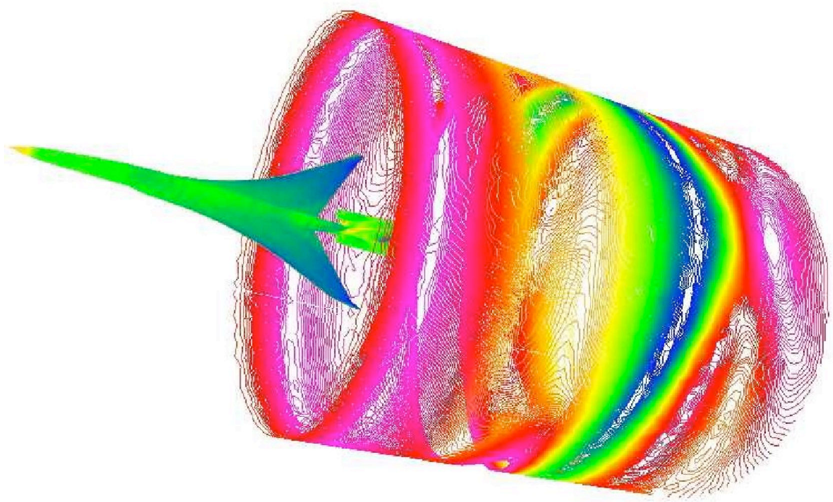
Fundamental Aeronautics Program

Supersonics Project

Reference Document



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This document was developed over the past several months by NASA to define the rationale, scope and detailed content of a comprehensive Fundamental Aeronautics Supersonic research project. It contains reference to past work and an approach to accomplish planned work with applicable milestones, metrics and deliverables. The document also references potential opportunities for cooperation with external organizations in areas that are currently considered to be of common interest or benefit to NASA. This document should be considered a reference document and not a completed research plan.

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1.0 Technical Plan

1.1 Relevance

This document is offered in response to the ARMD Fundamental Aeronautics Solicitation. The document defines a five year research project aligned with the ARMD principals of maintaining intellectual stewardship of aeronautical core competencies for the nation in the supersonic flight regime and of focusing research in areas that are appropriate to NASA's unique capabilities. The document supports the Fundamental Aeronautics (FA) Program strategy of developing systems level multidiscipline capabilities for supersonic civilian and military applications.

NASA investment in such capabilities is timely and appropriate. From before the first flight of the X-1, through the development of early supersonic military and civilian aircraft designs, to the understanding of Solid Rocket Booster plume effects on the supersonic performance of the Space Shuttle, NASA's researchers and facilities have played a key role in finding the solutions to the problems of supersonic flight. At the present time, this expertise is being called on again to assist the nation in overcoming new challenges in the supersonic flight regime. Recent advances have contributed to a resurgent interest in supersonic cruise flight. Sonic Boom reduction technology may make overland supersonic cruise a reality. However, it is only through NASA investment in new technologies and improved design methods that the benefits of increased cruise speed will become a reality for the general public. These benefits include improved quality of life through reduced travel time for business and pleasure, rapid delivery of high value cargo including time critical medical items and rapid response of disaster first responders. Supersonic cruise technology is also of interest to the U.S. Department of Defense Agencies. DOD studies have indicated that the capability of rapidly striking targets at long range could be a key element of the U.S. future defense strategy. Supersonic cruise vehicles are considered to be potentially important elements of this strategy. The significant barrier common to both military and civilian supersonic cruise is efficiency. One representation of the magnitude of efficiency improvement required to make such systems viable is shown in figure 1.1a (*AIAA 2002-0143, Quiet Supersonic Platform Program, Wlezien, Dr. R; and Veitch, Dr. L.*). It is clear that breakthroughs are required to achieve such improvements. For civil aircraft, the technical challenges are even greater. Similarly high levels of efficiency must be achieved under strict limits on environmental factors such as airport noise, sonic boom, and high altitude emissions.

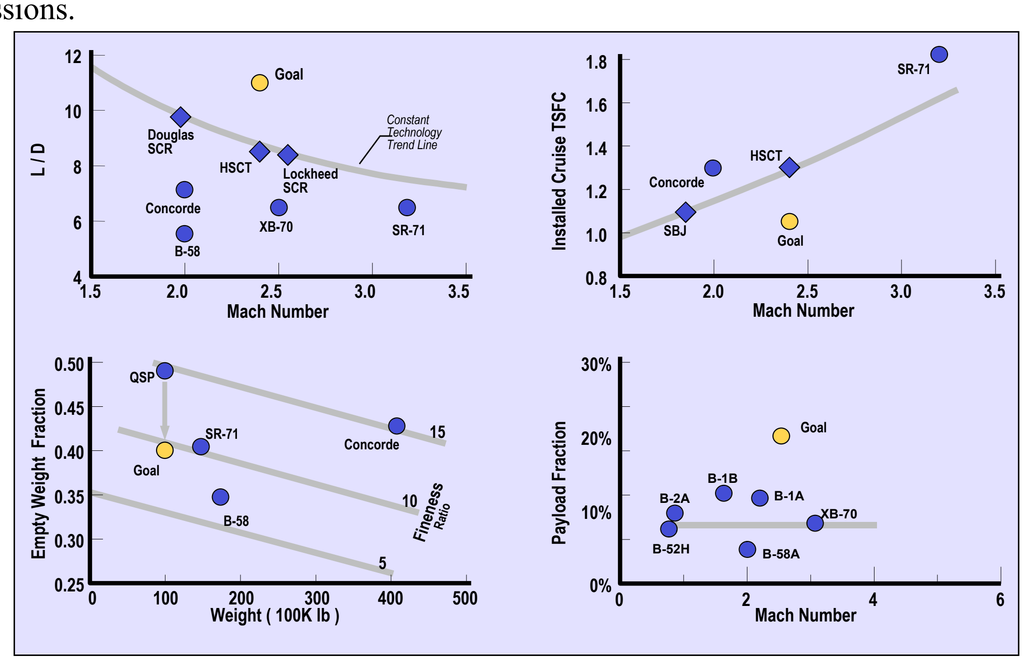


Figure 1.1a, Supersonic efficiency improvements required to develop a small, high payload supersonic vehicle

Vehicle operations in the atmosphere of other planets and moons represent an entirely different set of supersonic flight challenges. As illustrated in figure 1.1b, one example is the use of supersonic parachutes or propulsion for Mars and other planetary entry, descent and landing (EDL) . Current plans for human and large science missions to Mars require increases in landed mass of nearly two orders of magnitude over the current maximum capability of approximately one metric ton. Success of these missions will be dependent in part on developing new analytical tools that can be used to minimize the design cycle and qualification cost of EDL systems.

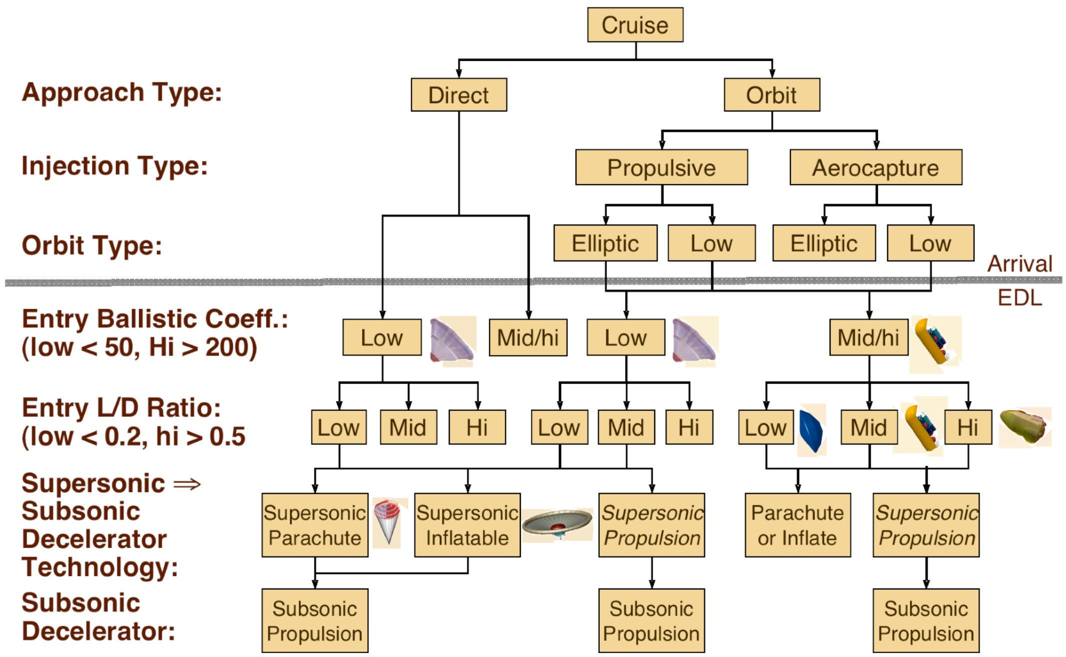


Figure 1.1b Mars EDL Decelerator Taxonomy. Extracted from "The Mars EDL Problem" Powell, et al., presentation to the NASA EMB April 4, 2006

Hypersonic cruise and ascent systems fly in the supersonic regime for certain portions of their flight profile. Certain aspects of the aerodynamic, aerothermodynamic and structural response analysis of these vehicles utilize methodology unique to supersonics. Improving these methods is an important aspect of reducing the uncertainty and related large engineering margins associated with current hypersonic system design.

The Supersonics Project team has defined a broad based research program that addresses the challenges of supersonic flight through the development of ***knowledge, capabilities, and technologies*** at the foundational, discipline, multidiscipline and systems levels. The team's plan is built on the accomplishments of the Fundamental Aeronautics planning workshops that were held in the fall of 2005. In those workshops, NASA researchers with experience in supersonics disciplines worked together to define the full scope of technical issues for this speed regime. As part of the process, the concept of these four levels of integration was utilized to develop a "level diagram", which described the essential discipline activities, and their interactions at increasing levels of integration. The Supersonics Project team has refined those workshop results through interaction with industry, government and academic experts, and continued interaction with NASA's internal expertise. The resulting program plan is summarized in the "level diagram" shown in Figure 1.1c.

The proposed effort consists of a set of linked activities that build up from Level 1, as shown in Figure 1.1c. At this level, the activities address the development of physical ***knowledge*** in the foundational disciplines such adaptive grid generation for flows with multiple, intersecting shock waves and material property development for high temperature metals and composites. Knowledge developed at this level is broadly applicable. In the implementation of these research activities, the Supersonics Project team recognizes that there are opportunities to partner with activities in other FA Thrust Areas, other ARMD projects, and the other NASA mission directorates. The Level 1 knowledge is incorporated into improved ***capabilities*** at Level 2. These capabilities include improved discipline tools for aerodynamic force and moment prediction, flow control, structural life prediction and combustor emissions calculations. At Level 3, improved discipline capabilities are integrated to develop new ***systems level capabilities*** primarily at the integrated airframe and integrated propulsion system. Examples of this integrated capability are inlet control system design, variable cycle engine operability, aeroservoelastic analysis and optimization and highly efficient configuration design. These discipline and systems level capabilities are envisioned to be applicable to multiple supersonic vehicle types, and will leverage not only related research activities in NASA, but DOD research programs as well. The ultimate integration occurs at Level 4. At this level ***multidiscipline design and analysis capabilities*** link airframe and propulsion systems capabilities to provide the integrated solutions to the challenges of supersonic flight. At all levels, particularly at Level 2 and 3, the development of discipline and systems level capabilities will lead to the creation of new ***technologies***, which in themselves may represent a solution, or part of the solution to one of the major supersonic technical challenges.

In developing the level 4 plans, the Supersonics Project team recognized a need to focus on a relevant subset of the supersonic technology challenges. The team has selected challenges in two different vehicle classes. The first challenge is eliminating the efficiency, environmental and performance barriers to practical supersonic cruise vehicles. For the second challenge area the Supersonics project team is proposing to address supersonic methodology and technology for the High Mass Mars Entry System (HMMES) in partnership with the Hypersonics project team. Recognizing that the solutions to the challenges for both vehicle classes are highly integrated, the team is proposing to partner with both the Hypersonics and Subsonic Fixed Wing teams to develop rapid Multi-disciplinary Design, Analysis and Optimization methods and frameworks that this team can in turn apply to its selected vehicle class challenges. The Supersonics team has identified a set of major technical challenges associated with the two selected vehicle classes.

Efficiency Challenges

Supersonic Cruise Efficiency: To achieve economic viability, supersonic cruise civil aircraft need to achieve unprecedented levels of cruise efficiency, without excessively penalizing performance in other speed regimes. Cruise efficiency, comprising airframe and propulsion efficiency needs to be increased by a combined total of approximately 30% in order to provide the required supersonic cruise range.

Light Weight and Durability at High Temperature: Significant reduction in high temperature airframe and propulsion system weight is a key element of achieving practical supersonic flight. New material and structural systems must achieve these weight targets without effecting life or damage tolerance. Overall, a reduction on the order of 20% of structural and propulsion system weight is envisioned to be required.

Environmental Challenges

Airport Noise: Supersonic aircraft must meet the same airport noise regulations as subsonic aircraft, without incurring significant weight or cruise performance penalties. This challenge is particularly difficult because supersonic cruise requires lower bypass ratio than state-of-the-art subsonic aircraft. Approximately 20 EPNdB of jet noise reduction relative to an unsuppressed jet will be required to meet this challenge.

Sonic Boom: In order to achieve maximum utility, supersonic overland flight must be achievable. This requires that the aircraft must be designed and operated so that no unacceptably loud sonic boom noise is created over populations. It is estimated that a reduction of loudness on the order of 30 PLdB relative to typical military aircraft sonic booms will be required.

High Altitude Emissions: Supersonic aircraft cruise most efficiently at altitudes where exhaust emissions have a potentially large impact on the atmosphere. The impact must be minimized or eliminated. As an example, the emission of oxides of Nitrogen must be reduced from 30 g/kg of fuel to 5.

Performance Challenges

Aero-Propulso-Servo-Elastic (APSE) Analysis and Design: Slender supersonic aircraft exhibit unique Aero/Propulsive/Servo/Elastic behavior. Controlling this behavior is key to designing a vehicle that is safe, comfortable and easy to fly. Controlling flutter, gust, and maneuver loads in a manner that is synergistic with the vehicle structural design, is an important element of reducing empty weight.

Entry Descent and Landing Challenges

Supersonic Entry Deceleration: Critical phases of planetary entry descent and landing occur at supersonic speeds. Envisioned exploration systems will required a 2 order of magnitude increase in landed mass, with improved position accuracy. New supersonic deceleration systems need to be conceived, designed and validated for these missions.

Multidisciplinary Design, Analysis and Optimization Challenges

Understanding and exploiting the interactions of all these supersonic technology challenges is the key to the creation of practical designs. This requires the development of a flexible integration framework in which variable fidelity analysis tools can be used in a "plug and play" fashion depending on the type of problem being studied.

The fundamental research activities will rely primarily, but not exclusively, on the combined expertise of NASA researchers. In order to supplement critical missing as well as complimentary skills, this effort will bring additional expertise to the execution of this program in the following manner:

1. Involvement of the university and industry communities through a NASA Research Announcement (NRA) solicitation and partnering with the existing University Affairs Offices at each center to leverage the existing NASA educational programs (e.g., Graduate Student Research Program, NASA Faculty Fellowship Program, NASA Postdoctoral Program). Critical missing expertise at NASA will be highlighted in the NRA process in order to compliment the NASA effort.
2. Solicitations through the use of the SBIR and the STTR mechanism to bring the talent of small businesses and industry to participate jointly or separately. The request for proposals will be structured along discipline topics.
3. Industry involvement through the use of consortia. The Industry RFI activity has occurred, and based on those responses, cooperative efforts will be defined.
4. Government agencies have been invited to participate with NASA in areas of common need.

The combined aeronautical talent and skills resident in our federal agencies, universities, small businesses and industry constitute a workforce that has the capability to meet the major technical challenges highlighted above.

SUPERSONICS

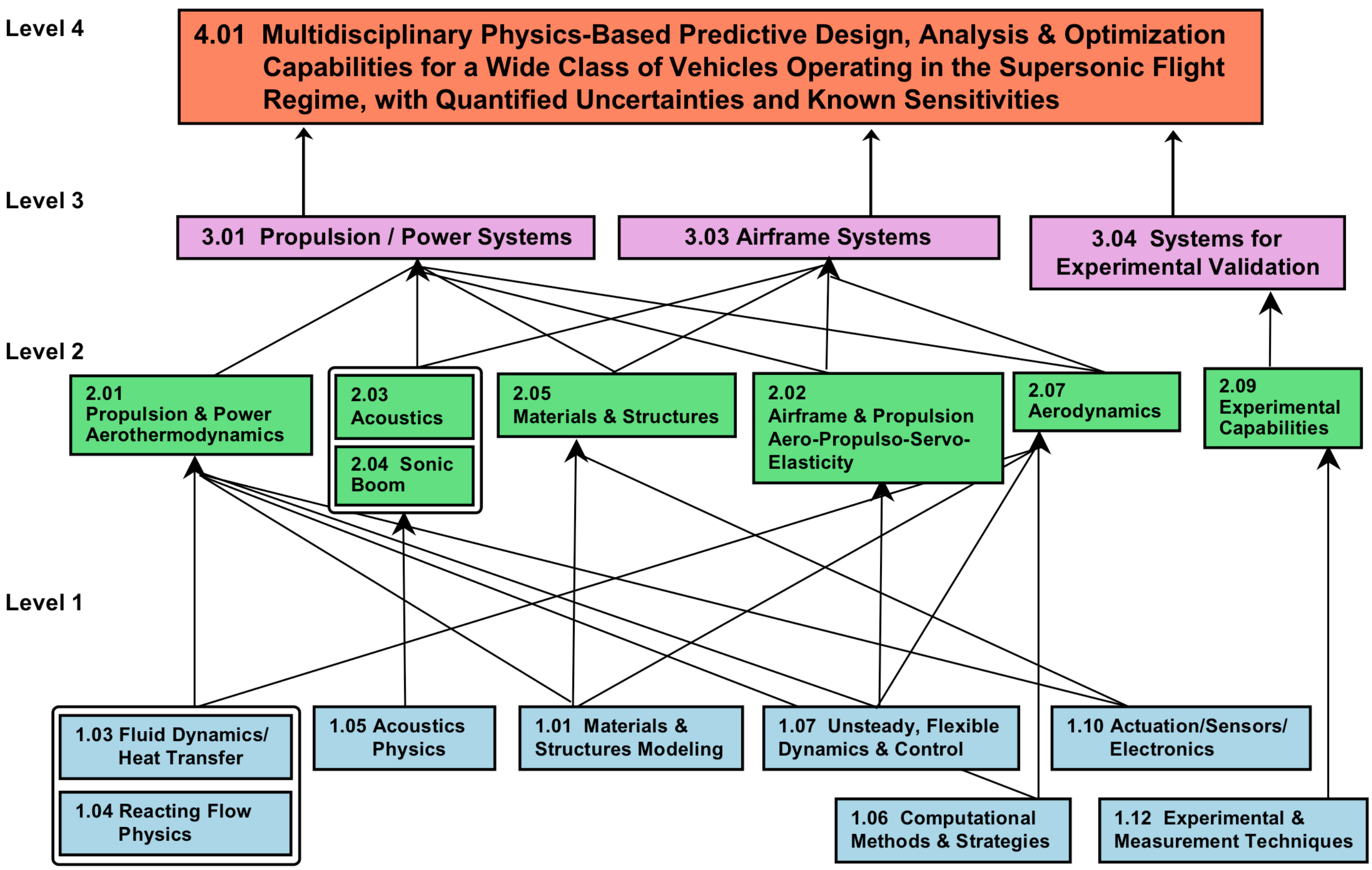


Figure 1.1c—Supersonics Level Diagram

1.2 Milestones and Metrics

The Supersonics project FY07-FY11 milestones are defined in Section 1.3 -Technical Approach for each of the Level 1 through Level 4 task areas. A compilation of the Level 1 through Level 4 Supersonics project milestones can also be found in Appendix A. The 10-year Milestone Roadmap (Figure 1.2.a) is a refined version of the one defined during the FAP workshop. Level 3 and 4 milestones are shown in Figure 1.2.a. The color of a Level 3 milestone represents the Level 4 milestone that it supports. The Level 3 and 4 milestones shown here are also representative of the prioritization in time of the major technical challenge areas. Although there is, for the most part, continuous work relative to all major technical challenges, the focus of the activities, particularly the systems level demonstrations, changes over the duration of the project. The 5-year Milestone Roadmaps (Figure 1.2.b) depict the proposed Level 1 through 4 project milestones for FY07-FY11.

The project anticipates that Level 3 and 4 milestones will be documented and tracked in an FAP guided configuration control process and Level 1 and 2 milestones will be documented and tracked in a project level process implemented by the Supersonics management team. Milestone reporting to the FAP and supporting centers will be summarized in a Quarterly Management Report (QMR) per FAP and center guidelines. As more detailed industry & OGA collaborations, and NRA tasks are incorporated into the detailed Supersonics plan, these efforts will be entered into the project milestone registry and configuration control process.

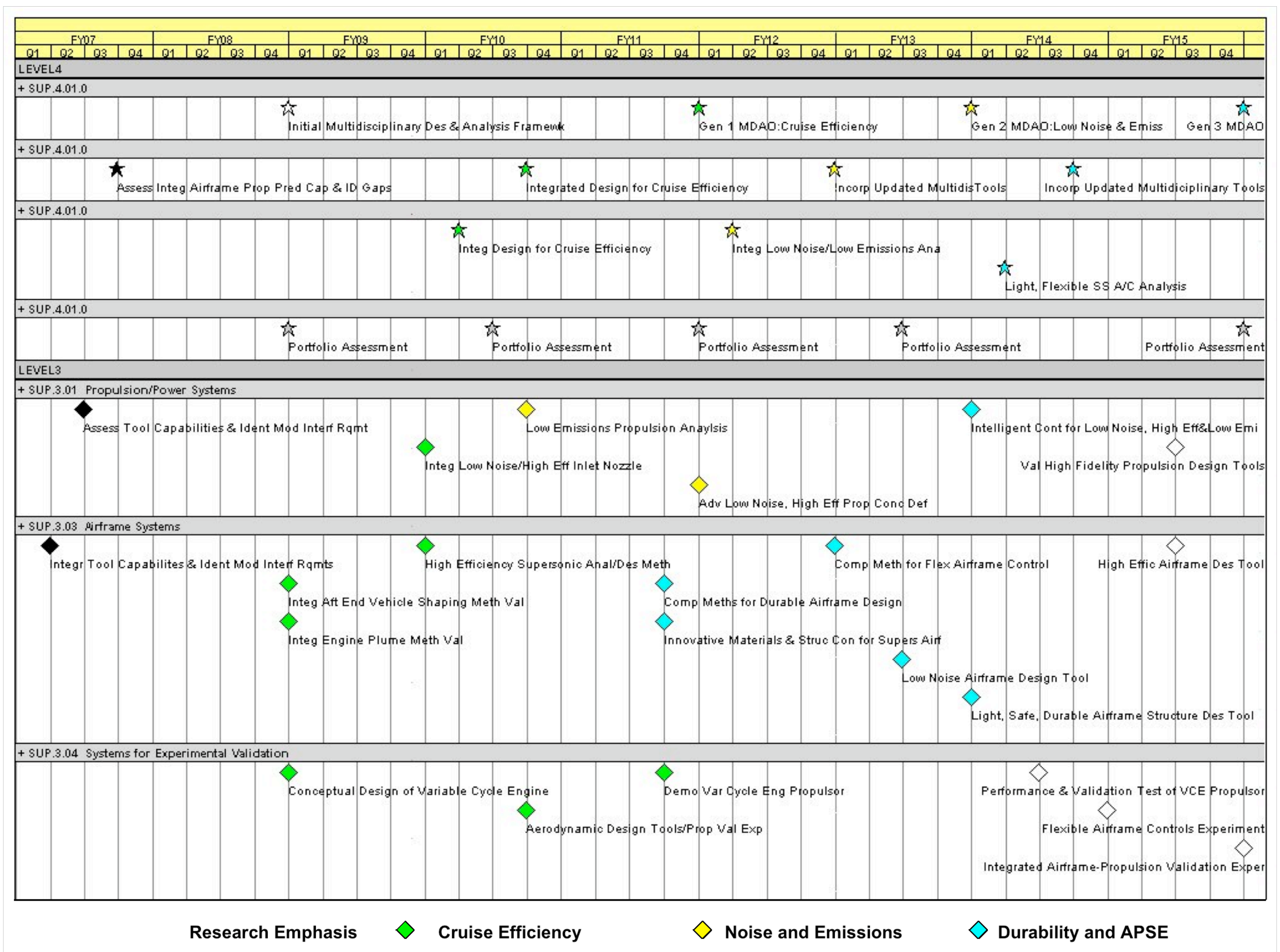


Figure 1.2.a—10-year Milestone Roadmap (FY07-FY16)

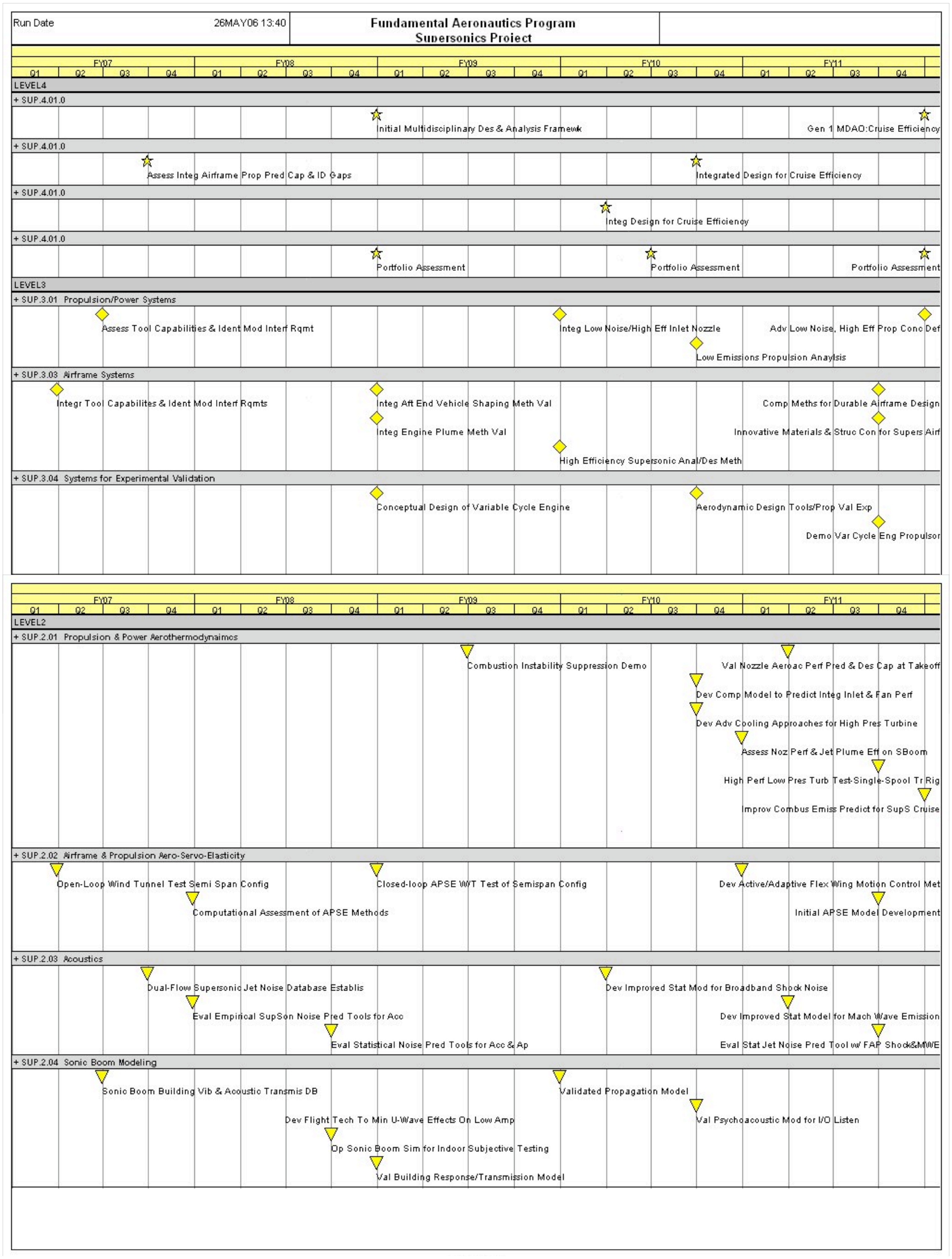


Figure 1.2.b—5 year Level 1 through Level 4 Milestone Roadmap (FY07-FY11)

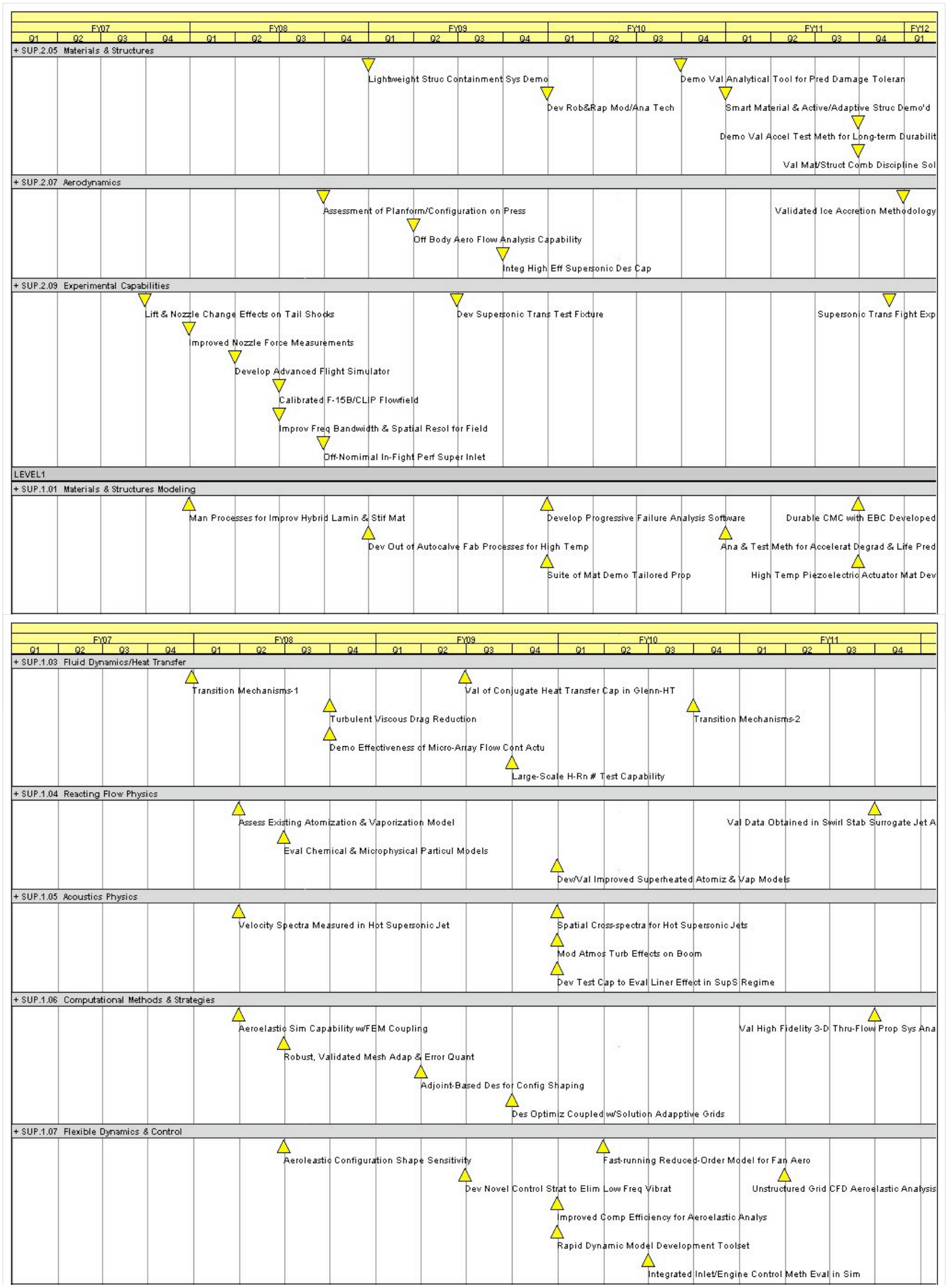


Figure 1.2.b—5-year Level 1 through Level 4 Milestone Roadmap (FY07-FY11) (cont'd)

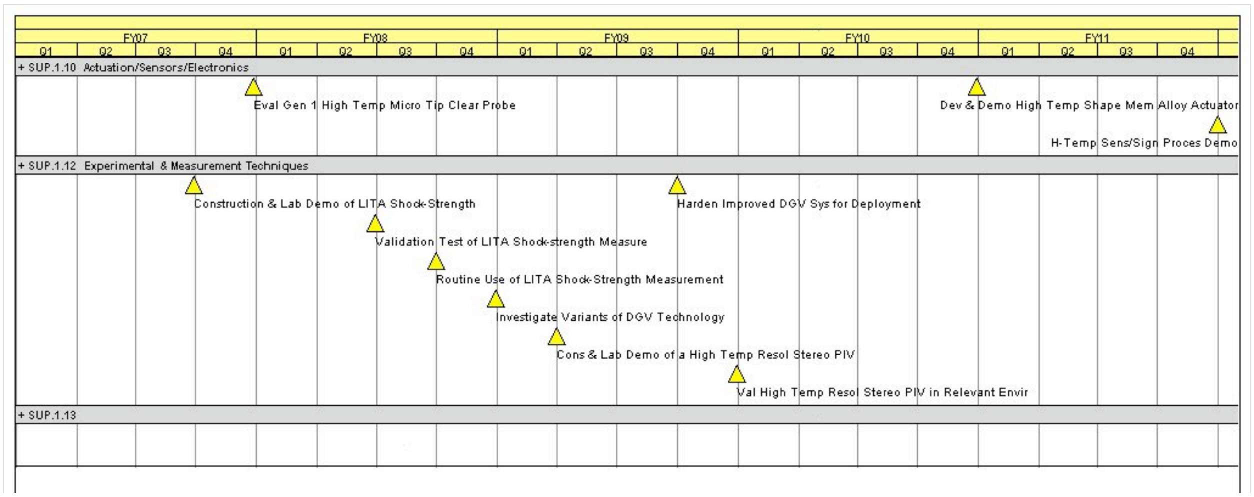


Figure 1.2.b—5 year Level 1 through Level 4 Milestone Roadmap (FY07-FY11) (concl)

1.3 Technical Approach

In this section the problem statement, previous related work, proposed research approach, technology validation strategy, key deliverables, milestones, and overall resources required for each of the Level 1 through 4 elements are discussed. The numbering scheme corresponds to the Level diagram in Figure 1.1 starting with 1.01 Materials and Structures Modeling through 4.01 Multidisciplinary Physics-Based Tools. Note that elements 1.02 Mechanics, Surface, and Tribological Science, 1.11 IVHM and Reliability, and 2.06 Mechanical Components & Tribology, which resulted from the original workshop, are not included in this document because these elements are being addressed as part of the other projects within FAP. Additionally, elements 1.08 Control Methods & Strategies and 1.09 Dynamic Modeling and Simulation have been incorporated into the renamed element 1.07 Flexible Dynamics and Control; furthermore element 2.08 Guidance, Navigation, Controls & Dynamics has been incorporated into the renamed element 2.07 Airframe & Propulsion Aero-Propulso-Servo-Elasticity (APSE).

SUP.1.01 – Materials and Structures Modeling

SUP.1.01 Materials & Structures Modeling – Major Technical Challenges Addressed			
X	Supersonic Cruise Efficiency	X	High Altitude Emissions Reduction
X	Lightweight and Durability at High Temperature		Aero-Propulso-Servo-Elasticity (APSE)
	Airport Noise Reduction	X	Supersonic Entry Descent and Landing
	Sonic Boom Modeling		Multidisciplinary Design, Analysis & Optimization

Problem Statement: Supersonic propulsion systems require advanced materials to enable long term durability at high temperatures and new concepts for weight reduction, increased efficiency, and reduced emissions. Supersonic airframes require lightweight high temperature material/structural systems and validated analytical methods for modeling their response to loading, damage and environmental conditions. In the materials area, high temperature resins, alloys and ceramics are needed, as well as hybrid material systems combining the best features of all materials.

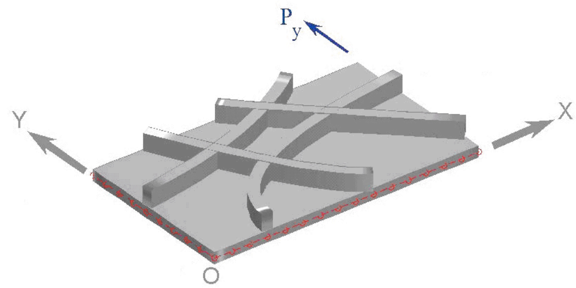
Previous Related Research: NASA's High Speed/ Ultra-Efficient Engine programs developed ceramic composites to increase combustor efficiency and power while retaining fabricability, durability, and oxidation protection. Advanced superalloy EPM103 airfoil and ME3 disk materials have problems with creep, fatigue, and environmental stability after long, high temperature supersonic cruise. Proposed concepts such as nanostructured 450°F polymers, aerogel, honeycomb, metallic foam, and lattice block, promise large payoffs for use in lightweight acoustic absorbers and containment structures when they mature. New, high temperature (300°C) shape memory alloys (Prop21) and piezoelectric ceramics will enable lighter, simpler, and more reliable control devices and morphing structures such as inlets, ducts and nozzles.

The proposed research leverages advancements in materials, processing, and fabrication technologies made by NASA and its contractors and university partners in the High Speed Research Program (HSR). HSR developed new high temperature resin systems and established extensive material databases for high temperature composite and metallic materials. The databases include the effects of temperature, humidity, and processing characteristics. The program also began the development of an approach to accelerated life prediction in advanced composite materials to quantify their long-term durability, new finite element analysis tools for composite and sandwich structures, and progressive failure analysis (PFA) analytical tools for damage tolerance in composite structures. The ITAS and Vehicle Systems programs developed non-autoclave processing and direct metal deposition methods that can be used for tailored material/structural concepts.

Research Approach

- Propulsion materials development, modification and validation. CMC performance will be modeled and verified as a function of fiber lay-up architectures and matrix additives. Knowledge of advanced EBC concepts will be gained to employ HfO_2/ZrO_2 moisture resistant top coats and chemically compatible silicate bond coats. Low conductivity Thermal Barrier Coating (TBC) materials will be improved by diffusionally stable cation clusters in multiply doped ZrO_2 lattices and further enhanced by creep-resistant segmented bond coats. Disk composition and microstructure will be tailored for expected temperature/stress regions and life modeled in thermo-mechanical fatigue. Novel acoustic absorber structures will be optimized for strength/density/toughness/impact by design models that take advantage of individual advanced polymer, aerogel, or metallic component properties. Advanced high temperature (e.g., clay modified) polymers (600 °F) will be developed and qualified in high temperature static, impact, and oxidative tests. New models and databases for creep, thermo-mechanical fatigue, environmental degradation, impact, and wear will be developed to enable life prediction for new high temperature materials. Thermodynamic assessments of the effects of alloying on phase stability will guide the development of new, NiPtTiHfX shape memory alloys with 500°C capability; the alloy will then be tested for energy/strain transformation output and oxidative/coating performance.

- Airframe materials development This work will emphasize modification of existing and synthesis of new materials in order to achieve the processing characteristics and high temperature performance required for supersonic aircraft. Non-autoclave fabrication for high temperature materials will be developed. A suite of PMC and hybrid laminate materials will be developed. Al/PMC laminates will be developed for speeds below Mach 2 and Ti/PMC laminates for speeds above Mach 2. The chemical, physical, and mechanical properties of the materials will be characterized, and performance will be validated through testing and analysis.



Structural concept with tailored stiffener array.

- Advanced laminated, hybrid, and sandwiched composites, New constitutive models will be developed for functionally graded materials, and smart materials. PFA tools will be extended to include more damage mechanisms and effects such as de-lamination, damage-stiffener interaction, and dynamic effects. The damage laws will also be developed for emerging material/structural systems. Long term durability will be evaluated for thermal, mechanical and moisture effects.

Technology Validation Strategy: Material developments will follow the classic strategy of generating material physics-based concepts, compositional design, fabrication, characterization, and validation testing of key constituents in world class materials laboratories. Concept feasibility will be demonstrated by combining computational design tools, materials processing and composite fabrication. The validation approach will include design, analysis and testing to prove tools at each step; from coupon to element to subcomponent.

SUP.1.01 Materials and Structures Modeling - Key Deliverables	Date
Computational design and manufacturing processes for high temp hybrid laminates	2007
Upgraded progressive failure analysis software for material / structural systems	2009
Durable ceramic matrix composite with environmental barrier coating	2010
Design and fabrication processes for combined discipline structural solutions	2010
High temperature piezoelectric actuator materials	2011

SUP.1.01 Materials & Structures Modeling- Milestones

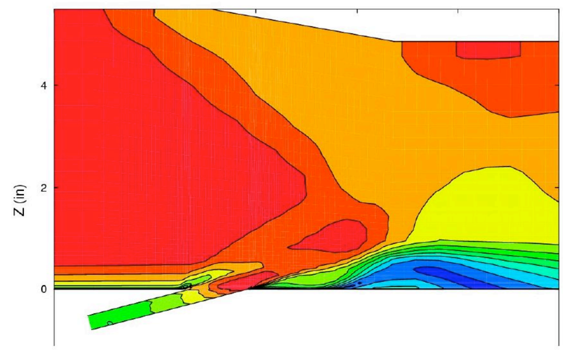
Number	Title	Year	Metric	Successors
SUP.1.01.01	Manufacturing processes for improved hybrid laminate and stiffened materials suitable for elevated temperature service	4Q2007	Demonstrate combined plasma spray/VARTM fabrication of a Ti-Gr reinforced hybrid laminate panel ≥ 1 ft^2 with less than 2% void content. First demo of metal on to carbon fibers	1.01.07, 2.05.09
SUP.1.01.03	Develop out of autoclave fabrication processes for high temperature composites	4Q2008	Selection of process that provides laminates with < 2% void content completed.	2.05.06
SUP.1.01.05	Develop progressive failure analysis software applicable to built up structure for existing and emerging material/structural systems	4Q2009	Experimental validation of predicted failure mechanism and load, within 15%, on simple stiffened coupon	2.05.06
SUP.1.01.07	Suite of materials demonstrating tailored properties related to controlled material properties, selective reinforcements, and design elements	4Q2009	Demonstrate the capability to adjust material anisotropy by 20% by altering reinforcement orientation and/or stiffener placement	2.05.09
SUP.1.01.08	Durable CMC with EBC developed	3Q2011	CMC with 15 ksi/1000 hours stress rupture and EBC with 1300ºC/1000 hours with ≤ 5 mg/cm2 weight loss developed.	2.05.07
SUP.1.01.10	Analysis and test methods for accelerated degradation and life prediction for materials subjected to long term mechanical /environmental cyclic loading conditions	4Q2010	Validation of coupled analysis/test methods allowing for accurate selection/ranking of material systems based on prediction (within +-10%) of time-based degradation and development of key damage mechanisms under realistic flight conditions completed. Validation results documented.	2.05.07
SUP.1.01.12	High temperature piezoelectric actuator materials developed	3Q2011	Material with: Transition Temp (goal = 600ºC) Piezoelectric Coefficient (400 pC/N) Frequency Response (up to 10 kHz) developed.	2.05.09

SUP.1.03 – Fluid Dynamics/Heat Transfer

SUP.1.03 Fluid Dynamics/Heat Transfer – Major Technical Challenges Addressed			
X	Supersonic Cruise Efficiency		High Altitude Emissions Reduction
X	Lightweight and Durability at High Temperature		Aero-Propulso-Servo-Elasticity (APSE)
	Airport Noise Reduction	X	Supersonic Entry Descent and Landing
	Sonic Boom Modeling		Multidisciplinary Design, Analysis & Optimization

Problem Statement: Develop and demonstrate fundamental understanding and improved fluid dynamic flow and heat transfer codes that will enable improved prediction methods for airframe and propulsion physics, including: (1) quiet tunnel environment; (2) high speed transition; (3) laminar flow concepts; (4) inlet analysis with minimum bleed and shock wave boundary layer interactions (5) elimination of flow separation and stall; and (6) improved heat transfer and cooling concepts.

Previous Related Research: Prior knowledge in high speed transition analysis and experiments, turbulent viscous drag reduction and general flow control issues is extensive but incomplete. In the turbulent boundary layer area significant advances have been made in understanding the physics. The state-of-the-art methods include numerical direct simulations, however effective control methodologies are still lacking.



CFD Solution of Microjet Installation.

Research Approach: The research approach in this area consists of a balanced approach investigating fluid dynamics and heat transfer issues for both airframe and engine. These are important, fundamental building blocks that will support a higher level integration within this thrust. Specific research areas include:

- Investigation of high speed transition will focus on analytical development and wind tunnel testing of models of increasing complexity in both quiet and conventional wind tunnel environments. The primary objective is a detailed, physics-based understanding of boundary-layer characteristics (stability, transition, etc.) at relevant conditions. The goal is to reach a high level of certainty in analytically describing simple body experiments with various relevant stability modifiers under known environmental conditions. A companion effort will study requirements and approaches for large scale, high Reynolds number validation.
- Turbulence and flow control work will focus on a continued search for effective intervention and control methodologies to lessen turbulent viscous drag, promote maximum laminar flow and avoid destructive interferences due to flow separation, shock boundary layer interactions and shock impingements.
- A research effort in supersonic flow control of shock wave boundary layer interactions is underway between NASA and AFRL/VA. NASA will provide CFD analysis and DOE method studies on the advanced flow control actuators to be tested at GRC. AFRL will integrate the advanced flow control actuators into a model system and conduct wind tunnel tests as well as independent CFD analysis.
- A combined approach of experimental and computational studies using the Glenn-HT code will be pursued to better understand the relevant physics of serpentine passage cooling. The effects of unsteadiness, rotation, turbulence length, and scale, surface roughness, transition, conjugate heat transfer, and other relevant physical phenomena on heat transfer and cooling performance will be investigated for improved cooling designs.
- Studies will examine various improved cooling concepts such as pre-cooled cooling air, pulsed cooling flows or flow control of the cooling circuits, swirled and impingement internal cooling concepts, and internal cavity flows. Pre-cooled cooling air is particularly advantageous for the supersonic flight propulsion system in order to lower the temperature of the turbine cooling air below the relatively high compressor discharge

temperature.

- Identification of the critical icing and flight conditions will be carried out in order to generate an experimental database, which will be used to develop improved predictive capability.

Technology Validation Strategy: Validation data for the CFD model of micro-array flow effectors will be acquired through laboratory testing in the 15cm x 15 cm wind tunnel. Data from a Honeywell single-stage HPT that is being tested at the Ohio State University Gas Turbine Laboratory funded by the existing URETI will be used to validate the conjugate heat transfer analysis capability. The flow control concept for flow attachment and transition control will be validated using data from small and large scale wind tunnel and flight experiments.

SUP.1.03 Fluid Dynamics / Heat Transfer - Key Deliverables	Date
CFD method for micro array boundary layer control	2008
Flow control concept for flow attachment and transition control	2009
Conjugate heat transfer analysis capability	2009
Requirements for large-scale and high Reynolds number test capability	2009
Validation of high speed transition prediction capability	2010

SUP.1.03 Fluid Dynamics/Heat Transfer- Milestones				
Number	**Title**	**Year**	**Metric**	**Successors**
SUP.1.03.01	Turbulent Viscous Drag Reduction	3Q2008	Net turbulent viscous drag reduction at cruise of 10% on a swept flat plate model	2.07.06
SUP.1.03.03	Transition Mechanisms-1	4Q2007	Documented, calibrated mean and fluctuation boundary layer profiles on swept surfaces. Experimental accuracy of mean quantities will be within 10% and unsteady quantities within 15 %	2.07.06
SUP.1.03.04	Large -Scale, High Reynolds Number Test Capability	3Q2009	Establish numerical validation requirements for test environment (wind tunnel and/or flight testing) to address scale and Reynolds number issues at cruise conditions	2.07.06
SUP.1.03.05	Transition Mechanisms-2	3Q2010	Documented, calibrated mean and fluctuation boundary layer profiles on swept surfaces. Experimental accuracy of mean quantities will be within 5% and unsteady quantities within 10%	3.03.09
SUP.1.03.07	Demonstrate effectiveness of micro-array flow control actuators	3Q2008	Demonstrate effectiveness of supersonic flow control on shock wave boundary layer interaction. Predictions of shape factor of boundary layer agree with experimental data to within +/- 10%.	2.01.05
SUP.1.03.08	Validation of conjugate heat transfer capability in Glenn-HT code	2Q2009	Demonstrate 10% improvement vs. current SOA in turbine heat transfer prediction using conjugate Glenn-HT code	3.01.05

SUP.1.04 – Reacting Flow Physics

SUP.1.04 Reacting Flow Physics – Major Technical Challenges Addressed			
	Supersonic Cruise Efficiency	X	High Altitude Emissions Reduction
	Lightweight and Durability at High Temperature		Aero-Propulso-Servo-Elasticity (APSE)
	Airport Noise Reduction		Supersonic Entry Descent and Landing
	Sonic Boom Modeling		Multidisciplinary Design, Analysis & Optimization

Problem Statement: The high temperatures encountered at supersonic cruise conditions provide unique challenges for reacting flows. These include understanding and modeling liquid fuel atomization and vaporization under very high temperature conditions, conjugate heat transfer, particulate transport and formation, particulate sampling and measurement techniques, detailed and reduced chemical kinetics, and validation databases. These are required in order to develop physics-based design codes that can be used to design combustion systems that demonstrate acceptable emissions performance at supersonic cruise conditions.

Aircraft particle emissions experiment.

Previous Related Research: A consortium of aerospace companies and government agencies developed a structured/unstructured grid, massively parallel, turbulent combustion, multi-phase CFD code, the National Combustion Code (NCC). NCC has been used to provide analysis support for aerospace propulsion technology projects, including the performance of modern combustor sector rigs and advanced fuel injectors for emissions reduction. Extensive work has been conducted in-house in applying and developing measurement techniques suitable for high pressure flames. Development of advanced techniques for detailed and reduced chemical mechanism analysis has also been ongoing at GRC.

Research Approach:

- Develop foundational knowledge at supersonic flight conditions- Leverage research from model development/validation tasks performed under the Subsonic Fixed-Wing document. Development and implementation of a superheated multi-component atomization/vaporization model and a conjugate/radiation heat transfer model will address issues due to the high fuel and air temperatures entering the combustor. Particulates research will be conducted in sampling methodology development and validation, emission database development and dissemination; and particle transport and transformation model development and validation. Aerosol collection probes will be evaluated to develop improved sampling systems. Existing datasets will be supplemented by conducting measurements in engine, aircraft, and combustor test venues. The data will be used to refine and validate soot and secondary aerosol formation models.
- Experimental validation- Utilize a suite of advanced diagnostic measurement techniques in a series of experiments to address mixing, swirl, chemical kinetics, liquid fuel evaporation and mixing, speciation, temperature and pressure effects. Use Raman spectroscopy to measure major species concentration and temperature, PLIF to measure jet fuel and minor species concentration, PDV and PIV to determine flow field velocity, turbulence intensity, and fuel drop sizes.
- Develop detailed chemical mechanisms- Utilize a series of laboratory scale kinetics experiments. This will be augmented by quantum mechanical calculation of those reactions and species properties not amenable to direct measurement. Alternative fuel formulations more suitable for the higher fuel temperatures encountered at supersonic cruise will also be investigated.

Technology Validation Strategy: This task will provide validation data pertaining to chemical kinetics, fuel composition, and high pressure diagnostics through the use of shock tubes, flow reactors, flame tubes, and high pressure burners.

SUP.1.04 Reacting Flow Physics - Key Deliverables	Date
Superheated vaporization model implemented and validated in URANS/VLES/LES	2009
Particulate microphysics model developed and validated in NCC	2009
Combustion code validation data at supersonic cruise conditions	2011

SUP.1.04 Reacting Flow Physics- Milestones				
Number	**Title**	**Year**	**Metric**	**Successors**
SUP.1.04.02	Assess existing atomization & vaporization models at superheated conditions	1Q2008	Documentation of predictions with available data completed. Baseline accuracy band established for drop size and mass distribution.	1.04.08, 2.01.04
SUP.1.04.04	Evaluate chemical and microphysical particulate models	2Q2008	Documentation of predictions with available data completed. Baseline accuracy band established for particle number and size distribution for 3 data sets.	1.04.06, 2.01.04
SUP.1.04.08	Develop/validate improved superheated atomization & vaporization models	4Q2009	Prediction of drop volume flux and Sauter Mean Diameter improved by 50% over the baseline models.	2.01.04
SUP.1.04.12	Validation data obtained in swirl stabilized surrogate Jet A fueled burner at simulated supersonic cruise conditions	3Q2011	Spatially-resolved, single-point, quantitative meas. of major species (N_2, O_2, H_2O, CO_2, CO, H_2, HC's) and temperature with less than 10% uncertainty. Publish results.	2.01.04

SUP.1.05 – Acoustics Physics

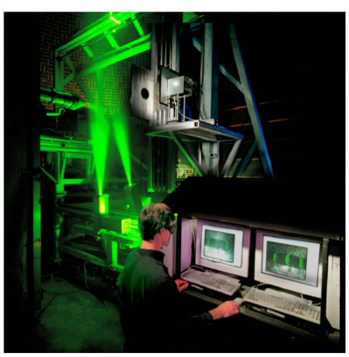
SUP.1.05 Acoustics Physics – Major Technical Challenges Addressed			
	Supersonic Cruise Efficiency		High Altitude Emissions Reduction
	Lightweight and Durability at High Temperature		Aero-Propulso-Servo-Elasticity (APSE)
X	Airport Noise Reduction		Supersonic Entry Descent and Landing
X	Sonic Boom Modeling		Multidisciplinary Design, Analysis & Optimization

Problem Statement: Development of physics-based acoustic prediction codes requires understanding of how turbulent flow creates acoustic sources and impacts the propagation of sound. The mechanisms of broadband shock noise, Mach wave emission, and turbulent scattering of sonic booms are not adequately understood to formulate robust physics-based prediction codes. The need for robust prediction/design tools for exploring supersonic jet noise reduction was identified in the NIA 2005 report, "Responding to the Call: Aviation Plan for American Leadership."

Previous Related Research: Fundamental aeroacoustic experiments have previously been conducted to provide understanding and models for prediction tools. Examples include large-scale PIV, Rayleigh-scattering based density spectral measurements, large-eddy simulations (LES) of jets, and in-flow acoustic liner characterization. A majority of this work was aimed at flow regimes pertinent to subsonic commercial flight. For supersonic aircraft new sound source mechanisms and propagation/absorption considerations may dominate at higher jet speeds.

Research Approach: Fundamental experiments will be conducted to support development and validation of noise creation and propagation models.

- High-order turbulence statistics, such as space-time correlations of velocity and temperature, will be obtained in hot supersonic jets for the first time using temporal PIV and Rayleigh-scattering techniques.
- Unsteady flow noise mechanisms unique to supersonic aircraft will be investigated experimentally to develop either ad hoc models or reduced order direct simulation methods: (1) unsteady interactions of supersonic jet plumes examined using twin jets, (2) noise of shock-induced separation in the divergent portion of convergent-divergent nozzles will be explored and characterized, (3) Mach wave emission will be explored using offset stream nozzles, 4) broadband shock noise dependence on shock structure and turbulence will be separated by tests using air-injection nozzles.
- Large Eddy Simulation (LES) methods will be developed as prediction tools and used as numerical experiments for advanced insight and model development for supersonic jet aeroacoustics. .
- Sonic Boom propagation through a turbulent atmosphere and into buildings will be modeled. Candidate methods include finite element and energy methods for building response and transmission. Probabilistic methods will be required for modeling propagation through turbulence.
- Fluid mechanics of acoustic liners in hot transonic ducts will be investigated using a modified duct facility with hot mixed transonic flow, allowing liner technology to be applied to supersonic aircraft.



Dual PIV systems for obtaining space time correlations in the SHJAR facility.

Technology Validation Strategy: High-order statistical methods will be validated in cold, low speed flows against accepted instrumentation. LES schemes will be validated against jet experiments with flow statistics measured by advanced PIV techniques. Sonic boom scattering models confirmed in small-scale facility and with flight tests undertaken in the SUP.2.04 Sonic Boom Modeling task.

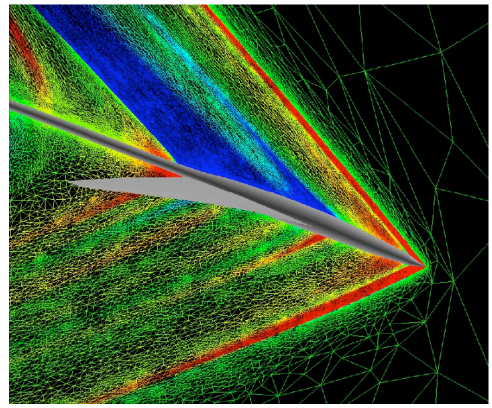
SUP.1.05 Acoustic Physics - Key Deliverables	Date
Velocity spectra datasets for developing noise models for hot supersonic jets	2008
Test capability for low supersonic/high temperature liner evaluation	2009
Spatial cross-spectra datasets for developing noise models for hot supersonic jets	2010
Validated sonic boom turbulence scattering model	2010

SUP.1.05 Acoustics Physics- Milestones

Number	Title	Year	Metric	Successors
SUP.1.05.02	Velocity spectra measured in hot supersonic jets	1Q2008	Map turbulent velocity spectra over first 20 jet diameters of round jets at temperature ratios between 1and 3 and Mach numbers from 0.5 to 2. Turbulence spectra repeatability within 10%.	1.05.05, 2.03.03, 2.03.04
SUP.1.05.05	Spatial cross-spectra for hot supersonic jet noise statistical prediction	4Q2009	Obtain space-time correlations of velocity components, transformed to wave number-frequency space covering two decades in each dimension. Cross-spectra repeatability within 15%.	2.03.04
SUP.1.05.08	Model atmospheric turbulence effects on boom propagation	4Q2009	Develop computational techniques to estimate mean and variance for the effect of turbulence on boom propagation within 25% of measured ground signature data	2.04.06
SUP.1.05.09	Develop test capability to evaluate liner effectiveness in low supersonic (M<1.2) regime, in the presence of high temperatures	4Q2009	Obtain baseline dataset of liner properties covering a range of transonic Mach numbers (M<1.2) at temperatures up to 1500ºF	2.03.07

SUP.1.06 – Computational Methods and Strategies

SUP.1.06 Computational Methods and Strategies – Major Technical Challenges Addressed			
X	Supersonic Cruise Efficiency		High Altitude Emissions Reduction
	Lightweight and Durability at High Temperature	X	Aero-Propulso-Servo-Elasticity (APSE)
	Airport Noise Reduction	X	Supersonic Entry Descent and Landing
X	Sonic Boom Modeling		Multidisciplinary Design, Analysis & Optimization


Error adapted mesh for near-field sonic boom prediction.

Problem Statement: The research goal is to develop and mature advanced computational methods and strategies to enable robust, efficient, and error quantified CFD analysis/design. This foundational knowledge supports the development of capabilities for highly efficient, environmentally compatible supersonic vehicle concepts, fully integrated within a variable fidelity framework for multi-disciplinary (MD), multi-objective optimization.

Previous Related Research: Current CFD approach relies on prior experience for grid construction, and on manual or gradient-based adaptation for subsequent grid refinements. The inefficiency of this process restricts the region of solution accuracy to a rather small number of body lengths surrounding the vehicle. This has adverse consequences on the accuracy of the ground level boom signature. Recent work has established the foundation for automated grid generation and error based adaptation to allow accurate propagation of shock waves in an efficient manner.

A 2001 NRC report identified the development of automated, high-fidelity, MD optimization tools and methods as one of the top five research areas required to achieve breakthroughs in supersonic technologies. Current SOA involves a combination of low-fidelity models iterated with supplementary analysis with high-fidelity simulations. This procedure is cumbersome, and conventional designs dominate. High-fidelity, multi-objective MD analysis and optimization has not yet become state of the art.

Research Approach: The core components of the proposed project include mathematically rigorous frameworks for:

- Grid adaptive CFD with built-in error quantification and sensitivity analysis.
- Variable fidelity optimization framework in multi-disciplinary context.

The technology maturation path combines a sequence of algorithmic and CFD process improvements with validation exercises ranging from adjoint based solution adaptation and sensitivity analysis for full flow field analysis, configuration shape optimization, to highly efficient, environmentally compatible configuration design. This ambitious effort with enormous cross-cutting benefits is tightly integrated with synergistic components of other FAP subprojects.

Technology Validation Strategy: A modular validation strategy based on unit problems, modern software development practices, and a formal verification and validation framework. Configuration geometry, and experimental data from SUP 2.07 and SUP 3.03 will be utilized to validate computational simulations.

SUP.1.06 Computational Methods and Strategies Key Deliverables	Date

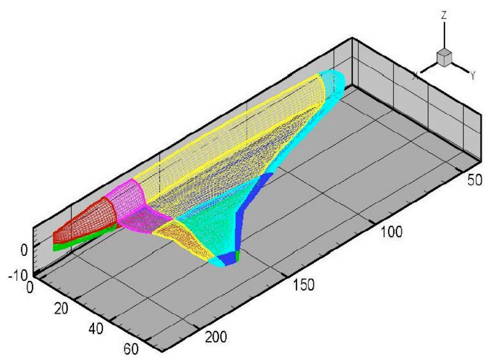
Aeroelastic simulation capability with FEM coupling	2008
Validated analysis tools with grid adaptive CFD for full flowfield configuration analysis	2010

SUP.1.06 Computational Methods & Strategies- Milestones				
Number	**Title**	**Year**	**Metric**	**Successors**
SUP.1.06.01	Aeroelastic Simulation Capability w/FEM Coupling	1Q2008	Demonstration of capability for tightly-coupled analysis of time-dependent aerostructural effects for a representative supersonic vehicle in one week.	2.07.06
SUP.1.06.02	Robust, Validated Mesh Adaptation and Error Quantification for Near field CFD	2Q2008	Demonstration of capability for near field CFD analysis to user-specified error tolerance in one day.	2.07.06
SUP.1.06.03	Adjoint-Based Design for Configuration Shaping	1Q2009	Adjoint based design for configuration shaping demonstrated. Direct design optimization of a configuration completed in two weeks.	2.07.06
SUP.1.06.04	Design Optimization Coupled w/Solution Adaptive Grids	3Q2009	Demonstration of capability for direct design optimization for constrained cruise efficiency in two weeks.	2.07.06
SUP.1.06.06	Validate the high fidelity 3-D through-flow propulsion system analysis with the Propulsor Simulator.	3Q2011	Compare the detailed performance and flow data from the “Propulsor Simulator” at critical flight conditions with predictions of measured thrust within 10%.	3.04.04, 4.01.05

SUP.1.07 –Flexible Dynamics and Control

SUP.1.07 Flexible Dynamics and Control – Major Technical Challenges Addressed			
X	Supersonic Cruise Efficiency		High Altitude Emissions Reduction
	Lightweight and Durability at High Temperature	X	Aero-Propulso-Servo-Elasticity (APSE)
	Airport Noise Reduction		Supersonic Entry Descent and Landing
	Sonic Boom Modeling		Multidisciplinary Design, Analysis & Optimization

Problem Statement The unique structural configuration of supersonic aircraft combined with nonlinear unsteady aerodynamics and rigid-body dynamics yields highly complex, nonlinear, dynamic phenomena. These phenomena can affect ride quality, gust loads, and flutter. In addition, sub-optimal wing deformations and/or engine/inlet orientations to the freestream flow will have an undesirable impact on cruise efficiency. The engines of a supersonic aircraft may also encounter various aeroelastic vibration problems as well associated with a required wide range of operation. Such vibrations can lead to high dynamic stresses that would severely limit the high cycle fatigue life of the blades. These challenges point to the need for collaborative development of aeroelastic, dynamics and control tools and technologies. Collaborative development will enable subsequent integration of these tools and technologies into a design methodology applicable to integrated airframe-propulsion analysis.



CFD grid of supersonic configuration.

Previous Related Research: The state-of-the-art aeroelastic/flight dynamic analysis for airframe and propulsion design relies primarily on linear methods. Although highly efficient, linear methods cannot predict the nonlinear coupled aeroelastic/flight dynamic interactions at transonic speeds. Current approaches for high fidelity aeroelastic modeling are based on the coupling of a three-dimensional CFD code to a structural dynamic model but at a high computational cost. Traditionally, an assessment of the cruise efficiency of an engine presumes that the engine is attached to a rigid, steady wing. Methodology supporting the modeling of the flexible, unsteady nonlinear dynamics of a slender supersonic aircraft have been proposed, but not fully developed.

Research Approach: Development/validation of nonlinear aeroelastic/flight dynamic analysis and design techniques and nonlinear engine aeroelasticity methods.

- Improve airframe aeroelastic/flight dynamic prediction, including body freedom flutter, utilizing non-linear analysis
- Improve computational efficiency in nonlinear aeroelastic analysis (airframe and engine) through incorporation of methods such as the Harmonic Balance approach and Reduced-Order Modeling techniques
- Rapid flight dynamic model development and related rigid-body control strategies
- Rapid design level analysis and sensitivity analysis.
- Integrated system dynamic models will be developed for integrated inlet/engine control. System identification methods for flexible aircraft with unsteady aerodynamics will be developed. Novel sensors and intelligent automated testing methods will be developed. Investigations of adaptive, robust, reconfigurable, uncertain, and distributed decentralized control design methods will be undertaken to improve safety of supersonic aircraft. The aforementioned tasks will require collaboration with universities and industry.

Technology Validation Strategy: Collaboration with airframe and engine companies and other government organizations will be established in order to develop an aeroelastic/flight dynamic test & validation database. Collaborative analytical validation against this data will be conducted.

SUP.1.07 Flexible Dynamics and Control - Key Deliverables	Date
Rapid flight dynamic model development and related control strategies	2009
Integrated inlet / engine control methodology and simulation results	2010
Aeroelastic analysis tools with improved computational efficiency (airframe, engine)	2011
Unstructured Grid CFD tool for aeroelastic analysis	2011

SUP.1.07 Flexible Dynamics and Control- Milestones				
Number	**Title**	**Year**	**Metric**	**Successors**
SUP.1.07.01	Improved computational efficiency for aeroelastic analysis	4Q2009	Demonstrate 50% reduction in airframe flutter boundary analysis cycle time with prediction accuracy within 15% of high-fidelity model.	2.02.05, 2.02.06
SUP.1.07.05	Aeroelastic configuration shape sensitivity	2Q2008	Complete integration of configuration shape sensitivity analysis in an aeroelastic analysis system; Demonstrate 30% improvement in vehicle design cycle time using these methods	2.02.06
SUP.1.07.03	Fast-running reduced-order Navier-Stokes model for fan aeroelastics	1Q2010	Demonstrate 75% reduction in analysis cycle time as compared to a full-order Navier-Stokes calculation; within 80% accuracy of the full-order Navier-Stokes calculation for prediction of engine fan flutter and dynamic stresses.	2.01.05
SUP.1.07.06	Unstructured grid CFD aeroelastic analysis	1Q2011	Complete initial demonstration of an unstructured grid CFD based unsteady aero solution in an aeroelastic analysis system; Demonstrate accuracy to within 5% error of experimental loads and flutter data	2.02.08
SUP.1.07.07	Integrated inlet/engine control methods evaluated in simulation	2Q2010	Safe operating envelope (angle of attack and sideslip) for the aircraft with integrated inlet/engine control increased by 10% and 90% rise time for thrust transients decreased by 10% over the baseline separate inlet and engine control design.	2.02.08, 2.01.05
SUP.1.07.08	Develop novel control strategies to eliminate low frequency vibrations in long slender aircraft configurations	2Q2009	Demonstrate improvement in flying qualities for representative flexible vehicle in offset landing approach task with turbulence from HQ Levels II-III to Level I per MIL-STD-1797 in piloted motion simulation.	2.02.08
SUP.1.07.09	Rapid dynamic model development toolset	4Q2009	Demonstrate verified implementation of a complete simulation package in 3 work months or less (50% reduction) in time	2.02.08

SUP.1.10 – Actuation/Sensors/Electronics

SUP.1.10 Actuation/Sensors/Electronics – Major Technical Challenges Addressed			
X	Supersonic Cruise Efficiency	X	High Altitude Emissions Reduction
	Lightweight and Durability at High Temperature		Aero-Propulso-Servo-Elasticity (APSE)
	Airport Noise Reduction	X	Supersonic Entry Descent and Landing
	Sonic Boom Modeling		Multidisciplinary Design, Analysis & Optimization

Problem Statement: Present supersonic systems have extremely limited monitoring of operating parameters or ability to respond to changing conditions especially in extreme environments. In order to enable future supersonic cruise flight vehicles that are efficient and environmentally compatible, the inclusion of intelligence into the system design and operation is necessary. The supersonic system will have to incorporate technology that will monitor system conditions, analyze the sensor data, and modify the operating parameters to achieve improved performance. In particular, measurement and actuation technology development is needed relative to the supersonic major technical challenges of supersonic cruise efficiency, sonic boom and high altitude emissions reduction.

Previous Related Research: These tasks are based on years of research in related areas. For example, previously a scanning mode shock position sensor has been invented and demonstrated. Silicon carbide (SiC) systems have demonstrated significant potential with e.g. world record prolonged (>2000 hrs) operation of SiC transistor as well as corresponding development and testing of high-temperature SiC pressure sensors and actuators, as well as a high temperature electronics nose including SiC elements. A microwave tip clearance sensor approach has been developed allowing high temperature engine operation combined with initial development of high temperature shape memory alloys for shape memory alloy actuators. The development of sensor and actuator technology related in a closed loop emissions control system improves the data fed to that system and its ability to control system responses.

Research Approach: The activities within this task include:

- Smart Lightweight Actuators - Develop "smart," lightweight actuators using active materials and high temperature microwave blade tip clearance sensors capable of operating under the engine simulated combustion conditions.
- High temperature sensors and signal processing- A high sensitivity, wide bandwidth pressure sensor capable of operating reliably at elevated temperatures will be developed to detect the onset of instabilities for active combustion control. The pressure and SiC based gas sensors will be integrated with SiC electronics for signal processing and communications. The approach is to develop smart sensor systems that, where appropriate, will be able to process the raw sensor outputs, compensate for the effects of temperature and other external influences, and send only relevant information to system controllers.

Technology Validation Strategy: Performance evaluation of the sensor/actuator/electronic system will typically take place in ground test facilities including wind tunnels, test chambers, and combustion rigs. Interest has been expressed by industry to test sensor systems and this has previously been done to validate technology.

SUP.1.10 Actuation/Sensors/Electronics - Key Deliverables	Date
High temperature sensors/actuators/signal processing	2011
Demonstration of high temperature microwave blade tip clearance probe and a high temperature shape memory alloy actuator	2011

SUP.1.10 Actuation/Sensors/Electronics- Milestones				
Number	**Title**	**Year**	**Metric**	**Successors**
SUP.1.10.07	Develop and demonstrate high temperature shape memory alloy actuator utilizing novel SMA materials	4Q2010	Bench top test of shape memory actuator at temperatures up to 450C in air with a range of motion of up to 0.05 inch in an active feedback with measurements from tip clearance probe.	2.05.09
SUP.1.10.13	High Temperature sensors/signal processing demonstrated -	4Q2011	Demonstrate operation of sensor with electronics to determine an environmental state and process the data at 500C for 100 hours	2.01.04
SUP.1.10.14	Evaluate Gen 1 high temperature microwave tip clearance probe under engine simulated conditions	4Q2007	Test microwave tip sensor up to 1100 C or failure in engine simulated conditions.	2.05.09, 1.10.07

SUP.1.12 – Experimental Measurement Techniques

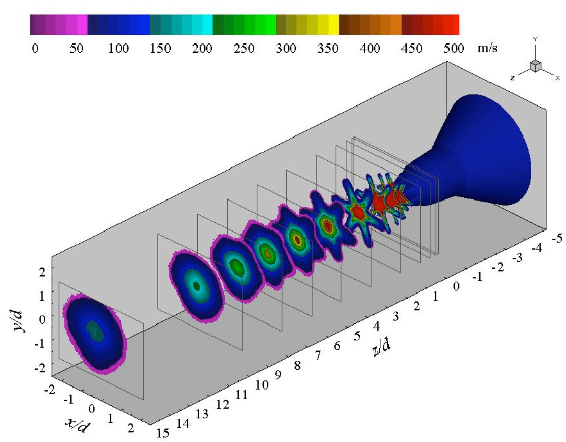
SUP.1.12 Experimental Measurement Techniques – Technical Challenges Addressed			
X	Supersonic Cruise Efficiency		High Altitude Emissions Reduction
	Lightweight and Durability at High Temperature		Aero-Propulso-Servo-Elasticity (APSE)
X	Airport Noise Reduction	X	Supersonic Entry Descent and Landing
X	Sonic Boom Modeling		Multidisciplinary Design, Analysis & Optimization

Problem Statement: Multi-disciplinary diagnostic technologies applicable to problems in aerothermodynamics, propulsion systems, supersonic inlets, and acoustics, are needed to support the goals of the Supersonics project. Validation of new airframe designs and propulsion systems and validation of physics-based CFD codes requires accurate non-intrusive measurements of off-body flow field properties. Maturation of existing diagnostics and development of new diagnostics can provide the higher temporal and spatial resolution flow field mapping, shock-position determination, and state variable measurement needed. Novel application of fiber optics and robust schemes for signal detection and processing can greatly ease integration into test facilities, lower costs, and pave the way to integrated vehicle sensor systems.

Previous Related Research: Traditional flow measurement techniques have been the backbone of supersonic off body flow field measurements for many years. Although reliable and accurate, they are intrusive and limited data collection rate. Multi probe measurements have been demonstrated, but have only shown small improvements. The current state of the art in optical diagnostics enables high spatial resolution, planar measurement of the mean flow velocities. State variable properties at discrete points in space can also be measured.

Research Approach: For the wide range of flow properties desired, a multifaceted approach will be pursued.

- Rapid off body pressure measurement. The utility of longitudinal and lateral multi-port pressure measurement to improve off body data collection rates will be investigated.
- Particle Image Velocimetry (PIV). Use of CMOS camera technology and metal machining lasers to enable high temporal resolution measurements will be studied.
- Doppler Global Velocimetry (DGV). Time averaged velocity measurements and fiber optic bundles for imaging scattered light will be studied to reduce overall system cost/complexity and simplify implementation.
- Schlieren Shock Measurements. The Background Oriented technique will be used to track complex shock interactions, with the potential for real time feedback. Digital imaging based large scale schlieren systems will enable the study of shock structures around full scale aircraft in flight.
- Laser Induced Thermal Acoustic (LITA) The development of robust transmission and detection optics will facilitate the implementation of point-based techniques for the measurement of temperature, pressure and velocity.
- In-flight Infrared Thermography. Digital recording techniques and advanced cameras will be investigated.



Particle Image Velocimetry measurements of a mixing enhanced chevron nozzle at GRC in 2004.

Technology Validation Strategy: The diagnostic techniques developed here will first be demonstrated in lab scale flows. Second level applications will be in relevant supersonic environments such as GRC's Nozzle Acoustic Test Rig, Langley's Unitary Plan Wind Tunnel, and Ames' Unitary Wind Tunnel.

SUP.1.12 Experimental Measurement Techniques - Key Deliverables	Date
Demonstration of time resolved PIV in supersonic nozzle flows	2010
LITA shock-strength measurement validation test at UPWT	2008
Improved-technology DGV validation test at UPWT	2010

SUP.1.12 Experimental Measurement Techniques- Milestones

Number	Title	Year	Metric	Successors
SUP.1.12.02	Construction and laboratory demonstration of LITA shock-strength measurement system	3Q2007	Demonstrate differential pressure measurement with accuracy of 1%. Publish results.	1.12.04
SUP.1.12.04	Validation test of LITA shock-strength measurement system	2Q2008	Characterize shock strengths from a simple model in LaRC UPWT by LITA & by pressure probe. Show 20% reduction in net uncertainty over pressure probe data.	1.12.07, 2.07.06
SUP.1.12.05	Construction and Laboratory demonstration of a high temporal (10kHz) resolution Stereo PIV system	1Q2009	Demonstrate 10 kHz Stereo PIV system to shear layers in nozzle flows to determine turbulent decay rates/scales, 1000x higher sampling rate than current state of the art in PIV. Publish Results.	1.12.14
SUP.1.12.07	Routine use of LITA shock-strength measurement	3Q2008	Demonstrate LITA shock-strength measurements for a supersonic configuration model in LaRC UPWT with 20% reduction in net uncertainty over pressure probe data.	2.07.06
SUP.1.12.09	Investigate variants of DGV technology for potential performance improvements to current SOA system	4Q2008	Demonstrate improved performance and design of DGV components with a goal of 20% reduction in deployed system cost.	1.12.17
SUP.1.12.14	Validate High Temporal Resolution Stereo PIV in Relevant environment	4Q2009	Demonstrate High Temporal Resolution Stereo PIV system in the NATR/SHJAR facility with 1000x higher sampling rate than current state of the art in PIV. Publish Results.	1.05.05, 2.03.04
SUP.1.12.17	Harden improved DGV system for deployment to NASA supersonic testing facilities	3Q2009	Demonstrate robust installation and use of DGV in LaRC UPWT and 20% reduction in deployed system cost.	2.07.06

SUP.2.01 Propulsion and Power Aerothermodynamics

SUP.2.01 Propulsion and Power Aerothermodynamics – Technical Challenges Addressed			
X	Supersonic Cruise Efficiency	X	High Altitude Emissions Reduction
X	Lightweight and Durability at High Temperature	X	Aero-Propulso-Servo-Elasticity (APSE)
X	Airport Noise Reduction	X	Supersonic Entry Descent and Landing
X	Sonic Boom Modeling		Multidisciplinary Design, Analysis & Optimization

Problem Statement: The aerothermodynamic challenges associated with an environmentally-compatible and efficient supersonic propulsion system will be addressed in this task. Specifically, this task will focus on tools and technologies that will enable: (1) a distortion-tolerant fan with a very wide operating range; (2) an inlet with minimum bleed for high performance and stable shock position; (3) a low-noise nozzle with high performance at both takeoff and cruise (4) combustor designs that minimize harmful cruise emissions and particles, and (5) performance validation data for a low pressure turbine operating at low Reynolds number.

Previous Related Research: Critical interaction between the inlet and the fan causing unstart of the inlet and engine must be assessed. Improved analysis methods and advanced technologies like local flow control are needed in both the inlet and fan. Bleed drag is often found to be the most significant component of supersonic inlet drag at cruise. Therefore, eliminating the bleed drag and the weight and complexity of the bleed system is a major thrust in modern supersonic inlet design. The HSR program developed a mixer/ejector nozzle that met the program's noise goal, but was exceptionally heavy and oversized. The HSR work showed a clear need for further work, with emphasis on a multi-disciplinary approach to insure meeting all three goals of noise, thrust and weight. The HSR program also considered cruise emissions that may cause ozone destruction and climate change. Release of increased amounts of aircraft emissions, nitrous NOx; carbon dioxide; water vapor; and particulates, into the stratosphere needs to be addressed with better understanding.

Research Approach:

- Understanding high speed fan operability and stability—Use data from an existing Revolutionary Turbine Accelerator (RTA-HYP) fan and determine the feasibility to meet the requirements of a supersonic engine. Flow control will be assessed to cope with the large variations in blade loading, performance, and operability.
- Assess inlet-fan interactions—As part of the design of supersonic inlets for high-performance and acceptable stability and operability, inlet/fan interaction simulations are needed. Simulations are needed to obtain an accurate understanding of the total pressure and flow angle distribution at the interface of the inlet and fan. Also, because of the difficulty of predicting these critical operating conditions, which are mostly at off-design, a parallel effort to develop an LES method for inlet/fan integration analysis will be conducted.
- Developing supersonic inlet concepts and technologies—Regardless of whether an external or mixed compression inlet is employed, shock sensing technology is needed. For the external compression inlet, maintaining the terminal shock position as close to the cowl lip as possible (minimizing subcritical spillage) is important for maintaining high cruise efficiency. For mixed compression inlets, terminal shock sensors need to be researched and developed that can provide their more direct "enabling security" against unstart in addition to the traditional consistent pressure sensing method.
- Develop and assess nozzle concepts—A low-noise nozzle that can be integrated with a variable cycle engine for a supersonic transport will be developed. Experimental verification of thrust and acoustic performance will be undertaken as funding allows. The current analysis capability (WIND code) will be assessed through past studies and additional validation and verification where necessary. Improvements to the analysis capability will include advanced turbulence and conjugate heat transfer models.
- Develop and assess concepts for the HPT/LPT— The high pressure turbine will experience maximum temperature during supersonic cruise. This will lead to high cycle fatigue in the high pressure turbine components and dramatically shorten the life. Innovative cooling concepts and analysis methods will be

developed to ensure the life and durability. A low pressure turbine stage will be tested at low Reynolds Numbers conditions experienced during supersonic cruise to better understand performance issues.

- Develop and assess combustor concepts—Continuing research is critical to establishing a detailed understanding of combustion reactions and combustor burner designs to minimize the harmful aircraft cruise emissions and their potential impact on the Ozone Layer. Active combustion control will provide requirements for and evaluate fuel actuation systems consisting of multiple high-frequency embedded fuel actuators. Model-based and adaptive phase-shifting control methodologies will be developed and tested in a simulation environment to assess their capabilities to detect and suppress combustion instabilities. Combustion CFD modeling, improved understanding of particulates, laser diagnostics testing, potential active combustion control concepts as well as potential alternative fuel formulations will be utilized to design and fabricate a low emissions combustor concept that will be tested at realistic supersonic cruise conditions in a flame tube rig.

Technology Validation Strategy: The validation of the integrated inlet/fan system, the low-noise nozzle, and the low Reynolds number LPT requires collaboration with industry in order to secure model hardware to test in NASA facilities (the existing RTA fan rig developed by the Hypersonics project will be utilized with the inlet model to assess integrated performance). NASA will explore partnering opportunities for the development of advanced Core Engine Technologies. Validation data required for the innovative cooling concepts and improved analysis capability for the HPT will be obtained from cascade testing.

SUP.2.01 Propulsion and Power Aerothermodynamics - Key Deliverables	Date
Assessment of integrated inlet/fan system performance	2009
Demonstration of combustion instability suppression for low NOx combustor configurations in simulation	2009
Validated exhaust nozzle performance and noise predictive capability for take-off conditions	2010
Optimized design of VCE nozzle for low noise and high thrust (Shared deliverable with 2.03)	2010
Low emission combustor concept for supersonic cruise conditions	2011
Validation of low Reynolds number effects on low pressure turbine performance	2011
Innovative cooling concepts and improved analysis capability for high pressure turbine	2011

SUP.2.01 Propulsion and Power Aerothermodynamics- Milestones				
Number	**Title**	**Year**	**Metric**	**Successors**
SUP.2.01.03	Assess nozzle performance and jet plume effects on sonic boom and propulsion airframe integration issues at supersonic conditions to Mach 2.0+ in 10'x10' or 8'x6' SWT	4Q2010	Predictions of nozzle thrust coefficient, static pressure profiles, and boat tail drag agree with experimental data to within 5%.	3.01.05, 3.04.04
SUP.2.01.04	Improved Combustor Emissions Predictions for supersonic cruise.	4Q2011	Validate exit temperatures and emission predictions with experimental results. Predictions of exit temperature and Nox agree with experimental data to within 10% and 20% respectively.	3.01.05
SUP.2.01.05	Develop computational models to predict integrated inlet and fan performance and operability	3Q2010	Validate fan stability w/ and w/o inlet distortion. Predictions of pressure recovery, distortion, and static pressure distributions agree with experimental data to within 10%.	3.01.05, 3.04.04
SUP.2.01.06	High Performance Low Pressure Turbine Test in Single-Spool Turbine Rig	3Q2011	Validate turbine performance at low Reynolds Number. Predictions of aerodynamic efficiency agree with experimental data to within 5%.	3.01.05
SUP.2.01.08	Develop advanced cooling approaches for high pressure turbine	3Q2010	Validate turbine cooling effectiveness at supersonic cruise including conjugate effects. Demonstrate 50% improvement over adiabatic wall analysis.	3.01.06
SUP.2.01.09	Validate VCE nozzle aeroacoustic performance prediction and design capability at takeoff conditions in NATR	1Q2011	Predictions of nozzle thrust coefficient, static pressure profiles, and takeoff noise agree with experimental data to within 5%.	3.01.05, 3.04.04
SUP.2.01.10	Combustion instability suppression demonstrated for low NOx combustor configurations in simulation	2Q2009	Combustion closed-lop control achieves a reduction of at least 50% in peak pressure amplitude as compared to open-loop unstable low-emissions combustor concept	2.01.04

SUP.2.02 – Airframe and Propulsion Aero-Propulso-Servo-Elasticity

SUP.2.02 Airframe and Propulsion Aero-Propulso-Servo-Elasticity – Major Technical Challenges Addressed			
X	Supersonic Cruise Efficiency		High Altitude Emissions Reduction
	Lightweight and Durability at High Temperature	X	Aero-Propulso-Servo-Elasticity (APSE)
	Airport Noise Reduction		Supersonic Entry Descent and Landing
X	Sonic Boom Modeling		Multidisciplinary Design, Analysis & Optimization

Problem Statement: The unique structural configuration of supersonic aircraft combined with nonlinear aerodynamics and rigid-body effects results in highly complex nonlinear aeroelastic/flight dynamic phenomena. These aeroelastic phenomena affect ride quality, gust loads, flutter, flight dynamics and control, and, possibly, engine performance. The aeroelastic/flight dynamic phenomena simultaneously influence the airframe and propulsion system controls, producing undesirable effects on performance and flying characteristics. This Aero-Propulso-Servo-Elastic (APSE) system needs to be thoroughly understood in order for supersonic flight to be safe, comfortable, and efficient. The solution to APSE related issues, and the exploitation of ASE/APSE phenomena for improved performance and efficiency need to be incorporated into analysis and design capabilities for slender supersonic aircraft.

Previous Related Research: A vast body of analytical, computational, wind tunnel and flight data exists on the Aero-Servo-Elastic (ASE) system for transonic transport and supersonic fighter aircraft. Systems for control of undesirable ASE phenomena (e.g., flutter suppression) have been demonstrated, as have systems that exploit ASE for improved performance (e.g., Active Flexible Wing). Considerably less data is available for supersonic cruise configurations. Elements of the HSR program conducted initial investigation of the requirements for addressing the APSE system in the preliminary design process.

Semi-span ASE model.

Research Approach: This work will focus on the development and validation of capabilities for APSE analysis and design for slender supersonic aircraft.

- ASE/flight dynamic experimental validation data Collect high fidelity data on ASE effects including nacelle and fuselage flexibility using wind tunnel and flight experiments.
- ASE/flight dynamic analysis and design tool development. Using experimental data for validation, assess effectiveness of current analysis tools. Identify gaps and initiate development of improved analysis and design tools. Ride and Handling quality, gust loads and flutter suppression control law development is to be included.
- APSE analysis and design tools. Key rigid-body/flexible airframe and propulsion interactions will be identified. An initial APSE analysis tool set will be defined and integrated. APSE related control issues will be identified. Particular emphasis will be placed on integrating propulsion dynamic system models into the ASE analysis tool suite.

Technology Validation Strategy:
Initial validation will be based on completion of tests of an existing semi-span model and on available flight databases. Validation of the APSE analysis tools will require development of a new wind tunnel model with some form of propulsion simulation. Flight data will be valuable for components of the model such as inlets and control surfaces. An industry partner will be sought to infuse configuration design realism into the model development.

SUP.2.02 Airframe and Propulsion Aero-Propulso-Servo-Elasticity (APSE) - Key Deliverables	Date
ASE/flight dynamic experimental database	2008
ASE/flight dynamic analysis and design tools	2009
APSE initial analysis tool	2010

SUP.2.02 Airframe and Propulsion Aero-Propulso-Servo-Elasticity (APSE) - Milestones				
Number	**Title**	**Year**	**Metric**	**Successors**
SUP.2.02.01	Open-loop Wind Tunnel Test Semi-span config	1Q2007	High-quality open-loop data acquired, 3000 data points to include pressures, deflections, and flutter within 10% repeatability for pressures & loads. Data acquired includes an assessment of aeroelastic engine/inlet position control.	2.02.02
SUP.2.02.02	Computational assessment of APSE methods	4Q2007	Demonstrate effectiveness of reduced order modeling methods by comparison with experimental data from 2.02.01. Predictions agree within 10% of measured flutter data. Demonstrate aeroelastic control of engine/inlet position.	2.02.03
SUP.2.02.03	Closed-loop APSE W/T Test of Semi-span config	4Q2008	Demonstrate effectiveness of ASE model development & control law design resulting in a 15% reduction in gust loads & 10% reduction in wing aeroelastic amplitude while reducing the required control surface amplitudes by 15%. Demonstrate aeroelastic control of engine/inlet position.	2.02.04
SUP.2.02.04	Open-loop Flight Dynamics/Aeroelastic Wind Tunnel Test of Full Span config	1Q2012	High-quality open-loop data acquired, 3000 data points to include pressures, deflections, and flutter within 10% repeatability for pressures and loads. Data includes integrated rigid-body dynamics/aeroelastic response and aeroelastic engine position control.	2.02.08, 3.03.09
SUP.2.02.05	Initial APSE Model Development	3Q2011	Identify propulsion/airframe aeroelastic interaction effects on flutter and dynamic stresses greater than 20% of isolated analysis from wind-tunnel tests and analyses. Includes an assessment of engine/inlet position control.	2.02.08, 3.03.09
SUP.2.02.06	Develop active/adaptive flexible wing motion control methodologies	4Q2010	Increase flutter dynamic pressure by 20% for flight test article (increase relative to open loop flutter speed) and demonstrate engine/inlet position control.	3.03.09
SUP.2.02.08	APSE control design methods report (includes flying qualities/flight dynamics)	4Q2012	Completed report outlining successful design approach on methods that address rigid-body & flexible effects simultaneously in order to achieve a 5% improvement in vehicle cruise performance & 20% reduction in design cycle time as compared to HSR. Demonstrate engine/inlet aeroelastic position control for improved cruise efficiency.	3.03.09

SUP.2.03 – Acoustics

SUP.2.03 Acoustics – Technical Challenges Addressed			
	Supersonic Cruise Efficiency		High Altitude Emissions Reduction
	Lightweight and Durability at High Temperature		Aero-Propulso-Servo-Elasticity (APSE)
X	Airport Noise Reduction		Supersonic Entry Descent and Landing
	Sonic Boom Modeling		Multidisciplinary Design, Analysis & Optimization

Problem Statement: Noise from supersonic exhaust plumes is a dominant reason why no commercial supersonic aircraft exists today and why location of military airbases is a political problem. Accurate prediction tools that also show the designer how to modify aircraft design to reduce noise are needed. For supersonic aircraft, several unique noise mechanisms arise for which prediction tools must account beyond those being developed for subsonic aircraft: broadband shock noise and Mach wave emission. Prediction tools must account for the complexity of variable, radically non-axisymmetric geometry, internally generated noise sources, and tight integration with airframe. Finally, prediction codes must give diagnostic information about noise sources to enable design optimization.

Previous Related Research: The HSR Program taught the current generation of engineers that the current noise prediction tools, being almost entirely empirically based, were inadequate for designing the radically different nozzle systems required for quiet operation of high performance aircraft. The proposed development aims to create the tools that will be needed by future supersonic aircraft design activity.

Research Approach: We propose to develop jet noise prediction tools and control strategies for successful engineering of quiet supersonic aircraft. Specifically, the following tasks are proposed:

- <u>Assess supersonic noise prediction tools</u>—Current jet noise prediction tools (empirical, statistical, direct simulation) will be applied to a suite of jet flows representative of those found in supersonic aircraft to baseline accuracy and applicability. Jet flow and noise data for dual flow jets with moderate shocks is virtually non-existent and will be obtained. This will set the benchmark for improvement in prediction tools.
- <u>Develop statistical physics-based models for noise prediction and jet noise engineering</u>—Models for broadband shock noise and Mach wave emission from nozzles of arbitrary shape that augment the subsonic jet noise codes will be the main activity. Statistical noise models will be created using observations from Acoustics Physics (SUP.1.05) tasks. CFD turbulence models for turbulent kinetic energy and enthalpy will be developed and validated for unstructured grid CFD using advanced turbulence measurements from the Acoustics Physics (SUP.1.05) task. Unsteady phenomena not amenable to statistical modeling will be characterized and code applicability limits established.
- <u>Exercise advanced prediction codes on potential noise reduction concepts</u>—As physics-based models are developed they will be validated against flows, which have potential for noise reduction. Shock noise will be modified using microjet injection, separating shock noise parameters from basic flow conditions. Mach wave emission will be modified by offsetting the core stream and separating noise mechanisms from basic scaling parameters. Complicated variable cycle nozzles will be optimized for noise in conjunction with aero performance to help make the prediction tools engineer-friendly.

Technology Validation Strategy: Cross-facility checks on jet noise database performed between LaRC and GRC rigs. Statistical noise prediction codes will be assessed before and after noise model development. Applicability of prediction codes will be tested against exploratory data from the Acoustic Physics (SUP.1.05) task and during the validation of the VCE design task.

SUP.2.03 Acoustics - Key Deliverables	Date
Dual flow shock noise database	2008
Statistical model for 3D shock noise	2010
Optimized design of VCE nozzle for low noise and high thrust	2010
Validated statistical noise prediction code for supersonic jets	2011

SUP.2.03 Acoustics- Milestones

Number	Title	Year	Metric	Successors
SUP.2.03.01	Evaluate empirical supersonic noise prediction tools for accuracy and applicability	4Q2007	Quantify and decompose error in spectral directivity by noise source in dual flow jets up to M=2, 2000°R.	2.01.03, 2.03.03, 2.03.04, 3.01.04
SUP.2.03.03	Evaluate statistical noise prediction tools for accuracy and applicability	3Q2008	Quantify and decompose error in spectral directivity by noise source in dual flow jets up to M=2, 2000°R.	2.01.03, 2.03.04, 3.01.04
SUP.2.03.04	Develop improved statistical model for broadband shock noise	1Q2010	Error in 3D shock noise spectral directivity less than empirical predictions of round jet.	3.01.05
SUP 2.03.05	Dual-flow supersonic jet noise database established	3Q2007	Demonstrate rig independence in spectral directivity to within 1dB in third octave.	2.03.01, 2.03.03
SUP 2.03.06	Develop improved statistical model for Mach Wave Emission	1Q2011	Prediction of MWE noise third-octave spectral directivity agrees with experimental data to within 1dB.	2.03.07
SUP 2.03.07	Evaluate statistical jet noise prediction tool with FAP shock and MWE source prediction components.	3Q2011	Quantify and decompose error in spectral directivity by noise source in installed jets up to M=2, 2000°R. Prediction of third-octave spectral directivity agrees with experimental data to within 2 dB.	3.01.05
SUP.2.01.09 Shared milestone	Validate VCE nozzle aeroacoustic performance prediction and design capability at takeoff conditions in NATR	1Q2011	Predictions of nozzle thrust coefficient, static pressure profiles, and takeoff noise agree with experimental data to within 5%.	3.01.05, 3.04.04

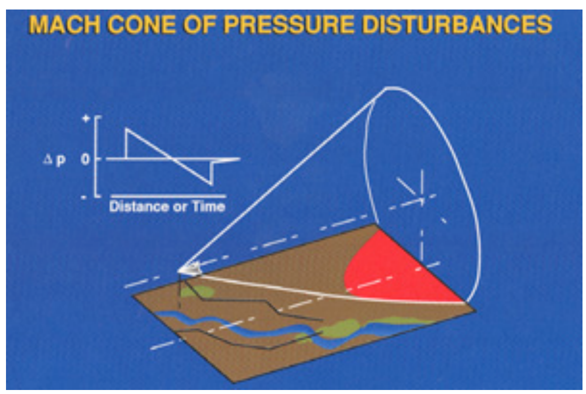
SUP.2.04 – Sonic Boom Modeling

SUP.2.04 Sonic Boom Modeling – Major Technical Challenges Addressed			
	Supersonic Cruise Efficiency		High Altitude Emissions Reduction
	Lightweight and Durability at High Temperature		Aero-Propulso-Servo-Elasticity (APSE)
	Airport Noise Reduction		Supersonic Entry Descent and Landing
X	Sonic Boom Modeling		Multidisciplinary Design, Analysis & Optimization

Problem Statement: The research goal is to model sonic boom impact as perceived both indoors and outdoors. The ability to model sonic boom propagation from the aircraft to the ground is necessary. All relevant physical phenomena need to be included in such models. This will enable the accurate prediction of sonic boom levels under realistic atmospheric conditions and for all flight conditions. Also, in order to fully understand human reaction to sonic booms, it is necessary to be able to predict the transmission of booms into buildings. Interior noise levels and structural vibration are of interest since both are important characteristics of the indoor environment.

Previous Related Research: Modeling of sonic boom propagation through the atmosphere is well understood in terms of the underlying physics associated with non-linear effects and atmospheric absorption. The additional effects due to the presence of turbulence in the atmosphere are not well understood; the resultant variability in ground signatures is profound and important to the quantification of boom impact. Additionally, turbulence effects can mask other effects and make validation of related prediction models difficult. Modeling of human reaction to sonic booms has concentrated primarily on booms as perceived in an outdoor listening environment. These efforts have relied on simulation since it is impossible to systematically vary the key characteristics of sonic boom waveforms using actual supersonic flight vehicles. Through this modeling and simulation approach, validated methods to predict the relative loudness and annoyance of booms have been developed that are based on fundamental characteristics of the human hearing system and are applicable to arbitrary sonic boom shapes and amplitudes. The indoor situation, in which vibration and rattle are expected to be important phenomena, has received relatively little attention. The most relevant previous research has been concerned with Army firing ranges and the development of land use planning guidelines for military bases.

Research Approach:



- Sonic boom atmospheric propagation model: Develop improved models for analysis of the propagation of sonic booms in realistic atmospheres. The new models will include improved representation of all relevant physical phenomena. Atmospheric turbulence models developed in section 1.05 will be incorporated. Develop flight test techniques required to validate molecular relaxation, rise time, and turbulence effects on loudness.
- Indoor acoustic response model: A model for predicting the indoor acoustic and vibration environment will be developed and validated. Building response and transmission models developed in section 1.05 will be key elements.
- Psychoacoustic model: Analytical models of the effects of noise, vibration and rattle on perceived annoyance of sonic booms will be developed and validated using simulations.

Technology Validation Strategy: Validation of the propagation model will rely on existing databases where possible. In some instances, it is likely that dedicated flights will be needed for specific atmospheric conditions. Validation of building response and acoustic transmission models will be performed at the component level using laboratory experiments. Full-scale validation will rely on existing data with supplemental flight data where necessary. Psychoacoustic model validation will rely on simulators that have been validated using existing flight data.

SUP.2.04 Sonic Boom Modeling - Key Deliverables	Date
Sonic boom building vibration and acoustic transmission database	2007
Validated building response / transmission model	2008
Validated sonic boom propagation model	2009
Validated psychoacoustic model for indoor listening	2010

SUP.2.04 Sonic Boom Modeling- Milestones				
Number	**Title**	**Year**	**Metric**	**Successors**
SUP.2.04.01	Sonic boom building vibration and acoustic transmission database	2Q2007	Database based on at least 1 highly instrumented house. Vibration/transmission for walls and windows quantified up to 4kHz.	2.04.04
SUP.2.04.03	Operational sonic boom simulator for indoor subjective testing	3Q2008	Uniform (+/-3dB) frequency response (to 2500Hz) demonstrated.	2.04.07
SUP.2.04.04	Validated building response/transmission model	4Q2008	Correlation of measurement and model within +/- 4dB in 1/3 octave bands demonstrated.	2.04.07
SUP.2.04.06	Validated propagation model	4Q2009	Correlation of predicted and measured means within 3dB, estimates of variance quantified.	3.04.03
SUP.2.04.07	Validated psychoacoustic model for indoor and outdoor listening	3Q2010	Average response to individual booms predicted with 95% confidence interval of less than 3dB	3.04.03
SUP.2.04.09	Develop flight technique to minimize u-wave effects on low amplitude N-wave	2Q2008	Low amplitude N-waves with no u-wave within 10 seconds	2.04.03

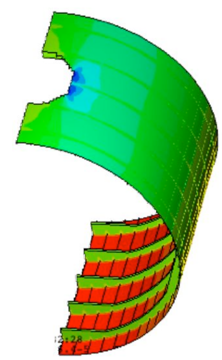
SUP.2.05 – Materials and Structures

SUP.2.05 Materials and Structures – Major Technical Challenges Addressed			
X	Supersonic Cruise Efficiency		High Altitude Emissions Reduction
X	Lightweight and Durability at High Temperature		Aero-Propulso-Servo-Elasticity (APSE)
X	Airport Noise Reduction	X	Supersonic Entry Descent and Landing
	Sonic Boom Modeling		Multidisciplinary Design, Analysis & Optimization

Problem Statement: The research goal is to develop material/structural systems with the properties needed for supersonic flight across multiple disciplines. Materials and Structures Modeling (SUP.1.01) task emphasis was on developing manufacturing processes and validated analytical capabilities; this element will focus on integrated structural concepts that satisfy multidisciplinary needs. Development of non-traditional, tailored, hybrid concepts offers the best opportunity to meet structural demands, ensure service lifetime performance, and accommodate the unique aerodynamic demands of supersonic flight vehicles.

Previous Related Research: Multiple fuselage, wing and engine structural concepts were evaluated during the HSR Program for primary flight loads, damage tolerance requirements, and long-term durability. Limitations in structural performance, particularly stiffness of highly loaded thin wing structures and damage tolerance and elevated temperature durability of pressurized fuselage structures were identified. Advances made in metallic and composite materials, processing/fabrication, and computational modeling and design tools offer opportunities to re-evaluate solutions for supersonic vehicles.

Research Approach:



Stress in damaged composite.

- Examine the use of new and innovative multifunctional material/structural systems for the highly loaded slender fuselage and thin wing profile peculiar to supersonic aircraft. Emerging computational tools will be used to design non-traditional, tailored structural concepts that are weight-optimized for elevated temperature properties, durability, stiffness and damage tolerance. Emerging materials (e.g., improved hybrid laminates, graded property metallics) and tailored geometries (e.g., directed placement of stiffeners, selective reinforcement, or novel core-stiffened combinations) will be developed. In high efficiency inlet design, vehicle speed and flow conditions will determine the shock position, orientation, and inlet performance. Smart materials and active/adaptive structures will be developed to provide advancement over current SOA to provide improved efficiency and reduced inlet weight.
- Structural analysis and life prediction tools will be applied to assess the performance benefits under supersonic flight conditions. With input from aeronautics disciplines, designs will be tailored to concurrently manage dynamic considerations, such as aeroelastic wing flutter or aeroacoustic noise. Further development will enable incorporation of integrated sensors and active controls.
- Advanced damage tolerant structural concepts and lighter weight components will be developed by utilizing high temperature polymers developed in Materials and Structures (SUP.1.01). The supersonic propulsion system will require a lightweight structural containment system that is damage-tolerant and capable of operating at high temperatures. The current SOA is a metallic fan case. The advancement in SOA will be the use of lightweight composite materials that can provide adequate containment given higher energy loads (caused by the higher rotational speeds of the high speed fan) and higher temperatures.

Technology Validation Strategy: Performance benefits of novel hybrid and stiffened structures will be demonstrated through computational modeling and analysis validated by sub-element testing and comparison with traditional concepts. Advanced composite materials, coatings, and structural concepts, as well as life prediction and aeroelastic code improvements, will be validated via rig and laboratory testing.

SUP.2.05 Materials and Structures - Key Deliverables	Date
Multi-disciplinary optimization demonstrating structural weight savings	2007
Demonstration of lightweight structural fan containment system	2008
Robust coupled analysis tools for solving multidisciplinary problems	2009
Validated analytical tool for predicting damage tolerance of built-up structure	2010
Validated accelerated test method for long-term durability and life prediction	2011
Demonstration of smart material & active / adaptive structures for engine component actuation	2011

SUP.2.05 Materials and Structures- Milestones				
Number	**Title**	**Year**	**Metric**	**Successors**
SUP.2.05.02	Lightweight Structural Fan Containment System demonstrated	4Q2008	Demonstrate a composite supersonic engine fan blade containment system that is 20% lighter than the High Speed Research Program metallic containment system.	3.01.05
SUP.2.05.03	Develop robust and rapid modeling/analysis techniques for solving multidisciplinary problems	4Q2009	Demonstrate fan blade structural response prediction within 15% of high-fidelity model prediction with a 60% reduction in analysis time.	3.01.05, 3.03.07
SUP.2.05.06	Demonstrate validated analytical tool for predicting damage tolerance of built-up structure	3Q2010	Experimental validation of predicted failure load, within 15%, and failure mechanism on built-up stiffened panel	3.01.05, 3.03.07
SUP.2.05.07	Demonstrate validated accelerated test method for long-term durability and life prediction for combined mechanical and environmental loads	3Q2011	Verified test methods that allow for a 30% more accurate selection & ranking of material systems based on measurement of time-based degradation & assessment of key damage mech. & failure modes under realistic mission profile flight conditions.	3.01.05, 3.03.07
SUP.2.05.08	Smart material & Active/Adaptive Structures demonstrated.	4Q2010	Demonstrate 10% reduction in design weight for supersonic inlets using SMA / active structures relative to HSR baseline.	3.01.05
SUP.2.05.09	Validated material/structural combined discipline solution concurrently demonstrating high structural performance and aerodynamic control	3Q2011	Demonstrate computational methods and fabrication processes to incorporate design elements for aeroelastic control in a material/structural panel concept with a 20% increase in stiffness.	3.03.07, 3.03.08

SUP.2.07 – Aerodynamics

SUP.2.07 Aerodynamics – Major Technical Challenges Addressed			
X	Supersonic Cruise Efficiency		High Altitude Emissions Reduction
	Lightweight and Durability at High Temperature	X	Aero-Propulso-Servo-Elasticity (APSE)
X	Airport Noise Reduction	X	Supersonic Entry Descent and Landing
X	Sonic Boom Modeling	X	Multidisciplinary Design, Analysis & Optimization

Problem Statement: The research goal is to improve aerodynamic design and analysis capability for highly efficient, supersonic vehicles. Additional research aspects of this area will include low-speed, high-lift performance with implications on airport noise and potential environmental effects. The primary technical challenge is to develop robust CFD-based methods for rapid design and analysis of supersonic cruise aircraft that are highly efficient, and, if required, meet imposed flowfield constraints. Low-speed takeoff and landing performance is also a critical aspect of the overall design with and additional benefit of reduced airport noise.

Previous Related Research: While significant progress has been made in achieving higher cruise and off design efficiency, the methods used for design are generally lower-order flow solvers using a global design criterion. This approach has led to some inaccuracies in performance predictions, especially for parts of the flowfield associated with propulsion/airframe integration. In addition, the impact of imposed flowfield constraints has resulted in increased drag for the configuration, since this is typically not a direct objective of the design. Recent work at NASA has begun exploring the application of adjoint-based optimization to the highly efficient supersonic configuration problem. The state of the art in ice accretion simulation capabilities has yet to be expanded to this vehicle class.

Research Approach:

- High efficiency supersonic cruise—NASA has the unique capability to conduct this research because of its facilities and experience, especially in the areas of knowledge-based design methods, innovate concepts, supersonic performance prediction and supersonic testing. The proposed knowledge-based design code takes advantage of its inherent characteristic of not needing to compute sensitivity derivatives, along with recent developments in zonal design and grid adaptation for unstructured grids, to create a very efficient design system. This efficiency allows large grids to be used so that details of the propulsion/airframe integration are accurately modeled and viscous effects are included to ensure proper shock locations. This approach of tailoring the geometry locally to produce a desired supersonic off body flowfield may also provide an advantage over the current global method. New test techniques for acquiring flowfield measurements (i.e., velocity, pressure, temperature, etc.) will help validate computational methods for on and off body flowfield prediction.
- Low-speed/high-lift—Develop experimental capability for generation of databases of critical, flow phenomena associated with this vehicle class. Assess capability of existing methods and identify technology gaps to pursue for improved prediction fidelity of these methods. Later in the research program updated, validated methods will be used to design more optimal flow effectors for off-design conditions.

Technology Validation Strategy: Validation will be achieved through the use of various computer clusters, wind tunnels, and flight vehicle assets.

SUP.2.07 Aerodynamics - Key Deliverables	Date
Grid adaptation capability to ensure valid pressure signature to midfield	2007
Assessment of planform effects and novel configurations on pressure signature	2009
Validated off body aerodynamic flow analysis capability	2010
Integrated high efficiency & environmentally compatible supersonic cruise aero. design capability	2011

SUP.2.07 Aerodynamics- Milestones				
Number	**Title**	**Year**	**Metric**	**Successors**
SUP.2.07.03	Assessment of Planform/Configuration on Pressure Signature	3Q2008	Configuration level assessment of airframe pressure signature and aerodynamic performance with improved computational tools. Assessments agree with experimental data within 10%.	2.07.05
SUP.2.07.05	Off-body Aerodynamic Flow Analysis Capability	1Q2009	Validation of 3-D off-body CFD flow analysis capability through comparison to wind tunnel and flight data. Predictions of L/D and off body flowfield at supersonic cruise agree within 10% of wind tunnel and flight data.	2.07.06
SUP.2.07.06	Integrated High Efficiency Supersonic Cruise Aero. Design Capability	3Q2009	Documentation of design methodology completed. Results compared to wind tunnel test data. Correlation of results documented. Predictions agree within 5%.	3.03.06
SUP.2.07.07	Validated Ice Accretion Methodology	4Q2011	Validation of 3D ice growth prediction for supersonic configurations completed. Accuracy shown to be within 10% of experimental data. Methodology documented.	3.03.09

SUP.2.09 – Experimental Capabilities

SUP 2.09 Experimental Capabilities – Major Technical Challenges Addressed			
X	Supersonic Cruise Efficiency		High Altitude Emissions Reduction
	Lightweight and Durability at High Temperature	X	Aero-Propulso-Servo-Elasticity (APSE)
X	Airport Noise Reduction	X	Supersonic Entry Descent and Landing
X	Sonic Boom Modeling		Multidisciplinary Design, Analysis & Optimization

Problem Statement: The Supersonics project seeks to provide and utilize critical experimental capabilities for supporting supersonic design efforts and to validate computational methods. Experimental capabilities are key to producing meaningful validated tools for aeronautics. These experimental capabilities include ground test facilities, wind tunnels, and flight test articles.

Previous Related Research: Research experience has been gained over the last 15 years utilizing various NASA experimental capabilities including DFRC F-15/ F-18 Supersonic Research Aircraft, LaRC Unitary Plan, Transonic Dynamics Tunnel, and High-Speed Low-Density Tunnels, LaRC Full Motion Simulators, Ames 9×7 Supersonic Wind Tunnel, Glenn Aero-acoustic Propulsion Laboratory, Glenn 10×10, 8×6, and other Supersonic research facilities.

Research Approach:

- Conduct a flight experiment to assess the effects of lift and engine nozzle variations on the tail shock structure utilizing an F-15 (#837). Canard/wing/tail lift distribution and nozzle exit area will be varied to obtain a database of those effects on shock structure and propulsive efficiency for purposes of code validation.
- Existing facilities will be calibrated and improved in order to better serve the supersonic research community. Typical facility improvements include the implementation of the thrust balance in the GRC Nozzle Acoustic Test Rig, flow calibration of the DFRC F-15B Centerline Instrumented Pylon (CLIP) test fixture, and improved sensor arrays for field acoustic flyover measurements in support of the sonic boom modeling activity. If procurement resources permit, the addition of combustion capability to the GRC 1 x 1 SWT; improved air-to-air and in-situ imaging on DFRC F-15 and F-18 research aircraft; and the improvement of other supersonic facilities and laboratories will be accomplished.

DFRC F-15B testbed.

- A transition flight experiment will be conducted to validate models developed in section 1.03
- Conduct a flight experiment to assess an advanced supersonic inlet with a channeled centerbody. The proposed flight testing will examine inlet performance at on and off design conditions. The effects of upstream flow disturbances on inlet performance will be evaluated by varying angle of attack and angle of sideslip. Distortion due to the channels will be evaluated and compared to an equivalent area smooth centerbody inlet design. The data collected during flight testing will be used to validate the design tools.
- Simulation facilities and models will be upgraded with capabilities and models to support supersonic aircraft requirements. For example, an advanced flight simulator will be developed that models flexible structures and controls often critical in supersonic configurations.
- Assessment of the existing capabilities and readiness will be also conducted in respect to anticipated requirements. Requirements will be established to determine advocacy for new or modified facilities to support aerodynamics, aeroelastic, aeroservoelastic, acoustic, structures and materials, propulsion, and flight

test facilities.

Technology Validation Strategy:
These experimental capabilities will be the source for technology validation for the Supersonics project. Validation will occur through comparison of flight or wind tunnel data to other test data or computational results.

SUP.2.09 Experimental Capabilities - Key Deliverables	Date
Improved nozzle force measurement capability	2007
Improved sensor arrays for field acoustic flyover measurements	2008
Advanced flight simulator that models flexible structures and controls	2008

SUP.2.09 Experimental Capabilities- Milestones				
Number	**Title**	**Year**	**Metric**	**Successors**
SUP.2.09.01	Lift And Nozzle Change Effects on Tail Shocks (LANCETS)	3Q2007	Investigate control of aft shock structure using nozzle and/or lift tailoring with the goal of a 20% reduction in near-field tail shock strength. Decouple nozzle & tail shock to initiate an understanding of the relationship between propulsive efficiency & shock strength.	3.03.03, 3.03.05
SUP.2.09.02	Calibrated F-15B/CLIP Flowfield	2Q2008	Defined flowfield for angularity, turbulence, and local Mach at key locations. Angularity to 0.25°, turbulence within 2% freestream, and local Mach to 0.05.	2.07.06
SUP.2.09.03	Improved freq. bandwidth and spatial resolution for field acoustic flyover measurements	2Q2008	Completed sensor array with minimum 2x bandwidth increase based on current arrays.	2.04.06
SUP.2.09.05	Develop Advanced Flight Simulator	1Q2008	Completed development of an advanced flight simulator that adequately models flexible structures and controls.	1.07.08
SUP.2.09.06	Improved nozzle force measurements	4Q2007	Repeatable thrust measurements with accuracy of 0.25% for the entire range of the flow rate for the High Flow Jet exit rig.	2.01.09
SUP.2.09.07	Determine off-nominal in-flight performance of an advanced supersonic inlet with a channeled center body	3Q2008	Provide repeatable inlet face pressure recovery data (with ±5 psf accuracy) for smooth and channeled center body configurations for performance code validation.	2.01.05
SUP.2.09.08	Development supersonic transition test fixture (for F-15 CLIP)	2Q2009	WAYPOINT- Design, fabrication, envelope expansion, and initial aero characterization of test fixture on F-15 CLIP completed	2.09.09
SUP.2.09.09	Supersonic transition flight experiment on most promising concept identified in SUP.1.03	1Q2011	Documented boundary layer profiles and transition locations of supersonic test article. Transition location measured within 2% of local chord for code validation	3.03.09

SUP.3.01 – Propulsion/Power Systems

SUP.3.01 Propulsion/Power Systems – Major Technical Challenges Addressed			
X	Supersonic Cruise Efficiency	X	High Altitude Emissions Reduction
	Lightweight and Durability at High Temperature	X	Aero-Propulso-Servo-Elasticity (APSE)
X	Airport Noise Reduction	X	Supersonic Entry Descent and Landing
X	Sonic Boom Modeling	X	Multidisciplinary Design, Analysis & Optimization

Problem Statement: Efficient supersonic cruise along with low jet noise remains elusive. Without actual supersonic aircraft, systems integration studies remain the only way to evaluate advanced concepts, including new engine cycles, new inlet/nozzle concepts, new airframes and propulsion/airframe integration (such-as distributed propulsion, VCE, exoskeletal, PDE, wave rotor, etc.). Vehicle System Integration and Analysis (SUP.3.02) will rely on the performance prediction capabilities developed under this task to better quantify the uncertainties inherent in new technologies and their impact on the vehicle system performance.

Previous Related Research: The current SOA in supersonic aircraft research comes primarily from the NASA HSR program, relatively limited military applications, and the current work on supersonic business jets. The purpose of this research is to reduce the uncertainty of the propulsion component performance (and therefore, the system level performance uncertainty), identify the most robust system configuration, and the most promising technologies required for the robust system configuration.

Research Approach: Improved level of propulsion performance predictions will be achieved in several technical disciplines including the performance, weight, noise, thermal management and cost for supersonic applications, thus reducing overall propulsion system performance uncertainty levels. Activities will include baselining current methods, using higher order analysis and test data from Level 1 and 2 fundamentals.

- Advanced Studies: Develop the ability to simulate advanced propulsion concepts, such as a VCE; Propulsion systems analysis studies will be updated to define the conceptual design of the integrated components of a VCE system (inlet, fan, core engine, low pressure turbine, bypass duct with the bypass valve/exit guide vane, mixer/ejector, and nozzle). Subsequently, partnerships will be sought for hardware testing in facilities such as the 10x10 tunnel.
- Code Integration: Develop objects and toolboxes to streamline integration of multi/fidelity and multi-discipline codes (e.g., NPSS framework).
- Acoustics: Integrate and expand capabilities into a logical equation-based methodology.
- Sonic Boom: Develop the ability to assess propulsion impacts on aircraft sonic boom

Technology Validation Strategy: Increasing system analysis fidelity will result in a quantifiable reduction in the uncertainty associated with system and component level performance. This will be achieved through vehicle systems integration and analysis by using a framework to baseline and implementing process improvements to evaluate productivity increases, reduction of uncertainty, etc., and other metrics defined using newly developed capabilities. Exit criteria may include: reduction of setup time, decreased runtime, and having different fidelity codes running simultaneously. Industry, academia or other government agencies may provide additional validation data.

SUP.3.01 Propulsion / Power Systems - Key Deliverables	Date
Integrated inlet-nozzle aero-acoustic prediction methodology	2010
Advanced low-noise, high-efficiency propulsion system concepts for incorporation into vehicle system integration and analysis	2011

SUP.3.01 Propulsion and Power Systems- Milestones				
Number	**Title**	**Year**	**Metric**	**Successors**
SUP.3.01.01	Assess Tool Capabilities and identify model interface requirements	2Q2007	WAYPOINT- Quantification of gaps and uncertainties using available data completed	3.01.04, 4.01.02
SUP.3.01.04	Integrated Low Noise/High Efficiency Inlet-Nozzle Aero-Acoustic Methodology	4Q2009	Overall engine simulation aeroacoustic prediction matches the isolated methodology prediction to within 1% tolerance.	3.01.05, 4.01.14, 4.01.15
SUP.3.01.05	Advanced Low Noise, High Efficiency Propulsion Concepts Defined	4Q2011	Propulsion system concept defined that achieves target takeoff noise within 10% and target cruise SFC within 5%	4.01.15
SUP.3.01.06	Low Emissions Propulsion Analysis	3Q2010	Identify major particulate emissions effects of the integrated combustor nozzle, cooled high pressure turbine system. Major effects will be classified as those that add 20% or more particulates to the isolated combustor levels.	4.01.15
SUP.3.01.07	Intelligent Control for Low Noise, High Efficiency & Low Emissions	4Q2013	Propulsion system concept defined which incorporates adaptive control features that enable target takeoff noise levels to be achieved within 5%, target cruise SFC within 5% and target high altitude emissions levels within 10%	

SUP.3.03 – Airframe Systems

SUP.3.03 Airframe Systems – Major Technical Challenges Addressed			
X	Supersonic Cruise Efficiency	X	High Altitude Emissions Reduction
X	Lightweight and Durability at High Temperature	X	Aero-Propulso-Servo-Elasticity (APSE)
X	Airport Noise Reduction	X	Supersonic Entry Descent and Landing
X	Sonic Boom Modeling	X	Multidisciplinary Design, Analysis & Optimization

Problem Statement: The solution to the technical challenges of the supersonic flight regime will depend in part on the ability to design and analyze highly integrated vehicles. This approach will require tools that will accurately capture the interactions between analysis disciplines and vehicle components with non traditional arrangement. The challenge is to develop an analysis system that incorporates the appropriate level of fidelity without becoming large and unreasonable to use, maintain and modify.

Previous Related Research: A prototype integrated analysis model was developed during the Efficient Aerodynamic Shapes and Integration (EASI) project with aerodynamic and performance analysis codes. Other efforts at design framework development, incorporating variable complexity analysis have been explored in both universities and industry.

Research Approach: The proposed approach will focus on the phased development of a variable complexity analysis tool suite for highly integrated supersonic vehicle airframes. The tool suite is to be compatible with the integrated MDAO framework being developed at level 4.

- Improved integration of existing tools - will be achieved by utilizing the commercial framework ModelCenter. The design capability will seamlessly integrate both performance and aerodynamic analysis codes. Emphasis will be placed on geometry tools and the integration of lower fidelity analysis codes with higher order CFD gridding tools and flow solvers.
- Configuration shaping for high efficiency– The initial implementation of the analysis framework will focus on developing a capability to perform 3-D shaping of an airframe for best cruise efficiency (high L/D) while meeting imposed flowfield constraints such as inlet flow angle or shock strength. This analysis will include a representation of relevant propulsion effects such as inlet spillage and nozzle plume.
- Integrated structural analysis for light weight. The second phase of the integrated analysis system development will focus on incorporating structural analysis capability that can effectively assess innovative configuration arrangements and fabrication techniques for supersonic airframes.
- Integrated flexible aircraft control. The third phase of the integrated analysis capability will explore the integration of tools for flexible aircraft analysis (flutter and flight dynamics) and the interaction of the aerodynamic, structural and control systems designs.

Highly Integrated supersonic transport aircraft configuration

Technology Validation Strategy: Subscale and full-scale experiments (lab, wind tunnel or flight research) will be used to validate the technologies and design tools for airframe systems optimization of noise, emissions and performance for advanced conventional and unconventional vehicle concepts. Partnering with industry and OGAs is a key element for successful validation at this level on integration. Partnership opportunities are being pursued.

SUP.3.03 Airframe Systems - Key Deliverables	Date
Aft-end vehicle shaping and engine plume design and analysis tool	2008
Highly efficient, environmentally compatible supersonic vehicle conceptual design optimization tool	2009
Innovative materials and fabrication concepts for supersonic airframes	2011
Computational Methods for Flexible Airframe Control	2011

SUP.3.03 Airframe Systems- Milestones

Number	Title	Year	Metric	Successors
SUP.3.03.01	Assess Tool Capabilities and identify model interface requirements	1Q2007	WAYPOINT- Quantification of gaps and uncertainties using available data completed	3.03.03, 3.03.05, 4.01.02
SUP.3.03.03	Integrated aft end vehicle shaping methodology validated analytically	4Q2008	Correlation with high fidelity CFD completed. Lower-fidelity model predictions of off-body pressures agree with high-fidelity CFD predictions within 5%.	3.03.06
SUP.3.03.05	Integrated Engine plume methodology validated analytically	4Q2008	Correlation with high fidelity CFD completed. Lower-fidelity model predictions of engine plume effect on off-body pressures agree with high-fidelity CFD predictions within 5%.	3.03.06
SUP.3.03.06	High Efficiency Supersonic Cruise Analysis and Design Methodology Developed	4Q2009	Establish capability to design and analyze supersonic vehicles that achieve efficiency improvement within 10% of the defined targets including engine plume effects	3.04.03, 4.01.14
SUP.3.03.07	Computational Methods for Durable Airframe Design	3Q2011	Demonstration of capabilities for assessing the damage tolerance and durability of supersonic airframes with residual strength and life predictions within 15% of experimentally determined values	3.03.10
SUP.3.03.08	Innovative Materials and Fabrication Concepts for Supersonic Airframes	3Q2011	Innovative light weight materials and processes with 10% weight savings and 20% cost savings over conventional approaches	3.03.10
SUP.3.03.09	Computational Methods for Flexible Airframe Control	4Q2012	Establish capability for APSE design with Level 1 handling qualities.	4.01.06, 3.03.10
SUP.3.03.10	Light, Safe, Durable Airframe Structure Design Methodology	3Q2014	Establish capability for light, safe, durable airframe structure design that achieves target requirements defined for airframe weight and life targets within 10%.	

SUP.3.04 – Systems for Experimental Validation

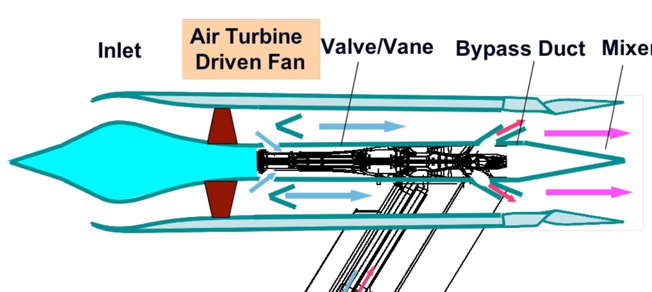
SUP.3.04 Systems for Experimental Validation – Major Technical Challenges Addressed			
X	Supersonic Cruise Efficiency		High Altitude Emissions Reduction
	Lightweight and Durability at High Temperature	X	Aero-Propulso-Servo-Elasticity (APSE)
X	Airport Noise Reduction		Supersonic Entry Descent and Landing
X	Sonic Boom Modeling	X	Multidisciplinary Design, Analysis & Optimization

Problem Statement: Validation of system level technologies, design tools and analysis capabilities is complex and resource intensive. An integrated design of the experimental system must be developed. The facilities required for ground based validation tend to be large and complicated, such as large wind tunnels and end-to-end engine test facilities. Some validation can only be accomplished through the development of an experimental flight vehicle. Cost effective, collaborative approaches must be realized.

Previous Related Research: There are a number of examples of innovative low cost approaches to systems level validation. The DARPA NASA F-5 Shaped Sonic Boom Demonstration used a multi company cost sharing approach to design validation prior to hardware development. The Northrop X-45 Pegasus used an innovative low cost airframe manufacturing approach. The X-29, X-31 and other experimental aircraft utilized a number of components from pre-existing aircraft.

Research Approach: The Supersonics project team has defined two critical areas for integrated system level experimental validation. These are integrated airframe design for low boom and low drag and variable cycle engine inlet and bypass performance validation. Both of these areas offer opportunities for applying innovative approaches. In addition, both offer the opportunity to incorporate other technology validation at little additional cost.

- Aerodynamic Design Tools & Propagation Validation Experiment Validation of the integrated toolset for design of high efficiency supersonic cruise aircraft with imposed flowfield constraints, including nozzle plume effects is an ideal candidate for a new design flight aircraft flight experiment. The additional need to validate sonic boom modeling tools makes a strong case for a flight experiment. Partnerships will be considered to implement a collaborative approach to discipline level technology validation leading to a decision to go forward with a flight experiment.
- Performance and validation testing of a propulsion simulator of a variable cycle engine. A propulsion simulator, thrust/drag producing inlet, fan, bypass duct, mixer/ejector nozzle and nacelle/pylon will be developed for wind tunnel testing in the NASA 8×6 Foot Supersonic Wind Tunnel. The wind tunnel facility utilizes a high pressure air heater to match the core/LPT exit flow entering the mixer/ejector nozzle and an air turbine or electric motor to drive the fan. This testing eliminates the need for an expensive core engine and LPT hardware with high operating temperatures. Handling the air flow variability in an operating propulsion system will be a major cycle development challenge.



Supersonic VCE Propulsion Simulator

Technology Validation Strategy: The resources required to complete the design, development and test of large integrated systems requires that innovative, collaborative partnerships be developed. The Supersonics project team will develop partnership approaches for both of the validation experiments described above.

SUP.3.04 Systems for Experimental Validation - Key Deliverables	Date
Aerodynamic Design Tools & Propagation Validation Experiment	2010
Validation data for the bypass system of a VCE Engine	2011

SUP.3.04 Systems for Experimental Validation- Milestones				
Number	**Title**	**Year**	**Metric**	**Successors**
SUP.3.04.02	Conceptual Design of Variable Cycle Engine to Define the Components for Development	4Q2008	WAYPOINT- Design definition completed to level adequate for PDR level review	3.04.04, 4.01.05
SUP.3.04.03	Aerodynamic Design Tools & Propagation Validation Experiment	3Q2010	Flight measured off body flowfield parameters within 10% of pretest predictions. Ground measurements, including propagation effects, agree within 10% of predictions.	4.01.05
SUP.3.04.04	Variable Cycle Engine Propulsor (inlet-fan-bypass stream- nozzle) Performance and Operability Validation Experiment	3Q2011	Successful operation over conditions of design flight envelope demonstrated. Predictions of nozzle thrust coefficient, inlet recovery, and stall margin agree with experimental data to within 2%, 2%, and 5% respectively.	4.01.05

SUP.4.01 – Multidisciplinary Physics Based Predictive Design, Analysis and Optimization

SUP.4.01 Multidisciplinary Physics Based Predictive Design, Analysis and Optimization – Major Technical Challenges Addressed			
X	Supersonic Cruise Efficiency		High Altitude Emissions Reduction
	Lightweight and Durability at High Temperature		Aero-Propulso-Servo-Elasticity (APSE)
X	Airport Noise Reduction	X	Supersonic Entry Descent and Landing
X	Sonic Boom Modeling	X	Multidisciplinary Design, Analysis & Optimization

Problem Statement: The ultimate achievement of overcoming all of the technical challenges to efficient, environmentally compatible supersonic flight will require an integration of analysis tools and an application of multidiscipline design, analysis and optimization (MDAO) on a scale greater than previously achieved. Ultimately, this capability will need to reside with the entities that design and build supersonic vehicles. As part of a research program, NASA has three legitimate reasons for embarking on activities in this area. The first is to improve the understanding of the requirements for MDAO frameworks in aircraft design. The second is to guide the development of analysis tools (physics based and others) that will support the design process. The third is the development of a design capability that NASA can use to evaluate the impact of its tool and technology development efforts.

Previous Related Research: MDAO has been an active research and development area for many years. There have been several significant efforts at building this capability for supersonic aircraft. The HSR program's Design Optimization Synthesis System (DOSS) achieved some success by using response surfaces to represent discipline behavior. Probably the best example of a long-term effective effort is the NPSS; jointly sponsored by NASA and major aerospace companies. More recent activities (e.g., Stanford, Georgia Tech) have focused on the development of design frameworks that allow tools of various levels of fidelity to be linked with analysis, optimization and data management processes. Under the EASI project, NASA researchers initiated an exploration of the application of these frameworks in both subsonic and supersonic airframe design.

Research Approach: This element is closely tied to the Propulsion Systems (SUP.3.01) and Airframe Systems (SUP.3.03) elements. These elements are directed at particular aspects of the integrated solution to the major technical challenges of supersonic flight. This element, SUP.4.01, ties analysis and design framework development with integration of specific tools and techniques related to MDAO for supersonic cruise aircraft.

- Framework Development - To be conducted jointly with the Subsonic Fixed Wing (SFW) project of FAP. This work will include improving the flexibility and throughput of design frameworks and the development of tools for rapidly linking analysis tools into these frameworks. A key area of work is the development of guidelines for determining the level of analysis sophistication that is required to represent specific disciplines in the design process. Exploration of design friendly parametric geometry and data handling will also be conducted.
- Challenge Problem - A representative multidiscipline challenge for supersonic aircraft will be chosen and studied. This example problem will be selected in consultation with NASA's research partners. One candidate is the simultaneous optimization of airframe, inlet, engine and nozzle characteristics for high efficiency with sonic boom and community noise constraints.

Technology Validation Strategy: Complete validation of design tools requires a design to be evaluated against set requirements. With the cooperation of its industry partners, the NASA team will carry the MDAO validation as far as possible; using comparisons to reference designs, limited experiments, and existing design case studies.

SUP.4.01 Multidisciplinary Physics Based Predictive Design, Analysis & Optimization - Key Deliverables	**Date**
Assessment of the state of the art of design frameworks and analysis tools for multidiscipline design of supersonic aircraft	2007

Initial framework and analysis tool suite for supersonic aircraft design optimization	2009
Completed initial design study and analysis of gaps in framework and tool suite	2011

SUP.4.01 Multidisciplinary Physics-Based Design, Analysis, and Optimization Capabilities- Milestones				
Number	**Title**	**Year**	**Metric**	**Successors**
SUP.4.01.02	Assess Integrated Airframe-Propulsion Prediction Capability & ID Gaps	3Q2007	WAYPOINT - Initial assessment of tool sets for integrated propulsion & airframe analysis. Quantification of gaps & uncertainties for system assessment of cruise efficiency. Establish benchmark analysis cycle time. Document gaps in analysis tool set.	4.01.03
SUP.4.01.08	Portfolio Assessment and Advanced System Concepts Review	4Q2008	WAYPOINT - Assess effectiveness of Supersonic Project portfolio (I.e. tools and technologies) on the key technical challenges	4.01.09
SUP.4.01.03	Initial Multidisciplinary Design and Analysis Framework	4Q2008	Demonstrate a 2-day analysis cycle time for integrated prediction of cruise efficiency under imposed flowfield constraints, given a vehicle geometry and propulsion system concept. Quantify uncertainty in the prediction.	4.01.04
SUP.4.01.14	Integrated Design for Cruise Efficiency	1Q2010	Demonstrate a 2-day cycle time of an integrated propulsion-airframe performance analysis that achieves within 10% of defined targets for cruise efficiency	4.01.04
SUP.4.01.04	Incorporate Updated Multidisciplinary Tool Sets	3Q2010	WAYPOINT - MDAO framework updated with improved validated tools from Level 1-3.	4.01.05
SUP.4.01.09	Portfolio Assessment and Advanced System Concepts Review	2Q2010	WAYPOINT - Assess effectiveness of Supersonic Project portfolio (I.e. tools and technologies) on the key technical challenges	4.01.11
SUP.4.01.05	Gen 1 MDAO: Cruise Efficiency	4Q2011	Demonstrate 2 week MDAO cycle time for cruise efficiency under imposed flowfield constraints with 2X reduction in design uncertainty (ref. 4.01.03)	4.01.06, 4.01.07
SUP.4.01.11	Portfolio Assessment and Advanced System Concepts Review	4Q2011	WAYPOINT - Assess effectiveness of Supersonic Project portfolio (I.e. tools and technologies) on the key technical challenges	4.01.12
SUP.4.01.15	Integrated Low Noise/ Low Emissions Analysis	1Q2012	Demonstrate 2-day cycle time for integrated configuration-level noise and emission analysis; Achieve integrated configuration-level design within 10% of defined target for airport noise and high altitude emissions.	4.01.06
SUP.4.01.06	Incorporate Updated Multidisciplinary Tools	4Q2012	WAYPOINT - MDAO framework updated with improved validated tools from Level 1-3.	4.01.07
SUP.4.01.07	Gen 2 MDAO: Low Noise & Emissions	4Q2013	Complete MDAO cycle incorporating low noise, low emissions design. Demonstrate 2X (ref. SUP.4.01.02) reduction in cycle time and uncertainty.	4.01.18
SUP.4.01.12	Portfolio Assessment and Advanced System Concepts Review	2Q2013	WAYPOINT - Assess effectiveness of Supersonic Project portfolio (I.e. tools and technologies) on the key technical challenges	4.01.13

Appendix A- Acronym Listing

3D	3 Dimensional
AF	Air Force
AFOSR	Air Force Office of Scientific Research
AFRL	Air Force Research Laboratory
AFRL/TGF	Air Force Research Laboratory / Tri-sonic Gas Facility
AIAA	American Institute of Aeronautics and Astronautics
Al	Aluminum
AN	Airport Noise
APNASA	Average Passage NASA CFD Program
APSE	Aero-Propulso-Servo-Elasticity
ARC	Ames Research Center
ARMD	Aeronautics Research Mission Directorate
ASE	AeroServoElasticity
AuRA	Autonomous Robust Avionics (Project)
B49	Building 49
BL	Business Lead
BS	Bachelor of Science
BWB	Blended Wing Body
C	Celsius
CE	Cruise Efficiency
CE5	Center East 5 (room location)
CDISC	Constrained DISC
CFD	Computational Fluid Dynamics
CFD/EFD	Computational Fluid Dynamics
CLIP	Centerlines Instrumented Pylon
CMC	Ceramic Matrix Composites
CMOS	Complimentary Metal-Oxide Semiconductor
CPM	Center Project Manager
CW17	Center West 17 (room location)
DARPA	Defense Advanced Research Project Agency
DAVE-ML	Dynamic Aerospace Vehicle Exchange Markup Language
dB	Decibel
DFRC	Dryden Flight Research Center
DGV	Doppler Global Velocimetry
DISC	Direct Iteration Surface Curvature
DL	Discipline Lead
DOE	Department of Energy
DOS	Design Optimization System
DUR	Durability
EASI	Efficient Aerodynamic Shapes and Integration (Project)
EBC	Environmental Barrier Coating
EM	Emissions
EPETS	Exhaust Plume Effect on Tail Shock
EPM	Enabling Propulsion Materials (Project)
ERB	Engine Research Building
FAA	Federal Aviation Administration
FAP	Fundamental Aeronautics Program
FEM	Finite Element Model

FTE	Full Time Equivalent
FY	Fiscal Year
GE	General Electric
GNCD	Guidance, Navigation, Control and Dynamics
GRC	Glenn Research Center
HfO_2	Hafnium Oxide
HQ	Headquarters
HQ	Handling Qualities
HSR	High Speed Research (Program)
HYP	Hypersonics (Project)
IAPG	Interagency Advanced Power Group
ICP	Inductively Coupled Plasma
IHPTET	Integrated High Performance Turbine Technology Program
ITAS	Integrated Tailored Aero-Structures (Project)
JPDO	Joint Planning and Development Office
JSF	Joint Strike Fighter
k	a measure of conductivity
K($)	Thousand Dollars
LaRC	Langley Research Center
LCO	Limit Cycle Oscillations
LES	Large Eddy Simulations
LITA	Laser Induced Thermal Acoustic
LPT	Low Pressure Turbine
M	Mach
MD	Multi-Disciplinary
MDAO	Multidiscipline Design, Analysis and Optimization
ME3	Major Element 3 (alloy development iteration 3)
MESA	Multiple Effectors/Multiple Sensor Arrays
MIT	Massachusetts Institute of Technology
MOU	Memorandum Of Understanding
MS	Master of Science
NASA	National Aeronautics and Space Administration
NATR	Nozzle Acoustic Test Rig
NAVAIR	Naval Air Systems Command
NCC	National Combustion Code
NGATS	Next Generation Air Transportation System
NIA	National Institute of Aerospace
NiPtTiHfX	Nickel Platinum Titanium Hafnium compounds
NOx	Nitrogen Oxides
NPSS	Numerical Propulsion Simulation System
NRA	NASA Research Announcement
NRC	National Research Council
NTF	National Transonic Facility
OGA	Other Government Agencies
P&W	Pratt & Whitney
PDE	Pulse Detonation Engine
PDV	Planar Doppler Velocimetry
PFA	Progressive Failure Analysis
PhD	Doctor of Philosophy
PI	Principal Investigator

PIV	Particle Image Velocimetry
PLIF	Planar Laser-Induced Fluorescence
PM	Project Manager / Program Manager
PMC	Polymer Matrix Composites
POC	Point Of Contact
PS	Project Scientist
psf	pounds per square foot
QAT	Quiet Aircraft Technology (Project)
QMR	Quarterly Management Reports
QSP	Quiet Supersonic Platform
R&D	Research and Development
RFI	Request for Information
RFP	Request for Proposal
ROM	Reduced-Order Modeling
RTA	Revolutionary Turbine Accelerator (Project)
SAA	Space Act Agreement
SAP	Systems Analysis and Product (Systemanalyse und Programmentwicklung)
SB	Sonic Boom
SBIR	Small Business Innovation Research
SCIA	Supersonic Cruise Industry Alliance
SFW	Subsonic Fixed Wing (Project)
SHJAR	Small Hot Jet Acoustic Rig
SiC	Silicon Carbide
SLDT	Supersonic Low Disturbance Tunnel
SMA	Shape Memory Alloy
SOA	State of the Art
SPO	System Program Office
SRW	Subsonic Rotary Wing (Project)
STTR	Small Business Technology Transfer (Programs)
SUP	Supersonics (Project)
SWBLI	Shock Wave Boundary Layer Interactions
SSWT	Supersonic Wind Tunnel (at ARC)
SWT	Supersonic Wind Tunnel (at GRC and LaRC)
TDT	Transonic Dynamics Tunnel
TGIR	Turning Goals Into Reality
Turbo-AE	Turbo-Aeroelasticity
TWG	Technical Working Group
UEET	Ultra-Efficient Engine Technology (Program/Project)
UPWT	Unitary Plan Wind Tunnel
URANS	Unsteady Reynolds-Averaged Navier-Stokes
V&V	Verification & Validation
VARTM	Vacuum Assisted Resin Transfer Molding
VCE	Variable Cycle Engine
VLES	Very Large Eddy Simulation
W1,W6,W8	West 1, 6, 8 (room location)
w/ and w/o	with and without
WYE	Work Year Equivalent
XML	Extensible Markup Language
ZrO_2	Zirconium Oxide