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Unique Research Challenges for High-Speed Civil Transports

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Unique Research Challenges for High-Speed Civil Transports

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ABSTRACT

Market growth and technological advances are expected to lead to a new generation of long-range transports that cruise at supersonic or even hypersonic speeds. Current NASA/industry studies will define the market windows in terms of time frame, Mach number, and technology requirements for these aircraft. Initial results indicate that, for the years 2000 to 2020, economically attractive vehicles could have a cruise speed up to Mach 6. The resulting research challenges are unique. They must be met with new technologies that will produce commercially successful and environmentally compatible vehicles where none have existed. Several important areas of research have been identified for the high-speed civil transports. Among these are sonic boom, takeoff noise, thermal management, lightweight structures with long life, unique propulsion concepts, unconventional fuels, and supersonic laminar flow.

INTRODUCTION

The growing need for higher speeds in long-range transportation and the projected technological advances assure the advent of a new generation of high-speed airliners (1 to 4).* These aircraft will cruise at supersonic or even hypersonic speeds to serve the Atlantic and currently developing Pacific markets. Technology development for these new aircraft can be based in part on knowledge gained from previous programs, such as those for the Concorde and YF-12. Current programs, particularly the U.S. National Aero-Space Plane, should contribute significant technological advancements. Yet, the research challenges for high-speed civil transports are not simply outgrowths from other programs. These challenges are unique in their focus on new technologies and stringent requirements for commercial success and environmental compatibility of the resulting aircraft.

Any successful, new commercial aircraft must match market needs. The time/speed contours shown on the global map in figure 1 provide an insight into the resulting requirements for vehicle performance. These contours correspond to range limits for 3-hour flights originating at Los Angeles. The range calculations were made for Mach numbers of 3, 4, and 5 with a 0.2g constraint on longitudinal acceleration and deceleration. The contours clearly indicate the benefits of high speed, particularly in the Pacific Rim market. In addition, reduced trip time will undoubtedly stimulate significant growth in the long-range transportation market. A similar market-stimulation situation was of overwhelming importance in the successful introduction of jet-powered airliners more than 25 years ago.

Commercial requirements influence numerous aspects of the design for high-speed civil transports. These new airliners must have the range and payload capabilities to match the markets. They must also have operating and initial costs that make them competitive with advanced subsonic transports. In addition, new high-speed transports must achieve the levels of comfort, safety, and environmental acceptability found in subsonic transports. Commercial designs must focus on high utilization and low maintenance factors that differentiate commercial from military design. The need to achieve airworthiness certification at an affordable price constrains the design to use

*Numbers in parentheses designate references at end of paper.

technologies with reduced risks. To address these considerations, an aggressive well-coordinated program must be developed for implementation by the research and development community.

AIRPORTS AND AIRLINE ROUTES

The challenges of new high-speed transports may not be met by conventional evolution of the existing air-transportation system. Aircraft that cruise at speeds above Mach 4 may require new airports. Achieving good propulsion efficiency at high values of cruise Mach number leads to very high velocities in the jet exhaust. The resulting jet noise is expected to cause serious difficulties in meeting community noise requirements. These same vehicles need the energy content and cooling capacity of cryogenic fuels. The use of dedicated airports ("superhubs") may be the best way to alleviate both noise and fuel-handling problems for these aircraft (5 and 6).

Possible route structures for superhubs serving major world traffic are illustrated in figure 2. An important point is indicated by the dashed overland routes; unless these overland routes can be a part of the interlocking route structure, the superhub concept will not be viable. Also, while this concept can avoid sonic-boom limitations on most routes, it certainly does not eliminate them. The problems of boom focusing during acceleration or turns remain to be analyzed for each potential route structure.

TECHNOLOGY STATUS

Previous experiences with existing, supersonic aircraft are helpful in guiding the required new research. Significant data exist on supersonic-cruise military aircraft, such as the B-58, B-70, and YF-12 (7 to 10), respectively. The Concorde, which first flew in 1969, provides the only operational experience for a supersonic commercial transport (11 and 12). Much research was accomplished in support of the U.S. program to build a supersonic transport (SST). After termination of that program, research continued in the NASA Supersonic Cruise Research (SCR) Program from 1971 to 1981 (11 to 18).

Many years have passed since the last effort in the U.S. to develop and produce a supersonic-cruise transport (2, 18, 19, and 20). New efforts will benefit from advances such as the recent developments in high-temperature materials, digital-computer controls, and fiber optics. New studies, that account for these developments, are needed to identify the best market opportunities for high-speed transports and determine the relevant research programs.

CURRENT STUDIES

NASA, Boeing Commercial Airplane Company, and Douglas Aircraft Company are currently involved in studies to examine the market potential, technology requirements, and environmental issues for advanced high-speed civil transports. The initial scope of the studies is indicated in figure 3. Study topics include economics, configuration development, vehicle-mission analysis, airport infrastructure, and required research. As indicated in the figure, the work covers an extreme range of parameter values. An example of this is the initial consideration of cruise Mach numbers that range from 2 to 25. An important part of the study is the analysis of a series of vehicle concepts developed for different cruise speeds. These concepts are representative rather than optimized; they serve as a focus for evaluation of technology and economics.

The studies have tended to group configuration concepts according to fuel type and structural materials appropriate for given ranges of cruise Mach number. (See figure 4.) As an example, JP fuel is appropriate for Mach 2 to 4. In that same range, the vehicle could be constructed of advanced aluminum, titanium, and some thermoplastics; it could be powered by a variable-cycle turbine engine. Between Mach number 4 and 6, more advanced technology would be required for the materials and propulsion system (perhaps a multicycle engine concept); special hydrocarbon fuels, liquid methane or liquid hydrogen could be used. If methane or hydrogen were used, the vehicles would need advanced cryogenic fuel tankage with the supporting fuel infrastructure at the airports. Cruise speeds above Mach 6 require even more exotic materials, complex combinations of propulsion systems, and cryogenic hydrogen.

The initial results of the market studies for high-speed transports have clearly indicated that Mach 6 is the upper bound for an economically viable system for the time frame 2000 to 2020. Productivity, market demand, and economics are all strong functions of block time, i.e., the increment of time spent between airports. The analysis presented in figure 5 accounts for the effects of longitudinal acceleration on flights over an appropriately long route (approximately the distance between Los Angeles, California, and Melbourne, Australia). These data show that reductions in block time are insignificant for increases in cruise speed above Mach 6. The analytic results also indicate that, for a 0.1g limit, the fraction of time spent as cruise approaches 0 for a maximum speed approaching Mach 12. In this case, the vehicle could not even reach Mach 12 before it would have to begin deceleration.

TECHNOLOGY CHALLENGES

Past research, operational experience, and current analyses have identified a series of significant technological challenges associated with high-speed civil transport aircraft. As would be expected, the severity of the challenges increases with increasing Mach number. The following discussions highlight some of the more important technical challenges.

Sonic Boom - As mentioned earlier, the economic viability of a high-speed transport will be affected by any speed limitation for flight over land. Current over-land constraints for supersonic commercial aircraft are associated with sonic boom (21). Research to reduce or even eliminate the perceived sonic boom has made considerable progress during the era of the U.S. SST and SCR programs (18).

As indicated in figure 6, the reshaping of a typical supersonic transport could significantly alter the sonic boom signature on the ground and reduce the perceived boom level (22). It is important to note that reshaping the vehicle for sonic boom also tends to reduce drag and, consequently, improves cruise performance. Unfortunately, there are associated penalties at low-speed; the typical reduction in aspect ratio can degrade landing and takeoff performance as well as increase requirements for takeoff power (hence takeoff noise). Sensitive configuration tradeoffs such as this require a high degree of confidence in the enabling technologies. The high potential for significant gains identifies this as an extremely important research challenge (23).

More research is also needed on human response to sonic booms. Data from both actual flyovers and anechoic chambers have documented human and structural response to boom overpressures above 1 lb/sq ft. The shaded area in figure 6 corresponds to available human-response data. Although the modified configuration has a lower overpressure, there are insufficient data to evaluate the benefit. Studies have also shown that acoustic signature (wave shape) is also important to human response, that is, finite rise time in the signature reduces perceived boom level for a given overpressure. Unfortunately, some methods that lead to improved human response (through signature shape) result in unfavorable response of structures on the ground. Research is, therefore, needed to establish a lower bound on sonic boom level as a function of both human and structural response.

Thermal Management - The technological challenge for thermal management becomes a significant concern due to aerodynamic heating at Mach numbers above 3. Studies indicate that aerodynamic heating makes active cooling unavoidable at Mach 5 or greater; cryogenic fuels are needed to cool parts of the engines and air frame. Data from the YF-12, which has no active cooling, give some indication of the complexity of the problem (24). As shown in figure 7, an internal structural element (a web) experienced continued heating after the adjacent skin reached equilibrium temperature.

Thermal management poses another unique problem to the operation of high-speed civil transports. Any of these vehicles that cruise above approximately Mach 3 may need a substantial cool-down period after landing. This cool-down time could increase the turnaround time at the airport such that it reduces the vehicle productivity advantage for high-speed flight.

Materials - The significance of materials research is shown in figure 8 for a representative Mach 4 cruise aircraft. The data indicate that substantial reductions in takeoff gross weight are achieved through reductions in empty operation weight, and hence, structural weight. The major technological challenge for low-weight, high-temperature materials may be related to the high utilization required for commercial success. Many materials promise at least adequate specific strength at the elevated temperatures associated with high-speed flight (fig. 8). However, there is generally inadequate data on the effects of heat soak and heat cycles. These factors are expected to degrade material properties from that typically shown in strength/temperature charts.

Propulsion - The list of propulsion challenges is presented in figure 9 along with calculated results indicating the sensitivity of the total gross weight of a representative Mach 4 aircraft to changes in propulsion performance. There is a very limited data base for the development of engine cycles, inlets, and nozzles for commercial transports that operate at high Mach numbers. Noise suppression has been addressed for supersonic-cruise vehicles in the SCR program (14 and 18), but that has not been applied to vehicles with cruise speeds above Mach 3. Significant research is needed on jet noise suppression to control noise affecting communities near the airports.

Unconventional fuels pose potentially severe challenges for commercial operation (5, 6, 25 and 26). The use of cryogenic fuels requires the development of a fuel distribution system that is far more complex than systems for conventional fuel. Economics and safety are paramount issues. Endothermic fuels have potential as the needed heat sink for high-speed flight. These noncryogenic, hydrocarbon-based fuels absorb heat from the vehicle as they convert fuel from the molecular form for storage in aircraft tanks to that required for combustion. Unfortunately, this process requires additional complexity in the propulsion system and the handling of aircraft fuel. The heat-sink advantages must, therefore, be carefully considered in comparison to both the increased cost of fuel production and the increased complexity in the aircraft systems.

Aerodynamics - There are several areas of aerodynamic research which have significant potential for improving the performance of a high-speed civil transport. These are indicated in figure 10 to be laminar flow, high lift for landing and takeoff, and propulsion integration.

Laminar flow research has established an advantage in drag reduction for subsonic aircraft (27). If significant amounts of supersonic laminar flow can be obtained, the drag reduction could greatly improve range and payload. In addition, the reduced heating associated with laminar flow may in itself provide significant performance benefits in material life, thermal management, and structural weights.

The landing and takeoff aerodynamic characteristics need to be developed through the use of planform shaping and high-lift devices such as canards and vortex flaps to provide stability, control, and handling qualities. To alleviate the takeoff noise, the aerodynamic configuration will have to provide good lift-to-drag ratio for reduced power requirements. All these low-speed features must be optimized to provide minimum penalty to cruise performance.

As illustrated in figure 10, efficient high-speed propulsion systems must have large nozzles which aggrevate the propulsion-integration problems at transonic speeds. The high-speed transport will have thrust reversers, perhaps thrust vectoring for trim and control, and jet-noise suppressors. These features must be well integrated or severe weight and performance penalties will result.

CONCLUDING REMARKS

Market growth and technological advances are expected to lead to a new generation of long-range transports that cruise at supersonic or even hypersonic speeds. Current NASA/industry studies will define the market windows in terms of time frame, Mach number, and technology requirements for these aircraft. Initial results indicate that, for the years 2000 to 2020, economically attractive vehicles could have a cruise speed up to Mach 6. The resulting research challenges are unique. They must be met with new technologies that produce commercially successful and environmentally compatible vehicles where none have existed. Several important areas of research have been identified for the high-speed civil transports. Among these are sonic boom, takeoff noise, thermal management, lightweight structures with long life, unique propulsion concepts, unconventional fuels, and supersonic laminar flow.

REFERENCES

1. Ausrotas, Raymond A.: The Market Potential of Future Supersonic Aircraft. SAE Tech. Paper 861684, October, 1986.

2. Kayton, Gerald G.; Driver, Cornelius; and Maglieri, Domenic J.: The Revolutionary Impact of Evolving Aeronautical Technologies. AIAA paper no. 84-2445, 1984.

3. Rosen, Cecil C., III; Burger, Robert J.; and Sigalla, Armand: Aeronautical Technology 2000: A Projection of Advanced Vehicle Concepts. AIAA paper no. 84-2501, 1984.

4. Feir, Jack B.: Evaluation of Routing and Scheduling Considerations for Possible Future Commercial Hypersonic Transport Aircraft. NASA CR-132632, 1974.

5. Boeing Commercial Airplane Company: An Exploratory Study to Determine the Integrated Technology Air Transportation System Ground Requirements on Liquid-Hydrogen-Fueled Subsonic, Long-Haul Civil Air Transports. NASA CR-2699, 1976.

6. Brewer, G. D., ed.: LH2 Airport Requirements Study. NASA CR-2700, 1976.

7. Miller, Jay: Aerograph 4 - Convair B-58. Aerofax, Inc. (Texas), 1985.

8. Pace, Steve: Aero Series vol. 30- North American Valkyrie, XB-70 . Aero Publishers (Tab Books Inc.), Blue Ridge Summit, PA, 1984.

9. Miller, Jay: Aerofax Minigraph 1 - Lockheed SR-71 (A-12/ YF-12/ D-21). Aerofax, Inc. (Texas), 1985.

10. Taylor, John W. R., ed.: Jane's All the World's Aircraft, 1965-1966. McGraw-Hill Book Co., New York, 1965, pp. 230-231, 274-276, 256-258.

11. Blackall, T. E.: Concorde - the Story, the Facts and the Figures. G. T. Foulis and Co., Ltd. (Henley-on-Thames, Oxfordshire, England), 1969.

12. Taylor, John W. R.; and Munson, Kenneth, eds.: Jane's All the World's Aircraft, 1978-1979. Franklin Watts Inc., New York, 1978, pp. 82-84

13. Hoffman, Sherwood; and Varholic, Mary C.: Contracts, Grants, and Funding Summary of Supersonic Cruise Research and Variable-Cycle Engine Technology Programs, 1972-1882. NASA TM 85650, 1983.

14. Fishbach, L. H.; Stitt, L. E.; Stone, J. R.; and Whitlow, J. B., Jr.: NASA Research in Supersonic Propulsion -- A Decade of Progress. NASA TM-82862, 1982.

15. Hoffman, Sherwood: Bibliography of Supersonic Cruise Aircraft Research (SCAR) Program from 1972 to Mid-1977. NASA RP 1003, 1977.

16. Hoffman, Sherwood: Bibliography of Supersonic Cruise Research (SCR) Program from 1977 to Mid-1980. NASA RP 1063, 1980.

17. Hoffman, Sherwood: Bibliography of Supersonic Cruise Research (SCR) Program from 1980 to 1983. NASA RP 1117, 1984.

18. McLean, F. Edward: Supersonic Cruise Technology. NASA SP-472, 1985.

19. Ferri, A.: Possibilities and Goals for the Future SST. J. of Aircraft., vol. 12, no. 12, December 1975, pp. 919-929.

20. Rowe, W. T.: Technology Status for an Adanced Supersonic Transport. SAE paper no. 820955, August 1982.

21. Maglieri, Domenic J.; Carlson, Harry W.; and Hubbard, Harvey H.: Status and Knowledge of Sonic Booms. Noise Control Engineering, vol. 15, no. 2, September-October 1980, pp. 57-62.

22. Von Gierke, H. E.; and Nixon, C. W.: Human Response to Sonic Boom in the Laboratory and the Community. J. Acoust. Soc. Amer., vol. 51, 1972, pp. 766-782.

23. Driver, Cornelius; and Maglieri, Domenic: Some Unique Characteristics of Supersonic Cruise Vehicles and Their Effect on Airport Community Noise. AIAA paper 80-0859, 1980.

24. Jenkins, Jerald M.; and Kuhl, Albert E.: Recent Load Calibrations Experience with the YF-12 Airplane. YF-112 Experiments Symposium, NASA CP 2054, Vol. 1, pp 47-72, September, 1978.

25. Goodger, Eric; and Vere, Ray: Aviation Fuels Technology. MacMillian Pub., Ltd., 1985, pp. 208-213.

26. Lander, H.; and Nixon, A. C.: Endothermic Fuels for Hypersonic Vehicles. J. of Aircraft, vol. 8, no. 4, April 1971, pp. 200-207.

27. Hefner, Jerry N.; and Wagner, Richard D.: Laminar Flow Research Applicable to Subsonic Aircraft. International Symposium on Aeronautical Science & Technology of Indonesia, Jarkarta, Indonesia, June 24-27, 1986.

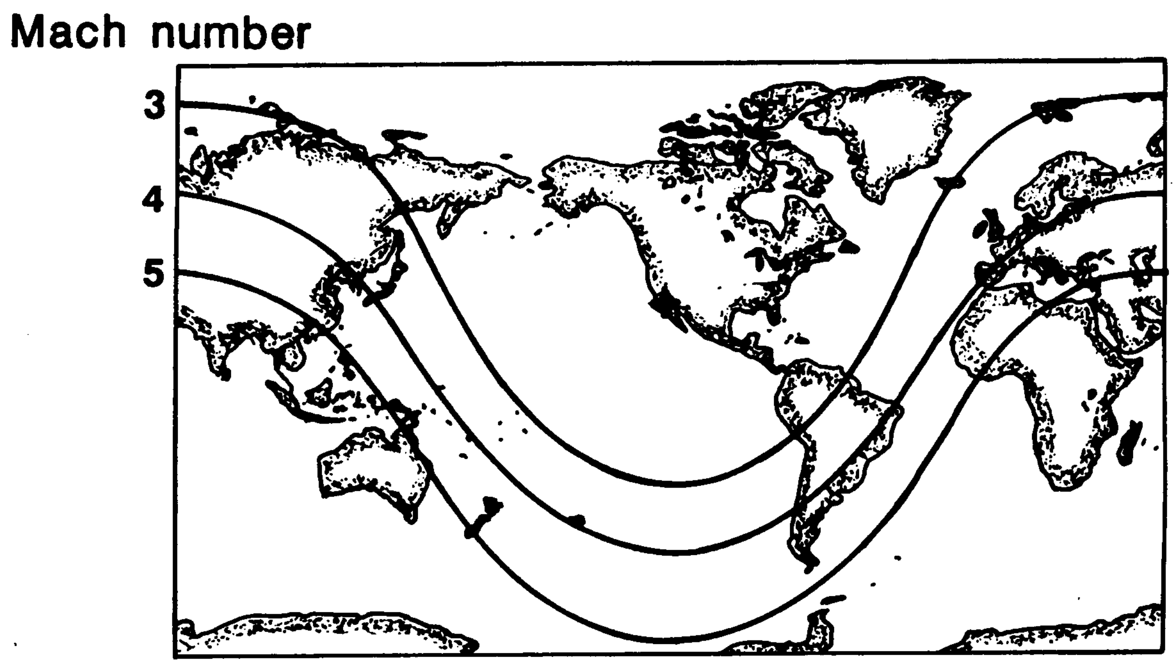


Figure 1.- Boundaries of range for three-hour flights from Los Angeles with 0.2g limits on longitudinal acceleration.

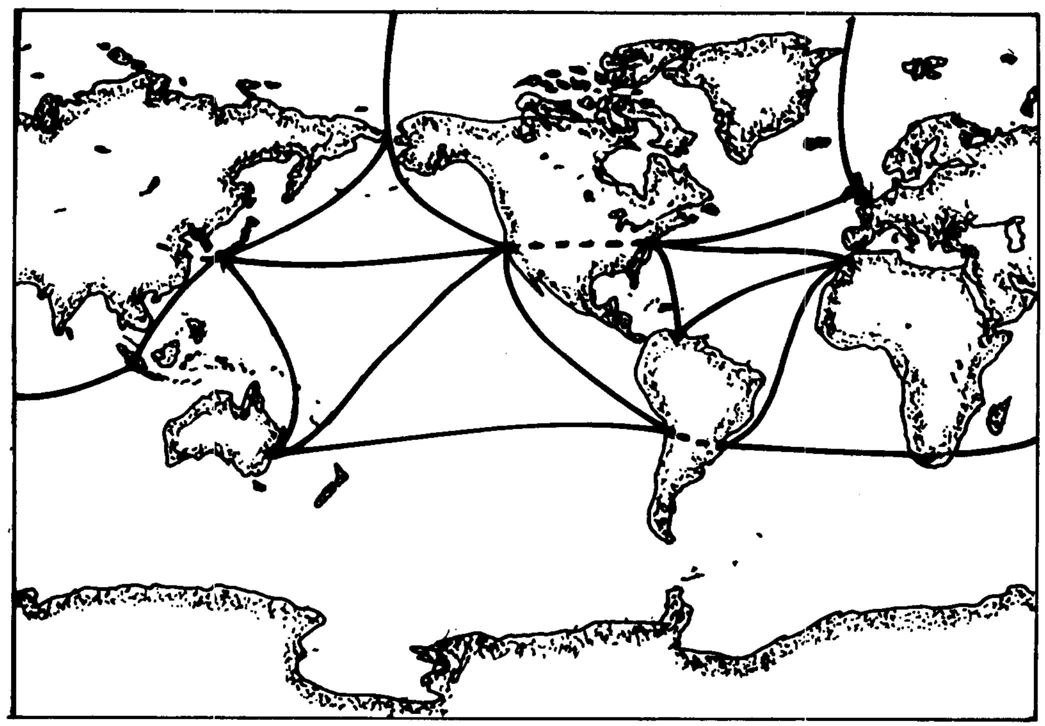


Figure 2.- Potential routes between dedicated, superhub airports for high-speed civil transports.

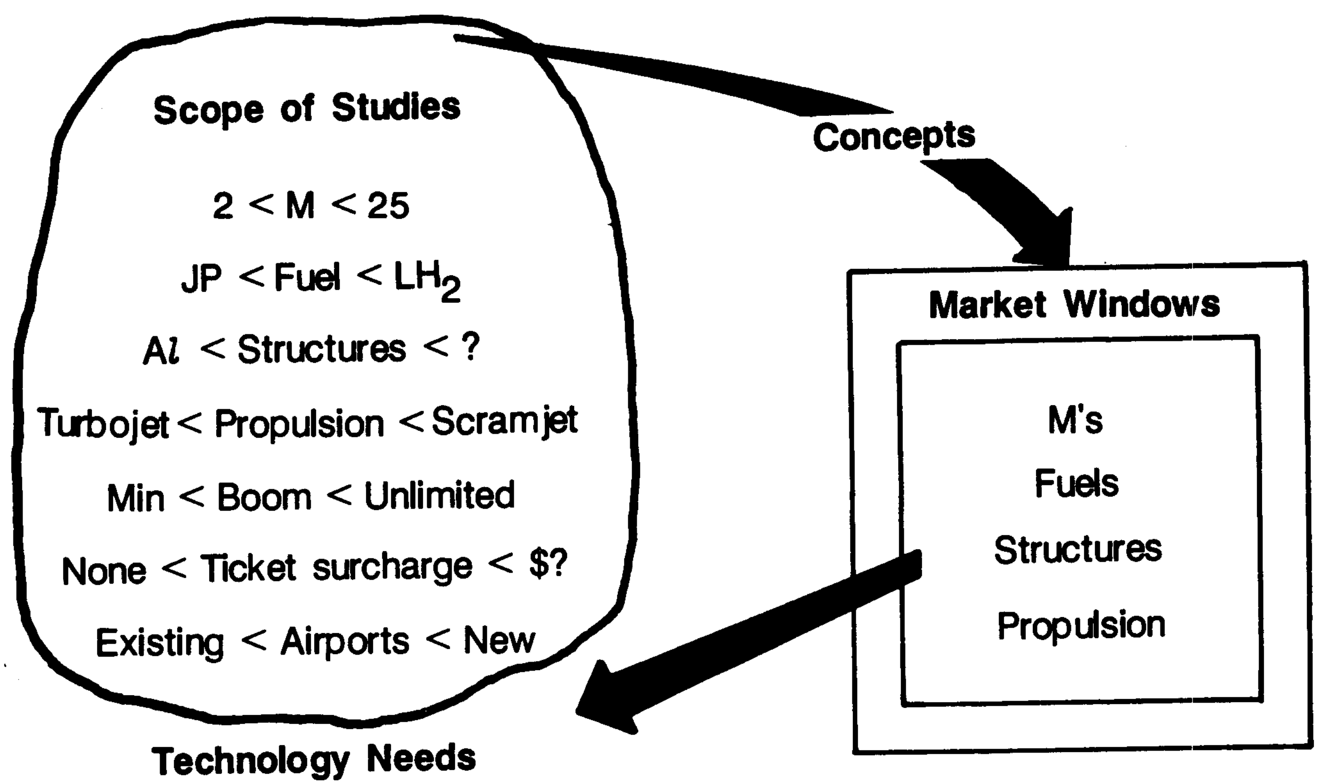


Figure 3.- Conceptual approach of NASA/industry studies for high-speed civil transports.

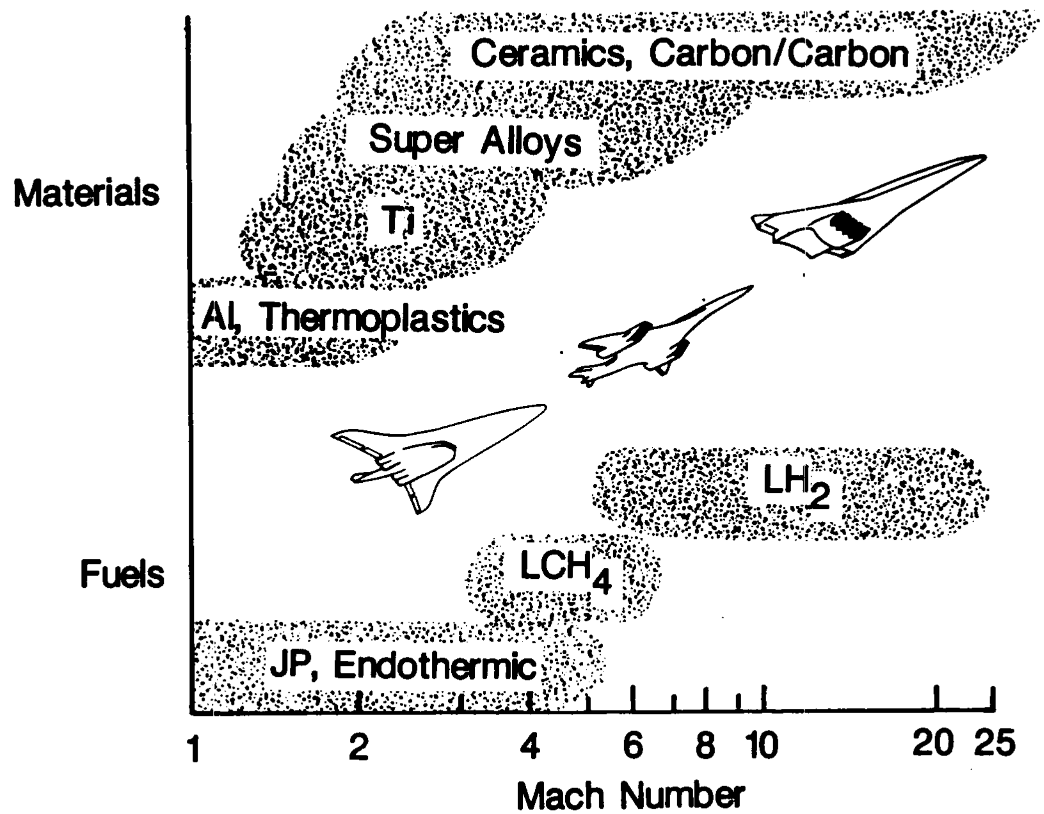


Figure 4.- Material and fuel selection for Mach number ranges.

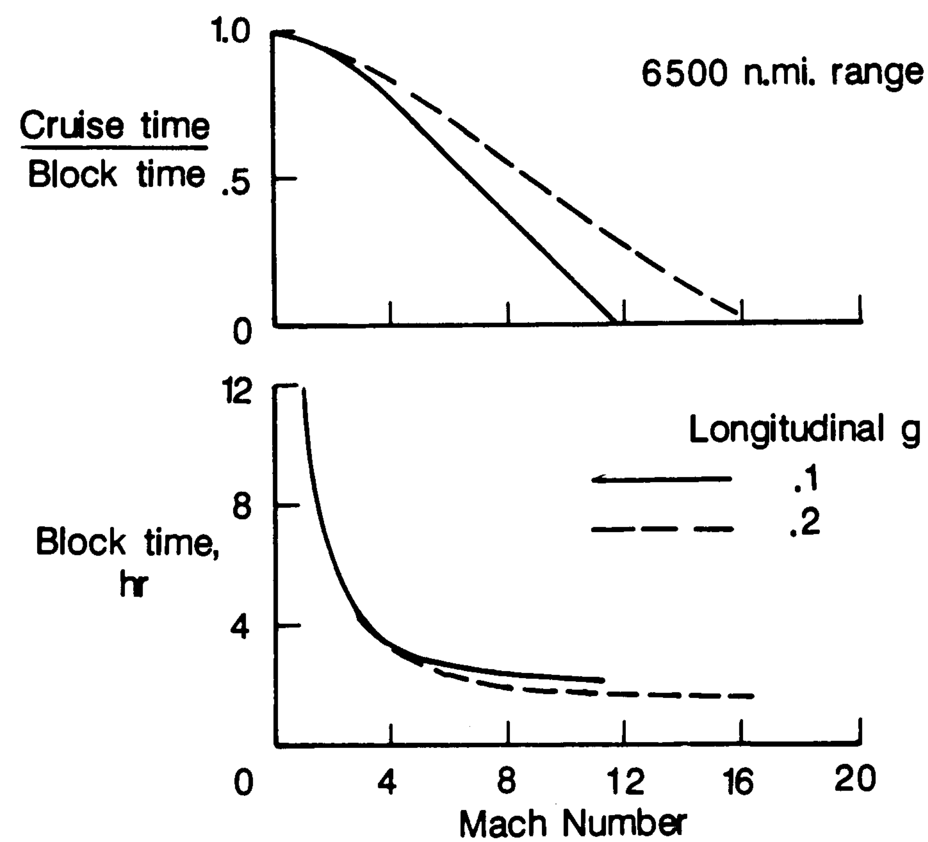


Figure 5.- Significance of acceleration limits on mission performance for great-circle route of 6500 nautical miles.

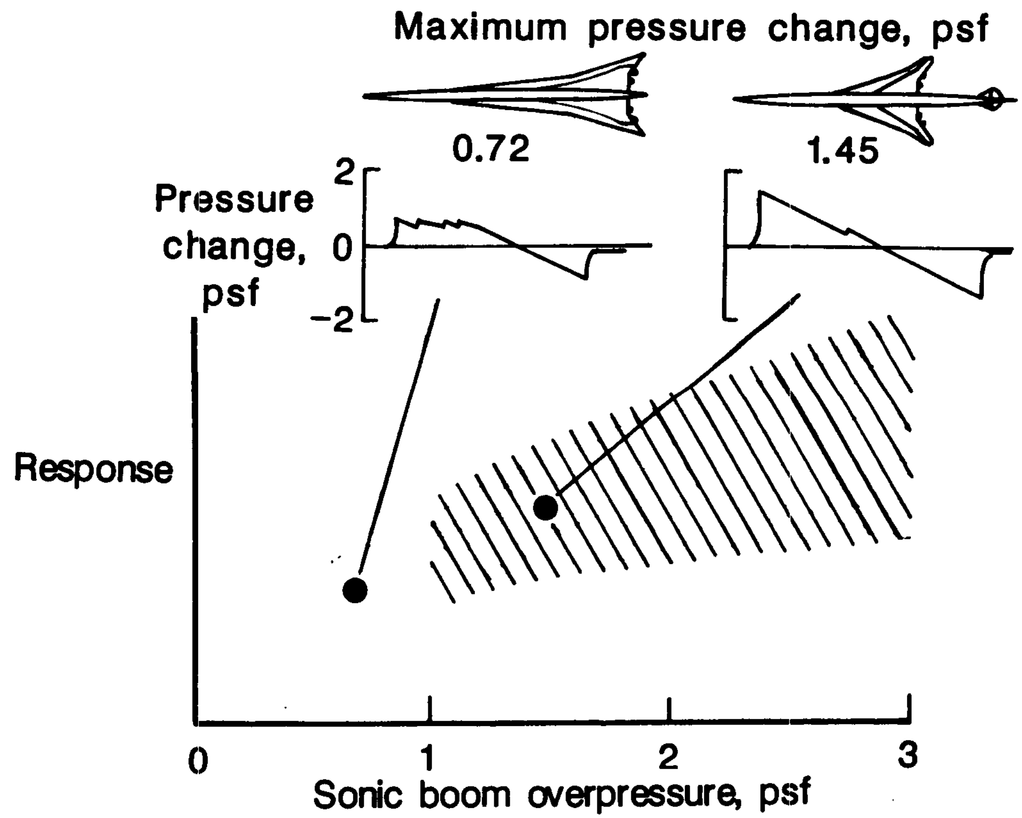


Figure 6.- Configuration design effects and response data for sonic-boom overpressure.

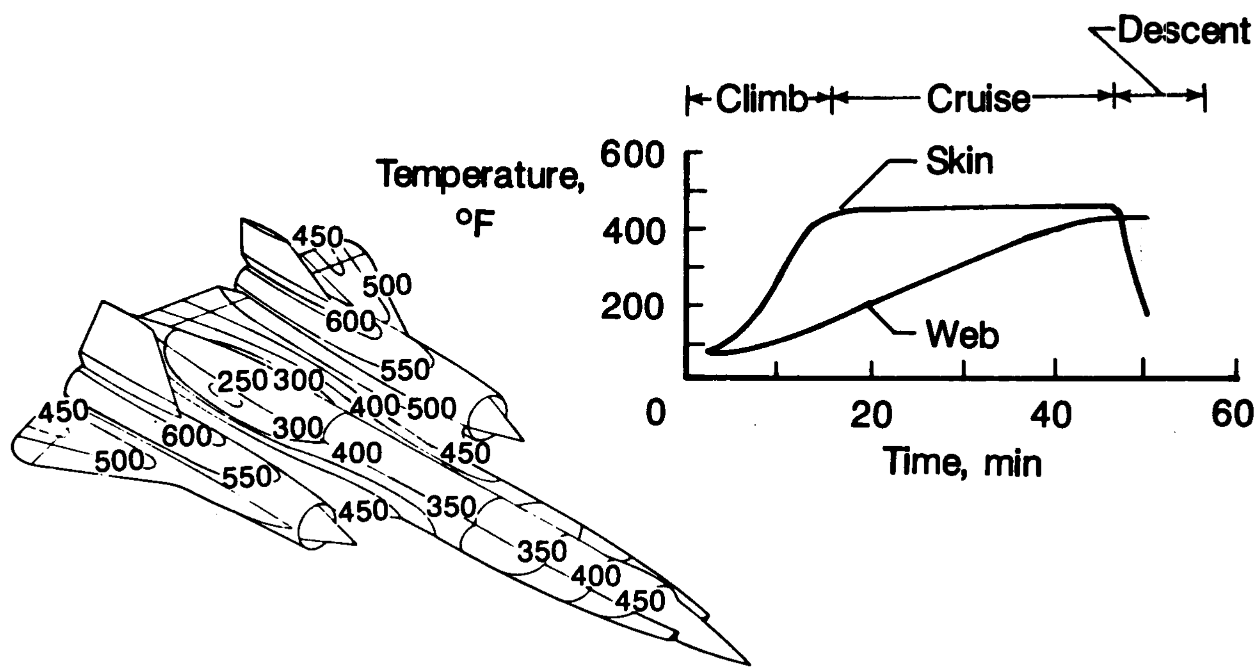


Figure 7.- Thermal patterns in cruise and representative thermal history for the YF-12.

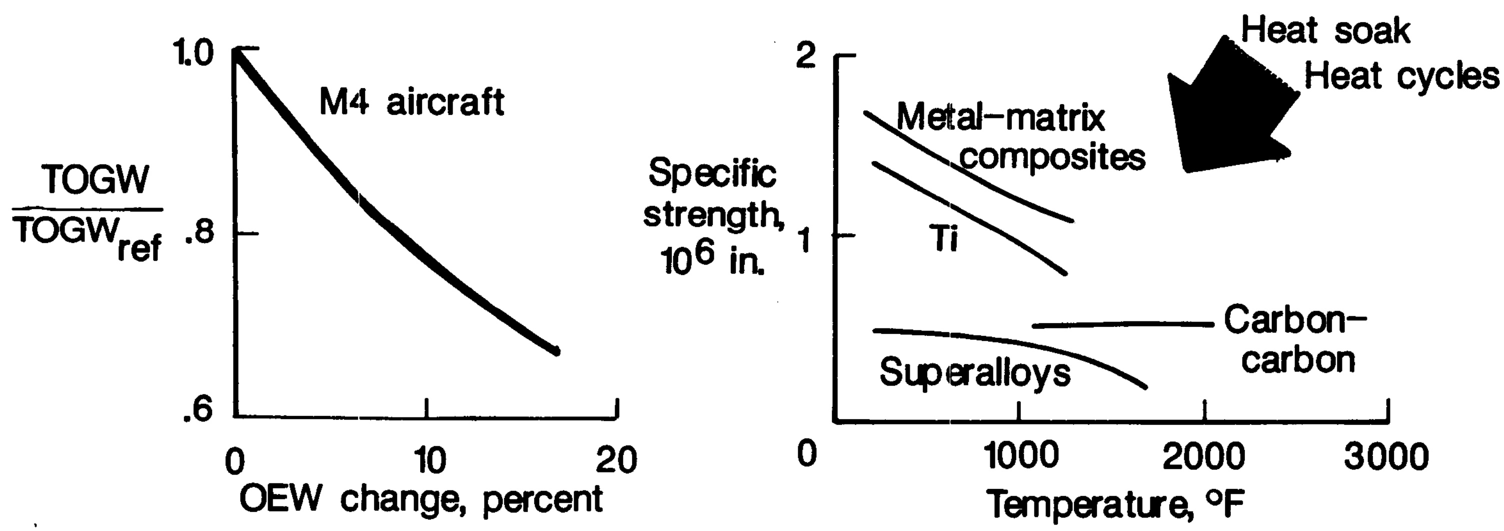
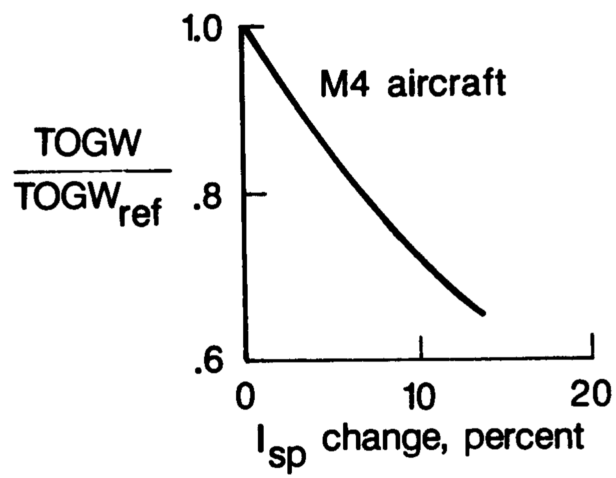


Figure 8.- Significance of material research.



- Novel engine cycles
- High–Mach inlets and nozzles
- High–temperature materials, structures and sensors
- Noise suppression
- Integrated controls
- Designer fuels

Figure 9.- Significance of propulsion research and research topics.

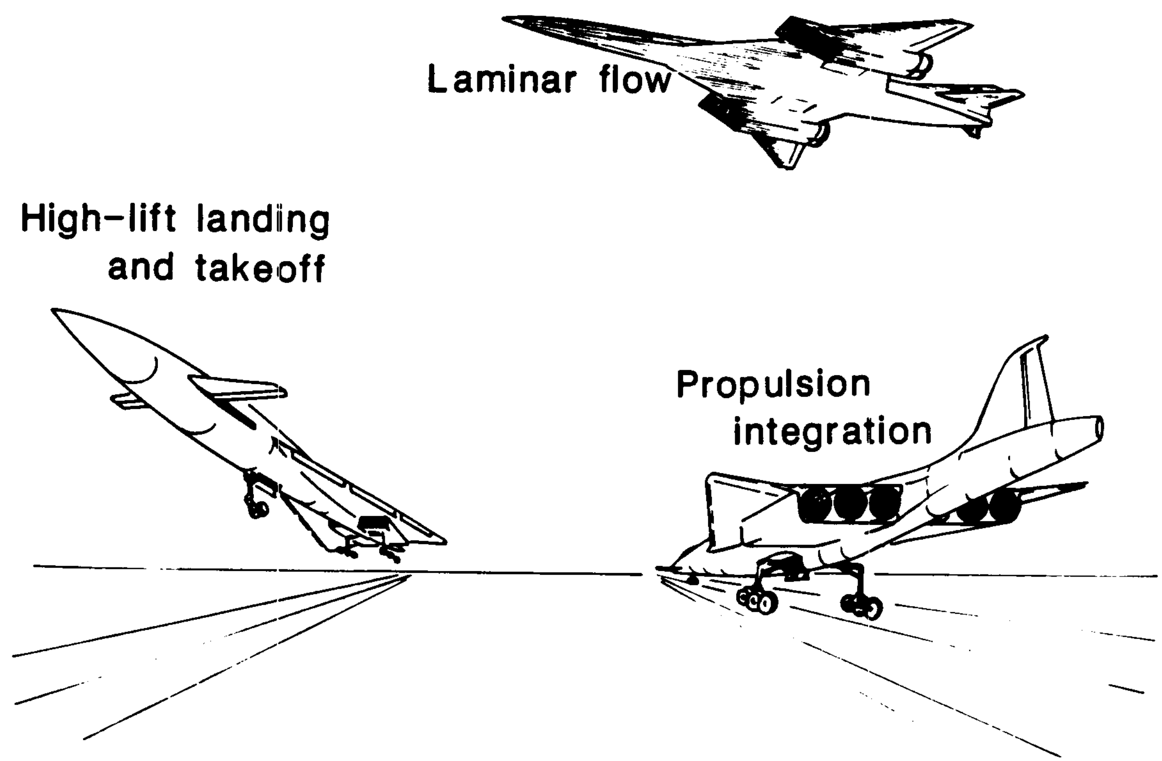


Figure 10.- Aerodynamic research challenges.

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