NATIONAL RESEARCH COUNCIL

Commercial SUPERSONIC Technology

The Way Ahead

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COMMERCIAL SUPERSONIC TECHNOLOGY

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High speed flight is a major technological challenge for both commercial and business aviation. As a first step in revitalizing efforts by the National Aeronautics and Space Administration (NASA) to achieve the technology objective of high speed air travel, NASA requested the National Research Council (NRC) to conduct a study that would identify approaches for achieving breakthroughs in research and technology for commercial supersonic aircraft. This report documents the results of that effort. The report describes technical areas where ongoing work should be continued and new focused research initiated to enable operational deployment of an environmentally acceptable, economically viable commercial aircraft capable of sustained supersonic flight, including flight over land, within the next 25 years.

Finding 1. An economically viable, environmentally acceptable supersonic commercial aircraft with a cruise speed of less than approximately Mach 2 requires continued development of technology on a broad front (see Finding 2). In addition, research in the following five areas of critical importance could lead to important breakthroughs, but only if current research is augmented by new, focused efforts (or significant expansions of existing efforts):

- airframe configurations to reduce sonic boom intensity, especially with regard to the formation of shaped waves and the human response to shaped waves (to allow developing an acceptable regulatory standard)
- improved aerodynamic performance, which can be achieved through laminar flow and advanced airframe configurations (both conventional and unconventional)
- techniques for predicting and controlling aero-propulsive servo-elastic and aircraft-pilot servo-elastic (APSE) characteristics, including high-authority flight- and structural-mode control systems for limiting both types of APSE effects in flight and tools for defining acceptable handling and ride qualities
- automated, high-fidelity, multidisciplinary optimization tools and methods for design, integration, analysis, and testing of a highly integrated, actively controlled airframe-propulsion system
- variable cycle engines for low thrust-specific fuel consumption, high thrust-to-weight ratio, and low noise

Finding 2. An economically viable, environmentally acceptable commercial supersonic aircraft with a cruise speed of less than approximately Mach 2 requires continued advances in many areas, particularly the following:

- airframe materials and structures for lower empty weight fractions and long life, including accelerated methods for collecting long-term aging data and the effects of scaling on the validity of thermo-mechanical tests
- engine materials for long life at high temperatures, including combustor liner materials and coatings, turbine airfoil alloys and coatings, high-temperature alloys for compressor and turbine disks, and turbine and compressor seals
- aerodynamic and propulsion systems with low noise during takeoff and landing
- cockpit displays that incorporate enhanced vision systems
- flight control systems and operational procedures for noise abatement during takeoff and landing
- certification standards that encompass all new technologies and operational procedures to be used with commercial supersonic aircraft
- approaches for mitigating safety hazards associated with cabin depressurization at altitudes above about 40,000 ft
- approaches for mitigating safety hazards that may be associated with long-term exposure to radiation at altitudes above about 45,000 ft (updating the Federal Aviation Administration's advisory circular on radiation exposure, AC 120-52, to address supersonic aircraft would be a worthwhile first step)

Finding 3. An economically viable supersonic commercial aircraft with a cruise speed in excess of approximately Mach 2 would require research and technology development in all of the areas cited in Findings 1 and 2. In addition, significant technology development would be needed to overcome the following barriers:

- climate effects and depletion of atmospheric ozone caused by emissions of water vapor and other combustion by-products in the stratosphere
- high temperatures experienced for extended periods of time by airframe materials, including resins, adhesives, coatings, and fuel tank sealants
- noise suppression at acceptable propulsion system weight

Conclusion 1. Research and technology development in the areas listed in Findings 1 and 2 could probably enable operational deployment of environmentally acceptable, economically viable commercial supersonic aircraft in 25 years or less—perhaps a lot less, with an aggressive technology development program for aircraft with cruise speeds less than approximately Mach 2.

Conclusion 2. Candidate technologies for overcoming environmental barriers to commercial supersonic aircraft with a cruise speed in excess of approximately Mach 2 are unlikely to mature enough to enable operational deployment of an environmentally acceptable, economically viable Mach 2+ commercial supersonic aircraft during the next 25 years.

Recommendation 1. NASA should focus new initiatives in supersonic technology development in the areas identified in Finding 1 as they apply to aircraft with cruise speeds of less than approximately Mach 2. Such initiatives should be coordinated with similar efforts supported by other federal agencies (e.g., the DARPA Quiet Supersonic Platform Program).

Recommendation 2. For the technologies listed in Finding 2, NASA should allocate most of the available resources on goals and objectives relevant to aircraft with cruise speeds of less than approximately Mach 2. NASA should focus remaining resources on the areas listed in Finding 3 (i.e., the highest risk areas for cruise speeds greater than approximately Mach 2). Again, NASA activities should be coordinated with similar efforts supported by other federal agencies.

Recommendation 3. NASA and other federal agencies should advance the technologies listed in Findings 1 and 2 and Recommendations 1 and 2 to technology readiness level 6 to make it reasonably likely that they will lead to the development of a commercial product.

Customer Requirements, Vehicle Characteristics, and Technology Goals for Economic and Environmental Performance of Notional Commercial Supersonic Aircraft

	Supersonic Business Jet	Overland Supersonic Commercial Transport	High-Speed Civil Transport	State of the Art[a]
Customer Requirements				
Speed (Mach number)	1.6 to 1.8	1.8 to 2.2	2.0 to 2.4	
Range (NM)	4,000 to 5,000	4,000 to 5,000	5,000 to 6,000	
Payload (passengers)	8 to 15	100 to 200	300	
Sonic boom low enough to permit supersonic cruise over land	Yes	Yes	Yes, if possible[b]	No
Vehicle Characteristics				
Payload weight fraction[c]	~0.07	0.15 to 0.20	~0.20	
Aircraft empty weight fraction[d]	~0.44	~0.40	~0.37	
Vehicle empty weight fraction[e]	~0.38	~0.34	~0.32	~0.36 (larger aircraft) to 0.38 (smaller aircraft)
Fuel weight fraction	~0.49	0.40 to 0.45	~0.43	
Takeoff gross weight (1000 lb)	140	200 to 250	600	
Technology Goals				
Economic Performance				
Lift-to-drag ratio	7.5 to 8.0	9 to 10	10 to 11	~7.5 to 8.5
TSFC/M (lb/hr/lb/Mach number)[f]	~0.60	~0.52	~0.49	~0.60 (Mach 1.6) to 0.55 (Mach 2.4)
Engine thrust-to-weight ratio at sea level	5	5	6	~4 (for large engines) to 5 (for small engines)
Environmental Performance[g]				
Community noise	less than Stage 3[h]	less than Stage 3	less than Stage 3	Stage 3
Sonic boom overpressure (psf)	<1 (with a shaped signature)[i]	<1 (with a shaped signature)	<1 (with a shaped signature)[b]	~2 for large aircraft, ~ for small aircraft (with no shaping)
NO_x emissions index at cruise (g NO_x/kg fuel)[j]	<15	<15	<15 (lower speeds), ≤5 (higher speeds)	~25[k]
Water vapor emissions index (g water/kg fuel)[l]	~1,400	~1,400	~1,400 for lower speeds, possibly 0 at higher speeds	~1,400

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[a] State of the art is estimated for technologies that have matured to a TRL of 6 or higher.

[b] Only if intended for supersonic flight operations over land. Otherwise, sonic boom levels are not limiting.

[c] Weight of the payload divided by TOGW; payload is defined here as everything not necessary for controlled flight, including avionics (except the flight control system), mission equipment, and outfitting.

[d] Weight of the aircraft with no fuel or payload divided by TOGW.

[e] Weight of the aircraft with no fuel or payload *or engines* divided by TOGW.

[f] Thrust-specific fuel consumption divided by Mach number (TSFC/M) is inversely proportional to overall propulsion system efficiency. In principle, for a given propulsion system state of the art, TSFC/M varies approximately as the one-quarter power of the Mach number over the range of speed (Mach 1.6 to 2.4) of interest here. However, this has not been demonstrated in operational engines.

[g] CO_2 is an environmental constraint because it influences climate change, but CO_2 is not listed here because it is likely to be controlled by limiting total fuel consumption, not by imposing limits on emissions by individual aircraft.

[h] Current U.S. and international limits on noise for subsonic aircraft during takeoff, climb-out, and approach to landing are referred to as Stage 3 limits. Quieter Stage 4 limits are already under review.

[i] Sonic booms have a pressure wave with a very rapid rise time. Shaping of sonic booms would increase the rise time of the sonic boom pressure wave, reducing the effect of booms on people for a given overpressure limit. However, even with a shaped signature the maximum acceptable overpressure is unknown, although it seems certain to be less than 1 pound per square foot (psf).

[j] NO_x emissions are important to ozone depletion, local air quality, and climate change.

[k] State of the art for supersonic engines is about 25. Most commercial jet aircraft have an NO_x emissions index of about 7 to 15 (MCT, 2001).

[l] Water vapor emissions in the stratosphere are important to ozone depletion and climate change.