



# An Overview of 2014 SBIR Phase I and Phase II Air-Breathing Propulsion

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# **An Overview of 2014 SBIR Phase I and Phase II Air-Breathing Propulsion**

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## **Abstract**

NASA's Small Business Innovation Research (SBIR) program focuses on technological innovation by investing in development of innovative concepts and technologies to help NASA mission directorates address critical research needs for Agency programs.

This report highlights nine of the innovative SBIR 2014 Phase I and Phase II projects that emphasize one of NASA Glenn Research Center's six core competencies—Air-Breathing Propulsion. The technologies cover a wide spectrum of applications such as development of X-ray computed tomography (CT) imaging method for the measurement of complex 3D ice shapes, phased array techniques for low signal-to-noise ratio wind tunnels, compact kinetic mechanisms for petroleum-derived and alternative aviation fuels, and hybrid electric propulsion systems for a multirotor aircraft. Each featured technology describes an innovation, technical objective, and highlights NASA commercial and industrial applications.

This report provides as an opportunity for NASA engineers, researchers, and program managers to learn how NASA SBIR technologies could help their programs and projects, and lead to collaborations and partnerships between the small SBIR companies and NASA that would benefit both.

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<sup>1</sup> Lewis' Educational and Research Collaborative Internship Project (LERCIP).





# Development of X-ray Computed Tomography (CT) Imaging Method for the Measurement of Complex 3D Ice Shapes

## *A non-intrusive method of measurement*

When ice accretes on a wing or other aerodynamic surface, it can produce extremely complex shapes. The development of larger ice shapes is generally believed to be influenced or built up from smaller scale surface structures. It is important to characterize the geometries of these ice shapes, not only to ensure an adequate representation of the geometry for subsequent aerodynamic effects studies but also to provide data to validate icing codes, understand the basic physics involved with the ice accretion, and provide a basis for modeling the ice accretion. To address the above issue, Spectral Energies proposes to use an X-ray computed tomography (CT) imaging method to demonstrate that X-ray CT scanning can be used to measure 3D ice features. Spectral Energies also proposes to conduct a preliminary trade/design analysis to establish directions for a more detailed Phase II study that would address specific recommendations to integrate X-ray CT imaging with icing wind tunnels.

## Applications

### NASA

- ▶ Characterize and measure complex 3D ice shapes
- ▶ Use for measurement of ice shapes at NASA Glenn's icing wind tunnels

### Commercial

- ▶ Characterize complex 3D wing icing, engine icing, and icing for commercial testing facilities



## Phase I Objectives

- ▶ Demonstrate that X-ray CT scanning can be used to visualize surface and internal features in ice that are consistent with aircraft ice accretion
- ▶ Assess the visualization of those features in the presence of "obstructing" materials
- ▶ Provide a preliminary assessment of the feasibility of X-ray CT methods for use with NASA and other icing tunnels

## Benefits

- ▶ Fully visualize complex 3D shapes including 3D features of ice
- ▶ Non-intrusive method
- ▶ Can generate data sets that can be used for numerical simulations

## Firm Contact

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Proposal number: A1.02-8970

# UAS Power Amplifier for Extended Range of Non-Payload Communication Devices

*Combining unmatched power efficiencies with linear amplifier performance to support a variety of RF communication data links and waveforms.*

The high-efficiency and linear UPEND RF C-band power amplifier was designed, simulated and partially prototyped in Phase I to provide range extension for the NASA/Rockwell Collins Control and Non-Payload Communication (CNPC) data link. In Phase II NuWaves will address the needs of both amplitude-modulated and constant-envelope waveforms by developing multiple MMICs and packaging them together as needed. Separate die will be fabricated for the Doherty amplifier and the linearizer circuits, wire bonded and packaged into two different component-level integrated circuits – one with and one without the linearizer. Two different connectorized PA module variants will be developed using these two component-level ICs, adding the necessary power supply circuitry, supporting circuitry, and mechanical and thermal design to address different NASA and commercial market needs.

## Applications

### NASA

- ▶ Non-payload command and control for UAS in the context of NAS integration
- ▶ UAS payload communications (video and sensor data)
- ▶ Telemetry, tracking, and telecommand
- ▶ Deep-space communications
- ▶ Synthetic Aperture Radar (SAR)
- ▶ Airborne weather radar systems

### Commercial

- ▶ Unmanned systems command and control and payload communications
- ▶ Terrestrial and airborne tactical communication radios
  -
- ▶ Broadcast communications, such as television camera-mounted data links
- ▶ Telemetry and training systems
- ▶ SAR



## Phase II Objectives

- ▶ Design, develop, prototype and test:
  - 1) A high-efficiency linear C-band PA for amplitude-modulated waveforms
  - 2) A high-efficiency C-band PA for constant-envelope waveforms
- ▶ Transition the initial MMIC design into two die, one of which will be integral in both PA variants, the other of which will be incorporated into the linear PA only.

## Benefits

Range extension for wide variety of systems and platforms due to extremely low size, weight and power (SWaP), broad power supply range

- ▶ Optional bidirectional circuitry for half-duplex / time division duplex (TDD) data link support
- ▶ Scalable to higher frequencies such as X-, Ku-, K-, and Ka-bands

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Proposal number: A2.01-9239

# Advanced Technology MEMS-based Acoustic Array

The Interdisciplinary Consulting Corporation (IC2) in collaboration with the University of Florida proposes the development of large-channel count, high-density, relatively-inexpensive directional microphone arrays for noise source measurement using microelectromechanical systems (MEMS) based piezoelectric microphones and advanced packaging technology. The goal of this research is to develop an advanced phased-array technology to revolutionize array measurement capabilities within economic viability constraints. Specifically, this array technology will be developed to "Phased array and acoustic holography techniques to measure source noise in low signal-to-noise ratio wind tunnel environments." as per Subtopic A3.02 Quiet Performance of the NASA FY 2014 SBIR/STTR Solicitation. This work is aimed at meeting the aerospace industries' need for economically viable array technology that meets required performance metric. MEMS-based piezoelectric microphones are proposed which will enable compact, high-density acoustic arrays. The approach is designed from the ground-up to leverage mass-producible microphones, electronics and packaging to fully enable future commercial production. The end result is a development path towards a high-density, high-channel count, fully integrated, acoustic array realized in a cost-effective production-ready architecture. The work plan involves a two stage development process that will lead to a number of stand-alone products. A prototype, single-package, microphone will be developed to demonstrate the performance of individual channels in an array. A large number of prototype microphones will be integrated into a hybrid array to compare to existing arrays based on industry standard, research-grade microphones used in wind tunnel testing. The commercialized production techniques used in the hybrid array will be leveraged to develop an integrated array to demonstrate high-density microphone array placement.

## Applications

### NASA

- ▶ Wind tunnel instrumentation for phased-array beamforming to enable noise source localization
- ▶ Ground and flight testing environments
- ▶ Support for multiple NASA GRC facilities such as:
  - Aero-Acoustics Propulsion Laboratory
  - Small Hot Jet Acoustic Rig
  - Nozzle Acoustic Test Rig
  - Advanced Noise Control Fan Rig

### Commercial

- ▶ Wind tunnel instrumentation for phased-array beamforming to enable noise source localization on commercial aerospace components
- ▶ Ground and flight testing of commercial aircraft
- ▶ Monitoring acoustic dose for OSHA standards for:
  - Condition based maintenance
  - HVAC systems
  - Gas turbine power plants
  - Automotive industry



## Phase I Objectives

- ▶ Design microphone using formal optimization
- ▶ Identify commercial foundries to fabricate microphone
- ▶ Develop packaging technology and package several prototype devices
- ▶ Characterize device
- ▶ Identify commercial packaging houses to package microphones
- ▶ Prototype deployment to NASA centers and industry customers

## Benefits

- ▶ Dramatic reduction of cost per channel, which allows for larger channel counts
- ▶ Increased dynamic range required for low SNR wind tunnels
- ▶ Greater flexibility in array placement in wind tunnels
- ▶ Enables access to high fidelity arrays for an expanded base of researchers

## Firm Contact

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# Phased Array Technique for Low Signal-to-Noise Ratio Wind Tunnels

## *A testing method for UAV noise measurements*

Noise measurement of aerospace vehicles is difficult and usually requires expensive, specialized facilities. With the proliferation of UAVs there is a need for noise data, both for ISR and non-military vehicles. Wind tunnel testing is common and much less expensive. The innovation is a novel in-flow microphone array combined with the state of the art Functional Beamforming algorithm that makes it practical to measure UAV noise in a non-acoustic wind tunnel.

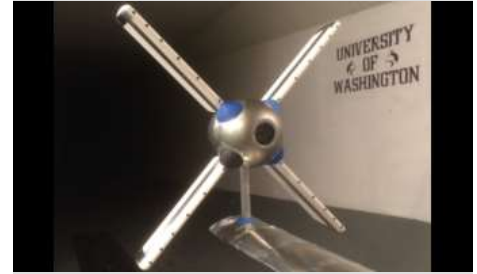
### Applications

#### NASA

- ▶ Noise measurement in acoustic and non-acoustic wind tunnels, including but not limited to:
  - AACL at NASA Glenn
  - 9-by-15 wind tunnel at NASA Glenn
  - NFAC at NASA Ames

#### Commercial

- ▶ Noise measurement testing for organizations such as:
  - UAV manufacturers
  - Northwest UAV
  - Air Force
  - Navy



### Phase II Objectives

- ▶ Determine the measurement noise floor of the wing array design in a representative non-acoustic wind tunnel as a function of frequency
- ▶ Determine the measurement noise floor of a wall array design in a representative non-acoustic wind tunnel as a function of frequency
- ▶ Evaluate both array types for representative UAV noise sources
- ▶ Construct and test arrays in Kirsten Wind Tunnel
- ▶ Perform in-situ calibration

### Benefits

- ▶ Decreased cost
- ▶ Possible to measure UAV noise in a non-acoustic wind tunnel

### Firm Contact

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Proposal number: A3.02-9794

# Compact Kinetic Mechanisms for Petroleum-Derived and Alternative Aviation Fuels

*A model for replication of specific real fuel combustion kinetic behavior*

To be useful for computational combustor design and analysis using tools like the National Combustion Code (NCC), low-dimensional chemical kinetic mechanisms for modeling of real fuel combustion chemistry must be sufficiently compact so that they can be utilized in multi-dimensional, multi-physics, reacting computational fluid dynamics (CFD) simulations. Despite advances in CFD-appropriate kinetic mechanism reduction for kerosene-range fuels, significant combustion property variation among current and prospective certified fuels remains a challenge for meaningful CFD-advised design of high pressure, low-emissions combustors. The proposed project will leverage Princeton's ongoing work in aviation fuel surrogate formulation and modeling as well as kinetic mechanism development for emissions and high pressure combustion to produce and demonstrate a meta-model framework for automated generation of fuel-flexible compact chemical kinetic mechanisms appropriate for 3-D combustion CFD codes.

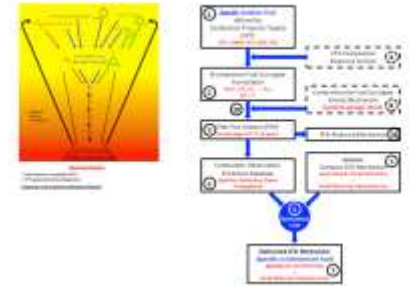
## Applications

### NASA

- ▶ Computational design of low-emissions, efficient combustors via NCC and other codes
- ▶ Physics-based CFD development of next-generation engines
- ▶ Reacting flow simulation platforms such as NASA's National Combustion Code

### Commercial

- ▶ Noise measurement testing for organizations such as:
  - UAV manufacturers
  - Northwest UAV
  - Air Force
  - Navy



## Phase II Objectives

- ▶ Develop a stand-alone software application for generation of tailor-made, fuel-specific compact mechanisms
- ▶ Demonstrate compact mechanism performance in computation-intensive CFD applications

## Benefits

- ▶ Accurately represents global combustion properties of specific fuels
- ▶ Allows for evaluation of fuel property effects on combustor performance and emissions
- ▶ Generates detailed and mathematically reduced kinetic models
- ▶ Replicates specific real fuel combustion kinetic behavior

## Firm Contact

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Proposal number: A3.03-9123

# Physics-based Radiator Design, Sizing, and Weight Estimation Tool

*For conceptual design of more-, hybrid- and all-electric next gen aircraft*

Hybrid electric distributed propulsion (HEDP) systems have proven worthy for further consideration by approaching NASA's goals for N+2 and N+3 energy consumption, noise, emission and field length. The thermal management associated with these systems has been recognized as a major challenge to be overcome. ESAero's recent 2012 Phase I SBIR (NNX13CC24P) identified the radiator as a driving component within the thermal management system (TMS). Its design has profound first order effects on the weight, performance, and aerodynamic drag of the TMS, and second order effects on the weight and performance of the overall propulsion system. During the proposed Phase I SBIR, ESAero will upgrade the existing physics-based radiator design, analysis, and weight estimation conceptual design tool by improving the flexibility and fidelity of thermodynamic analysis and predicting the effects of integrating the radiator core within a well-designed duct. These modifications are expected to dramatically improve the predicted weight and performance of the radiator and negate nearly all of the radiator drag.

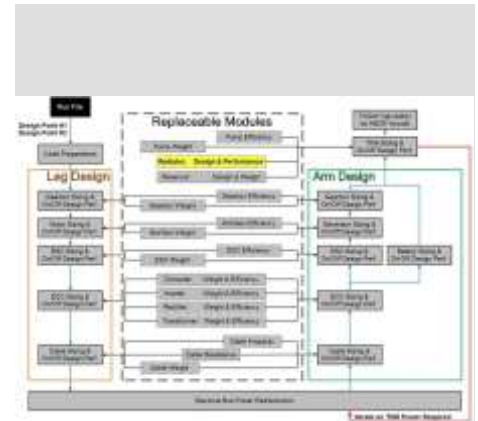
## Applications

### NASA

- ▶ Facilitation of conceptual design of HEDP systems on aircraft to benefit multiple NRA projects
- ▶ Investigation for several nuances native to vastly different HEDP propulsion system architectures
- ▶ Support for the motivation for HEDP systems

### Commercial

- ▶ Guide aerospace primes and AFRL toward the identification of feasible HEDP architectures



## Phase I Objectives

- ▶ Develop an improved radiator design, sizing and analysis tool
- ▶ Configure radiator core and upgrade analysis system
- ▶ Establish radiator duct design algorithm
- ▶ Verify and validate tool
- ▶ Integrate into overall framework

## Benefits

- ▶ Shows promise for meeting NASA's goals for energy consumption, emissions, noise, and field length
- ▶ Profound first order effects on weight, performance, and aerodynamic drag of the TMS
- ▶ Second order effects on weight and performance of the overall propulsion system
- ▶ Improves the flexibility and fidelity of thermodynamic analysis

## Firm Contact

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# Hybrid Electric Propulsion System for a VTOL/Multirotor Aircraft

*A scalable electric propulsion system with increased endurance, safety, and reliability*

Distributed Electric Propulsion and multirotor Electric Aircraft open up new aircraft design paradigms and enable new vehicle capabilities. These electric propulsion systems have low flight endurance due to the poor energy density of batteries. The multiple electrical systems involved may also lead to an increased failure rate due to the high number of components.

LaunchPoint Technologies proposes to build a scalable hybrid electric propulsion system that will achieve extended flight endurance and high reliability.

During Phase I, LaunchPoint showed the feasibility of a manned hybrid electric VTOL vehicle that can achieve the endurance, speed, and fuel efficiency of a high aspect fixed wing aircraft while still providing VTOL capability for a commuter-type application. High energy density aviation fuel provides energy storage and a power dense gen-set converts the fuel to electricity for the system continuous power requirement in parallel with a battery pack for peak power demand. This results in a much longer endurance than a battery electric vehicle while still reaping the design benefits of electric propulsion technology. Fly-By-Wire design techniques are applied to the electric aircraft propulsion system leading to a highly reliable architecture called "Propulsion-By-Wire", which provides a tremendous increase in reliability and safety of the vehicle.

In Phase II LaunchPoint Technologies will develop the hybrid power source of a "Propulsion-By-Wire" system for two power levels. LaunchPoint will build and fly a long endurance 1 kW hybrid electric multirotor vehicle and will build and bench test a 6 kW hybrid power source to demonstrate scalability to larger systems.

## Applications

### NASA

- ▶ NASA's Greased Lightning project / GL-10, led by Bill Fredricks
- ▶ Leaptch vehicle demonstrator
- ▶ Heist project

### Commercial

- ▶ Extend range on existing electric UAS vehicles
- ▶ Highly reliable electric propulsion for eventual FAA certified UAS flight over people for news gathering, public safety



## Phase II Objectives

- ▶ Develop a 1 kW "Propulsion by Wire" hybrid power system for a 12 kg class multirotor
- ▶ Integrate the "Propulsion by Wire" power system with a small commercially available multirotor and conduct free flight testing, demonstrate increased endurance
- ▶ Develop and bench test the 6 kW Hybrid Power Source component for a scaled up Propulsion by Wire system

## Benefits

- ▶ Increased endurance for multirotor electric and distributed electric propulsion vehicles
- ▶ Highly reliable architectures
- ▶ Increase in safety compared to conventional VTOL systems
- ▶ Meets notional airworthiness requirements for flight over people
- ▶ Increased fuel efficiency

## Firm Contact

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# Digital Schlieren System for Flow Diagnosis

*A versatile, robust, portable digital focusing schlieren system for wind tunnel applications*

The innovation of this program was the development of a new digital focusing schlieren technology for flow diagnostics in high speed wind tunnels. The key challenge was to adapt to high speed illumination with a projection system that would have minimal impact on the wind tunnel surface. Adapting the illumination system for projection through windows was also addressed.

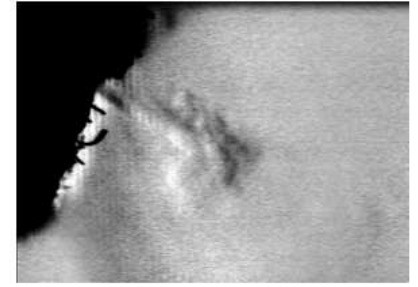
## Applications

### NASA

- ▶ Aerodynamic research and development problems associated with:
  - Turbulent flow fields
  - Boundary layers
  - Shock waves
  - Flow interactions
  - Aero optics
  - Flow control
  - Drag
  - Boundary layer transition
  - Flow separation.

### Commercial

- ▶ Viewing large-scale phase objects in transparent media
- ▶ Aero-optics
- ▶ Flow diagnostics
- ▶ Flow-control
- ▶ Heating, ventilation, air conditioning
- ▶ Refrigeration
- ▶ Thermal management
- ▶ Air drying systems
- ▶ Ballistics
- ▶ Leak detection



## Phase I Objectives

- ▶ Develop a versatile, robust, portable, user-friendly digital focusing schlieren system that will be useful for a wide range of wind tunnel applications

## Benefits

- ▶ Robust
- ▶ User friendly
- ▶ Productive
- ▶ Useable in test facilities and environments previously prohibitive of such testing
- ▶ Reduced manufacturing costs
- ▶ Reduced size and weight
- ▶ High power instrument

## Firm Contact

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# High Temperature Fiber Optic Thermal Imaging System

## *A non-intrusive method of measurement*

A prototype high temperature, single optical fiber thermal imaging system will be developed, tested, and delivered to GRC. The components of the instrument will be specified in detail, designed, fabricated, and purchased where appropriate. The illumination and imaging system will be assembled and system tests will be performed. Given a set of calibration images produced by the diagnostic, the image analysis needed to recover a thermal image of a surface will be developed and demonstrated. System resolution tests will be performed. The thermal imaging laboratory system will be modified to be appropriate to a prototype commercial instrument. The thermal imaging prototype will be tested and debugged at Thoughtventions and its operating characteristics defined. The thermal imaging system and operating manual will be completed and delivered and field tested at GRC for their ongoing use.

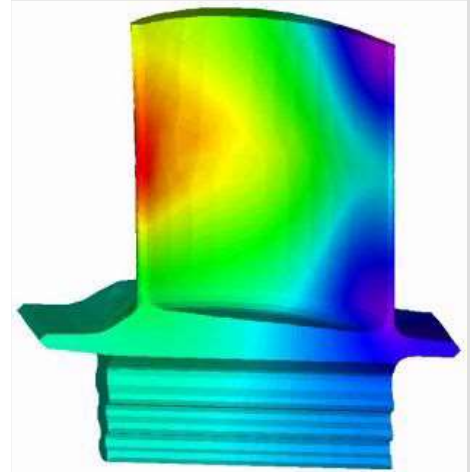
## Applications

### NASA

- ▶ Jet engine turbine and combustor ground test facilities
- ▶ Engine test facility at NASA Glenn
- ▶ High temperature facilities with limited optical analysis where thermal mapping is crucial for equipment diagnosis

### Commercial

- ▶ Fiber thermal imaging systems for sale for use in jet engine research programs and later, production. Companies of interest include:
  - Air force
  - Pratt & Whitney
  - General Electric
  - Rolls Royce
  - SNECMA.



## Phase I Objectives

- ▶ Develop the illumination and imaging system by completing the design, fabricating and purchasing components, and assembling the system
- ▶ Develop image analysis system and perform resolution tests
- ▶ Develop instrument by modifying the thermal imaging system
- ▶ Test, document, and deliver system

## Benefits

- ▶ Provides data on engine thermal issues that are of critical importance
- ▶ Provides turbo machinery and combustor imaging at high temperatures
- ▶ Overcomes problems with optical access, illumination, pressure sealing, image spatial and temporal resolution, and instrumentation ruggedness

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