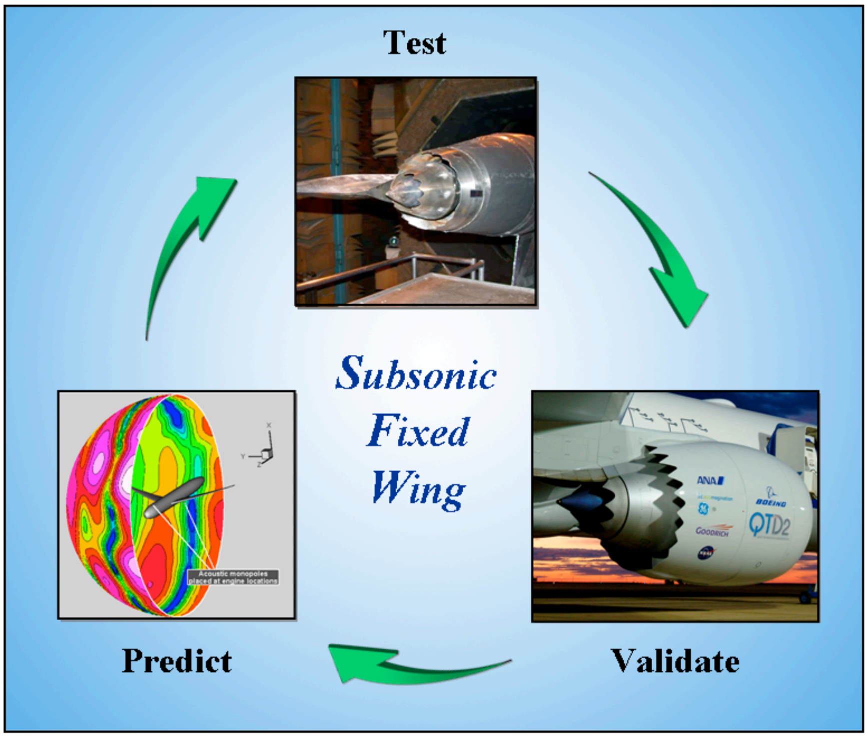
Fundamental Aeronautics Program

Subsonic Fixed Wing 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 Subsonic Fixed-Wing 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.

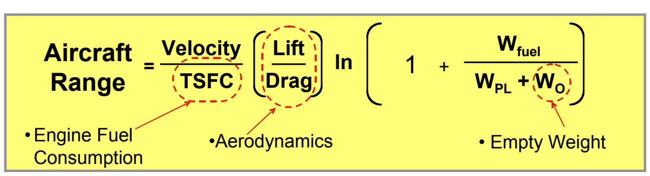
Technical Plan

1.1 Relevance

Problem Statement: This document is focused on meeting the challenge to "re-establish our dedication to the mastery of the core competencies of aeronautics to develop multi-disciplinary capabilities that will enable both civilian and military communities to build platforms that meet their specific needs." ("Reshaping NASA's Aeronautics Research Program", October 17, 2005, Dr. Lisa Porter). Research directed towards this challenge is needed to enable advanced aircraft concepts that provide increased energy efficiency and performance but with lower noise and emissions. This general statement of need can be supported with two more specific examples, one drawn from industry and one from government.

From 1981 to 2001, aviation operations in the United States increased by 2.5 times, driven by a long and steady period of economic and population growth. Going forward, long range forecasts by the NGATS (Next Generation Air Transportation System) projects an additional 3X growth by 2025. Clearly, with emissions and noise concerns considered as limits to aviation system growth, mitigation strategies are critically important to the nation's economic well being. Faced with increased stringency in the regulatory standards for noise and emissions, a "clean sheet" design effort exploring novel commercial transport configurations optimized for low noise and emissions is envisioned. These concepts have the potential to be radically different from today's conventional commercial transport configurations. This design problem is an ideal application for the products of this proposal.

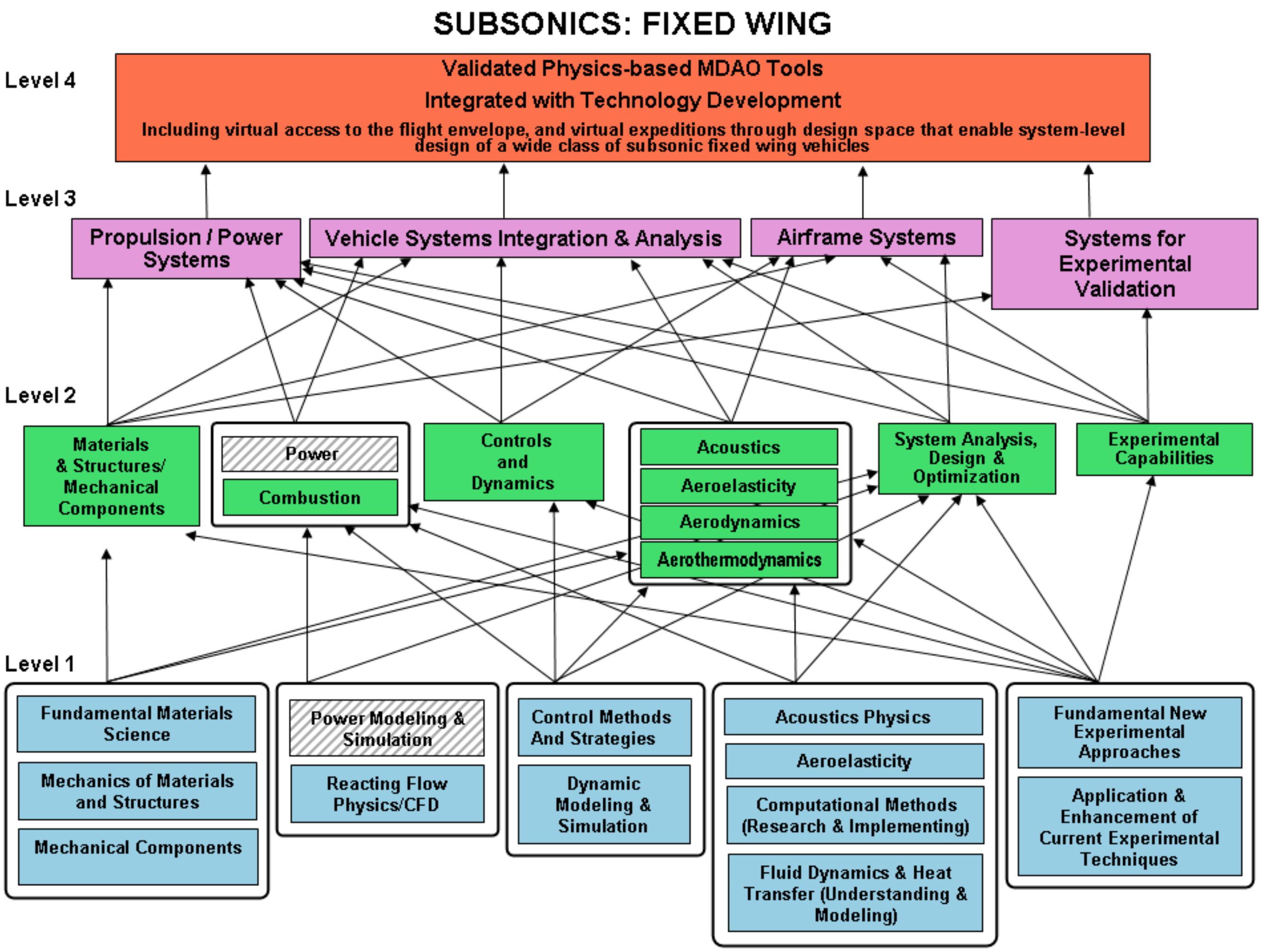
In response to the National Energy Policy Act of 2005, Michael Wynne (Secretary of the Air Force) has created an Energy IPT chartered to take a broad based approach to reduce the Air Force's energy costs through technology. As shown below by the Breguet range equation, technology advances are needed to lower specific fuel consumption (SFC), increase lift to drag ratio and lower empty weight. Fundamental technology research in all three of these areas is included in this document. However, the ultimate challenge is to successfully integrate the right technologies into an optimal configuration that balances conflicting design objectives and meets the myriad of design constraints present in real world design problems. NASA needs robust, highly accurate tools and methods for performance prediction, experimental testing, and finally a verification and validation strategy that will create the opportunities to corroborate our prediction capabilities.



Distance traveled for given amount of fuel: Breguet Range Equation

The two examples, discussed, are representative of the many design problems that will have a need for this proposed research. Improved prediction capabilities are needed government and industry wide to combat the alarming rate of over budget and behind schedule acquisition programs. Independent program reviews repeatedly identify a common theme consisting of a lack of upfront technical fidelity underlying cost, schedule and technology assumptions.
To meet these challenges, this proposal has an overarching goal of developing fast and effective physics based multi-system analysis and design tools with quantified levels of uncertainty that

enable virtual access to the flight envelope and virtual expeditions through the design space. This is represented by the Level 4 "Multi-Disciplinary Analysis and Optimization (MDAO)" area shown below.



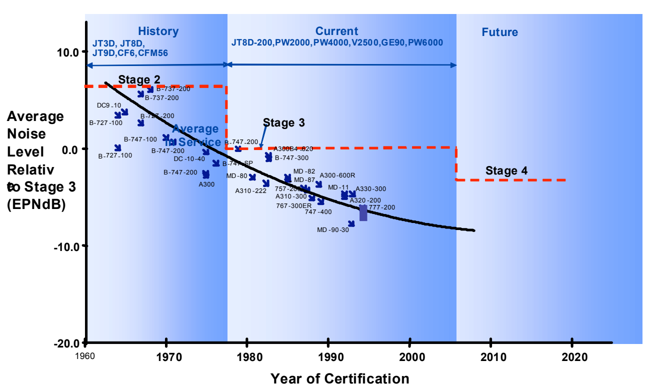
Subsonic Fixed Wing Level 1 to Level 4 Integration Diagram ("cross-hatched" topics currently deferred)

Current State of the Art:

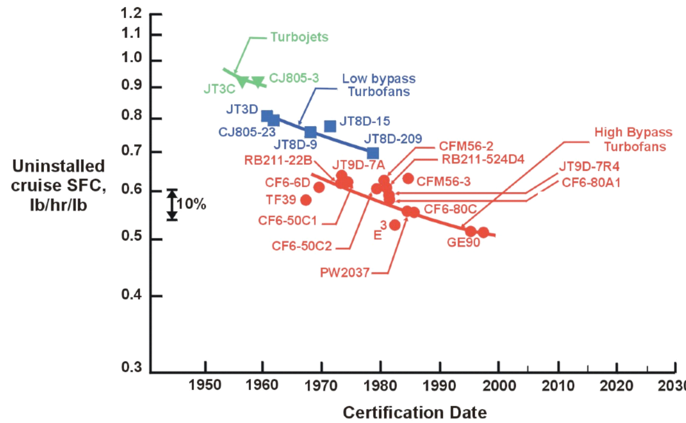
MDAO – The MDAO state of the art consists of a set of discipline specific analysis tools (e.g., aerodynamics, propulsion, structures, noise, cost etc.), a sizing and synthesis core (an executive function that integrates discipline inputs to size a configuration and predict system performance), and an optimization capability. These elements are tied together in an engineering framework (i.e., an environment that enables the direct linking of discipline codes, sizing and synthesis codes, optimizers and post-processing functions to increase efficiency and open up the design space). In general, industry has led the development in this area. Lockheed Martin's Advanced Development Program has developed a process and toolset named "Rapid Conceptual Design" (RCD) is representative of the state of the art. Academia has tended to focus on improving the discipline specific analysis tools and focused applications. Georgia Tech's Aerospace Systems Design Laboratory is a good representative of the state of the art in academia. Government organizations have typically lagged industry. However the AFRL, NASA, and NAVAIR, have started and continue to support efforts to develop capabilities similar to what could satisfy the Level 4 goal articulated above. AFRL's Common Analysis Environment (CAE) is a good representative of the state of the art for government owned L4 capability. The Joint

Program and Development Office (JPDO) is another government entity that has recognized the importance of integrating multi-disciplinary tools. However, their focus is concentrated at the airspace system level, not at the vehicle level. In actuality, the capability developed in this project will be utilized as a module within the JPDO architecture.

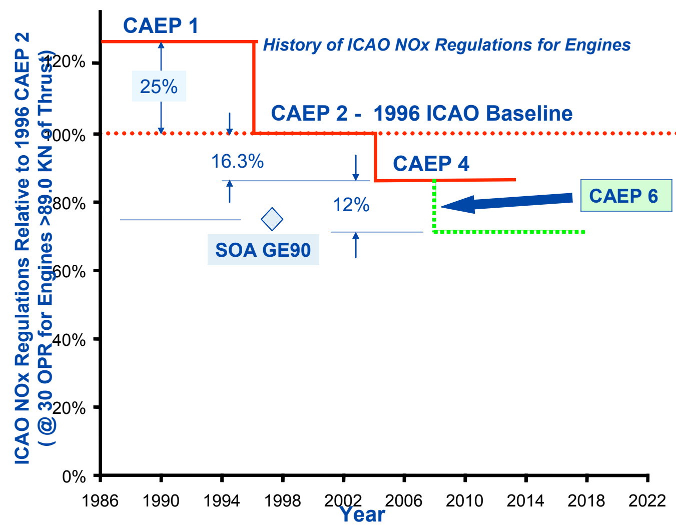
Noise, Emissions, and Performance – Historically, technology has enabled significant reductions in aircraft noise, SFC and emissions (such as Landing-Takeoff NO_X) (see charts). NASA's role is to help develop these technologies. Subsequently, the FAA/ICAO defines regulations after the technologies have been sufficiently matured. The chart shown uses NOx reduction as an example of progress on emissions reduction, but work is also included for reduction of carbon monoxide, particulates, and unburned hydrocarbons (toxics). The GE90 and Boeing's 777, although still commonly viewed as state of the art, contain technology now over a decade old. Although best in the market presently, these systems will not provide the requisite noise and emissions levels needed to attain the NGATS projection of 3X growth while maintaining, or reducing, current noise and emissions levels.



Historical trends of noise levels



Historical trend of cruise SFC



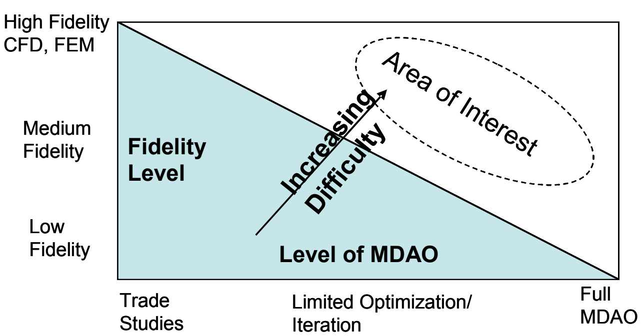
LTO NO_X regulations over time

Benefit of the Research:

MDAO – NASA is uniquely positioned to significantly advance the MDAO state of the art. NASA currently possesses the comprehensive experience, facilities, databases, and technical knowledge to achieve this goal as evidenced by our proposal content which spans Level 1 to Level 4. Required capabilities include a fundamental understanding of flow physics and materials, the ability to translate that fundamental knowledge into a component/sub-component (Level 2), then into a system, or sub-system (Level 3) and finally to a complete vehicle system level design and optimization (Level 4).

Although industry, government and academia have impressive Level 4 capabilities as evidenced in the current state of the art discussion above, many gaps and challenges remain to be addressed. Most integrated MDAO systems are highly customized (and proprietary) to specific configurations and analysis processes. A change in the configuration of interest usually necessitates a lengthy and complex redevelopment effort of the modeling environment. In almost all cases, the underlying analysis tools that form the critical foundation of the integrated MDAO system are deterministic and empirical in nature, do not quantify uncertainty and do not handle unconventional geometries well, if at all. In addition, directly integrated variable fidelity capability is rare.

This document has been designed to directly address these challenges. A flexible integration framework will be utilized to respond to multiple user needs. This framework must be reconfigurable and enable a "plug-and-play" capability to include higher fidelity discipline modules from Level 1 through Level 3.



Fidelity versus MDAO Challenge

As illustrated, above, as the level of fidelity is increased, the scope of MDAO suffers due to the demanding nature of the high fidelity analysis, in terms of model fidelity and computational resources required. While numerous decomposition processes and approximation methods have been utilized to help alleviate this problem, further effort is needed to increase analysis model robustness, efficiency, automation, parametric modeling and implementation of user-friendly approximation and decomposition techniques. This document will show how advances in these areas at Levels 1 and 2 will be rolled up into Levels 3 and 4, thus enabling a shift to physics-based, integrated, variable fidelity methods. This shift will be accompanied by an emphasis on quantifying uncertainty to better focus the high fidelity effort and increase the credibility of the integrated analysis results.

Noise, Emissions, and Performance – To achieve the NGATS vision of tripling throughput with no increase in environmental impact will require an infusion of new technology. As the following table shows, system studies indicate that significant noise and emission reductionsare attainable while still improving performance for future generations of conventional aircraft. The development of unconventional systems, such as a hybrid wing configuration, could further improvements. **The improvements shown in the table require major changes to engine cycle and airframe configurations. In conjunction with industry, this will be the focus of the project.** The work described will focus on identifying advancements in critical discipline areas, such as materials & structures, aerodynamics and propulsion, to help achieve these targets.

	"N+1" Generation Conventional	"N+2" Generation Hybrid Wing
Noise (cum below Stage 3)	- 42 dB	- 52 dB
Emissions (LTO NOx) (below CAEP/2)	- 70%	- 80%
Performance: Aircraft Fuel Burn (relative to 737/CFM56)	- 15%	- 25%

Noise, Emission, Fuel Burn Targets Attainable from Major Changes in Engine Cycle/Airframe Configurations and Advanced Technologies

Use of sensitivities, like the example below, will be developed for advanced engine cycle/airframe configurations, and used to identify the most fertile research opportunities. The intent is to create a balanced technology portfolio that maximizes the potential impact on noise, emissions and performance. The example given below illustrates evolutionary reductions in emissions and noise by optimizing around a fixed engine cycle/airframe configuration. However, the purpose of this document is to enable significantly larger improvements through advanced technology, major changes in engine cycles, and highly integrated engine/airframe configurations.

The project has identified several specific examples of system level validation opportunities. These activities will enable the SFW to leverage limited fiscal resources through partnerships to allow validation of advanced prediction methods that can be incorporated into the MDAO system. In addition, they will provide a platform to evaluate technologies developed within discipline teams.

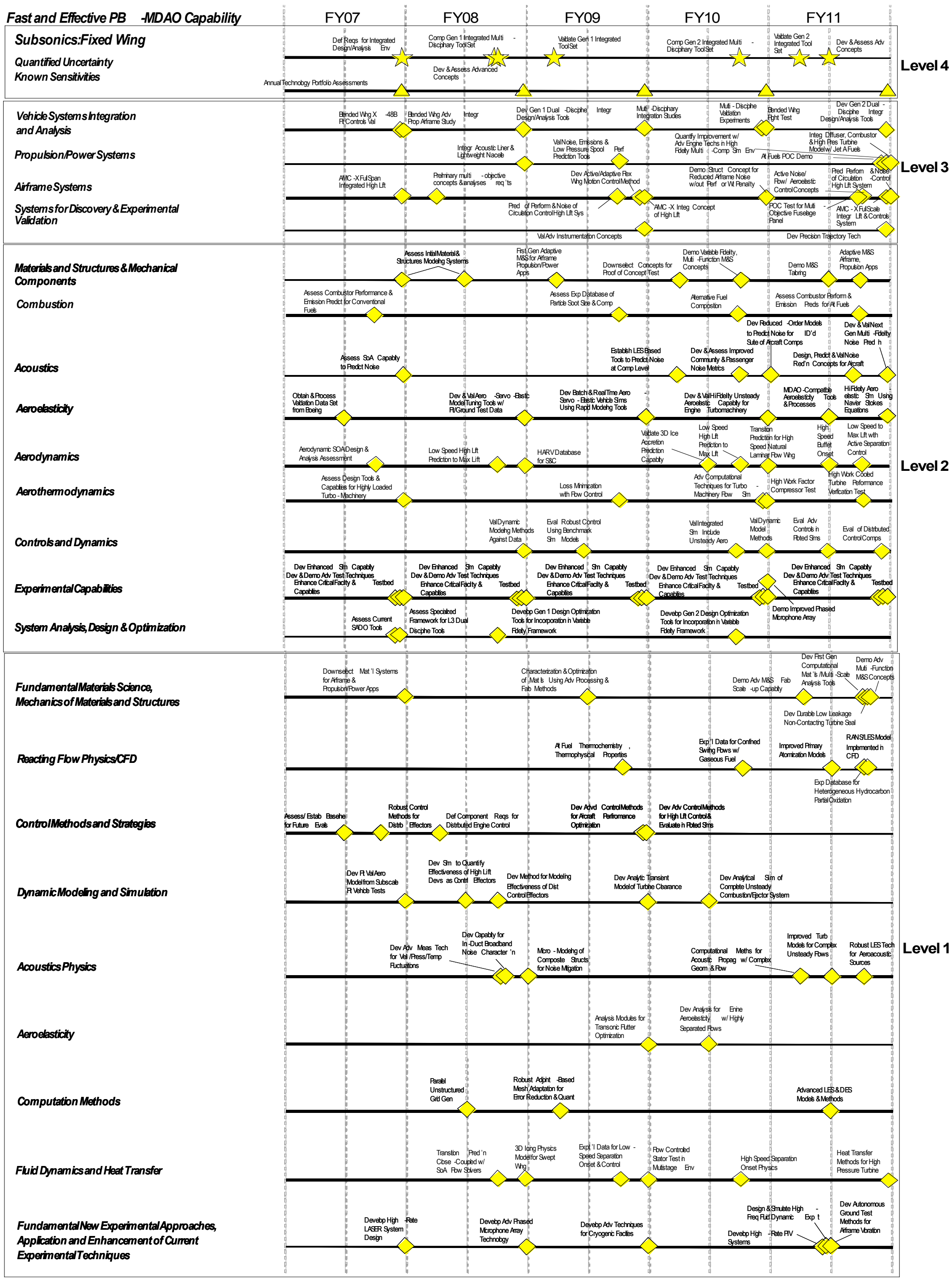
Although the primary focus is intended to be on transport aircraft, the project will also conduct assessments to identify the potential benefits of new technologies that can enable a wide array of sizes of subsonic vehicles such as Very Light Jets (VLJs) and new capabilities such as Extreme Short Takeoff and Landing (ESTOL).

	Fuel Burn	LTO NO_x	Noise
Vehicle:			
➡ -10% C_{D_i}	-4.4%	No change	-0.6 dB cum
➡ -10% C_{D_0}	-6.5%	No change	-0.9 dB cum
➡ +10% $(L/D)_{cruise}$	-9.6%	No change	-1.2 dB cum
➡ -10% OEW	-3.1%	No change	-1.2 dB cum
➡ -10% SFC	-11.1%	No change	-0.6 dB cum
Engine:			
➡ +2 pts. Fan η_p	-2.5%	-2.8%	-0.4 dB cum
➡ +2 pts. HPC η_p	-2.2%	-7.5%	-0.1 dB cum
➡ +2 pts. HPT η_a	-2.3%	-2.7%	-0.1 dB cum
➡ +2 pts. LPT η_a	-2.6%	-1.9%	-0.2 dB cum
➡ -20% Charg. Cooling	-1.3%	-1.5%	-0.1 dB cum
➡ -25% Pod Weight	-3.2 %	No change	-0.4 dB cum

Performance Sensitivities for a Fixed Engine Cycle and Airframe Configuration (Current Generation, Single-Aisle Midsize Airplane)

1.2 Milestones and Metrics

Subsonic Fixed Wing Project planning kicked off with workshops in September and November 2005 from which a 10-year plan was developed. That plan was presented publicly at the annual AIAA Conference in Reno in January 2006. The plan has been revised, and the key milestones for the first five years are shown below.



Along with refining the roadmap, technical plans were fleshed out, including quantifiable metrics for the milestones, at another planning workshop in February 2006. The milestone metrics, along with the annual assessments of progress at Level 4 (System), are key to measuring the overall progress of the project.

1.3 Technical Approach

A major focus of the project is to develop improved prediction methods and technologies for lower noise, lower emissions, and higher performance for subsonic aircraft. Higher performance includes energy efficiency and operability technologies that enable advanced airframe/engine systems. The sensitivity coefficients presented in the relevance section will be used to prioritize work. Estimates for weight reduction, enhanced lift, lower drag, higher thermal efficiency, noise reduction, NOx reduction, particulate/soot reduction, and alternative fuels efficiency will be used in system studies to determine the best “bang for the buck”. Initial studies will concentrate on existing state-of-the-art aircraft/engine systems such as the Boeing 777 with GE-90 engines, and similar systems that are feasibly sized to 150 passenger and regional jet vehicle classes. While there are no specific system level goals for noise, emissions and performance, technologies will be evaluated using best available trade studies for existing engines/aircraft. It is expected that the selected aircraft/engine systems and advanced technologies evaluated in the studies will be general enough to have broad benefits across a range of vehicle classes. Initially, the project will concentrate on evaluating the best “tube and wing” configurations using podded engines. Potential validation opportunities have been identified with industry partners that are expected to meet the nearer term noise/emissions/performance targets which were discussed, earlier. Improvements will be made to prediction methods using this validation data. This will provide the foundation for evaluating advanced vehicle concepts such as hybrid wing/engines where current prediction methods are unreliable. The ten year strategy is to provide validated prediction tools that can be used to perform system trade studies aimed at evaluating advanced concepts capable of meeting longer term noise, emissions, and performance targets.

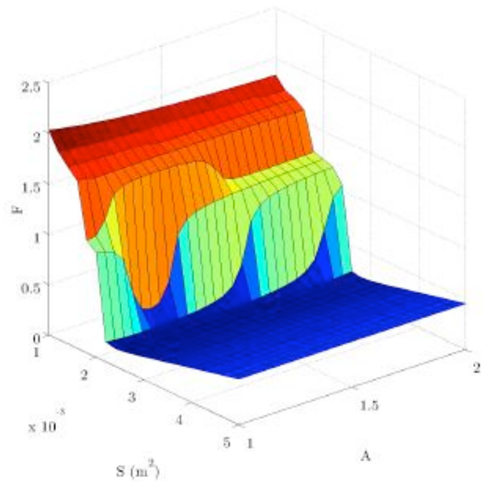
Each Level 2 Discipline Team is responsible for integrating Level 1 through Level 4 research activities that either support their discipline or provide support for other research activities that depend on their work. Level 1 research provides the tools for each discipline to advance the state-of-the-art for prediction and measurement methods for better understanding of the physics. Level 2 activities refine and apply the tools for a specific discipline. Level 3 combines the work from several disciplines to begin evaluating propulsion and airframe systems. The Systems Analysis, Design, and Optimization team has identity at Levels 2 through 4 and is responsible for defining the requirements for integrated multi-discipline design, analysis and optimization. Each Level 2 team will establish the current state-of-the-art in prediction methods through assessment tasks that will be performed over the first year of the project. This will include analysis of existing data for comparisons with current prediction methods, and publishing archival documents (NASA SP) that quantify the level of agreement and verify the metrics that will be used to evaluate improvements over the course of the project. There will be periodic evaluations conducted by system analysts that track progress toward the ultimate goal of providing fast and effective multi-disciplinary design and optimization capability. A major goal of the project is to demonstrate the ability to accurately predict system level changes in noise, emissions and performance as a function of changes in parametric design space. Details of the technical approach are described next starting with Level 4 and ending with Level 1.

SFW.4.01—Fast and Effective Physics Based MDAO Capabilities

Problem Statement: Current design/analysis tools have inherent limitations that preclude modeling unconventional systems to the same fidelity as conventional configurations. SFW's goal is to "develop fast and effective physics based multi-disciplinary analysis and design tools with quantified levels of uncertainty that enable virtual expeditions through the design space." Realizing this goal will enable unconventional vehicle synthesis and analysis through a shift from empirically based, non-integrated, low fidelity deterministic methods to more physics based, integrated, variable fidelity probabilistic methods. This new capability will enable the critical sizing and early configuration trade studies of both conventional and unconventional designs to provide guidance for prioritizing resources. The new capability would support the annual portfolio assessment; thereby providing a status of technical progress.

Previous Related Research: The Conceptual Design Shop (CDS) project was planned and prototyped in FY03/04 and executed during FY05. CDS shared many of the same goals and objectives with this proposed effort, and produced a low fidelity integrated framework. The new challenge is to advance that work with variable fidelity capability, and validation, drawing on the best tools from the Level 2 discipline areas and Level 3 multi-disciplinary integration efforts.

Research Approach: Using the lessons learned from CDS, a conceptual design-level framework will be developed and codified in a System Architecture and Implementation Plan where requirements will be captured and an implementation strategy detailed. This strategy will provide systems engineers with validated, variable fidelity models from the discipline areas



"Virtual Expeditions Through the Design Space"

at Levels 1 and 2 and multi-discipline integration development efforts at Level 3. Technology assessment and integration studies, including the evaluation of advanced concepts, will be conducted at the aircraft system, mission and transportation fleet level. Multiple subsonic aircraft will be utilized for this work. Activities include technology portfolio assessments and benefit/feasibility studies of advanced technologies developed within Level 1 and 2 discipline areas.

Technology Validation Strategy: The usefulness and accuracy of the full-up system will be demonstrated during the development and assessment of advanced concepts arising from partnerships. The system's predictive capabilities will be validated using the data from the industry/government partnership experiments.

Milestones:

SFW.4.01				
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.4.01.01	Define Requirements for Integrated Design/Analysis Environment	4Q 2007	L4 Requirements Document and a System Architecture and Implementation Plan	

SFW.4.01.02	SFW Technology Portfolio Assessment	4Q 2007 4Q 2008 4Q 2009 4Q 2010 4Q 2011	Annual report quantifying potential noise/emission/performance benefits from current SFW technology portfolio	SFW.3.01 SFW.3.02 SFW.3.03 SFW.3.04
SFW.4.01.03	Development and Assessment of Advanced Concepts	3Q 2008 2Q 2011	Work w/partners to integrate SFW technologies into advanced concepts. Produce assessment of the potential benefits of SFW technologies applied to advanced concepts.	SFW.3.08.07
SFW.4.01.04	Complete Gen 1 Integrated Multi-Disciplinary Tool Set	3Q 2008	Predict NOx to within 15%, predict TO/landing performance within 10%, predict cruise performance within 5%, predict TOGW within 10%, predict noise within 5 dB for reference conventional system (B777 + GE90 and B737 + CFM56)	SFW.3.01 SFW.3.02 SFW.3.03 SFW.3.04 SFW.2.05.05 SFW.2.05.02 SFW.2.05.03 SFW.1.09.02
SFW.4.01.05	Complete Gen 2 Integrated Multi-Disciplinary Tool Set	3Q 2010	Predict NOx to within 5% (conv.) & 10% (unconv.), predict TO/landing performance within 5% (conv.) & 10% (unconv.), predict cruise performance within 2.5% (conv.) & 5% (unconv.), predict TOGW within 5% (conv.) & 10% (unconv.), predict noise within 2.5 dB (conv.) & 5 dB (unconv.). Reference conv. system: B777 + GE90 and B737 + CFM56), reference unconv. sys: BWB.	SFW.2.05.02 SFW.2.05.03 SFW.2.05.05 SFW.1.09.02
SFW.4.01.06	Validation of Integrated Tool Set w/Experimental Data (with Industry/Government partner)	1Q 2009 (Gen 1) 1Q 2011 (Gen 2)	50% reduction in prediction error based on calibration of computer model with test data. (Validation of uncertainty defined in SFW.4.01.04 & SFW.4.01.05)	SFW.3.01 SFW.3.02 SFW.3.03 SFW.3.04

Resources:

Key Deliverables:

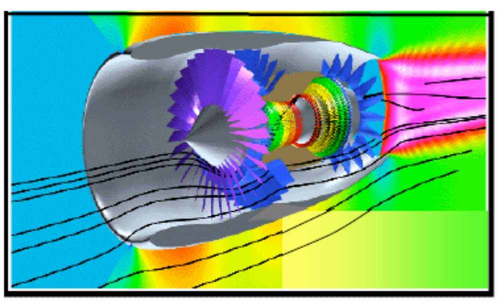
Product	Description	Date
Req'ts and SAIP	Requirements and System Architecture & Implementation Plan	4Q FY07
Portfolio Assessment Reports	Quantitative assessment of SFW technology portfolio and update of progress metrics and technology investment strategy	Annually
Advanced Concepts Analysis Reports	Demonstration of variable fidelity, multidisciplinary systems analysis capability applied to unconventional concepts	3Q FY08 2Q FY11
Validated Design & Analysis Capability	Validation of integrated multi-fidelity framework (using Gov't/Industry Test Results)	1Q FY09 1Q FY11

SFW.3.01—Propulsion/Power Systems

Problem Statement: A multi-disciplinary approach is essential for developing advanced propulsion and power systems that meet goals of reduced noise and emissions, and increased performance. Technologies are needed to enable engine cycle changes, such as Ultra-High Bypass (UHB) ratio engines to reduce noise and decrease specific fuel consumption (SFC). Emissions reductions can be achieved through advanced combustor designs. Alternative jet fuels (Fischer-Tropsch, bio-fuel) can be developed to reduce emissions and increase the Nation's energy independence. High power density cores with distributed engine controls need to be developed that increase propulsive efficiency, and reduce engine weight.

Previous Related Research: Activity will build upon previous work from NASA's aeronautics programs where research was conducted on low emission combustor concepts, propulsion noise reduction technologies, intelligent propulsion system technologies, high temperature materials, and alternative power systems.

Research Approach: The research thrust will provide robust predictive tools to evaluate advanced propulsion concepts. New technologies will be validated on test platforms for the next generation engines (i.e., UHB). Best available prediction tools will be assessed and used to evaluate multi-discipline concepts such as integrated acoustic liners with lightweight nacelles estimated to give about 3 dB additional fan noise reduction. Propulsion system predictive tools will be assessed for accuracy and compared to estimates shown in milestone SFW.3.01.02. Stator flow control for turbomachinery, reduced leakage seals, high thermal barrier coatings, distributed engine control and lightweight fan containment concepts will be evaluated in high fidelity simulations to provide an additional 4% decrease in SFC beyond cycle benefits of higher bypass ratio engines. Additional fan noise reduction of about 3 dB will be achieved using over the rotor acoustic treatment and "soft" stator vanes in multi-component evaluations for noise and performance. An integrated combustor/diffuser/high-pressure turbine simulation will be developed to quantify emissions and particulates from Jet A fuels. Alternative fuels will be developed and tested in proof of concept engines or sector tests, as available, to verify 70% NOx reduction relative to CAEP 2 levels. Overall, the approach shall incorporate advanced flow control methods, advanced technologies for lightweight high temperature materials, adaptive structures, aeroelastic analyses (and icing accretion will be used to evaluate advanced propulsion concepts and conduct exploratory studies on secondary power concepts).



Simulation of flow through a conceptual high bypass turbo-fan engine

Technology Validation Strategy: Potential partnerships with industry have been identified that could provide validation data for engines. NASA will use high fidelity prediction tools to model the engine system for comparisons with rig and engine data. Advanced technologies evaluated in system studies for lower noise, lower emissions, and increased performance will be negotiated with industry partners for validation tests. NASA will pursue engine test opportunities pending the success of a joint Air Force/NASA collaborative effort to identify suitable alternative fuels.

Milestones:

SFW.3.01	Propulsion/Power			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.3.01.01	Integration of acoustic liner and lightweight nacelle	4Q 2008	Conceptual design for 3dB fan noise reduction and integrated rub strip/fan containment system relative to conventional fan/nacelle systems.	

SFW.3.01.02	Validate Noise, Emissions and Low Pressure Spool Performance Prediction Tools against experimental data from the UHB static engine test in 2008.	3Q 2009	Compared to engine data, component noise prediction (fan and jet) is within 3dB; fan and LPT efficiency prediction is within 2%; hybrid emission model NOx prediction is within 20%.	SFW.2.01.01 SFW.2.01.04 SFW.3.01.02 SFW.2.03.01 SFW.1.05.03 SFW.1.05.04 SFW.1.05.05 SFW.4.01.02 SFW.4.01.06
SFW.3.01.03	Quantify noise, emissions and performance improvements with advanced engine technologies in a high fidelity multi-component simulation environment.	4Q 2011	Cruise SFC reduction of 4% with flow controlled compressor stators, low leakage seals, improved thermal barrier coatings, distributed engine control and light weight composite fan case; fan noise reduced by 3dB using over-the-rotor nacelle treatment and soft vane stators	SFW.2.01.01 SFW.2.01.04 SFW.3.01.02 SFW.2.03.01 SFW.1.05.03 SFW.1.05.04 SFW.1.05.05 SFW.4.01.02 SFW.4.01.06 SFW.2.08.08
SFW.3.01.04	Integrated diffuser, combustor and high pressure turbine model with Jet A fuels	4Q 2011	Effects of integrated combustor-nozzle-high pressure turbine with cooling air on gaseous and particulate emissions quantified	SFW.2.03.01 SFW.3.01.02
SFW.3.01.05	Alternative fuels proof of concept demonstration	4Q 2011	Work with partners (industry, OGA) to demonstrate alternative hydrocarbon jet fuel in engine test to meet low emissions requirements target NOx reduction of 70% from CAEP 2.	SFW.2.03.03 SFW.2.03.04 SFW.1.05.01

Key Deliverables:

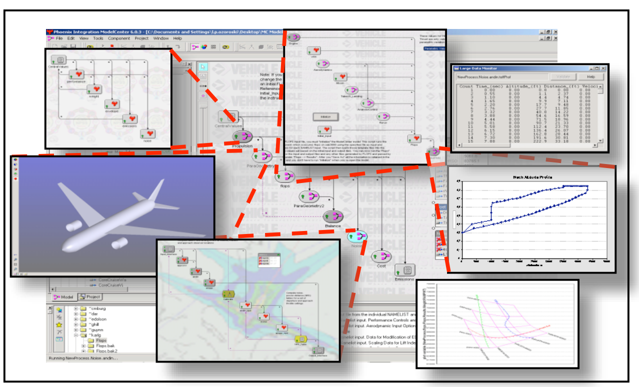
Product	Description	Date
Requirements Specification document	Identify requirements for achieving high performance, low noise and low emissions propulsion systems.	FY08
NASA, Industry, Academia Technology Report	Assess multi-discipline, multi-fidelity performance and tool improvements needed for UHB engines, advanced and adaptive cycle engines, and high power density core engine systems.	FY09
Validated propulsion technologies, analysis tools and models	Advanced technologies demonstrated, models and predictive analysis tools validated for UHB engines achieving low-noise, low-emissions, high performance propulsion and power systems.	FY11
Analysis, Models, Tools	Demonstration of advanced technologies and validation of predictive tools capabilities.	FY11

SFW.3.02—Vehicle Systems Integration and Analysis

Problem Statement: Currently in-house capability to efficiently integrate and utilize medium- and high-fidelity discipline level tools and methods for the design, analysis and assessment of new technologies and unconventional configurations is limited. This effort will develop physics-based, multi-disciplinary design and analysis tools and the "surrogate models" required to link them to the Level 4 aircraft conceptual design capability.

Previous Related Research: The Conceptual Design Shop (CDS) project was planned and prototyped in FY03/04 and executed during FY05. CDS shared many of the same goals and objectives with this proposed effort. The Numerical Propulsion System Simulation (NPSS) developed at GRC successfully demonstrated an integration of multiple-fidelity propulsion analysis tools into a single framework. Several commercial software packages provide basic framework capabilities and infrastructure. ModelCenter from Phoenix Integration, and AML, from TechnoSoft Inc have been used in several previous agency engineering and analysis projects.

Research Approach: Using the L4 System Architecture and Implementation Plan, this element will identify the optimal framework architecture to successfully integrate multiple L2 discipline design/analysis tools. The work will include enforcing syntax consistency between inputs and outputs of the framework analysis tools, and developing, or procuring, a parametric geometry library that encompasses both traditional and advanced aerospace vehicle configurations. Also, the project will integrate the L2 analysis capabilities using specialized integration frameworks with process, study and visualization improvements.



Example of integrated engineering design and analysis

Special linkages will be developed to couple these multi-disciplinary tools to the L4 aircraft conceptual design capability. Upon completion, benchmarking efforts will demonstrate sub-system (L2) integration methodologies prior to system integration at L4, as well as, provide application-level validations for L1 foundational discipline work. Design and optimization studies will be conducted to quantify the benefits of multiple, coupled disciplines. These system studies will also demonstrate L3 integration and validate design capabilities and experiments planned for the L4 system test.

Technology Validation Strategy: Capstone full up system tests (candidates: Next-gen single aisle, UHB Engine, BWB X48B), will be utilized to validate the integrated analysis capability against experimental data. This will demonstrate the L3 capability and its integration at L4.

Milestones:

SFW.3.02	Vehicle Systems Integration and Analysis			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.3.02.01	Blended Wing X48B – flight controls validation	4Q 2007	Validate flight control system near departure at low speed (Edwards test range)	SFW.2.08.07 SFW.2.05.05
SFW.3.02.02	Blended Wing Advanced integrated propulsion airframe study	4Q 2007	Optimized engine placement for stage 3 -52dB cum. Identify technology development needs for low noise configuration.	
SFW.3.02.03	Develop Dual-disciplinary Integrated Design/Analysis Tools (Gen 1)	4Q 2008	Improve accuracy to within 3% (SFC) & within 10% (wing wt.) for a conventional configuration	SFW.2.10.02
SFW.3.02.04	Multi-disciplinary Optimization Studies	4Q 2009	5% reduction in takeoff gross weight for unconventional configurations and 1% reduction in takeoff gross weight	SFW.3.02.01

			for conventional configurations.	
SFW.3.02.05	Multi-disciplinary Validation Experiment(s) for Systems Analysis (candidates: Next-gen single aisle, UHB Engine, BWB X48B)	4Q 2010	50% reduction in prediction error based on calibration of computer model with test data. (Validation of uncertainty defined in SFW.3.02.01)	SFW.3.02.01 SFW.3.02.02
SFW.3.02.06	Blended Wing Flight test	4Q 2010	Validate stage 3- 52dB cum at scale low and high speed conditions. Validate flight controls system throughout flight envelope.	SFW.2.05.05
SFW.3.02.07	Develop Multi-disciplinary Integrated Design/Analysis Tools (Gen 2)	4Q 2011	Improve accuracy to within 1.5% (SFC) & within 5% (wing wt.) for a conventional configuration. Improve accuracy to within 3% (SFC) & within 10% (wing wt.) for a unconventional configuration	SFW.2.10.03 SFW.3.02.03 SFW.2.05.05 SFW.1.09.02

Key Deliverables:

Product	Description	Date
Design/Analysis Simulation	Develop 1st generation dual-disciplinary integrated design/analysis tools	2Q FY08
Tool Integration Report	Conduct multi-disciplinary integration studies using new capability	1Q FY09
Validated Integrated Analysis Capability	Conduct multi-disciplinary validation experiments to validate prediction capability	2Q FY10

SFW.3.03—Airframe Systems

Problem Statement: Validated multi-disciplinary design tools and applied technologies are needed to enable development of advanced conventional and unconventional vehicle concepts. These tools & technologies must integrate across all design requirements to achieve optimal performance and consider such issues as noise, emissions and performance. Multifunctional integration has not been exploited to the fullest to improve efficiency, reduce noise or emissions. Technology improvements in structures & materials, controls & dynamics, acoustics, aeroelastics, and aero/aerothermodynamics are needed.

Previous Related Research: Activity will build upon previous work from NASA's aeronautics programs as well as our industry and DOD partners where preliminary research to support advanced airframe systems development was done in advanced structures & materials, aeroelasticity, noise prediction/reduction, advanced flow prediction, flow control, aircraft controls and flight dynamics.

Research Approach: Multidisciplinary design tools and technologies will be developed, integrated, and validated to optimize airframe systems throughout the design space to realize improvements in noise, emissions & performance. Key demonstration opportunities that involve partnering with industry and other government agencies will be pursued. The primary areas of research that will be integrated include the development of: aeroelastic methods, lightweight multifunctional materials and structures (savings of 10% OEW could result in savings of 7.2% in fuel burn); advanced flow prediction of separation onset & progression for high lift (doubling CL_{max} may reduce fuel burn by 4.5%), pressure

Hybrid wing concept

gradient and skin friction (reduced CDo of 10% may save 9% in fuel burn), enhanced predictive tools for operability, dynamics, stability & control, & noise prediction/ reduction methodologies (reduction of 42dB cum in conventional or 52dB cum in BWB). Technologies and tools will be validated by demonstration of airframe systems that meet multiple objectives such as reduced weight, noise reduction, drag reduction, high lift, flow control, improved control & dynamics, and active/passive aeroelastic control.

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 essential and will be pursued.

Milestones:

SFW.3.03	Airframe Systems			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.3.03.01	AF Advanced Mobility Concept (AMC-X) Full span integrated high lift	4Q 2007	Demonstrate CLmax= 6 at scale conditions	
SFW.3.03.02	Preliminary concepts & analyses req'ts definition for multi-objective fuselage structural concept with integrated interior noise attenuation.	1Q 2008	Report documenting preliminary definition of concepts & analysis requirements. Goal is identification of M&S combinations that offer potential airframe weight and interior noise level reductions (3 dB reduction is current target).	SFW.4.01.02 SFW.4.01.04
SFW.3.03.03	Develop active/adaptive flexible wing motion control methodologies	4Q 2009	Increase flutter dynamic pressure by 20% for flight test article (increase relative to open loop flutter speed)	SFW.2.05.02 SFW.2.05.03 SFW.2.05.05
SFW.3.03.04	AMC-X integrated concept of high lift	4Q 2009	Combined demo of both CLmax=6 and 0.8 Mach number at scale conditions	SFW.2.06.02
SFW.3.03.05	Prediction of performance and noise of circulation-control high-lift system	3Q 2009	Demonstrate prediction of lift to within (10%-2009) and noise to within (12dB-2009) against (2007,2009) AMC-X tests	SFW.2.06.02 SFW.2.06.07 SFW.2.04.31
SFW.3.03.06	Demonstrate flexible/deployable structural concept for reduced airframe noise without performance or weight penalty.	4Q 2010	Demonstrate 6dB high-lift component noise reduction via flexible/deployable structure with less than 5% component weight penalty and less than 2% CL-max loss - 14x22 test	SFW.2.06.02 SFW.2.04.41
SFW.3.03.07	Prediction of performance and noise of circulation-control high-lift system	4Q 2011	Demonstrate prediction of lift to within (5%-2011) and noise to within (8dB-2011) against (2007,2009,2011) AMC-X tests	SFW.2.06.02 SFW.2.06.07 SFW.2.04.31
SFW.3.03.08	Proof-of-concept test for multi-objective fuselage panel that combines weight reduction with interior noise reduction technologies	3Q 2011	Enable a 3 dB interior noise reduction while reducing weight by 10% over a conventional solution. Experimental data correlated with analysis model predictions to assess adequacy. Prediction of response (structural and noise) to within 15%.	SFW.2.01.03 SFW.4.01.02 SFW.4.01.06

SFW.3.03.09	Active Noise/Flow/Aeroelastic Control Concepts	3Q 2011	Performance prediction of structurally integrated actuator and resulting noise/flow/aeroelasticity effect within 5% (lift increment) and 5dB for low speed high lift conditions	SFW.2.06.02 SFW.2.06.04 SFW.2.06.07 SFW.2.05.02 SFW.2.05.03 SFW.2.05.05 SFW.3.03.03
SFW.3.03.10	AMC-X Full scale integrated lift and controls system	4Q 2011	Low speed test of full scale integrated system demonstrating CLmax=6	SFW.2.06.02 SFW.2.06.04 SFW.2.06.07 SFW.2.08.04
SFW.3.03.11	Adv. control effector impact on vehicle performance	4Q 2011	Flight demonstrate 1% drag reduction using performance adaptive flight control on a BWB configuration	SFW2.08.03

Key Deliverables:

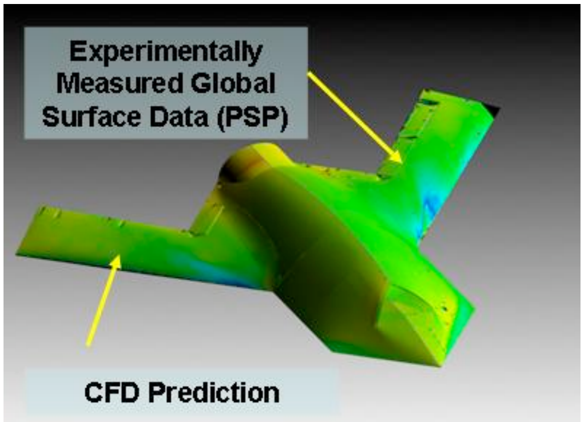
Product	Description	Date
Multi-objective Fuselage Panel SFW.3.03.08	Report and databases summarizing the proof-of-concept demonstration of a multi-objective fuselage panel that combines weight reduction (-10%) with interior noise reduction (-3dB) technologies	2011
Computational Tool for Prediction of Performance and Noise of Circulation Control High-lift System SFW.3.03.05	Validated computational tool for prediction of performance (+/- 10%) and noise (+/-12dB) of circulation control high-lift system (AMC-X ESTOL)	2010
Design Methodology for Active Noise/Flow/Aeroelastic Control SFW.3.03.09	Validated performance (+/-5%) and noise (+/-5dB) prediction of structurally integrated actuator for low-speed high-lift conditions	2011

SFW.3.04—Systems for Experimental Validation

Problem Statement: Validation of the advanced concepts required for acoustic noise reduction, engine emission reduction, and enhanced vehicle performance will depend upon an integration of various experimental capabilities into the design cycle. We will develop advanced experimental measurement techniques based on guidance from other disciplines with a focus on providing data for developing advanced predictive capabilities as well as validating advanced concepts in either wind tunnel tests or flight tests as appropriate.

Previous Related Research: NASA has performed many system validation studies on its own and with other commercial and government partners. These include full system designs (such as the blended wing body concept currently underway) to component validation strategies (such as novel active flow control designs). To support these studies, NASA has developed many advanced measurement capabilities, some of which will be expanded in this program. Examples include wind tunnel diagnostics and testing techniques, sensors for harsh environments, structures and materials testing, and flight validation concepts.

Research Approach: The other disciplines were extensively polled to determine which measurements are of high priority. Key areas which can share hardware and data processing that are expected to be addressed include: high spatial and temporal resolution optical diagnostics for acoustic noise and turbulence modeling, chemical sensor systems for integrated intelligent engine design, advanced techniques for testing structures and materials, advanced simulation capabilities, and development of advanced flight testing techniques, including low-cost remotely piloted testbeds capable of providing validation opportunities for advanced concepts.



Experimental surface pressure measurements on a deflected model compared with CFD prediction on an undeflected model

Technology Validation Strategy: We will initially validate new experimental capabilities for feasibility and accuracy in small scale tests, which are nonetheless designed to be realistic with respect to noise levels and limitations encountered in large scale testing. Final validation for productivity and practicality will be done in large scale tests.

Milestones:

SFW.3.04	Experimental Capabilities			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.3.04.01	Validate advanced instrumentation concepts	4Q 2009	Demonstrate instrumentation to validate predictive capabilities, specifically unsteady PSP on AMC-X (FY2009), microphone array on X48B (2009), and unsteady PIV on GTV in 2008.	SFW.2.09.01 SFW.2.09.02 SFW.2.09.04
SFW.3.04.02	Precision trajectory technique development	4Q 2011	Validated model for precise trajectory control within a 10 meter bounding tube.	

Key Deliverables:

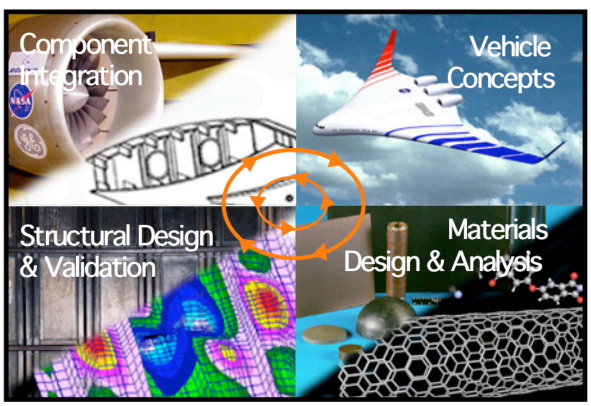
Product	Description	Date
Databases for model validation	Provide databases to validate predictive capabilities in complex tests, specifically high frequency PIV on UHB Engine Validation (FY2008), unsteady PSP on AMC-X (FY2009), and Microphone Array on X-48B (FY2009).	4QFY08 4QFY09
Validated Precision Trajectory Control Model	Validated model for precise trajectory control within a 10 meter bounding tube.	4Q FY11

SFW.2.01—Materials & Structures

Problem Statement: The primary goal is to reduce the component and subsystem weight to support system performance enhancement, while maintaining, or enhancing, structural performance or durability through application of novel structural concepts and multifunctional materials. Ultimately, this discipline should influence the structural concept design space at L3 through optimization of structures for meeting the selected set of system-level objectives: light weight, higher temperature, noise reduction, and high lift. This discipline must also consider the effects of reducing weight and engage other disciplines as required. For example, a link to the aeroelasticity discipline will be maintained so that the effects of the increased flexibility of lighter-weight structures can be adequately addressed.

Previous Related Research: Advances in airframe and propulsion/power systems composite and metallic M&S technology from previous focused and fundamental research aeronautics programs will be leveraged. While the emphasis of these previous programs was on goals tied to specific aircraft systems, they addressed the same issues as for SFW, noise attenuation, reduced emissions, and performance efficiency. These, along with the technology advances achieved by industry, DOD and DOE, will be used to assess the state-of-the-art.

Research Approach: The work performed at L2 is intended to integrate the L1 tools and technologies to develop, test and validate multifunctional materials and structural concepts at the sub-component level. Issues related to scale-up at the material, structural concept, and fabrication levels will be addressed. Necessarily, the range of applicability of the analytical tools will also be expanded. Multi-scale modeling tools must be linked with variable fidelity structural analysis tools to provide a flow of information to the higher-level analyses. A linkage between the L1 & L2 M&S tools and the L3 & L4 tools will also be maintained. A two-way flow of information is expected in which the lower-level tools provide input into the systems analysis and trades being performed at the higher levels to improve the fidelity of technology assessment, while the higher-level analyses will provide requirements and system performance benefits that will provide direction for the L1 and L2 M&S activities. Thus, although the L3 goals have been selected (see Problem Statement) the relative importance of these objectives may change as systems analysis results are refined. The structural concepts and multifunctional materials developed through activities at L1 and L2 will be used to address these multidisciplinary objectives.



Relationship of vehicle concept to material and structural concepts

Technology Validation Strategy: Technology validation will be accomplished through element- and sub-component-level experiments correlated with analytical predictions. Relevance of new technologies will be demonstrated through maturation and insertion into system designs that synergistically consider materials, structural designs, and system analyses. Opportunities to partner with industry and DOD demonstrator projects will be pursued.

Milestones:

SFW.2.01	Materials and Structures			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.2.01.01	Assess initial task materials and structures concept selections and identify other materials, structures and analytical modeling systems with high pay-off potential.	a. 4Q 2007 b. 2Q 2008	a. Complete first year systems analyses to establish firm metric baseline and identify materials, structures and tool development focus. b. M&S research direction assessment based on systems analysis guidance and implement	SFW.1.01.01 SFW.3.01.02 SFW.3.01.03 SFW.3.03.02

			material systems, processing methods and materials/ structures modeling methods to be pursued in SFW.	
SFW.2.01.02	Demonstrate first generation adaptive and/or multifunctional materials and structures capability for an airframe and a propulsion application (in a relevant environment).	1Q 2009	Multifunctional concept for noise reduction demonstrates 10% weight savings over conventional solution using non-integrated functionalities. Fabricate and test active wing LE/TE to support high-lift wing design. Fabricate/demonstrate durable metal foam structural sandwich panels with 10% noise reducing capability improvement compared to today's state-of-the-art fan case sound absorbing insulation.	SFW.2.01.01 SFW.1.01.01 SFW.1.02.01 SFW.4.01.03 SFW.3.01.03 SFW.3.03.02 SFW.3.03.06 SFW.3.03.08 SFW.3.03.09
SFW.2.01.03	Down-select concepts for multi-objective structure (e.g. panel, subcomponent, etc.) proof-of-concept test for airframe and for propulsion systems.	1Q 2010	Selected concept targets 10% reduction in structure weight and 3dB reduction in interior noise levels. Selected concept will provide high temperature structural CMC material which is 10% lighter-weight with a 5% noise reduction capability for a turbine housing cone application.	SFW.2.01.01 SFW.2.01.02 SFW.1.01.01 SFW.1.01.02 SFW.3.01.03 SFW.3.03.08
SFW.2.01.04	Develop and demonstrate variable fidelity analysis methods to support multifunctional materials and multi-objective structures concepts.	3Q 2010	Demonstrate model/experimental agreement to predict structural response to combined loads to within 5% for high-fidelity models and predict within 15% of experimental results (or high-fidelity results) for low-fidelity models for wing and/or fuselage components. Develop multi-fidelity analysis tool to accurately simulate blade-out trajectory, blade contact and containment structural response within 20% agreement of experimental results.	SFW.1.01.02 SFW.1.02.01 SFW.4.01.05 SFW.3.01.02 SFW.3.01.03 SFW.3.02.07 SFW.3.03.09
SFW.2.01.05	Characterize lightweight metallic, composite, and hybrid materials to locally tailor stiffness, strength, durability and damage tolerance, energy absorption, and noise reduction properties	2Q 2011	Demonstrate material and structural tailoring (tow-steering, selective reinforcement, nano-structuring) to enable weight reductions of up to 20% in wing structure, relative to Boeing 777. Reduce fan case component weight by 20%, compared to GE90 nominal weight, through the development of higher-strength and -stiffness nano-polymer matrix composite materials.	SFW.1.01.01 SFW.1.01.02 SFW.1.01.03 SFW.4.01.06 SFW.3.01.03 SFW.3.03.08 SFW.2.01.06
SFW.2.01.06	Demonstrate the viability of an adaptive, multifunctional structural concept and ability to meet or exceed required performance goals for an airframe and a propulsion system applications (operating in a relevant environment)	3Q 2011	Structural concept demonstrated for multi-objective fuselage panel that meets 3dB interior noise reduction and 10% weight reduction goals for SFW .3.03.08. Demonstrate Active Fan Nozzle Structure concept benefit to improve engine fuel efficiency by 1% and reduce fan noise by 3 dB.	SFW.1.01.01 SFW.1.01.02 SFW.1.02.01 SFW.3.01.03 SFW.3.03.02 SFW.3.03.06 SFW.3.03.08 SFW.3.03.09

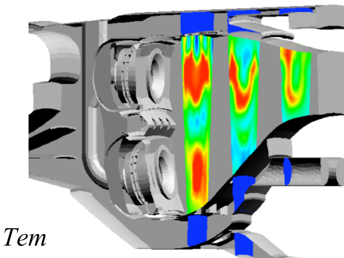
Key Deliverables:

Product	Description	Date
Report	Assess benefits, tradeoffs and impacts on current M&S portfolios and project schedules resulting from changes in direction/M&S research focus, based on first year system analyses guidance.	3Q FY07

1st & 2nd gen. Adaptive and/or Multifunctional Mat'ls & Struct.	Adaptive and/or multifunctional materials with capabilities demonstrated in relevant environment for an airframe and a propulsion/power application	3Q FY08 (1st gen) 3Q FY11 (2nd gen)
Variable Fidelity Analysis Tools	Variable fidelity (i.e., detailed FEM vs closed-form analysis) analysis methods developed to support multifunctional materials and multi-objective structures concept development.	3Q FY10
Adaptive and/or Multifunctional Struct. Concept	Viability of an adaptive, multifunctional structural concept to operate in a relevant environment, demonstrated for an airframe and a propulsion/power application.	3Q FY11

SFW.2.03—Combustion

Problem Statement: To meet the challenges of ultra-high bypass ratio engines and high power density cores, which can dramatically improve efficiency and reduce fuel burn, emissions and noise, and to achieve the President's vision of reducing U.S. dependency on foreign oil, the next generation of propulsion systems will require a fundamental understanding of the combustion process and of new alternative fuels.



Tem the combustor of a modern turbofan engine

Previous Related Research: A number of combustion areas were identified in the NIA report as key technologies for the advancement of subsonic aircraft. The proposed work will focus on reduction of aircraft emissions (specifically NOx and particulates) and the development of alternative jet fuels. Proposed activities will build upon previous work from the NASA EECP, EEE, AST, HSR, Propulsion & Power, and UEET programs, along with knowledge of technology work in the Air Force IHPTET and VAATE programs

Research Approach: Innovative low emissions combustor concepts will be developed using knowledge bases of combustion chemistry, turbulence modeling, fuels chemistry, and improved quantitative prediction tools. Improvements to the accuracy of predictive tools and to the knowledge base of combustion chemistry and turbulence modeling will be achieved by developing fundamental databases on emissions production using advanced diagnostics for accurate, non-intrusive measurement tools at realistic operating conditions and developing/validating particle sampling, measurement, and prediction methodologies for use in high pressure, velocity and temperature environments. For alternative jet fuels (Fischer-Tropsch, bio-fuel), a knowledge base will be developed of the physical, chemical and kinetic properties of fuels and combustion to mitigate the limitations that current distillate fuels place on the design and operation of combustors. Proposed activities include: determining the chemical and physical characteristics of a fuel (or fuels) that will permit revolutionary engine designs (e.g., multipoint injection distributed combustion) while maintaining applicability to the legacy aircraft fleet; developing Fischer-Tropsch jet fuel synthesis kinetics; deriving fuel specifications based upon aircraft needs while maintaining an affordable and storable product; tailoring the fuel characteristics for future propulsion systems.

Technology Validation Strategy: Baseline predictive accuracy of existing physical models for turbulence-chemistry interactions and spray atomization/vaporization, based on data from advanced diagnostics experiments, will be established using an existing parallel turbulent combustion multi-phase time-accurate CFD code (NCC) and existing experimental data sets for non-reacting and reacting flow. Bench scale (flow reactor/shock tube, heated tube) experiments will be conducted to help develop and refine jet A/alternative fuels chemical kinetics and the thermo-physical properties of individual species and mixtures.

Milestones:

SFW.2.03	Combustion			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.2.03.01	Assess combustor performance and emission predictions for conventional fuels	3Q2007	Complete assessment of code capabilities for emissions and flow field predictions against available experimental data for high pressure (upto P>20 atm and upto T>1000F) to determine current code limitations. Results will establish the baseline accuracy band for CO, NOx, particulates, unburned hydrocarbons, and flow field predictive capabilities.	
SFW.2.03.02	Assess experimental database of particle soot size and composition	3Q2009	Report comparing particle size, mass, and composition to engine and combustor operating conditions.	
SFW.2.03.03	Alternative fuel composition	3Q2010	Develop fuel formulation(s) that show better or equivalent combustion characteristics, improved efficiency and lower emissions compared to Jet-A, targets include: increase fuel heat sink capability by 200F (baseline; Jet A 300F); and reduce fuel system, including fuel line and injector, coking tendency by ½ (deposition rate of mass/time as a function of temperature).	SFW.1.05.01
SFW.2.03.04	Assess combustor performance and emission predictions for alternative fuels	3Q2011	Complete assessment of code capabilities for CO, NOx, particulates, unburned hydrocarbons, and flow field predictions against available experimental data for alternative fuels to determine current code limitations. Results will establish the baseline accuracy band.	SFW.2.03.01 SFW.1.05.01

Key Deliverables:

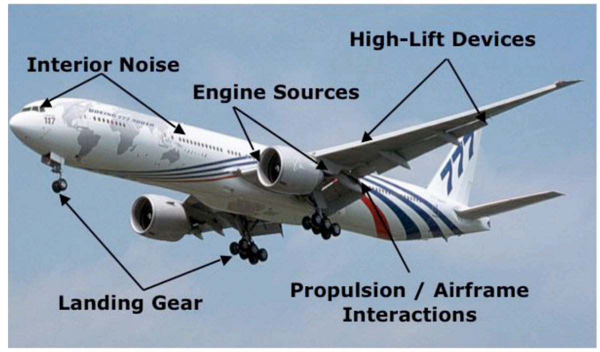
Product	Milestone Description	Date
Report	SFW.2.03.01 Assess combustor performance/emissions predictions	3Q2007
Particulate Report	SFW.2.03.02 Particle size/composition related to engine conditions.	3Q2009
Fuels Data	SFW.2.03.03 Characterize desirable alternative fuels composition	4Q2010
CFD Validation Data	SFW.2.03.04 Sub-critical fuel injection/turbulence/kinetics models	4Q2011

SFW.2.04—Acoustics

Problem Statement: Fundamental understanding of the physics of noise generation by aircraft is essential for enabling designers to perform accurate tradeoffs of noise against other performance factors, and in the development of noise reduction technologies that have minimal impact on the other aspects of aircraft operation.

Previous Related Research: Significant strides in understanding, modeling and mitigating aircraft noise were made under the auspices of the AST and QAT programs, but major challenges remain in many areas. A recent NIA report calls for improved understanding of aircraft noise sources, the propagation mechanisms of scattering, shielding and atmospheric effects, together with community noise impact.

Research Approach: The main objective of the proposed research effort is to develop a validated aircraft noise prediction capability that allows both detailed component investigations and system optimization studies. Another objective of this effort is to develop and validate noise reduction concepts to enable the anticipated 3X growth in air travel (NGATS Report). The focus of the effort is in six main areas: airframe noise, turbomachinery noise, jet noise, cabin noise, acoustic liners, and propulsion airframe aeroacoustics. Key Level 2 developments in the prediction area include: incorporating effects of turbulence anisotropy in airframe noise modeling; noise from supersonic tip speed fans; noise from three-dimensional hot jets; cabin noise using energy-based FEM methods; liner performance using low-order models derived from DNS and experimental data; aeroacoustics of propulsion airframe integration for both conventional and unconventional aircraft configurations; long range propagation; and the effect of operations on community noise. The aircraft level prediction element is focused on integration of improved modular multi-fidelity component tools and validation of the resulting capability at



Aircraft Noise is a complex amalgam of sources, interactions, transmission and propagation.

Levels 3 & 4. In the noise reduction area, the primary focus is on the development of generic noise reduction concepts for airframe and engine components and their validation in laboratory or test rig (Levels 1 & 2). Further development of the successful concepts (to Levels 3 & 4) would be done in collaboration with industry. Such opportunities will be used to validate both noise prediction capability and noise reduction concepts.

Technology Validation Strategy: Key metrics include sound pressure level, sound power level and noise directivity. In the prediction area, the goal is to reduce by 50% the current level of data-theory error band, which is typically around 6 dB. In the noise reduction area, the goal is to demonstrate component level noise reduction in the 2–4 “EPNdB” range.

Milestones:

SFW.2.04	Acoustics			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.2.04.01	Assess SOA capability to predict aircraft noise on component and system basis	4Q 2007	Prediction accuracy will be measured in component SPL directivity (dB) and EPNdB for aircraft.	
SFW.2.04.11	Establish ability of LES-based computational tools to directly predict noise generation at the component level (e.g., *flap edge noise)*	1Q 2010	Predict turbulence/noise power spectral amplitude to within 3dB of corresponding experimental data.	SFW.1.08.21 SFW.1.08.31 SFW.1.08.51 SFW.2.04.01
SFW.2.04.12	Develop reduced-order models from the LES simulations (or experimental data) to predict noise for the identified suite of aircraft components.	4Q 2010	Predict turbulence/noise power spectra to within 3 dB for amplitude and to within the nearest one-third octave band for peak frequency compared with LES-based computational tools or experimental data.	SFW.1.08.21 SFW.1.08.31 SFW.1.08.51 SFW.2.04.01 SFW.2.04.11
SFW.2.04.21	Develop/improve and validate next generation multi-fidelity component noise prediction capability.	4Q 2009	Predict component noise to within 3 dB of benchmark data.	SFW.1.08.11 SFW.1.08.21 SFW.1.08.31 SFW.1.08.41 SFW.1.08.51 SFW.2.04.01 SFW.2.04.31
SFW.2.04.22	Develop/improve and validate next generation multi-fidelity aircraft noise and propagation prediction capability.	4Q 2011	Predict aircraft noise to within 3 dB of flight test data.	SFW.1.08.11 SFW.1.08.12 SFW.1.08.21 SFW.1.08.22 SFW.1.08.31 SFW.1.08.32 SFW.1.08.41 SFW.1.08.42 SFW.1.08.51 SFW.1.08.52 SFW.2.04.01 SFW.2.04.12 SFW.2.04.21 SFW.2.04.31 SFW.2.04.32
SFW.2.04.31	Design, predict and validate noise reduction concepts for engine and airframe components. Includes P&W UHB fan rig wind tunnel tests and Boeing QTD3 airframe & PAA wind tunnel tests in 2007-2008.	4Q 2008	Demonstrate 50% reduction in the strength of the noise source, the efficiency with which it radiates, and the rate of its absorption by liners.	SFW.1.08.11 SFW.1.08.21 SFW.1.08.31 SFW.1.08.41 SFW.2.04.01
SFW.2.04.32	Predict and validate advanced low-noise airframe configuration benefits. Includes Boeing blended wing acoustic test of a 3% scale model BWB in 2008-2009.	4Q 2009	Demonstrate technology for 52 dB (cum) noise reduction below stage 3.	SFW.1.08.11 SFW.1.08.21 SFW.1.08.31 SFW.1.08.51 SFW.2.04.01 SFW.2.04.31

SFW.2.04.33	Develop aggressive noise reduction concepts and operational procedures for low-noise aircraft.	3Q 2011	Assess the feasibility of 6 dB aircraft noise reduction beyond reference aircraft.	SFW.1.08.01 SFW.1.08.02 SFW.1.08.11 SFW.1.08.12 SFW.1.08.21 SFW.1.08.31 SFW.1.08.41 SFW.1.08.42 SFW.1.08.51 SFW.1.08.52 SFW.2.04.01 SFW.2.04.11 SFW.2.04.12 SFW.2.04.21 SFW.2.04.31 SFW.2.04.32 SFW.2.04.33
SFW.2.04.41	Develop and assess improved community noise impact models.	3Q 2010	Validate prediction of aircraft system noise on community to within 2 dB using existing flyover databases and airport noise data.	SFW.1.08.11 SFW.2.04.01

Key Deliverables:

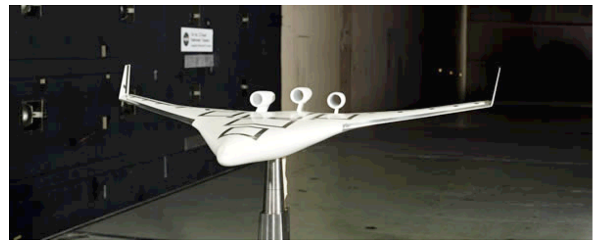
Product	Description	Date
Draft Report	Assessment of current SOA in aircraft noise prediction	4Q FY07
Technology	Validated Noise Reduction Concepts for Aircraft (interim)	4Q FY08
Suite of Codes	Validated Next Generation Multi-Fidelity Noise Prediction Capability	4Q FY11

SFW.2.05—Aeroelasticity

Problem Statement: There is a growing requirement for both general purpose and unconventional aircraft to operate with higher efficiencies in multiple flight regimes within uncertain, nonlinear, time-varying aeroelastic flight environments. Furthermore, as weight is removed from the primary airframe structure of these aircraft, the inherent flexibility of the airframe will increase and the need for aeroelastic design and active flexible motion control will become more prominent. Similarly, as propulsion systems move to smaller high power density cores and large diameter fans of Ultra-High Bypass engines for improved efficiency and reduced noise, aeroelastic vibration problems in turbomachinery must be avoided throughout the entire operating range. Required features in a high-fidelity propulsion aeroelastic analysis include modeling of multistage effects and non-synchronous vibrations.

Previous Related Research: One of the major gaps in the aircraft design is the lack of affordable design and analysis tools which incorporate aeroelastic effects. Incompatibility of tools/ practices with other disciplines, large computa-tion time and unknown transonic, nonlinear and non-synchronous aeroelastic characteristics are the major current barriers to incorporating aeroelasticity into MDAO processes.

Research Approach: The proposed work in aeroelasticity and aeroservoelasticity will enable analysis and design of advanced aircraft concepts. The design and operational spaces of conventional configurations are also expanded, thereby enabling more energy efficient and higher performance vehicles. Required features include modeling of multistage effects, flow control, and non-synchronous vibrations. The major objectives are uncertainty characterization of aeroservoelastic systems, model development suitable for MDAO tools, and validation of methodologies and tools through the use of high fidelity model simulation and experimental testing.



3%-Scale BWB-LSV Model in Langley 14x22 Wind Tunnel

Design tools and active-adaptive control methodologies with uncertainties in the aeroelastic systems will be developed with: (1) variable fidelity aeroelastic analyses, including unsteady aerodynamic interaction between vibrating-blade rows; (2) on-line aeroelastic health monitoring system together with robust active control schemes using disparate actuation devices; (3) aeroservoelastic model tuning tools using ground, wind tunnel, and flight test data; (4) rapid and reduced order aeroelastic analysis as well as pre/post processors for aeroelastic optimization; (5) High fidelity simulations for validation using high performance computing; and (6) damping technology that is effective, durable, operable in extremely large acceleration fields and high temperatures, and non-intrusive to the flow aerodynamics. High fidelity computations include use of the Navier-Stokes equations for flows and 3D finite-elements for structures that can include multi-functional material.

Technology Validation Strategy: Analysis and design tools would be created and validated against experimental and possibly flight test data to allow quantification of the accuracy of models and of the types of error to be expected.

Milestones:

SFW.2.05	Aeroelasticity			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.2.05.01	Obtain and process validation data set from Boeing	2Q 2007	Develop validation data set for unsteady aeroelastic codes: generate high-quality oscillatory data for a rigidized wing for detailed validation of unsteady CFD pressures, (5 span stations, with 40 unsteady measurements per chord, at 9 of reduced frequencies, at 20 of test conditions)	
SFW.2.05.02	Develop & validate aero-servo-elastic model tuning tools with flight/ground test data	4Q 2008	Incorporate methodology with MDAO tools; model aircraft structural dynamic characteristics such that the primary mode frequency is within 5% of measured ; off-diagonal terms of generalized mass matrix are within 10%	
SFW.2.05.03	Develop batch & real-time aero-servo-elastic vehicle simulations using rapid modeling tools	4Q 2009	Produce time-accurate correlation between CFD-based simulations and rapid analyses are within 15% accuracy; correlation between test articles and simulation are within 20% accuracy	
SFW.2.05.04	Develop and validate high fidelity unsteady aeroelastic capability for engine turbomachinery	4Q 2010	Predict engine blade forced response vibration amplitude in high power density core within 25% of measured data	SFW.1.09.05
SFW.2.05.05	High Fidelity aeroelastic simulation module using the Navier-Stokes equations	4Q 2011	Compute 2000 aerodynamic influence coefficients for nonlinear flow regime within 10 hours wall clock time of super cluster such as Columbia by 2011, using about 2 million CFD grid points	
SFW.2.05.06	MDAO-compatible aeroelasticity tools and processes	2Q 2011	Incorporate methodology with MDAO tools to predict aeroelastic characteristics within 25% of full-blown analysis results at subsonic conditions	

Key Deliverables:

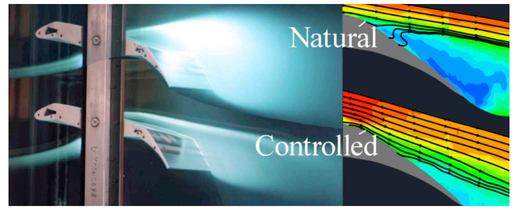
Product	Description	Date
Draft Report	Assessment of current SOA in aeroelastic design processes	4Q FY07
Suite of Codes	Validated aeroservoelastic model tuning tools with ground and flight test data	4Q FY08
Simulation Codes	Batch & real-time aeroservoelastic vehicle simulations including rapid modeling	4Q FY09
Simulation Code	Validated high fidelity unsteady aeroelastic code for engine turbomachinery	4Q FY10
Suite of Codes	High fidelity simulation module using the Navier-Stokes equations directly coupled structures for modeling wings with moving control surfaces and spoilers	4Q FY10

SFW.2.06—Aerodynamics

Problem Statement: Efficient flight has at its foundation the understanding and prediction of fluid flow around complex geometries. The goal is to improve aerodynamic efficiency throughout the flight envelope via improved prediction capabilities with validation for advanced technology concepts, giving end-users a larger, viable design space for aircraft-specific trades between performance characteristics. The underlying challenge is high confidence, preflight prediction of complex flow phenomena at flight conditions. SOA reliance on empirical RANS models and subscale tests limits the development of advanced technology concepts and causes overly conservative design margins.

Previous Related Research: Recent national and international assessments of the SOA identified the prediction of flow separation onset and progression throughout the flight envelope, and its impact on aircraft performance, as the most important fundamental flow issue to be addressed. Reynolds number effects were also identified as a significant barrier issue. Attached turbulent flow is handled well, but designs for extensive laminar flow present a major challenge.

Research Approach: Technologies for improved aerodynamic efficiency and prediction capability will be developed for 1) cruise, 2) low-speed high-lift, and 3) stability, control, and loads. Flow separation onset and progression will be the central fluids theme, with laminar flow/transition secondary. Current deficiencies in modeling separation, with attendant issues such as transition, turbulence, and unsteadiness will be addressed at the foundation level characterized by unit problems. Improved tools will be evaluated at the discipline through vehicle systems levels by improved correlation with critical aircraft performance parameters, demonstrated robustness through advanced technology design applications, and faster time to solution. High-lift prediction



High lift flow separation

and performance will be the central discipline theme; these flows embody most phenomena critical for subsonic fixed wing flight and are historically very difficult to predict. Depending on the specific aircraft mission, performance benefits can be traded in many ways, such as enabling ESTOL, lower noise, a smaller (reduced drag) cruise wing, or reduced weight.

Low-Speed High-Lift: Tasks will directly target high-lift system prediction and performance through CLmax, and include optimization at flight Reynolds number, iced aerodynamics, and flow control (separation and circulation) for performance enhancement. A key level 3 integrated validation test will use a 3D high-lift wind tunnel model with flow control actuation integrated into realistic aircraft structure to demonstrate improved performance.

Cruise Efficiency: Limited tasks will be directed at cruise L/D through drag reduction via laminar flow, and enabling reduced buffet margins.

Full-Envelope Stability, Control, and Loads: Limited tasks will be directed at evaluating prediction capabilities and identifying deficiencies primarily using existing data.

Technology Validation Strategy: Validation at the configuration, component, and physics level will occur at relevant Mach numbers in the highest Reynolds number facility suitable and affordable for a given technology demonstration.

Milestones:

SFW.2.06	Aerodynamics			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.2.06.01	Aerodynamic SOA Design & Analysis Assessment	3Q 2007	Delivery of document with assessment of SOA in aerodynamic prediction and design tools	
SFW.2.06.02	Low-Speed High-Lift Prediction to Maximum Lift	3Q 2008 3Q2010	Demonstrate prediction (CL within 4% through CLmax) for civil transport SOA high-lift system at landing conditions	SFW.1.10.02 SFW.1.10.01 SFW.1.10.05

SFW.2.06.03	Utilization of the HARV Database for development of a computational, stability and control capability	4Q 2008	Delivery of High-Alpha Research Vehicle database, including CAD definition of flight vehicle, and documentation in form suitable for use as reference for CFD stability and control predictive capability assessments	
SFW.2.06.04	3D Ice Accretion Prediction Capability validated (tentative)	2Q 2010	3d ice shape prediction on civil transport wing within experimental repeatability (eg: mass within 10%)	SFW.1.11.04 SFW.1.10.02 SFW.1.10.01
SFW.2.06.05	Transition Prediction for High Speed Natural Laminar Flow Wing	4Q 2010	Laminar flow extent predicted within 5%chord across span at cruise M (.8) for civil transport-class wing	SFW.1.11.02 SFW.1.10.01
SFW.2.06.06	High Speed Buffet Onset	2Q 2011	Demonstrate high speed buffet margin prediction within 10% of experiment at high Reynolds number	SFW.1.11.08 SFW.1.10.02 SFW.1.10.01
SFW.2.06.07	Low-Speed to Maximum Lift with Active Separation Control	3Q 2011	Demonstrate lift improvement due to active flow control and prediction of lift increment to within 5% through CLmax at landing conditions	SFW.2.06.02 SFW.1.10.01 SFW.1.10.02 SFW.1.10.05

Key Deliverables:

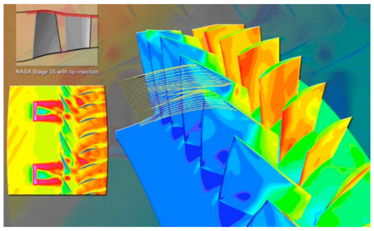
Product	Description	Date
High Lift Database and Report	Initial experimental database for advanced high-lift system, including pretest predictions; benchmark time to solution	4Q FY08
High Lift Prediction Guidelines	Guidelines for prediction of advanced high-lift systems through CLmax, experimental database update	2Q FY10
High Lift Performance	Concept for improved high-lift performance demonstrated, predictive capability including time to solution for concept benchmarked	4Q FY11

SFW.2.07—Aerothermodynamics

Problem Statement: Major research and technological advances are required in order to develop ultra-high bypass (UHB) engines and high power density cores, which can dramatically improve efficiency and reduce fuel burn, emissions and noise. Improved fundamental understanding is required to accurately simulate the aerothermodynamics of highly loaded turbomachinery. Innovative methods such as flow control are required in order to increase fan and compressor work factors without sacrificing efficiency and operability. Improvements in turbine cooling effectiveness, secondary flow, and component matching are also important for UHB engines.

Previous Related Research: Despite some success by NASA, DoD, and engine companies toward increasing turbomachinery work factors, efficiency and operability levels still remain below desired thresholds. Both NASA and industry partners have been working on highly loaded turbomachinery and flow control techniques. NASA has investigated smart material actuators, fluidic concepts, and active and passive flow control concepts such as passive porosity and circulation control for inlets and nozzles.

Research Approach: NASA will build upon previous research work in turbomachinery by improving the understanding of flow physics in highly loaded turbomachinery. Active and passive flow control techniques will be implemented to improve operability and efficiency. NASA will test a highly loaded research compressor with and without flow control, and a highly-loaded high-pressure turbine to understand the impact of secondary and internal cooling flows on efficiency and performance. Physics-based computational models and analysis tools will be developed that can accurately predict and characterize complex flow phenomena in fans, compressors, and turbines. These flow phenomena include shocks, inlet distortions, and recoverable and rotating stalls. Turbine heat transfer design and analysis codes that accurately model effects such as surface roughness, transition, and conjugate heat transfer will be developed. Computational techniques for predicting ice growth on fans, inlet cones, and core engine components, and its effects on engine operability will be developed and validated by component testing.



Axial compressor with discrete flow injection to delay the onset of rotating stall

Technology Validation Strategy: A detailed assessment of the current SOA of propulsion system-related analytical, computational, and experimental capabilities will be performed. New experiments will be conducted for highly loaded compressor and turbine configurations. Improved component designs and new flow control ideas will be validated using simulations, laboratory experiments and continuous flow rotating rigs.

Milestones:

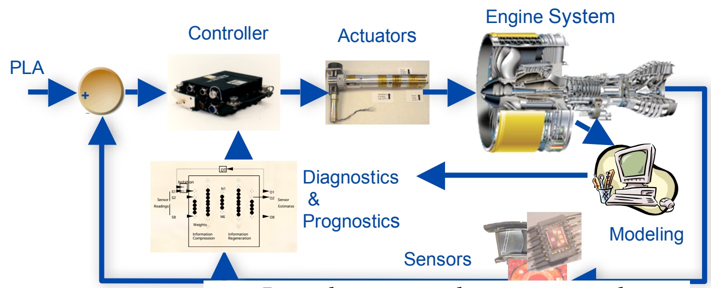
SFW.2.07	Aerothermodynamics			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.2.07.01	Loss minimization with flow control	3Q 2009	Demonstrate compressor stator loss reduction of 2.5% using stator flow control methods	SFW.1.11.01 SFW.1.11.06 SFW.1.11.07
SFW.2.07.02	Advanced computational techniques for turbomachinery flow simulation	4Q 2010	New RANS-based techniques for highly loaded turbomachinery developed and validated. Other advanced computational techniques for improving turbomachinery flow prediction investigated and compared to current RANS approaches	SFW.1.10.04 SFW.1.11.03 SFW.1.10.01
SFW.2.07.03	High-work factor compressor verification test	4Q 2010	Achieve a 20% increase in work factor per stage demonstrated while maintaining stall margin, efficiency, and tolerance two inlet flow distortion.	SFW.1.11.07
SFW.2.07.04	High-work cooled turbine performance verification test	3Q 2011	Code validation-quality test data for 5.5 pressure ratio single-stage turbine generated for high density core engine	SFW.1.10.04 SFW.1.11.03 SFW.1.11.10
SFW.2.07.05	Assess design tools & capabilities for highly loaded turbo-machinery	2007, 2008,2009, 2010,2011	Provide input for integration into systems models of turbomachinery design tools (1-D and 2-D) for highly loaded compressors and turbines with flow control	
SFW.2.07.06	Integrated inlet/fan aero-performance prediction capability	3Q 2011	Develop models and validate against existing test data	SFW.1.10.02 SFW.1.10.03

SFW.2.07.07	Computational capability for fan/compressor stall prediction	3Q2010	Develop and validate 3-D unsteady computational tool to predict stall margin with 20% improvement in accuracy over current empirical models.	
SFW.2.07.08	Aero/thermal modeling for icing analysis (tentative)	4Q2009	Development of first generation ice accretion model for engine icing validated with cascade experiment.	SFW.1.10.02 SFW.1.10.01 SFW.1.11.04 SFW.1.11.12
SFW.2.07.09	VAFN nozzle concept demonstrated	2Q2010	Demonstrate VAFN on an engine during flight	
SFW.2.07.10	Computational investigation of scarf inlet	2Q2011	Computational investigation of scarf inlet and compare to existing inlet	
SFW.2.07.11	Sub-scale circulation control thrust-vectoring nacelle test	1Q2008	Target thrust vectoring angle demonstrated in the rig test	

Key Deliverables:

Product	Description	Date
Turbomachinery Computational Capability Assessment Report	Industry-wide assessment of current turbomachinery design/analysis codes and models	3Q FY07
Physics-Based Simulations	Develop and extend modeling and simulation capabilities for efficient highly loaded turbomachinery (with/without integrated flow control)	4Q FY09
Flow Control Validation Report	Validate proof-of-concept of flow control techniques in a laboratory environment	4Q FY10
Report on Flow Control Effects on Highly Loaded Turbomachinery	Generate test data and determine the effects of flow control on highly loaded turbomachinery and validate simulations	4Q FY11

SFW.2.08—Controls and Dynamics



Propulsion control system example

Problem Statement: Enabling advanced aircraft configurations such as "Blended Wing Body (BWB)," "Extreme Short Take Off and Landing (ESTOL)" and high performance "Intelligent Engines" will require advancement in the state of the art of dynamic modeling and flight/propulsion control. Control methods need to be developed and validated for "optimal" and reliable performance of complex, unsteady, and nonlinear systems with significant modeling uncertainties. The emphasis will be on developing technologies for improved aircraft performance, enabling robust control of unconventional configurations, and active control of components for improved propulsion efficiency and lower emissions.

Previous Related Research: This effort will build upon work which has been done during the Blended Wing Body project between Boeing, Lockheed Martin, Northrop Grumman, LaRC, and DFRC and universities. This effort also builds off of collaborative efforts between LaRC, DFRC, ARC, and Boeing for the Adaptive Control Systems project. For propulsion systems, the proposed research will build upon the work done previously under the Intelligent Propulsion System Foundation Technology program.

Research Approach: The research approach will combine development of dynamic models and simulations of the integrated component/control system being considered, defining actuation requirements and developing prototype actuators, developing and applying innovative control methods as appropriate and conducting laboratory/rig level experiments and non-real time as well as piloted simulations to validate closed-loop system performance achievable with the advanced control concepts. Development and validation of multidisciplinary predictive tools for unsteady, nonlinear flight vehicle dynamics, control, and overall performance of unconventional vehicle configurations (such as BWB and ESTOL) will be conducted in conjunction with development of robust and distributive control techniques. Technologies for real-time optimization of flight control to minimize drag during flight will be further matured. For enabling "Intelligent Engines," the focus will be on developing technologies for enabling distributed engine control to reduce overall controls and accessories weight for the propulsion system and increase control system reliability. Exploratory work will be done in developing actuation technologies for active flow control in compressions systems and increased understanding of unsteady ejector concepts.

Technology Validation Strategy: The technologies development and validation strategy will be – assess/predict, test/verify, and validate. The controls and dynamics methods will be applied to benchmark models and simulations, and then tested in a range of environments: from laboratory to flight as the technologies mature.

Milestones:

SFW.2.08	Controls & Dynamics			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.2.08.01	Validate dynamic modeling methods against data from existing data sets.	4Q 2008	Model prediction of dynamic motions fully within the uncertainty bounds of existing test data.	
SFW.2.08.02	Evaluate robust control approaches for distributed efftectors using benchmark simulation models	2Q 2009	Control approach provides robustness against modeling uncertainty identified in SFW.1.07.03	SFW.1.06.02 SFW.1.07.03
SFW.2.08.03	Evaluate performance optimization control in flight vehicle testbed	2Q 2009 4Q 2011	Develop performance adaptive flight control concepts for 1% drag reduction on BWB using flight validated simulation.	1.06.03
SFW.2.08.04	Evaluate advanced control for high lift configurations in a flight vehicle test-bed	4Q 2010	Analysis of pilot-in-the-loop simulations of high lift test bed determining control power requirements for level one handling qualities	1.06.04
SFW.2.08.05	Validate dynamic modeling methods against data from advanced dynamic test techniques and sub-scale model tests.	4Q 2010	Prediction of dynamic motions within the uncertainty bounds of the test data from sub-scale models.	SFW.2.08.01
SFW.2.08.07	Evaluate advanced control approaches for distributed effectors in piloted simulations	2Q 2011	Piloted simulation results indicate level 1 handling qualities for the tested envelope.	SFW.2.08.02 SFW.2.08.05
SFW.2.08.08	Preliminary evaluation of distributed control components through hardware in the loop simulation	4Q 2011	Prototype components meet the distributed engine control requirements as defined in SFW.1.06.05	SFW.1.06.05

Key Deliverables:

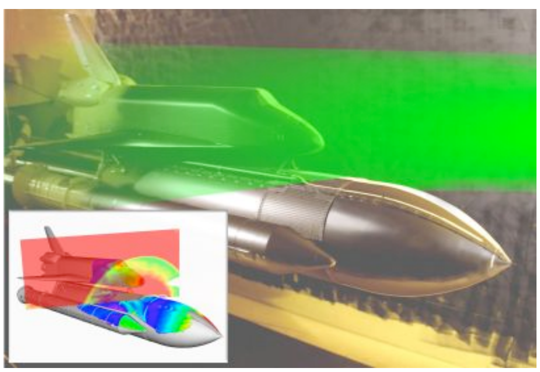
Product	Description	Date
Report	Architectures and component development status for distributed engine control	3Q2011
Code	Experimentally validated integrated simulation including unsteady aerodynamics	4Q2010
Report	Results from flight test of advanced control design for performance optimization	4Q2011

SFW.2.09—Experimental Capabilities

Problem Statement: Advanced experimental capabilities will be key to providing high-quality data for validation of developed predictive capability and performance benefits of advanced technology concepts. There will be an added benefit of upgrades to the measurement capabilities of the various facilities (i.e. wind tunnels, flight testing capabilities, material evaluation facilities, etc.) that are vital to the success of the Subsonic Fixed Wing project goals of improving aircraft performance and reducing noise and emissions.

Previous Related Research: This effort will build upon research undertaken during previous subsonic vehicle programs within NASA, such as the AST and Vehicle Systems Programs, as well as past and present partnerships with other government agencies (DOD, DOE, etc.), industry, and academia. Past research will be leveraged and used to identify the gaps in experimental capabilities that will be required for next generation testing.

Research Approach: The focus of the proposed program is to demonstrate advanced experimental capabilities that will support the improvement in performance and reduction in noise, and engine emissions for next generation air vehicle designs. This will necessarily build upon the specific concepts developed in Level 1 and extend the capabilities so that they can support the validation experiments described in Level 3 and 4 to support the development of the MDAO strategy. Key development areas include: demonstration of enhanced simulation capabilities to collect data about flight motion; application of high temporal resolution PIV to shear layers to determine turbulent decay rates/scales; deployment of advanced microphone arrays for noise source identification; robust, highly sensitive miniature sensors for measuring combustion process and emissions in an engine environment; enhanced testing techniques for the evaluation of novel lightweight structures and materials; demonstration of high speed PSP and velocimetry techniques; advanced instrumentation capabilities for measuring icing to map flow around ice shapes; flight validation of advanced concepts; and deployment of low-cost remotely piloted testbeds for advanced concept validation. These demonstrations and deployments will also serve to upgrade and increase the experimental capabilities available in NASA facilities. Thus it is envisioned that some support from ATP will also be pursued to augment resources.



Field measurements for CFD validation

Technology Validation Strategy: Validation of experimental techniques has been coordinated with the other disciplines within the Subsonic Fixed Wing project to determine minimum criteria for success.

Milestones:

SFW.2.09	Experimental Capabilities			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.2.09.01	Develop enhanced simulation capability	4Q2011	Develop and validate software capabilities for real-time data visualization and simultaneously visualizing experimental data and computations solutions 100x quicker than current capabilities (up to days depending upon fidelity). ˚Develop and demonstrate enhanced flight dynamic test techniques capable of 6 DOF to predict flight motion in low speed, low Re conditions.	

SFW.2.09.02	Develop and demonstrate advanced test techniques	4Q2011	Develop and demonstrate Pressure Sensitive Paint (PSP) capable of making global measurements of unsteady pressure up to 10 kHz. Demonstrate improved spectral efficiency of at least 2x SOA of aeronautical telemetry using Multi-h CPM.	
SFW.2.09.03	Demonstrate improved phased microphone array for noise model validation	4Q 2010	Application of improved phased microphone array in a suitable facility to verify airframe noise scaling effects accurate to +/- 1 dB of actual	SFW.1.13.03
SFW.2.09.04	Enhance critical facility & testbed capabilities	4Q2011	Flight demonstration of a fiber-optic based wing shape sensor providing wing position accurate to within 5% displacement on a flexible wing with 1cm span resolution. ˚Develop validated liquid water content measurements (LWC) for icing clouds with a MVD greater than 50 microns, droplet distribution measurement capability for SLD conditions with 1 inch resolution across test area. ˚Develop and apply advanced videogrammteric system for aeroelastic measurements capable of measuring deformation of 1 part in 10,000 with acquisition rates up to 500 Hz	SFW.1.13.04 SFW.1.13.05 SFW.1.13.06

Key Deliverables:

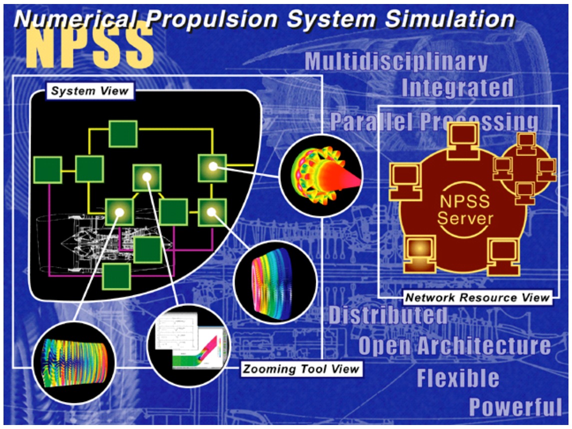
Product	Description	Date
PIV Demonstration	Demonstrate current SOA PIV (10 kHz) to shear layers in nozzle flows to determine turbulent decay rates/scales	3Q FY07
Microphone Phased Array	Demonstration of improved microphone phased array with improved calibration capability and spatial resolution	2Q FY09
PIV Measurement System	Demonstrate PIV system capable of 50 kHz data rate for turbulence measurements.	4Q FY11

SFW.2.10—Systems Analysis, Design and Optimization

Problem Statement: The challenge of enhancing system-level design and analysis capabilities in order to perform accurate tradeoffs between performance, noise and emissions must include the incorporation of more physics-based methodologies. Also, current interdisciplinary design/analysis involves a multitude of tools not necessarily developed to work together. This incompatibility can hinder their application to complete system design and analysis studies.

Previous Related Research: The NPSS, a collaborative NASA/industry development activity, has become the industry standard for propulsion performance prediction.

Research Approach: The research activities in this element will focus in four primary areas. First, a detailed assessment of the current in-house systems analysis tools will be conducted. This effort will include quantifying the uncertainty (i.e., benchmarking) of the individual tools by modeling several conventional airframe/propulsion systems and comparing predicted performance against actual engine and aircraft characteristics. Besides benchmarking



Description of NPSS capabilities – example of propulsion systems simulation

uncertainty, this effort will also provide insight into the modeling deficiencies, or gaps, that exist within the current systems analysis tool set. Second, an evaluation will be conducted to identify the appropriate framework architecture that will be used to develop the multi-disciplinary design and analysis tools at Level 3. This evaluation will investigate the capabilities and limitations of the COTS model integration frameworks, such as Phoenix Integration's ModelCenter, and in-house integration frameworks, such as NPSS. Third, using insight gleaned from the first task defined above, work will be conducted to improve the current models and to develop a more physics-based modeling capability for aircraft conceptual design and analysis. These new capabilities are needed to more accurately model advanced and/or unconventional architectures that may arise from the Level 4 advanced concept development effort. The majority of this work would be geared toward reducing the intrinsic uncertainty in the analysis tool suite. This could best be accomplished through the development of physics-based methods to replace existing empirical correlations. Successful completion of the systems analysis methods development work will require leveraging available resources with the other FA projects. Fourth, improved algorithms and procedures will be developed to enable efficient gradient calculations, rapid grid morphing, and robust solution of constrained optimization problems with highest-fidelity physics models and large numbers of design variables.

Technology Validation Strategy: Detailed engine/airframe data must be obtained to develop the best simulations of the current technology configurations. Contact will be established with engine/aircraft companies to explore developing cooperative agreements that will enable access to necessary data.

Milestones:

SFW.2.10	System Analysis, Design, & Optimization			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.2.10.01	Assessment of Current SADO Tools	4Q 2007	Benchmark current systems analysis predictive tools' uncertainty and design/analysis cycle times on a conventional configuration	
SFW.2.10.02	Assessment of Specialized Frameworks for Level 3 Dual-disciplinary tools	4Q 2007	Report detailing ease of use, flexibility, and performance of competing framework options	
SFW.2.10.03	Development/Enhancement of Design and Optimization tools and techniques for incorporation in Variable Fidelity Framework (Gen 1)	3Q 2008	Reduce turnaround (design/analysis cycle) time by 25% from benchmark values defined in 2.10.01	SFW.2.10.01
SFW.2.10.04	Development/Enhancement of Design and Optimization tools and techniques for incorporation in Variable Fidelity Framework (Gen 2)	3Q 2010	Reduce turnaround (design/analysis cycle) time by 50% from benchmark values defined in 2.10.01	SFW.2.10.03 SFW.4.01.06

Key Deliverables:

Product	Description	Date
Gap Analysis	Assessment of current system analysis/design tools	4Q2007
Framework Assessment Report	Assessment of Specialized Frameworks for Level 3 Dual-disciplinary tools	4Q 2007
Systems Analysis Tools/Methods	Development/Enhancement of systems analysis tools for incorporation into variable fidelity framework	3Q 2008 3Q 2010

SFW.1.01—Fundamental Materials Science; SFW.1.02—Mechanics of Materials and Structures; SFW.1.03—Mechanical Components

The goal for the Level 1 (L1) Materials, Structures, and Mechanical Components research is to develop innovative lightweight material systems and novel structural concepts to meet the high performance airframe and propulsion systems requirements of N+2 aircraft ("current generation + 2"). These requirements include significant weight reductions, increased lifetime and operability, increased operating temperatures, reduced repair costs, and informative structural status data. A key technology area that will provide a foundation for success is the development of multifunctional materials and structures (MMS). Multifunctional materials take advantage of the inherent attributes of their molecular structure to provide benefits for a range of engineering properties such as mechanical, thermal, electrical and optical. Multifunctional structures rely on manufactured or engineered combinations of discreet functions. Examples include incorporating actuators into a flexible airfoil to achieve a morphing wing or adding sensors for optimization for structural loads. The technical challenge is to develop tools and methods for the design, analysis, and manufacture of MMS for airframe and propulsion system structures and subsystems. The level of experimental validation will be subject to the resources of the project.

The L1 materials and structures (M&S) discipline area will pursue its goal through fundamental research in two thrust areas: 1. Computationally Guided Multifunctional Materials Development, and 2. Novel Structural Concepts Development. The development of new broad-based tools and MMS technologies will be targeted, and they will feed into the higher-level activities of the project to address the development of multi-objective systems that must meet multiple system objectives simultaneously. The system objectives selected include lightweight, reduced noise, high lift, and increased temperature. Initially, multifunctionality will focus on incorporating one or more of the following functions into the material and/or structure: structural sensors, lightning strike protection for composite airframes, fan blade-out containment for engine cases, and/or noise mitigation for airframes and propulsion systems. Other functions such as aeroelastic tailoring for lightweight structures with increased flexibility, or integrated actuators and shape-change mechanisms for aerodynamic controls may also be pursued. The tools developed at L1 will also be used to provide input into higher-level systems analysis tools. These tools will accelerate the development, maturation, and insertion of new materials and structural concepts into airframe and propulsion structures designs. This will be accomplished by improving the fidelity of the systems level trades and optimization across competing multidisciplinary needs and by identifying the maximum benefits to vehicle performance.

Thrust 1–<u>Computationally Guided Multifunctional Materials Development</u>: A computational materials approach will be used to guide the development of new multifunctional materials and fabrication/manufacturing methods.

Physics-based models (including computational chemistry and multi-scale analysis models that address length scales from the atomistic (nano) to the continuum (macro)) will be developed that integrate chemistry, processing, and property predictions to increase the fundamental understanding of materials science, establish the interconnectivity of the multiple disciplines required to provide parametric analysis tools, and develop examples of key structure-property relationships (e.g., thermal, electrical, mechanical) for novel materials. Validation of the models will be by comparison of analytical predictions to key experimental data. Development of a validated computational approach to materials design will enable tailoring of key properties, such as strength, durability and damage tolerance, stiffness, sensory characteristics, acoustic damping, and thermal and electrical conductivity, to address multifunctional applications. The requirements that guide material development activities will be identified through system analyses, as well as from the needs of the structural concepts developed under Thrust 2 described subsequently.

Thrust 2–<u>Novel Structural Concepts Development</u>: The identification and development of new structural concepts will take advantage of and/or define requirements for the lighter, stronger, higher temperature, multifunctional materials developed in Thrust 1. Examples of L1 concept development activities include advanced joining concepts (e.g., bonding and stitching), utilization of novel stiffener configurations, geometries, and tow-steered composite laminates for load-path control. The initial development of multifunctional structural concepts will also occur in this thrust area. Fundamental advances in fabrication methods, such as advanced out-of-autoclave methods for polymeric and metallic matrix composites and electron beam free-form fabrication of metallic structures will be developed. Analytical tools will also be developed to aid in the development and optimization of these new concepts.

Computational/analytical tools, variable-fidelity analysis and multi-scale modeling methods will be coupled with experimental work to validate the models for use in the design of N+2 vehicles.

The specific research areas at L1 will be:
a. Computationally guided design, synthesis and processing coupled with evaluation of MMS that encompass polymeric, metallic, hybrid, ceramic, and/or ceramic matrix composite material systems for airframe and propulsion structures
b. Modeling and experimental development of active, adaptive structures technology for flow, structural shape, and vibroacoustic control, and high temperature shape memory alloys for propulsion systems
c. Multi-scale and variable fidelity analysis methods for the development and evaluation of MMS
d. Innovative materials for lightweight propulsion engine cases, ducts with blade-out containment
e. Embedded spectroscopy for health monitoring from outside the hot sections of propulsion systems

Milestones:

SFW.1.01	Fundamental Materials Science			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.1.01.01	Complete materials and structural systems review/evaluation based on anticipated airframe and engine systems level performance benefits and potential for reducing aircraft weight, noise and emissions and enhancing aircraft performance efficiency and specific fuel consumption.	4Q 2007	Candidate materials evaluated and ranked subject to anticipated system level performance benefits and potential for improvements in strength, durability, max use temp and functionality potential.	SFW.3.03.01 SFW.3.01.02 SFW.3.01.03 SFW.3.03.02 SFW.2.01.01

SFW.1.01.02	Characterize, optimize and quantify improvements in materials and structures properties and durability using advanced processing and fabrication methods.	2Q 2009	Quantify and track improvements in strength, durability, damage tolerance, maximum use-temperature and functionality throughout materials development. Demonstrate 500 deg F use-temperature capability and 20% lighter-weight nano-PMC composite material as compared with today's thermosetting resins.	SFW.1.01.01 SFW.3.01.03 SFW.2.01.03 SFW.2.01.04 SFW.2.01.06
SFW.1.01.03	Demonstrate advanced materials and structures fabrication scale-up capability of processing methods.	1Q 2011	Demonstrate fabrication of structural panel (≥ 1' x 1') with properties equivalent to analogous coupon-scale material and local property variances within ± 5% across the area of the scaled up panel.	SFW.3.03.08 SFW.2.01.06
SFW.1.01.04	Develop first-generation computational materials and multi-scale analysis tools to predict bulk properties	3Q 2011	Demonstrate capability to predict bulk material properties of advanced multi-functional materials from computational materials/multi-scale models. First-order properties to be considered include stiffness and electrical/thermal conductivity. Second-order properties include strength-related properties. Target correlation of predicted values to experimentally measured values is ±10%.	SFW.4.01.06 SFW.3.01.03 SFW.3.03.08 SFW.2.01.06
SFW.1.02	**Mechanics of Material Science**			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.1.02.01	Develop and demonstrate damage mechanics & remaining-life prediction methods developed for advanced multifunctional material & structural concepts.	3Q 2011	Key parameters ID'ed and intrinsic sensing methods demonstrated to within 10% of conventional NDE techniques and/or conventional post-analysis methods. Damage mechanics & remaining-life-prediction methods demonstrated to within 10% of experiment. Demonstrate ability to identify >95% of the damage incurred by a thermal barrier coatings by luminescence sensing of coated-superalloys exposed in simulated engine operational environments.	SFW.1.02.01 SFW.3.01.03 SFW.3.03.09 SFW.2.01.03 SFW.2.01.06
SFW.1.02.02	Develop durable, low leakage non-contacting turbine seal enabling a reduction in overall SFC, resulting in reducing emissions and enhancing engine performance.	3Q 2011	Demonstrate the 2x durability (wear life with a leakage flow factor of 0.006 lbm-in-vR/lbf or lower) improvement of advanced finger seals (referenced to GE90 engine brush seal durability) tested at temperatures, thermal transients and under dynamic event characteristics experienced in propulsion system applications.	SFW.3.01.03

SFW.1.02.06	Scaling methods for stiffness	3Q 2008	Scaling methods for stiffness demonstrated through validation tests. Sub-scale predictions used to predicted larger-scale behavior to within 15%	SFW.2.01.03 SFW.2.01.06 SFW.2.01.07

Key Deliverables:

Product	Description	Date
Initial characterization of improvements to downselected mat'ls	Quantify & track improvements in strength, durability, damage tolerance, maximum use-temperature and functionality of initially optimized downselected material candidates using advanced processing and fabrication methods.	3Q 2008
1st Gen computational materials/multiscale analysis tools	Demo capability to predict bulk material props of adv. multi-functional materials (such as nano-structured materials) from computational materials/ multi-scale (nano to macro scale) models to within 10% of experimentally measured values.	3Q 2011
Manuf & Fab. Processing Tech.	Fab demo of a structural panel (≥ 1' x 1') with properties equivalent to analogous coupon-scale material and local property variances within ± 5% across the area of the scaled up panel	3Q 2011

SFW.1.05—Reacting Flow Physics/CFD

Clean and efficient combustion will need significant steps beyond the current emissions reduction design methodologies. Work will focus on developing RANS/LES models, atomization models and reduced chemical mechanisms, both conventional and alternative fuels, for integration into CFD codes for improved gaseous emission and particle predictions. Tests will be conducted to obtain temporally and spatially resolved data useful for code validation and combustor design. Data will be collected at representative engine operating conditions (T~1000 F, P=20 atm); as opposed to current correlations developed at ambient conditions (T~70F, P=1atm). Those critical information and tools will transfer to combustor designers and propulsion system integrators for aircraft propulsion and power systems technology advancement, performance improvement, and system optimization.

Milestones:

SFW.1.05	Reacting Flow Physics/CFD			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.1.05.01	Alternative fuel thermochemistry, thermophysical properties	3Q2009	Develop database for alternative hydrocarbons (Fischer-Tropsch, bio-fuels) using accepted testing standards; characterize fuels (freezing point, break point, etc) in comparison to current Jet-A.	
SFW.1.05.02	Experimental data for confined swirling flows with gaseous fuel	3Q2010	Using temporally and spatially resolved data useful for code validation and design, Obtain measurements of joint chemical-species-temperature with <10% uncertainty in high pressure (<30 atm) gas-phase reacting flows.	SFW.2.03.01
SFW.1.05.03	Improved primary atomization models	2Q2011	Develop atomization models for CFD codes based on data collected at representative engine operating conditions (T~1000 F, P=20 atm); as opposed to current correlations developed at ambient conditions (T~70F, P=1atm). Improve predictive accuracy band by 50% of the baseline	SFW.2.03.01 SFW.1.05.02

			accuracy band (SFW .2.03.01): Spatial distribution of drop volume flux, drop velocity and drop SMD	
SFW.1.05.04	RANS/LES model implemented in CFD	3Q2011	Reduce predictive accuracy band of the following quantities to about 50% of the baseline accuracy band (SFW.2.03.01): NOxEI, COEI, temperature profile factor.	SFW.2.03.01 SFW.1.05.02 SFW.1.05.03
SFW.1.05.06	Experimental database at laboratory scale for heterogeneous hydrocarbon partial oxidation	3Q2011	Demonstration of reformation reaction and catalyst technology by improving the reaction rate by 5X over current SOA.	

Key Deliverables:

Product	Milestone Description	Date
Data/Reports	Experimental data for confined swirling flows with gaseous fuel	3Q2010
Computer Models	RANS/LES model implemented in CFD	3Q2011

SFW.1.06—Control Methods and Strategies
SFW.1.07—Dynamic Modeling and Simulation

As subsonic fixed wing aircraft evolve into innovative configurations with enhanced control effectors and propulsion systems, new control methods and strategies will need to be developed to evaluate the capability of these systems to achieve optimal design performance with safe operation. Under past efforts, LaRC and DFRC have developed and demonstrated robust control methods for optimizing aircraft performance. A goal is to develop control methods for enabling real-time optimization of aircraft configuration and operation for enhanced performance, and robust flight control with innovative control effectors on unconventional configurations such as BWB and ESTOL. GRC has developed preliminary methods for active control of propulsion components and has identified additional technology development needs for enabling "Intelligent Engines." Another goal is both to develop methods for controlling flow over compression systems and alternative strategies for implementing distributed engine control. These will be investigated as part of Intelligent Engine technologies.

The control methods and strategies will be validated via piloted simulations in existing simulation facilities as well as hardware-in-the-loop testing with small lab facilities.

Dynamic Modeling and Simulation: New dynamic modeling and simulation techniques will need to be developed to investigate dynamic performance issues and support development of control strategies for innovative configurations. Under past efforts, ARC has investigated low speed dynamic characteristics of flight systems; LaRC and DFRC have developed new modeling methods for unsteady, nonlinear flight dynamics. A goal is to develop advanced methods to accurately model dynamics of innovative aircraft concepts with a focus on nonlinear and unsteady methods. Effectiveness of new flight control effectors and overall performance of innovative aircraft configurations will be assessed with non-real time and real time simulations. GRC has developed preliminary capability for dynamic modeling of transient turbine tip clearance, and unsteady ejector systems. A goal is to improve the accuracy. The approach will begin by comparing existing turbine clearance and unsteady ejector dynamic models with experimental data and methods.

Milestones:

SFW.1.06	Control Methods & Strategies			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.1.06.01	Assess current control technologies for aircraft performance optimization and establish baseline for future progress evaluations	2Q 2007	Baseline representative of State-0f-the-Art and provides effective means to evaluate benefits with advanced control techniques.	
SFW.1.06.02	Develop robust control methods for control of systems with distributed effectors	3Q 2007	Control methods provide a decrease of design margin of 3 dB due to modeling uncertainties.	
SFW.1.06.03	Develop advanced control methods for aircraft performance optimization	4Q 2009	Simulation evaluation demonstrates real-time performance optimization capability and >1% SFC reduction over the baseline	SFW.1.06.01 SFW.1.07.01
SFW.1.06.04	Develop advanced control methods for control of high lift configurations and evaluate in piloted simulations	4Q 2009	Control and high lift device integration resulting in at least Level 2 Handling Qualities for low speed flight.	SFW.1.07.02

SFW.1.06.05	Define component requirements for distributed engine control	1Q 2008	Develop environmental requirements such as operating temperature capability for electronics, volume and weight limitations for components, and performance requirements such as communication bandwidth, data latency etc. to enable smart sensors and actuator	
SFW.1.07	**Dynamic Modeling & Simulation**			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.1.07.01	Develop flight validated aero model from subscale flight vehicle tests	4Q 2007	BWB aero model matches flight data within 10%	
SFW.1.07.02	Develop simulation to quantify effectiveness of high lift devices as control effectors	2Q 2008	High lift devices meet control effectiveness requirements for ESTOL capability.	
SFW.1.07.03	Develop methods for modeling control effectiveness of distributed control effectors	3Q 2008	Accuracy of modeling methods quantified by comparing simulation and experimental data	
SFW.1.07.04	Develop analytic transient model of turbine clearance	4Q 2009	Model prediction closely matches existing (empirical model and experimental) data (target within 10%).	
SFW.1.07.05	Develop validated analytical simulation of a complete unsteady combustion and ejector system	2Q 2010	Simulation code "accurately" predicts pressure gain combustion and turbomachinery response to unsteady flow fields.	

Key Deliverables:

Product	Description	Date
Report	Documentation of robust control methods for control of systems with distributed effectors	4Q2007
Report	Documentation of component performance requirements for distributed engine control	2Q2008
Report	Simulation integrating high lift devices as control effectors	2Q2008
Model	Analytical transient model of turbine clearance	4Q2009

SFW.1.08—Acoustics Physics

The goal of the activities in Acoustics Physics is to improve understanding of the engine and airframe noise generation mechanisms with the dual aims of (1) advancing the state of the art in modeling and prediction of noise, and (2) developing generic noise control and mitigation technologies. Fundamental areas to be addressed in the prediction area include: a robust Large Eddy Simulation (LES) capability for aeroacoustic noise-source computation; the development and improvement of computational methods for acoustic scattering through complex near-field geometries and flows associated with an aircraft; acoustic propagation to the community; techniques enabling simultaneous measurement of velocity/pressure/temperature fluctuations for code validation; and improved turbulence models from which aeroacoustic noise sources may be predicted. In the noise reduction area, the focus is on the development of multi-function materials, smart materials and tailored materials for noise reduction, together with development of large unstructured grid capabilities for detailed CFD analysis of installed configurations. The examples here include: metallic foam for fan noise reduction & blade containment, shaped memory alloys for nozzle chevrons for jet noise reduction, and micro-modeling of aircraft composite structures for cabin noise transmission mitigation. Many of the above are not restricted in relevance to the subsonic fixed-wing project, but could benefit other FA projects.

Milestones:

SFW.1.08	Acoustics Physics			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.1.08.01	Develop micro-modeling prediction of aircraft composite structures for noise transmission mitigation. (Interim Assessment)	4Q 2008	Validate micro-modeling prediction to within 3 dB of the measured value.	
SFW.1.08.02	Develop micro-modeling prediction of aircraft composite structures for noise transmission mitigation.	2Q 2011	Optimize composite panel structure for 4 dB transmission loss improvement.	SFW.1.08.01
SFW.1.08.11	Develop/improve computational method(s) for computing acoustic reflection and scattering by aircraft structures.	2Q 2008	Predict directivity and spectra for benchmark problems to within 3 dB.	SFW.2.04.01
SFW.1.08.12	Develop/improve computational method(s) for computing acoustic reflection and scattering by complex geometries and flowfields associated with an aircraft and long-range propagation of sound to the community.	1Q 2011	Predict directivity and spectra to within 3 dB compared to measured data.	SFW.1.08.11 SFW.2.04.01
SFW.1.08.21	Develop a robust Large Eddy Simulation (LES) prediction capability for aeroacoustic applications. (Interim Assessment)	2Q 2008	Demonstrate feasibility of such simulations using established benchmark problems.	SFW.2.04.01
SFW.1.08.22	Develop a robust Large Eddy Simulation (LES) prediction capability for aeroacoustic applications.	3Q 2011	Predict turbulence power spectrum to within 3 dB of measured level.	SFW.1.08.21 SFW.2.04.01 SFW.2.04.21
SFW.1.08.31	Develop advanced techniques for simultaneous measurement of velocity/pressure/temperature fluctuations for code validation. (Interim Assessment)	3Q 2008	Increase spatial resolution of the data by a factor of 3 compared with the SOA in 2006.	SFW.2.04.01
SFW.1.08.32	Develop advanced techniques for simultaneous measurement of velocity/pressure/temperature fluctuations for code validation.	4Q 2011	Increase spatial resolution of the data by an order of magnitude compared with the SOA in 2006.	SFW.1.08.31 SFW.2.04.01
SFW.1.08.41	Develop capability for characterization of the amplitude, spectral and spatial distribution of the in-duct broadband noise. (Interim Assessment)	3Q 2008	Demonstrate the ability to measure spectrum of in-duct acoustic power to within 1 dB of measured farfield acoustic power level using artificial sources with no flow inside the duct.	SFW.2.04.01
SFW.1.08.42	Develop capability for characterization of the amplitude, spectral and spatial distribution of the in-duct broadband noise.	1Q 2011	Demonstrate the ability to measure spectrum of in-duct acoustic power to within 3 dB of measured farfield acoustic power level under realistic flow condition.	SFW.1.08.41 SFW.2.04.01
SFW.1.08.51	Develop improved turbulence models for unsteady flows with complex physics. (Interim Assessment)	4Q 2008	Predict flow characteristics such as shear layer spreading rate to within 50% of measured value.	SFW.2.04.01
SFW.1.08.52	Develop improved turbulence models for unsteady flows with complex physics.	2Q 2011	Demonstrate the ability to predict noise using improved turbulence models to within 3 dB of measured noise levels.	SFW.1.08.51 SFW.2.04.01

Key Deliverables:

Product	Description	Date
Modeling Capability	Develop micro-modeling of aircraft composite structures for noise transmission mitigation.	2Q FY11
Prediction	Develop a robust Large Eddy Simulation (LES) prediction capability for	3Q FY11

Tools/Codes	aeroacoustic applications	
Diagnostics Tools	Develop techniques enabling simultaneous measurement of velocity/pressure/temperature fluctuations for code validation	4Q FY11

SFW.1.09 Aeroelasticity

Development of improved predictive tools and execution of discipline-level validation experiments will require progress in our fundamental modeling capabilities, test techniques, and experimental data base. Fundamental efforts are required for modeling transonic aeroelastic phenomena, geometric nonlinearities associated with structural deformation, mistuning effects and multibody dynamics. This will require advances in higher order modeling of mistuning effects, turbulence, highly separated flows and fluid/structure interactions. A particular emphasis will be placed on highest-order methods in turbulence, transition and fluid/structure interaction modeling, along with highly efficient models for aeroelastic instabilities.

Implementation of the new computational capabilities described above will be standardized where feasible to facilitate addition to the tool sets described in the higher level milestones. Attention will be paid to high fidelity, physics based modeling for all aeroelastic computations that include nonlinear fluids and geometric/material non-linear structures. High fidelity computations include use of the Navier-Stokes equations for flows and 3D finite-elements for structures.

Test technique development will also be emphasized, particularly for structural dynamics ground testing and on-line health monitoring for aeroelastic applications.

Milestones:

SFW.1.09	Aeroelasticity			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.1.09.02	Analysis modules for transonic flutter optimization	4Q 2009	25% flutter speed and flutter frequency compared to detailed analysis	
SFW.1.09.05	Develop analysis for engine aeroelasticity with highly separated flows	2Q 2010	Predict (within 20% of measured) the operating condition of a fan/compressor at which aeroelastic vibrations occur with separated flow as the primary mechanism	

Key Deliverables:

Product	Description	Date
Suite of Codes	Analysis modules for transonic flutter optimization	4Q 2009
Suite of Codes	Develop computational fluid dynamics tools for buffet and gust modeling	4Q 2013
Simulation Code	Develop analysis for engine aeroelasticity with highly separated flows	2Q 2010

SFW.1.10—Computational Methods (Research & Implementing)

The ability to accurately predict aeroacoustic, aeroelastic, aerodynamic, and aerothermodynamic behavior by computational methods is critical to advancing our fundamental understanding in these areas. In addition, improved and novel computational methods are needed to enable numerical optimization-based design processes, including those that employ the highest-fidelity models. Achieving program milestones will require the development of new computational techniques and improved implementation of existing methodologies. A particular emphasis will be placed on developing capabilities to accurately predict unsteady flows in complex 3D geometries, both for internal and external flows. This will require advances in grid generation techniques, including adaptive grids, sliding grids, and grid generation for moving/morphing bodies and gap regions. Improved efficient and robust numerical methods that ensure high-order accuracy and low dispersion/dissipation will be developed, along with approaches that quantify uncertainty and estimate computational error. Efficient implementation on large-scale parallel/distributed computers will reduce overall time-to-solution. New turbulence models will be developed, particularly to enable reliable prediction of unsteady and separated flows. These will include Reynolds-averaged Navier-Stokes (RANS) models, Large Eddy Simulation (LES) techniques, and hybrid RANS/LES approaches such as Detached Eddy Simulation (DES). Discipline specific issues and implementation needs, such as rotating-frame models for turbomachinery simulations and acoustic source models for noise prediction, will be addressed. New physics-based models will be tested, implemented, and validated in simulation codes by comparison to experimental results. Algorithms to enable rapid design/optimization through adjoint methods, geometry parameterization, grid morphing, efficient gradient computation, constraint evaluation, as well as tools to provide user insight to the design space will be developed. Implementation of the new computational capabilities described above will be standardized where feasible to facilitate addition to the tool set described in the level 4 milestones.

Milestones:

SFW.1.10	Computational Methods			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.1.10.01	Improved RANS-based models and methods	4Q 2007 4Q 2009 4Q 2011	RANS-based computation models of highly loaded turbomachinery and high-lift wing flows with 30% improved predictive accuracy in flow separation patterns/locations and of aerodynamic losses due to stage interactions, secondary flows, leakages, and bleed flows compared to current physics-based models, with no decrease in computational efficiency	
SFW.1.10.02	Parallel unstructured grid generation	2Q 2008	Demonstrate scalable reduction in processing time for massive (100 million plus grid elements) unstructured grids for a complex high-lift geometry from days to minutes (eg. 3 days wall clock with single processor to 15 minutes with 200 processors)	
SFW.1.10.03	Robust adjoint-based mesh adaptation for error reduction and quantification	1Q 2009	CFD analysis for complex high-lift configuration to user-specified tolerance (eg: CL to .01) in one day	
SFW.1.10.04	Advanced LES and DES-based models and methods	2Q 2011	LES, DES and/or other hybrid based computation models of highly loaded turbomachinery and high-lift wing flows with 50% improved predictive accuracy in flow separation patterns/locations and of aerodynamic losses due to stage interactions, secondary flows, leakages, and bleed flows separation compared to current physics-based models, with quantified decrease in computational efficiency	SFW.3.02.01

Key Deliverables:

Product	Description	Date
Grid Generation Tool	Unstructured grid generation tool enabling rapid parallel processing for complex, massive grids	2Q2008
Turbulence Models	Improved RANS turbulence models for flow separation (external and internal)	3Q2009

SFW.1.11—Fluid Dynamics and Heat Transfer (Understanding & Modeling)

Development of improved predictive tools will require progress in our fundamental understanding of fluid flow and heat transfer phenomena. Particularly critical are advances in the understanding, prediction, and control of separation and transition, especially for unsteady flows and for flows in complex geometries. Likewise, the understanding, prediction, and control of turbulence and ice accretion are essential to the development of needed predictive capabilities. These areas will provide the major focus for our level 1 research activities. Complex aerodynamic systems (such as high-lift airfoils or turbomachinery) involve the interaction of multiple flows, often at different scale, and accurate prediction of such interactions is critical for advances in both active and passive, unsteady and steady flow control techniques and devices that will expand the design envelope. The effects of system rotation, high free-stream turbulence, and conjugate heat transfer must be investigated to improve turbomachinery design and predict turbine heat transfer, blade cooling, and off-design performance. Both experimental data and computational results will be used to generate databases that will lead to improved physical understanding, and facilitate model development.

Milestones:

SFW.1.11	Fluid Dynamics & Heat Transfer			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.1.11.01	Definition of unit investigation series for separation physics understanding and modeling	2Q 2007	Detailed plan incorporating NRA and industry partnership inputs to include physics level experiments and modeling for separation onset, control of separation, and interaction with circulation and turbulence	
SFW.1.11.02	Transition prediction closely-coupled with SOA flow solvers	3Q 2008	module coupled with unstructured and structured grid flow solvers and transition predicted within 5% chord for simple geometry	
SFW.1.11.03	Conjugate heat transfer analysis for cooled turbine	3Q 2008	Conjugate analysis capability demonstrated for cooled turbine blades	
SFW.1.11.04	3d icing physics model for swept wing configuration (tentative)	4Q 2008	new 3d ice accretion model formulated	
SFW.1.11.12	Engine ice accretion physics (tentative)	1Q2009	Characterization of mixed phase ice growth physics leading to development of an initial theoretical model for the process	
SFW.1.11.05	Experimental data for low speed separation onset and control	3Q 2009	Experimental data acquired characterizing separation onset and progression with emphasis on off-body flow field including turbulence data	SFW.1.11.01 SFW.2.06.02
SFW.1.11.06	Simulation and matching of advanced multistage compressor	3Q 2009	Aerodynamic performance and matching of advanced multistage compressor demonstrated on highly loaded two stage compressor rig; simulation of onset of stall completed	SFW.3.01.02
SFW.1.11.07	Flow controlled stator test in multistage environment	4Q 2009	Flow-controlled stator for aerodynamic blockage management and matching in advanced multistage compressor demonstrated	SFW.2.07.01
SFW.1.11.08	High speed separation onset physics	3Q 2010	Experimental data acquired and documented characterizing 3d separation and onset and progression at highest feasible Reynolds for high speed flow with emphasis on off-body flow field including turbulence data	SFW.1.11.01
SFW.1.11.10	Heat transfer methodologies for high pressure turbine	4Q 2011	Methodology for predicting combined turbine aerodynamics and heat transfer developed and validated	

Key Deliverables:

Product	Description	Date
Ice Accretion Model	3D icing physics model for swept wing configuration	4Q 2008
Report	Experimental dataset for low speed separation onset and control over broad parameter space	3Q 2009

SFW.1.12—Fundamental New Experimental Approaches;
SFW.1.13—Application & Enhancement of Current Experimental Techniques

The goal for Level 1 Fundamental Experimental Approaches and Enhanced Experimental Techniques research is to develop tools and methodologies to enable currently impractical measurements in support of the overall goals of the Subsonic Fixed Wing program: reduce acoustic noise, reduce engine emissions, and enhance performance of future airspace vehicles. Much of the research will be guided by the requirements of other disciplines and seek to provide critical data for advanced prediction code development, prediction validation, and methods to experimentally characterize and validate advanced design concepts. The research areas at Level 1 include:

a. Improved high performance optical techniques operating with high temporal resolution for measuring acoustic noise related phenomena as well as providing data for turbulence modeling
b. Advanced measurement techniques capable of identifying acoustic noise sources
c. Advanced stand-alone capabilities for measuring airframe vibrations in a ground testing environment
d. Improved Pressure Sensitive Paint (PSP) formulations for use in cryogenic facilities
e. Developing a flow angularity system capable of operating in a cryogenic facility, including identifying appropriate seeding materials
f. Producing a design for a high speed laser system capable of > 50 kHz operation
g. Employing advanced laser systems designs to design and simulate high frequency fluid dynamic experiments

Milestones:

SFW.1.12	**Fundamental New Experimental Approaches**			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.1.12.02	Develop autonomous ground test methods for measuring airframe vibrations	2Q 2011	Development of a multi-point vibrometry systems capable of making stand-off structural vibration measurements on a 16x16 array of measurement locations.	
SFW.1.13	**Application & Enhancement of Current Experimental Techniques**			
Number	**Title**	**Year**	**Metric**	**Dependencies**
SFW.1.13.02	Develop high-rate LASER system design	4Q 2007	Partner with laser manufacturers to develop laser design for system capable of >50 kHz operation	
SFW.1.13.03	Develop advanced phased microphone array technology	4Q 2008	Develop a 128 microphone array capable of measuring Sound Pressure Levels > 130 dB at acquisition rates up to 100 kHz	
SFW.1.13.04	Develop advanced techniques for cryogenic facilities	4Q 2009	Develop Pressure Sensitive Paint coatings capable of making global surface pressure measurements at cryogenic conditions with accuracies to 2% relative to discrete pressure taps. Develop flow angularity measurements system capable of measuring cryogenic flows to 1 degree	
SFW.1.13.05	Develop high-rate PIV systems	Q2 2011	Develop Stereo Particle Imaging Velocimetry (PIV) system capable of operating up to 50 kHz for measuring acoustic effect due to turbulence	
SFW.1.13.06	Design & simulate high-frequency fluid dynamic experiments	2Q 2011	Design experiments to create >50 kHz flow structures, develop computer simulation, and develop data analysis	SFW.1.13.02

			to extract velocity map from computer simulation.	

Key Deliverables:

Product	Description	Date
Flow angularity measurement system	Demonstrate a flow angularity measurement system for cryogenic facilities and quantify accuracy and uncertainty of the results	4Q FY08
Laser system design	Laser design for an experimental system capable of measuring dynamic phenomena at > 50 kHz compared to today's 10 – 20 kHz	4Q FY07
Multi-point vibrometry system	Multi-point vibrometry system capable of measuring airframe vibrations in a ground test facility at multiple points simultaneously	4Q FY11