Shape of the Future Long-Haul Airplane

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This paper reviews the possible evolution of different types of commercial long-haul transport airplanes. Emphasis is on the shape of the airplane configuration as influenced by design requirements and performance goals. The point of view is taken that a radical departure in airplane shape will take place only if it is associated with a radical new benefit or with new, vastly superior capability. Airplane configurations are discussed that are considered technically feasible within a practical level of near-term technology. Supersonic and transonic aircraft are considered, as well as different types of subsonic transports. It is indicated that superior second-generation supersonic transports are quite feasible technically; in particular, it is shown that problems of fuel consumption, efficient overland flight, and questions on noise and nitric oxides have straightforward engineering solutions. Transonic airplanes are feasible but would have a different geometry than subsonic aircraft to provide the versatility necessary to compete at one end of their capability with supersonic transports and at the other end, for shorter ranges, with subsonic transports. The shape of subsonic transports is not expected to change noticeably, although recent advances of airfoil technology imply that new subsonic transports would have wings with higher aspect ratios and somewhat less sweep. On the other hand, a number of specialized subsonic airplanes are possible with shapes different from those flying today; these include large specialized freighter aircraft and very long range (or long endurance) laminar flow control or nuclear powered aircraft.

I. Introduction

THE classical shape of the high aspect ratio swept-wing subsonic jet transport has been with us for over 25 years. It is a very efficient airplane configuration. It is the basic shape, with minor variations, of all of today's long-haul transport aircraft. Why, then, consider departures from such a highly successful shape? Departures will come only if change can bring about a new, unique capability. Thus, supersonic transports, such as the TU-144 and the Concorde, have departed from the classical high aspect ratio swept-wing configuration to provide a very substantial increase in speed. It is possible to conceive different types of long-haul airplanes introduced to provide different new capabilities. They will have different configurations addressing different problems.

The configurations considered in this paper are limited to a reasonably accessible and familiar state-of-the-art or technology level; therefore, emphasis is on their technical feasibility. More radical airplane configurations could have been conceived assuming a more advanced future state-of-the-art, but such speculation was considered outside the scope of the paper.

Beginning with the shapes of higher-speed airplanes, Sec. II begins with configuration variations necessary to bring about a second-generation supersonic transport; fuel conservation and efficient overland operation are emphasized. The transonic airplane is examined in Sec. III, with emphasis, first, to provide fast overland service without sonic boom and then, additional faster speed over water. For high versatility this higher-speed capability is to be provided without degradation to efficiencies over relatively short route segments. The effect of technological advances upon the shape of conventional subsonic transports is discussed in Sec. IV, with emphasis on advanced airfoils applied to provide improved fuel efficiency. Configuration variations for the highly fuel-efficient laminar flow airplane are considered in Sec. V and long-haul specialized mission freighter configurations in Sec. VI. Section VII considers the effects of alternate fuels on configurations with emphasis on nuclear propulsion system and cryogenic fuel, respectively. Environmental questions are addressed in Sec. VIII with emphasis on airport noise and stratosphere jet exhaust.

Presented as Paper 75-305 at the AIAA 11th Annual Meeting and Technical Display, Washington, D.C., Feb. 24-26, 1975; submitted April 21, 1975; revision received March 15, 1976. The authors are grateful to their many colleagues at Boeing who have provided data for the preparation of this paper. The laminar flow control aircraft concepts have benefited from the advice of W. Pfenninger. In addition, many of the other aircraft concepts have benefited extensively from research work done at the NASA, Ames, Langley, and Lewis Research Centers, and also in certain cases, from direct NASA research contract support.

Index category: Aircraft Configuration Design.

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II. Supersonic Transport

The reason for the supersonic transport is that travelers usually have shown preference for the quickest point-to-point service. Supersonic transports, the Concorde and TU-144, are already with us and the shape of a future, so-called second-generation SST may follow from certain evolutionary requirements of additional capability such as improved fuel economy.

A. Second-Generation SST

It is reasonable to assume that the jump in airplane productivity from today's SST to the next generation will be of the same magnitude as that provided by the Boeing 747 over the Boeing 707 in the evolution of subsonic jet airplanes. This may come about either by means of an increase in payload or a combination of increase in payload and speed. Equivalent to speed as an improvement is range to provide increased point-to-point nonstop long-range flight capability. Also, the next generation of SST's should have both better supersonic and better overland subsonic performance so that a) nonstop transpacific flight and b) nonstop intercontinental flight between inland city pairs become possible. Further, a second-generation SST will have to address seriously the economic problem of high-speed transport fuel consumption and provide a substantial reduction in that element of airplane operating costs.

B. SST Design for Lower Fuel Consumption

For lower fuel consumption it will be necessary to increase the supersonic aerodynamic efficiency of the airplane by incorporating design features that reduce wave drag. If the transonic drag can be reduced at the same time, it will be possible to design the SST with an engine that is no bigger than that required to match the airplane drag at high altitude, high

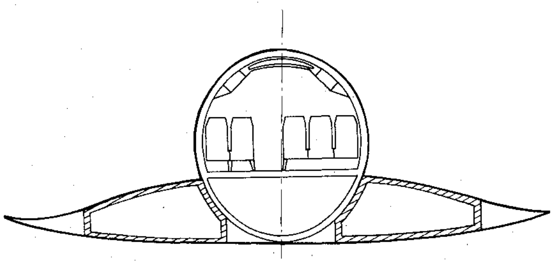

Fig. 1 Cross section of 1970 U. S. SST prototype.

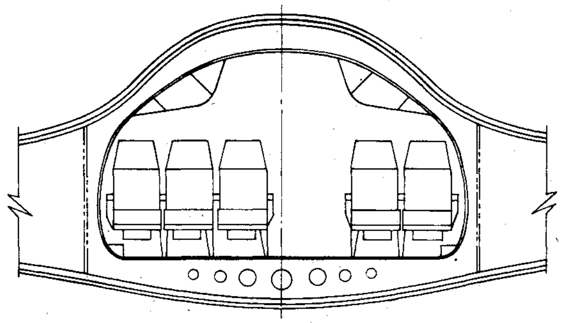

Fig. 2 Cross section of low-drag supersonic airliner.

Mach number cruise, and which also does not need the addition of a fuel-thirsty afterburner.

To eliminate the afterburner it will be necessary to design the airframe so that extra afterburning thrust is not needed anywhere in the flight envelope. Since the transonic portion of climb to cruise altitude is one of the most critical portions of a supersonic aircraft's mission, particular care will have to be given to develop an airframe shape that has low transonic as well as supersonic drag. If this is achieved, the desired goal of reducing fuel consumption can be met by having a small engine that is also efficient and well matched to the airplane.

To lower wave drag at all Mach numbers requires complete integration of airplane fuselage and wing structure. In Fig. 1 is shown a cross-section view of the cancelled 1970 U. S. SST. Integration of airplane wing and structure, proposed for a fuel-efficient SST, is illustrated conceptually in Fig. 2. In this approach, wave drag is reduced by elimination of the extra frontal area that the wing box adds to the fuselage area. As can be deduced from Fig. 2, wetted area, and hence skin friction drag, also is reduced. A comparison of the two airplanes across the Mach number range is shown in Fig. 3. The important, fuel-saving improvement in obvious.

In addition to an integrated wing-fuselage the designer will have to rely even more on the standard aerodynamic approaches to reduce supersonic and transonic drag. These include area ruling, camber and twist, propulsion system placement, variable camber, negative trim drag, etc. Calculations have shown that a configuration designed according to such principles (and assuming the availability of the right engine) would lead to a supersonic airplane meeting a fuel consumption level substantially less than what had been thought achievable in 1970. It is estimated that improvements in fuel per passenger mile of 25 and 30% on the New York-Paris and New York-Rome routes, respectively, could be achieved for an airplane approximately the size of the 1970 U. S. SST. Even greater fuel reduction clearly would be possible through use of new materials, active controls, and more advanced aerodynamic wing planforms, but these would need further research and development.

C. Efficient Overland Subsonic Flight

Because of sonic boom it has been found undesirable to operate aircraft at supersonic speeds over populated areas in many parts of the world. Since most long-range routes include flight over land masses, an advanced SST must be highly efficient in its subsonic flight capability.

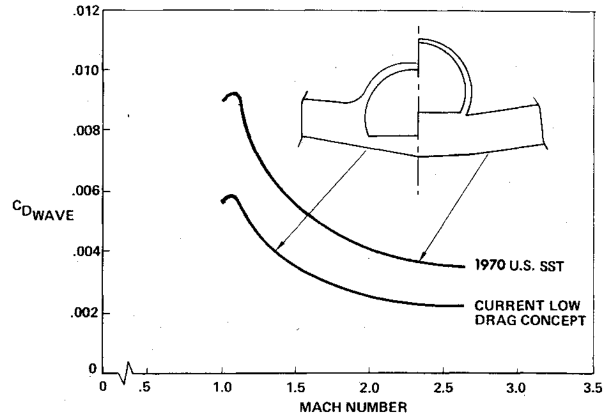

Fig. 3 Supersonic and transonic drag reduction.

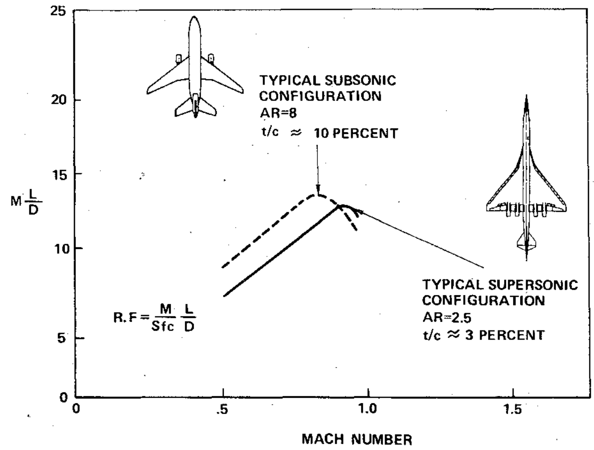

Fig. 4 Subsonic lift/drag characteristics of supersonic airplane.

The supersonic airplane maintains a good value of the product of lift-drag ratio and Mach number at high subsonic speed, despite its lower wing aspect ratio, as shown in Fig. 4. The main efficiency problem of the supersonic airplane in subsonic flight is the engine specific fuel consumption. This is because of many well understood reasons, such as thermodynamic cycle characteristics, intake matching, boattail drag, etc. It is also because of poor engine-airframe match. The poor subsonic engine efficiency has been one of the primary reasons why the search for better supersonic engines has been focused recently on multicycle engines. A complete discussion of this type of engine is beyond the scope of this paper, but its effect on engine-airframe match will be mentioned here.

A supersonic airplane has more drag at supersonic speed than at subsonic speed. When a fixed-cycle engine is chosen to match the drag at supersonic speed it is too big for subsonic flight where it must be throttled back to an inefficient mode. The ratio of subsonic drag to supersonic drag of a typical supersonic airplane is shown in Fig. 5. The comparable ratio of subsonic thrust to supersonic thrust of three types of supersonic engines also is shown in the figure. The thrust in each case is at a throttle setting for best efficiency. The engine that would match the airplane best, across the board, is the one where the thrust ratio is about equal to the drag ratio. Multicycle engines of the types being studied today, in this country, come closest to meeting this goal. If such an engine eventually is developed, a superior airplane will result, because the airplane will benefit not only from the better cycle characteristics and the better airflow schedule, but also from the better engine airframe match. A multicycle engine, in itself, will not alter the shape of the airplane. Installation studies of multicycle engines have shown that an installation comparable to what had been considered for the 1970 U. S. SST can be achieved.

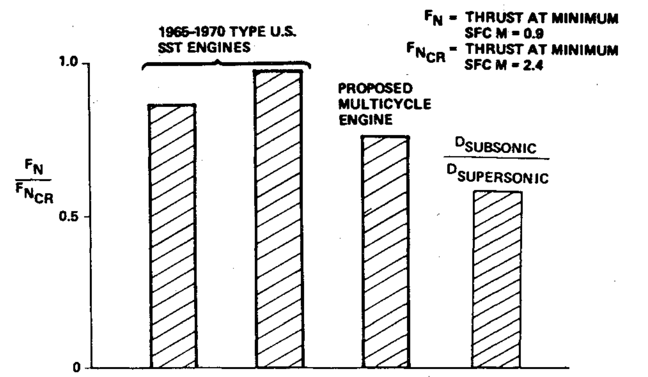

Fig. 5 Subsonic thrust of supersonic engines at throttle setting for best efficiency.

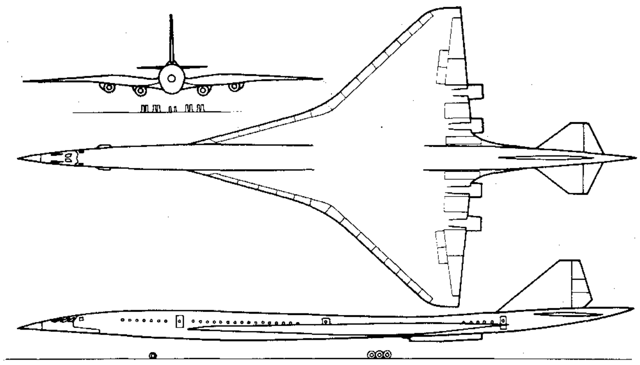

Fig. 6 Supersonic airliner.

For good subsonic flight and, incidentally, good takeoff and landing noise characteristics, the airframe will retain features that had been introduced already in the design of the 1970 U. S. SST. These will include leading edge and trailing-edge flaps programmed with Mach number to maintain good flow over the wing at all flight conditions, and a separate trimming surface, such as a horizontal tail, to trim the airplane for least drag at all flight conditions.

D. Shape of the Future SST

Design features that will enable development of much improved second-generation supersonic transports may incorporate major wave-drag reduction features such as increased wing slenderness, more area ruling, and greater blending between the wing and the fuselage. A multicycle engine will improve efficiency in all flight regimes while meeting noise goals without special economic penalty. To support these configuration features while maintaining a good structural weight, reliance will be placed upon honeycomb structure reinforced, perhaps, by composite elements to provide structural stiffness. It is expected that the airplane would be made of materials, such as titanium, that will enable it to meet the goal of higher speed. A typical airliner capable of carrying 275 passengers at Mach 2.7 is shown in Fig. 6.

III. Transonic Transports

Two general types are conceivable: The oblique-wing airplane capable of operating above Mach 1.0 and the near-sonic airplane designed to operate just below Mach 1.0.

A. Oblique-Wing Transonic Airplane

This type of airplane would be optimized to fly at the threshold Mach number, that is, the fastest Mach number, at which supersonic flight is possible without sonic boom. The precise value of the threshold Mach number is a function of airplane flight altitude and the meteorological conditions. Over the United States it typically varies from about Mach 1.00 to about Mach 1.35. This variability of Mach number, together with the possibility to go even faster over water, leads one to consider variable sweep for this type of aircraft. One also might wish to operate the airplane over shorter ranges subsonically, say at Mach 0.8 or even less. The single-pivot variable-sweep wing, illustrated in Fig. 7, leads to low drag at many flight conditions, is structurally feasible, and appears to be considerably more promising than the more conventional dual-pivot variable-sweep wing. In addition to variable sweep, the design of such an aircraft will have to emphasize wave-drag reduction that is no less than must take place in the design of a supersonic transport. The effect on the shape of the configuration will be more noticeable, however, because of the broader fields of wave-drag interference at transonic Mach number. A typical transport configuration designed to carry 200 passengers across the U.S. at the threshold Mach number is shown in Fig. 7.

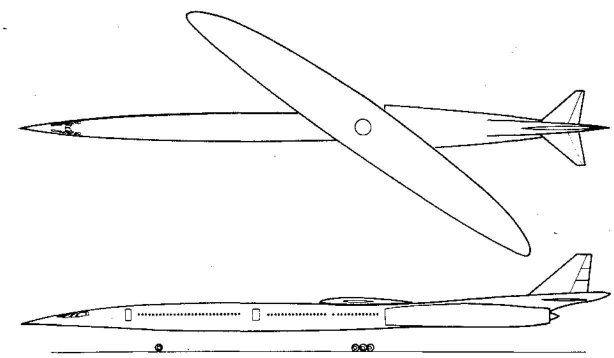

Fig. 7 Transonic airliner.

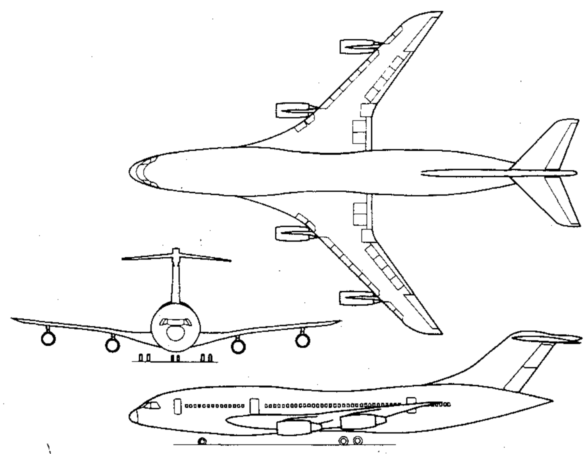

Fig. 8 Near-sonic airliner.

B. Near-Sonic Transport

This type of aircraft was being studied a few years ago to operate efficiently at the highest possible Mach number just below Mach 1.0 with little wave drag. It was based upon the use of advanced airfoils (see Sec. IV) and area ruling. A typical airplane concept is shown in Fig. 8. Because of the lower Mach number there is less emphasis on slenderness than for the oblique-wing transonic airplane shown in Fig. 7, but the area ruling is more pronounced. Studies of this type of concept have shown that a roughly 15% speed improvement would be possible over current subsonic jets. To date, however, this was found to be too small an incremental speed capability to warrant introduction of a brand new type of airplane.

IV. Conventional Subsonic Transports

As mentioned earlier, today's subsonic transports have a shape of great efficiency. It is likely that when change of shape occurs in the future it will be evolutionary. Possible changes associated with advances in technology are discussed below under the headings: A. advanced airfoils; B. propulsion system; C. advanced structural materials; and D. flight controls system.

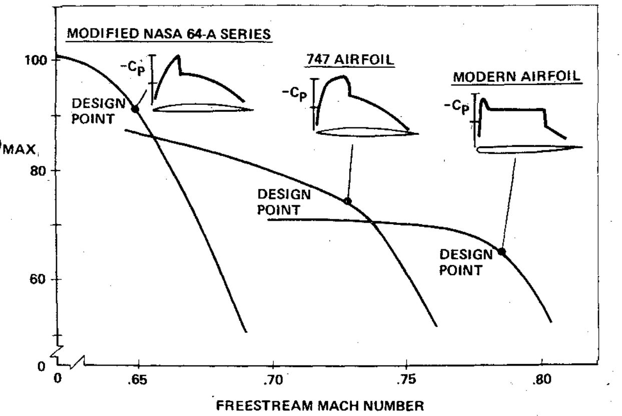

Fig. 9 Progress in airfoil aerodynamics.

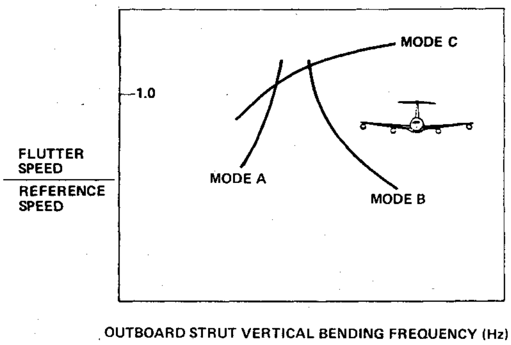

Fig. 10 Effect of outboard strut elastic properties on the flutter speed of a four-engine airplane.

A. Advanced Airfoils

In the last decade a great deal of attention has been focused on airfoil development. The primary objective of this research has been to increase the Mach-number capability of high aspect ratio wings. Without advanced airfoils, such wings could not achieve speed capability much higher than about Mach 0.85. Until then, the standard approach for higher speed had been to resort to much thinner sections with an associated penalty in structural efficiency and weight. The evolutionary performance of a number of airfoils designed and wind tunnel tested at Boeing is shown in Fig. 9. It is interesting to speculate on how this advance in airfoil technology might be exploited best in the design of a new airplane. At first it had been thought that airplanes designed to operate nearer Mach 1.0 than today's airplanes would be the obvious result of these advanced airfoils (as indicated in Sec. III). More recently, emphasis has switched to different uses. One such use could be to trade the airfoil's extra speed capability for extra thickness, leading to airplane efficiency improvement because of a lighter structure. This application of airfoil technology is not ideal, however, for a long-haul transport airplane. The reason is that the thicker airfoils, efficient though they may be from a wing structures standpoint, have increased form drag; and in the evaluation of design parameters for a long-haul transport airplane, this increase in drag negates, in terms of extra fuel burned, the advantages of lighter wing structure.

A different way to exploit the advantage of new airfoil technology is by reducing wing sweep, thereby gaining drag reduction because of increased aspect ratio. Because of other possible adverse factors, such as increased wing weight, it is not clear what would be the best choice of aerodynamic aspect ratio on a long-haul transport airplane. Many factors must be considered. In a study of a conventional four-engined configuration it was found that the engine arrangement had a relatively beneficial effect on the flutter properties of the wing. As shown in Figs. 10 and 11, it is possible to "tune" an

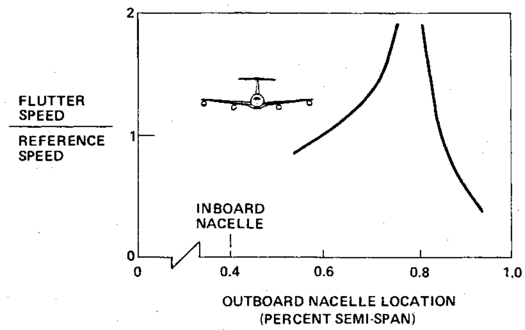

Fig. 11 Effect of outboard nacelle location on the flutter of a four-engine airplane.

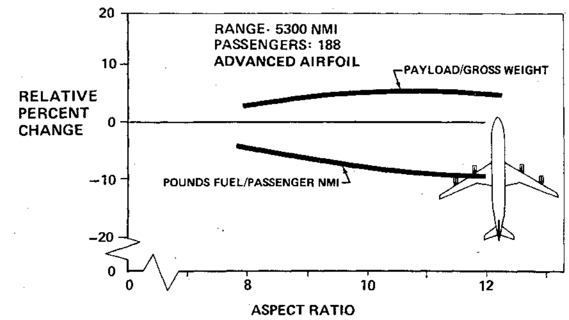

Fig. 12 Effect of aspect ratio on the payload and fuel efficiency of a four-engine subsonic airplane with advanced airfoil.

outboard engine position and strut structural characteristics to minimize weight penalties because of flutter on higher aspect ratio wings.

The effect of wing aspect ratio on overall airplane performance is shown in Fig. 12, where the ratio of payload to airplane gross weight and fuel use is plotted vs aspect ratio. The improvment in payload fraction is not very large, but the improvement in fuel use is quite noticeable. Therefore, it is likely that, when a new subsonic transport airplane appears, it will have wings with somewhat higher aspect ratio.

B. Propulsion System

The advent of the high bypass ratio turbofan engine had allowed aircraft designers to offer the wide-bodied second-generation subsonic jet transports with their extra capability of much larger payloads. This resulted directly from the additional efficiency, in terms of specific fuel consumption, that the high bypass ratio engine provided as well as the engine's inherently greater takeoff thrust. A question that may be asked is, "Would a further large increase in bypass ratio have a similar influence upon the design of a new long haul transport?" The answer is not obvious because of airplane configuration effects. A comparison of airplanes with bypass ratios of 6 and 12 is shown in Fig. 13. Performance of these airplanes is shown in Fig. 14, where payload to gross weight ratio and fuel consumption, respectively, are shown plotted against the bypass ratio of the engine. It can be seen that increases in engine bypass ratio from those current today would not have a large beneficial effect, but, on the contrary, would lead to efficiency losses. Two main effects are responsible for this result. Increases in bypass ratio result in poor thrust performance at flight altitudes for cruise. This means that higher bypass ratio engines become relatively very large, leading to airplane weight and drag penalties. These losses are compounded by installation effects such as interference drag between the nacelle and the wing, and airplane configuration difficulties such as ground clearance when the size of the engine cowl is large as compared to the size of the airplane. The improvements in specific fuel consumption with bypass ratio have not been found sufficient to counteract those adverse effects for long-haul transport aircraft. A substantial increase

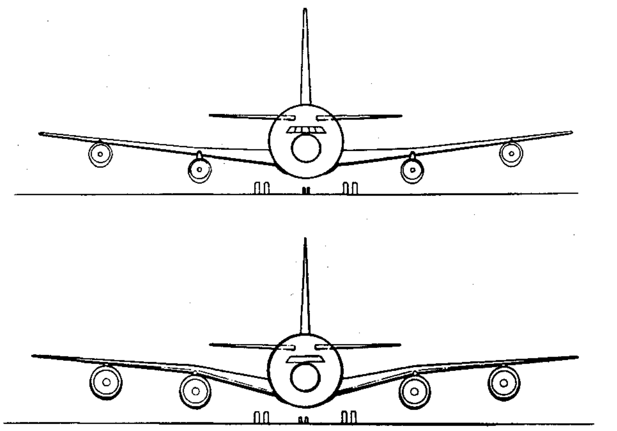

Fig. 13 Installation of bypass ratio 6 and bypass ratio 12 turbofan engines on a four-engine subsonic transport.

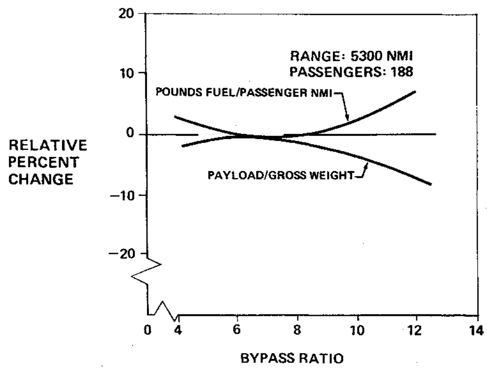

Fig. 14 Effect of engine bypass ratio on the payload efficiency of a four-engine airplane.

in specific thrust and/or reduction of engine weight will be needed to counteract this trend.

C. Advanced Structural Materials

It is self-evident that availability of lighter structural materials will lead, everything else being the same, to more efficient airplanes, since the weight savings could be traded directly for airplane payload and/or range. An interesting question is "Will the availability of such materials lead to airplanes having a different shape?" To seek the answer, an investigation was carried out to compare the effect of conventional and lightweight composite structures, respectively, on the optimum aspect ratio for a conventional subsonic transport. A four-engined airplane with advanced airfoils was considered. As can be seen in Fig. 15, the improvement in airplane efficiency with the advanced materials is very noticeable. On the other hand, a very large change in the value of the optimum aspect ratio was not observed. This was probably because of the four-engined configuration where the outboard engine location could be optimized for flutter. More interesting applications of advanced structural materials are likely for more specialized configurations such as supersonic transports or the laminar flow control airplane of Sec. V where the leverage of this technology would be particularly significant, and where it would allow airplane configurations that would not be possible without this technology.

D. Flight Controls System

Earlier studies have shown that of all the possible applications of advanced flight controls technology, relaxed stability is the one that in general leads to the largest performance payoff. The payoff is basically because of two effects: a reduction in trim drag and a possible reduction in horizontal tail size. The first effect is very important on supersonic aircraft where the longitudinal lift distribution has an important effect on drag, but much less significant on a well

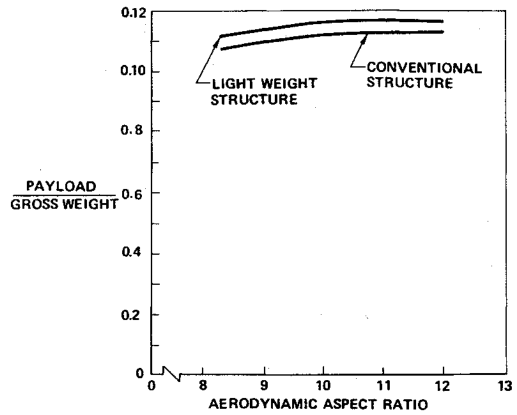

Fig. 15 Effect of lightweight structure on the choice of aspect ratio for a four-engine subsonic airplane.

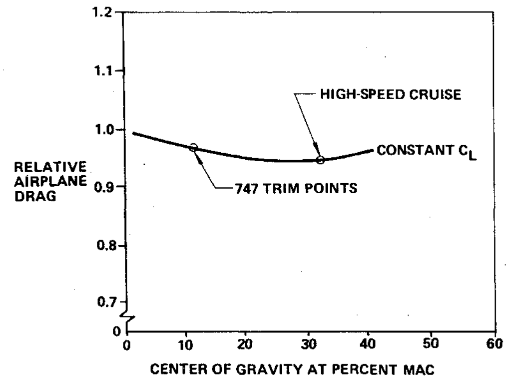

Fig. 16 Effect of center-of-gravity location on the drag of a Boeing 747.

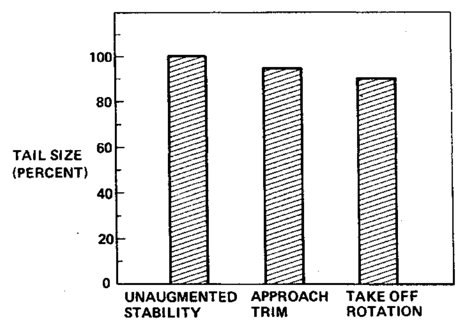

Fig. 17 Horizontal tail size considerations for a four-engine subsonic airplane.

designed subsonic airplane. Shown in Fig. 16 is the relative drag change of a Boeing 747 airplane as a function of center-of-gravity movement, assuming that the latter could be moved at will to seek a position of least drag. It is seen that the airplane as designed has a very small trim drag penalty and that it would not benefit visibly from an artificial relaxed stability system that would allow positioning of the center of gravity at a location for least drag. It is also doubtful that the inclusion of such a system would lead to noticeable reductions in horizontal tail size. As indicated in Fig. 17, stability is not the only criterion to tail size. Design conditions associated with takeoff and landing requirements tend to be equally critical on subsonic airplanes, so that major tail area reductions are not likely in the future long-haul subsonic airplane. Relaxed stability and other active controls technology may have, however, a major role in determining the shape of aircraft of the type illustrated in Secs. V-VII.

E. Shape of the Future Subsonic Jet Transport

It is not possible that technology alone will dictate the shape or introduction of a new subsonic jet transport. Both the

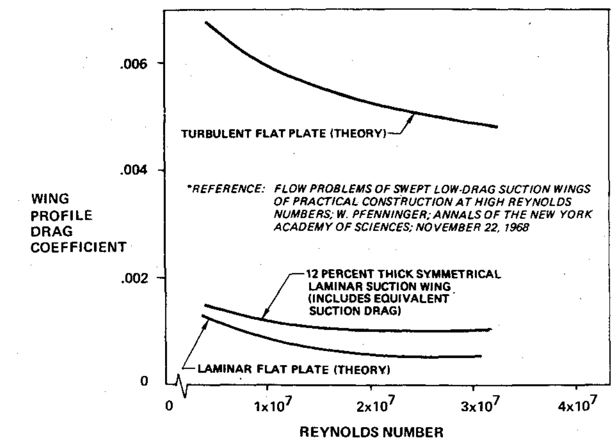

Fig. 18 Effect of boundary-layer suction on wing drag.

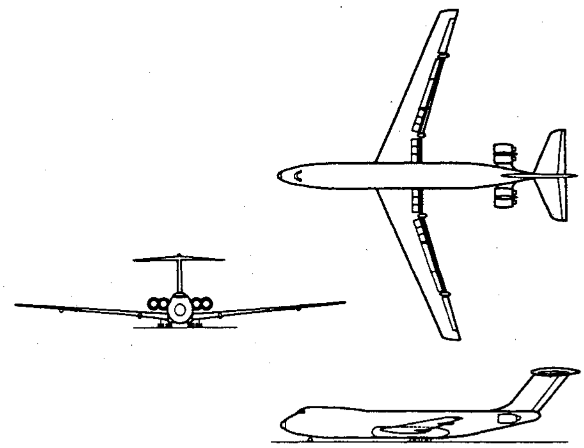
Fig. 19 Laminar flow control transport - concept 1.

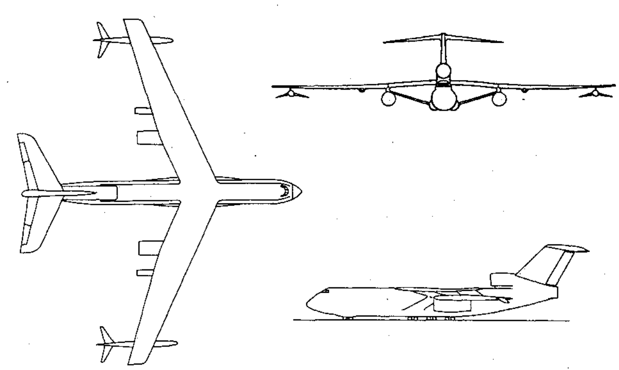
Fig. 20 Laminar flow control transport - concept 2.

timing and size of the airplane will be dictated by specific new market needs. Technology will introduce small evolutionary modifications, and the most noticeable of these on the shape of the airplane may be an increase in the aspect ratio of the wing.

V. Laminar Flow Control Airplane

Laminar flow control aircraft are interesting because they can offer two unique capabilities: either very long range or very low fuel usage for a given range. This type of airplane is most likely to emerge with the former capabilitity to satisfy some special military requirement. If that happens, commercial transport aircraft may follow.

The primary characteristic of a laminar flow control aircraft is a much lower profile drag. This is the result of applied suction on the wing surface to keep the boundary layer laminar. In Fig. 18 is shown the drag of a laminarized wing in comparson with a wing where the boundary layer is not laminarized by suction. This is a well-known result. It is seen that a substantial reduction of profile drag can be accomplished. The limits to this drag reduction have to do with the flight Reynolds number, the wing planform, and the care taken to eliminate disturbances (acoustic or mechanical) from interfering with the laminarization process. Lower Reynolds number makes laminarization easier so that we expect this type of airplane to fly at higher altitudes (low-unit Reynolds number) and also to have higher aspect ratio wings (low Reynolds number, directly, because of shorter chord and indirectly, because high aspect ratio wings operate best at high altitudes). We also would expect such an airplane to have lower wing loadings which, combined with a higher aspect ratio, would lead to a better balance between profile drag and induced drag. The wing planform sweep will be reduced to minimize laminarization problems at the leading edges, and the high-lift system is likely to be simpler, taking advantage of the suction apparatus to improve the lift capability of simple flaps.

Features of a laminar flow control aircraft are shown in Fig. 19. The airplane is shown with the engines on the fuselage. This is to prevent acoustic disturbances of the engines from affecting the delicate stability of the laminarization process on the wing. An alternative approach would be to install the engines in special low-disturbance nacelles and mountings so that these could be located under the wing. Special pods are shown on the wing. These contain auxiliary propulsion devices operating on the air from the sucked boundary layer and adding to the overall efficiency of the system.

Another concept for this type of airplane is shown in Fig. 20. The very high aspect ratio wing is braced externally with laminarized, low-drag, composite-stiffened struts. Cargo also is carried in pods along the wing span to minimize wing weight, and special flaps on the wing, together with control surfaces on the wing-mounted pods, are used to influence gust, maneuver, dynamic, and fatigue loads. This type of airplane would be optimized to fly at very high altitudes in a fuel-conserving mode.

The most difficult problems associated with the laminar flow control aircraft are not, however, associated with the configuration arrangement. They have to do with the careful design of the integrated wing structure and suction system to accomplish a practical design that would be neither too heavy, nor too expensive to manufacture or maintain. Considerable added research is required to solve the configuration problems of the laminar flow control airplane before this technology is ready for incorporation into a production airplane.

VI. Specialized Mission Freighters

The air freight market is growing very rapidly, but so far the design constraints associated with cargo have not had a dominant effect upon the shape of the aircraft. In general the fuselage of transport aircraft has been designed for passengers. When fuselage, landing gear, and wing are integrated in the design of a conventional low-wing airplane, underfloor volume becomes available ahead and behind the wing-stub. This is the "lower hold" of the passenger airplane; it contains the passengers' bags and some cargo. Today, about half of the total air cargo in the free world is carried in the lower hold of passenger aircraft. Most of the rest is carried in what are basically freighter versions of current airplanes. Currently, wide-bodied jet freighters can accommodate large shipments in 8×8 ft internal containers, and so a new market is being initiated. Eventually, even more specialized very large freighters may be needed.

In Fig. 21 is shown one of the many concepts of a specialized freighter airplane designed to bring natural resources from otherwise inaccessible areas of the world, such as polar masses. This type of aircraft will be well over 10^6 lb in gross weight. It will be desirable, in order to minimize structural weight, to place all the cargo in the wing which, ac-

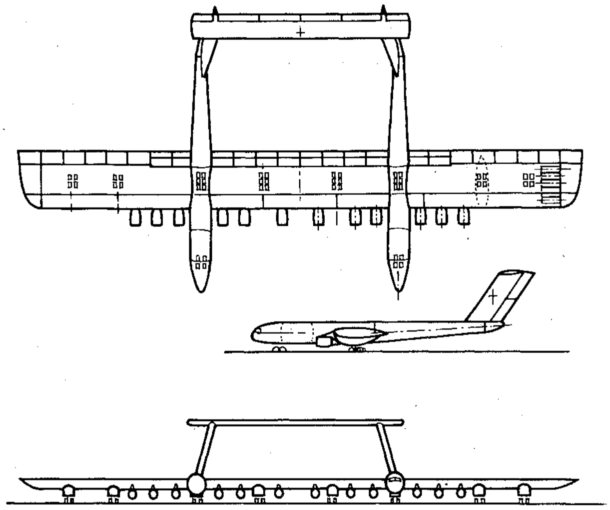

Fig. 21 Very large subsonic jet freighter.

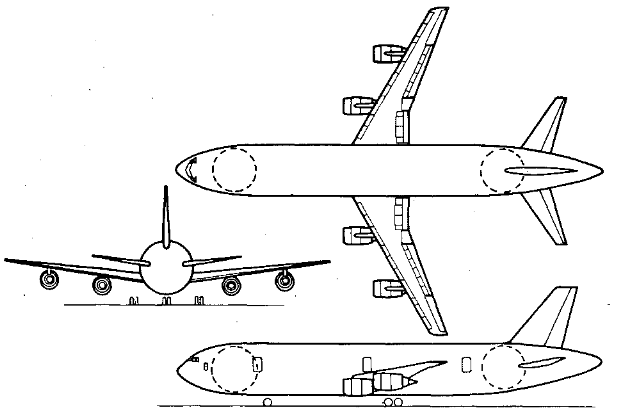

Fig. 22 Passenger jet transport designed for liquid hydrogen fuel.

cordingly, is shown untapered, unswept, and of constant airfoil section. Load-relief methods such as those mentioned in Sec. V for the laminar flow airplane would be used to minimize structural weight.

It is unlikely that new engines will be developed for only this application, so that the first versions of this type of airplane will have to be designed with a larger number of smaller existing engines. The design of the landing gear will require great care to ensure that the wing is properly supported throughout its span when on the ground.

VII. Effect of Alternate Fuels on Airplane Configurations

Airplanes can be designed, if necessary, to operate on fuels other than petroleum derivatives. As has been shown during the second World War, they can operate quite efficiently on a synthetic fuel combining carbon (from, say, coal) with hydrogen. But they also can operate directly on cryogenic fuels without major impact upon the airplane configuration.

A typical example of a transport fueled by liquid hydrogen is shown in Fig. 22. A special feature of this airplane is the large fuel tanks at either end of the passenger cabin. It is most efficient to carry the fuel in the fuselage of a wide-bodied aircraft because this minimized the drag penalty involved with a large increase in fuel volume. As can be seen, the liquid-hydrogen subsonic airplane is not likely to be substantially different in shape from its kerosene counterpart.

Comparable to the cryogenic airplane is the airplane powered with an onboard nuclear reactor such as shown in Fig. 23. When this type of transport is developed, it probably will follow the introduction of a military counterpart designed because nuclear propulsion has offered some special range,

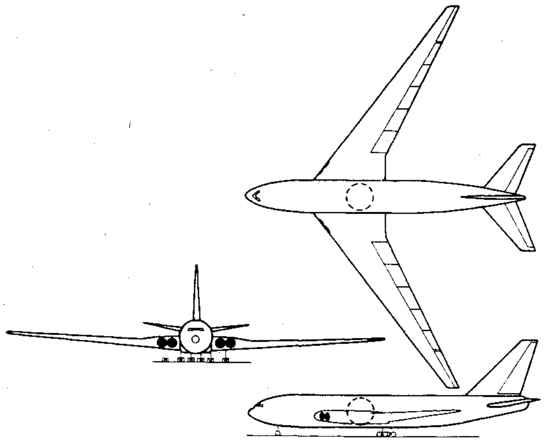

Fig. 23 Large subsonic transport with nuclear propulsion.

endurance, or fuel-saving capability. Again, the shape of the airplane may not be fundamentally different from that of today's airplanes, but it will be very large. A nuclear reactor, even with a relatively small power output, is quite heavy (approximately 4×10^5 lb). Hence, it is not practicable to design a small nuclear airplane. On the other hand, the larger the nuclear airplane, the more efficient it becomes. This is because reactor weight increases very slowly with power output; approximately to one-third power. Since airplanes with gross weights in excess of 10^6 lb have wings large enough to begin to hold cargo, a nuclear freighter becomes possible and might have a configuration similar to the one shown in Sec. VI.

VIII. Long-Haul Transport and the Environment

The effect that transport aircraft may have on the environment has been the concern of airplane designers for many years. As a result airplanes in general, and the long-haul airplane in particular, are one of the cleanest and least disturbing modes of transport. Be that as it may, it is necessary to consider the adverse effect airplanes may have on the environment. Two subjects will be covered below, with emphasis on the effect on future airplane configuration shape: the noise airplanes make in the vicinity of airports, and the impact of jet efflux in the statosphere.

A. Airport Noise

Even though long-haul traffic constitutes only a small fraction of airport movements (about 16% at New York and less than 5% at Los Angeles), attention must be given to noise in their design because the long-range airplane is at heavy weight when operating at maximum capability.

It would appear that future configuration changes aimed at noise reduction should not affect adversely the fuel efficiency of the airplane. The reason is obvious; but, in particular, the efficiency of a long-range airplane is very sensitive to fuel consumption. Sound-absorbing obstructions inside engine nacelles are very costly in fuel and should be avoided. On the other hand, many of the configuration changes discussed in this paper would have a beneficial effect upon airplane noise. Thus, for the supersonic transport, adoption of a multicycle engine and design features aimed at improving overland subsonic flight will enable second-generation supersonic aircraft to meet noise levels similar to those that must be met legally by subsonic aircraft certified for operation inside the United States. This same type of engine, coupled with variable sweep, will have a beneficial effect upon the yawed-wing transonic airplane. There will be a tendency for new subsonic aircraft to be designed with higher aspect ratio wings as a means of exploiting advanced airfoils for fuel economy. This will influence airport noise beneficially. Laminar flow control aircraft of the future, with their even higher aspect ratios, will have reduced noise especially as the boundary-layer suction system could be used on takeoff and landing in a noiseminimizing mode. In general, all technology advances in areas such as structures, systems, flight controls, propulsion, and aerodynamics that enable a given airplane mission to be flown with a lighter airplane will lead to lower airplane noise when their introduction becomes practical. For a long-haul airplane the technical advances with highest leverage on airplane gross weight are cruise-drag reduction and specific fuel-consumption reduction. Any technology advances in these areas will lead most directly to airport noise reduction.

B. Statospheric Jet Efflux

The second area under the subject of long-haul transport and the environment has to do with jet efflux in the stratosphere. A hypothesis has been advanced that the deposition of oxides of nitrogen in the stratosphere will lead to the catalytic destruction of ozone which, in turn, will permit more ultraviolet radiation to reach the surface of the earth with significant disadvantageous biological results; specifically, an increase in the incidence of skin cancers in human beings who are exposed to the increased radiation. The various steps in this long and simplistic cause-and-effect chain actually have not been validated and, in any case, the postulated effect of nitrogen-oxide depostion is not significant in the altitude band of current subsonic jet traffic. The potential problem is at the higher altitudes generally associated with supersonic flight.

Configuration changes can have favorable effects. The second-generation supersonic airliner with drag-reducing features would use smaller engines and burn much less fuel per passenger mile as discussed in Sec. II. Therefore, it will produce fewer oxides of nitrogen. Further, supersonic multicycle engines have been conceived where a substantial proportion of the fuel would be burned in low-temperature combustors where nitric oxide would not form. Recent NASA projections indicate substantial reductions in nitric-oxide generation because of technological improvement in conventional combustor design. Accordingly, it is estimated that the nitric-oxide emissions of a new supersonic transport would be reduced substantially from what had been expected in 1970, eliminating whatever problem there may have been.

Similar engine and combustor technology may have to be developed, if necessary, for future fuel-efficient subsonic aircraft as well. This is because many of the configuration features that improve fuel consumption lead, one way or another, to flight altitudes higher than those where today's aircraft operate. Thus, exploiting advanced airfoils with higher aspect ratio wings for fuel economy is accomplished with increase in cruise altitude. Similarly, the much higher aspect ratio and lower wing loading of the laminar flow airplane lead to fuel-saving flight in the upper atmosphere and so does the lower wing loading of the hydrogen airplane. Indeed, for the design features discussed in this paper, many of those were shown previously to help airport noise are the same that lead to higher cruise altitudes.

Above all, there is a need to define the problem more accurately with scientific measurements. The high-altitude experimental data available today have not provided any proof of the many hypotheses on the adverse effect of aircraft in the higher atmosphere. The data show that the environment is changing continuously in a manner that is not understood completely. Much more atmospheric testing is necessary.

Concluding Remarks

This discussion has centered on the commercial long-haul supersonic, transonic, and subsonic transports and on their configurations. On the question of the second-generation supersonic transport, it is clear that configuration changes and an advanced, versatile engine will be necessary to provide the improvement that will justify introduction of such an airplane in an environment where successful first-generation supersonic transports and their derivatives are operating. The achievement of these improvements is, however, clearly possible and is well within the current and foreseeable state-of-the-art.

The transonic aircraft would offer quick service on long land or sea routes or combinations thereof. Because such an airplane would have to operate over a wide range of Mach numbers, the simple variable-geometry yawed wing could lead to the best airplane configuration.

It is not expected that future conventional subsonic long-haul airplanes will differ substantially in configuration from those current today. It is likely that the need to satisfy specific market requirements rather than technology advances will be the driving force toward a new design. Once the market slot has established the need for the airplane it will benefit, of course, from every practical advance in technology. For the freight market, a large conventional subsonic configuration may be followed eventually by an even larger airplane with distributed-span loading. Such a freighter would be large enough to realize the fuel-saving potential of a nuclear power plant, and it is possible that, even if it did not start as a nuclear airplane, it would be adaptable to nuclear power in some follow-on derivative.

It is not possible to dismiss the laminar flow control airplane in the light of high fuel costs and the loss of United States overseas bases. If a military need can develop the necessary technology and design techniques, they would undoubtedly find application in the commercial field.

This paper has considered future airplanes only from a technical feasibility point of view. Many other conditions must be met before actual construction of a new airplane can be considered. They include, among other things, requirements of the market and a healthy industry. Advanced airplanes such as large freighters or laminar flow control transports would require enormous capital investments, well beyond those experienced by new airplane programs to date, at least in the United States.