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AN AIRPLANE DESIGN HAVING A WING WITH A FUSELAGE ATTACHED TO EACH TIP

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Abstract

This paper describes the conceptual design of an airplane having a low aspect ratio wing with fuselages that are attached to each wing tip. The concept is proposed for a high-capacity transport as an alternate to progressively increasing the size of a conventional transport design having a single fuselage with cantilevered wing panels attached to the sides and tail surfaces attached at the rear. Progressively increasing the size of conventional single body designs may lead to problems in some area's such as manufacturing, ground-handling and aerodynamic behavior. A limited review will be presented of some past work related to means of relieving some size constraints through the use of multiple bodies. Recent low-speed wind-tunnel tests have been made of models representative of the inboard-wing concept. These models have a low aspect ratio wing with a fuselage attached to each tip. Results from these tests, which included force measurements, surface pressure measurements, and wake surveys, will be presented herein.

Introduction

Airplane Design Concepts.

Conventional Designs. - In designing an airplane the objective is to provide the desired volume and the required operational systems into an economical and efficient structural and aerodynamic shape. The conventional airplane design has a single fuselage with wing panels attached to each side of the fuselage and tail surfaces attached at the rear (see Figure 1). Increasing the load-carrying capability of such an airplane has been accomplished by

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progressively increasing the physical size of the airframe. Increasing the physical size of such airframes, however, may lead to problems in manufacturing, in airport compatibility, and in aerodynamic behavior.

Alternative Airplane Designs. Alternative designs to the conventional body-wing-tail airplane design may include the use of multiple bodies, the use of lifting bodies, and all-wing concepts. Some early designs that illustrate these alternatives are shown in figure 2. Multiple body arrangements provide increases in total volume without excessive increases in the overall length or width by distributing the volume of a large single body into two or more smaller bodies. Multiple bodies also permit various alternate locations of the wing surfaces and the stabilizing and control surfaces. Lifting body concepts are designed with bodies having an airfoil shape so as to provide lift. All-wing concepts are designed so as to provide all of the desired volume within a lifting wing

Some low-speed aerodynamic characteristics for a multiple-body configuration are presented in Figure 3. These results are extracted from an investigation conducted over 40 years ago in which the concern was the effect of body length and mass distribution on the aerodynamic behavior of a single-body concept (ref.1). The 3-body arrangement has the same wing planform and the same total volume as the conventional single-body arrangement. A comparison of the longitudinal characteristics for the single-body and the 3-body concept shows that the 3-body arrangement has a higher lift curve slope and a lower drag-due-to-lift. The increase in lift for the 3-body arrangement occurs even though the exposed wing area is reduced. Presumably the outer bodies restrict spanwise flow on the wing and the effectiveness of the wing in producing lift is increased. Hence a given lift is reached at a lower angle of attack and this is translated into a lower drag due to lift.

The Inboard-Wing Design. - The concept of an airplane having an inboard-wing with fuselages attached to each wing tip was proposed as a means of increasing the capacity of an airplane without increasing the overall length or

span of the configuration when compared to a conventional single-body design. The concept is illustrated in Figure 4 which shows two Boeing 747 fuselages attached to the tips of a rectangular inboard wing that has an area twice that of a basic 747 wing. A size comparison shown in Figure 5 depicts the conversion of a 450-passenger conventional airplane to a 900-passenger airplane by means of the single-body design approach or the alternate inboard-wing, multiple body design approach. It is obvious that with the inboard-wing, twin-body design the passenger capacity is doubled with no increase in length and some reduction in span. In addition, it was anticipated that the fuselages would function as endplates so that two-dimensional flow might be achieved on the wing and the strength of the tip vortex would be reduced. Preliminary tests (refs. 2 and 3) indicated that the anticipated flow characteristics on the surface and in the wake were achievable but that results at a higher test Reynolds number were desirable and that pressure distribution measurements would be useful. Subsequently, some wind-tunnel tests have been made to provide force data and wake characteristics at a Reynolds number higher than that for the original tests. In addition, some tests have been made to provide pressure distribution measurements on the wing and fuselage. Some results from these later tests are presented herein.

Experimental Investigations

Pressure Distribution Tests. Additional tests have been made in the ViGYAN tunnel with the original model modified to accommodate surface pressure orifices on the wing and fuselage. Wing pressures were measured on the upper and lower surface at two stations - 46 and 86 percent of the exposed semispan. Fuselage pressures were measured on the upper and lower surface centerlines for the full length of the fuselage and on the inboard and outboard side centerlines in the vicinity of the tail. In addition, some force tests were made for the model with the pressure tubing removed. Tests in the ViGYAN tunnel were made at a Reynolds number of about 600,000 per foot.

Higher Reynolds Number Tests. Some test results have been obtained in the Virginia Tech Stability Tunnel for a Reynolds number range from about 255,000 per foot to about 1,775,000 per foot (ref. 4). The configuration used in the Virginia Tech tests differed slightly from the one used in the ViGYAN tests in that the wing was

mounted as a low wing rather than a high wing and the horizontal tail was attached to the fuselages rather than to the tips of the vertical tails. (See Figure 6).

Discussion

Pressure Distributions. - The pressure distribution at the wing semispan stations of 46 and 86 percent is shown in Figure 7 for an angle of attack of 4 degrees. There is only a slight decrease in the upper surface pressure coefficients at the outboard station indicating that the lift distribution across the wing span is essentially rectangular. Because of the nearly uniform lift distribution, the spanwise flow on the wing surface should be minimized and the possibility of maintaining a natural laminar boundary layer on the wing with an attendant reduction in skin friction drag is enhanced.

Reynolds Number Effects. - Because of the sensitivity of the skin friction drag to Reynolds number, some tests were made for an inboard-wing configuration in the Virginia Tech Stability Tunnel for a range of Reynolds number. The Reynolds number variation was accomplished by using two models of different sizes and by varying the airspeed in the wind tunnel. Some results from these tests are presented in Figure 8. For the higher Reynolds number, changes in the boundary layer over the wing are such that a given lift occurs at a lower angle of attack resulting in a lower drag and a higher lift-to-drag ratio.

Horizontal Tail Location. As noted previously, the models used in the Virginia Tech tests were slightly different than the model used in the ViGYAN tests. Some insight regarding the vertical location of the horizontal tail can be obtained from a ViGYAN test in which the horizontal tail was lowered from the design location at the tip of the vertical tails to a location 30 percent below the tip of the vertical tails. Results for the two tail locations (Fig. 9) show that the higher tail achieves a given lift at a lower angle of attack and accordingly a lower drag and a higher lift-to-drag ratio. This increase in effectiveness of the higher horizontal tail is probably due to the tail being less affected by the wing downwash. It is likely that a still lower tail position, such as that for the Virginia Tech model, would result in the tail effectiveness being more adversely affected by the wing wake.

Wing Leading-Edge Extension. The wing for the ViGYAN model was modified with a 3-inch extension of that portion of the wing forward of the maximum thickness point. Thus the aspect ratio of the wing was reduced, the area was increased, and the maximum thickness ratio was reduced from about 12 to about 9. Some results from wind-tunnel tests with the extended wing and the original wing are shown in Figure 10. The results indicate a higher lift curve slope for the extended wing so that a given lift is reached at a lower angle of attack. Accordingly, the drag at lift is reduced. The drag at zero lift is also reduced because of the lower thickness ratio and the ratio of lift to drag is increased.

Vortex Strength. Some tests were made in the Virginia Tech tunnel to study the wake characteristics behind the model by visual means as well as with pressure measurements. The results indicated that the maximum swirl velocities in the vortex were less for the complete configuration than for the plain wing at the same total lift. It is believed that any remaining vortex would be dissipated if a jet were emitted from the base of the fuselage. Such an effect is reported in reference 5 wherein the high-energy wake of an engine directed into a vortex disrupts the vortex axial flow and causes the vortex to dissipate. Hence, further design studies should include the effects of jet flow such as might be expected from aft body-mounted engines.

Epilogue

The basic objective of the inboard-wing design was to develop a large transport airplane having about twice the payload capacity of current transports but with no increase in length or span. Such an objective can be achieved by using an inboard wing with fuselages attached to each tip. The restrained size eases the manufacturing process and eases the ground handling and airport compatibility concerns.

The end-plating effect of the fuselages allows for essentially two-dimensional flow on the wing. This introduces the possibility of establishing a natural laminar boundary layer on the wing of a full-scale airplane with an attendant reduction in skin-friction drag.

The arrangement of the complete configuration reduces the strength of the trailing vortex from what would be expected for an exposed wing tip.

The complete dissipation of the trailing vortex might be realized by introducing engine jet flow at the base of the fuselage. The elimination of the vortex could have a meaningful effect on the trailing aircraft spacing problem.

The end-supported wing design may offer some structural weight advantages in comparison to the cantilever-supported conventional wing because of differences in wing bending and twisting.

Models thus far tested have verified the basic concept of the inboard-wing design but no attempt has been made to optimize the design. With optimization in mind, future work should address such things as jet flow effects, wing section thickness ratio, supercritical airfoil shapes, fuselage shaping and contouring, wing-body blending, tail airfoil sections, tail location, inlet and nozzle design, engine location, and flap and control considerations.

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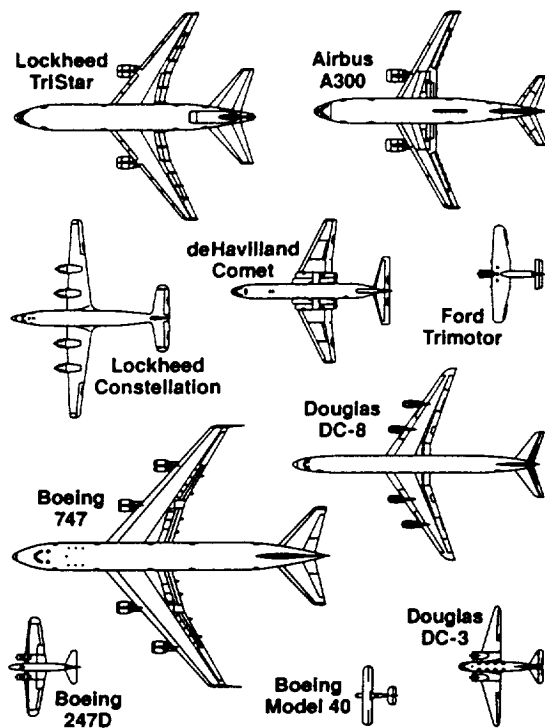


Figure 1.- Civil air transports of conventional design.

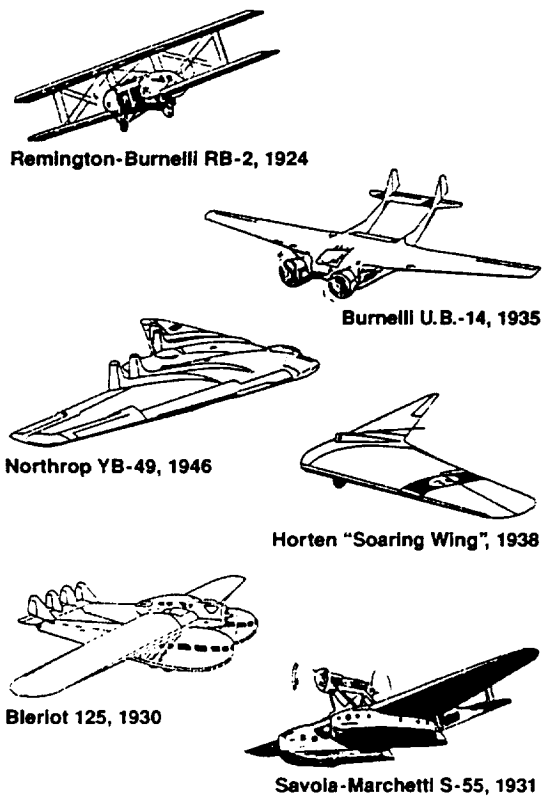


Figure 2.- Alternative airplane designs.

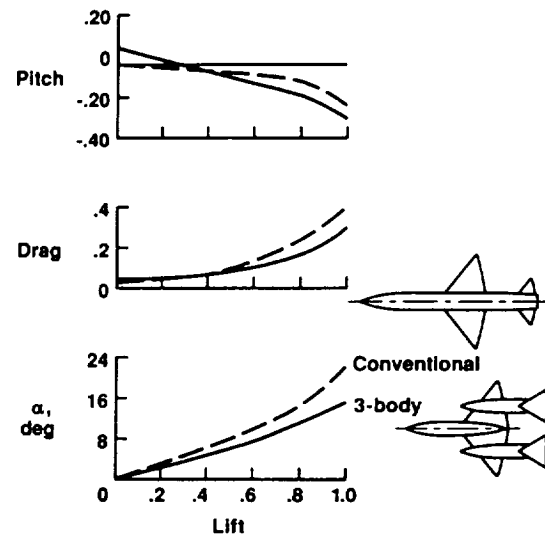


Figure 3.- Low-speed aerodynamic characteristics for a conventional and an alternative airplane design.

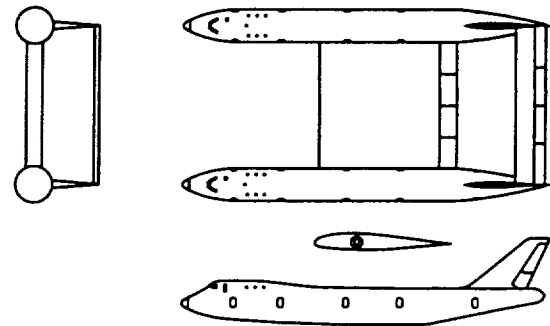


Figure 4.- An inboard-wing concept using two Boeing 747 fuselages.

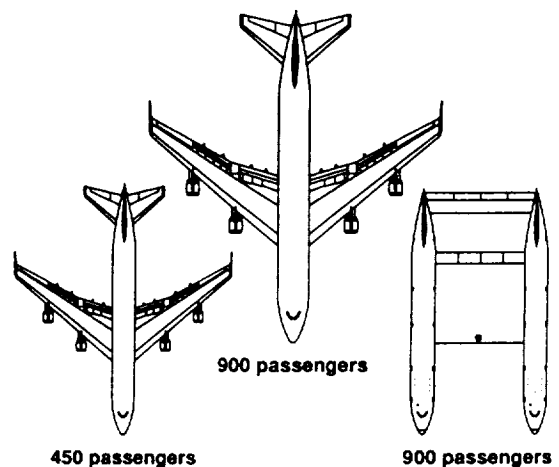


Figure 5.- Size comparison for a high capacity transport airplane.

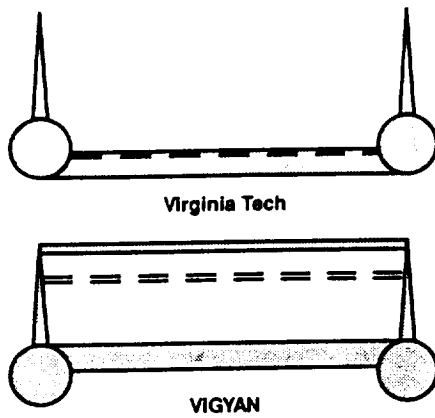


Figure 6.- Wind tunnel model configurations.

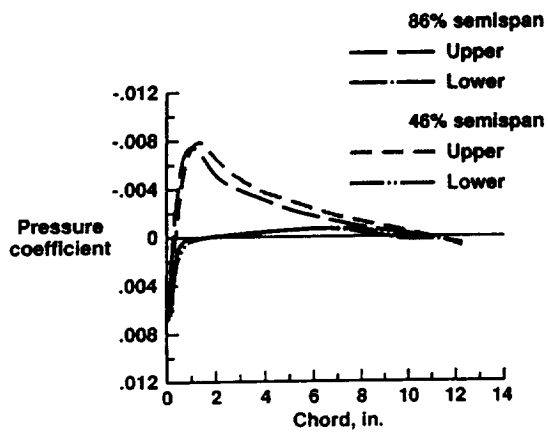


Figure 7.- Pressure distribution on the inboard wing at semi-span stations of 46 and 86 percent. Angle of attack is 4 degrees.

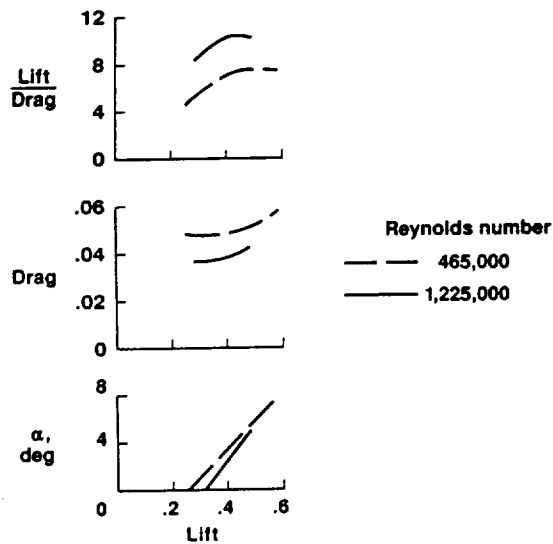


Figure 8.- Some Reynolds number effects for the Virginia Tech models.

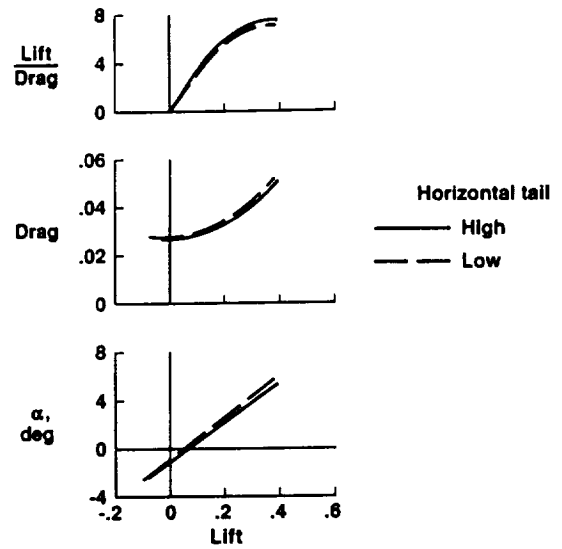


Figure 9.- Effects of horizontal tail height for the ViGYAN model.

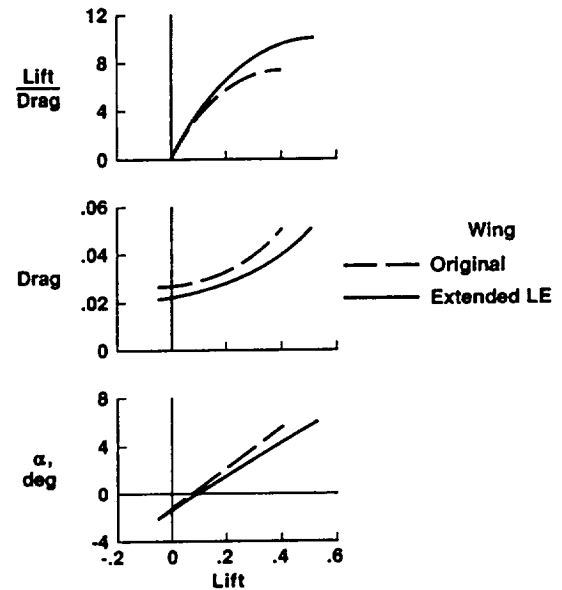


Figure 10.- Effects of wing leading-edge extension for the ViGYAN model.