open circuit version (e.g. $r_1 = 10$ ft, $r_2 = 15$ ft, $h = 20$ ft) exceeds 5000 hp (even with a power factor[3] $\lambda \equiv [\frac{1}{2}\rho U^3 \pi r_1^2$ /input power] $\simeq 1$); the running cost ~ £300 ($510) per hour.

An Equivalent Vertical Water Tunnel

The drag force on a free faller is given by $F_D = [\frac{1}{2}\rho U^2 A] \times C_D$ (standard notation) where, at terminal velocity U, $F_D = w \cdot g$ (body weight). When immersed in water with doubled body weight ($2\ w \cdot g$) buoyancy forces are cancelled hence $U^{(\text{water})} = U^{(\text{air})}\sqrt{\rho^{(\text{air})}/\rho^{(\text{water})}}$ (assuming that the drag coefficient $C_D{}^{(\text{air})} = C_D{}^{(\text{water})}$). Thus if $U^{(\text{air})} = 176$ fps then $U^{(\text{water})} = 6.3$ fps. Fortuitously the kinematic viscosity of air is 1.6×10^{-4}ft^2/sec (and $\rho^{(\text{air})} = 0.08$ lb/ft^3) while that of (warm) water is 0.6×10^{-5}ft^2/sec. Thus almost perfect dynamical similarity is achieved. Further, the power requirement is about one thirtieth that of an equivalent wind tunnel with the same power factor λ (e.g. $5000/30 \simeq 170$ hp).

Conclusions

1) The proposed state of stable equilibrium has been demonstrated with a very crude working scale model (Fig. 1b) and the apparently unrealistic velocity profile [features (1) and (2)] is rather easy to achieve in practice.

2) Flow separation at the walls was quite easily prevented by suction.

3) Swirl was a major problem although it produced the previously stated requirement (2). Eliminating swirl with honeycomb or wide vanes (i.e. requiring a blade width $> r_1$, Fig. 1a) greatly reduced efficiency (i.e. $\lambda < 1$). Either 1) incorporating honeycomb while increasing efficiency with a return circuit[3], or 2) eliminating swirl by placing the fan downstream (i.e. above) the working section might prove too expensive.

4) A vertical water tunnel is vastly superior to the suspended harness for training purposes while also allowing for studies of dynamically similar flows at extremely low power consumption and cost.

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Mach 6 Flowfield Survey at the Engine Inlet of a Research Airplane

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Introduction

ONE early conceptual design for a new high-speed research airplane, which resulted from a joint USAF/NASA study, has been reported in Ref. 1. The vehicle is to be air launched from a B-52 and rocket boosted to Mach 6. An important research experiment is the testing of an airframe-integrated scramjet, which is mounted on the lower surface of the vehicle. During heat-transfer tests conducted on a 1/29-scale epoxy model of the configuration,[2] it was noted that there was a pronounced streak of low heating (cold streak) on the centerline of the bottom surface of the fuselage. It was speculated that the cold streak was caused by inflow on the forebody of the delta planform, and this inflow caused a thickening of the boundary layer along the centerline. Since one of the primary objectives of the research airplane would be the testing of an integrated airbreathing propulsion system, it was feared that the centerline cold streak and associated boundary-layer thickening on the centerline of the forebody would affect the performance of the scramjet engine. Therefore, flowfield surveys were conducted to better define the nature of the vehicle forebody flowfield at the inlet location of the scramjet engine. It is the purpose of this Note to present some results of the flowfield survey.

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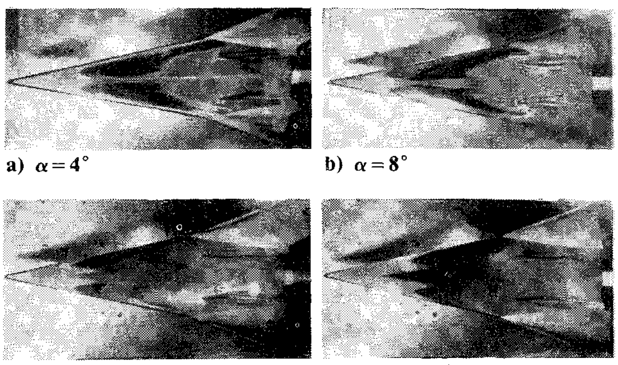
Results and Discussion

Phase-change paint heat-transfer patterns on the bottom of the 1/29-scale epoxy model at four angles of attack are shown in Fig. 1. The configuration has a flat-bottom forebody extending to the scramjet engine inlet. The vertical sides of the scramjet engine are simulated in Fig. 1 by two engine side plates located just slightly downstream of the point at which the wing joins the fuselage. The scramjet inlet would be located at the plane joining the upstream ends of the two engine side plates. The phase-change pattern for $\alpha = 4°$ in Fig. 1 is the same data as shown for a similar view in Ref. 2. The cold streak along the centerline of the forebody exists for both $\alpha = 4°$ and $\alpha = 8°$. At $\alpha = 12°$ there is just a trace of the cold streak downstream of the unmelted paint located about one-third of the distance along the forebody. At $\alpha = 16°$, the cold streak on the centerline apparently has disappeared. The series of photographs in Fig. 1 indicates that the cold streak tends to weaken appreciably for increasing angles of attack between $\alpha = 8°$ and $\alpha = 12°$.

An oil flow photograph is shown in Fig. 2 at $\alpha = 4°$ and a Reynolds number of 15.5×10^6, based on freestream flow conditions and the body length, $L = 0.508$ m (20 in.). The



a) $\alpha = 4°$ b) $\alpha = 8°$ c) $\alpha = 12°$ d) $\alpha = 16°$

Fig. 1 Bottom view of phase-change heat-transfer patterns on the epoxy model at $R_{\infty,L} = 13 \times 10^6$ and Mach 6.

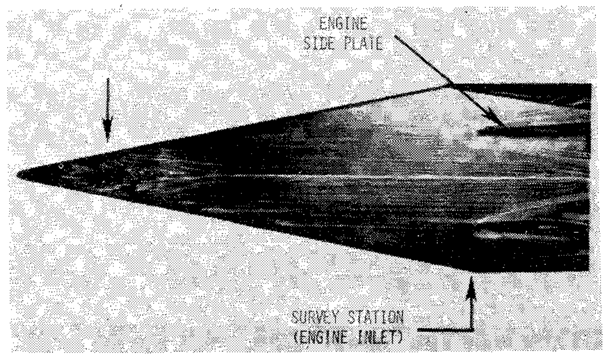


Fig. 2 Oil flow on the epoxy model forebody.

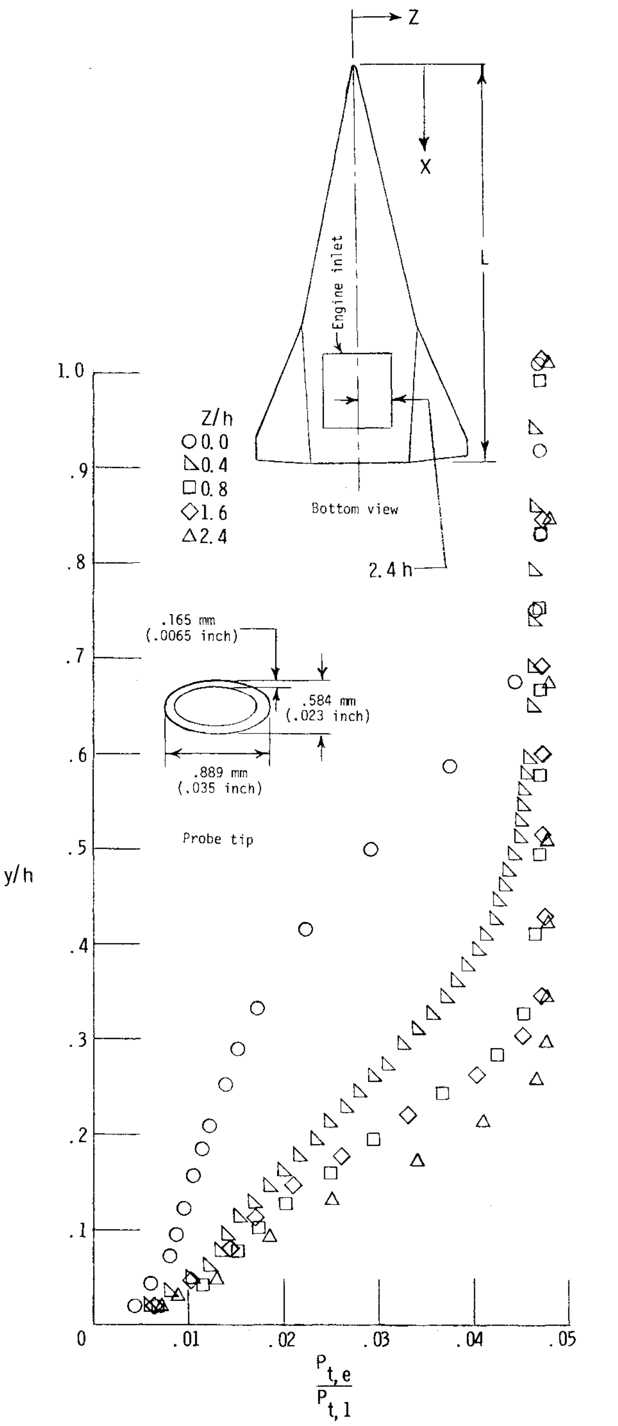


Fig. 3 Boundary-layer pitot profiles at the engine inlet station on the brass model at Mach 6, $\alpha = 4°$, $R_{\infty,L} = 15.5 \times 10^6$. Engine height $(h) = 1.534$ cm (0.600 in.).

epoxy model used for the surface oil flow is the same model that was used to obtain the heat-transfer data shown in Fig. 1. The engine side plates can be seen on the downstream portion of the model. A region of very low shear (similar to a separation bubble) can be seen in Fig. 2 below the arrow near the apex of the model. In this region, the oil pattern indicates flow convergence (inflow). The surface patterns of flow convergence are pronounced for flow lines going into the region of low shear. In addition, the surface oil flow indicates an accumulation of oil on the centerline downstream of the low shear bubble. From this oil flow photograph, it might be suspected that there would be a thickening of the boundary layer along the model centerline due to the flow convergence on the forebody.

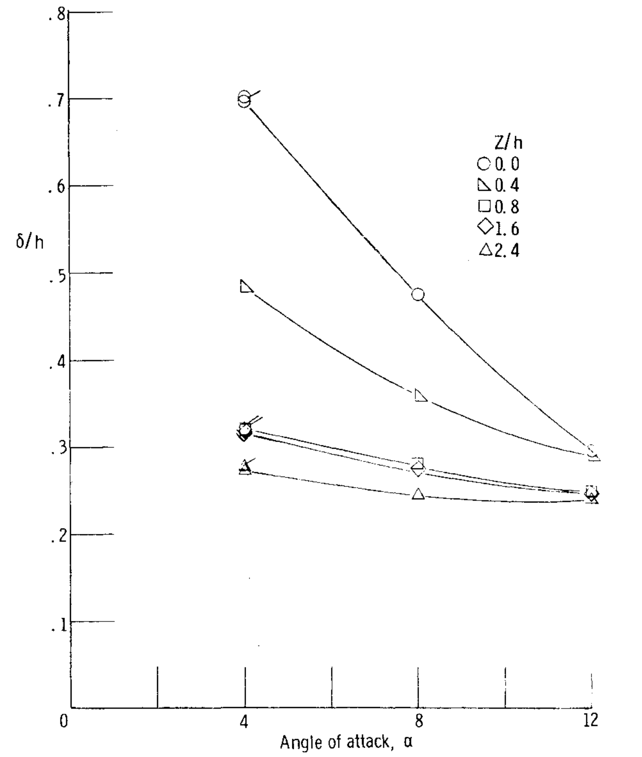


Fig. 4 The spanwise variation of boundary-layer thickness on the brass model as a function of angle of attack. Engine height $(h) = 1.524$ cm (0.600 in.). (Flagged symbols are values from total temperature profiles.)

A flowfield survey was undertaken in the region of the engine inlet location because of strong indication of a flow anomaly on the forebody centerline. The flowfield surveys were made on a 1/30-scale brass model, geometrically similar to the model tested in Ref. 2. The tests were conducted in the Langley Mach 6, 20-in. tunnel, at Reynolds number of 11.20×10^6, based on distance to the engine inlet. The survey was made at the engine inlet location $(X/L = 0.724)$ at five spanwise Z stations, with the total pressure probe traversing from the model wall to the fuselage bow shock. The abscissa of Fig. 3 is the ratio of local pitot pressure $P_{t,e}$ to tunnel stagnation pressure $P_{t,1}$. Boundary-layer profiles in Fig. 3, at five spanwise locations, are presented in terms of y/h, where h is the engine height. These data indicate that the boundary layer in the area of the centerline $(Z/h = 0)$ is more than twice as thick as the boundary layer at the three outboard stations. The $Z/h = 0.8$ and $Z/h = 1.6$ stations have about the same boundary-layer thickness, whereas the most outboard station is slightly less than the two adjacent inboard stations.

The spanwise variation of boundary-layer thickness for angles of attack of 4°, 8°, and 12° is shown in Fig. 4. The boundary-layer thickness on the centerline $(Z/h = 0)$ shows a marked decrease with increasing angle of attack, as does the station slightly off the centerline $(Z/h = 0.4)$. At $\alpha = 4°$, the centerline boundary layer is about two and one-half times as thick as at the outboard station $(Z/h = 2.4)$. At $\alpha = 8°$, the centerline boundary-layer thickness is about twice that at the outboard station. The flagged symbols in Fig. 4 are boundary-layer thicknesses obtained with a total temperature probe which show excellent agreement with the pressure data. The tip of the total temperature probe was just slightly larger than the pressure probe shown in Fig. 3.

Conclusions

The cold streak found in heating contours on the centerline of the forebody is caused by a thickening of the boundary layer on the centerline. At $\alpha = 4°$, the boundary layer on the centerline is 0.7 of the scaled engine height, and outboard stations are approximately 0.3 of the scaled engine height. The thickening of the boundary layer on the centerline decreases with angle of attack. Since boundary-layer thickening degrades engine performance, further research is required to develop optimum forebody shapes, which provide acceptable inlet flowfields for airframe-integrated scramjets.

References

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Technical Comments

Comment on "Advanced Subsonic Transports – A Challenge for the 1990's"

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IN a recent paper, Black and Stern[1] too quickly dispose of a decade or more in the projected appearance of an advanced technology transport without truly exposing the fundamental constraint on aeronautical progress in the proper historical context. The delay cannot be written off simply as one pending a general economic upturn leading, in turn, to improved air transportation economics and increased fuel efficiency through the judicious application of advanced technology. For convenience, the advanced technology is recognized here as the array: supercritical aerodynamics, composite materials, active controls, and cleaner, quieter, and more efficient propulsion.

Since about 1965, the year aptly designed by Hoener[2] as that heralding the renaissance or rediscovery of the airplane, the AIAA literature has provided extensive coverage of prospects for aeronautics, particularly with respect to civil aviation (Refs. 3-29, for example). Not one of these (including projections for the new air transports of the 1980s by Black et al.[20,21]), nor actually any at all, is recognized in Ref. 1, even though the underlying thrust common to a majority of the sources cited is germane to placing in proper perspective the observation relative to R&D effort, including transportation systems analysis, being promoted by Black and Stern: namely, that future technology advances will require substantial R&D before they can be incorporated into commercial designs. For the nearer term, they conclude that worldwide economic, social, and political environments and the rising cost of fuel presage long and profitable lives for the present wide-bodied jets and their derivatives. This conclusion echoes those of contemporary Refs. 22 and 23, both of which point to the small likelihood that an advanced technology transport can be expected before, presumably, 1985, in view of economic considerations and the absence of an as yet unpredicted technological breakthrough or advance. Indeed, in Ref. 23, the 10 years ahead are referred to as the decade of derivatives.

In the years 1964-68, which span the period between the presentations of the 27th and 31st Wright Brothers Lectures, Schairer,[3] Hawkins,[4] Bisplinghoff,[5] Brizendine and Strang,[6] Raymond,[7] Chatham,[8] and Harper[9] addressed to varying degrees the general topic of future progress in aeronautics. The singular transmission providing the common denominator to these essays is an urgent call for renewed and continued emphasis on and commensurate support of R&D in view of the growth potential, socioeconomic overtones, and impact on the U.S. economy of civil aviation. To this group must be added the sage counsel offered the readership of AIAA publications by Karth[10] in 1968, in which he called attention to the strong relationship existing between technology and social progress, the requirement for the former to be responsive to the latter, and the fact that a strong case could be made to continue supporting vigorous R&D efforts in the U.S. subject to the realization that directions and priorities would have to change from time to time. It was in 1968, also, when Harper concluded that aeronautics R&D had neglected to examine the socioeconomic impact of its activities and that it would require a well-organized, agressively pursued R&D program, taking full advantage of all new technology, to reduce to a financially acceptable level the technical risks associated with improved air-transport capability.

From 1970 on, or commencing roughly with the presentation of the 33rd Wright Brothers Lecture by Cleveland,[11] the advanced technology has been a consideration in the references cited, with more and more emphasis being directed toward its specific potential for high-subsonic- and transonic-speed transports (Refs. 12-23, for example). Concomitantly, studies directed more to the interaction of technical, social, political, and economic forces than to the advanced technology *per se* have appeared as well (Refs. 24-29, for example).

In view of the foregoing, it would appear that Black ana Stern have long been preempted in their pronouncements that the design requirements for advanced subsonic transports will be established, to a large degree, by future economic, social, and political conditions and that these requirements will necessitate an extensive and in-depth (advanced) technology base that is not only relevant to the airplane but also to the total air transportation system. As noted earlier, the airplane was rediscovered in 1965; unfortunately, in the very critical, immediately subsequent years, the formulation and support of an R&D program that would first recoup lost ground and then accelerate the technical progress leading to the economically viable and environmentally acceptable air transportation system now projected to, at least, the 1990's by Black and Stern did not see fruition, the conclusions, recommendations, pleas, warnings, and forebodings of authoritative sources notwithstanding. Paradoxically, the very branch of the federal government whose Senate Committee on Aeronautical and Space Sciences, after 2 years of deliberations, recommended adoption of a more comprehensive and coherent policy for aeronautical R&D in 1968 has yet to recognize the full impact of unchecked erosion of the R&D base.

That the decade or more delay projected in Refs. 1, 22, and 23 for the appearance of advanced technology transports is rooted more in deteriorated aeronautical R&D support throughout the post-Sputnik era rather than in the market downturn and rising fuel costs of the 1970's is no more poignantly illustrated than by succinctly reviewing the promise versus the progress of composite materials, one of the key building blocks of the advanced technology. In 1968,

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Index categories: Air Transportation Systems; Aircraft Economics (including System Economics); Aircraft Performance.

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