Advanced SST Concepts Studied

Arrow wing development, stability augmentation advances are expected to further second-generation design for 1980s

By David A. Brown

Hampton, Va.—Development of the arrow wing concept and improvements in stability augmentation system technology and philosophy are expected to make possible an advanced supersonic transport in the decade of the 1980s which will be able to operate economically over 5,000-naut.-mi. ranges while meeting stringent environmental constraints.

Initial work, including considerable wind tunnel testing of the wing planform, has been done here at the National Aeronautics and Space Administration’s Langley Research Center. A firm program still is several months away.

An additional two years of work at the present rate of activity would be required before the basic study is completed, after which a policy decision would be necessary on whether or not to proceed and, if so, how to do so.

Under present plans, remaining work on the basic study would include three wind tunnel models—two for low speed work and one for high speed—to test both optimized and variable conditions.

Another program not now planned would be needed to develop aeroelastic flutter characteristics and integrate them with the structural design of such an aircraft.

This program would be well beyond the wind tunnel work now planned, however, and is not provided for in the funding available.

Another area currently outside the scope of the program is the powerplant requirement for an advanced SST. However, preliminary indications are that a variable-cycle engine, which can operate as a turbofan during takeoff and low speed flight and as a straight jet during supersonic flight, is the best for the aircraft.

As a general rule, the turbofan engine has good noise characteristics during takeoff and good fuel specifics during low speed operations, but its specific fuel consumption during supersonic flight would be 15-20% higher than a straight jet.

A straight jet with an afterburner is considered impractical for an advanced supersonic transport because of its noise characteristics on takeoff and also because of its relatively high cruise fuel specifics.

Best alternative to a successful variable cycle engine is considered to be a large, dry turbojet with a noise suppressor. This would be the most efficient engine in the supersonic cruise regime in which the aircraft would operate most of the time and...
is the one now considered most likely to be used.

USAF currently has a variable cycle engine program as do the British.

The present Langley study has been conducted under the direction of Mark R. Nichols, chief of Langley’s High-Speed Aircraft Div., and by Arvid L. Keith, Jr., and Willard E. Foss, Jr., of the division’s performance analysis branch.

The study has centered on a so-called second generation supersonic transport, which Nichols defined as an aircraft which would surpass present supersonic transports by substantial margins in the areas of performance, economics, safety and social acceptability.

The aim was to determine what benefits such an aircraft would derive through application of technology forecast for 1975-85.

Work started from the baseline data developed in the Scat series of supersonic concepts at Langley over a decade ago.

Of these original designs, four were selected for further study when the now-defunct U.S. supersonic transport program was subsequently established.

These were Scat designs 4, 15, 16 and 17. Eventually, Scat 16 became the technical predecessor of the Boeing 2707 supersonic transport and Scat 17 was the technical forerunner of the runner-up Lockheed supersonic design.

In reviewing this early work at the start of the present study, the Scat 4 and 15 designs were again studied. Scat 4, originally suggested by Richard T. Whitcomb, developer of the area rule and the supersonic wing, embodied the basic arrow wing planform, although it did not have some of the other features later embodied.

Scat 15 was a variable-geometry aircraft initially, using the arrow wing concept when the wings were fully swept. A later derivative, Scat 15F, did not have the variable-geometry feature. This was the concept selected on which to base the present design.

The Scat 15F design appeared to be the best technical approach to follow now because of advances in wing design and avionics systems either achieved or anticipated by the 1980s.

Foremost of these is further development of the arrow wing concept, so-called because it is shaped like an arrowhead. Considerable wind tunnel testing has been completed on this wing configuration and indicates that a major advance in supersonic lift/drag ratio can be achieved without a concurrent penalty in subsonic efficiency, according to Nichols.

Present supersonic transports—the Anglo-French Concorde, the Soviet Tupolev Tu-144, and the canceled U.S. Boeing 2707-300—all were designed with near-delta wing planforms which gave lift/drag ratios of 7-8.

Nichols estimated that a properly designed arrow wing supersonic transport could have lift/drag ratios in the 9-10 range and possibly as high as 10.5 on large aircraft incorporating wing-body blending.

At subsonic speeds, the lift/drag ratio would be approximately the same as that of present-day supersonic transport designs.

Nichols noted that this is despite the less favorable aspect ratio of the arrow wing as opposed to the delta-wing design of present supersonic transports because the arrow wing normally operates at a lower wing loading.

Main drawback of the arrow wing design—and one which initially prevented its selection for use with the first-generation U.S. supersonic transport—is its poor longitudinal stability in low-speed flight. Initial tests indicated the wing had a tendency to pitch up sharply at angles of attack less than those required for takeoff. A second pitching tendency occurred at high angles of attack, making for some concern in the event of a deep stall condition.

Wind tunnel work on the concept at Langley now has established that major improvements in the pitch characteristics can be achieved by increasing the radius of the leading edge of the wing, plus adding tailored leading edge flaps.

For example, an arrow wing design with a leading edge radius of 0.2% exhibits sharp changes in pitching moment tendencies at about 5 deg. angle of attack and again at about 25-30 deg. angle of attack.

If this radius is increased to 1% and flaps added, virtually all changes in pitching moment tendency can be eliminated.

Another determination has been that an increase in the Reynolds number beyond the relatively small values used in test work also improves the aircraft pitching tendencies.

Thus, Nichols said, it is possible that a full-scale aircraft might require leading
Other configurations under study in the current NASA program include a modified arrow wing design (top) with engines spaced evenly under the wing and a fore-and-aft arrangement (bottom) with two engines mounted on stub wings on the forward fuselage. Latter design appears to offer the best low-speed lift characteristics of any studied, but effects of forward engines on structure and passengers are uncertain.

edge flaps on a significantly smaller scale than wind-tunnel test models, or a full-scale aircraft might be able to eliminate them entirely and still retain acceptable pitch characteristics.

Nichols anticipates, however, that even if optimum stability characteristics could be obtained aerodynamically, an advanced fly-by-wire stability augmentation system (SAS) will be used.

There are several reasons for this. Aerodynamically, the SAS would improve ride and handling qualities. But more importantly, it can be used to reduce the trim drag by permitting a major reduction in the subsonic static stability margin and can reduce the structural weight by alleviating aerodynamic loads on the airframe.

This highlights one of the philosophical changes that has taken place in recent years, Nichols noted. At the time the original U.S. supersonic transport was being designed, the concept of a continuously required or continuously operating SAS was rejected.

Even later, when the Boeing variable-geometry design encountered stability problems, the so-called hard SAS solution was rejected because it was feared it would not have sufficient reliability.

Now, designers are willing to accept the integral or hard SAS, Nichols believes, because they can see benefits from it other than just improved stability augmentation and also because reliability history has been good.

Several positions are being considered for the engines. Wind tunnel tests at Langley have indicated that engine location can play a major role in aircraft performance, without changes in the engine performance.

Initial version of the Langley-designed arrow wing supersonic transport did not obtain adequate lift at acceptable angles of attack during takeoff and landing. In early wind tunnel work, a wing angle of attack of 9.5 deg. was required for a desired lift coefficient of 0.55.

It was determined that the most effective method of improving this would be to increase the size and aspect ratio of the inboard flap.

This required moving the engines, which had been in separate nacelles spaced under the wing, into dual nacelles located outboard. A larger flap then could be installed which reduced the needed wing angle of attack to 4.5 deg. Fall-out benefits from this improvement included a landing gear shortened by 4 ft. and a less complex variable geometry nose for landing and takeoff vision.

Another engine relocation now being studied is a fore-and-aft arrangement with two of the four engines mounted under the wings in nacelles and two mounted forward and over the wing.

This appears to result in an approximate 10% increase in the lift increment, although studies are as yet incomplete. One possible reason is the jet-induced circulation flow around the wing.

This arrangement also could have a beneficial effect in noise control, because the wing would be beneath the forward engines and would tend to mask their noise from the ground.

Effect of the engine noise on both the passengers and the airframe structure from this arrangement still is to be determined.

Noise control has been a major part of the Langley program, Nichols noted.

The basic aircraft is envisioned now as about 300 ft. long with a gross weight of 650,000 lb. Cruise flight would be at Mach 2.7 at 60,000 ft.

In such an aircraft, optimized for performance only, the sonic boom overpressure would be about 2.3 psf. Reducing the cruise weight by as much as 30% would cut this only to about 2 psf. This can be further reduced, in theory at least, to about 1.5 psf by aerodynamic shaping of the configuration, but the effect of this shaping on the performance and economics of the airframe still is unknown.

With this in mind, Nichols said, the aircraft was designed as an overwater only cruise vehicle. This decision had two effects:

- Noise in the immediate area of the airport and community became the dominant design concern related to environmental protection, subject to any later discoveries pertaining to adverse environmental effects. In the noise area, it has been determined that takeoff sideline noise is the most critical and the present...
New York-Johannesburg runs would result in an uneconomical aircraft.

With these factors established, Nichols noted, the primary aim became increasing the payload fraction of the aircraft to provide satisfactory economic characteristics.

One factor that figures prominently in attaining this goal also affects the environmental aspects. This is engine performance.

Basically, Nichols said, the engines required for the aircraft would have to generate approximately 60,000 lb. thrust each and still be able to meet the 108 epndb. noise limit.

In order to do this, a minimum of 5% engine noise suppression on a dry turbojet will be a requirement and to accomplish this, additional noise suppression research work will be necessary to make the aircraft feasible. This is particularly true, he said, if the second-generation supersonic transport is to meet the Civil Aviation Research and Development (CARD) study goal of a reduction of noise around the airport and community of 10 epndb. per decade.

Best engine now envisioned for the aircraft would have a compression ratio of 15 at sea level, standard day conditions, and would operate with a turbine inlet temperature of 1,200°C.

Such an engine, Nichols predicted, would have approximately the same basic weight as the General Electric GE4 which was to have powered the Boeing 2707-300 but would have 30% more airflow.

Also, it would have a cruise specific fuel consumption about 15% less than the GE4 with partial afterburning, which would represent a gain in range payload performance of about the same magnitude as that anticipated from the arrow wing.

Use of composite and other advanced materials has not been detailed in the Langley study, except to note that some major benefits are likely. The study estimates now that if 30% of the structure can be of composite material, a total weight reduction of about 15% can be achieved.

Another area in which gains are anticipated, but not yet fully explored, is in the area of fuel reserve requirements.

The first-generation supersonic transports will have a fuel reserve alone of approximately 1.5 times the aircraft’s payload.

The Langley study indicates that a considerable reduction in this percentage will be possible in future supersonic transports without compromising safety.

Specifically, a fuel reserve weighing slightly less than the payload—equal to approximately 6.25% of the takeoff weight—would be possible as a result of improvements in air traffic control technique and equipment and the increase in aircraft range, which would open more alternate airports.

Growth in the low-speed capability of the arrow wing design is shown graphically. Additional flap lift was gained by moving engine nacelles outboard, and circulation lift was achieved by moving one pair of engines forward.

A federal requirement of 108 epndb. sideline noise limit is one of the major design goals for an advanced supersonic transport.

Range requirement is greater than the present 3,180-naut.-mi. New York-Paris route, which is the basis of first-generation aircraft. Nichols said the optimum appeared to be about 5,000 naut. mi., since most of the heavily traveled routes lie in the area between 4,000 and 4,800 naut. mi. Designing a transport for such long routes as the 6,500-naut.mi. Los Angeles-Sydney or the 6,900-naut.-mi. New York-Johannesburg runs would result in an uneconomical aircraft.

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