Federal Aviation Administration

AVS Research, Engineering and Development

AVS RE&D Portfolio:

Propulsion and Fuel Systems (A11B)

Research Plan: 2022- 2027

January 26, 2022

Part 1: BLI Definition and Scope

Program Area: Propulsion and Fuel Systems (A11B)

FAA Domain: Aircraft Safety Assurance

BLI Scope: Propulsion and Fuel Systems

The Propulsion and Fuel Systems Program conducts research on new and legacy aircraft propulsion systems in order to develop the technical basis for rules, policy, and guidance used for certification and continued airworthiness. A significant focus of the current research program (Operational Capabilities 1 – 3) is to reduce the threat of uncontained jet engine rotor failures. Uncontained engine failures occur when high-energy rotating components break into fragments that escape the engine case, which could affect other parts of the aircraft posing a serious safety threat to passengers and the continued operation of the aircraft. At least nine such uncontained events have occurred over the past 6 years, with one instance in which a fan blade failure resulted in the first fatality on a major US commercial flight in nearly a decade. Causes of these events vary, but generally involved some form of inherent material anomaly or in-service damage that reduced the engine's structural integrity and led to the premature rotor failure. To combat uncontained engine events, a three-prong safety strategy has been adopted consisting of research activities intended to:

(1) prevent the failure from ever happening.
(2) predict or forewarn of the impending failure to allow preventative action; and
(3) mitigate or minimize the risk and threat when failures do occur.
These research activities are described briefly here.

To prevent engine rotor failures, research is being conducted to ensure the structural integrity of critical turbine engine components through the application of higher sensitivity inspections and computational design tools that take into account the rare occurrence of anomalous manufacturing and material conditions. Current efforts are addressing material anomalies found in nickel and titanium engine alloys. To predict failures, a program will be initiated that will develop robust methodologies that can alert the flight crew of an impending engine failure by analyzing key operational parameters and exceedance of established thresholds. The alerts would allow the engine to be inspected prior to the next flight. To mitigate and minimize uncontained hazards, a research activity to develop data and analysis methods able to evaluate engine fragment impacts and minimize catastrophic risk will continue.

Additional areas of propulsion research under this BLI include Engine Health Monitoring (EHM) and Electric Propulsion under the Operational Capabilities 4 and 5, respectively.

EHM technology is used to prevent engine safety events by establishing robust health monitoring thresholds for key engine gas path health parameters such as temperatures, pressures in internal cavities and fuel/oil systems, vibration levels etc.

Electric propulsion is a new R&D area needed to address the high level of interest across the aviation industry in adopting electric propulsion technology for a variety of new and conventional aircraft designs and architectures, and to identify associated risks and design and certification considerations.

Part 2: Service/Office Research Requirements and Research Gap Analysis

1.0 Operational Capability: *Characterization and Effect of Material Defects*

Definition: Characterization and Effect of Material Defects to prevent engine uncontained rotor failures.
Sub-elements are:
1.1 Characterization and Effects of Ni Anomalies on the fatigue capability of rotors;
1.2 Characterization and Effects of Micro-Texture Regions (MTRs) on the fatigue capability of Titanium rotors, Cold Dwell Fatigue (CDF);
1.3 Development of supporting Damage Tolerance Analysis Methods, Tools and Data.

These efforts address NTSB, BEA (French NTSB) recommendations and Engine & Propeller Strategic Policy need of regulatory guidance to address these failure mechanisms. They are also in line with recommendations generated by the FAA's Engine-Aircraft Integration Safety Team (a Congressional action item).

Primary S/O: Tim Mouzakis AIR-621
Secondary S/O: Michael Gorelik AIR-600

S/O Priority: 1

Outcome: Development of regulatory guidance and implementation by the engine manufacturers into their rotor lifting systems to address Ti and Ni material anomalies, which will result in reduction of aircraft engine rotor failures as documented by the AIA Rotor Integrity Steering Committee (RISC) database.

Research Gap Analysis

Research Questions	Contribution	Research Output
1.1 What are the effects of Ni material anomalies on fatigue life of engine LLPs?	30%	This research will identify, prepare, and test specimens containing nickel material anomalies and evaluate the effects of defects on fatigue life and crack growth. Data will support AC 33.70-6, Damage Tolerance of Nickel Anomalies in High Energy Rotors and help the FAA to address NTSB recommendations.
1.2 What conditions cause cold dwell fatigue (CDF) of titanium LLPs and can its effect (debit) on fatigue life be quantified?	30%	Data and advisory material describing the conditions and effects of CDF that will help FAA address the BEA recommendations. This research will be conducted in collaboration with an ongoing USAF MAI (Metals Affordability Initiative) program on CDF.
1.3 What data and risk assessment models need to be developed and	40%	Enhanced versions of the DARWIN probabilistic design code that can analyze nickel material anomalies and titanium cold dwell fatigue of life limited engine rotors.

implemented into DARWIN s/w code to accurately characterize risk and probability of fracture of engine LLPs from nickel material anomalies and titanium CDF?		Addressing newly identified safety threats by heavily leveraging prior FAA's R&D investments.

2.0 Operational Capability: *Containment and Risk Mitigation of Uncontained Turbine Engine Failures*

Definition: Containment and Risk Mitigation of Uncontained Turbine Engine Failures
Sub-elements are:
2.1 Modeling of engine fragment impact and damage progression in metal and composite containment and aircraft structures
2.2 Uncontained Engine Debris Damage Assessment Model (UEDDAM)
2.3 Open rotor engine safety assessment (support of emerging technology)
Sub-elements 2.1 and 2.2 address NTSB recommendations to the FAA from recent uncontained engine failures.

Primary S/O: Tim Mouzakis AIR-621
Secondary S/O: Mike Dostert, AIR-624

S/O Priority: 3

Outcome: Reduction of turbine engine blade and disk uncontained failures and inlet / cowl separations as documented in Continued Airworthiness Assessment Methodologies (CAAM) Committee report of safety-significant propulsion system malfunctions.

Research Gap Analysis

Research Questions	Contribution	Research Output
2.1 Is predictive impact and damage modeling of engine blade fragment containment mature with current simulation tools and what additional capabilities need to be developed?	40%	Metal and composite material models and associated FAA technical reports for guidance. Test cases and modeling guidance developed with LS-DYNA Aerospace Working Group to ensure consistency and reliability of engine related impact modeling.
2.2 What updates to uncontained debris fragment models and the UEDDAM vulnerability analysis code are necessary?	20%	Updates of UEDDAM software to add features, improve runtimes, and include revised debris fragment models from recent events. Also, user guidance, training and associated FAA technical reports.
2.3 What technical data for open rotor blade release trajectory analysis is needed for FAA to determine certification	40%	Open rotor blade release trajectory analysis test plan, execution and report for guidance.

requirements for these new engine types?		

3.0 Operational Capability: *Improvement of NDE capabilities for life-limited engine components*

Definition: Improvement of NDE capabilities for life-limited engine components.
Sub elements are:
3.1 Improved Billet UT inspection for detection of Ni material anomalies (NTSB Rec);
3.2 Improved Nickel forging and finished parts UT inspection (NTSB Rec);
3.3 Develop effective NDE capabilities for inspection of Micro Texture Regions (MTRs) in Ti rotor-grade alloys (BEA recommendation).

Primary S/O: Tim Mouzakis, AIR-621
Secondary S/O: N/A

S/O Priority: 2

Outcome: Improved NDE methods during the manufacture and field service of critical engine rotors will more effectively detect anomalies and defects prior to failure. The expected outcome will be a reduction of engine rotor failures as documented by the AIA Rotor Integrity Steering Committee database.

Research Gap Analysis

Research Questions	Contribution	Research Output
3.1 Improved Ni Billet Inspection. What is an acceptable inspection standard for large nickel billets used by the commercial airline industry?	40%	New industry standard for inspecting Ni billet that will result in better anomalies detection capabilities and safety improvements. This research will leverage previous FAA efforts on titanium to apply higher sensitivity ultrasonic methods such as multi-zone and advanced phased arrays to Ni billet.
3.2 Improved Ni forging and finished parts UT inspection. What inspection practices for forged/finished and in-service parts are necessary and what are the best NDE practices and standards?	30%	Improved methods to inspect forgings and finished parts that will result in better anomalies detection capabilities and safety improvements.
3.3 What NDE methods are best able to detect MTRs and what standards are available or need to be developed?	30%	NDE to detect micro texture regions (MTRs) in titanium. Cold dwell fatigue is more likely to occur in titanium alloys containing MTRs. New inspection techniques to detect MTRs, and NDE guidance and standards for inspection of MTRs. This research will be conducted in collaboration with an ongoing USAF MAI program on CDF.

4.0 Operational Capability: *Engine Safety Event Prevention thru EHM (Engine Health Monitoring)*

Definition: Engine Safety Event Prevention thru EHM (Engine Health Monitoring). Methodology to establish robust safety thresholds for engine gas path health parameters, temperatures, pressures in internal cavities and fuel/oil systems, vibration levels and broadband signatures.

Primary S/O: Deepak Kamath AIR-627
Secondary S/O: N/A

S/O Priority: 4

Outcome: The safety thresholds to be used to generate alerts to enable inspection & maintenance decisions prior to the next flight, in order to prevent propagation of the unsafe condition to a hazardous or catastrophic failure in the next flight.

Research Gap Analysis

Research Questions	Contribution	Research Output
4.1 How much engine module performance deterioration can the embedded engine models and tracking filters available in the industry detect reliably; and is that capability sufficient for annunciation of internal failures (such as inter-stage seal failure) before it progresses to a hazardous or catastrophic event (turbine disk overheating and uncontained failure)?	30%	Quantitative Guidance and baseline thresholds on engine module performance parameters to detect system unsafe conditions that have the potential to progress to hazardous or catastrophic conditions for the engine and aircraft. Approach: Analyze the trends, scatter and consistency for engine gas path module health parameters (e.g. flow scalers/efficiencies for Fan/Booster, HPC, HPT, LPT) and fuel/oil system or internal cavity parameters (pressures, temperatures, contamination) for 'normal Aging' of engines. Use a sample population of recent model engines e.g. CFM Leap, PW Geared Turbofan and RR Trent 1000/XWB which have embedded engine models with tracking filters for gas path health monitoring. Establish normal statistical variation in engine gas path and fuel/oil system health parameters, analytics parametric correlations, and develop thresholds.
4.2 Can synchronous or non-synchronous vibration limits be used reliably to detect gas turbine structural issues such as bearing wear, damper degradation, wear or partial failures of seals, fuel nozzles,	30%	Quantitative Guidance and baseline thresholds on engine fan, core rotor vibration parameters for a typical engine to detect system unsafe conditions that have the potential to progress to hazardous or catastrophic conditions for the engine and aircraft. Approach: Quantify the synchronous and nonsynchronous vibration levels and signatures

blades or other gas path hardware?		for engine rotors, bearings and accessory drives in different flight phases and ambient conditions for 'normal aging and variation' of engines. Target a sample population of recent model engines e.g. GEnx, CFM Leap and PW Geared Turbofan, which have broadband vibration monitoring capability. Establish normal statistical variation in engine vibration levels and develop methodology for analytical thresholds for different phases of flight.
4.3 Can non-synchronous or synchronous vibration limits be used to detect unsafe conditions with gear boxes, drive shafts that can lead to hazardous engine or airplane effects?	30%	Quantitative Guidance and baseline thresholds on engine gear box(es) and driveshafts for a typical engine, to detect system unsafe conditions that have the potential to progress to hazardous or catastrophic conditions for the engine and aircraft. Approach: Evaluate the engine health parameter thresholds using actual field event data from FMD (Failures, Malfunction & Defects) events; and effect of simulated failures (such as interstage seal failures) on engine module performance (e.g. HPT, HPC) and turbomachinery cavity or disk space temperatures. Confirm ability to detect unsafe condition in pre-event flight and in the event flight.
4.4 Evaluate the engine health parameter thresholds using field data from normal (non failure) flights in extreme operating conditions and high time engines.	10%	Evaluate potential for false alerts.

5.0 Operational Capability: *Electric Propulsion*

Definition: Evaluate key certification considerations for electric propulsion systems, including endurance and durability assessment, development of mission spectra, and fire protection.

Primary S/O: Mark Bouyer, AIR-627
Secondary S/O: N/A

S/O Priority: 5

Outcome: Establish technical criteria for testing electric engines that are used for propulsion and control surfaces in VTOL aircraft. Develop an understanding of associated mission profiles and methods for their characterization.

Research Gap Analysis		
Research Questions	**Contribution**	**Research Output**
5.1 What necessary components can be defined for Endurance/Durability testing for electric engines used in single-engine airplanes and distributed propulsion aircraft to include the following considerations? No standard Mission Profile exists for testing for Endurance/Durability for electric engines Endurance: Exposure to limits or combination of physical limits Durability: Mechanical variation over course of flight Reliability testing for high voltage electronic systems used in electric engines that have no previous exposure to aircraft applications Safety analysis relies on demonstration, analysis, and experience Electric engines introduce new technology that involves critical hardware, software and functions with no field experience. Potential consequences of failure is rate of LOPC/LOTC, Fire, Loss of control	100%	Develop technical criteria for: High-voltage engine controls features, and physical limits associated with electric engine technology Establish technical criteria for testing electric engines that are used for propulsion and control surfaces in VTOL aircraft Develop technical criteria and simulation tools for: Research to establish, determine or verify reliability rates for safety-critical features and functions Directly related to aircraft-level safety goals Research related to Endurance/Durability testing will contribute to this research

Part 3: RE&D Management Team Programming

BLI Planning 3 Year Funding Profile (FY22-24) as of 1/28/2022

YEAR	Appropriation or Formulation Contract Funding ($)	INITIAL BLI TEAM PLANNING CONTRACT FUNDING – AFN BLI Target minus the Hold Back ($)	AVS-1 APPROVED CONTRACT FUNDING ($)
FY22 formulation or appropriation (if known)	**$955,764**		
FY23 formulation	**$3,099,803**		
FY24 AFN funding allocation target		**$1,085,481**	**$3,440,587**

BLI Plan 5 Year Outlook (FY22-27)

Complete (C)	**In Progress (IP)**	**Programmed (P)**	**Need (N)**

Research Activities	FY22	FY23	FY24	FY25	FY26	FY27
Operational Capability 1.0: *Characterization and Effect of Material Defects*						
1.1 What are the effects of Ni material anomalies on fatigue life of engine LLPs?	*IP*	*P*	*N*	*N*	*C*	*C*
1.2 What conditions cause cold dwell fatigue (CDF) of titanium LLPs and can its debit effect on fatigue life be quantified?	*IP*	*P*	*N*	*N*	*C*	*C*
1.3 What data and risk assessment models need to be developed and implemented into DARWIN to accurately characterize risk and probability of fracture of engine LLPs from nickel anomalies and titanium CDF?	*IP*	*P*	*N*	*N*	*N*	*C*
Research Activities	**FY22**	**FY23**	**FY24**	**FY25**	**FY26**	**FY27**
Operational Capability 2.0: *Containment and Risk Mitigation of Uncontained Rotor Blade Failures*						
2.1 Is predictive impact and damage modeling of engine blade fragment containment mature with current simulation tools and what additional capabilities need to be developed?	*IP*	*P*	*N*	*N*	*N*	*N*
2.2 What updates to uncontained debris models and the UEDDAM vulnerability analysis code are necessary?	*IP*	*P*	*N*	*N*	*N*	*N*
2.3 What technical data for open rotor blade release trajectory analysis is needed for FAA to determine certification requirements for these new engine types?	*N*	*N*	*N*	*C*	*C*	*C*
Research Activities	**FY22**	**FY23**	**FY24**	**FY25**	**FY26**	**FY27**
Operational Capability 3.0: *Improvement of NDE capabilities for life-limited engine components*						
3.1 What is an acceptable inspection standard for large nickel billets used by the commercial airline industry?	*IP*	*IP*	*IP*	*C*	*C*	*C*

3.2 What inspection practices for forged/finished and in-service parts are necessary and what are the best NDE practices and standards?		*P*	*N*	*N*	*N*	*N*
3.3 What NDE methods are best able to detect MTRs and what standards are available or need to be developed?	*N*	*P*	*N*	*N*	*N*	*N*
Research Activities	**FY22**	**FY23**	**FY24**	**FY25**	**FY26**	**FY27**
Operational Capability 4.0: *Engine Safety Event Prevention thru EHM (engine health monitoring)*						
4.1 How much engine module performance deterioration can the embedded engine models and tracking filters available in the industry detect reliably; and is that capability sufficient for annunciation of internal failures (such as interstage seal failure) before it progresses to a hazardous event (turbine disk overheating and uncontained failure)?	*N*	*P*	*C*	*C*	*C*	*C*
4.2 Can synchronous or non-synchronous vibration limits be used reliably to detect gas turbine structural issues such as bearing wear, damper degradation, wear or partial failures of seals, fuel nozzles, blades or other gas path hardware?	*N*	*P*	*IP*	*IP*	*C*	*C*
4.3 Can non-synchronous or synchronous vibration limits be used to detect unsafe conditions with gear boxes, drive shafts that can lead to hazardous engine or airplane effects?	*N*	*P*	*IP*	*IP*	*C*	*C*
4.4 How can engine health parameter thresholds using field data from normal (non-failure) flights in extreme operating conditions and high time engines can be used to establish the possibility of false alerts?	*N*	*P*	*IP*	*IP*	*C*	*C*
Research Activities	**FY22**	**FY23**	**FY24**	**FY25**	**FY26**	**FY27**
Operational Capability 5.0: *Electric Propulsion*						
5.1 What necessary components can be defined for Endurance/Durability testing for electric engines used in single-engine airplanes and distributed propulsion aircraft to include the following considerations?			*N*	*N*		

Part 4: BLI Team Members

Participants Name	Role	Routing Symbol
Jorge Fernandez	BLI Chair	AIR - 670
Maria DiPasquantonio	REDMT Voting Member	AIR-600
Michael Gorelik	CSTA, BLI Lead	AIR-600
Tim Mouzakis	Sponsor SME	AIR-6A1
Deepak Kamath	Sponsor SME	AIR-627
Mark Bouyer	Sponsor SME	AIR-627
Mike Dostert	Sponsor SME	AIR-6A1
Dan Cordasco	Performer SME	ANG-E282
Dave Galella	Performer SME	ANG-E282