NASA Overview: Vertical Flight Research

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Revolutionary Vertical Lift Technology

AHS Propulsion Specialists' Meeting
October 27, 2015

Topics

- **Aeronautics Research Mission Directorate Strategy and Drivers**
- **ARMD Re-structured Program and Projects**
- **Vertical Flight Applications and Opportunities**

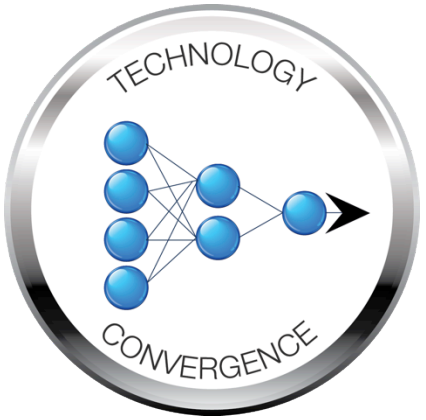
Three Aviation Mega Drivers

NASA Aeronautics research strategy proactively addressing critical long-term needs

Traditional measures of global demand for mobility - economic development and urbanization - are growing rapidly and creating transportation and competitive opportunities and challenges

Large and growing energy and environmental issues create enormous affordability and sustainability challenges

Revolutions in the integration of automation, information, communication, energy, materials and other technologies enable opportunity for transformative aviation systems



NASA Aeronautics Six Strategic Thrusts

Safe, Efficient Growth in Global Operations

- Enable full NextGen and develop technologies to substantially reduce aircraft safety risks

Innovation in Commercial Supersonic Aircraft

- Achieve a low-boom standard

Ultra-Efficient Commercial Vehicles

- Pioneer technologies for big leaps in efficiency and environmental performance

Transition to Low-Carbon Propulsion

- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

Real-Time System-Wide Safety Assurance

- Develop an integrated prototype of a real-time safety monitoring and assurance system

Assured Autonomy for Aviation Transformation

- Develop high impact aviation autonomy applications

http://www.aeronautics.nasa.gov/pdf/armd-strategic-implementation-plan.pdf

ARMD Programs Address Strategic Thrusts

Airspace Operations and Safety Program (John Cavalowsky)

Advanced Air Vehicles Program (Jay Dryer)

Safe, Efficient Growth in Global Operations

Innovation in Commercial Supersonic Aircraft

Ultra-Efficient Commercial Vehicles

Transition to Low-Carbon Propulsion

Real-Time System-Wide Safety Assurance

Assured Autonomy for Aviation Transformation

Integrated Aviation Systems Program (Ed Waggoner)

Transformative Aeronautics Concepts Program (Doug Rohn)

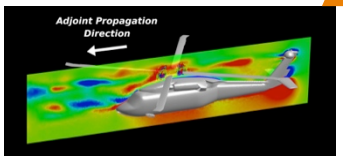
Enhancing Vertical Lift Capabilities

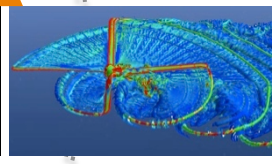
FUTURE CAPABILITIES

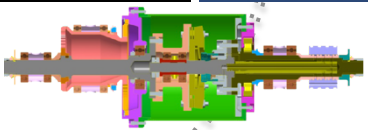
Transformative Concepts

(e.g. hybrid electric, autonomy, new concepts)

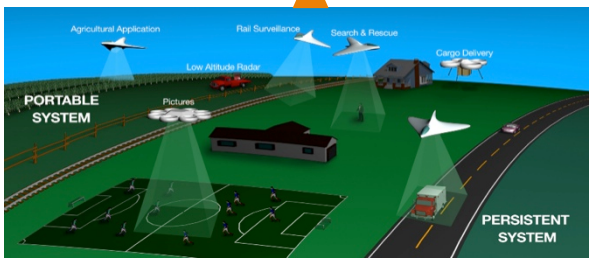
Research focus in Subsonic Rotary Wing and Rotary Wing Projects (2006–2014)







Revolutionary Vertical Lift Technology Project (2015+)
Innovative technologies, tools & concepts (e.g. low noise, efficient propulsion, & optimization technologies)



Unmanned Traffic Management System

- Key to safely opening new markets
- Important de-confliction with existing vertical flight

ARMD Programs/Projects With Possible Application to Vertical Lift

Airspace Operations and Safety Program

- Airspace Technology Demonstrations
- Shadow Mode Assessment in NAS
- Safe Autonomous Systems Ops
- UAS Traffic Management

Advanced Air Vehicles Program

- Aeronautics Evaluation and Test Capabilities
- Advanced Air Transport Technology
- Advanced Composites
- Commercial Supersonic Technology
- Revolutionary Vertical Lift Technology

Integrated Aviation Systems Program

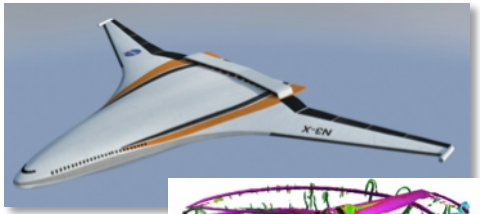
- Environmentally Responsible Aviation
- UAS in the National Airspace System
- Flight Demonstrations and Capabilities

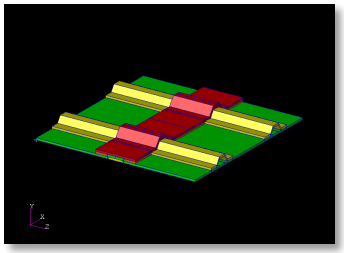
Transformative Aeronautics Concepts Program

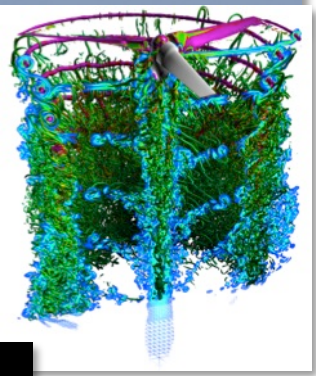
- Convergent Aeronautics Solutions
- Transformative Tools and Technologies
- Leading Edge Aero Research for NASA (LEARN)

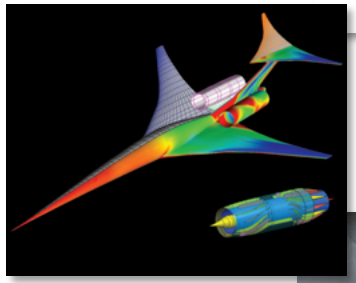
Advanced Air Vehicles Program

Cutting-edge research that will generate innovative concepts, technologies, capabilities & knowledge to enable revolutionary advances for a wide range of air vehicles.









Advanced Air Transport Project (AATT) Conducts fundamental research to improve aircraft performance and minimize environmental impacts from subsonic air vehicles

Revolutionary Vertical Lift Technology Project (RVLT) Develops and validates tools, technologies & concepts to overcome key barriers, including noise, efficiency, & safety for vertical lift vehicles

Advanced Composites Project (AC) Conducts research to reduce the timeline for development and certification of composite structures for aviation

Commercial Supersonics Technology Project (CST) Develops tools and explores concepts for potential advanced capabilities & configurations for low boom supersonic aircraft.

Aeronautical Evaluation & Test Capabilities Project (AETC) Ensures the strategic availability, accessibility, & capability of a critical suite of aeronautics ground test facilities to meet Agency & national aeronautics testing needs

NASA Aeronautics Vertical Lift Propulsion Investment

- **Revolutionary Vertical Lift Technology (~$6.5M)**
  - Advanced Variable Speed Power Turbine
  - High Efficiency Gas Generators
  - Two-speed/variable Transmission Technology
  - Advanced Drive System Technology
  - Hybrid (composite/metal) drive system components
  - Condition Based Maintenance
  - Conceptual Design Tool for Propulsion Systems
- **Design Environment for Novel Vertical Lift Vehicles (DELIVER) (~$1M)**
  - Conceptual design tools for small and non-conventional vertical lift vehicle trades
- **Advanced Air Transport Technology (~$2M)**
  - Evaluation of Alternative Fuels (ACCESS)
  - Electric Motor Power Density
  - Hybrid-Electric Propulsion systems

Revolutionary Vertical Lift Technology Project

Develop and Validate Tools, Technologies and Concepts to Overcome Key Barriers for Vertical Lift Vehicles

Vision

- *Enable next generation of vertical lift vehicles with aggressive goals for efficiency, noise, and emissions to expand current capabilities and develop new commercial markets*

Scope

- *Technologies that address noise, performance, efficiency, safety, community acceptance and affordability*
- *Conventional and non-conventional very light, light, medium, heavy and ultra-heavy vertical lift configurations*

NASA Vertical Lift Project Research Areas

Ames Research Center

- Aeromechanics
- Computational Methods
- Flt Dyn & Ctrl
- Experimental Capability
- System Analysis
- Autonomy

Glenn Research Center

- Drive Systems
- Engines
- Hybrid Electric Systems
- Icing
- System Analysis
- Condition Based Maintenance

Langley Research Center

- Acoustics
- Aeromechanics
- Experimental Capability
- Computational Methods
- Crashworthiness
- Autonomy

- *Typical NASA research is TRL 1-5, sometimes 6*
- *Typical NASA products are feasibility studies, technology demonstrations, research reports*
- *Partnerships enable faster technology transition to DoD and industry*

RVLT Project Areas of Investment, FY15

Multi-Speed Propulsion

Variable-Speed Turboshaft Engines
- Variable-speed power turbine
- High-efficiency gas generators

Multi-Speed Lightweight Drive Systems
- Advanced gearbox components and configurations
- Variable-speed transmission
- Condition based maintenance

Multi-Disciplinary Design, Analysis, and Optimization

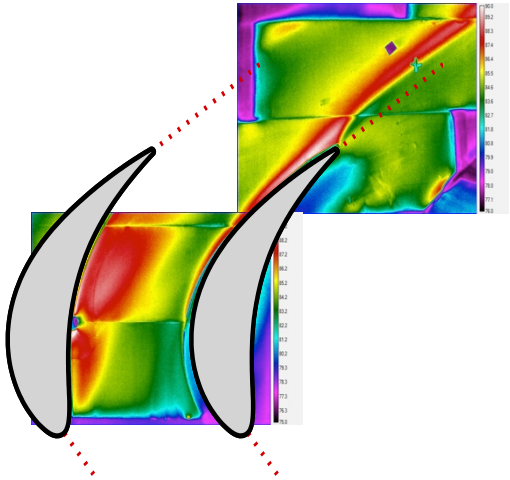
Validated Multi-Disciplinary Design Tools
- High-fidelity modeling
- Conceptual design and sizing tools
- Experimental validation and methods

Optimization Environment for Conceptual Design
- OpenMDAO framework

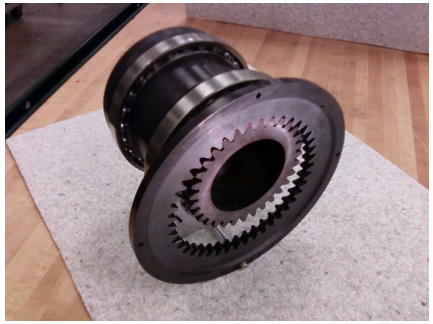
Safe and Certifiable VTOL Configurations

Low Noise Optimized Rotor
- Acoustics
- Aeromechanics and Rotor Performance

Safety and Environment
- Impact Dynamics
- Community Noise and Response
- Icing

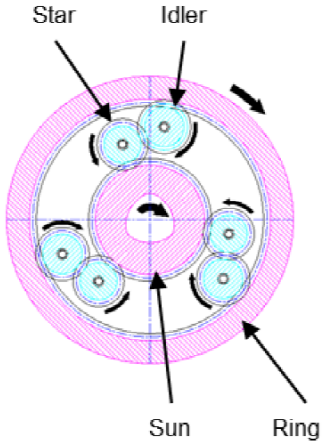


Sample IR Thermography Images from Heated Endwall with Inlet Flow Angle, β_1 = 40.0°. NASA in-house measurements.



Offset Compound Gear

Dual Star-Idler Gear Arrangement



Variable Speed Power Turbine Tech Demo

Objective

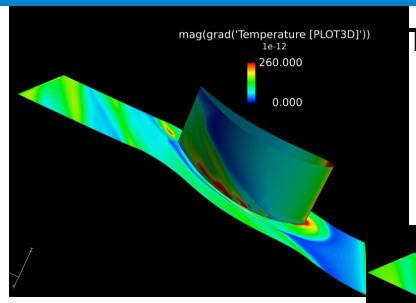
Demonstrate 50% improvement in efficient operational capability using a Variable Speed Power Turbine concept

Technical Areas and Approaches

- Aerodynamics research: high-efficiency turbine component design for a wide-range of incidence angle variation; efficient turbine operation at low Reynolds number; reduce wake-induced unsteadiness
- Rotordynamics research: address mechanical challenges resulting from variable shaft speeds
- Component test: In partnership with Army and industry, demonstrate VSPT rig at flight Mach and Reynolds number conditions to advance technology to TRL 4

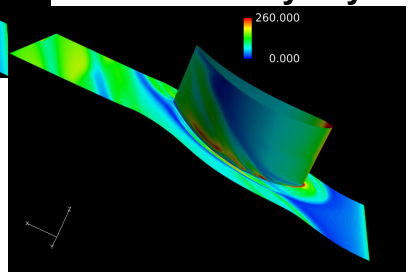
Benefit/Pay-off

- Dramatic improvement in speed capability & efficiency of conventional, compound, & tiltrotor configurations
- Enables fuel-efficient commercial rotorcraft concepts with flight speeds required for insertion in the NextGen airspace
- Provides data for next-generation engine technology

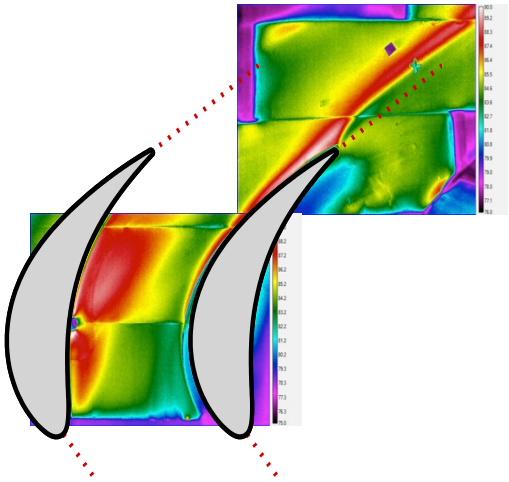


Thin Boundary Layer

Thick Boundary Layer



Blade heat transfer, low turbulence. NASA in-house calculations.



Sample IR Thermography Images from Heated Endwall with Inlet Flow Angle, β_1 = 40.0°. NASA in-house measurements.

NASA In-House VSPT Research

PROBLEM Current power turbines are designed for single operating speed, and performance degrades rapidly as power turbine speed decreases.

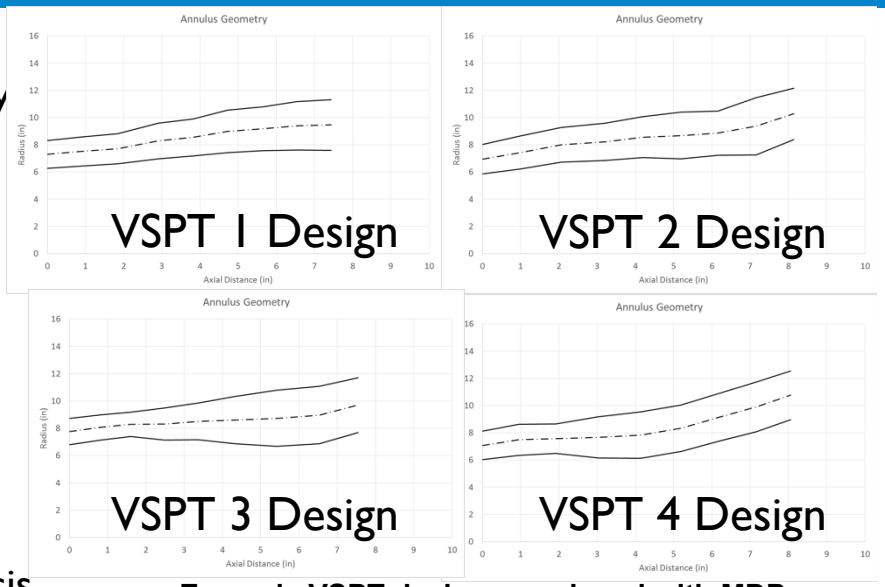
OBJECTIVES Demonstrate 50% improvement in efficient operational capability using a Variable Speed Power Turbine concept

APPROACH Conduct R&D required to advance the technology readiness level of VSPT technology to TRL 4

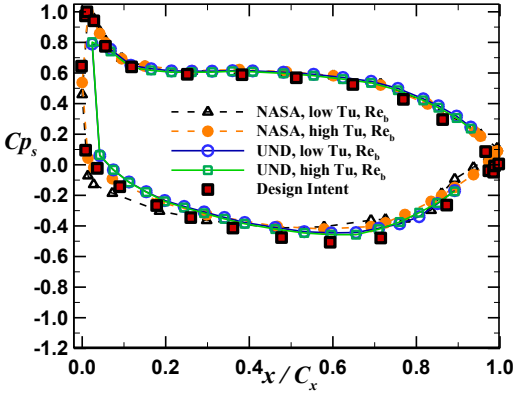
ACCOMPLISHMENTS

- Enhanced the Object-Oriented Turbomachinery Analysis Code (OTAC), created complete turbine performance maps, and developed a multi-design point (MDP) method to design turbines which satisfy performance requirements at several different operating conditions
- Evaluated an in-house code for capturing transition
- Obtained IR data at five VSPT flow conditions.
- Documented benchmark quality dataset for VSPT-relevant incidence-tolerant blading at engine relevant *M*, *Re*, *Tu*

SIGNIFICANCE More robust design and analysis tools will contribute to the design of advanced VSPT technology



Example VSPT designs produced with MDP which satisfy power requirements at 5 different operating conditions



VSPT blade loading – NASA and U North Dakota high and low inlet turbulence intensity (*Tu*) loading compared to design intent

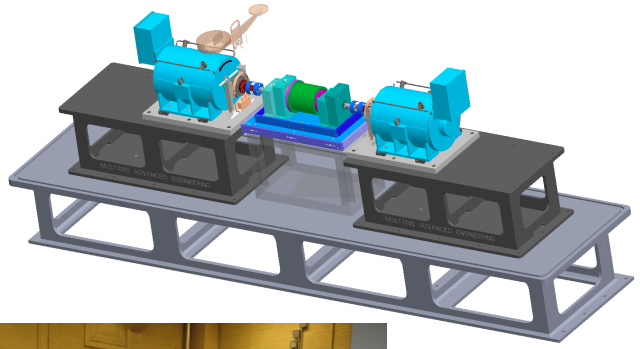
Two-Speed Drive System Tech Demo

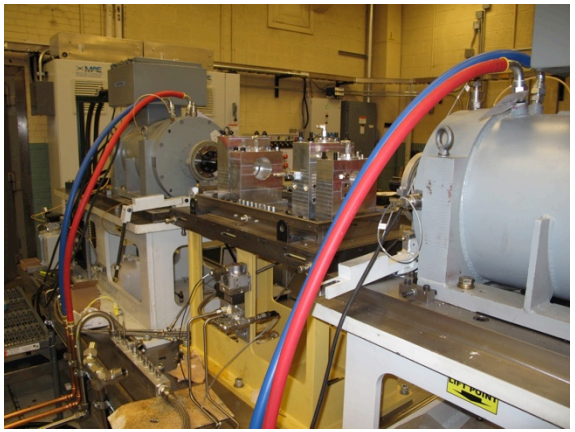
Objective

Demonstrate two-speed drive system with less than 2% power loss while maintaining current power-to-weight ratios

Technical Areas and Approaches

- Design and test viable concepts for a two-speed drive transmission configuration
  - Develop a unique facility to test scaled transmission configurations
- Evaluate new technologies to reduce system weight, losses and cost – e.g., hybrid metal/composite gears, health monitoring, operation under loss of lubrication, windage





Variable Speed Transmission Test Rig

Benefit/Pay-off

- Improved rotorcraft aerodynamics performance, empty weight fraction and safety
- Demonstration of innovative multi-speed drive system designs
- Development & demonstration of advanced drive system components and technologies
- Improvement in maintenance & operational costs

Hybrid bull gear (10" diameter) to be tested in realistic environment

Two-Speed Dry-Clutch Transmissions Evaluated

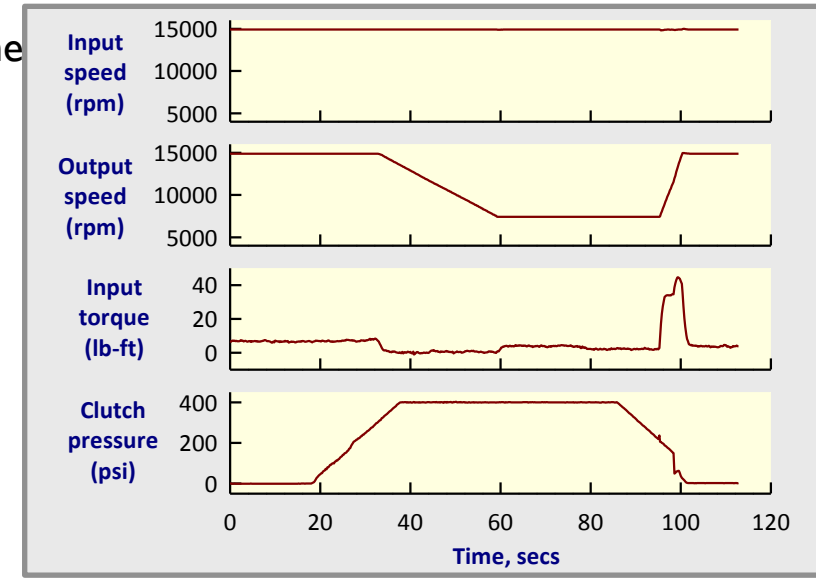
PROBLEM Next generation vertical lift vehicles will need the capability to vary main rotor rpm by as much as 50%

OBJECTIVE Demonstrate a transmission concept that can shift speed by 50% while transmitting high torque

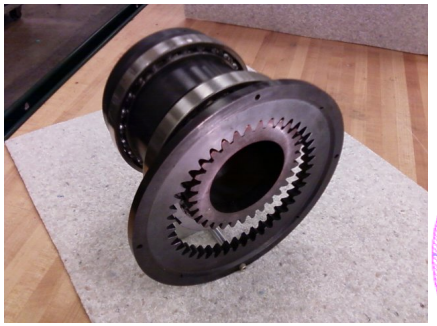
ACCOMPLISHMENTS

- The NASA-patented Offset Compound Gear (OCG) two-speed transmission successfully completed sample shifting scenarios (up-shift and down-shift) of 50% at full operating speed
- The NASA-patented Dual Star-Idler (DSI) two-speed transmission successfully completed sample shifting scenarios (up-shift and down-shift) of 50% at full operating speed
- Wet clutch system designed and fabricated to address issues
- Lessons learned were thoroughly documented and published

SIGNIFICANCE Promising OCG and DSI concepts for advanced drive systems were tested using NASA's new variable-speed transmission test facility. Several issues were uncovered that point the way to further improvements using a wet clutch design based on the OCG. The wet clutch system will be tested in FY16.



Example: 50% speed shift data. Representative of both OCG and DSI.



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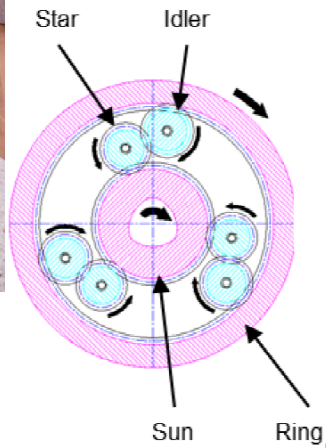
Dual Star-Idler Gear Arrangement



Enhanced Loss-of-Lubrication Technology

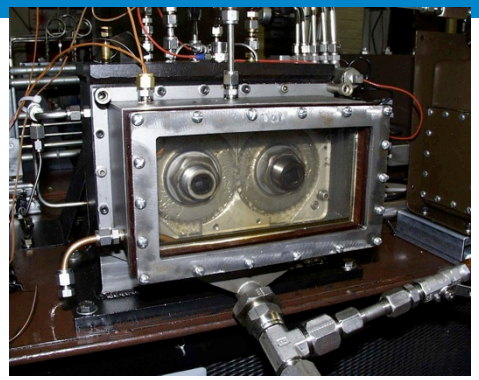
PROBLEM Unpredictable loss-of-lubrication behavior can drive qualification time and cost.

OBJECTIVES Conduct loss-of-lubrication simulation testing within an aerospace drive system environment to empirically determine the effects of materials, design, and operating conditions on the capability of the test spur gears to operate until gear tooth failure (loss of torque).

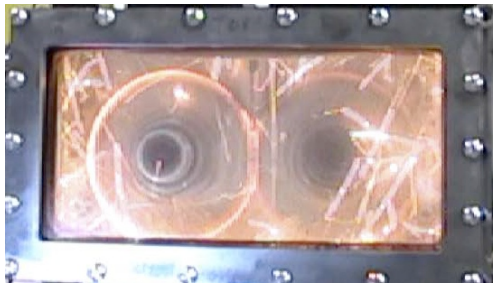
ACCOMPLISHMENTS

- Completed phase I screening process to determine initial material effect on loss-of-lubrication performance (more tests of each material necessary to validate current time to failure)
- Conducted instrumented gear (thermocouples) test in normal and loss-of-lubrication mode (NASA TM-2014-218396 Published October 2014; AHS Forum 71 paper)
- Phase II testing is on-going to determine behavior of different gear designs and hybrid gear configurations
- Work in collaboration with the Army Research Laboratory on-going to determine lubricant, additive, and other approaches to improve loss-of-lubrication behavior

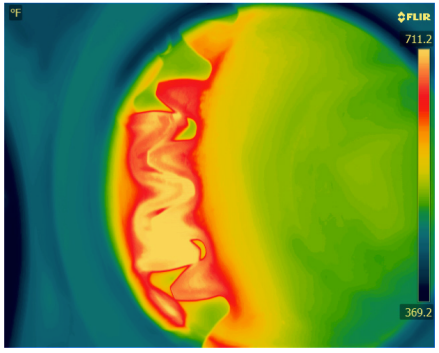
SIGNIFICANCE NASA's experimental efforts are determining best practices to improve loss-of-lubrication behavior at the design stage. Information gathered from instrumented gears useful for gear material choice, model development and model validation.



Spur gear test facility



Loss-of-lubrication test during final seconds of operation



Thermal image of unshrouded gear near test completion.

Condition Based Maintenance (CBM)

PROBLEM The FAA developed Advisory Circular AC-29-2C to provide guidance in the validation of rotorcraft Health Usage Monitoring System (HUMS) for maintenance credits - modified inspection and removal criteria of components based on HUMS. Component fault testing is one method of validation.

OBJECTIVES

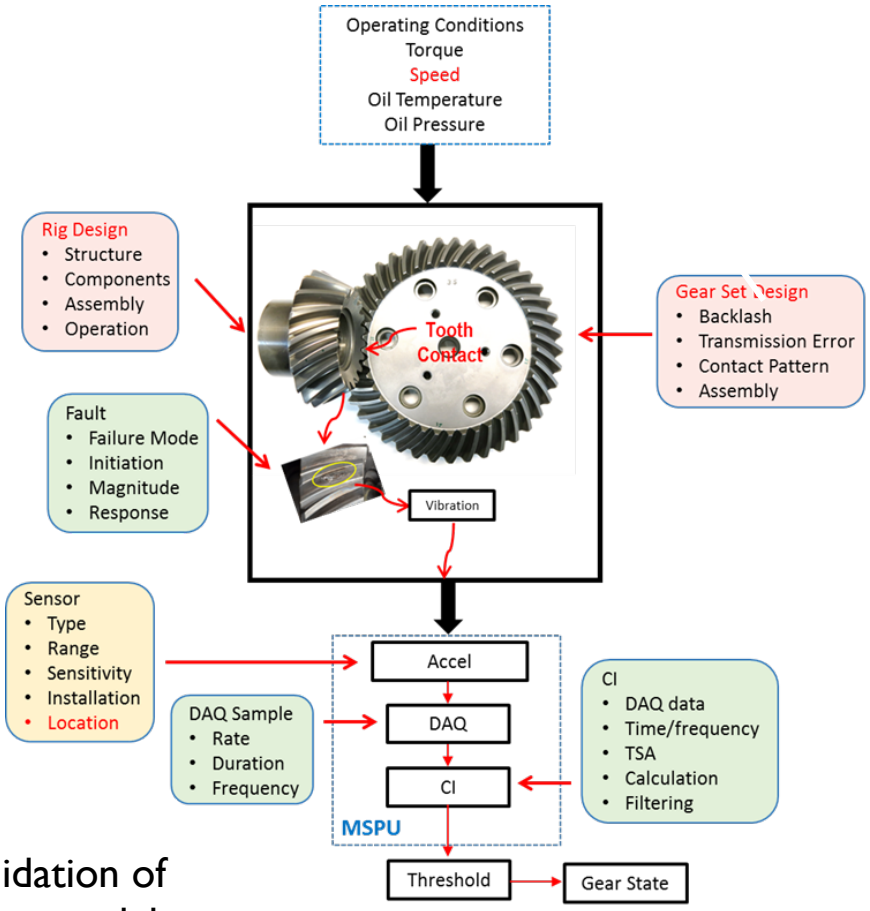
- Develop HUMS validation methods in test rig to represent fielded faults
- Identify limitations awarding maintenance credits using test rig fault tests

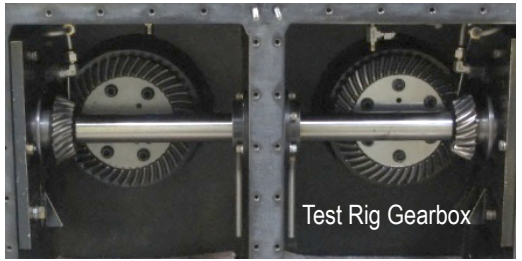
ACCOMPLISHMENTS

- Completed failure progress testing on 36 gear sets, creating a database of HUMS data correlated to operational data and gear tooth damage mode and degree

SIGNIFICANCE

- Rig test data used by DOD, academia and industry for validation of new gear health indicators and developing prognostic failure models
- Analysis of rig and helicopter data used to update US Army Aeronautical Design Standards, SAE and ASTM Standards.
- Results will be used to update the FAA (AC) 29–2C as it relates to rig fault tests





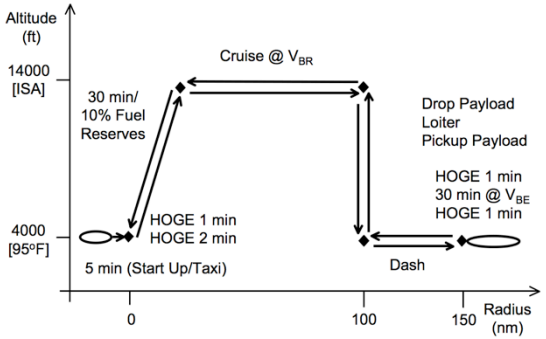
Design Environment for Novel Vertical Lift Vehicles (DELIVER)

DELIVER is a sub-project under the new Transformative Aeronautics Capability (TAC)/ Convergent Aeronautics Solutions (CAS) project

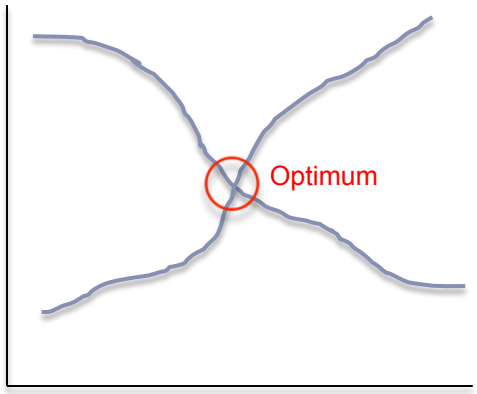
TAC/CAS sub-projects look at feasibility of an idea for a short amount of time (~2-3 years) with a low level of resources. After feasibility is assessed, the work either stops or transitions to a new funding source.

The foundation of the DELIVER feasibility assessment is to determine if an integrated design environment can capture the design trades needed for novel (unconventional, small, and/or alternative propulsion) vertical lift vehicles.

Current emphasis in 3 areas: noise models, hybrid-electric propulsion models, and autonomy models for mission and operational capability



Trade-space of vehicle options for mission requirements



Analysis of trade-offs in vehicle and mission performance

Advanced Air Transport Project (AATT)

AATT Goal: Explore and Develop Technologies and Concepts for Improved Energy Efficiency and Environmental Compatibility for Fixed Wing Subsonic Transports

Hybrid gas electric propulsion technical areas

Propulsion System Conceptual Design

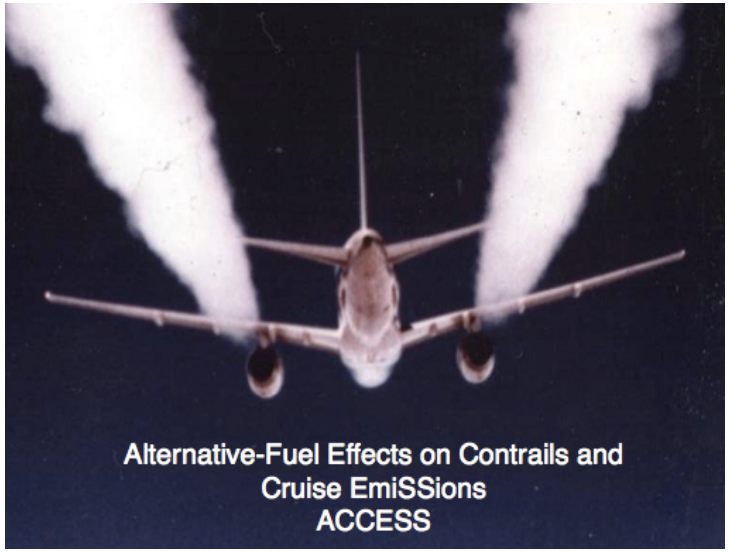
– System concepts for assessment of benefits

High Efficiency/Power Density Electric Machines

– Explore conventional and non-conventional topologies
– Integrate novel thermal management
– Advance development of component materials

Flight-weight Power System

– High power electric grid definitions, modeling, simulation
– High voltage power electronics, transmission, protection
– Materials development for lightweight power transmission
– Management & distribution for distributed propulsion



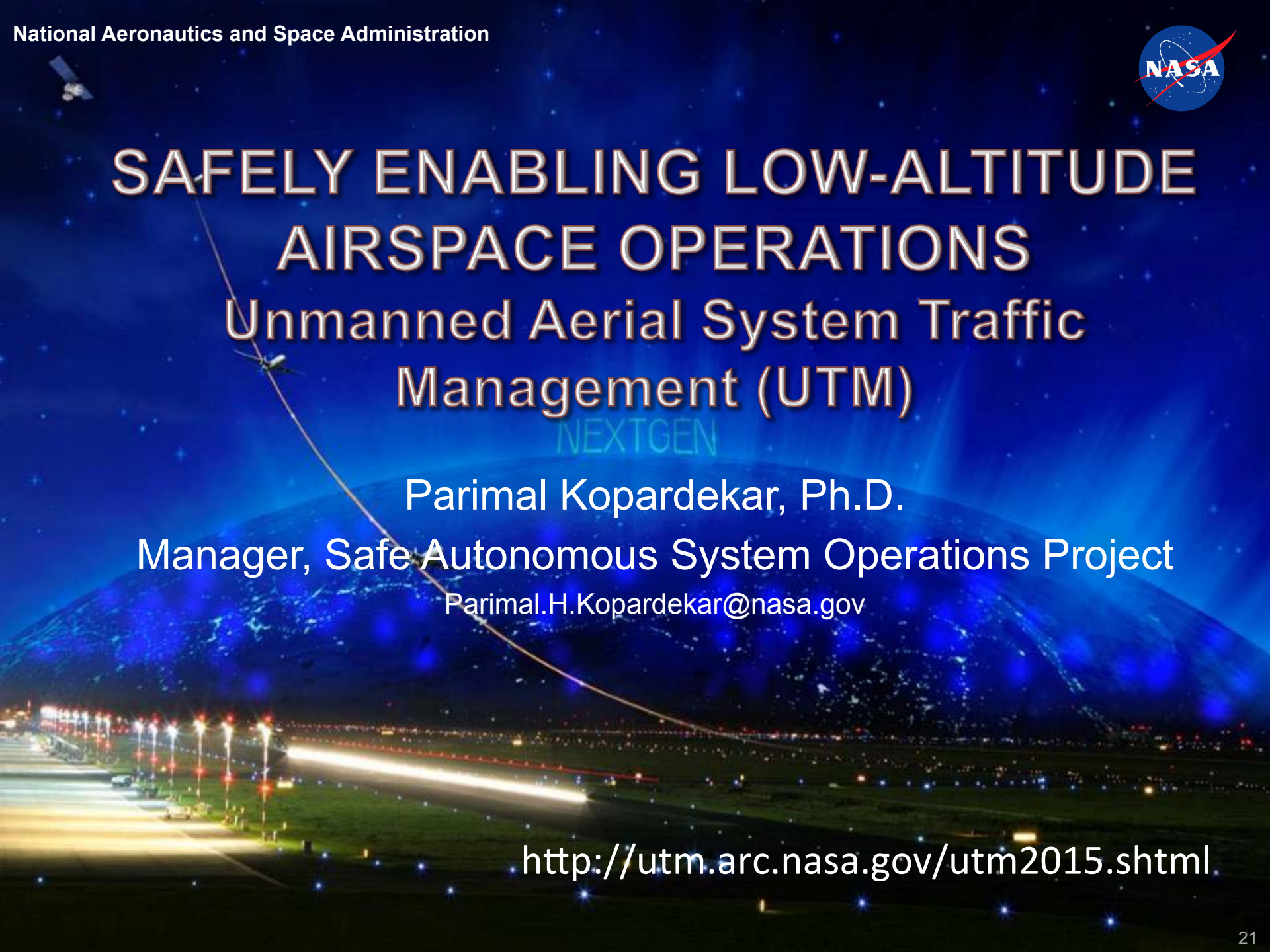
Integrated Subsystems

– Component interactions – validate performance & matching at steady-state and transient operation

Alternative fuels research to reduce the impact of aviation on air quality and climate and quantify their impact on performance

Participated in multi-partner Alternative-Fuel Effects on Contrails and Cruise EmiSSions (ACCESS) using DC-8 test aircraft with several sampling aircraft

http://www.nas.nasa.gov/assets/pdf/ams/2015/AMS_20150521_DelRosario.pdf



SAFELY ENABLING LOW-ALTITUDE AIRSPACE OPERATIONS

Unmanned Aerial System Traffic Management (UTM)

Parimal Kopardekar, Ph.D.

Manager, Safe Autonomous System Operations Project

Parimal.H.Kopardekar@nasa.gov

http://utm.arc.nasa.gov/utm2015.shtml

NASA/RVLT Research Approach

Three main paths to accomplish research:

- NASA in-house research
- Research with partners (Other Government Agencies, Industry, Universities)
- Sponsored research proposals through NASA Research Announcement (NRA); SBIR; other contracts

Glenn Research Center

NASA AMES Platinum Jubilee

NASA Langley 90th Anniversary

U.S.ARMY

DARPA

A&P Technology Joby
Pratt & Whitney Sikorsky Cobham
Launchpoint UTRC FAA
Boeing Bell ES Aero CDI
ONERA DLR NLR GE MTI
Sukra Helitek ISSI GTRI

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UNIVERSITY OF MARYLAND 18 56

Recent SBIR Activities

Title/ Performer	Year/Phase
Small VTOL UAV Acoustics Measurement and Prediction, Continuum Dynamics, Inc., 14-1-A3.06-9430 LaRC	2014 Phase 1
Validated Design and Analysis Tools for Small Vertical-Lift Unmanned Air Vehicle Noise Prediction, Delta Group International, LLC., 14-1-A3.06-8620 LaRC	2014 Phase 1
Hybrid-Electric and All-Electric Rotorcraft Analysis and Tool Development, Empirical Systems Aerospace, Inc., 14-1-A3.06-9367 ARC	2014 Phase 1
Hybrid Electric Propulsion System for a 4 Passenger VTOL Aircraft, LaunchPoint Technologies, Inc., 14-1-A3.06-9495 GRC	2014 Phase 1
A Computational Tool for High Advance Ratio Configurations, Sukra Helitech, Inc., 14-1-A3.06-8898	2014 Phase 1
Adaptive Liners for Broadband Noise Reduction, Cornerstone Research Group, Inc., A3.02-9830	2014 Phase 2
Hybrid-Electric Rotorcraft Tool Development, Propulsion System Trade Space Exploration, and Demonstrator Conceptual Design, Empirical Systems Aerospace, Inc., A3.06-9367	2014 Phase 2
Hybrid Electric Propulsion System for a VTOL/Multirotor Aircraft, LaunchPoint Technologies, Inc., A3.06-9495	2014 Phase 2
High Fidelity Prediction and Experiment of Small Multi-Rotor VTOL UAVs, Bain Aero LLC, A1.06-9364	2015 Phase 1
Non-Contact Magnetic Transmission For Hybrid/Electric Rotorcraft, LaunchPoint Technologies, Inc., A1.06-9338	2015 Phase 1
Vertical Lift by Series Hybrid Power, Aurora Flight Sciences Corporation, A1.06-9851	2015 Phase 1

External Opportunities

Leading Edge Aeronautics Research for NASA (LEARN) Fund for Non-NASA Researchers

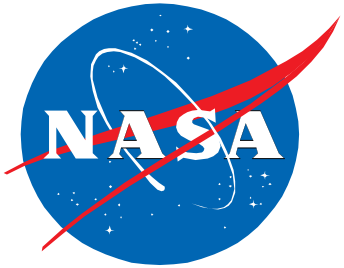
- **http://nari.arc.nasa.gov**

NASA ARMD Research Opportunities in Aeronautics (ROA 2015)

- **http://www.aeronautics.nasa.gov/nra.htm**

Summary

- NASA Aeronautics Research Mission Directorate has restructured to implement a forward-looking Strategic Plan
- Vertical lift flight research is integrated into projects as appropriate, with RVLT still the largest single investment in vertical lift
- On-going efforts in
  - Efficient Turbomachinery
  - Advanced Drive Systems
  - Hybrid Electric Propulsion
  - Alternative Fuels
- Opportunities for collaboration and innovation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