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9.2 Minimum Vertical Tail Drag

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For an airplane with no asymmetric power problem (a glider or a cross-shafted twin) and with no directional stability constraint (a control configured vehicle, or a skillful pilot) there still exists a requirement for a vertical tail large enough to perform a coordinated turn reversal, that is to maintain nearly zero side-slip when banking from a coordinated turn in one direction to a coordinated turn in the other direction. Presumably this vertical tail maneuver load requirement establishes a minimum tail size and a corresponding minimum tail drag.

This is explained by the aid of Figure 1. In a coordinated turn the angular velocity about the aircraft Z axis, R, is proportional to the sine of the roll angle ϕ times the ratio of the acceleration of gravity g to the flight speed V. Differentiation of the expression for R shows that the angular acceleration during a turn reversal is proportional to the roll rate $P = d\phi/dt$, and is a maximum as the aircraft rolls through wings level where $\cos\phi = 1$.

When the lateral control is deflected to produce the roll rate P, it invariably produces an adverse yaw due to rolling

$$\Delta N = \frac{\rho}{2} V^2 S b C_{n_p} \frac{b}{2V}(P)$$

where C_{n_p} is a dimensionless stability derivative depending primarily on wing characteristics. For an elliptically loaded wing of moderate to high aspect ratio the local lift vectors are rotated nearly through the local helix angle $(2y/b)\left(\frac{Pb}{2V}\right)$ giving rise to a value of C_{n_p} approaching $-C_L/8$, the negative sign indicating a negative (adverse) yawing moment to be overcome by the vertical tail in phase with a positive rolling velocity. The adverse yaw due to ailerons themselves ($C_{n_{\delta A}}$) may actually make

$$\Delta C_n = C_{n_{\delta_A}} \delta_A + C_{n_p} \left(\frac{Pb}{2V}\right)$$

larger than $(-C_L/8)(Pb/2V)$ for a given value of P, but I retain the $-C_L/8$ result for simplicity.

When the vertical tail load is multiplied by the tail arm to provide the yawing moment necessary to overcome the inertial resistance of the aircraft to yawing $I_Z(dR/dt)$, and the adverse aerodynamic yawing moment due to rolling, it is found that the tail load may be expressed as

$$\text{Tail load} = mg\left(\frac{b}{\ell_V}\right)\left[\frac{1}{8} + 2\left(\frac{k_z}{b}\right)^2\right]\left(\frac{Pb}{2V}\right)$$

which is a convenient form since most lateral controls will produce a maximum value of the tip helix angle (Pb/2V) independent of speed if the control can be fully deflected.

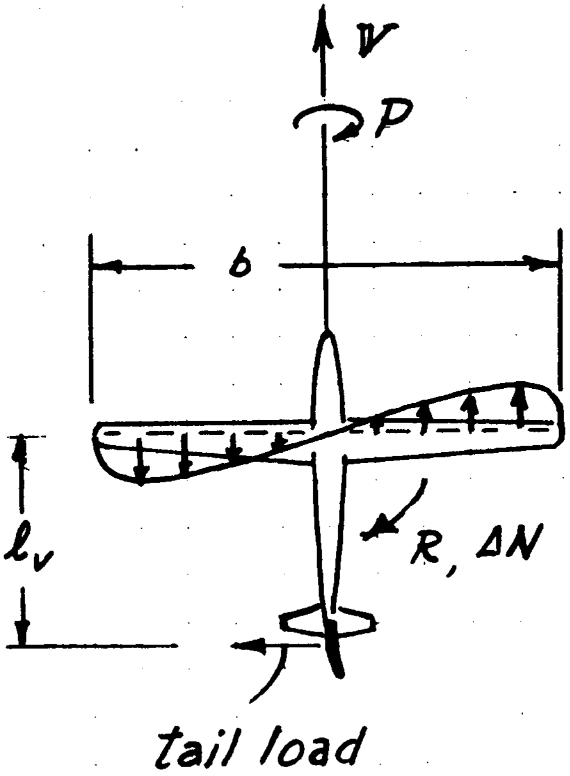
For example, let full aileron deflection produce a helix angle of 0.1 radian, let the vertical tail arm be 0.4 of the wing span, and let the radius of gyration in yaw be 0.25 of the wing span. The vertical tail load in a turn reversal is then

$$= mg\left(\frac{1}{0.4}\right)\left[\frac{1}{8} + 2\left(\frac{1}{4}\right)^2\right](0.1)$$

$$= 0.0625\ mg$$

independent of the flight speed.

If the maximum lift coefficient of the vertical tail is the same as the wing, a tail area of 0.0625 times the wing area is then required to perform a coordinated turn reversal at minimum flying speed. It is seen that an "STOL" conversion, which would double $C_{L_{max}}$ for the wing relative to the vertical tail, requires doubling the tail area. Short tail arm to wing span ratios ("tailless airplanes") are seen to require very large vertical tails for satisfactory lateral control. The desirability of increasing fuselage length in the interest of reducing vertical tail size is clearly seen.



a) Turn coördination:

$$R = \Omega \cos\phi = \frac{g}{V}\sin\phi$$

$$\frac{dR}{dt} = \frac{g}{V}\cos\phi\,(P)$$

b) Adverse yaw due to rolling:

$$\Delta N = \frac{\rho}{2}V^2 S b\, C_{n_p}\frac{b}{2V}(P)$$

$$C_{n_p} \cong -\,C_L/8$$

$$\text{Tail Load} = mg\left(\frac{b}{l_v}\right)\left[\frac{1}{8} + 2\left(\frac{k_z}{b}\right)^2\right]\left(\frac{Pb}{2V}\right)$$

$$\text{where} \quad I_z = \int (x^2+y^2)\,dm = m k_z^2$$

Figure 1. Tail Load Required for Turn Coordination

10. SUMMARY OF DISCUSSIONS ON RESEARCH RECOMMENDATIONS

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10.1 Discussion - Session I - Status of Drag Prediction Methods

Roskam reiterated the purpose of the conference: to formulate research and development needs in all drag areas associated with general aviation airplanes. Because of lack of discussion time after Session I, Roskam appointed a six-man committee headed by Ruhmel of Cessna Aircraft Co. to formulate the research needs coming out of this session. During Session II, Ruhmel presented the views of his committee. Ruhmel indicated that there was a need for the following types of wind-tunnel tests:

I) Full Scale
   a. Tests on one or two full scale airplanes (low and high wing) to determine their drag characteristics accurately.
   b. Drag clean-up tests on these airplanes in a manner analogous to tests conducted by M. McKinney on fighter airplanes during WWII.
   c. Wake survey and thrust measurements on these airplanes.

II) Component/Build-up Drag Tests
   a. Component/build-up drag tests on about three general aviation type airplanes: a twin, a high wing single and a low wing single. The idea is to generate sound baseline drag data on individual components and on their interference.
   b. A systematic series of drag tests on general aviation windshield shapes and fuselages of different length-to-diameter ratios.

III) A study of empirical and theoretical drag prediction methods in use today
   a. Make a study of which empirical and theoretical drag prediction methods appear to predict drag reasonably well.
   b. Determine if it is possible to mesh some of these methods into computer programs (for example, Smetana's finite element program).
   c. Apply the results of a. and b. to a number of existing general aviation configurations (preferably the ones tested under I and II) and see how well these analytical and/or empirical methods perform.
   d. Use the theoretical models (i.e., computer programs) to predict some "optimum" shape for a typical general aviation airplane and then verify this in the windtunnel. These computer programs should not be so complex that it takes a sub-branch of IBM to handle them. General aviation needs simple but accurate drag prediction methods.
   e. The end result should be methods and/or computer programs that have

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been verified for accuracy and which can be used in design. That means they should again be simple and suitable for parametric studies.

10.2 Discussions - Session II - Fuselage Drag

There seemed to be a strong consensus that there is a need for wind-tunnel testing a number of different general aviation fuselage shapes (and length-to-diameter ratios) as well as different windshield shapes. The point was made by Larrabee that if these tests are indeed run they should be carried out also to high angles of attack and sideslip. Tumlinson indicated such fuselage tests should be run both in and out of the presence of appropriate wings. Smetana made the point that these data should then be correlated against computer program predictions. Loftin pointed out that although testing a limited number of shapes would be all right, we should be careful not to generate large amounts of experimental data such as was done in the past (remember the 209 wing-fuselage combinations tested by NACA).

Smetana stated that it was essential to have good full scale fuselage and fuselage plus wing drag data on a high and a low wing airplane. He said that was the only way to check the theoretical models (computer programs) and build confidence in them. Smetana also felt that it would be important to get good pressure distribution data, for the same reason. McKinney agreed but wanted to emphasize the need for small scale model data when it comes to doing detail configuration build-up drag tests.

A lengthy discussion evolved on the subject of propeller/fuselage interference. It was agreed that there appears to be a lack of accurate ways of predicting propeller performance in the presence of fuselages and nacelles. Particularly propeller interference effects on the total configuration are a mystery. An experimental and analytical look at existing and new fuselage propeller arrangements was felt to be needed.

Windecker indicated that they had evaluated five different propellers from five different manufacturers. He said that the performance of all five deviated considerably from the predictions. He supported the need for this type research.

McCormick felt that propeller performance predictions were well inside the state-of-the-art. Ruhmel disagreed. He said that if you take something like a Cessna Skymaster, that there was no way to accurately predict the propulsion-drag sum-total of front-propeller + fuselage + aft-propeller.

10.3 Discussions - Session III - Wing Drag

Several attendees expressed the need for tunnel research in the area of leakage through flap and control surface gaps. Wentz said that some work is being done in this regard on the GA(W) airfoils at W.S.U. There was a feeling that more work on this was needed with these aft-cambered airfoils, since they have more potential for "pumping" air through gaps.

Kohlman mentioned that by merely sealing the flap and spoiler flaps on the ATLIT airplane a 4 mph cruise speed increase was registered. One practical problem that needs manufacturing attention was brought out by Neal. Manufacturing tolerances can play a very important role here. There may be a need to define the sensitivity of the new airfoils to flap, spoiler and aileron gap and/or seal tolerances.

Larrabee made a pitch for airfoil computer optimization using different geometric constraints (for example, from a manufacturing viewpoint). Anderson indicated that Ames (R. Hicks) has the capability to do just that with their existing airfoil optimization program. Ecklund and Tumlinson both agreed that manufacturing constraints on airfoil shapes should be closely watched. Kohlman said that a good look is needed into the Reynolds number sensitivity of the new airfoils. If the trend is toward higher wing loadings through smaller chords, then maybe someone ought to look at optimizing the new airfoils at lower Reynolds numbers.

McKinney made a pitch for more work in the area of spoiler control and high lift control on the new airfoils. He cautioned against too much parametric airfoil work at the expense of much needed control and high lift work. There seemed to be a consensus about the need for NASA's ongoing programs in airfoil theoretical development and continued airfoil wind tunnel testing.

10.4 Discussions - Session IV - External Nacelle Drag and Interference Drag

Neal made a pitch for both windtunnel tests and improved math modeling of wing-fuselage-nacelle combinations for business jets. He said that no reliable methods exist for predicting the correct arrangement of wing, nacelle and fuselage or fan-powered business jets. Particularly the fuselage-nacelle, wing-nacelle and nacelle-wing-overlap problems are not tractable in the current state-of-the-art. Another area that needs researching is the design of S-ducts in the case of business tri-jets.

A discussion between Anderson, Kohlman, Tumlinson and Ecklund brought out again the need for an updated propeller theory accounting for fuselage and nacelle interference (blockage) and for noise. Particularly the effect of the new airfoils on propeller development needs attention. Crupper also emphasized the need for accurate methods for predicting propeller performance in the presence of nacelles and/or fuselages.

McCormick and to some extent McKinney felt that propeller theory was reasonably well established, even in presence of symmetrical bodies. Ruhmel pointed out that current propeller theories were not sophisticated enough to allow the prediction of pressure and velocity distributions over associated bodies. He again cited the Cessna Skymaster as a typical configuration which cannot be handled satisfactorily by current propeller theories. Industry and research people seemed to disagree on this point.

In the area of cooling drag it was agreed that no good methodology exists to predict the drag nor the cooling effect of the internal handling of airflow around today's horizontally opposed reciprocating engines. Research needs in this area were also identified during the Cooling Drag Workshop held at the University of Michigan earlier this year.

Tulinius mentioned that he has a computer program that has been used with good results to handle the over the wing type of nacelle installation as found on the VFW-Fokker 614.

Nicks pointed out that Langley is working on a jet-nacelle study which may help provide some answers. Kalberer said that one of industry's problems is to decide on long or short nacelles in the case of front-fan engines. There is no consistent methodology to solve the complex interference problem between what is drag and what is thrust, in such instances.

Riddell cautioned against just looking at finding the best nacelle-propeller shaping. He said that the structural integrity problem of the propeller shaft and the propeller blade is always a problem particularly in new and different installations.

McCormick said that he has a computer program (developed for the Army Research Office) which predicts static thrust and thrust versus speed of free propellers. This program is documented and contains also a lot of experimental data. However, interference effects with nacelles and fuselages are not included.

10.5 Discussions - Session V - Trim Drag

Larrabee indicated that he had a fundamental disagreement with the trim drag procedures as presented in the session. Several people expressed opposing views regarding the need for research into the trim drag area. It did seem obvious from the discussion that there is a need for a well defined bookkeeping system to account for trim drag. Without that, it is hard to keep track of this drag item with any degree of accuracy. One item that came through loud and clear is the need to study fuselage plus wing shapes for producing positive C_{m_0}.

10.6 Discussions - Session VI - Drag of the Complete Configuration

There was time for only a very brief discussion after this session. No new ideas were brought out. Most attendees seemed to agree on the need for a detail component build-up drag test on three or four typical general aviation airplanes:

- high wing single engine
- low wing, single engine
- reciprocating twin
- jet twin

11. SUMMARY OF RESEARCH RECOMMENDATIONS

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11. SUMMARY OF RESEARCH RECOMMENDATIONS

The research recommendations listed below were perceived to be the most important ones by the editor of this document.

1. Full Scale Drag Tests

It is recommended that NASA run comprehensive full scale drag tests on the following airplanes:

a) A typical single engine high wing airplane (propeller driven)
b) A typical single engine low wing airplane (propeller driven)
c) A typical twin engine, propeller driven airplane
d) A typical twin engine, aft fuselage nacelle mounted business jet airplane.

The idea is to first establish accurate baseline data and second to perform drag clean-up tests on these airplanes. Wake surveys and thrust measurements should be included, so that the effects of thrust and drag can be separated. A clearly defined bookkeeping system should be used to accomplish this.

2. Model Component Build-up Drag Tests

It is recommended that NASA conduct a series of systematic model component build-up drag tests. These tests should utilize models of two or more airplanes tested under 1. These tests should be carried out to high angles of attack and sideslip.

3. Correlation with Theoretical Models

It is recommended that NASA perform a number of studies aimed at determining which drag prediction methods are best suited for drag prediction of: wing drag, fuselage drag, wing plus fuselage plus nacelle drag. It is recommended that the results of 1. and 2. be used to correlate theoretical results with experimental data.

4. Windtunnel Tests of Fuselage and Windshield Shapes

It is recommended that a series of windtunnel tests be run to determine the drag and pitching moment characteristics of fuselages of varying camber, slenderness and typical general aviation windshield shapes.

5. Propeller Interference

It is recommended that NASA conduct studies and tests aimed at defining the problem of predicting propeller performance in the presence of nacelles, wings, and fuselages.

6. Nacelle Interference

6.1 Props

It is recommended that NASA conduct studies and tests to determine minimum drag shapes and locations for reciprocating engine nacelle-wing installations.

6.2 Jets

It is recommended that NASA conduct studies and tests to determine: a) flow characteristics through S-ducts (as on tri-jets), b) drag of aft-nacelle installations, with particular attention paid to nacelle-wing overlap and interference and nacelle-fuselage interference.

7. Gaps

It is recommended that NASA perform studies and (or) tests to determine the drag sensitivity of aft-loaded airfoils to gaps and to seal tolerances.

12. ACKNOWLEDGMENTS

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