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3.5 Drag Reduction - Back to Basics

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Introduction - Perspective

From the beginning of manned flight, the iteration of lift, weight, drag, and thrust have been the balancing factors involved in so-called aeronautical engineering. Lift greater than weight is needed to get up, thrust greater than drag is needed to go anywhere. These fundamentals are still as true as ever. The list of variables involved in successful aeronautical engineering has grown significantly to include speed, cost, comfort, aesthetics, pollution, noise, etc., with perhaps the most significant current interest in fuel economy. There will surely be other tradeoffs to be faced, but never will we be able to ignore lift, weight, drag, and thrust.

In this conference, we will deliberately focus attention on drag reduction. Drag is the basic parameter affecting the ability of aircraft to go somewhere efficiently. A hot gas balloon can get up and stay up reasonably well, with essentially no consideration for drag. It goes when the wind blows, at no more than the speed of wind. But as soon as you decide to make it go faster than the wind, or in another direction, its drag becomes very important.

In the early days, airplanes were a lot like the free balloon--getting up and staying up was difficult enough without worrying much about going somewhere efficiently. The structures guys were hard pressed to make lightweight structures, and the aerodynamicists struggled to develop the lift necessary to keep them up. As the aerodynamicists really got to working on the drag problem, the propulsion guys came along and helped solve the problem by providing better engines and propellers--that may be one reason we have some unanswered questions about the science of low speed flight today. I often wonder what a few more years of studying the birds might have produced, had the propeller not allowed an effective alternate to the aerodynamic-propulsion techniques still employed by the birds.

At any rate, these are the kind of questions I think we should consider during this Drag Reduction Conference, as we look back to basics.

Wing Lift-Drag Relationships

In addition to providing almost all the lift, the wing produces the biggest percentage of the drag, about 50 to 60 percent during cruise for usual configurations. Since the wing is fundamental to lifting the weight, getting the required lift with the least drag has been the challenge for wing design through the years. If an airplane had some way of getting to cruise speed and altitude, the wing required for cruise might be roughly half the area of the wing required for acceptable takeoff, climb, and landing. Of course, under such ideal conditions, there would be little need for variable geometry. In this case, the wing designed only for cruise flight for a four-place airplane cruising at 200 miles per hour would contribute only about 30 percent of the drag.

To give the same airplane a good takeoff, climb, and landing capability with a plain wing of the same design, the wing would contribute about 70 percent of the total drag at 200 miles per hour. Of course, it is that situation which has led to the development of variable geometry high lift devices such as flaps and slats. With today's technologies, such devices reduce the wing drag penalty during cruise to about 50 percent of the total; however, there are several basic shortcomings of these devices which we might well consider.

First of all, the most common trailing edge flaps cause increased pitching moments which require increased down loads on the tail for trim. In a typical landing configuration, about ten percent of the lift of the wing is negated by the down load on the tail required for trim. In addition, high performance flaps which increase the wing area usually decrease the span efficiency with an associated penalty due to higher induced drag. It would be helpful if we had variable camber devices or variable span techniques to increase lift coefficient while keeping the center of pressure forward, and to minimize induced drag at high lift conditions. Birds use forward sweep, variable camber, variable aspect ratio and lifting tails every day. Such variable geometry features are tough to design and build; however, some of the newer technologies may make them more attractive possibilities than they have been in the past. The thicker wing section, for example, gives structural depth; new composite materials may simplify controlled bending of aerodynamic surfaces. While I am not proposing any particular solution to the problem, I do suggest that a thorough review of the basics which cause drag, and some imaginative consideration of techniques for reducing drag, may be productive.

Profile Drag

The resistance of an object moving through air is pretty clearly a function of the cross-sectional area, the wetted area, the shape of the object, and the friction caused by the scrubbing of the air over the object. Here again, the wing, although streamlined in appearance, contributes 20-40 percent of the total airplane parasite drag. There is only so much that can be done about the cross-sectional area associated with the volume required for passengers or payload, but there are many other smaller factors which add up in the profile drag account.

Sometimes the quantity and types of protrusions on modern general aviation aircraft make me think it would be helpful if aerodynamicists were forced to re-do some simple experiments on streamlining conducted in the early days of aviation. My teen-age son recently conducted a science experiment in a small wind tunnel to show the effects of streamlining by comparing a circular flat plate, a sphere, and a streamlined shape with a fineness ratio of 3 1/2, all having the same diameter. The difference in drag for the plate and the streamlined body is a factor of about 30, in case you don't remember. My son's teacher could not believe the measurements when the much larger body produced the dramatic reduction, and I think many aerodynamicists would be impressed as well. (I guess _I_ was, even though I knew Hoerner's data were to be trusted.)

Many airplanes flying today pay a large price in parasite drag for fixed landing gear, steps, antennae, windshields, and the usual joints, rivet heads, doors, and other discontinuities attributed to production. Hoerner has data on German tests of an actual ME-109 wing and on a section of a P-51 wing--both of course being real construction though quite different in detail. The data are not presented in a manner such that they can be compared over a range of conditions--they are single points--but they show the drag of the ME-109 wing to be 70 percent higher than that of the P-51 wing. According to Hoerner, the high drag of the 109 wing is due largely to manufacturing features: surface waviness, holes, cover plates, control gaps, ill-fitting slat, rivet heads, and bolt heads, whereas the P-51 wing was flush riveted, filled, sanded and painted. The desirability of achieving laminar flow was the motivation for the attention to smoothness on the P-51 wing, although it is doubtful that very much laminar flow existed. It is likely that the elimination of protuberances helped make most of the difference. Better fabrication techniques, or possibly surface coverings that might cover up production artifacts, may be worth more attention than they have been given in the production of many current airplanes. The possibility of applying a space age material coating over a standard production surface is being studied at Langley.

Propulsion Drag

Another form of drag many of us have gotten used to is that associated with internal flows around engines and accessories. To be sure, the matter is an interdisciplinary problem involving interfaces with the engine, propeller, and airframe. Until the jet engine came along and caused more aerodynamicists to concern themselves with internal flows, the matter of engine-nacelle drag was largely an empirical or experimental matter. The NACA's experimental work on cowlings in the 20's and 30's provided data for use with radial and in-line engines used extensively during the 1940's. The advent of the horizonally opposed engine brought with it many opportunities for better streamlining and while there are many good examples flying, I am not aware of a systematic set of data on the subject relevant to aircraft and engines of today. Considering the fact that recent workshops have indicated that from 5 to 25 percent of the total aircraft drag may be caused by cooling air flows, and knowing that the velocity inside cowlings may be well above 100 miles an hour, it is clear that drag reduction possibilities exist for future designs if attention is paid to internal flows.

From the standpoint of basics, a subsonic ramjet can be made to produce internal thrust with efficient heat addition to air flow. Assuming that the external drag of a cowl is a part of the airplane drag, the fact that the engine is adding heat energy is significant. To take advantage of this, the internal flows and the cooling flow exhaust must be treated carefully to reduce losses and to recover the air momentum along the thrust axis. While first priority for cooling air is obviously to cool the engine, there is nothing which says the design should not capitalize on the heat addition. Efficient baffling designs which preclude dumping of air, high speed flows past structure, supports and other drag producing items, may help make the most of the cooling air situation. A simple calculation based on data from Hoerner indicates that for a flight speed of 200 MPH, a cooling air flow receiving a 300 degree temperature rise through a 2-sq. ft. cowl would produce an internal thrust of about 25 pounds. By contrast, a cold engine would produce about 50 pounds of drag. A classic example of turning such potential losses into a gain was the design of the P-51 Mustang glycol radiator, which reportedly produced a net thrust for the complete installation.

Propellers have evolved in the face of many compromises, but their efficiencies continue to suffer because of basic tradeoffs. The propellers developed by the Wright Brothers provided an ideal efficiency of 80 percent and actually delivered 66 percent of the power available to the airstream. This was achieved by careful attention to theory and the fact that they were large and rotated at relatively low speeds. As engines have become smaller, their speeds have become higher and the unfavorable gearing have led toward small diameter, high speed propellers. Propeller efficiency is not only compromised somewhat, but the higher velocity scrubbing and outward flows around nacelles may contribute additional losses of a few percent.

Most of the general aviation jet aircraft benefit from the aft engine locations which tend to accelerate flows near the base of the airplane where wakes and boundary layers are pronounced. Rear mounted propellers have the same potential for flow improvements around the wing and fuselage, but of course, they are not as readily adapted to airplanes as the jet engine and have not found as much use.

Some Anomalies from the Past and Present

Since most of the ideas that occur to me have already been exercised in the past, I make it a practice to look back frequently to anomalies which may provide lessons for today. Many good ideas have failed to materialize into practice because of shortcomings in the technologies other than the disciplines being explored. What I am referring to is the fact that an aerodynamicist with a good idea may have been thwarted because of a structures or materials problem, for example, and advances in these other fields may have opened the door later without his knowing it. With this philosophy in mind, let me challenge your thinking a bit with some questions which arose out of looking back.

In the 1930's there was a lot of effort applied to the matter of drag reduction. This era produced airplanes like the Cessna Airmaster, the Lockheed Vega, and the Northrop Gamma. Larry Loftin, who has gathered data from many sources and done many calculations, provided estimates of the minimum drag coefficients for these examples which I averaged to be about 0.0270. Similar calculations for representative fixed gear monoplanes of today give an average of about 0.0370. I realize I am comparing the very best of the 30's with the average of today, but the question is, "What was it about those airplanes that made them appear to be better from a drag standpoint that might teach us something." You will have to decide, but let me mention a few things to stimulate your thinking.

First, the airplanes considered from the 30's were all tail draggers and the current examples considered all have nose wheels. Obviously, some penalty is being paid for nose gear; Hoerner gives numbers ranging from 6 to 12 percent, not including effects on propeller efficiency, but this alone does not account for the difference. Another characteristic of these airplanes of the 30's was a carefully cowled radial engine, whereas the examples of today all have horizontally opposed engines. The high performance airplanes of the 30's were also extremely smooth, usually employing many coats of dope over fabric or plywood and having few extrernal protuberances (before transponders, ELTs and the like were required). Frontal areas were reduced to a minimum, and careful attention paid to cross-sectional areas, fuselage shapes, wing taper, wing tips, and fairings.

The story for retractables is somewhat different. Some of the current retractable gear configurations compare favorably with the best of World War II and it appears that when paying the price of retractable gear, aerodynamicists are also concerned about other forms of drag. However, I do not suggest that you immediately conclude that doing as well as World War II aircraft is acceptable for today--that is not a good assumption.

Some more recent anomalies which are of interest because of their concepts should be mentioned. Gus Raspet and his colleagues at Mississippi State University worked hard to reduce drag. Gus recognized the importance of skin friction and did many experiments on methods of reducing it. Some work at MSU in 1967, not long after his accident, involved several research aircraft with highly advanced technologies. The XV-11A developed for the U.S. Army had a variable camber fiberglas wing with boundary layer suction and a pusher shrouded propeller. While only 40 hours of flight tests were conducted, significant indications of improvements were achieved. For example, stall speed was decreased from about 75 knots to about 52 knots with no change in wing area.

All of us are familiar with the work of Jim Bede--I think it is fair to say that his primary aerodynamic emphasis is on drag reduction. Almost every basic principle we have discussed has been considered by Jim in his decisions.

Another drag reduction effort of the last few years that impressed me was the work of Wil Schuemann. Starting with a Libelle high performance fiberglas sailplane, with an advertised L/D of about 39 at 59 MPH, Wil substantially improved its high speed capabilities without compromise to its low speed performance. His efforts involved a combination of improving the flow over the airfoil by modest leading edge modifications and by employing the basics of Dr. Hoerner to fillets, air leaks, control surfaces, and laminar flow surface considerations. His tests show that the cruise lift drag ratio at 100 knots was improved by 30 percent to a value of about 20; the fact that this was possible starting with an extremely clean configuration illustrates the possibilities for drag reduction by applying basic principles.

While talking about sailplanes and anomalies, it seems appropriate to note that there are many high performance sailplanes regularly employing the advantages of significant runs of laminar flow. While practical means have not yet been demonstrated for achieving these benefits on higher speed aircraft, there is a lot of pay dirt for drag reduction between fully turbulent and fully laminar flow. Considering the fact that friction drag accounts for 60-70 percent of the average airplane drag, work on compliant surfaces, boundary layer control, and other means of reducing skin friction are "musts" for research.

Summary

In a sweeping manner, and with some academic liberties, I have touched on many items that are on the agenda for this conference. Most of you are familiar with the basics, but you may not have had the opportunity to ponder them in one sitting for a long time. I am mindful that this country makes the best general aviation aircraft in the world--last year, about 15,000 of them. This is a fact for which we can be proud, and yet, we are gathered here to discuss the important matter of making them better.

I hope that while your meal was settling, our brief revisit to fundamentals has helped stimulate an open-minded consideration of old ideas with a new twist. Summed up, my comments were aimed at making two points: (1) We can enhance our fundamental knowledge if we carefully review and reconsider the basics unravelled by those who preceded us; and (2) With a good understanding of the basics, we must be as bold and innovative as the pioneers of the past in searching for means of applying new technologies.

4. PAPERS OF SESSION II - FUSELAGE DRAG