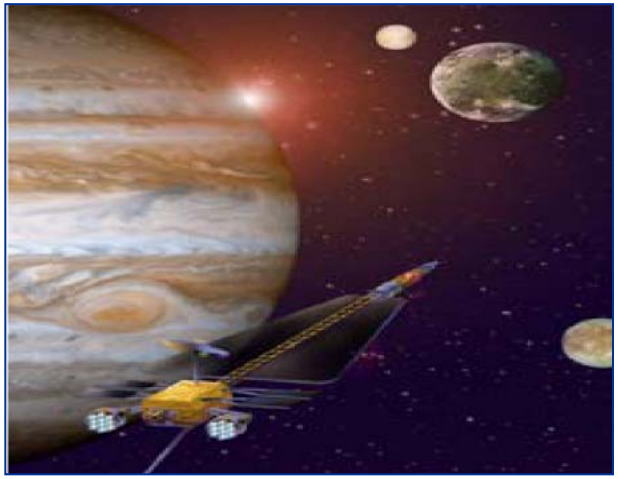
Advanced Energy Opportunities
NASA Glenn Research Center

Robert "Joe" Shaw
Chief
Business Development and Partnership Office

Demonstrated excellence in aerospace power, propulsion and communications

NASA Mission

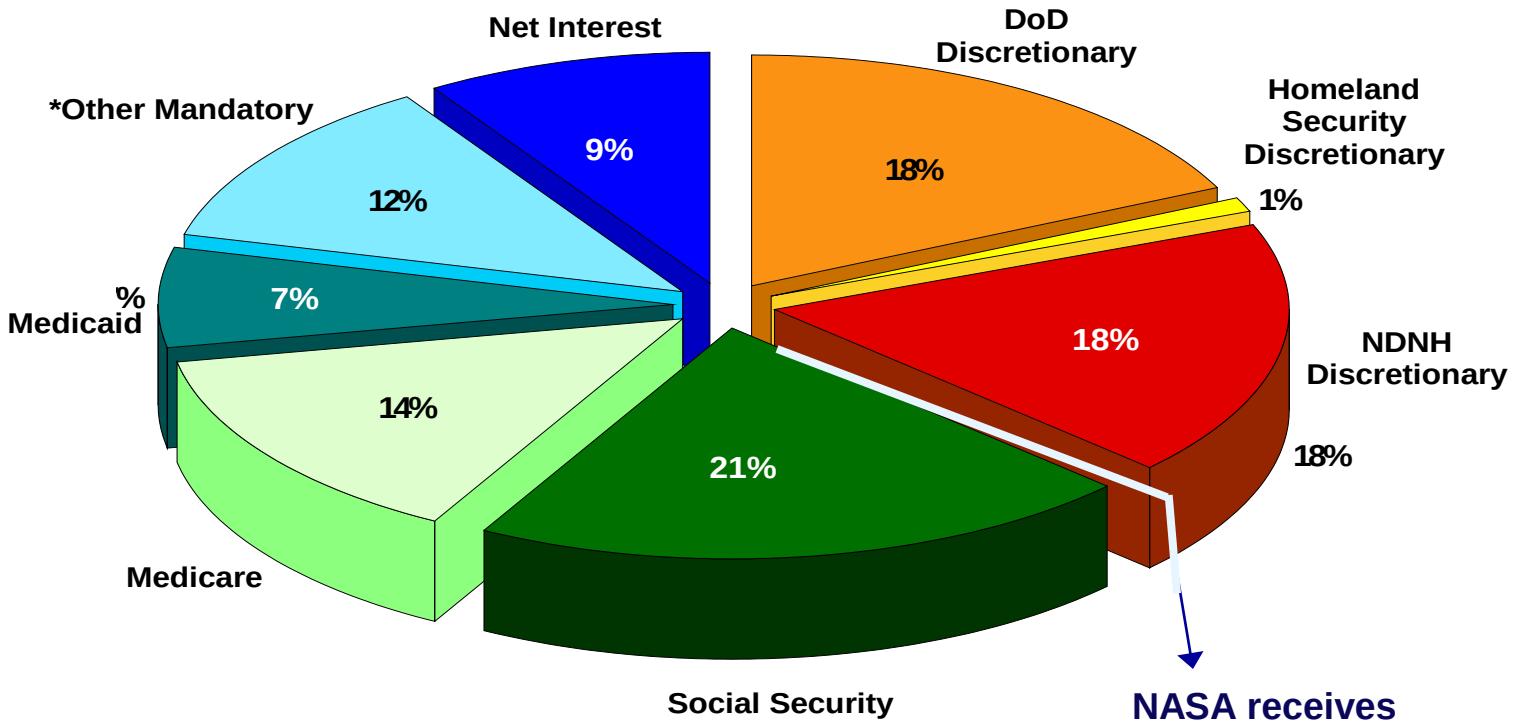
To Pioneer the Future in Space Exploration, Scientific Discovery, and Aeronautics Research



Federal Budget

2007 Outlays

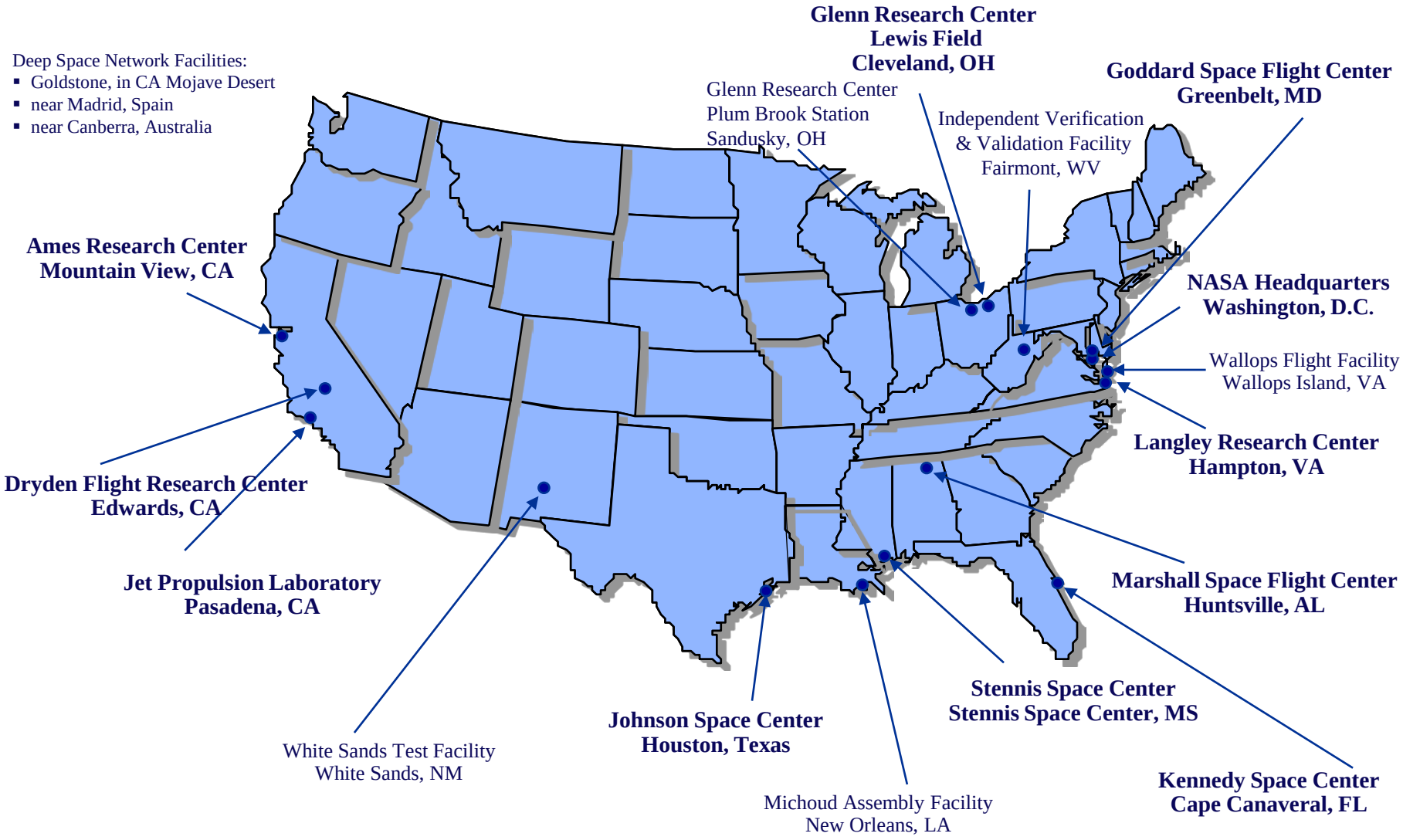
$2,770 Billion



NASA receives
0.61% of the Federal Budget

* Includes -- Means Tested Income Support, Federal Employee Retirement, and other.

NASA Centers and Installations



Glenn Research Center

Lewis Field

(Cleveland)

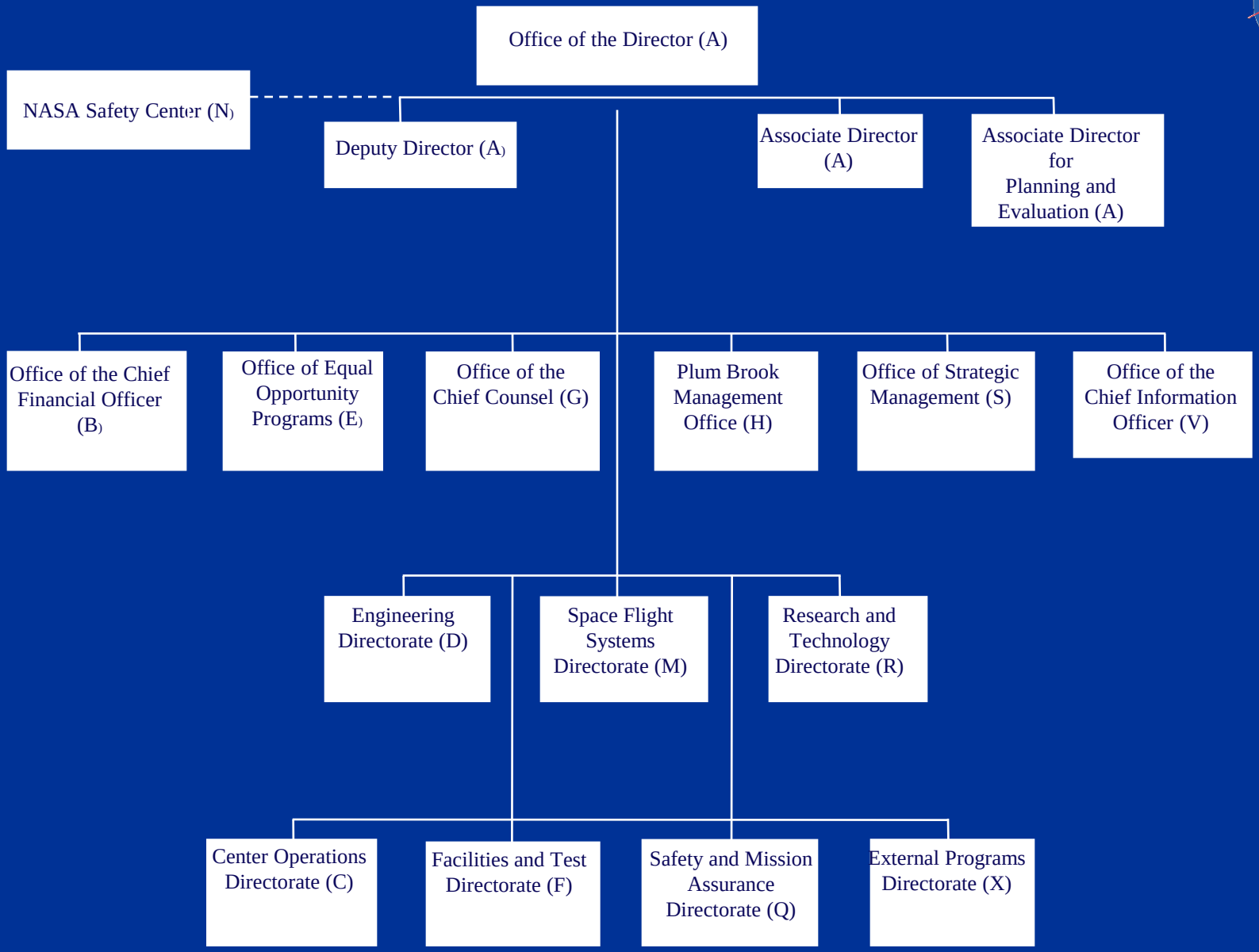
- 350 acres
- 1600 civil servants and 1735 contractors

Plum Brook Station Test Site

(Sandusky)

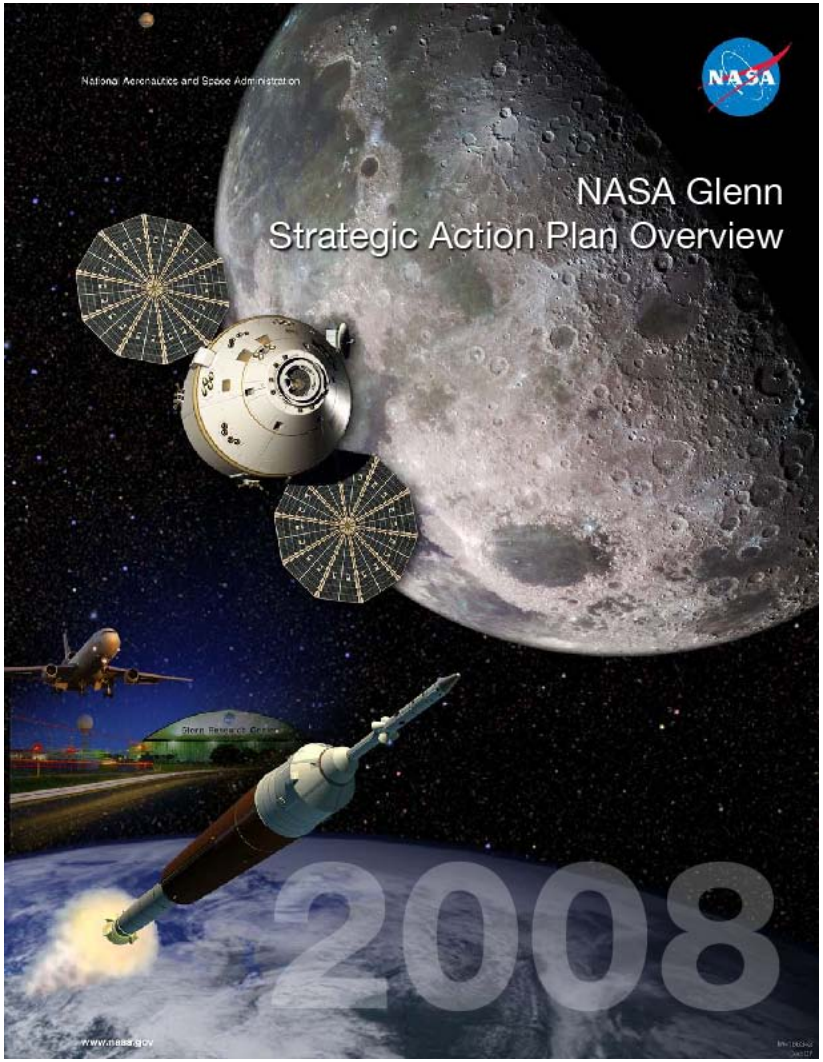
- 6400 acres
- 14 civil servants and 117 contractors

As of November 8, 2008


Office of the Director (A)
NASA Safety Center (N)
Deputy Director (A)
Associate Director (A)
Associate Director for Planning and Evaluation (A)
Office of the Chief Financial Officer (B)
Office of Equal Opportunity Programs (E)
Office of the Chief Counsel (G)
Plum Brook Management Office (H)
Office of Strategic Management (S)
Office of the Chief Information Officer (V)
Engineering Directorate (D)
Space Flight Systems Directorate (M)
Research and Technology Directorate (R)
Center Operations Directorate (C)
Facilities and Test Directorate (F)
Safety and Mission Assurance Directorate (Q)
External Programs Directorate (X)

Glenn Research Center Goals

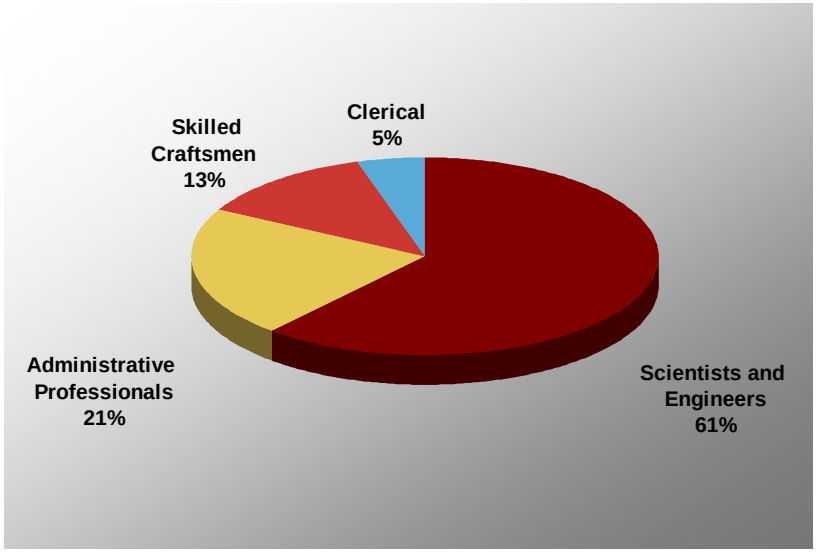
- **Be Valued as a Leader in Space Flight Systems Development**
- **Be Known for Excellence in Project Management**
- **Excel in Aeronautics and Space Research**
- **Become an Integral Part of the Ohio Community and the Nation**

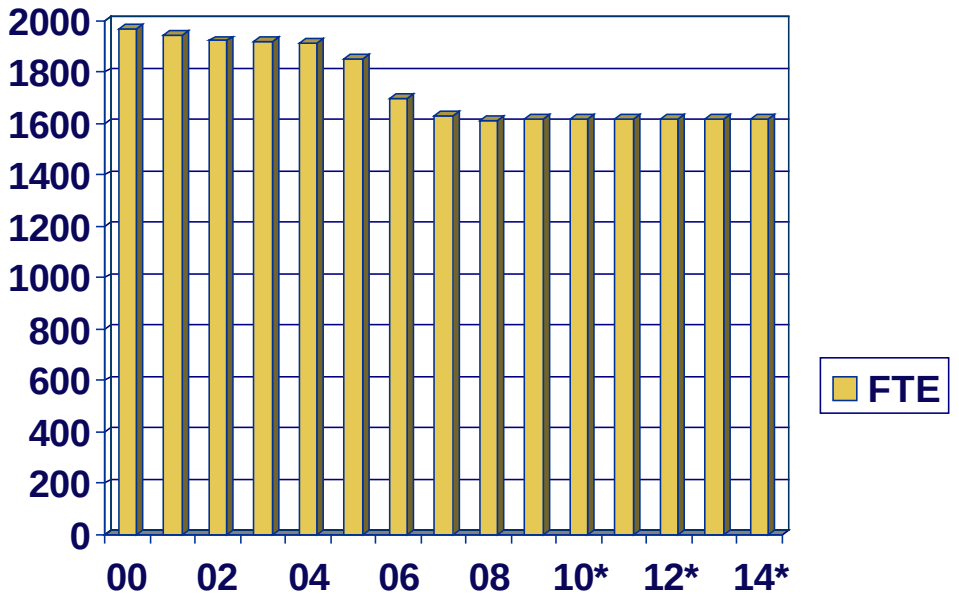


Civil Service Workforce

- **67 percent of workforce charges their time directly to the technical mission**
- **72 percent of scientists and engineers earned advanced degrees, 25 percent with PhDs**

Administrative and Clerical | **Scientists and Engineers** | **Skilled Craftsman**





As of 9/30/08

***Projected Workforce Level**

GRC Awards and Recognition

R&D 100 Awards

GRC has 105, the highest in the Agency in these disciplines:

- Aeropropulsion Systems
- In-Space Propulsion Systems
- Aerospace Communications
- Power and Energy Conversion

Space Act Awards:

177 GRC awards in FY 2008

Emmy Award

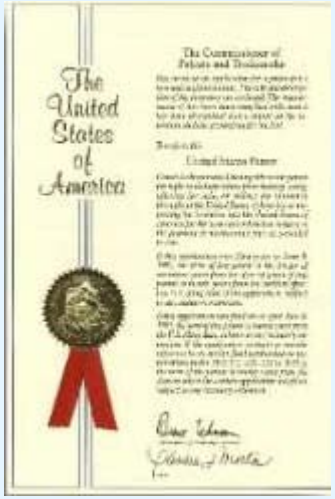
for Communications

TGIR Awards

Turning Goals into Reality
Washington, DC • 2004

37 GRC awards out of 86 NASA Agency (43%) Highest in the Agency

Patents:



13 GRC patents awarded in FY 2008

NASA Software Of the Year Award

5 GRC awards last 15 years

NASA Invention of the Year awarded in:

- 2004
- 2001
- 1996

The National Research Council

2003 Review Recognition for Project Management for "World-Class Space Communication Hardware"

GRC Competencies

Competencies	Glenn Research Center Facilities at Lewis Field or Plumbrook Station	Notes
Acoustics	Acoustic Dome (p 3**)	
Bio-Engineering	Several R&D labs	Recently established thrust
Combustion	Space Combustion Facilities, Combustion R&D Labs (p 24**)	
Communications	Antenna Test Facility, Communications Testbed, 35 R&D labs	
Electric (Ion) Propulsion	Space Simulation Vacuum Chambers (p 27**)	Battery powered ground vehicle – 70's-90's. Includes power
Electrical Systems	Spacecraft Electrical Systems Test Bed (p 30**)	Power – generation, management, distribution
Electrochemistry-Physics	Fuel Cell Test Facilities (p 31**)	Includes power, fuel cells and batteries. Some staff embedded in related competencies
Fluids, CFD, TurboMachinery	Engine Research Facilities, Icing Wind Tunnel (p 13**)	This competency supported Wind Turbine development in the 1970's and 1980's. Wind turbines could also include Structures, Materials, Mechanical Components, Acoustics and Icing.
Instrumentation, Controls, Electronics	31 R&D Labs, Clean Rooms (p 33**)	
Materials	142 R&D Labs, Large Multi-Axial Fatigue Facility (p 32**)	

** Facilities Brochure
http://facilities.grc.nasa.gov/documents/Facilities_Booklet_2005.pdf

GRC Competencies

Competencies	Glenn Research Center Facilities at Lewis Field or Plumbrook Station	Notes
Mechanical Components and Lubrication	Space Mechanisms Labs, Tribology R&D lab	
Modeling, Simulation & Visualization	Graphics and Visualization Laboratory, Cluster Computing (p 35**)	See Fluids, Combustion, Structures, Acoustics, Bio-Eng and Communications
Nanotechnology	Several Labs Included In Other Competencies	See Electrochemistry-Physics, Photovoltaics, Instrumentation, and Materials
Photovoltaics	Photovoltaic R&D Laboratories	Includes power
Program/Project Management	See Others	
Propellant Systems	Space Cryogenic Testing Facilities (p 25**)	Liquid Hydrogen systems/storage; Boron Nitride nanotubes being evaluated for gaseous hydrogen storage
Structures	62 R&D Labs (p 33**)	
Systems Analysis	World-Class Aerospace Analysis Tools	
Systems Engineering	Development and Verification Labs	
Thermal Energy Conversion	Power Systems Facility	Includes power

** Facilities Brochure
http://facilities.grc.nasa.gov/documents/Facilities_Booklet_2005.pdf

Photovoltaic Energy

Batteries and Fuel Cells

Clean Coal

Wind Turbines

Algae to Fuels

Flywheels

Advanced Energy Competencies
NASA Glenn Research Center

Advanced Energy Research and Development

Competencies

- Acoustics
- Combustion
- Electrical Systems
- Electrochemistry-Physics
- Fluids, CFD, Turbomachinery
- Mechanical Components and Lubrication
- Modeling, Simulation & Visualization
- Photovoltaics
- Propellant Systems
- Thermal Energy Conversion

Production

- Photovoltaics
- Wind
- Fuel cells
- Stirling Cycle
- Brayton Cycle
- Hybrid Concepts
- Nuclear
- Alternate Fuels

Storage

- Batteries
- Flywheels
- Nanostructured Devices
- Tankage

Transmission

- Power Management & Distribution
- Pipelines

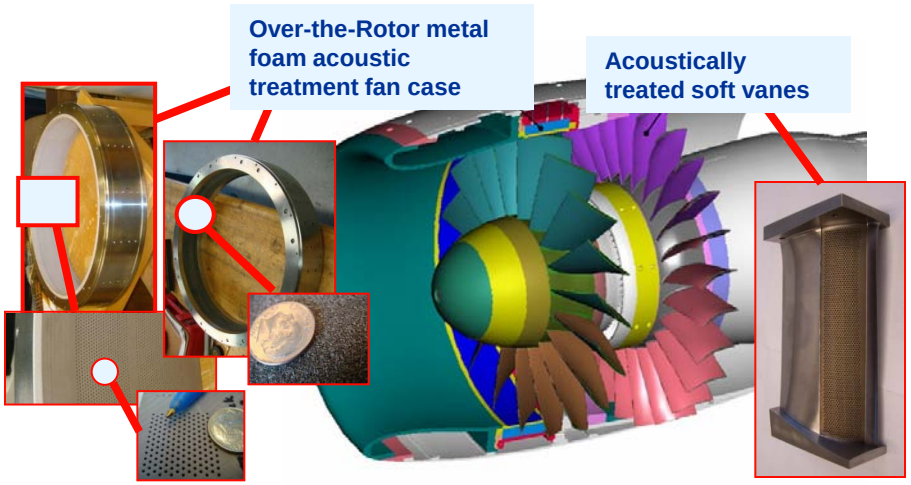
Cross Cutting Competencies

- Instrumentation, Controls, Electronics
- Materials
- Nanotechnology
- Program/Project management
- Structures
- Systems Analysis
- Systems Engineering

Acoustics

Description

- Fundamental and applied research for aircraft engine noise reduction
- Noise prediction methods for aircraft propulsion
- Noise source and flow property diagnostic methods and instrumentation
- Supporting subsonic and supersonic propulsion

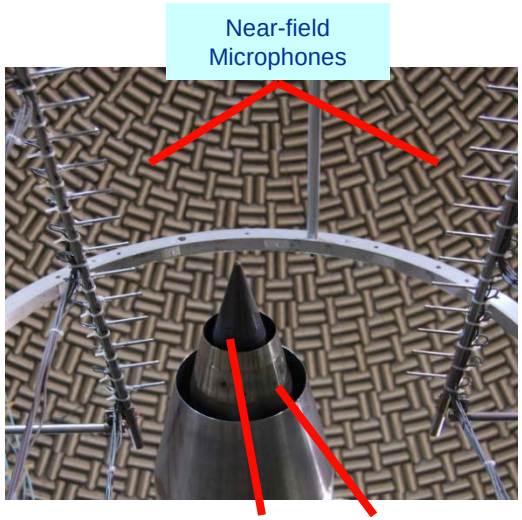


Facilities/Labs

- 9'x15' Wind Tunnel
- Advanced Noise Control Fan (fundamental noise research fan)
- Aeroacoustic Propulsion Laboratory (AAPL)
  - Small hot jet acoustic rig
  - Nozzle acoustic test rig
  - Advanced noise control fan

Focus Areas

- Technologies for fans and jets including steady/unsteady aerodynamics and performance assessments, near field phased microphone array/duct mode measurements, and acoustic measurements
- Computational Aeroacoustic methods
- Flow measurement methods including Laser Doppler Velocimetry, hot wires/films, and Particle Image Velocimetry (PIV)
- Consulting, e.g., fan noise associated with space applications, ARES acoustic environment definition/review, etc.



Dual Flow (Core and Bypass flows simulated) test nozzle

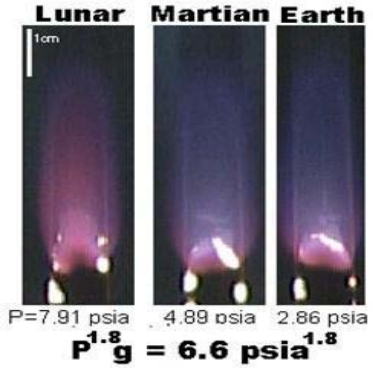
Accomplishments

- Quantified over-rotor tip treatment noise reduction and aero performance in collaborative engine test with Williams International (2008)
- Demonstrated acoustic performance of soft vane concept, 1+ decibel (dB) fan noise reduction, in TRL 4/5 test using UHB engine cycle (2008)
- Defined open rotor research plan with GE, P&W, Hamilton Sundstrand, LaRC (2008)
- Quantified -20 dB+ noise reduction below Stage 3 for P&W GTF engine concept (2006/2007)
- Completed tests to populate benchmark database for supersonic nozzle with aerodynamic, acoustic, temporal PIV, and phased array data (2007)

Combustion

Description

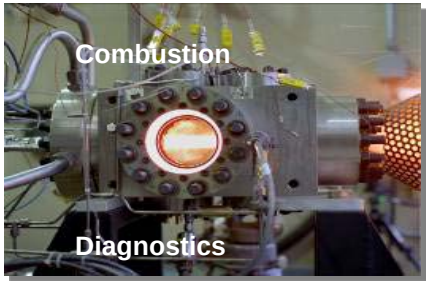
- Fundamental and applied research for engine combustor emissions reduction and alternative fuels
- Emissions prediction methods and validation
- Advanced fuel / air injector concepts
- Utilize access to low-gravity to develop technologies to support human exploration missions and to conduct fundamental research in combustion processes



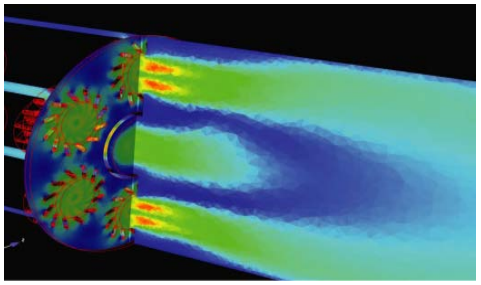
Material flammability testing

Facilities/Labs

- Low emissions test rig
- High pressure (up to 900 pounds force absolute) combustion test rig
- Fundamental diagnostics rig
- Ignition test rig
- Drop towers (2.2 and 5.2 seconds)
- International Space Station Combustion Integrated Rack



National Combustion Code computation of an advanced fuel injection concept



Focus Areas

- Combustion diagnostics development and validation experiments
- Combustion Computational Fluid Dynamics code validation experiments
- Low emissions combustion
- Particulates / particle measurements
- Active combustion control
- Alternative fuels
- Combustion physics
- Fire safety

Particulate emissions from B-52 bomber

Accomplishments

- Completed the 50/50 blend of JP-8 and Fischer-Tropsch fuel in ground test of commercial aircraft engine (2008)
- Completed subsonic active inlet flow control testing using the Versatile Integrated Inlet (2008)
- Achieved 50% Nitrous Oxides reduction in the annular combustor rig (2005-2006)
- Achieved 80% Nitrous Oxides reduction in the bench scale test rig (2006)
- Particulate data base from three different airports (2006)
- Development of an advanced aircraft fire detector (R&D 100 award –2005)
- Draft tests for material flammability for spacecraft materials selection (2006)

Electrical Systems

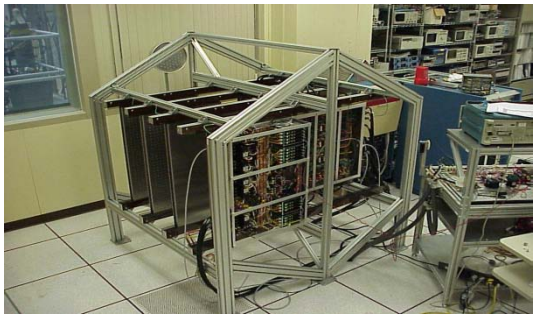
Description

- End-to-end, source-to-load power systems using key components
  - AC or DC distribution
  - Sources: photovoltaic, dynamic
- Energy Storage: Batteries, flywheels, fuel cells
  - Loads: motors, thrusters, power converters

Facilities/Labs

- End-to-end power system test bed
- Flight qualification testing:
  - Thermal vacuum
  - Electromagnetic Interference chambers
  - Vibration
- Flywheel spin rig facility
  - Rotor certification facility

Advanced flywheel system



Advanced electric power test-bed

Focus Areas

- Intelligent/modular power systems
- Power System Modeling (Dynamic and Performance)
- Power distribution units
- Advanced power components
- Switches/converters
- Flywheel energy storage and attitude control
- Advanced actuators

Accomplishments

- Developed end-to-end high-power test beds for International Space Station, Prometheus, Shuttle Electric Auxiliary Power Unit, Orion and Ares I (1990-current)
- Developed designs for Ares I and Altair power systems (2008)
- Demonstrated integrated momentum and power control with flywheel system operating at 60,000 rpm (2004)

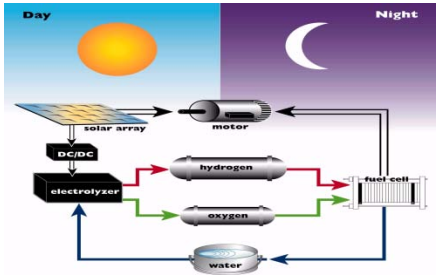
Electrochemistry

Description

- Fuel cells provide a primary source of power by converting hydrogen and oxygen to water and electricity
- Regenerative fuel cells combine a fuel cell with an electrolyzer capable of converting water back into hydrogen and oxygen (functions like a battery)
- Batteries - versatile, reliable, safe, modular, lightweight, portable energy sources
  - Lithium based batteries offer lower weight, smaller volume, and wide operating temperature range capability.

Facilities/Labs

- Fuel cell test facilities for performance, life testing of cell stacks/ systems (up to 25 kilowatts)
- Regenerative fuel cell test facility
- Dry room (1% relative humidity) for handling moisture sensitive materials used in lithium batteries
- State-of-the-art battery cycling facilities with >100 independent test channels
- Environmental chambers to evaluate performance as a function of temperature (-100 °F to +390 °F)



Regenerative Fuel Cell

Spirit/Opportunity Rover

Focus Areas

- Battery and fuel cell materials development
- Component design, development and characterization
- Electrochemical characterization of single cells and stacks
- Battery charge control methodologies
- Fuel cell/regenerative fuel cell balance-of-plant
- Passive fuel cell systems
- Technology validation, mission operations

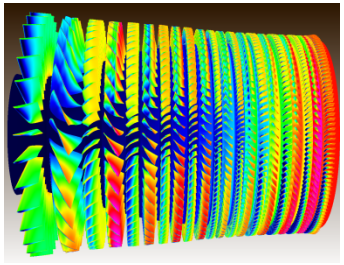
Accomplishments

- Evaluated battery technologies for Ares I, instrumental in the identification of Li-ion as the baseline technology (2008)
- Demonstrated operation of integrated non-flow through PEM fuel cell and balance of plant (2008)
- Built and demonstrated an advanced technology Li-ion battery as power for astronaut backpack at Desert Research and Technology Studies at China Lake (2007).
- First demonstration of closed-loop H2/O2 regenerative fuel cell system (2005)
- Fuel cell demonstration scientific balloons; Helios (2001)
- Batteries for flight program – Space Station power system management, support day to day operations (1999 - present)
- Developed lightweight nickel electrodes, demonstrated the feasibility of bipolar nickel hydrogen battery designs (1984)
- Gemini, Apollo, and Shuttle fuel cell technology development (1960's - 1970's)

Fluids, CFD and Turbomachinery

Description

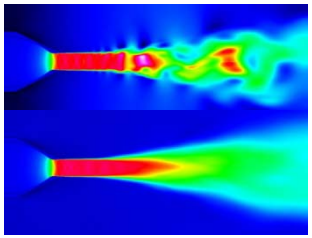
- Perform experimental and computational fluid dynamic (CFD) research for design and development of inlet and exhaust systems
- Research data from test facilities and computational codes for design tools and methodologies to advance the understanding of inlet and nozzle related flow physics, single and multistage compressor aerodynamics, operability, efficiency, and turbine heat transfer.
- Explore the fundamental principles of physics and chemistry through fluids research in the unique natural laboratory of space



RANS and LES simulation of compressors

Instantaneous

Time-Averaged



Large eddy simulation of mach 1.4

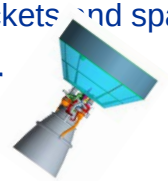
Focus Areas

- Multiphase flows and phase changes
- Model development (vortex generators, bleed, turbulence, inlet/fan integration)
- Code development (Wind, APNASA, GLENN-HT)
- Multistage compressor and turbine CFD code development
- Conjugate heat transfer turbine CFD code development
- Large Eddy Simulation method development for fan, compressor and pump analysis
- Development of Reynolds Averaged Navier-Stokes code (RANS)
- Analytical and computational modeling and experiments in multiphase flows in reduced and partial gravity

Facilities/Labs/Tools

- Supersonic wind tunnels (10'x10', 8'x6', 1'x1')
- Low speed wind tunnel (9'x15')
- 15cm x 15cm SWT- fundamental flow physics
- Diffuser test rig- evaluation of subsonic diffusers
- Low speed compressor test facility (W1A)
- Compressor test facilities; single; multistage (W7,W8)
- Small high speed compressor test facility (CE18)
- Turbine film cooled vane facility
- Transonic turbine blade cascade test facility (CW22)
- Vibration and Statics Load Lab
- Mechanical design using Pro/Engineer
- Mechanical analysis (NASTRAN, ANSYS, ADAMS)
- Drop towers, sounding rockets and space station

Thrust vector control

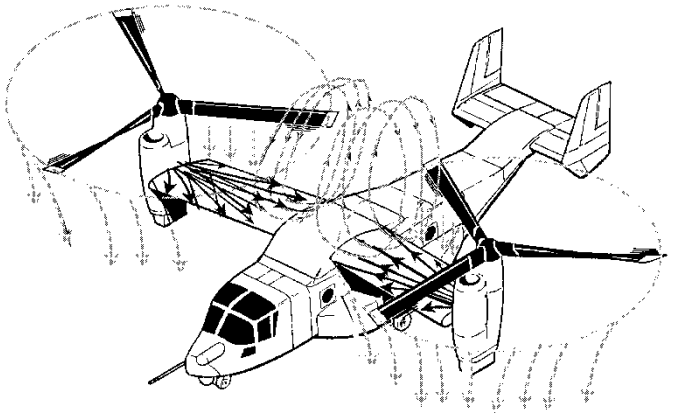


Accomplishments

- Completed refurbishment of small compressor test cell and testing of CC3 Centrifugal compressor (2009)
- Completed testing of Mach 4+ Fan for Turbine-Based Combined Cycle engine (2008)
- Research and Development 100 Award for multi-dimensional contact angle measurement device (2008)
- Heat transfer measurements for a film cooled turbine vane cascade (2008)
- Compressor CFD code assessment (2009)
- Conducted first microgravity tests of water reclamation system for spacecraft (2006)
- Developed lunar rover test bed (2006)

Fluids, CFD and Turbomachinery

Icing – Rotorcraft



Robust, validated coupling of rotor performance codes with ice accretion prediction code

Current state-of-the-art icing CFD capabilities are not adequate for design and certification

- Civil rotorcraft operations are now entering regularly scheduled revenue service and need safe performance in all weather conditions
- Design tools are required to assure safe operations in icing conditions
- Desire to reduce power consumption, weight and cost associated with conventional thermal rotor deicing systems
- Difficulties in simulating detailed flow fields are unique to iced rotors

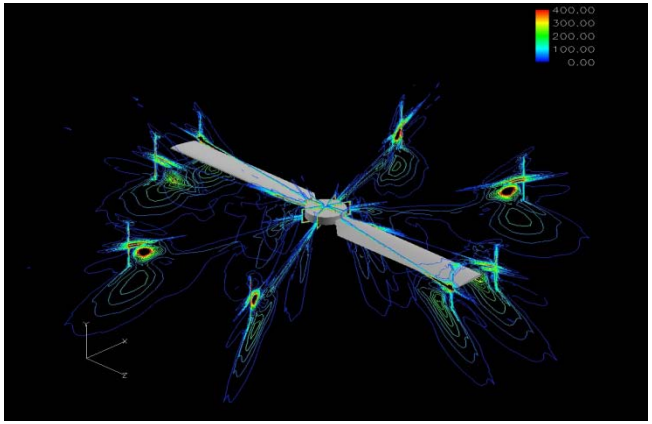
Rotary-wing-specific issues

- Effects of centrifugal and adhesive forces
- Wake/vortex interactions within the rotor disc
- 3D blade geometries (twist, sweep, etc)
- Large spanwise variation in flow properties
- Tracking of particle trajectories through actuator discs
- Multiple, complex scaling issues

Tilt rotor aircraft

Icing issues that apply across programs

- Automated generation of complex 3D grids
- Lack of turbulence models for simulating unsteady flow of all scales
- Large scale disparity (small ice roughness elements versus large ice structures)
- Post-stall regime (clean or iced blades)
- Earlier blade stall due to critical ice shapes
- Large computational resources required



Two-blade NACA0012 hovering tip vortex simulation

Fluids, CFD, Turbomachinery

Wind Power

ROOTS OF RENEWABLE POWER at NASA Glenn

Wind, because it is driven by the Sun, was among the alternative energy sources considered by the U.S. in response to the energy crisis of the 1970's, NASA in Cleveland devoted itself, as a national laboratory, to developing wind turbine technology. After obtaining initial funding from the National Science Foundation, (NSF) and the Energy Research and Development Administration (ERDA), NASA constructed and operated its first experimental 100-kilowatt wind turbine at Plum Brook in Sandusky, Ohio.

Mod-0 100kW Experimental Wind Turbine in Sandusky, Ohio

In the seven years between 1974 and 1981, NASA in Cleveland led the U.S. Wind Energy Program for large wind horizontal-axis turbines (the predominant systems used today). This was an extraordinarily efficient and successful government research and development activity. With continued funding from the Department of Energy (ERDA's successor), a total of 13 experimental wind turbines were put into operation. This included four major turbine designs.

Mod-0A 200kW wind turbine in Puerto Rico. Three others were installed in Rhode Island, New Mexico, and Hawaii.

Mod-1 2000kW wind turbine in North Carolina. It pioneered integration with installations near cities.

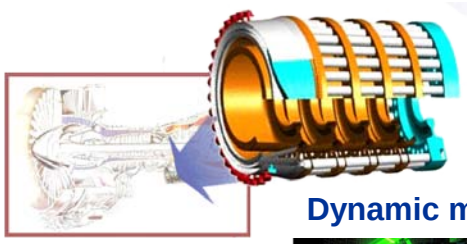
Mod-2 cluster of multiple 2.5 MW wind turbines in the state of Washington. Other Mod-2s were installed in California.

Mod-5B 3.2 MW (100 m diameter) wind turbines in the state of Hawaii was the largest in the world.

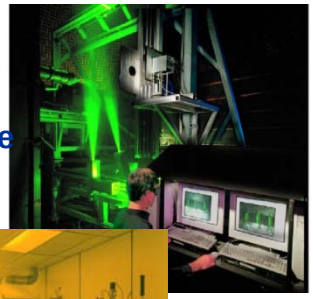
Instrumentation, Controls and Electronics

Description

- Sensor development for harsh environments
- Optical instrumentation and NDE
- Controls and dynamics
- Design, development and testing for space flight instrumentation
- Digital circuit board design and analysis for aerospace
- Electronics for cryogenic environment
- Intercalated graphite conductors and radiation shielding



Dynamic modeling



Particle imaging velocimetry for jet noise characterization

Microsystems facilities

Portable unit for metabolic analysis

Facilities/Labs

- Dynamic modeling
- Propulsion health monitoring
- Particle imaging velocimetry
- Flight electronics lab
- Micro computed tomography
- Microsystems fabrication clean rooms
- Silicon Carbide chemical vapor deposition
- Harsh environment micro/nano-device laboratories
- Cryogenic testing chambers (5) to near absolute zero
- Environmental testing facilities (vacuum, temperature, humidity control)

Focus Areas

- Intelligent control and propulsion health monitoring and physics-based modeling
- Optical flow path measurements
- NDE methods development
- Silicon Carbide based electronic devices and MicroElectroMechanical Systems (MEMS)
- Robotics technology development
- Crew Exploration Vehicle avionics
- Crew Launch Vehicle data flight instrumentation and control system development/analysis
- Biomedical sensors for space applications

Accomplishments

- 2550 ºF temperature sensitive paint sensor (2008)
- Doped nanocrystalline tin oxide-based microsensor developed for CO2 detection- Nano50 Award (2008)
- Combustion thermo-acoustic instability simulation results closely match experimentally observed instability frequency and dynamic characteristics (2008)
- Intelligent retrofit engine control architecture demonstrated in simulation to maintain “nominal throttle to thrust with engine degradation due to usage (2007)

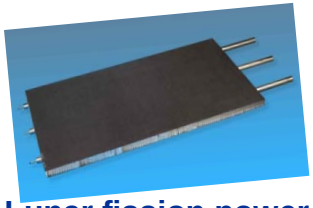
Materials

Description

- Advanced lightweight structural concepts and designs for aerospace applications
- Micromechanics and life prediction of aerospace components

High temperature shape memory alloy (0.06 inch diameter wire)

Advanced disk alloy



Lunar fission power composite radiator and heat pipe

Focus Areas

- Space environment effects testing and modeling (atomic oxygen, ultraviolet , solar, x-rays, high-energy particles, electrons)
- Aerospace propulsion materials (metals, polymers, ceramics, coatings, composites) offering higher temperature capability and reduced weight
- Failure mode determination, damage mechanics, and life prediction methodology
- Multifunctional materials and structures
- Adaptive materials and structures
- Computational materials
- Nanotechnology materials

Ceramic matrix composite vane with environmental barrier coating

Facilities/Labs

- Facilities for processing, joining, and characterizing advanced polymeric, metallic, ceramic, composite materials and coatings
- Full range materials analytical facilities, including optical, electron, and atomic force microscopy, x-ray diffraction, spectroscopy and chemical analysis
- Over 100 world-class thermo-mechanical and subcomponent test facilities encompassing a wide range of temperature, environmental, and load regimes
- Atmospheric and high pressure burner rigs

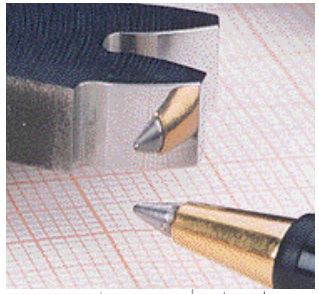
Accomplishments

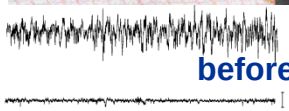
- Developed Atomic Oxygen (AO) erosion-yield predictive tool (2008)
- Completed proof testing of prototypical welded and bolted joints for the Ares I-X (AIX) Upper Stage Simulator (USS) (2008)
- Thermochromic polymers that change colors upon heating (2008)
- Flexible aerogels with near 100% compression recovery (2008)
- Determined life limiting factors in new turbine disk alloys 2008
- Shape memory alloy with 300 ºC temperature capability (2006)
- Coated ceramic composite system for turbine vane (2005)
- Low density single crystal nickel-base superalloy (2006)
- Polymer cross linked aerogel (2006)
- Polymer nanocomposite (2006)
- Repair of reinforced carbon/carbon composite Space Shuttle tiles (2005)
- Advanced probabilistic structural analysis tool (2005)

Mechanical Components and Lubrication

Description

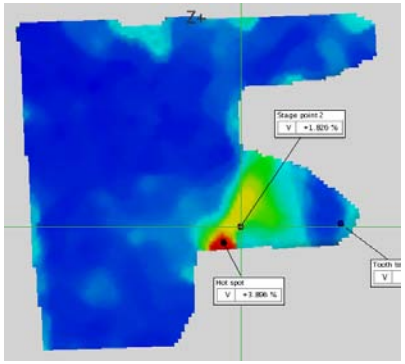
• Advanced mechanical component and system technologies to meet increased performance and reliability needs of future aerospace vehicles
• Gears and bearings
• Drive system technology
• Fundamentals of lubrication (tribology)





before

after Surface finish



Optically measured gear tooth strain

Facilities/Labs

• Contact fatigue rigs for spur gears (6)
• Fatigue rigs for spiral bevel / face gears (2)
• Spur gear bending fatigue test fixtures (3)
• Hybrid and fluid film bearing test facilities
• High speed helical gear train test facility
• 500 hp helicopter main rotor transmission test facility
• Gear noise / vibration test facility
• Space mechanisms tribology and component facilities
• Lunar mobility test facility

Focus Areas

• Component fatigue testing enabling development of advanced materials, processing and coatings for gears and bearings
• Advanced lubrication technology enabling high speed gear systems (rotary wing)
• Long life lubricants for space mission applications
• System testing of advanced components
• Analytical tool development for condition-based maintenance of mechanical components

Lunar mobility test facility

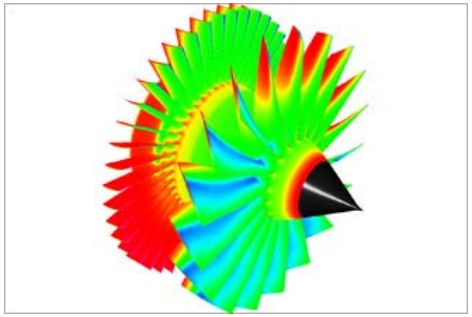
Accomplishments

• Validated 4x life improvement of gear super-finishing technology - now used in Sikorsky S-76 helicopter (2008)
• Gear fault detection methods used in US Army monitoring system in over 70 Blackhawk helicopters (2008)
• Advanced gear material contact and bending fatigue testing completed (2006)
• Advanced lubricant developed for extended loss-of-lube operation of gears (2005)
• Diagnostic tool developed for gear contact fatigue use data fusion and fuzzy logic (2003)
• PS/PM 300 High temperature solid lubricant coatings and composites (R&D 100 Award 2003)

Modeling, Simulation, and Visualization

Description

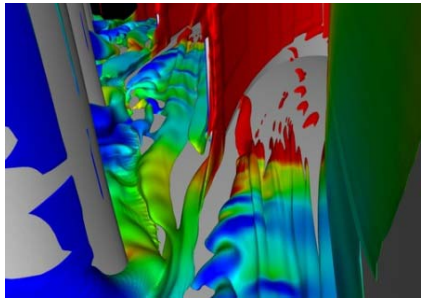
- Design and analysis of component and system operations
- Support design of new technologies
- Provide detailed understanding of experimental data
- Provides a unique debugging and visualization environment to augment larger, agency-wide systems



3D engine simulation

Facilities/Labs/Tools

- NASA Ames Columbia supercomputer
- Advanced computational concepts laboratory
- Glenn Reconfigurable User-interface and Virtual Reality Exploration Lab
- Large scale GX Linux clusters (~6)



Animation of temperature iso-surfaces

Focus Areas

- Aircraft and rocket propulsion
- Ice accretion
- Noise prediction
- Virtual reality techniques
- Microgravity environments
- Cryogenic fluid management
- Fire safety in space habitats
- Spacecraft power systems
- Materials modeling/analysis
- Astronaut health/biotechnology
- Spacecraft mission analysis/design

3D iced inlet simulation

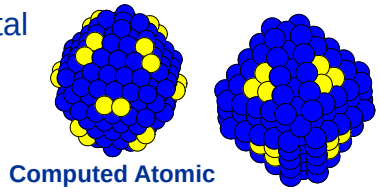
Accomplishments

- Distributed Observer Network (D.O.N.) mission simulation tools allow multi-user, interactive display of mission events (2008)
- Significant engine noise reduction achieved utilizing GRC codes (15 unique codes) (2008)
- LEWICE 2D/3D (LEWis ICE accretion program) utilized by industry to design more efficient aircraft deicing systems for safe operations (2006)
- SIZER enables preliminary vehicle synthesis, sizing and scaling functionality for mission planners and requirements analysis (2006)
- Virtual treadmill collaborations with Cleveland Clinic for astronaut health monitoring (2004)
- System power analysis trade capability for the International Space Station (2003)
- Commercialized micromechanics analysis code with Generalized Method of Cells, Ceramics Analysis and Reliability of Structures and GENOA-Progressive Failure Analysis (1999)

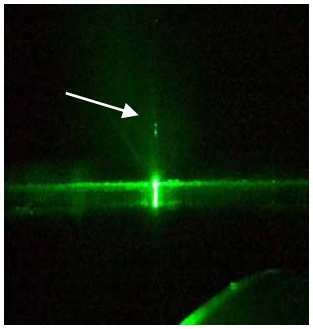
Nanotechnology

Description

- Modeling - atomistic computational alloy design
- Nanomaterials - synthesis of Boron Nitride, Metal Oxide, Carbon-nanotubes and smart polymeric materials for high temperature and harsh environment use
- Nanophotonics - optical trapping for device manipulation and fabrication
  - quantum dots/optical sources for low power quantum communication and sensing in extreme environments
- Nanoelectonics - harsh environment sensors and electronics for nano-electro-mechanical systems (NEMS) devices dynamic energy systems



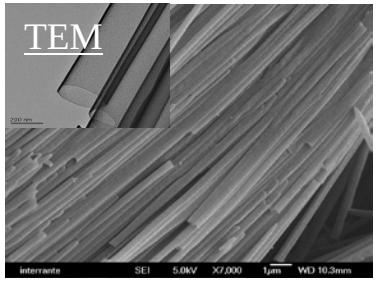
Computed Atomic Alloy Clusters



Optical levitation of microscale particles

Focus Areas

- Free surface alloy energetics for designing novel alloys for solid-state hydrogen storage and low cost fuel cell catalysts
- Multifunctional high temperature materials for propulsion, sensors and communications
- Micro/nano device fabrication techniques for harsh environment and environmental hazard sensing and secure, ultra low power, high efficiency data transmission
- Design and fabrication of harsh environment NEMS materials and devices



Silicon Carbide nanotubes

Facilities/Labs

- Desktop atomistic alloy nanoparticle modeling
- High temperature synthesis/processing facilities
- Inert atmosphere gloveboxes, clean rooms
- Thin film deposition chambers
- Laser tweezers
- Quantum entanglement optics lab and world class quantum optics systems
- Harsh environment NEMS research facility for prototype design, fabrication and characterization

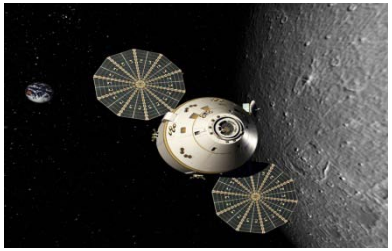
Accomplishments

- A purification process was developed for Boron Nitride nanotubes . (2010)
- Demonstrated a process to engineer single-walled to multiple walled carbon nanotubes structures. (2010)
- Demonstrated Boron Nitride nanotube composite with superior hydrogen storage (2006)
- Detected Hydrogen with Tin Oxide electrospun nanofibers (2006)
- Experimentally verified a light propagation model for predicting light scattering from an optically trapped particle (2006)
- Quantum communication demonstrated over 75 meters at 10^{-18} Watt (2006)
- First demonstration of Silicon Carbide nanotubes with controlled wall thicknesses (2004)

Photovoltaics

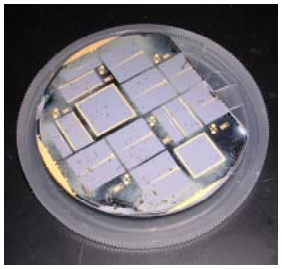
Description

- Solar cell and semiconductor materials growth
- Photovoltaic (PV) device fabrication
- Measurement / characterization of PV cells and solar arrays
- Modeling / measurement of plasma interactions of solar arrays within the space environment
- High performance / light weight PV systems for space applications



Novel deployable arrays for space applications

High efficiency flexible arrays



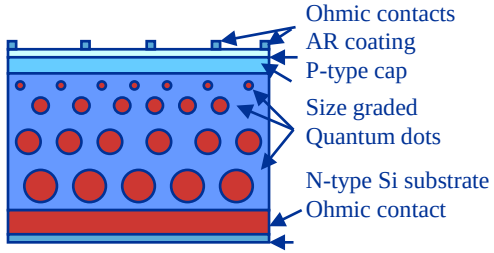
Solar cell growth on alternate substrates

Focus Areas

- Polycrystalline thin film III-V photovoltaics
- Independent analysis / testing and data verification for space applications
- Off-pointing performance analysis
- Dust mitigation
- Lunar and beginning of life performance optimized cell designs
- Solar cell measurement / calibration
- Extended temperature solar cells
- Nanomaterials and nanostructures
- Thermophotovoltaic technology
- Lightweight solar arrays / blanket development
- Low intensity / low temperature (LILT) solar cell performance

Facilities/Labs

- Several chemical vapor deposition reactors
- Plasma interactions facility
- World class space solar cell calibration and measurement facilities
- Lear jet high altitude solar cell calibration
- Electron microscopy facilities
  - Atomic force microscopy
  - Scanning tunneling optical resonance



Nano-photovoltaics

Accomplishments

- Subsystem testing of a 38 watt thermophotovoltaic (TPV) power system for exploration missions. (2008)
- Demonstrated 17.1% air mass 0,open circuit voltage = 1.023V, short circuit current = 28.3 milliamp, fill factor = 80.3 Gallium Arsenide on Silicon solar cells (2001)
- First demonstration of multi-junction III-V solar cells on Silicon (2005)
- On-orbit durability testing of Gallium Arsenide solar cells on Silicon on Space Station (2006)
- Integrated micro-power system on a 1 inch square chip successfully flown on Starshine 3 (2001)

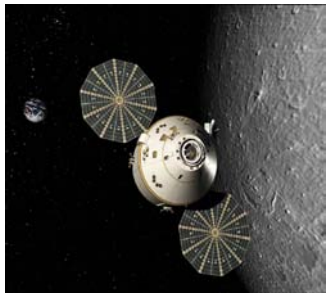
Program/Project Management

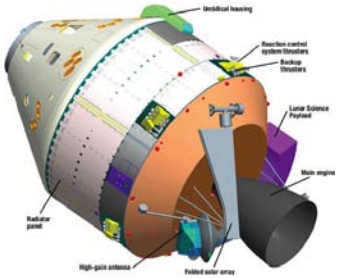
Centaur Launch Vehicles

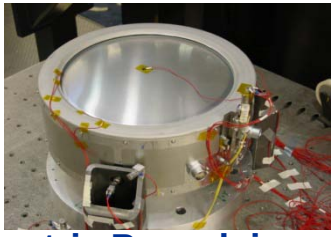
- Managed 119 launches (1963-1997)
- Over 91% launch success rate

Orion

- Currently managing the Service Module component





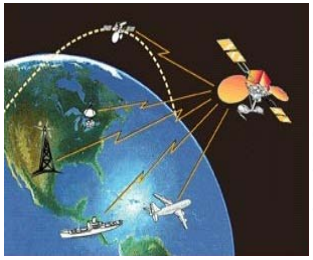


Electric Propulsion

- Invented first Hall and ion thrusters; designed, built and delivered Deep Space I Ion Engine

Aeropropulsion

- Managed Energy Efficient Engine Program, demonstrated 15% reduction in fuel consumption, enabling development of GE 90 turbine engine



Communications

- Developed first ever Ka band communications satellite
- Over 150 organizations in 31 states
- Conducted over 100 experiments

Space Station Freedom

- Designed the largest power system ever deployed in space

Microgravity

- Over 90% success rate in developing/managing 130 microgravity experiments on Spacelab, Spacehab, Mir and International Space Station

NASA Program/Project Management Training Levels

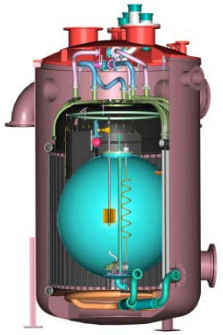
- 57 Level I Entry Level Project Managers
- 23 Level II Journey Project Managers
- 18 Level III Advanced Project Managers
- 6 Level IV Program Managers

Propellant Systems

Description

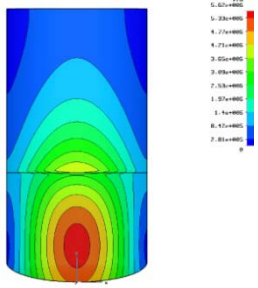
- Storage, management, and use of cryogenic propellants for ground and in-space applications
- *Reduced boil-off:* use of cryocoolers to achieve reduced or zero boil-off by eliminating heat leak into the storage tank, re-condensing gas, or potentially sub-cooling propellant
- *Efficient low-g venting* - thermodynamic vent system ensures that only gas phase is vented in low gravity without using settling thrusters
- *Propellant Gauging* - accurate determination of propellant mass in low-g or settled state
- *Densification* - technology to subcool cryogenic propellants to increase density, improve vehicle performance, eliminate boil-off

Long Duration Storage Technologies



Facilities/Labs

- Cryogenic test complex
  - Small multi purpose research facility
  - Thermal vacuum chamber
  - Multiple cryogens (Oxygen, Hydrogen, Methane, Nitrogen)
- Cryogenic components lab (Plumbrook K-Site)



Propellant Gauging Technologies

Slush Hydrogen and Densification

Focus Areas

- Mass gauging (optical, radio frequency, and pressure-volume-temperature)
- Single phase flow propellant management devices
- Advanced insulation and active cooling concepts
- Methane densification
- CFD modeling of fluid and thermodynamics
- Leak Detection
- Hydrocarbon fuel technologies

Accomplishments

- LOX/LCH4 ignition technology demonstrations (2007)
- Developed RP-2 fuel with ARFL and MSFC (2006)
- Liquid acquisition device fundamental performance with cryogens: (liquid Nitrogen–1999), (liquid Hydrogen- 2000),(liquid Oxygen–2005, 2007), (liquid Methane–2006)
- Radio frequency & Pressure-Volume-Temperature (PVT) mass gauges accuracy demonstrated in oxygen (2007, 2008)
- >200,000 gallons slush liquid Hydrogen produced (1988-1994)
- First ever zero boil-off concept feasibility demonstration with hydrogen (1998)
- Captive firing/mission simulation of complete Delta 3 oxygen/hydrogen upper stage (1998)

Structures

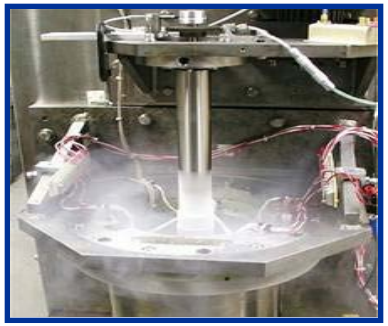
Description

- Fluid-structure interaction
- Impact mechanics and energy absorbing structures
- Predicting and verifying structural dynamics responses, loads, vibration, acoustic, and shock environments for flight structures
- Aero-elasticity and adaptive structures
- Structural and mechanical design from concept through fabrication and integration of aerospace flight structure
- Stress / deflection, modal, and buckling analysis
- Pressure vessel design and analysis

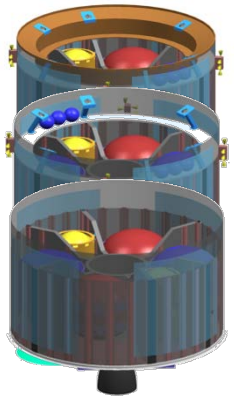
Focus Areas

- Structural dynamics analysis of CEV/CLV components
- Ballistic impact testing and analysis of orbiter windows, leading edge, thermal protection system, and external tank materials
- High fidelity aeroelastic computational tools
- Space and launch environments
- Finite element modeling techniques

Ballistic impact testing



Cryogenic motors

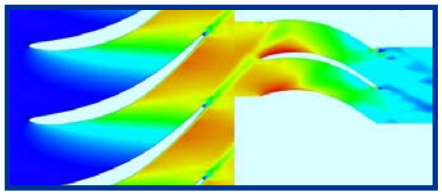


Service Module study

Facilities/Labs

- Aeroelastic and structural testing in supersonic and low-speed wind tunnels
- Adaptive structures lab
- Dynamic spin rig
- Turboeletric propulsion lab
- Ballistic impact test facility
- Structural statics and dynamics labs
- Acoustic testing lab

Fluid-structure interaction modeling



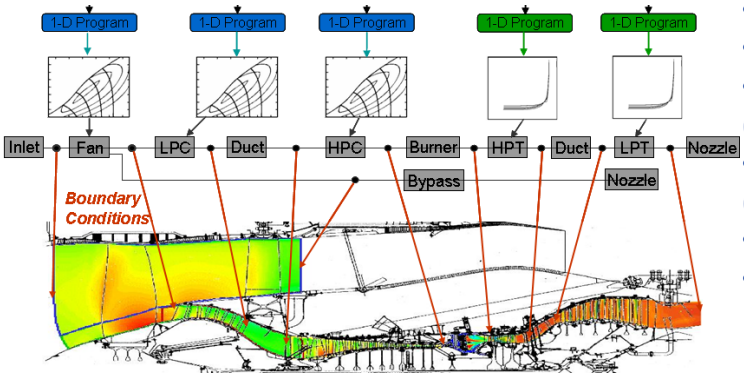
Accomplishments

- Crew Exploration Vehicle Integrated Environmental Testing Vibroacoustic Engineering Lead Role (2007 – present)
- Damping devices for aircraft engine blades (2008)
- Ballistic impact tests and analysis to support the shuttle to the return to operational status (2005-06)
- Crew Exploration Vehicle spacecraft adapter lead role and Service Module structural design key role (2004 - present)
- Crew Launch Vehicle ARES I-1 upper stage segment structural loads and dynamics lead role (2004 - present)
- Concept studies for CEV Service Module have had direct impacts on Lockheed Martin's configuration (2006)

Systems Analysis

Description

- Unique analysis abilities and tools
- Analysis of vehicle synthesis
- Mission analysis/design
- Propulsion and power analysis
- Concept development
- Aero safety analysis



Propulsion system simulation

Facilities/Labs/Tools

- Numerical Propulsion System Simulator (NPSS)
- Structural Airfoil Blade Engineering Routine (SABER)
- Flight Optimization System (FLOPS)
- Orbital Trajectory by Implicit Simulation (OTIS)
- Space Power Analysis for Capacity Evaluation (SPACE)
- Process Based Economics Analysis Tool (PBEAT)
- Logic Evolved Decision (LED)
- WATE – Weight Analysis of Turbine Engines

Lunar Lander

Focus Areas

- Advanced systems analysis and numerical optimizations methods
- Environmental impact analysis (noise and emissions)
- Program support
  - Requirement definitions
  - Analytical analysis
  - Independent verification and validation
  - Metrics, earned valued
  - Economic analysis
- Independent reviews
- Weight and conceptual layout
- Propulsion performance analysis
- Reliability and systems safety analysis

Rocket propulsion

Accomplishments

- NPSS National Consortium (2008)
- Multi-fidelity simulation of the GE90 engine (2008)
- Embedded propulsion concept development for Boeing Hybrid Wing Body (2008)
- Transient Engine Modeling for Control Technology Integration (2008)
- Green propellant thermal cycle evaluation (2006)
- International Space Station vacuum power design (2006)
- Analysis of Crew Exploration Vehicle/Crew Launch (2006)
- Lunar Surface Access Module designs (2006)
- Lunar surface power architecture (2006)

Systems Engineering

Description

- Engineering expertise in the development of multi-disciplinary space flight systems
- Development and maintenance of systems engineering processes
- Application of systems engineering processes at a system level
- Technical management of systems

Crew Exploration Vehicle

Crew Launch Vehicle

Focus Areas

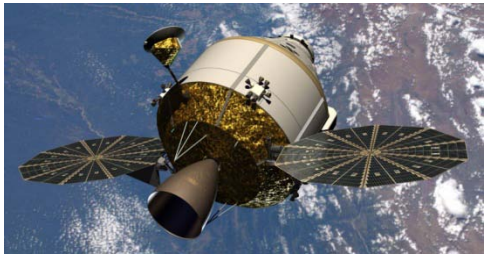
- System development
- Requirements development and management
- Verification and validation planning
- System integration
- Technical decision analysis
- Technical reviews

Space Station Fluids and Combustion Facility

Delta-III Vehicle in B-2 facility

Facilities/Labs/Tools

- Commercial software codes:
  - DOORS®
  - Cradle®
  - Sizer- a preliminary vehicle synthesis, sizing and scaling software tool



Crew Exploration Vehicle

Accomplishments

- Accelerated training program for new and experienced systems engineers. Over 30 graduates in 2007 and 2008.
- Accelerated training program for new systems engineers (2006)
- Leading the development of requirements for the Crew Exploration Vehicle (2005-present)
- Leading the systems engineering on various portions of the Crew Exploration Vehicle and Crew Launch Vehicle (2005-present)
- Successful development, integration and operations of microgravity experiments on shuttle and station (1992-present)

Thermal Energy Conversion

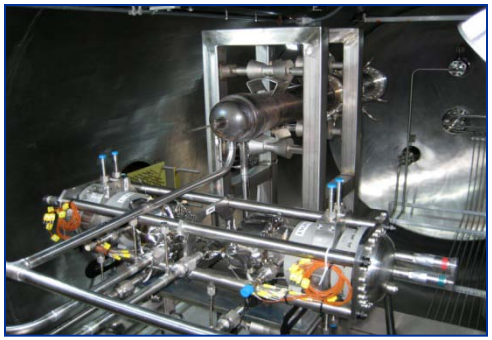
Description

- Thermal Energy Conversion
- Dynamic Power: Brayton, Rankine & Stirling
- Fission & Isotope Power Generation (partner w/DOE)
- Radiator System Development
- Modeling and Conceptual Design
- System Performance Modeling
- End-to-End System Testing

Advanced Stirling Radioisotope Generator Engineering Unit (ASRG EU)

Facilities/Labs

- Radiator & Lunar Simulation Facility
- Brayton & Alternator Test Facilities
- Heat Pipe Laboratory
- Stirling Research Laboratory
- Ambient test stand (6)
- Thermal Vacuum Facility (small)
- High Power FSP Prototypes
- Large Thermal-Vacuum Facility
- 24 meters x 8 meters diameter
- Solar Simulator
- Integrated end-to-end testing
- Lunar PMAD Facility
- Polymer Composites Laboratory
- High Temperature Creep Lab
- Stirling CFD Computer Cluster (374 parallel processor)



2 kWe Stirling Convertor

Focus Areas

- Brayton and Stirling Energy Conversion
- Heat Rejection Systems
- Electrical Controllers
- Power Management and Distribution
- Reactor & Isotope Heat Sources (partner w/DOE)
- Component Development: Organics, Alternators, Heat Exchangers, Composites, Magnets, etc.
- High Temperature Materials
- Reliability and Endurance 24/7 Testing

High Temperature Water Heat Pipe Lab

Accomplishments

- Over 200,000 hrs. of continuous operation 24/7 on ten (10) 100 We class Stirling convertors (2008)
- Demo of high efficiency 2 kWe Stirling Convertor (2008)
- Demo of 50 kW Brayton Alternator Test Unit (2006)
- Demo of 20 kW Dual Closed Brayton Test System (2007)
- Over 2 years of long-term life testing 24/7 of 500K Titanium-Water Heat Pipes (2008)
- Demo of 500K Polymer-Matrix Composite Radiator Panels (2006)
- Over 2000 hrs. of 24/7 operation of the Advanded Stirling Radioisotope Generator Engineering Unit (ASRG EU) (2008)

For Additional Information

- Wind Turbines
  - R.L.Thomas, DOE/NASA Lewis Large Wind Turbine Program, NASA TM-82991, 1982.
- Hydrogen Issues
  - NASA/DOE HEST (Hydrogen Energy Systems Technology) Study, June 1975.
  - Potential Structural Material Problems in a Hydrogen Energy System, *International Journal of Hydrogen Energy, Vol 3, pp. 105-118. Pergamon Press, 1978.*
- Electric Vehicles
  - *Collie, M.J. Electric and Hybrid Vehicles. ERDA and NASA Lewis Research Center, Report No.- 80A15658, Jan 1,1979.*
  - *Viterna, L.A., Ultra-Capacitor Energy Storage in a Large Hybrid Electric Bus. NASA TM-97-206319, 1997.*

Closing Thoughts

- NASA Glenn (Lewis) played an important role in energy development in the 70-80's to help address national needs.
- Trusted partner with DOE – Wind Turbines, Hydrogen Energy Studies, Auto Gas Turbines, Electric Vehicles, …
- Many of our current competencies (people, facilities) are aligned with current national needs regarding energy.
- We desire to partner, where appropriate, with organizations such as DOE to contribute to our country's emerging needs in energy.

Partnership Contact

- We look forward to exploring possible partnership efforts with your organization.

- To continue our partnership exploration, please contact:
  Dr. Robert “Joe” Shaw
  Chief, Business Development and Partnership Office
  Phone: (216) 977-7135
  Email: robert.j.shaw@nasa.gov
  For More information: http://newbusiness.nasa.gov/

- Glenn Research Center Websites
  - **General information about Glenn**
    - http://www.nasa.gov/centers/glenn/
  - **Glenn Test Facilities Guide**
    - http://www.nasa.gov/centers/glenn/testfacilities/
  - **Glenn Research Center Resume**
    - http://www.nasa.gov/centers/glenn/about/index.html