the slipstream.

Results are compared with those given by other theories and available experimental data. The effect of Mach number nonuniformity is explained.

Prediction of Span Loading of Straight-Wing/Propeller Combinations up to Stall.

M.A. McVeigh, L. Gray and E. Kisielowski

NASA Contractor Report, CR-2602, October 1975.

A method is presented for calculating the spanwise lift distribution on straight-wing/propeller combinations. The method combines a modified form of the Prandtl wing theory with a realistic representation of the propeller slipstream distribution. The slipstream analysis permits calculations of the non-uniform axial and rotational slipstream velocity field of propeller/nacelle combinations. This non-uniform field is then used to calculate the wing lift distribution by means of the modified Prandtl wing theory.

The analysis is programed for use on the CDC 6600 series digital computer. The computer program is used to calculate slipstream characteristics and wing span load distributions for a number of configurations for which experimental data are available. Favorable comparisons are demonstrated between the theoretical predictions and the existing data.

99

Airfoil Profile in a Nonuniform Flow.

J. Polasek

NASA Technical Memorandum TM-75272, March 1978.

A conformal representation method to calculate the flow about an airfoil in a nonuniform flow is described. The method is applicable to inviscid shear flow and cascade problems. Sufficient information is provided to program the method for use if desired.

100

Simulated Propeller Slipstream Effects on a Supercritical Wing.

H.R. Welge and J.P. Crowder

NASA Contractor Report CR-152138, June 1978.

A test was performed in the NASA Ames 14-Foot Wind Tunnel with a model consisting of a fuselage with a supercritical wing. A separate slipstream simulator, consisting of an ejector driven nozzle with swirl producing vanes, was used to represent current advanced propeller concepts. The tests were conducted at Mach numbers of 0.7 and 0.8. The wing was pressure instrumented with chordwise rows at several spanwise stations. Model force measurements were also made.

The results showed that the interference drag of the slipstream was about 3% of the total wing/body drag. Increasing the swirl angle from 7 degrees to 11 degrees resulted in the interference drag becoming favorable. The direction of swirl was shown to have an effect; up-inboard being preferable to up-outboard. Wing chordwise pressure distributions are provided in graphical form.

101

An Analysis of Prop-Fan/Airframe Aerodynamic Integration.

M.L. Boctor, C.W. Clay and C.F. Watson

NASA Contractor Report CR-152186, October 1978.

Aerodynamic design studies of different prop-fan installations were performed using proprietary computer codes. Aft fuselage and empennage mounts, as well as conventional wing mounts were considered. Summaries of each of the configuration studies are provided.

102

Aerodynamics of Wings in Subsonic Shear Flow.

A. Barsony-Nagy and M. Hanin

AIAA 13th Fluid & Plasma Dynamics Conference, Paper AIAA-80-1418, July 1980.

Lifting line and lifting surface theories are developed for wings in nonuniform subsonic parallel flow whose velocity and density vary in the vertical direction. Solutions and numerical results are given for the lift and induced drag of elliptic wings in a jet stream, a wake stream, and in a monotonic sheared stream.

103

Propeller Slipstream/Wing Interaction in the Transonic Regime.

M.H. Rizk

AIAA 18th Aerospace Sciences Meeting, Paper AIAA-80-0125, January 1980.

Journal of Aircraft, Vol. 18, No. 3, March 1981, pp. 184-191

An inviscid model for the interaction between a thin wing and a nearly uniform propeller slipstream is presented. The model allows the perturbation velocities due to the interaction to be potential although the undisturbed slipstream velocity is rotational. A finite difference scheme is used to solve the governing equations.

Numerical examples show that the slipstream has a strong effect on the aerodynamic behavior of the wing section within the slipstream and lesser effects elsewhere. The slipstream swirling motion strongly affects the wing load distribution, however, its effect on the wing°s total lift and wave drag is small. The axial velocity increment in the slipstream has a small effect on the wing lift, however, it causes a large increase in wave drag.

104

Prop-Fan Integration at Cruise Speeds.

H.R. Welge

AGARD Symposium on Aerodynamics of Power Plant Installation, AGARD Paper 33, May 1981.

The aerodynamic installation features of a highly loaded turboprop (prop-fan) on an aircraft for flight at Mach 0.8 are discussed. The aerodynamic flow envrionment in which the prop-fan must operate is shown for both wing and aft-fuselage installations based on analytical studies using advanced surface panel methods. The effects of various prop-fan slipstream parameters on the drag of a supercritical wing are presented.

The results indicate that only small drag penalties occur. Drag reductions are possible by tailoring the local wing section to account for the rotor-induced flow. Using these inputs, an integrated wing/nacelle is shown.

105

On Propeller-Tip Interference Due to the Proximity of a Fuselage.

A. Gail and H. Lu

Journal of the Aeronautical Sciences, Vol. 9, 1942, pp. 11-16.

The periodic changes of the air forces acting on a propeller blade element that passes close to a fuselage nose are theoretically investigated. This forcing function known to excite vibrations of propellers and airplane structures is harmonically analyzed.

The strength of the fundamental harmonic and the relative strengths of the relative strength of the higher harmonics are found to be dependent upon the location of the propeller plane downstream of the fuselage nose, and upon the ratio of the fuselage diameter to propeller diameter. The clearance between propeller-tip and fuselage side is found to have comparatively little effect within the usual limits available to the designer.

Considerations of Wake-Excited Vibrating Stress in a Pusher-Propeller.

B.W. Corson, Jr. and M.F. Miller

NACA Wartime Report, WR L-146, February 1944.

An equation based on simple blade-element theory and the assumption of a fixed wake pattern is derived and fitted to available data to show the first-order relation between the parameters of propeller operation and the intensity of the wake-excited periodic force acting on the blades of a pusher propeller.

The derived equation indicates that the intensity of the wake-excited periodic force is directly proportional to air density, to airspeed, to rotational speed, and to propeller-disk area. The derived equation indicates that the effect of power coefficient upon the intensity of the wake-excited periodic force is small. In normal operation, the vibratory force decreases with increasing power coefficient. If a pusher propeller is used as a brake, increasing the power coefficient will increase the vibratory forces.

107

R.P. Harrington and V. Zadikov

Journal of the Aeronautical Sciences, Vol. ,No. , July 1944, pp. 205-212.

The expressions for the aerodynamic interference of the fuselage of multiengined airplanes on the propellers for the general case of yawed flight are developed. Effects of the fuselage considered are the increased or decreased velocity components in the plane of the propeller.

The fore part of the fuselage is approximated by an ellipsoid of revolution. The disturbances attributed to the fuselage are considered as those due to an additional potential that satisfies the equation of continuity and the boundary conditions at the surface of the ellipsoid. The development is facilitated by the application of ellipsoidal harmonics.

Values of the disturbance velocity in terms of the flight velocity are worked out for a special case of propeller location. The effect of these velocities on the angle of attack of the propeller blade at 75 percent radius are given for yaw angles between ± 90 degrees.

An Investigation of the Mutual Interference Effects of a Tail-Surface - Stern Propeller Installation on a Model Simulating the Douglas XB-42 Empennage.

W.A. Bartlett, Jr. and A.A. Marino

NACA Wartime Report, WR L-625, November 1944.

The mutual interference effects of tail surfaces and a stern propeller were investigated on a model representative of the empennage and propeller installation of the XB-42 airplane. The test model is shown in Figure 108-1. The tests were conducted primarily to determine the effect of tail-surface - propeller spacing upon the periodic tail-surface loading coincident with propeller blade passage.

The pressure impulses on the control surfaces due to propeller blade passage were found to increase with propeller rotational speed or blade angle, or with decreased tail-surface - propeller spacing in both static and positive dynamic thrust. Average pressure distributions obtained at two chordwise stations on the left elevator indicated that the control-surface effectiveness increased with increasing thrust coefficient and decreased with increasing negative-thrust coefficient. An elevator deflection of 20 degrees decreased the envelope efficiency of the six-blade dual-rotating propeller in the low advance ratio range and increased the envelope in the high advance ratio range.

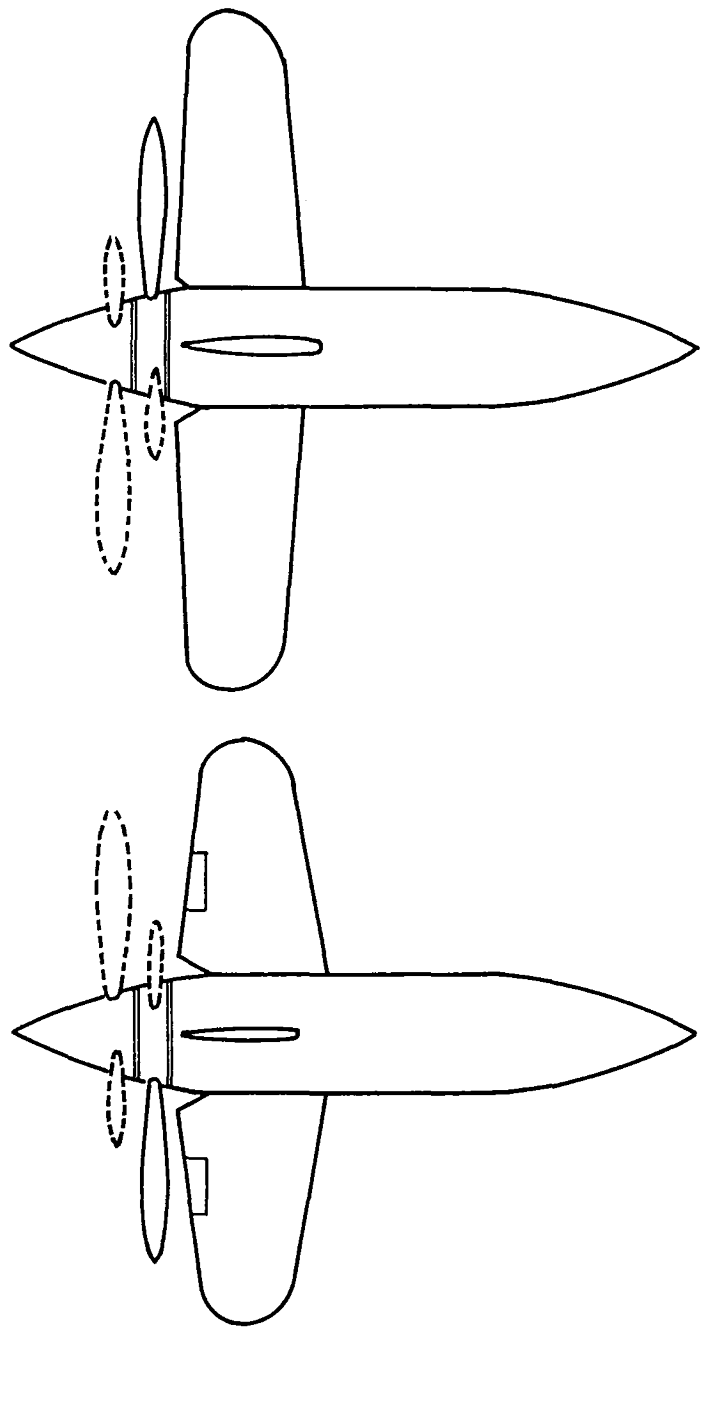

Figure 108-1. Test model used.

109

A Theoretical Investigation of Periodic Aerodynamic Forces and Fuselage Vibration Caused by Propellers:

Part I - On Periodic Aerodynamic Forces Produced by Propellers.

Navy Department, Bureau of Aeronautics, Contract No. a(S) 9652, September 1949.

Part III - On Periodic Aerodynamic Forces Produced by Propellers.

Navy Department, Bureau of Aeronautics, Contract No. a(S) 9652, May 1950.

P. Lieber and C. Grubin

Mathematical procedures are developed to calculate the periodic pressures due to single and counter-rotating propellers. The propeller is represented by a potential function, extending the Goldstein solution. A fuselage boundary is introduced by the use of sources on the longitudinal axis.

Results from the theoretical models are given. No comparisons with experimental results are included.

A Survey of the Flow at the Plane of the Propeller of a Twin-Engine Airplane.

J.C. Roberts and P.F. Yaggy

NACA Technical Note, TN 2192, September 1950.

The air flow at the plane of the propeller of a full-scale twin-engine airplane was surveyed to provide data for use in the calculation of oscillating aerodynamic loadings on propellers. The test model is shown in Figure 110-1.

The results showed that the measured upwash angles were much larger than the calculated wing-induced upwash angles. It appears that the nacelle and fuselage were responsible for a large portion of the upwash. With partial-span wing flaps deflected, the rate of change of upwash angle with lift coefficient was about the same as with flap retracted. At a given lift coefficient, however, the upwash angle was less with flaps deflected.

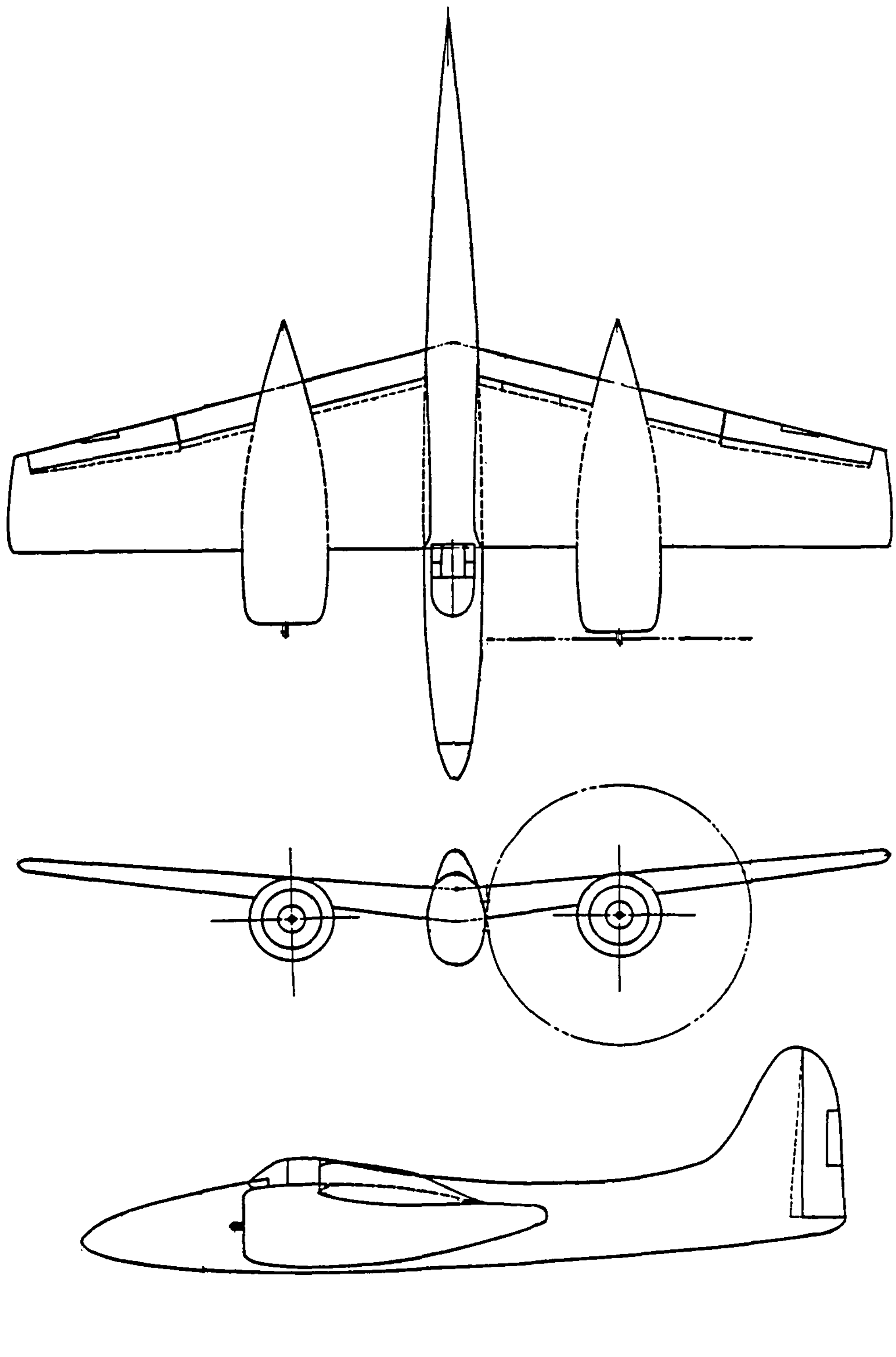

Figure 110-1. Test model used.

111

Vibratory Stresses in Propellers Operating in the Flow Field of a Wing-Nacelle-Fuselage Combination.

V.L. Rogallo, J.C. Roberts and M.R. Oldaker

NACA Technical Note, TN 2308, March 1951.

An investigation was made to determine the first-order vibratory stresses induced in propellers when rotating in the flow field of a wing-nacelle-fuselage combination. The test model is shown in Figure 111-1. Thrust measurements were obtained by means of propeller-wake surveys in order to define the magnitude of the force changes experienced by the blades.

Steady-state propeller theory was adequate for the prediction of the magnitude and distribution of the oscillating air loads, provided the known complete flow-field characteristics were used. With the known oscillating air load, an accurate prediction of nonresonant, first-order vibratory stresses was obtained.

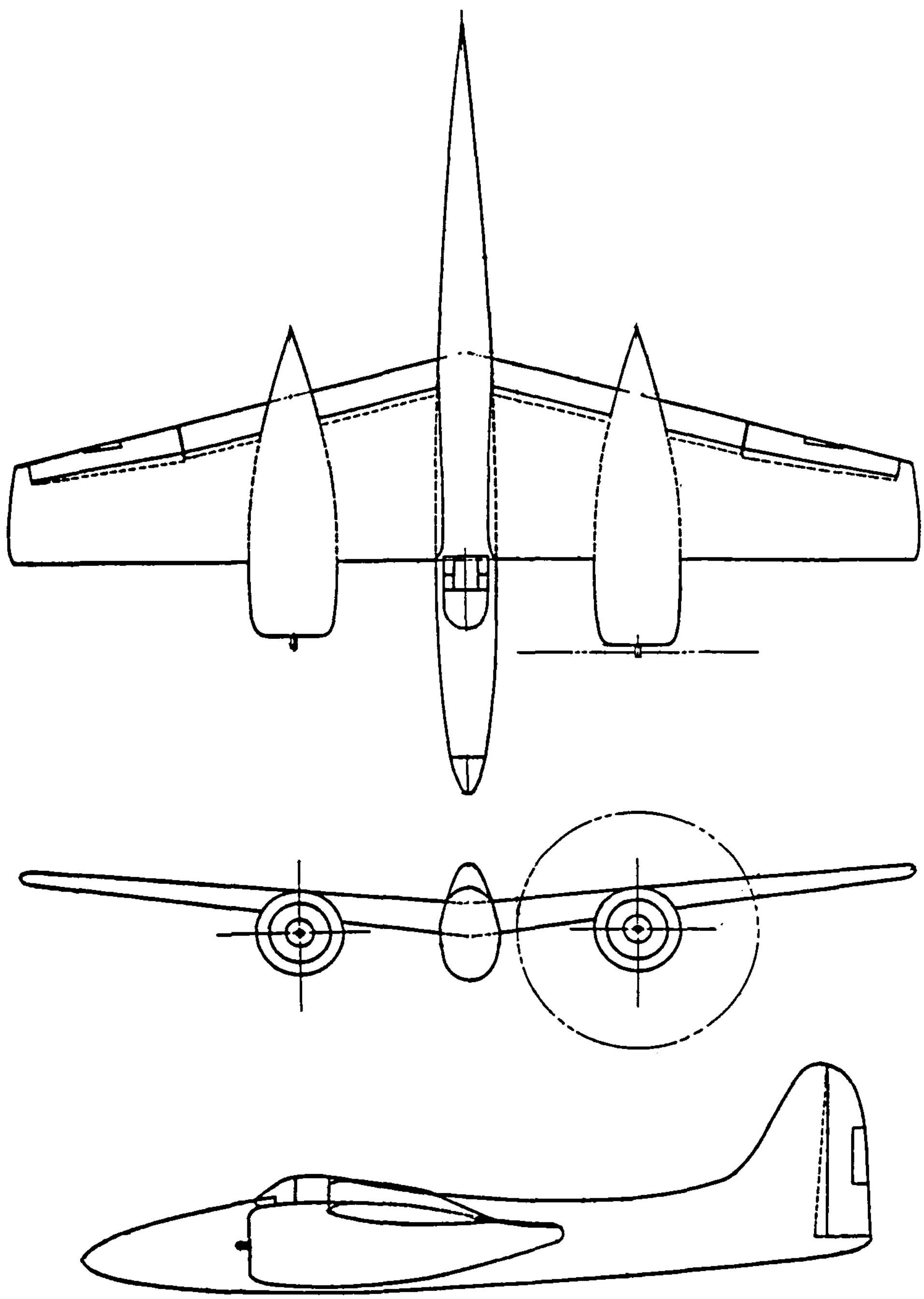

Figure 111-1. Test model used.

112

Investigation of Propeller Vibrations Excited by Wing Wakes.

W.H. Gray and W. Solomon.

NACA Research Memorandum, RM L51G13, January 1952.

The principal variables affecting the excitation of a propeller for vibration at a frequency of twice propeller speed in the wake of a wing were investigated. The test model is shown in Figure 112-1. The drag of the wing was made adjustable through a wide range by the use of 35-percent-chord flaps of the split, double split, and the aerodynamically balanced types. The spacing between flap trailing edge and the propeller plane was made adjustable to investigate the effects of wake width and intensity.

The vibratory stress was directly proportional to the free-stream velocity for a fixed value of the wing drag coefficient, and varied linearly with the wing drag coefficient for a fixed free-stream velocity. When the vibratory stresses were reduced by the resonant amplification factor to equivalent nonresonant stresses, these nonresonant stresses were found to increase with reduced spacing for a given wing configuration and airspeed.

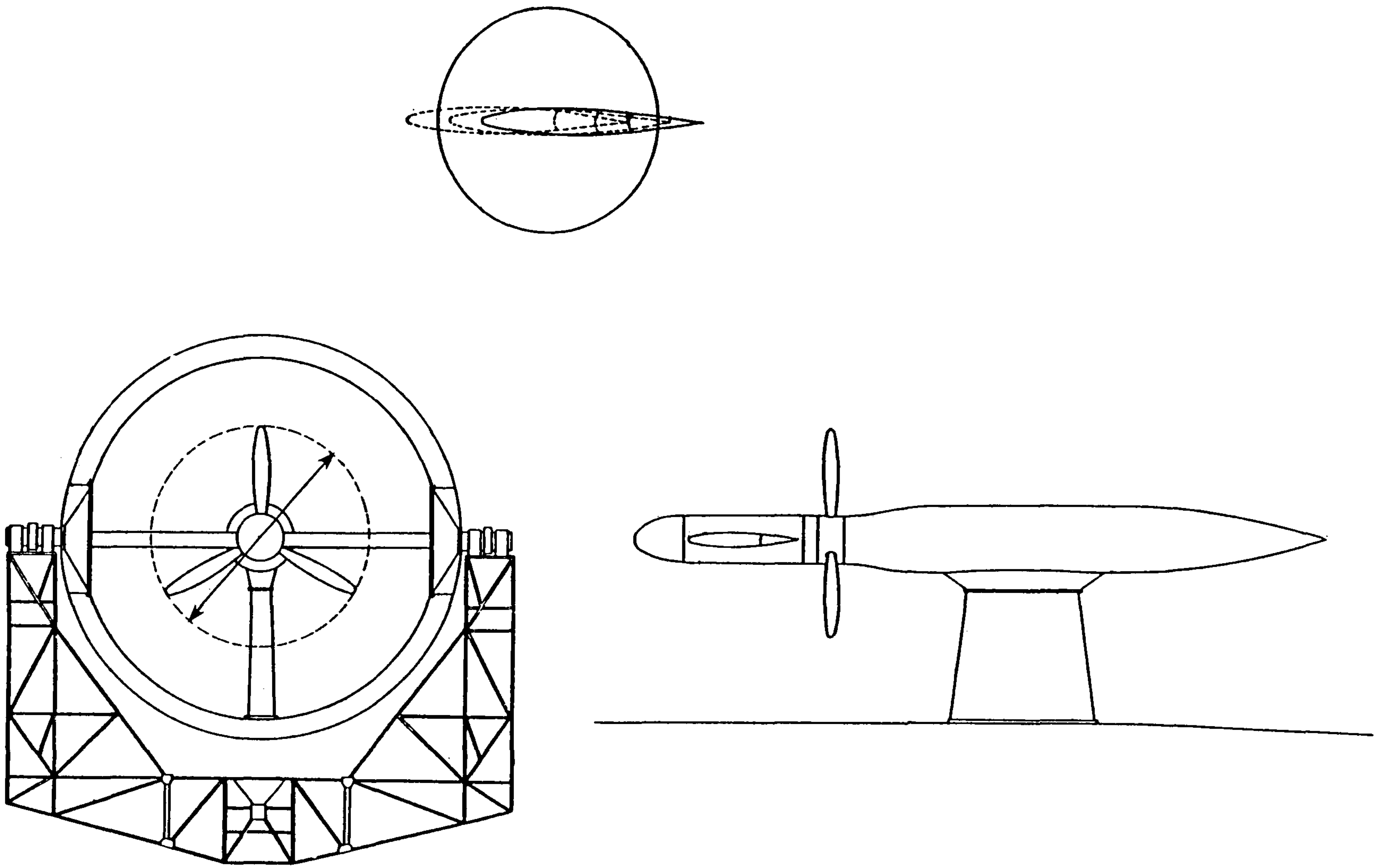

Figure 112-1. Test model used.

Effects of Wing Sweep on the Upwash at the Propeller Planes of Multiengine Airplanes.

V.L. Rogallo

NACA Technical Note, TN 2795, September 1952.

An Analysis is presented to give a qualitative picture of the effects of wing sweep on the upwash at the propeller planes of multiengine airplanes. In order to provide a basis for judging effects of sweep, comparisons are made of the upwash and upflow angles at the propeller planes of two hypothetical airplanes of the high-speed long-range type, one having an unswept wing and the other a sweptback wing. The effects of compressibility are considered. Charts are provided to enable the prediction of upwash in the chord-plane region ahead of wings of various plan forms.

114

A Theoretical Investigation of Aerodynamic Forces Generated by a Propeller on an Airfoil Situated Upstream.

P. Lieber, C. Grubin and K.S. Wan

WADC Technical Report 53-494, June 1953.

This is a modification of the method published by Lieber and Grubin (reference 109). The fuselage is now replaced by a flat plate to simulate the wing upstream of the propeller. Computed results from the method are provided in the form of tables and graphs.

Surveys of the Flow Fields at the Propeller Planes of Six 40 Degree Sweptback Wing-Fuselage-Nacelle Combinations.

V.L. Rogallo and J.L. McCloud III

NACA Technical Note, TN 2957, June 1953.

The flow fields at the propeller planes of six 40 degree sweptback wing-fuselage-nacelle combinations were surveyed to provide data to enable the study of the characteristics of the flow fields and their effect on propeller-oscillating aerodynamic loads. The test models are shown in Figure 115-1. The results of the surveys are presented in the form of angles that define the direction of the local velocity relative to the survey disk and as ratios of the local velocities to free-stream velocity.

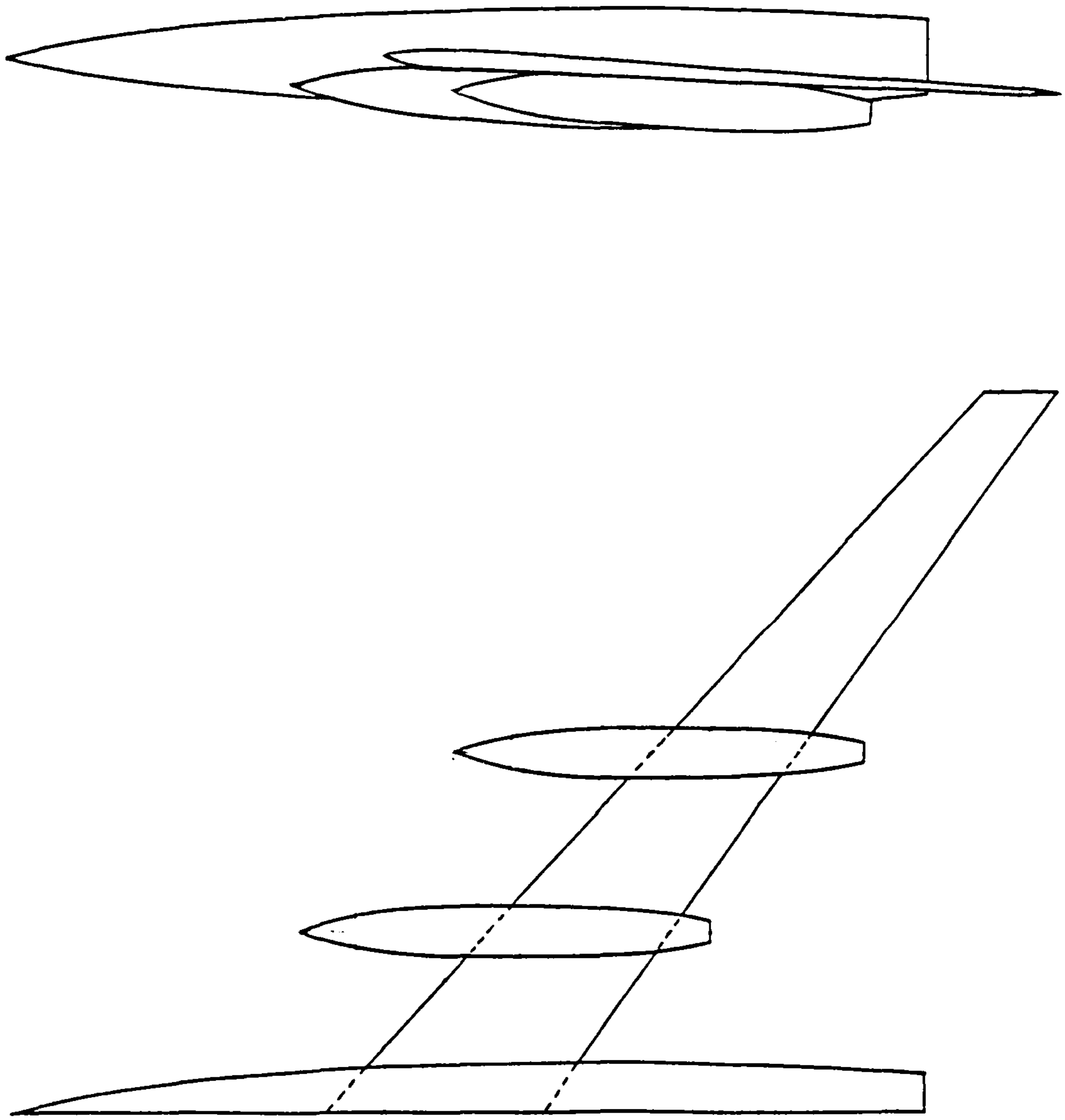

Figure 115-1. Test models used, model (a), configurations 1-4.

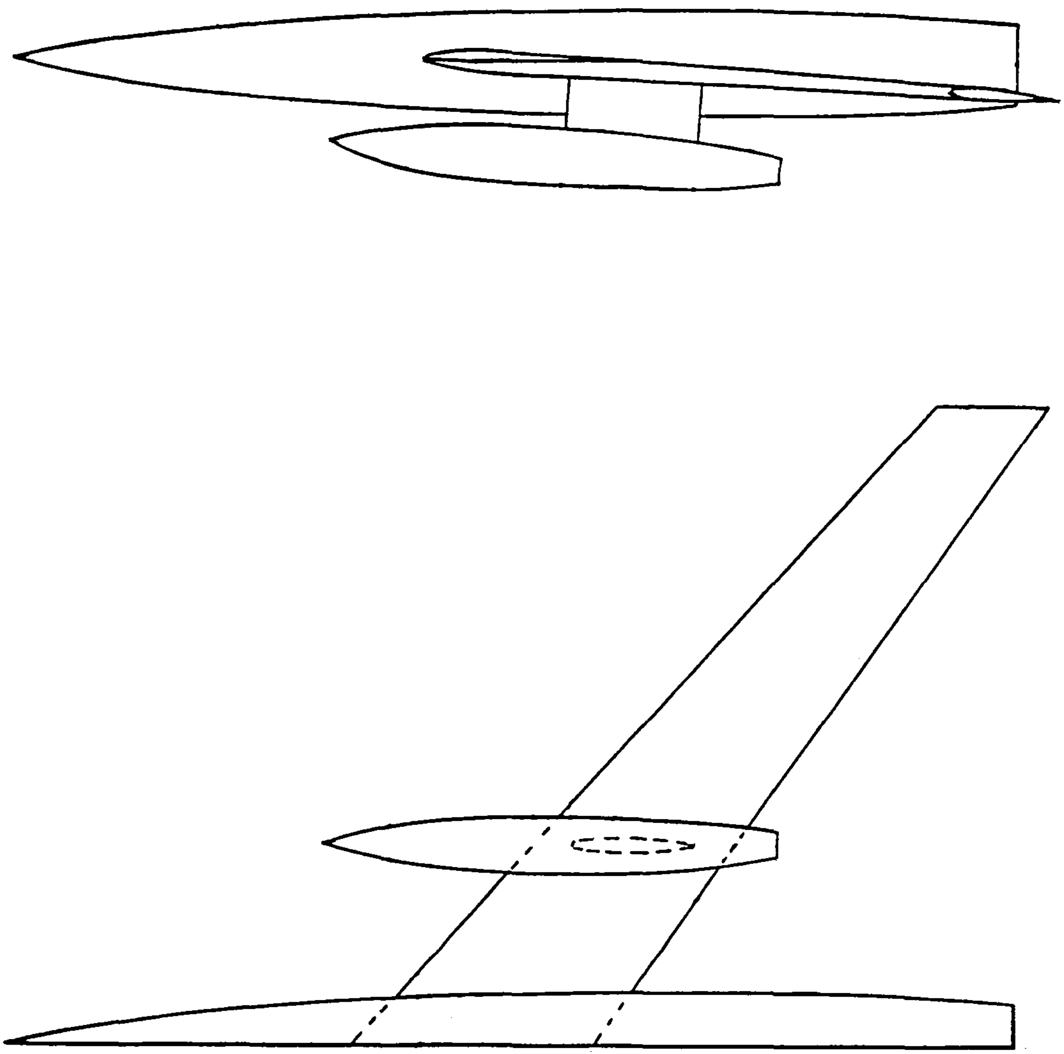

Figure 115-2. Test models used, model (b), configurations 5-6.

On the Calculation of the 1-P Oscillating Aerodynamic Loads on Single-Rotation Propellers in Pitch on Tractor Airplanes.

V.L. Rogallo and P.F. Yaggy

NACA Technical Note, TN 3395, May 1955.

A simplified procedure has been developed to calculate the 1-P oscillating aerodynamic thrust loads on single-rotation propellers in pitch at zero yaw on tractor airplanes. The application of this procedure requires only a knowledge of the upflow angles at the horizontal center line of the propeller disk. These angles may be obtained by computational methods thereby eliminating the need for experimental flow surveys.

The 1-P thrust loads and 1-P vibratory stresses computed by the simplified procedure are compared with those calculated using all the flow-field characteristics measured for several wing-nacelle-fuselage configurations. The configurations are shown in Figures 116-1 to 116-4. These comparisons show good agreement for the 1-P thrust loads and the 1-P vibratory stresses.

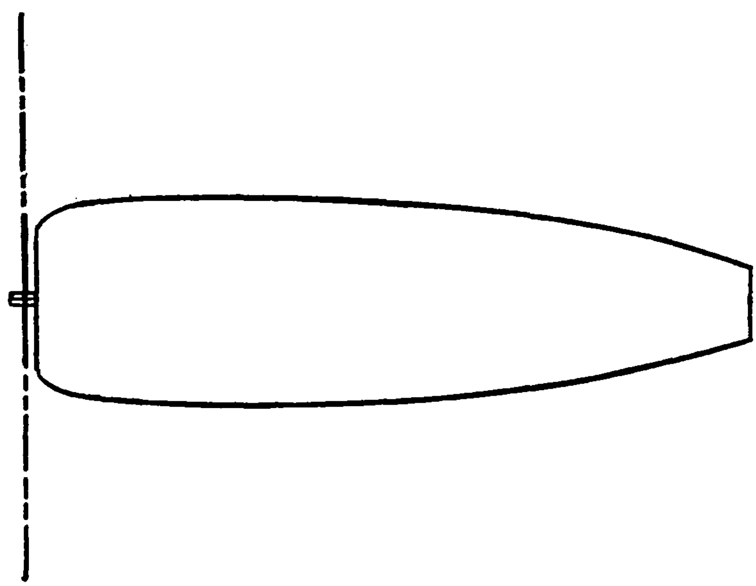

Figure 116-1. Test models used, model (a).

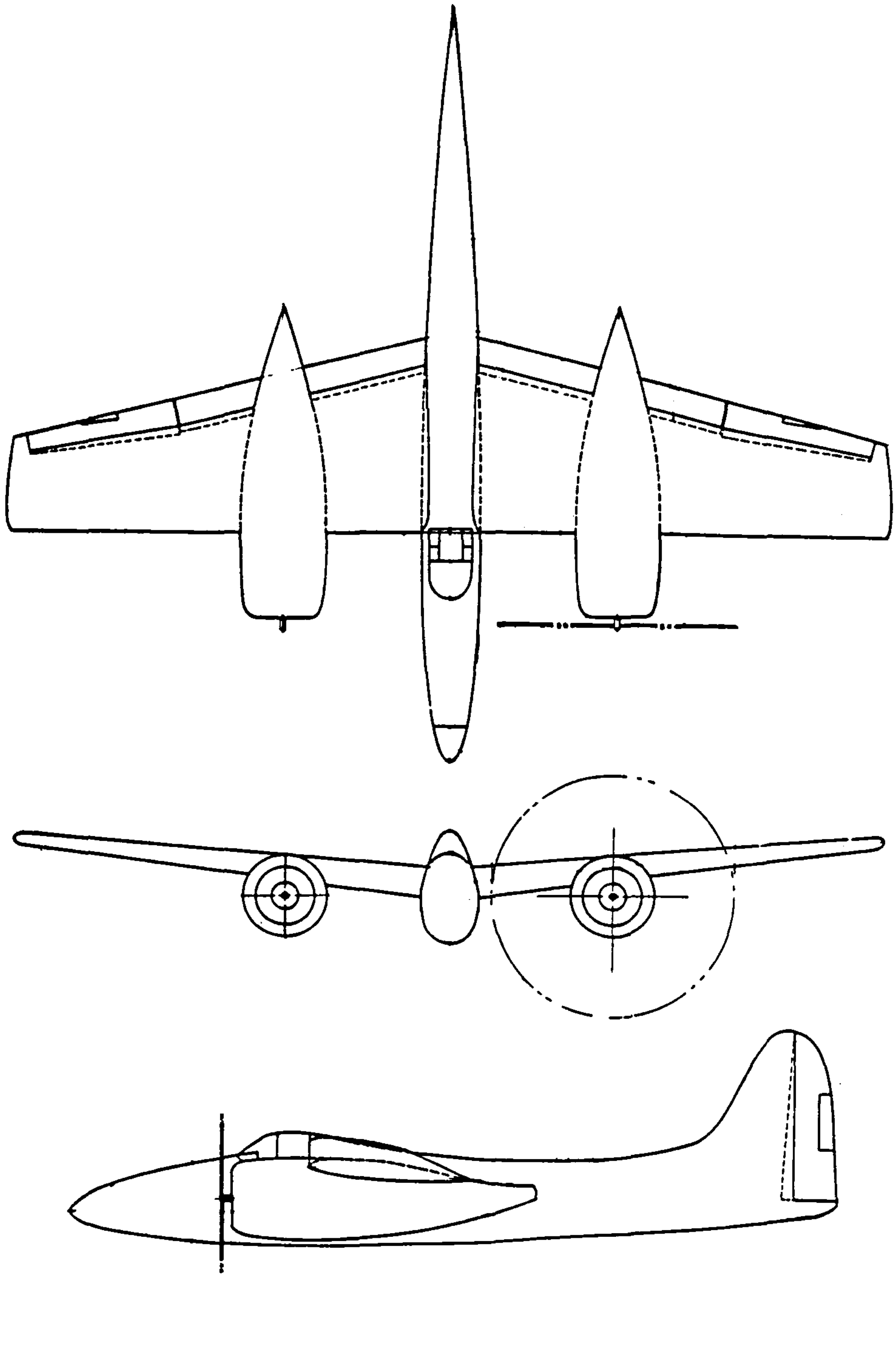

Figure 116-2. Test models used, model (b).

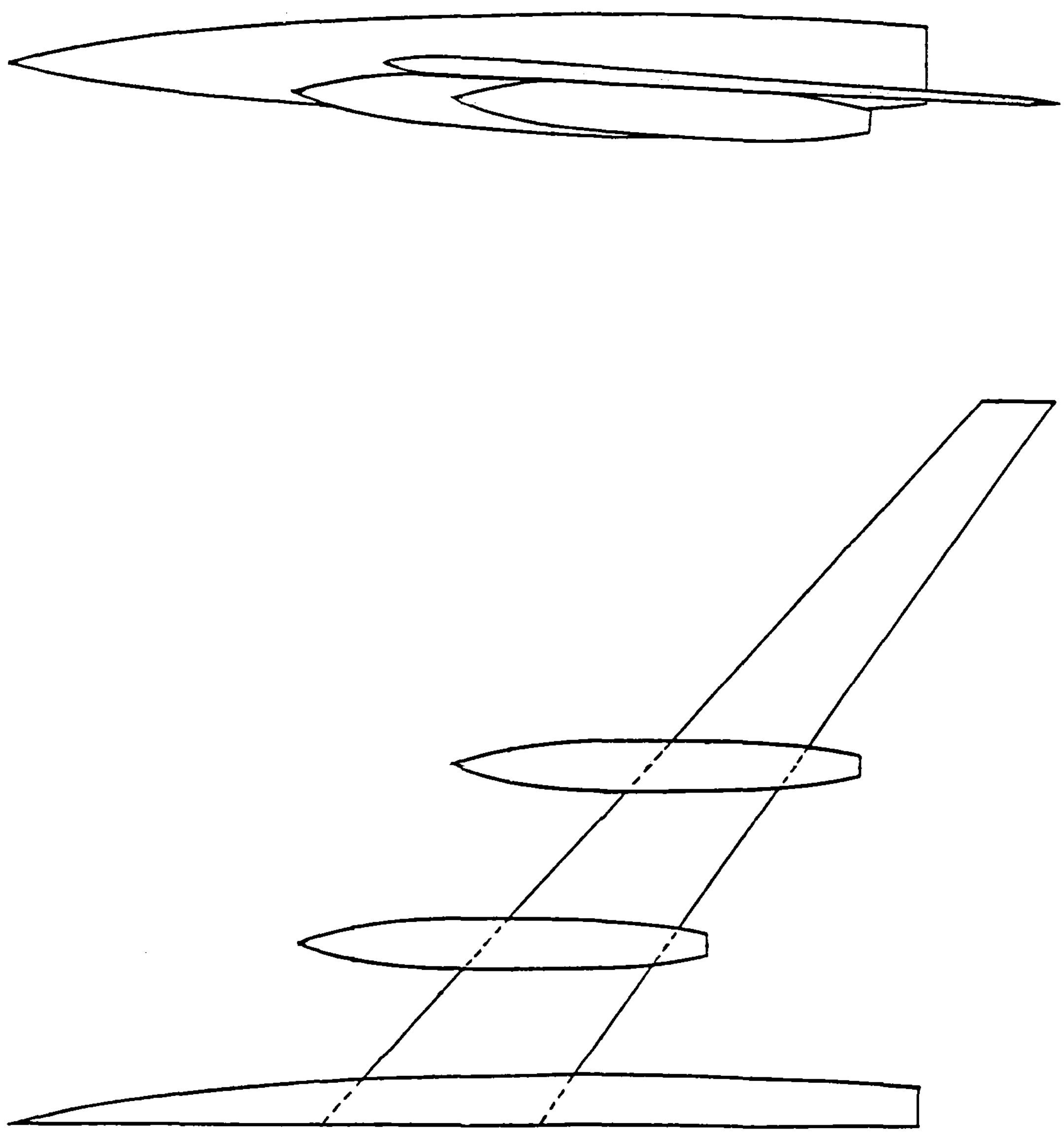

Figure 116-3. Test models used, model (c).

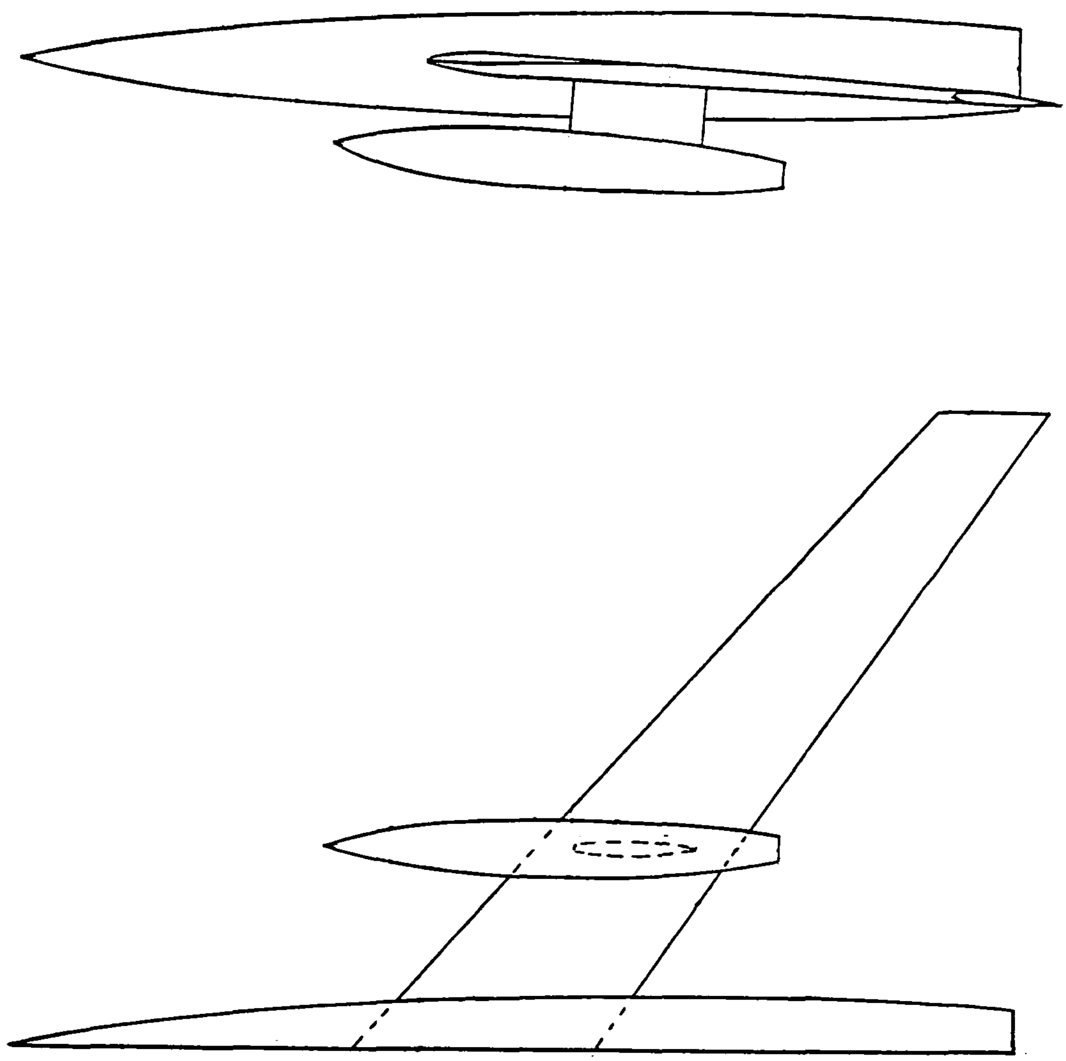

Figure 116-4. Test models used, model (d).

117

The Unsteady Forces due to Propeller-Appendage Interactions.

O. Pinkus, J.R. Lurye and S. Karp

Journal of Applied Mechanics, Vol. 30, June 1963, pp. 279-287.

A study of the nature of the unsteady forces in the field of a propeller rotating in the vicinity of an appendage is presented. The propeller is assumed to be one of high aspect ratio while the appendage is assumed to be of finite width and infinitely long. The problem is thus reduced to the unsteady flow about two flat plates. The mutual interference of the propeller blade and appendage is taken into account. The method of solution employs the technique of the substitution vortex which yields analytic expressions for the quasisteady, apparent mass and wake forces for both the propeller and appendage. These equations provide the magnitude and variation of the total forces as functions of tip clearance, distance, and relative size of appendage and propeller.

118

Pictures of Flow in a Propeller Slipstream Disturbed by a Wing. (Stromungsaufnahmen eines durch einen Tragflugel gestorten Propellerstrahls.)

J. Lotz

Aerodynamische Versuchsanstalt, Goettingen E.V., FB 899, December 1937.

NTIS PB 36561

Various configurations of a propeller and wing were studied in a water tunnel. Air bubbles were injected as the visualization medium. Pictures were taken from the side, from below, and at an angle from above. The configurations included propeller only and propeller with wing. Three different wing chords were used. The test conditions were for an advance ratio of 0.14, and a Reynolds number range of 2.8×10^4 - 7×10^4.

The pictures show that the slipstream adapts to the wing flow; the swirl is reduced significantly; and that the slipstream halves, split off by the wing, move spanwise in the direction of the swirl.

119

A Wind-Tunnel Investigation of Entry Loss on Propeller Turbine Installations.

J. Seddon and A. Spence

British Aeronautical Research Council, Reports and Memoranda R&M 2894, August 1948.

A wind tunnel test program was performed to develop design information for turbo-propeller inlets. Results show that annular entry inlet losses can be as high as 25 percent with the propeller blade roots accounting for 15 percent. Results for ducted spinner designs show inlet losses of only 5-10 percent.

Details of the various inlet designs tested are given with comparative results in tabular and graphical forms.

The Effect of the Propeller Slipstream on the Characteristics of Submerged Inlets.

N.K. Delany

NACA Research Memorandum RM A9G15, September 1949.

A wind tunnel investigation was carried out to determine the effect of the propeller slipstream on the characteristics of a submerged inlet. The test model is shown in Figure 120-1. The propeller had eight blades and was counter-rotating.

The results showed that propeller operation is detrimental to the ram-pressure recovery of submerged inlets if the shank sections of the blade are not producing positive thrust. The rate of increase of ram-recovery with thrust coefficient was approximately independent of inlet-velocity ratio, but decreased with increasing propeller blade angle and with model angle of attack.

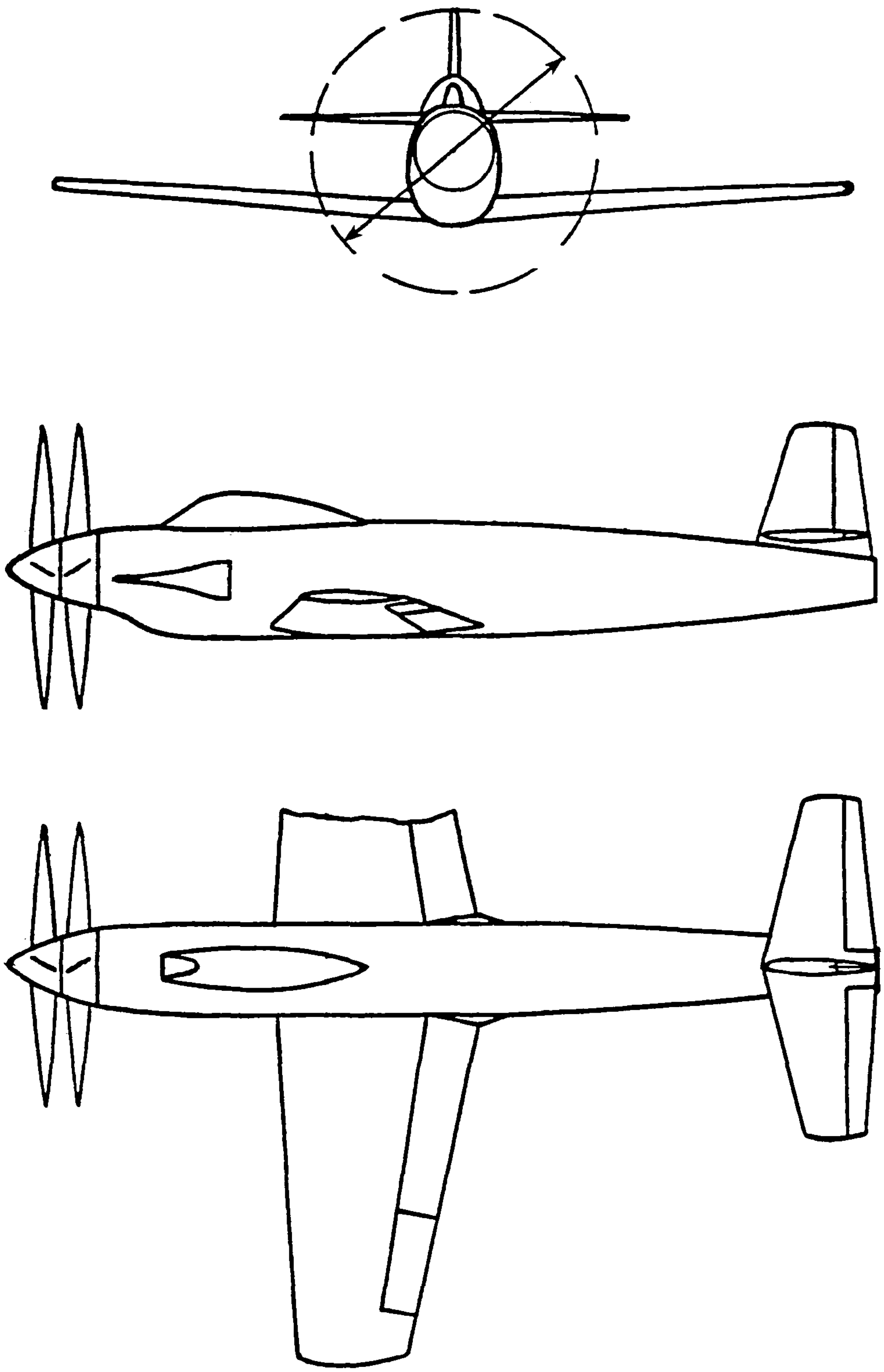

Figure 120-1. Test model used.

121

Flow Conditions in a Slipstream.

F. Weinig

Mississippi State University, Department of Aerospace Engineering, Translation by Georg Timm, August 1956.

This is a translation of an article published in 1936 which summarizes the available information concerning the behavior of the slipstream. Flow visualization and experimental data are included.

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1. Report No. NASA CR-3882	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle PROPELLER PROPULSION SYSTEM INTEGRATION - STATE OF TECHNOLOGY SURVEY		5. Report Date March 1985
		6. Performing Organization Code
7. Author(s) S. J. Miley and E. von Lavante		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Texas A&M University Department of Aerospace Engineering College Station, Texas 77843		11. Contract or Grant No. NAG1-214
		13. Type of Report and Period Covered Contractor Report
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code 505-43-43-01

15. Supplementary Notes

Langley Technical Monitor: Robert W. Koenig
Final Report

16. Abstract

A literature survey was performed to identify and review technical material applicable to the problem area of propeller propulsion system integration. The survey covered only aerodynamic interference aspects of the problem, and was restricted primarily to propeller effects on the airframe. The subject of airframe aerodynamic interference on the propeller was limited to the problem of vibration due to nonuniform inflow. The problem of airframe effects on propeller performance was not included.

A total of 121 references are given. The references are grouped into the subject areas of Aircraft Stability, Propulsive Efficiency, Aerodynamic Interference, Aerodynamic Interference-Propeller Vibration, and Miscellaneous.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Propeller(s) Propulsion Integration	Unclassified-Unlimited Subject Category 02

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	186	A09

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