NASA/TM—2015-218886

Low NOx Fuel Flexible Combustor Integration Project Overview

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October 2015

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Abstract

The Integrated Technology Demonstration (ITD) 40A Low NOx Fuel Flexible Combustor Integration development is being conducted as part of the NASA Environmentally Responsible Aviation (ERA) Project. Phase 2 of this effort began in 2012 and will end in 2015. This document describes the ERA goals, how the fuel flexible combustor integration development fulfills the ERA combustor goals, and outlines the work to be conducted during project execution.

1.0 Introduction

1.1 Environmentally Responsible Aviation (ERA) Project Technical Summary

The Environmentally Responsible Aviation (ERA) Project was created by NASA to explore and document the feasibility, benefits, and technical risk of vehicle concepts and enabling technologies that will reduce the impact of aviation on the environment.

Current-generation aircraft already benefit from NASA investments in aeronautical research that have yielded improved fuel efficiencies, lowered noise levels, and reductions in harmful emissions. Although substantial progress has been made, much more needs to be done.

The nation's air transportation system is expected to expand significantly within the next two decades. Clearly, a potential adverse impact from this expansion on the environment exists. The ERA Project invests in technologies with the potential to neutralize or reduce negative environmental impacts.

The ERA Project's primary goals are to:

- Explore and mature alternative unconventional aircraft designs with the potential to simultaneously meet mid-term goals (5 to 10 years) for community noise, fuel burn and nitrogen oxide (NOx) emissions as described in the National Aeronautics Research and Development Plan;
- Determine the potential impact of these alternate aircraft designs and technologies if successfully implemented into the air transportation system; and
- Determine the potential impact of these technologies on advanced tube-and-wing designs.

Major research challenges include:

- Documenting the feasibility, benefits and technical risks of vehicle concepts;
- Determining the certification hurdles and implications of new technologies and configurations;
- Exploring the performance characteristics of design concepts for aircraft for service entry by 2025; and,
- Enlarging the viable trade space (the degree to which performance objectives can be traded against each other to achieve best value) to assist industry in designing and building environmentally efficient vehicles for commercial aviation.

1.1.1 ERA System Description

Specifically, the ERA Project will invest in:

- Testing unconventional aircraft configurations that improve fuel efficiency through higher lift-to-drag ratio, more efficient propulsion systems, and lower weight designs;
- Developing technologies that reduce noise around airports and reduce NO_x emissions; and
- Assessing the ability of technologies such as laminar flow, composite structures, and fuel flexible combustors to achieve Project goals.

Work within the ERA Project is coordinated with system-level research performed by other programs within NASA's Aeronautics Research Mission Directorate as well as other federal government agencies. The ERA Project will disseminate all of its research results to the widest practical extent.

NASA has also put mechanisms in place to:

- Engage academia and industry, including working groups and technical interchange meetings;
- Define Space Act Agreements for cooperative partnerships; and
- Employ the NASA Research Announcement process that provides for full and open competition for the best and most promising research ideas.

1.1.2 ERA System Structure

The ERA Project contains three Subprojects:

- Airframe Technology;
- Propulsion Technology; and
- Vehicle Systems Integration.

Management of the ERA Project is organized according to the ERA Work Breakdown Structure (WBS), which is documented in ERA-01-PM-0001, "ERA Technology Development Project Plan". The ERA WBS is used for tracking cost and schedule performance.

The structure of the ERA Project organization is shown in Figure 1.

1.2 ERA ITD 40A Technology Summary

A series of increasingly stringent NOx emission standards by the International Civil Aviation Organization's (ICAO) Committee on Aviation Environmental Protection (CAEP) over the years have limited aviation emissions below 3,000-ft altitude. These standards cover the landing, takeoff, descent, and taxiing phases of engine operation (LTO) in a prorated fashion. ERA's goal is to develop and demonstrate a low NOx fuel flexible combustor that provides a 75 percent reduction in nitrogen oxides below the current standard that was defined at the 6th CAEP meeting, with no increase in particulate matter, while achieving a 50 percent reduction in fuel burned. System studies indicate that to meet the fuel burn reduction goals, advanced engines will be operating at higher pressures and temperatures that encourage NOx production (Fig. 2). Improving specific fuel consumption while simultaneously reducing NOx requires advanced combustor technology. Newer injector designs and air/fuel mixing concepts, such as lean direct injection, will be required to meet the emissions goals and provide fuel flexibility; however, leaner-burning concepts tend to have less stability margin and require more fuel staging and combustion control.

1.3 Needs

The need of the Low NOx Fuel Flexible Combustor Integration ITD is to demonstrate an advanced combustor for high pressure and high by-pass ratio engines to simultaneously meet fuel burn and NOx reduction goals.

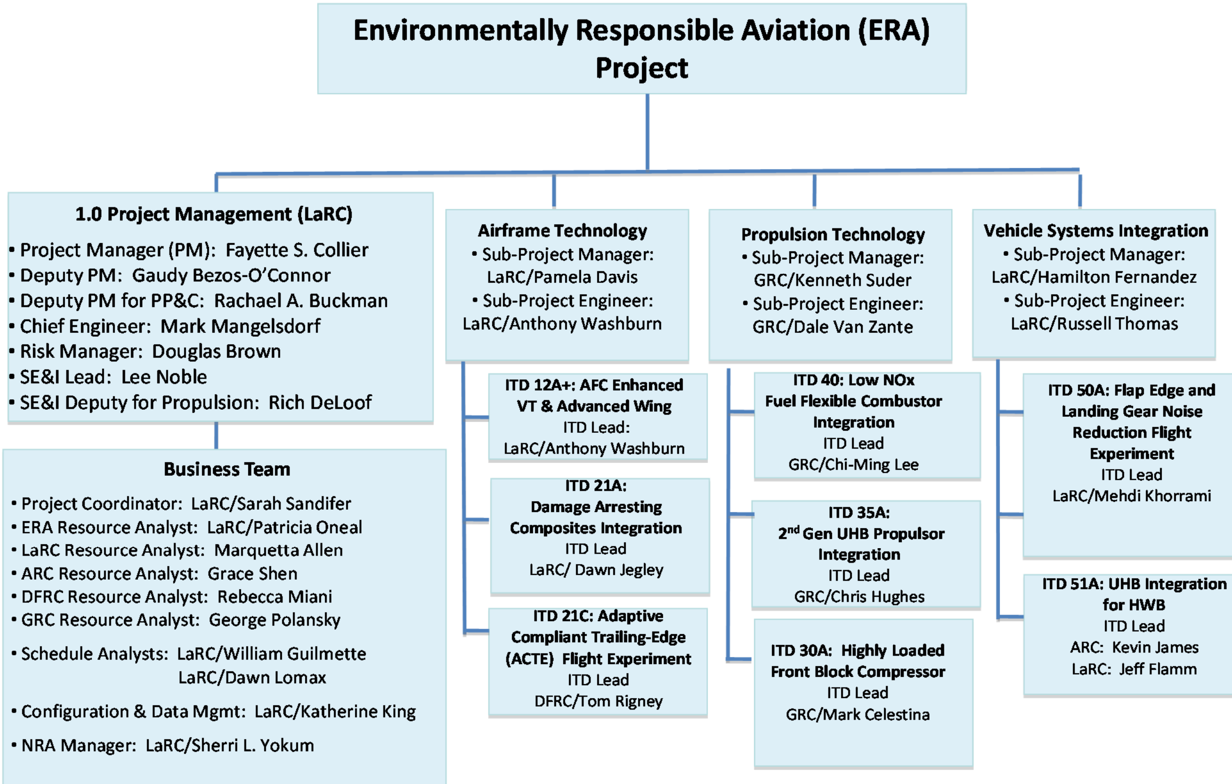

Figure 1.—ERA project structure.

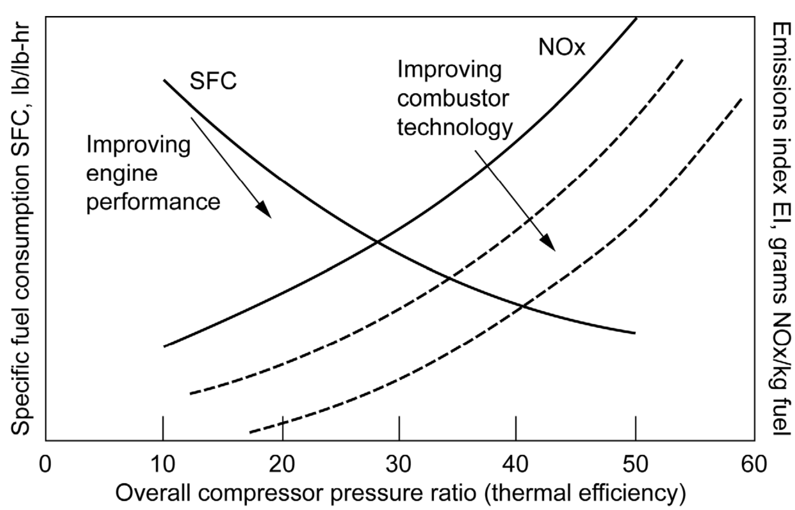

Figure 2.—Impact of overall engine cycle pressure ratio on NOx formation. Increasing pressure ratio reduces fuel consumption at the cost of producing NOx. However, the NOx curve can be lowered by improving the combustor and its sub-component technologies.

1.4 Goals

The goals of ITD 40A are:

- Demonstrate emission goals through sector rig and full annular combustor testing.
- Demonstrate effectiveness of conventional and alternative fuels to meet combustor performance, operability, and durability goals.

1.5 Objectives

The technology goals for the N+2 vehicle capability and timeframe are a part of the National Plan for Aeronautics R&D and Related Infrastructure. The goals are shown in Table 1 in the context of multiple generations of future aircraft and are denoted as N+1, N+2, and N+3 where N signifies the latest generation of aircraft currently in operation. The N+2 goals are highlighted, and are shown relative to a reference vehicle defined as the Boeing 777 twin-aisle transport with GE90 engines that entered into service in 1997. These challenging goals represent the corners of a trade space for aircraft design. NASA has been working technologies appropriate to each corner with an eye toward enabling synergistic combinations to meet multiple goals simultaneously, the likelihood of which increases the further into the future one looks as alternative configurations become more realizable. This ITD will raise the Technology Readiness Level (TRL) of enabling vehicle technology for reduced fuel burn and emissions.

The main objectives of this ITD are:

- O.ITD40A.0001: Demonstrate emissions and fuel burn reductions through multisector combustor testing.
- O.ITD40A.0002: Demonstrate durability, operability, and performance through full annular combustor rig testing.
- O.ITD40A.0003: Demonstrate injector performance using conventional and alternate fuels.
- O.ITD40A.0004: Deliver a state-of-the-art emissions, performance, and fuel flexibility database to enable a large scale engine ground demonstration for combustors to be integrated into the fleet by 2025.

TABLE 1.—NASA TECHNOLOGY GOALS FOR FUTURE SUBSONIC VEHICLES

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-52 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption‡ (rel. to 2005 best in class)	-33%	-50%	-60%

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines, N+2 values are referenced to a 777-200 with GE90 engines

** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

‡ CO2 emission benefits dependent on life-cycle CO2e per MJ for fuel and/or energy source used

2.0 ITD Technology

2.1 ITD 40A Technology Demonstration Flow

2.1.1 NOx Reduction Effort History and NASA Program Goals

The ERA Project is working with industry to develop combustor technologies for a new generation of low-emissions engine combustors targeted for the 2020 timeframe. These new combustors will reduce nitrogen oxide (NOx) emissions to half of current state-of-the-art (SOA) combustors, while simultaneously reducing particulate emissions.

NASA has been driving the NOx reduction effort in the aviation industry since the mid-70s, resulting in approximately 50 percent NOx reduction every generation (~15 years). The initial concerns were ground-level NOx producing ozone that interacts with the unburned hydrocarbons to form smog, a ground-level health issue. As a result, a series of increasingly stringent NOx emission standards by the International Civil Aviation Organization's (ICAO) Committee on Aviation Environmental Protection (CAEP) over the years were put in place to limit aviation emissions below 3,000-ft altitude. These standards cover the takeoff, climb, descent, and taxiing phases of the engine operation (LTO) in a prorated fashion. With forward-thinking research, the aviation propulsion industry has turned these past NASA-sponsored combustor concepts into flight hardware.

This continuing and primary NOx-reduction effort is even more difficult under ERA than it was under previous programs. After three decades of improvements, the existing NOx level is already pretty low and there is not much room to implement additional reductions (Fig. 3). At the same time, the ERA system-level goal also includes a 40 percent reduction in fuel consumption for the airframe platform. While much of these savings may be taken up by airframe drag reduction, the contribution from improving engine efficiency means increasing the engine Overall Pressure Ratio (OPR) to about 55 from the SOA 45. This increased combustor pressure and temperature also increases the NOx formation rate. Thus, this ERA NOx-reduction effort fights on two fronts.

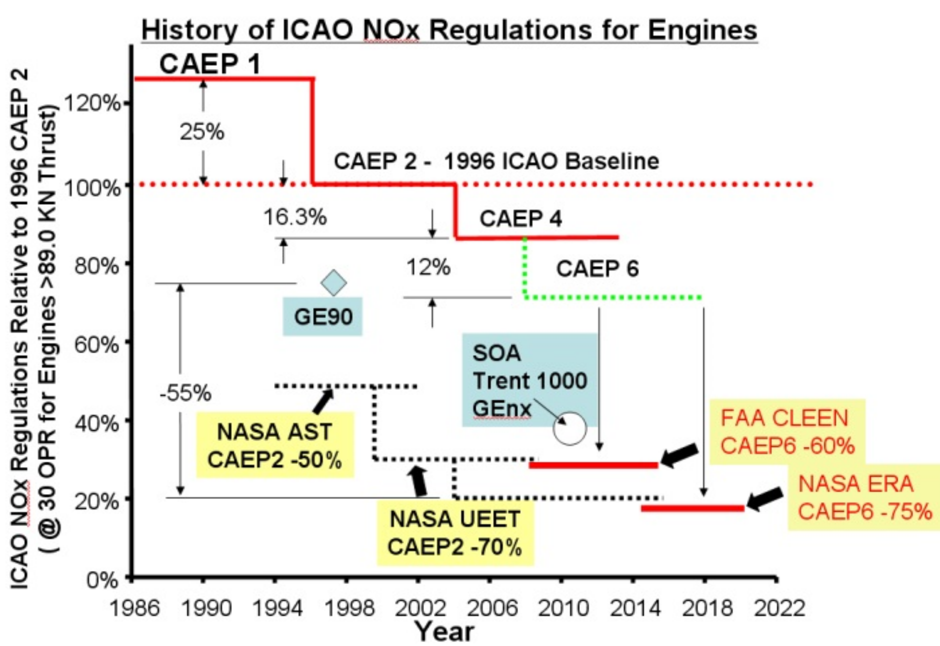

Figure 3.—Historical trends of ICAO LTO NOx limit and NASA program goals.

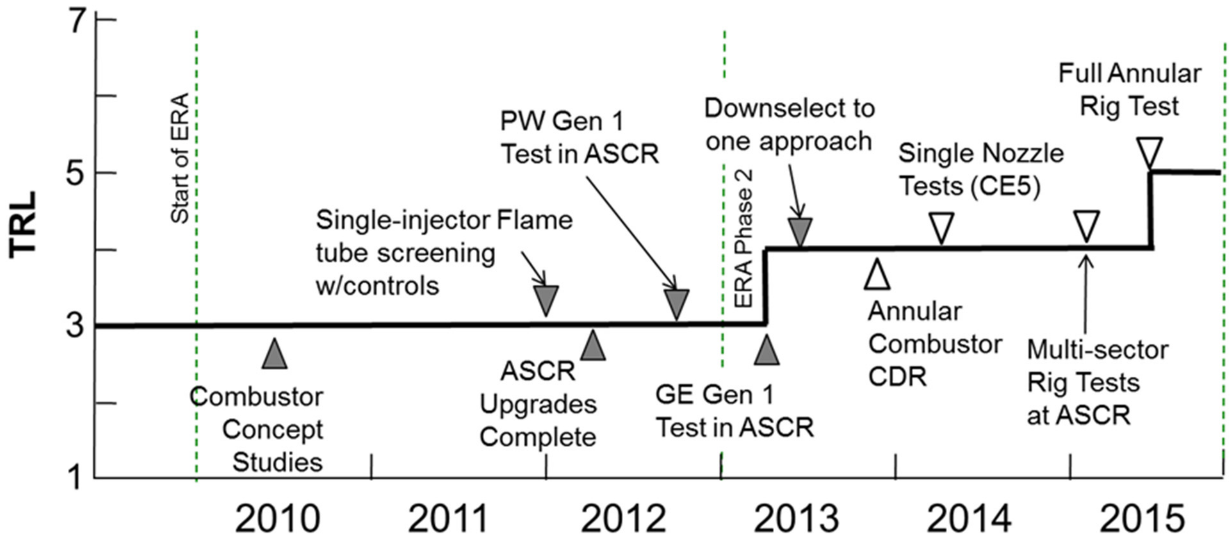

Figure 4.—Technology maturation roadmap.

A secondary consideration for this ITD is accommodation for using alternative fuels. The recent push for using blended fuel from distillate and hydrocarbon alternative fuel stocks derived from renewable sources creates additional opportunities and challenges. High quality hydro-treated stocks burn with reduced soot emission and no sulfur oxides. They are also more resistant to coking, allowing for more aggressive fuel injector designs to improve fuel distribution. Alternative fuels burn faster, however, allowing less time for making the fuel-air distribution uniform. Allowances for these characteristics need to be designed into the combustor technology from the onset.

During the execution of ITD 40A, combustor concepts will be demonstrated in a relevant environment through ground testing. Successful completion of the ITD will advance the concepts to TRL 5. Figure 4 shows the flow of TRL advancement during both Phases 1 and 2.

2.1.2 Phase 1 Effort Overview

The purpose of this low NOx fuel flexible combustor research is to advance the Technology Readiness Level (TRL) of a low NOx, fuel flexible combustor to the point where it can be integrated in the next generation of aircraft. To reduce project risk and optimize research benefit, NASA funded two groups of Phase 1 contracts. The first group of contracts were awarded to engine manufacturers General Electric Aircraft Engine and the Pratt & Whitney Company to screen more mature candidate combustor and sub-component concepts. The second group of contracts were awarded to fuel injector manufacturers Goodrich Corporation, Parker Hannifin Corporation, and Woodward Fuel System Technology to look at advanced fuel injector concepts suitable for operating on ultra-high pressure engines.

Industry partners General Electric (GE) and Pratt & Whitney (P&W) were contracted to develop combustor concepts that can achieve the 75 percent NOx reduction below CAEP/6 standard over the full LTO requirement regimes. These two contracts were cost-shared and leveraged concepts from past NASA-sponsored works and industry partners' internally-developed concepts. They covered the full set of combustor issues with full-sized injectors and liners as well as combustor system-level dynamics. Phase 1 activities started from flame tube tests ((Technology Readiness Level (TRL) 3)), which will be brought to TRL 5 in Phase 2 with a written plan to advance the technology to TRL 6. Phase 1 focused on proof of concept, and resulted in two different design concepts that both met the emissions goal. In 2012 at the end of Phase 1, two sector combustors were tested at the NASA GRC Advanced Subsonic Combustion Rig (ASCR). The results indicated 75 percent NOx emission reduction below 2004 CAEP/6 regulation level.

The three injector contracts looked at how to implement lean direct injection into a viable form for use on ultra-high pressure engines in order to operate over the full operating envelope from sea-level takeoff to relight and lean-blowout. They were cost-shared efforts and covered a range of subjects such as screening design iterations using NASA's National Combustion Code (NCC) computational fluid dynamics code and using advanced fuel delivery to control blowout and manage dynamics. These flametube-level tasks developed the underlying fuel injection enabling technologies that will be made available to the oncoming advanced combustors.

A progressive competition strategy was used with down-selection of sources from the initial phase combustor contracts to determine the second phase contractor. The competition for the second phase built on the results of the initial phase, and the award criteria for the second phase included successful completion of the initial phase requirements.

2.1.3 Phase 2 Effort Overview

At the end of Phase 1, P&W was chosen to further develop their combustor technology identified in Phase 1. Phase 2 will attempt to prove that the P&W concept is capable of meeting NASA's N+2 NOx goals by hardware demonstration that will advance the TRL from the current TRL 4 to 5 via a test campaign utilizing flametube and arc sector test rigs at NASA and P&W/university-provided facilities as well as a full annular rig provided by P&W.

A sector combustor rig will be used to demonstrate improved operability over the ERA Phase 1 combustor over the following operational conditions:

- Inlet temperature: ambient to 1300 °F
- Inlet pressure: 1 to 50 atm
- Flame temperature up to 3000 °F

Stability, operability, and performance acceptable for commercial airline operations must be demonstrated, in part by 100 hr of operation of a full annular test rig. The use of conventional and blended alternative fuels in all three test rigs (flametube, arc sector, and full annular) is required to deliver a state-of-the-art emissions, performance, and fuel flexibility database to enable a large-scale engine ground demonstration for combustors to be integrated into the fleet by 2025. This ITD will be fully successful when the full annular test rig achieves 75 percent LTO NOx reduction and 70 percent cruise-level NOx reduction referenced to a 2005 state of the art engine.

Phase 2 work includes:

- Single nozzle testing conducted at United Technologies Research Center (UTRC), NASA, Georgia Institute of Technology, and the University of Connecticut.
- P&W delivery of a new or refurbished multi-injector sector for evaluation at and with NASA at realistic engine conditions. Realistic engine conditions will define the combustor inlet pressure and temperature levels based on P&W's advanced engine concept capable of meeting the N+2 NASA noise, emissions, and performance goals.
- Multi-injector arc sector design, improvement, and testing at realistic engine conditions at UTRC and NASA for system integration and fuel flexibility.
- Demonstration of burning blends of 50 percent alternative fuel to 50 percent jet fuel in NASA's CE-5 flametube combustor and ASCR facilities, UTRC facilities, and partner provided full annular test rig, using injector company provided hardware.
- N+2-level NOx reduction demonstrated for 100 hr in a full-annular combustor in existing P&W facility.
- Enabling technologies identified in Phase 1 developed to a level that allows successful demonstration in the full annular rig.
- Additional technology development roadmaps will be generated which describe what is required to advance the technology from TRL 5 to 6.

2.2 Phase 2 Testing and Analysis Detailed Work Flow

ITD 40A provides CE-5 flametube and ASCR arc sector facility testing for single nozzle and arc sector hardware. P&W performs the analysis and provides the test combustor hardware (design, fabrication, and integration), and the support personnel during testing at NASA. NASA performs post-test data processing for ASCR. P&W also conducts single nozzle and arc sector testing at UTRC. P&W performs full annular tests at their X960 facility. Alternate fuel testing is performed both at P&W and NASA, with alternate fuel supplied by NASA.

The ITD workflow is shown in Figure 5.

2.2.1 Single Nozzle Sector Tests

Single nozzle evaluations conducted at UTRC, NASA, Georgia Institute of Technology, and the University of Connecticut will be focused on expanding the design space for the ACS combustor, particularly with respect to packaging, emissions, fuel flexibility, and operability including combustion dynamics. Testing at the universities will focus on fundamental understanding of the physics relative to fueled jet combustion and how it interacts with the pilot cross flow. These experiments will provide understanding of the controlling combustion mechanisms. Design parameters will be varied to define viable design space, jet-to-jet interaction behavior, and reaction envelopes. This information will be used to achieve jet fueling and jet packaging approaches that are consistent with jet combustion physics over the operating envelope. This effort will be conducted in a fashion so that important results can be shared publicly.

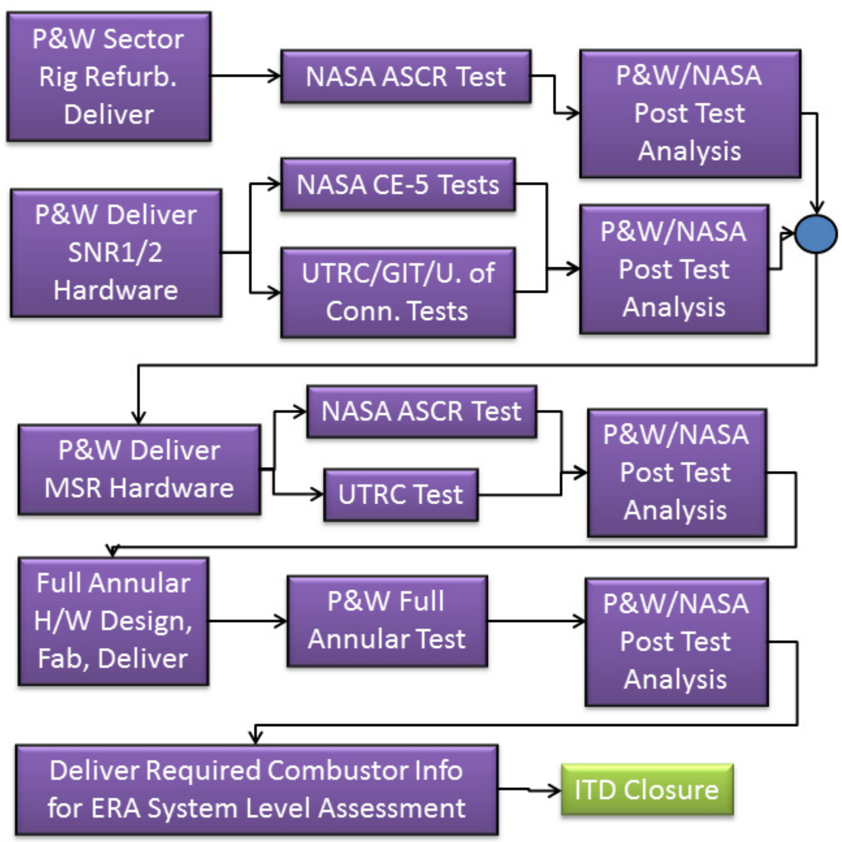

Figure 5.—ITD 40A workflow.

Testing at UTRC and NASA will focus on system behavior and emissions sensitivity through design of experiments (DOE) variation for a range of possible system layouts. Layout variations that will be studied include pilot-main separation, fueled jet size and location, effectiveness and design constraints for single-wall fuel jet injection, and design sensitivity to dynamic instabilities. In the DOE activity, system pressure, inlet air temperature, and fuel to air ratio will be varied to represent the engine cycle. This knowledge will lead to improvements to the design in preparation for arc sector testing. Single nozzle rigs with acoustic boundaries will also be used to test the combustion dynamics of various configurations with respect to operating conditions, fuel-air ratio, and fuel type. High-speed imaging of the acoustically coupled combustor, along with unsteady pressure measurements, will be used to diagnose the mechanisms of thermo-acoustic coupling that may be present.

NASA single-nozzle rig tests will be conducted in the CE-5 facility, and will assess the sensitivity of various configurations to fuel type. Pilot characteristics, such as lean blowout (LBO), efficiency, and robustness with respect to acoustics will be measured. These tests will make use of NASA's extensive laser diagnostic capability and CE-5's optical access to more extensively measure and understand the effects of fuel type on these operability characteristics.

2.2.2 Arc Sector Rig Tests

Arc sector testing will be performed at UTRC and NASA for system integration and fuel flexibility. Arc sector testing at NASA will initially focus on the robustness of the ERA Phase 1 Gen 1 combustor design with respect to fuel flexibility. The arc sector rig that was tested at NASA during Phase 1 will be refurbished. Changes in flame speed due to changes in fuel type should have minimal impact on the performance of the ACS combustor. This expected strength, among others, of the ACS combustor concept will be evaluated during fuel flexibility testing at NASA.

In the second year of the program, the NASA ASCR facility will be used to validate the performance of concept refinements found at UTRC that most effectively advance annular rig requirements. NASA arc sector testing will validate performance and emissions at high power operation and various other engine pressure and temperature conditions. P&W and UTRC will provide personnel to support all aspects of the test program at NASA. ASCR testing represents a critical risk-reduction element in the development process. ASCR provides rig-level access to realistic full engine pressures and temperatures, up to 1,300 °F T3, 50 atm, and flame temperatures of 3,000 °F, enabling performance to be measured over the complete range of conditions without making projections. Fuel flexibility will be included in the evaluation.

In preparation for NASA ASCR facility tests, UTRC arc sector rig testing will validate the performance of the second generation concepts, as explored in the single nozzle rig testing. Second generation concept testing at UTRC will provide initial validation obtaining low power emissions points, and determining how to best operate and stage the configuration. Arc sector testing will be conducted in designs that have combustor liners, combustor cooling, and combustor fuel nozzles that follow engine design requirements. System integration aspects will be assessed at temperatures and pressures that will substantiate and refine the design. Low power efficiency, lean blowout, and emissions performance will be measured. In addition, an acoustic boundary condition will be included to explore dynamic stability robustness of the design refinements with respect to pilot-main fuel flow splits. Those design features that appear to best meet production requirements and emissions and performance goals will be incorporated in the combustors that are provided to the NASA ASCR facility for testing.

2.2.3 Full Annular Tests

Full annular testing (100 hr) at the P&W facility will be performed for validation of combustor emissions, pattern/profile factor, lighting, lean blowout (LBO), operability, dynamics, and heat loading. Full annular testing is required to validate the stability, operability, and performance acceptable for commercial airline operation, advancing a combustor concept from TRL 4 to 5. For the ERA Phase 2 effort, P&W will fabricate a full annular rig of the Gen 2 concept developed for arc sector testing at NASA. This rig will be tested at the P&W X960 rig test facility in Middletown, CT. The process of designing, fabricating, and assembling a full-annular combustor will expose and help address mechanical design and packaging unique to the ACS architecture (including a full fuel system), thereby increasing the maturity of the design and enabling future engine implementation. Full annular testing will include measurements of exit temperature quality including pattern factor and profile factor, lighting, LBO, operability, and heat loading. A long-duration (100 hr) test will be completed, including testing with an alternative fuel blend. Emissions testing will be made for low power engine conditions that can be directly set in the annular rig facility. Full-power performance will be assessed using flow parameter scaling similar to the method used to evaluate the P&W TALON X combustor during product design trials for P&W's geared turbofan (GTF) engines under commercial development. Emissions measurements will be correlated with measurements made in arc sector test article testing at UTRC and NASA. Experience has shown that for Rich Burn, Quick- Mix, Lean Burn (RQL) combustors, NOx emissions measured in arc sector rigs are quantitatively predictive of full annular and engine measurements. In arc sector rigs, carbon monoxide (CO), UHC, and smoke are usually trend-wise predictive, while full annular rig tests are quantitatively accurate with respect to low power CO and unburned hydrocarbons (UHC), while still being trend-wise accurate with smoke.

Full annular tests will also measure the characteristics of stage-to-stage transition. Stage-to-stage transition learning will be used to improve combustor operation readiness. In addition, full annular tests will provide durability data to finalize the cooling design of combustor liners/panels in preparation for engine testing. Full-annular testing and the use of a full fuel system permit the evaluation of symmetry-breaking techniques for the mitigation of traveling-wave tangential-mode combustion acoustics. P&W expects that this learning, including heat loading on the panels, can be acquired in a few days of testing, and will be part of the 100-hr demonstration test in this program. This will complement validation of liner durability, transient operability, and system acoustics in engines that will follow this contract.

Full system level impacts, including boundary conditions and system inputs, are only completely validated through engine testing. In this program, the full annular rig test will establish that the ACS combustor is ready for engine testing. It will also provide critical operational and performance data that will be used to create engine test programs and operational plans.

2.2.4 Post-Test Analyses

Complete development of a concept is only possible if all aspects of the design are addressed. Many of these aspects are not easily tested even in arc sector and full annular rigs, but are evidenced during engine operation. These include acoustics, durability, and transient operation, as well as the impact of alternate fuels. Some specific areas of focus will include combustion acoustics, alternate fuels, durability/cooling, fuel staging, and general design tool improvement.

Combustion Acoustics—In the Phase 2 effort, P&W proprietary tools will be reviewed and adapted as necessary to the particular configuration and chemistry. Also, to enable the development, verification, and validation of the ACS system, each rig (single-nozzle and arc sector) will have acoustic boundaries so that ACS combustor acoustic performance can be measured and compared to predictions. Diagnostic measurements of unsteady pressure and unsteady heat release will be incorporated to provide a more sophisticated understanding of the thermoacoustic coupling mechanics and design stability boundaries in single-nozzle and arc sector environments. Learning from the acoustics characterization will be captured in P&W Engineering Standard Work (ESW).

Alternative Fuels—Prior to testing alternative fuel blends, differences in physical and chemical characteristics between pure petroleum fuel and an alternate fuel (50/50 blend) will be reviewed, followed by an assessment of the impact on combustor performance. The pretest assessment will focus on changes to pre-ignition and LBO limits. Testing will focus on emissions, ignition, and LBO phenomena. Results will be compared with and added to the existing database. Finally, fuel-type sensitivity assessment of the ACS concept will be conducted.

Durability/Cooling—The ACS refined designs will incorporate the best wall cooling technology available at P&W, including Floatwall and Impingement Film Floatwall (IFF) technologies.

These technologies are used in V2500, PW4000, and PW6000. These combustor liner cooling approaches enable TALON combustors to allow more air to be used for the control of NOx emissions while reducing wall cooling air requirements. For the ERA Phase 2 effort, these technologies and design approaches will be adapted to the ACS combustor to provide engine-level durability of the test articles. Experience from Phase 1 testing will be applied. Learning from the application of advanced wall cooling will be captured in P&W ESW.

Fuel Staging—During Phase 1, P&W teamed with fuel system companies to investigate novel means to deliver and meter fuel in staged systems. Individualized nozzle fuel injection can provide several advantages, such as fuel manifold simplification, altitude relight fuel shifting options, LBO control, and local combustor acoustic control, by creating small circumferential non-uniformities that can be turned on and off at different flight cycle conditions. P&W will incorporate ideas from these efforts into the Phase 2 annular rig design. P&W will continue to work with fuel system suppliers to further mature these concepts.

General Design Tool Improvement—All aspects of combustor design, P&W will continue to upgrade its tools, models, and approaches. During the Phase 2 effort, planned improvements in spray modeling, combustion radiation modeling, and acoustic models should have direct applicability to ACS combustor design and execution. Therefore, P&W has planned to conduct these improvements as part of the Phase 2 effort and apply them to refine the performance of the ACS combustor. These adaptations and improvements of P&W ESW tools and approaches will be conducted in parallel with rig testing. Rig data will provide insight on how best to use the design tools. P&W definitions for tool usage will be upgraded for the design of the annular rig.

3.0 ITD Technology Verification and Validation

Technology verification is the process that proves the technology meets its requirements and matches the design. Technology verification answers the questions, was the technology built the way the requirements and design specified? Was the technology built “right”?

Technology validation determines whether the technology being developed will meet the intended needs, goals and objectives of the ITD and the stakeholders. Technology validation answers the questions does the technology solve the problem or issue that it was intended to solve? Does it solve it to the expected extent? Was it the “right” technology?

3.1 Verification

Technology verification begins with the identification of a set of design (performance, functional, and environmental) requirements. When the requirements obtain stakeholder approval, the technology is developed in accordance with those requirements. The process of technology development begins by its investigation in a controlled environment using either testing or analysis as the preferred technology development method. At the conclusion of the investigation, the technology is evaluated against its design requirements resulting in a verified technology.

The technology verification for ITD 40A ends in Phase 2. ITD requirements, as documented in the ITD 40A Objectives and Requirements Document (ORD), will be verified by the ITD 40A Systems Engineer (SE). A Verification Compliance Sheet will be completed by the SE and submitted to ITD management for concurrence.

3.2 Validation

When the technology is verified, stakeholders review and determine whether the technology is promising enough to meet the stated needs, goals, and objectives. If it is determined to advance the technology then the technology functionality and performance is further examined to validate it as the right technology to meet the stakeholder expectations.

To extend the applicability and impact of a valid technology, it is assessed in the "real-world" operations using System Analysis. System Analysis is the process of investigating a system, identifying problems, using new information to solve those problems, and recommending improvements to the system. The information obtained from the System Analysis is used to evaluate the technology against expectations of the technology owner and stakeholders' potential usage. This evaluation can result in one of the following:

***Case 1*—**Technology performs as expected.

Action: Expand the technology to address additional needs and document the emergent qualities of the technology as it is in operations. New requirements will be developed for the next evolution of the technology.

***Case 2*—**Needs were clearly articulated and the technology falls short of expectations.

Action: Develop the correct set of requirements with stakeholders approval for the next evolution of the technology.

***Case 3*—**Needs were not clearly articulated and the technology falls short of expectations.

Action: Improve the process used for the elicitation of needs and involvement of stakeholders and then correct the definition of needs. Develop the correct set of requirements for the next evolution of the technology.

***Case 4*—**The problem space was not understood, and the needs were based on the ill-defined problem.

Actions: Improve the problem definition process and the elicitation processes. Re-evaluate the problem space and needs to ensure it is understood for the next evolution.

Technology validation for the ITD 40A technologies was performed in Phase 1 with analysis that led to developing multiple ground test activities. Once the technology was ground tested and the test data acquired, the functionality and performance of the technology were validated (assessed) against the needs, goals, and objectives as stated in the ITD 40A ORD. This analysis determined that the technologies being developed are appropriate to contribute to answering the ERA Technology Challenges. No further validation of ITD 40A is anticipated during Phase 2.

4.0 Reference Documents

NASA/SP-2007-6105 Rev 1	NASA Systems Engineering Handbook
NPD 1440.6	NASA Records Management
NPR 1441.1	NASA Records Retention Schedules
NPR 2810.1	Security of Information Technology (expired)
NPR 7120.8	NASA Research and Technology Program and Project Management Requirements
NID 7123.69	NASA Systems Engineering Processes and Requirements
NPR 8000.4	Agency Risk Management Procedural Requirements
NPR 8580.1	Implementing the National Environmental Policy Act and Executive Order 12114 (expired)

Appendix—Acronyms

ACS	Axially Controlled Stoichiometry
ASCR	Advanced Subsonic Combustion Rig
CAEP	Committee on Aviation Environmental Protection
CO	Carbon Monoxide
DOE	Design of Experiments
ERA	Environmentally Responsible Aviation
ESW	Engineering Standard Work
GE	General Electric
GIT	Georgia Institute of Technology
GRC	Glenn Research Center
GTF	geared turbofan
ICAO	International Civil Aviation Organization
IFF	Impingement Film Floatwall
ISRP	Integrated Systems Research Program
ITD	Integrated Technology Demonstration
LBO	Lean Blowout
LTO	Landing Takeoff
NASA	National Aeronautics and Space Administration
NCC	National Combustion Code
NO_x	Nitrogen Oxides
OPR	Overall Pressure Ratio
ORD	Objectives and Requirements Document
P&W	Pratt and Whitney
PSID	Pound per Square Inch Differential
R&D	Research and Development
RQL	Rich Burn, Quick- Mix, Lean Burn
SE	Systems Engineer
SOA	State-of-the-Art
TRL	Technology Readiness Level
UHC	Unburned Hydrocarbon
UTRC	United Technologies Research Center
WBS	Work Breakdown Structure