N76 10998

2.2 General Overview of Drag

S.A. Anderson
Ames Research Center

The importance of reducing drag for general aviation aircraft is increasingly evident for the reasons noted in Figure 1. This includes rising fuel costs and the demand for improved performance to meet foreign competition. Equally important is the impact of more stringent noise and pollution standards because these factors indirectly affect aerodynamic performance. Although the general principles of how to achieve drag reduction are known to aircraft designers, applications to general aviation aircraft are a significant challenge because this aircraft category is particularly sensitive to costs, maintenance, marketing, safety utility, and even stability and control.

How much do we really know about potential drag reductions for a typical high-performance business aircraft? A casual inspection of a current twin shows an abundance of brazier head rivets on all parts of the aircraft, several large external antennas, a lack of wing-fuselage filleting, lapped skin joints, many air inlets at obviously undesirable aerodynamic locations, and a single large-diameter exhaust pipe protruding at close to 90° to the airstream. On one twin turboprop aircraft, seven separate NACA flush inlets were located on each engine nacelle, some obviously of questionable value for pressure recovery. Although it is recognized that little systematic research on drag for current aircraft configurations has been conducted recently, many of the results of early NACA research can be usefully applied to current aircraft. Obviously, there is little similarity between the blunt, radial-engine transport aircraft of the late 1930's, for which most of the early research was conducted, to today's sleek business jet, so few would question the need for additional research.

As noted in the program for this workshop, it is timely to identify the state-of-the-art on aerodynamic drag reduction and develop a program plan for achieving meaningful results. There are, of course, many elements making up the total drag of an aircraft, including fuselage, wing, nacelles, trim, interference, tail, and cooling drag. The various topics to be covered in the next three days are shown on Figure 2. Note that although cooling drag can be a large percentage of total drag (as high as 25%), it has previously been covered in a NASA/University/Industry workshop and will not be considered explicitly at this workshop. As noted in Figure 3, the purpose of this paper is to review the relative drag contributions of these various elements, pausing briefly to note what is known about each from past research, thereby identifying gaps in the knowledge for further consideration by speakers who will follow with detailed discussions.

Basic Sources of Drag

It is important to identify the basic sources of drag in order to gain a better understanding of how improvements in performance can be made. Shown on Figure 4 are the following: (1) skin friction due to the air molecules rubbing the surface, the magnitude being a function of the flow conditions (laminar or turbulent) and the amount of wetted area; (2) induced flow or vortex flow primarily a function of wing aspect ratio; and (3) pressure effects associated with the profile or form of various parts of the aircraft.

Shown on Figure 5 is the variation of flat plate drag coefficient based on wetted area with Reynolds number for fully turbulent and laminar flow conditions. Note that at large R_e numbers typical of flight cruise conditions, the drag associated with turbulent flow is ten times higher than for laminar flow. In another example of the effect of flow conditions, Figure 6 compares the equivalent drag of a laminar flow airfoil and a circular wire. If nothing else, this is an incentive to avoid using exposed landing wires.

Drag Prediction Techniques

Moving along to the first topic of our workshop, the various drag prediction techniques in use today are noted in Figure 7. The empirical approach takes advantage of semi-analytical methods in which wind-tunnel and flight-test results of similar type aircraft are factored in to establish a data base. Wind tunnel measurements of drag for a new design are usually made, particularly for high-performance aircraft. Extrapolation of small-scale (low R_e no.) data to flight conditions can be difficult when including power effects and the accuracy of how well the small-scale model represents the actual aircraft. Finally, theoretical estimates, although used extensively in the past, have become more popular because of the availability of large capacity digital computers. Solutions of 3-dimensional viscous flow effects appear to remain a challenge even with very large (and expensive) digital computers such as the ILLIAC IV based at the NASA Ames Research Center.

Relative Contributions to Drag

An example of results from drag prediction methods developed at NASA-Ames is shown in Figure 8. The aerodynamics subroutine calculates a series of factors which are used to establish drag values. Form factors are used for each component to represent drag increases above that of a flat plate to account for 3-D effects, interference, roughness, and excrescences. These calculations were made for the Learjet, Citation, Cessna 340, Piper Arrow, and Cessna 150. Note first, not unexpectedly, that the wing and fuselage are responsible for the largest source of drag. Of interest in the last column is the amount to be added to match flight values of drag. This item varies greatly, going from less than 2 percent for the Learjet to 37 percent for the Cessna 150. Improvements are needed to more accurately account for such factors as 3-D effects, cooling drag, landing gear, slipstream drag, etc.

Factors Influencing Fuselage Drag

In the next item of our workshop agenda, Figure 9 gives several factors which affect fuselage drag. The surface conditions are very important because of the large wetted area. Windshield shape can significantly affect total drag at the higher Mach numbers. Fuselage shape in terms of fineness ratio, nose shape and rear-end shape must be carefully considered. Shown in Figure 10 is the effect of afterbody contraction ratio on drag. The contraction ratio must be greater than 2.0 to avoid a drag increase. A similar consideration must be given in the vertical plane.

Factors Influencing Wing Drag

Figure 11 lists several factors which are considered in selecting a wing for a new aircraft design. A large background of data is available from NACA research on airfoil sections and newer types such as the GAW-1 airfoil to challenge the designer in selecting the correct airfoil section for his aircraft. The NASA has underway a program on airfoil development aimed primarily at optimizing airfoils for specific operating conditions. Thickness ratio effects are generally well-documented. Planform and aspect ratio effects are also important as influenced by structural considerations. Wing-tip effects on induced drag will be covered specifically in a Langley Research Center paper describing the trade-offs on using "Winglets."

Another reminder of the importance of surface conditions and thickness ratio on drag is given in Figure 12. These NACA data tend to exaggerate the effect of roughness because the lower curve represents a mirror-finish surface condition. The trend today for the higher performance jets is to use thicker airfoil sections for structural and fuel volume considerations.

Factors Influencing Trim Drag

Of the various factors shown in Figure 13 which affect trim drag, tail location and static stability have recently been given increased attention. A tail location out of the slipstream ("T" tail designs) offer some drag decrease, and canard horizontal tail locations have appeared on experimental aircraft. In consideration of the small percentage of the tail surfaces to total drag indicated previously, one must be careful not to compromise stability and control in looking for performance imporvements. In this connection the control configured-vehicle (CCV) and relaxed static stability have received attention recently. An illustration of the effect of reducing static margin on the horizontal tail area required is shown in Figure 14. These curves indicate the variation of tail size with static margin to trim out the wing-fuselage pitching moment and the tail area needed for maneuvering. To achieve the minimum tail area and therefore the least amount of drag, the static margin must be slightly aft of the neutral point ($d_{\delta_e}/d_{C_L} = 0$) but ahead of the maneuver point ($dF_e/dA_z = 0$). Obviously, some for of stability augmentation must be provided to meet the FAR if minimum tail size is desired. At this point one would logically question the merits of reducing static margin for most General Aviation aircraft.

Considerations for Drag of Complete Aircraft

In the final analysis, drag of the complete configuration is the most difficult to rationalize. As noted in Figure 15, cost is a factor that must be considered in each aspect of aerodynamic drag reduction. Cost aspects will be discussed in a paper later in the workshop. In this regard use of composites may offer promise in that extremely smooth surfaces with attendant low drag can be achieved without high-cost manufacturing techniques. The second point, aerodynamic drag of the complete configuration, must take into account items such as wing nacelle and tail location, fuselage camber, wing and nacelle incidence, wing loading, cruise lift coefficient, etc. This area will be covered also on the last day of the workshop. The next item, propulsion system integration, is an important area, particularly for higher performance aircraft. Nacelle size and location can significantly affect high subsonic Mach number performance, as will be discussed by NASA Lewis Research Center. Fabrication details, the next item, must be considered in the light of cost and aircraft appearance. A smooth-looking aircraft not only has the potential for higher performance, but also sales appeal. Finally, an important point to know is the relative magnitude of the various sources of drag because of the many trade-offs in aerodynamic drag reduction. This leads to the next point of discussion.

In Figure 16 the relative drag values are compared for a high performance aircraft. Leading the list is the friction drag, with induced drag a close second. Cross flow or 3-D effects can cause drag problems and are unfortunately the most difficult to predict. Induced drag primarily a function of wing aspect ratio can be reduced by wing-tip modifications, as will be covered by Langley Research Center.

Historical Survey of Drag

Figure 17 presents the variation of drag based on wetted area as a function of time. Starting with the Wright Brother's design as the highest drag vehicle--not too surprising if you recall how large a drag penalty wires can create. The lowest drag values correspond to fighter aircraft such as the Douglas A-4 and LTV F-8.

There is no question that improvements have been made with time, but how well are we doing in realizing the goals of drag previously noted. Shown in Figure 18 is a comparison of flight drag data with flat plate skin fraction curves for turbulent and laminar flow conditions. The data which are for typical general aviation aircraft fall short of even achieving the turbulent flow drag values. The lowest drag value quoted is for the black buzzard (coragyps atratus) which in some 150 million years of evolution has no doubt managed to achieve reasonably good flow conditions without having to contend with cooling drag and propeller slipstream effects. There are indications that these idealized goals can be approached by aircraft with good surface finishes, such as the point for the Learjet at 30 million R_e.

Concluding Remarks

In conclusion, three main points should be kept in mind during the next three days (see Figure 19). We need to more accurately clarify the sources of drag for general aviation-type aircraft so that new designs can benefit from more accurate prediction techniques. Next, by knowing more about the sources of drag it will be possible to bring out the greatest potential for drag reduction. Finally, we must use our expertise to identify gaps in knowledge and point out areas which should receive high priority R and D efforts.

In closing, I would like to mention my personal drag reduction program carried out on a Vultee BY-13 trainer aircraft. By using NACA drag information, the high speed of this aircraft was improved from 160 to 210 mph, representing a change in equivalent flatplate area from 16.1 to 7.2 square feet.

NEED FOR DRAG REDUCTION

- RISING FUEL COSTS
- INCREASED FOREIGN COMPETITION
- NOISE AND POLLUTION

Figure 1. General Overview of Drag

- STATUS OF DRAG PREDICTION METHODS
- FUSELAGE DRAG
- WING DRAG
- EXTERNAL NACELLE DRAG & INTERFERENCE DRAG
- TRIM DRAG
- DRAG OF COMPLETE CONFIGURATION

Figure 2. General Aviation Drag Reduction Workshop Sessions

- HIGHLIGHT CAUSES OF DRAG
- INDICATE DRAG STATUS OF CURRENT A/C
- IDENTIFY GAPS IN KNOWLEDGE

Figure 3. Purpose of Presentation

- SKIN FRICTION
- INDUCED FLOW
- PRESSURE EFFECTS

Figure 4. Basic Sources of Drag

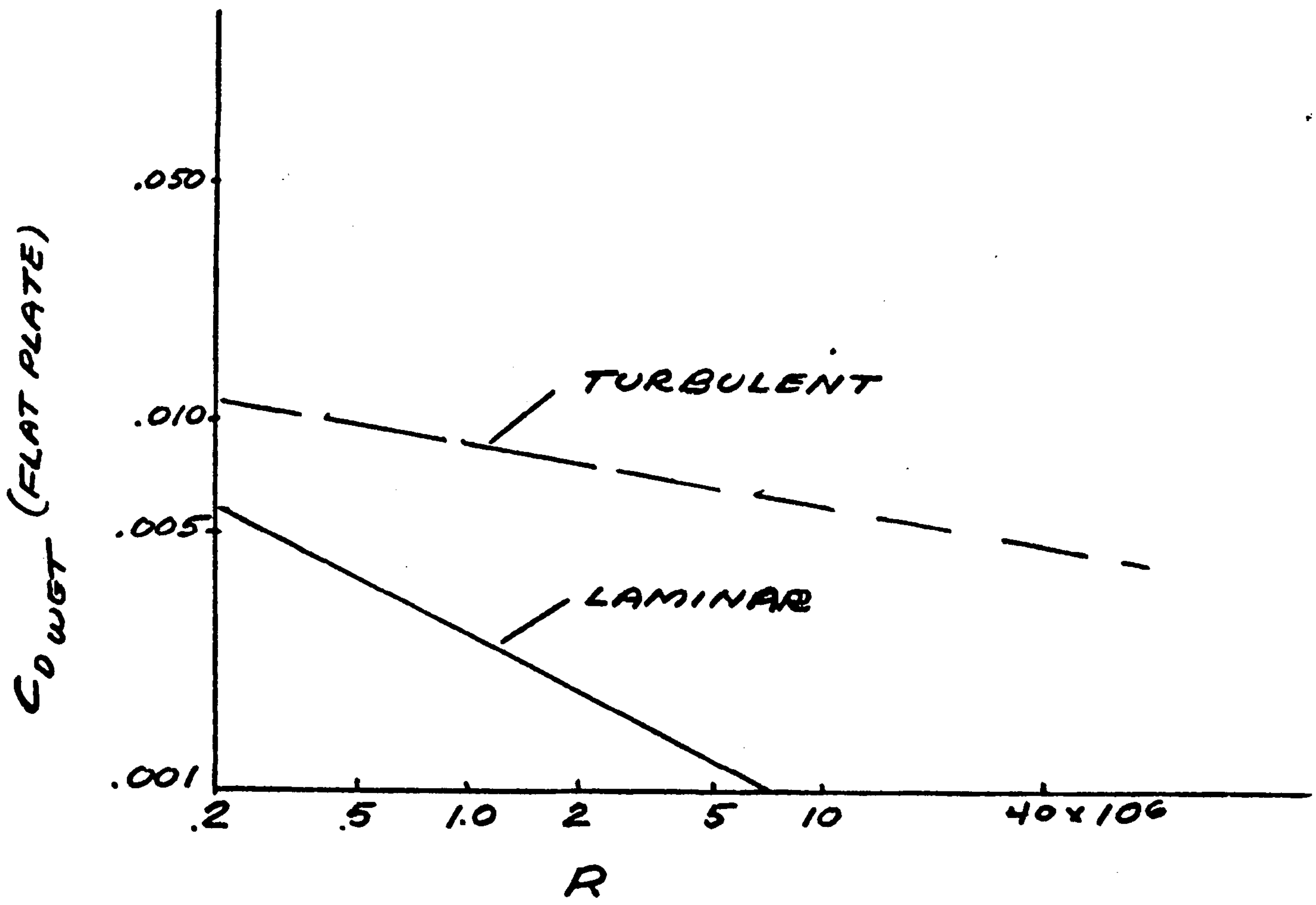

Figure 5. Effect of Flow Conditions on Flat Plate Drag

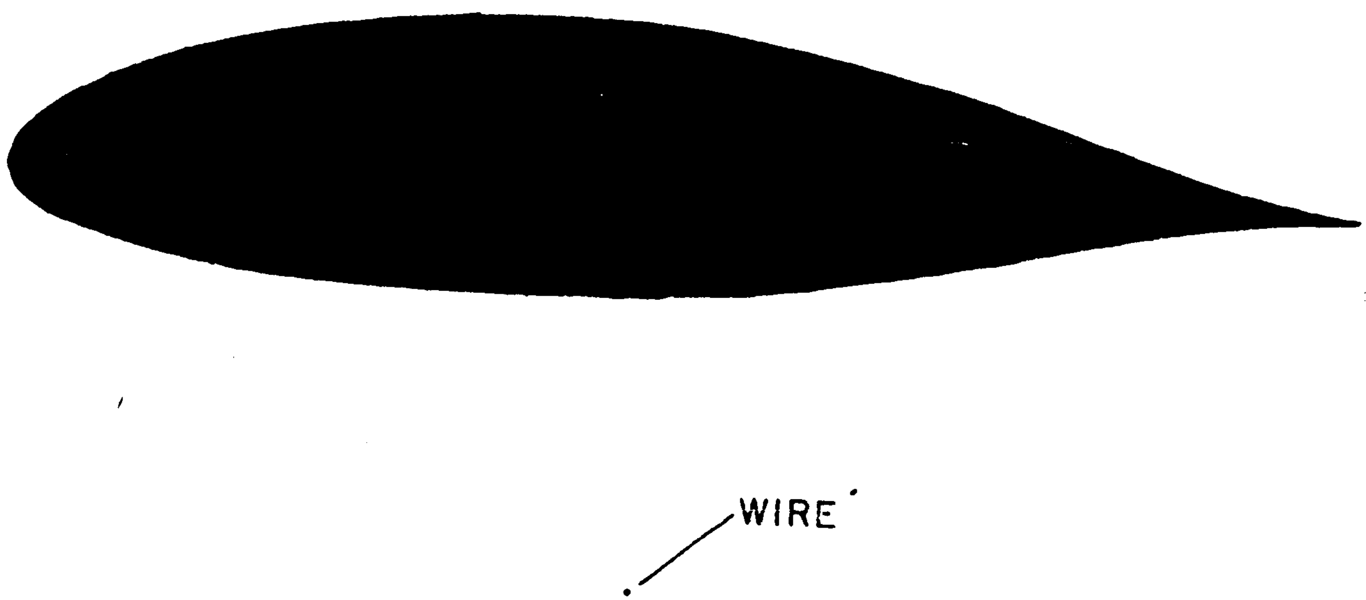

Figure 6. Airfoil Compared with Circular Wire Having Equal Drag

- EMPIRICAL METHODS
- WIND TUNNEL MEASUREMENTS
- THEORETICAL ESTIMATES

Figure 7. Drag Prediction Techniques

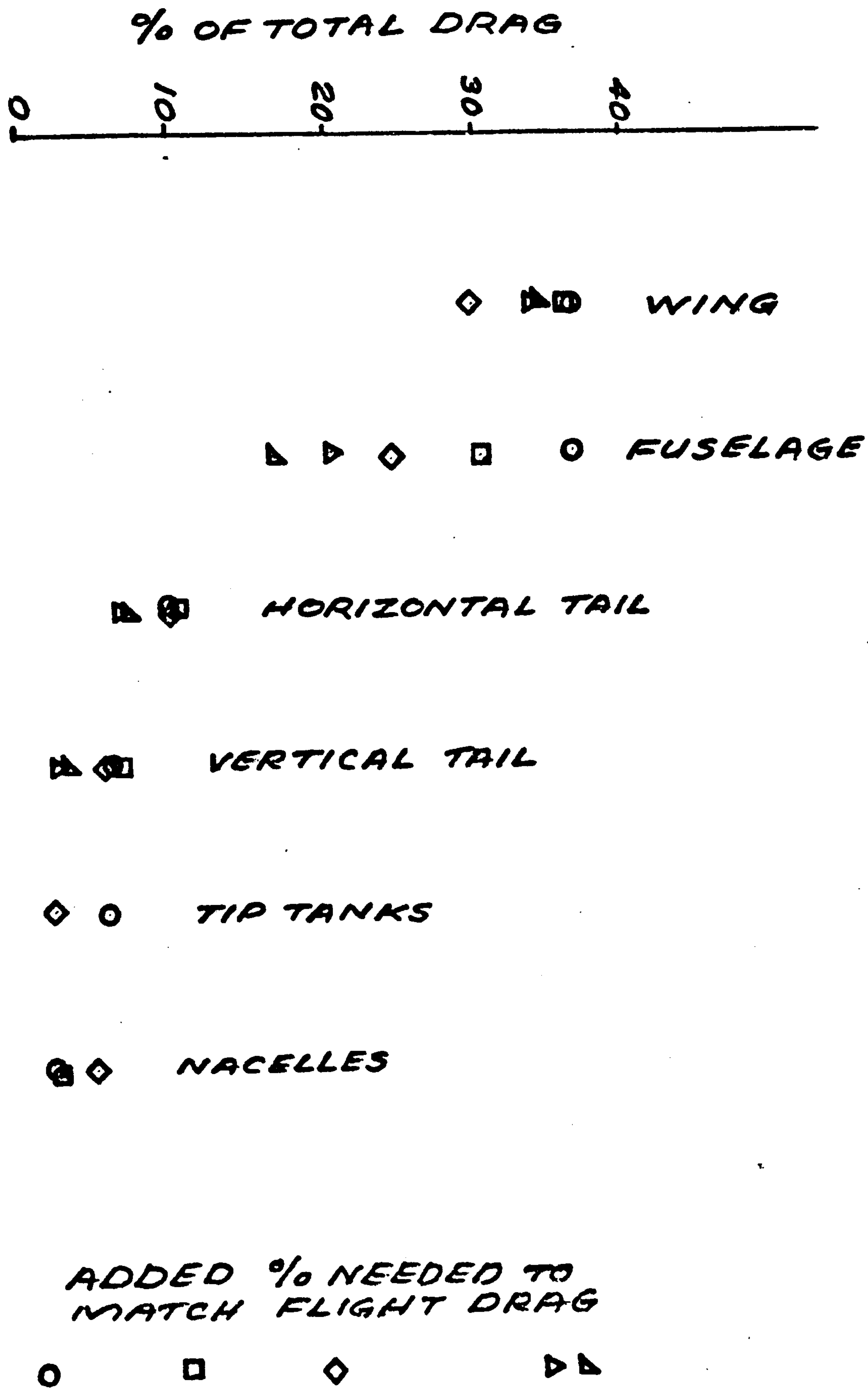

Figure 8. Relative Component Contribution to Drag

- SURFACE CONDITIONS
- FINENESS RATIO
- NOSE SHAPE
- WIND SHIELD ANGLE
- CONTRACTION RATIO

Figure 9. Factors Influencing Fuselage Drag

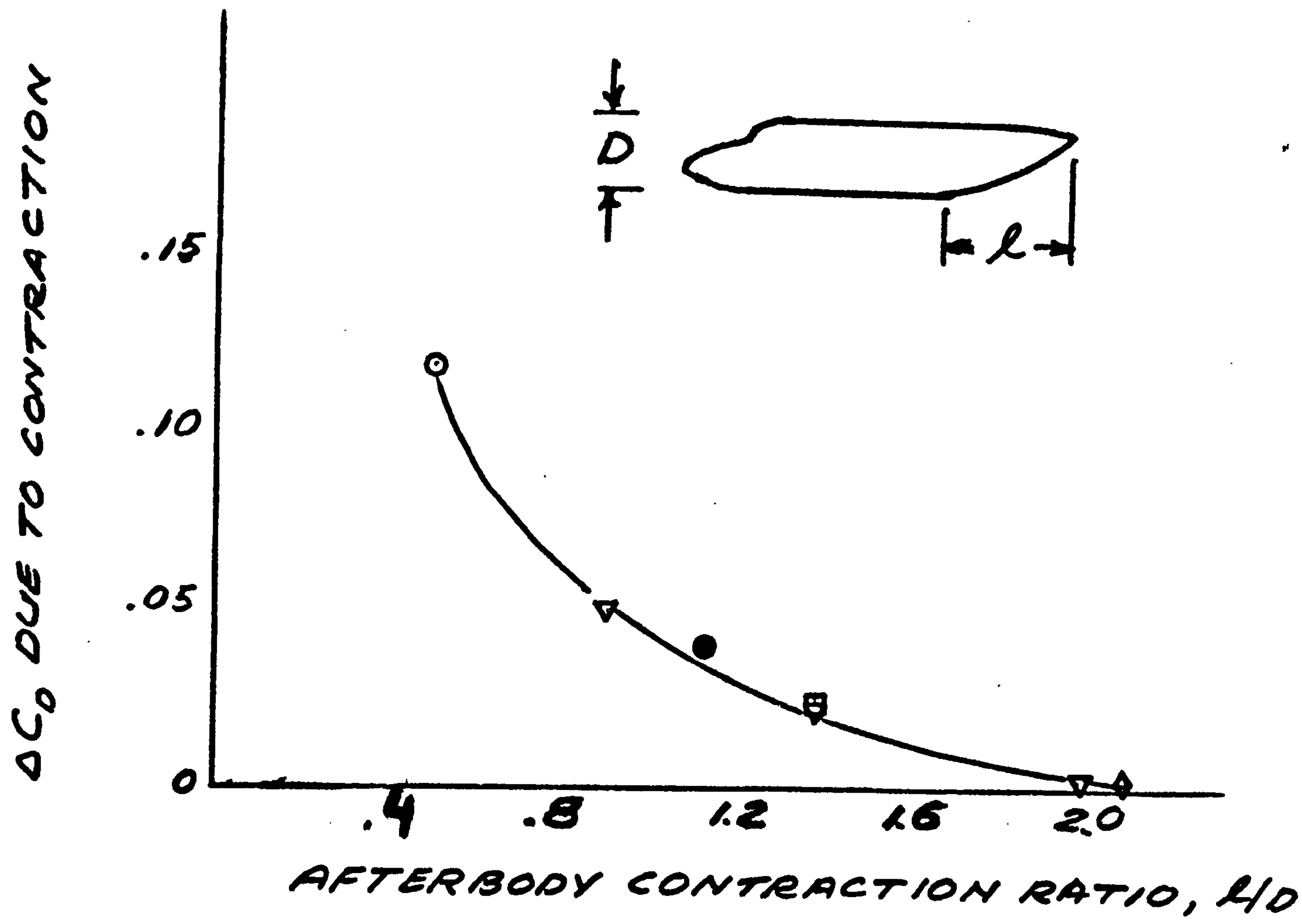

Figure 10. Effect of Afterbody Contraction Ratio on Drag

- AIRFOIL SECTION
- THICKNESS RATIO
- ASPECT RATIO
- PLAN FORM
- WING TIP
- SWEEP ANGLE
- SURFACE CONDITIONS

Figure 11. Factors Influencing Wing Drag

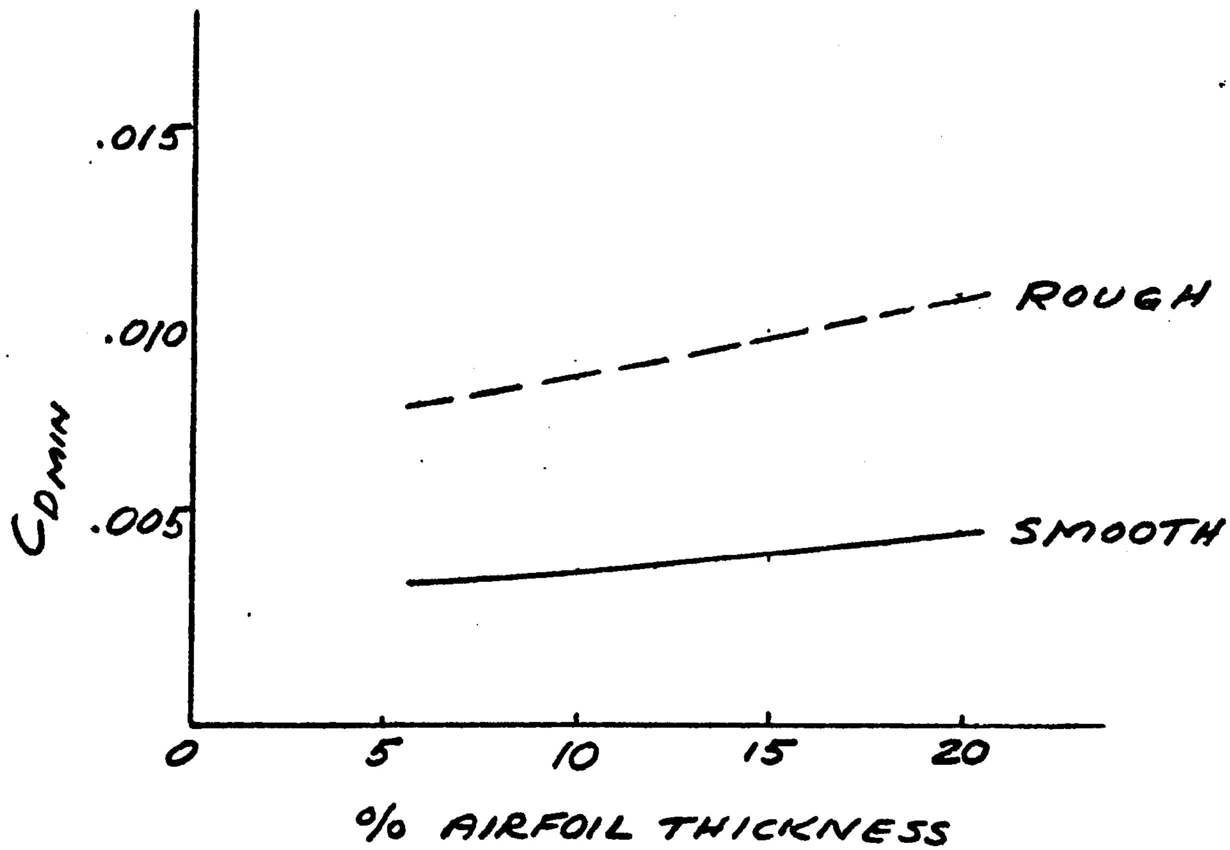

Figure 12. Effect of Roughness on Minimum Drag

- WING - FUSELAGE C_{M_0}
- TAIL LOCATION
- STATIC MARGIN

Figure 13. Factors Influencing Trim Drag

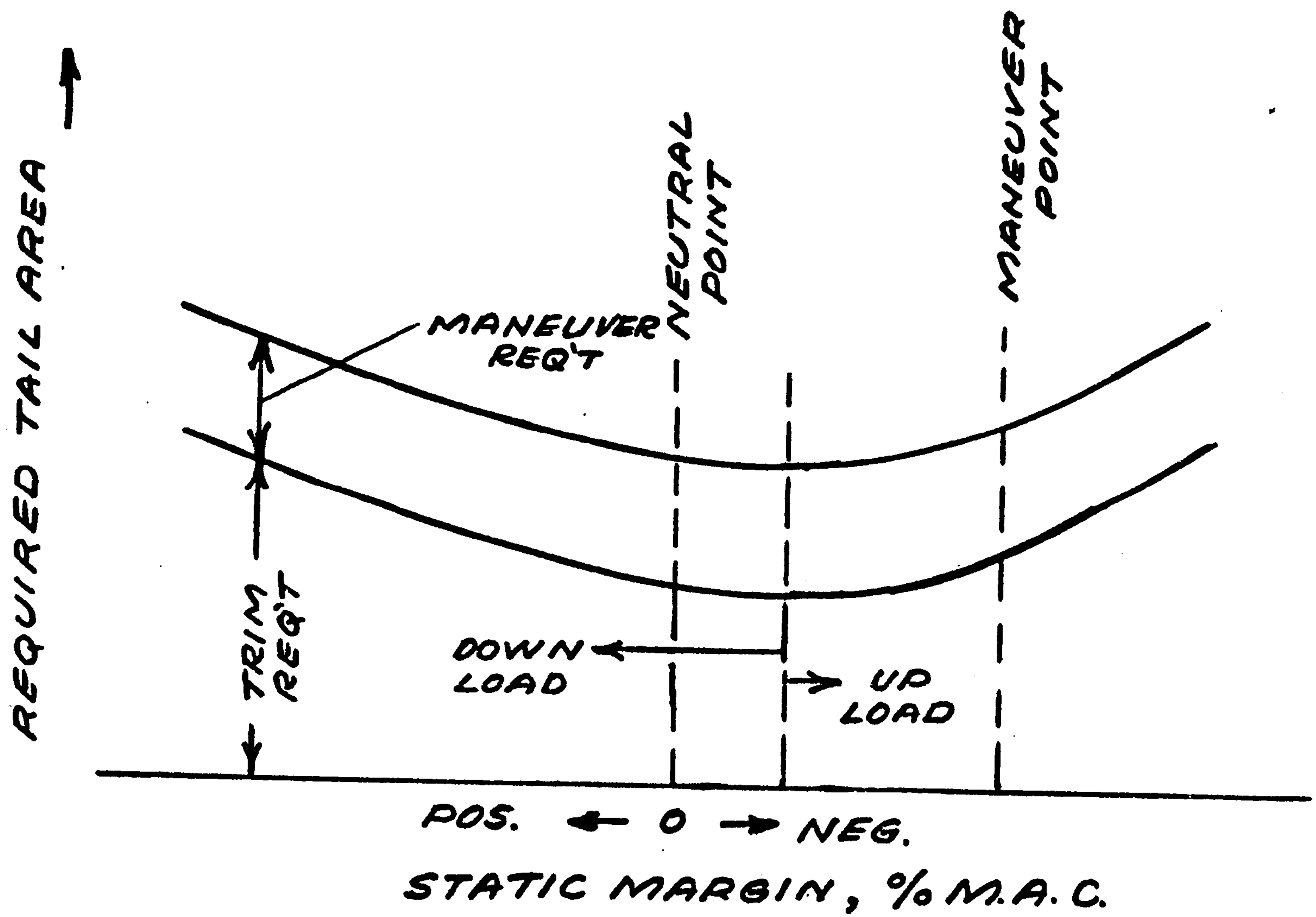

Figure 14. Typical Effect of Static Margin on Tail Size

- COST
- AERODYNAMIC DESIGN
- PROPULSION SYSTEM INTEGRATION
- FABRICATION DETAILS
- IDENTIFICATION OF SOURCES OF DRAG

Figure 15. Considerations for Drag of Complete Aircraft

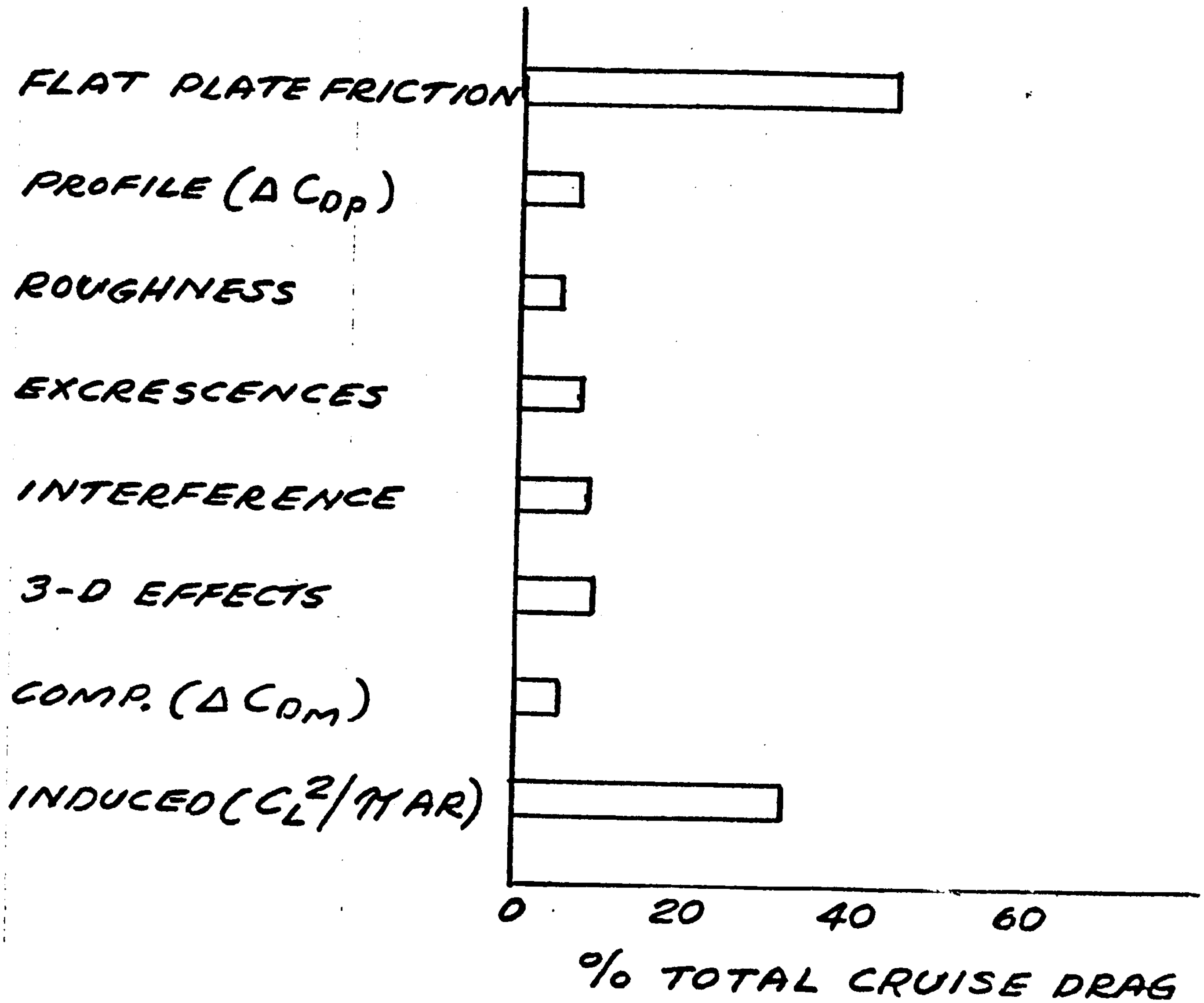

Figure 16. Typical Drag Buildup for Jet Transport

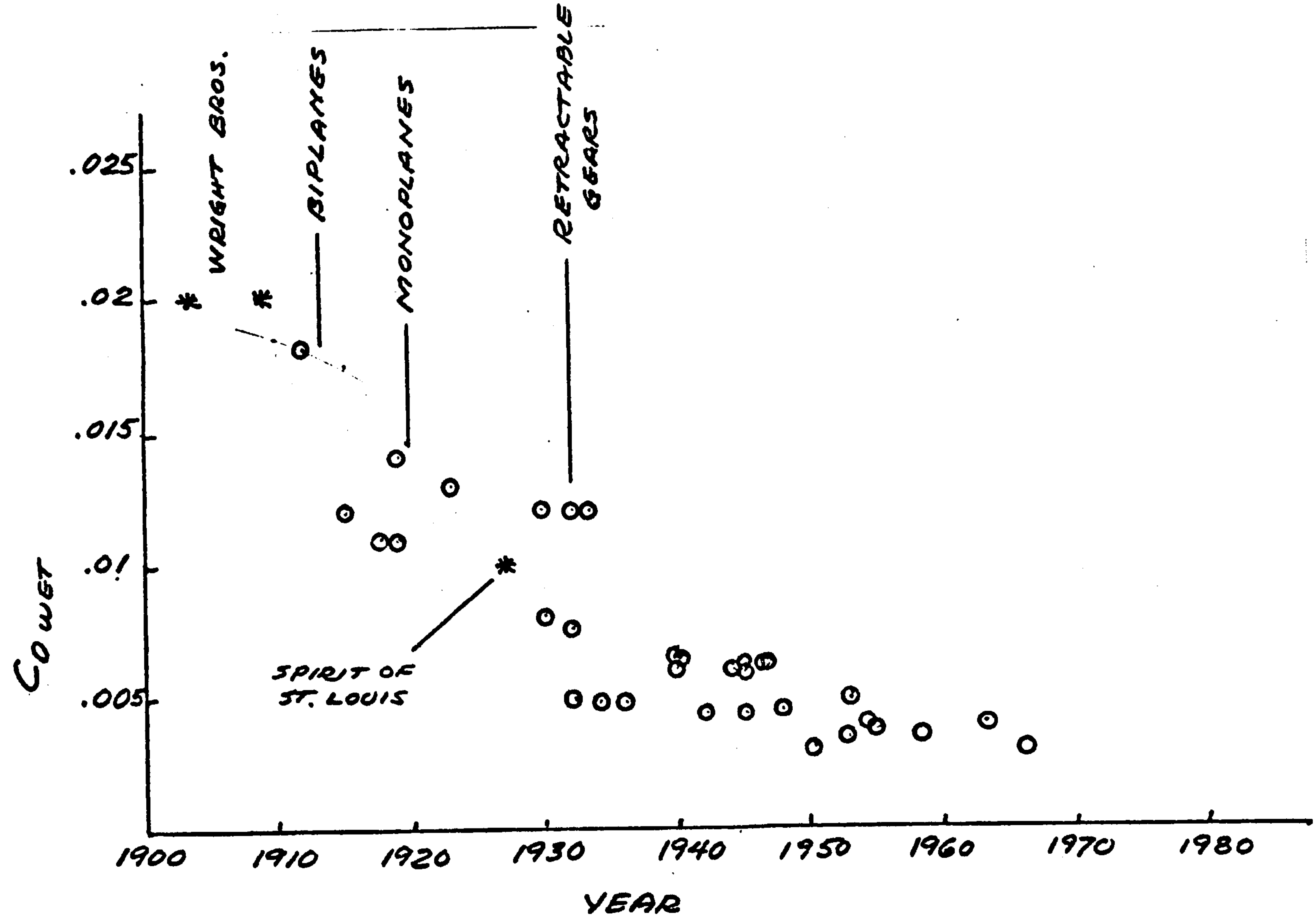

Figure 17. Historical Survey of Drag

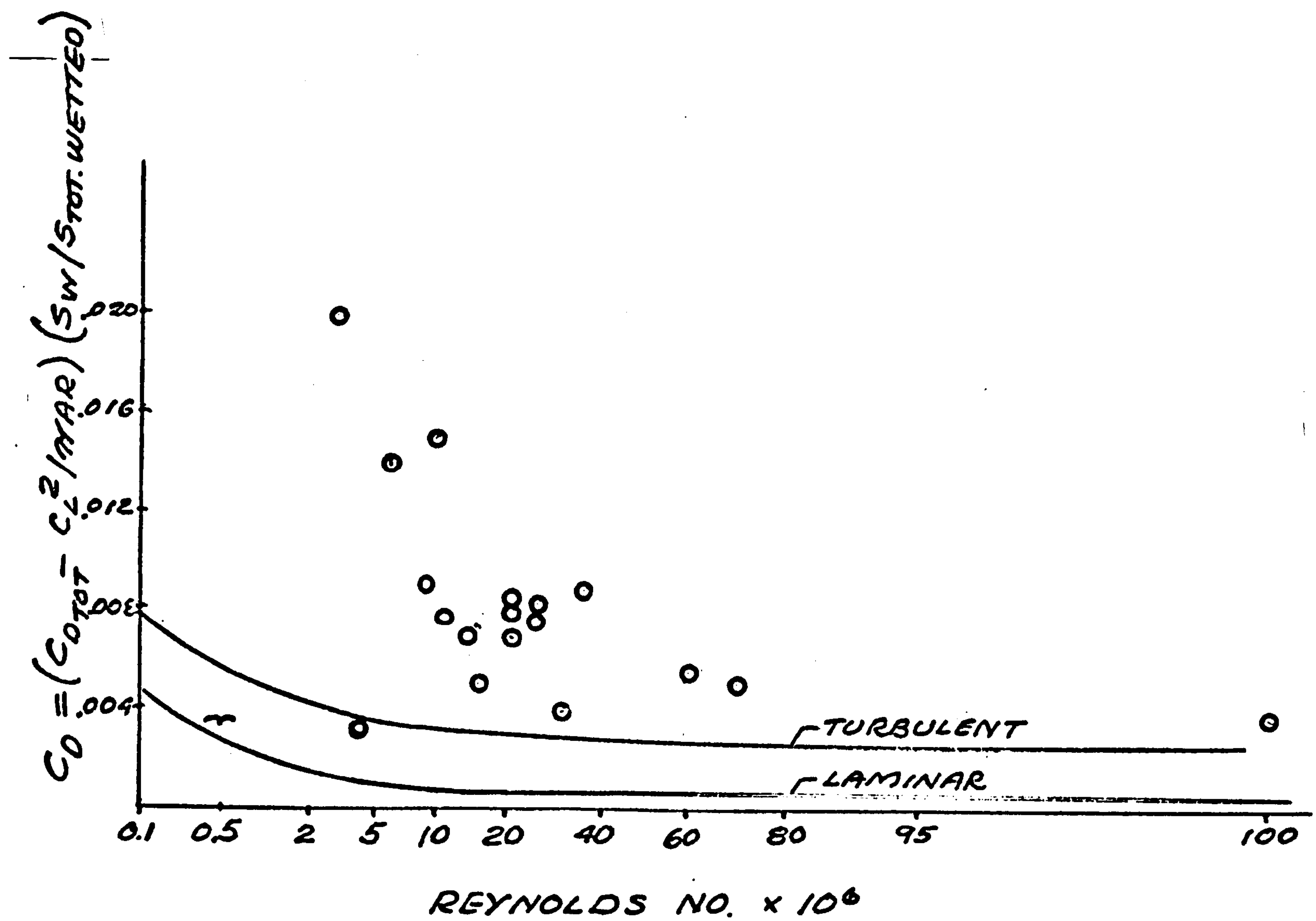

Figure 18. Comparison of Flight Data with Flat Plate Skin Friction

- NEED TO CLARIFY SOURCES OF DRAG FOR GENERAL AVIATION AIRCRAFT
- POINT OUT GREATEST POTENTIALS FOR DRAG REDUCTION
- IDENTIFY AREAS FOR R&D

Figure 19. Concluding Remarks

3. PAPERS OF SESSION I - STATUS OF DRAG PREDICTION METHODS

3.1 Overview of Drag Prediction Methods
D. Ruhmel, Cessna Aircraft Company

3.2 Prospects and Time Tables for Analytical Estimation of the Drag of Complete Aircraft Configurations
F. O. Smetana, North Carolina State University

3.3 Summary of Drag Cleanup Tests in the NASA Langley Full-Scale Tunnel
M. O. McKinney, NASA Langley Research Center

3.4 Simplified Theoretical Methods for Aerodynamic Design
J. Tulinius, NASA Langley Research Center

3.5 Drag Reduction/Back to Basics
O. W. Nicks, NASA Langley Research Center

3.1 Overview of Drag Prediction Methods

D. Ruhmel
Cessna Aircraft Company

This paper was not submitted for inclusion in these proceedings.

Preceding Page Blank