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4.5 The Economic Impact of Drag In General Aviation

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Introduction

Historically, one of the major goals of the aircraft designer has been to provide improved performance and it has also been recognized that one of the most significant controlling factors for achieving this goal has been the basic drag of the vehicle. As a result of the energy crisis, there has been even more current emphasis placed on the potential fuel conservation that might be derived through the incorporation of various advanced technology concepts including improvements in aerodynamic drag.

An example of the aircraft fuel saving benefits being considered was recently given during testimony before the House Subcommittee on Aviation and Transportation when NASA officials indicated that aircraft fuel savings of up to 50% might be achievable beyond 1985, with 5% to 10% fuel savings possible in the next few years. NASA indicated that these fuel savings would come about through "technical modifications, advances in aerodynamics, structures and controls combined into a new highly efficient wing, and new materials to reduce aircraft weight." The projected 40% to 50% fuel savings would become available through development and integration of "optimum aircraft systems."

Additional comments by other NASA officials have indicated that they place fuel saving technologies into three time levels, namely,

* Near term - fuel consumption to be reduced 35% of that of current wide-body transports - to be achieved by 1985 - through incorporation of supercirtical aerodynamics, composite materials, advanced propulsion, advanced avionics, and active controls;

* Far term - fuel consumption to be reduced to 55% of that of current wide-body transports - beyond 1985 - through various boundary layer flow control concepts; and

* Unconventional design concepts - goals yet to be defined.

NASA is not alone in their pursuit of fuel savings for all of the major manufacturers are also evaluating the problem as it relates to their present and future aircraft development programs. McDonnell-Douglas studies of a stretch DC-10 have shown that "drag reductions of 3.95% are attainable . . . . but there is a potential improvement of 11.2% if all the theoretical drag reduction could actually be gained in practice." The Boeing 727-300B airplane is reported to offer a 14% improvement in fuel burned per seat mile over the basis 727-200 version and for this the airlines would only pay about $2 million more per airplane. For an L-1011, Lockheed has estimated that in order to achieve a 20% improvement in direct operating costs it would require a combined 10% improvement in efficiency through aerodynamics, structures, and propulsion.

However, no matter how desirable improved fuel consumption may be, when one considers the question of "drag reduction" and its economic impact - be it for a transport or general avaiation airplane - it is necessary to evaluate two factors:

(1) the improvement in fuel flow (and thus lower direct operating costs) due to the drag reduction and
(2) the cost associated with the incorporation of the drag reduction technology.

Before undertaking a discussion on the economic impact of drag on general aviation airplanes, it seems that a necessary first step would be to define the types of aircraft to be included in such a study. A fairly standard definition of general aviation is that it includes all civil aircraft except those aircraft operated in the air carrier system. The activities of this segment of aviation then range from pleasure flying by an individual pilot to the professional corporate operation of a fleet of business aircraft. The type of aircraft found in general aviation can then include the amateur built airplane, the antique, a former WWII fighter, and a business jet. Thus it is that general aviation embraces a diverse range of equipment having a multitude of mission requirements.

Since the general aviation field includes an assortment and variety of aircraft, let us then determine what segment of general aviation aircraft most needs some thoughts and comments relating to the interdependence of drag and economics.

General Aviation Fuel Consumption

The general aviation population may be identified, and has been identified by the FAA, in the following manner: single engine (piston), multi-engine (piston), turbine, rotorcraft (piston and turbine).

These vehicles represent a fleet of some 151,000 flying machines. In terms of flying hours in 1974, general aviation airplanes flew a total of 30,400,000 hours. When turbine powered rotorcraft are included with the fixed wing turbine aircraft the total estimated time flown by turbine powered vehicles becomes 2,640,000 hours. These turbine powered hours then represent about 8.7% of all general aviation flying.

In 1974, the total jet fuel and aviation gasoline consumed by the United States domestic civil aviation fleet (including general aviation) was 9,064,000,000 gallons, with the general aviation portion of this total amounting to 800,000,000 gallons.

From these data it is seen that general aviation consumes only 8.8% of the total domestic aviation fuel. If military aircraft operations are added to this picture, the general aviation fuel consumption drops to only 6%. When the fuel consumption of all forms of transportation are considered, the total fuel used by general aviation represents just seven-tenths of 1% of this total.

As a final result of evaluating these numbers, it is noted that one segment of general aviation, namely the turbine powered vehicles - which represent 3.4% of the general aviation fleet and flies about 8.7% of the general aviation hours - consumes some 44.6% of the general aviation fuel.

A further comparison of the fuel consumption of the piston powered versus the turbine powered airplane is offered by the example that in one hour, twenty-three single-engine Cessna Model 150 airplanes will consume the same amount of fuel as one twin-engined turbofan Cessna Citation. At the large end of the business jet scale, ninety-four Model 150 airplanes in one hour will consume the same amount of fuel as one Grumman Gulfstream II.

These numbers then clearly indicate that if a study of the effect of drag on the economics of general aviation is to be made, the most promising area for meaningful improvement and results is in the category of turboprop and turbojet/turbofan powered airplanes.

Operating Costs

When considering the operation costs of an airplane, there are many items of expense that must be evaluated. However, a fairly common and accepted measure of the economy of an airplane is given by its direct operating costs.

A recent review of the direct operating costs for existing turbojet/fan business aircraft shows that the fuel cost per hour accounts for 50% to 76% of the direct operating cost, with the average being 63%. A comparison of the turboprop airplanes shows similar trends with fuel cost averaging 54% of the direct operating costs for these airplanes.

The fuel cost per hour is directly related to the fuel consumption of the individual airplane - which in turn is a function of the airplane drag and efficiency of the engines - and to the price of the fuel. The fuel consumption of the airplane can be controlled by the aerodynamic design and by the selection of the engine. However, these engineering aspects of the problem have no direct bearing on the price of the fuel.

In the 1964 to 1970 time frame, the price for jet fuel rose from 27 cents per gallon to about 35 cents per gallon.

An added burden to fuel pricing occurred in July 1970, when the Airport/Airways Development Act went into effect. One impact of this new law was an addition of a 7 cent per gallon fuel tax for general aviation aircraft. A review of the cost analysis for a Learjet, prepared in October 1973, shows a fuel cost of 42 cents per gallon including the 7 cent tax. The same cost analysis prepared in September 1974, used a fuel cost of 59 cents per gallon (tax included). By November 1974, the national average for turbine fuel was being quoted at 63 cents per gallon. In the time frame of a year (1973-1974), the price of turbine fuel (excluding the 7 cent tax) increased about 60%. In terms of an out-of-pocket expense, this fuel price increase from 42 to 59 cents per gallon results in a $39 per hour increase in the direct operating cost of a Learjet. For the operator averaging 500 flight hours per year, this amounts to an increase in the cost of operation of $19,500.

Airplanes tend to fly in terms of gallons of fuel per hour or pounds of fuel per hour. However, in the petroleum industry fuel quantities are quoted in barrels rather than gallons. Airline calculations show that for every one dollar per barrel of oil cost increase, either as a result of a direct price increase or by added tax, the price for turbine fuel increases 2.4 cents per gallon.

One very simple method to reduce fuel consumption is to reduce speed and the 55 mile per hour speed limit for automobiles is a classic example of such a solution.

As one means of fuel conservation, the airlines are also using reduced cruise speeds. However, the impact of the reduced speeds on fuel consumption depends upon the specific airplane and its route structure. As an example, the Boeing 737 can reduce its fuel consumption by 7% on a 500 n.m. trip by decreasing the cruise Mach number from 0.78 to 0.74, while incurring only a 3 minute increase in block time. In the case of a Boeing 747, a cruise speed cut-back from Mach 0.86 to 0.84 results in a 4% fuel reduction and an increase in block time of 16 minutes over a 4000 n.m. stage length. These same trends also hold true for the small business jet. In the case of a Learjet, a reduction in cruise speed from 0.81 to 0.77 will result in a total fuel reduction of about 3% over a 100 stage length with an increase in trip time of only 5 minutes. A reduction from 0.81 to 0.73 yields a fuel reduction of almost 5% and an increase in trip time of 11 minutes. Based on a Learjet fleet of 500 airplanes, with each airplane averaging 500 flying hours per year, a 5% reduction in fuel consumption translates into a fuel savings of about 6,500,000 gallons per year.

Drag Improvements

A speed cut-back offers an operational procedure for reducing fuel consumption. Yet, from a long term standpoint, it is desirable to obtain a fuel savings without imposing a speed reduction - even if that speed only results in a matter of a few minutes in flight time. Looking ahead to the future the real problem to be resolved is "What realistic improvements can be anticipated for the next generation of business aircraft?"

A recent magazine interview with Dr. Whitcomb posed the question, "What new designs do you see forthcoming in the near future for corporate and general aviation?" His answer was, "I do not think new designs of a radical nature are forthcoming in the near future, but all aircraft manufacturers are, of course, working on improvements to their current models."

This same basic viewpoint is being echoed for the large commercial air transports and this position has been summarized as follows: "Rising costs and reduced rate of technology advances indicate a long period of derivative commercial transport; large technological advances are required to justify an all-new aircraft."

From a historical standpoint, the general aviation market has not been noted for introducing major changes in the state-of-the-art technology. The changes occurring in general aviation airplanes have tended to be in the areas of improved systems and avionics, whereas the basic airframe and powerplant remain largely unchanged over a long period of time. This type of change does not indicate that general aviation lacks growth, for on the contrary, the general aviation industry provides a complete range of equipment designed to meet the flying needs of today.

This observation of conservative growth is not offered as a criticism of general aviation. If the general aviation industry were to embark on a program to incorporate high technology involving structures, aerodynamics or other advanced state-of-the-art concepts into this type of airplane they could certainly achieve this goal. However, unless supported by military or other government funding, the development costs of such efforts would be passed on to the customer. A serious consideration to be faced is that the resulting "new technology airplane" might not offer a significant improvement over the more conventional and proven concept.

Critics of general aviation technology are all too ready to point out that while the airlines have grown in speed and capability through the years the general aviation airplane has remained stagnant. As proof for this premise they site the growth of the airlines that can be traced from the single-engine airlines of the 20's through the modern twin-engine DC-3, the introduction of the jet powered Comet, the four-engined Boeing 707, the new wide body transport and the supersonic transport.

However, when we examine the general aviation airplane, we also can find significant progress. The "small airplane" has developed all the way from the Wright airplane of 1903 to the high performance business jet of today. Thus, to claim that general aviation has not grown requires that one totally ignore and misunderstand the scope and magnitude of the general aviation market.

The real reason that the so-called "light aircraft" has not experienced a significant change in performance with the passage of time is simply due to the fact that the basic laws of aerodynamics are not time dependent. Thus, it is in the real world, that an airplane of a given size, weight, and horsepower, built in the 1970's or 80's, will have comparable performance to a similar airplane built in the 1930's.

An excellent example of the evolution of an aircraft is seen in the Beech Model 35, better known as the Bonanza. This airplane made its first flight in December 1945. In the thirty years since its introduction, the Model 35 has experienced a continued history of product improvement and yet the basic airframe design, fabrication techniques and powerplant remain unchanged.

"Exceptions to the rule" do occur in all fields and general aviation has seen its share of innovative ideas. Within recent history the Windecker "Eagle" offered the promise of increased aerodynamic efficiency plus the forecast of manufacturing economy which would result in lower selling prices. Advertisements for this fiberglass airplane clearly stated that the Eagle represented "the greatest single advance in general aviation since the advent of the all-metal airframe." Yet in spite of these technical advantages, this airplane failed to achieve successful production and market status.

The twin-engine, two passenger "Derringer" also represented a step forward and advertisements of 1968 proclaimed: "The Derringer represents a completely advanced concept in light aircraft construction, with the same fine attention to details as found in a million dollar jet. It's the only light twin made using chem-milled, stretch-formed, flush-riveted skins on wings and fuselage. All exterior surfaces are aerodynamically smooth and clean for optimum efficiency." As with the Eagle, the Derringer failed to develop into a commercial product.

The Learjet also offers an excellent example of the continued development of an airplane. The original Learjet Model 23 made its first flight in October 1963, and the delivery of the 500th airplane in April 1975 finds us with a five airplane product line. The latest addition to the Learjet family includes the Model 35/36.

The Model 35/36 is powered by turbofan engines which offer fuel savings of 30-35% over the turbojet powered Model 25 airplane. The development of this capability required design, development, certification and production effort covering five years. The development cost for the program was about $7 million and the airplane selling price is about $360,000 more than the Model 25.

In terms of general aviation airplanes the recent AIAA fuel workshop has provided some comments on the potential of fuel saving by means of a reduction in the drag of "protuberances." This workshop suggested that a full-scale drag clean-up study of several representative general aviation aircraft be undertaken as a means of assessing the magnitude of improvement possible.

While on the subject of "roughness drag," I would like to offer a comment. I find it difficult to think of a more useless effort than a study on the effects of a drag clean-up program for general aviation airplanes. It does not require a trained aerodynamics engineer to produce a list of items that, if removed or eliminated from a specific airplane, would result in some drag reduction. The real problem in a drag clean-up effort is not an aerodynamics problem, but rather the problem is one of how to design, manufacture and then sell at a realistic price the so-called aerodynamic improvements that have been conceived. If this area is to be investigated, our efforts should not be spent on detailed performance improvements that might result from drag clean-up, but rather our time and monies should be spent developing economical methods of fabrication that can accommodate some of these aerodynamic changes.

In terms of an aerodynamic clean-up program, one of the first items to be considered for removal from the airframe are the antennas. As an example, we can look at the business jet - an airplane that can fly at Mach 0.81 at altitudes of 45,000 feet - surely an airplane that would have no external protuberances to blemish its high speed contours. Yet, a review of the avionics installations for this airplane shows that for any individual airplane a total of some 13 different external antennas could be installed.

An antenna drag analysis on the Learjet has shown that if all of these 13 different antennas were to be flush mounted, the drag reduction would represent only about 1% of the total cruise drag. As a result of this study, it was concluded that any flush-mounting program should encompass all of the antennas because the individual drag contribution of any one antenna installation is so small as to be negligible. It should also be noted that the one percent reduction in drag, due to flush mounting all of the antennas, would be difficult to detect in engineering flight test since this level is within our ± 2% data scatter for cruise drag measurements. An added consideration, to this antenna drag question, is that for today's navigation and communication equipment it is doubtful that all of the antennas could be flush mounted. Thus, the actual antenna drag reduction to be realized would be somewhat less than the ideal one percent goal.

During one of the development programs on the Learjet, an attempt was made to flush mount one of the VHF antennas. The actual hardware installation of the antenna did not present a problem, however, the fact that the antenna failed to function for certain station/airplane orientations was found to be objectionable. The other factor of concern was that changing from an external antenna to a flush mount antenna involved a price change from $50.00 to about $1,000.00.

Antennas are, of course, only one source of drag in the category that may be identified as "roughness drag." Included in roughness drag calculations are such irregularities as manufacturing gaps, steps, surface waves, protuberances, various air inlets and outlets, pitot probes, angle-of-attack vanes, drain lines, vortex generators, and all other such items. Individually, these items usually do not produce enough drag to even be measurable from flight tests, yet taken as a sum, these items do constitute a portion of the total. Based on a drag analysis of the Learjet, it is estimated that the total roughness drag accounts for about 5% of the total cruise drag.

From an ideal standpoint it would appear to be desirable to eliminate the "roughness drag." However, consideration of the engineering manhours required for the task plus the fundamental question of how manufacturing would cope with these requirements may very well lead one to conclude that "roughness drag" will remain with us for the next several years.

The supercritical wing certainly offers the opportunity for improved performance in tomorrow's business jet aircraft. One possibility, of course, is to retrofit a supercritical wing onto an existing airplane. Yet the installation of a wing change only may not offer an economic profitable plan when the projected performance gains are weighted against the time schedule and development cost associated with this type of program.

As a specific example, in order to build two prototype airplanes with supercritical wings, conduct the normal development program and FAR 25 certification would require some three years and a total cost of about \$8.5 million. In terms of airplane cost, this improvement would increase the price of the airplane about \$150,000.

In actual fact, in order for a major change to be incorporated into a given airplane, it must offer a "significant" improvement over existing airplanes.

Conclusions

To then offer a summary, the turbine powered vehicles (fixed wing and rotorcraft) including turboprops, turbojets, and turbofans comprise a very small segment of the general aviation fleet, yet these vehicles consume almost 45% of the general aviation fuel. In terms of general aviation fuel savings, the turbine powered airplanes offer the greatest opportunity for productive gains.

It is possible to achieve small drag reductions through aerodynamic clean-up programs, but the improvements are usually minor relative to the engineering and development costs. The drag improvement from such programs is probably on the order of 1 to 5%.

Improvements in airplane drag are possible within the next 5 to 10 years, but these improvements will occur on "new" models and their effects will be in the 5 to 10% range.

Major improvements in fuel consumption over existing turbofan airplanes are realistic for 1985 and beyond, but these changes will be in the 15 to 25% range and will be the combined result of improved aerodynamics plus additional improvements from more advanced turbofan engines.

And I would hope that this workshop will serve as a springboard for the cooperation and research needed to achieve these goals in the years ahead.

5. PAPERS OF SESSION III - WING DRAG

5.1 Methods for Reducing Wing Drag and Wing-Nacelle Interference
T. C. Kelly, NASA Langley Research Center

5.2 Drag Reduction through Higher Wing Loading
D. L. Kohlman, University of Kansas

5.3 Use of a Pitot Static Probe for Determining Wing Section Drag in Flight
L. C. Montoya, P. S. Bikle and E. Saltzman, NASA Flight Research Center

5.4 Flight Test Results with an Ogee Wing Tip
J. Vogel, Beech Aircraft Corporation

5.5 Wing-Tip Vanes as Vortex Attenuation and Induced Drag Reduction Devices
W. H. Wentz, Jr., Wichita State University

5.6 Wing Tip Vortex Drag
V. U. Muirhead, University of Kansas