Energy Collaboration Opportunities

Robert J. Shaw
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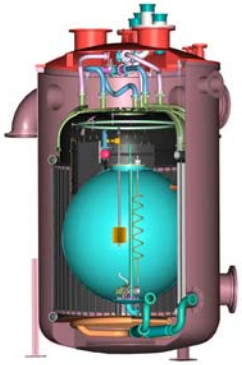
NASA Glenn Research Center

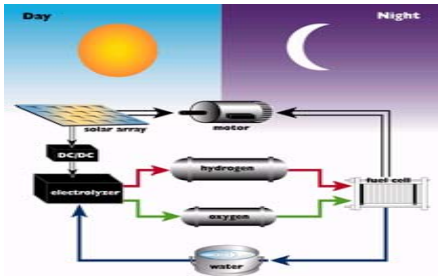
Experimental wind turbine In Sandusky Ohio

High efficiency flexible photovoltaic arrays

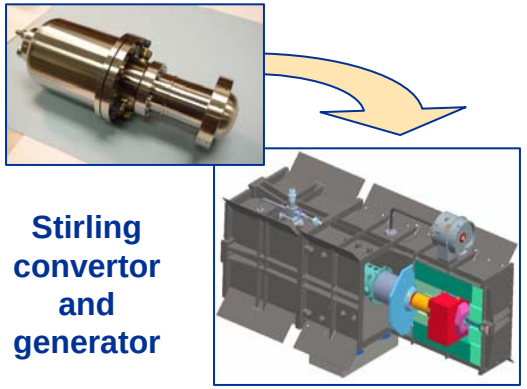


Long duration hydrogen storage

Solar simulator



Regenerative fuel cell



Stirling convertor and generator

Demonstrated track record of energy-related technologies since the 1970's

Version and Audit Information

Version : GRCEnergyCompetencies (5-7-08)

Disclaimer:
These charts continue to be updated and redesigned. We recommend that you check with Lynn Boukalik, (216 433-9701) (lynn.h.boukalik@nasa.gov) to ensure that you have the latest version. We are also maintaining an audit list of where this file is distributed, please tell us if you have distributed the file to others.

Ground breaking for the NACA Aircraft Engine Research Laboratory January 23, 1941

Glenn Research Center's Two Campuses

Cleveland (Brook Park and Fairview Park)

- **350 acres**
- **~1600 civil servants and 1200 contractors**

Plum Brook (Sandusky)

- **6400 acres**
- **~10 civil servants and 80 contractors**

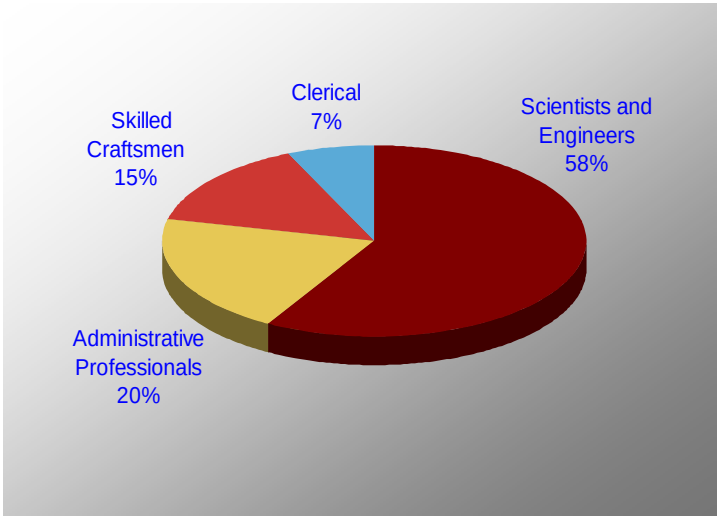
Civil Service Workforce

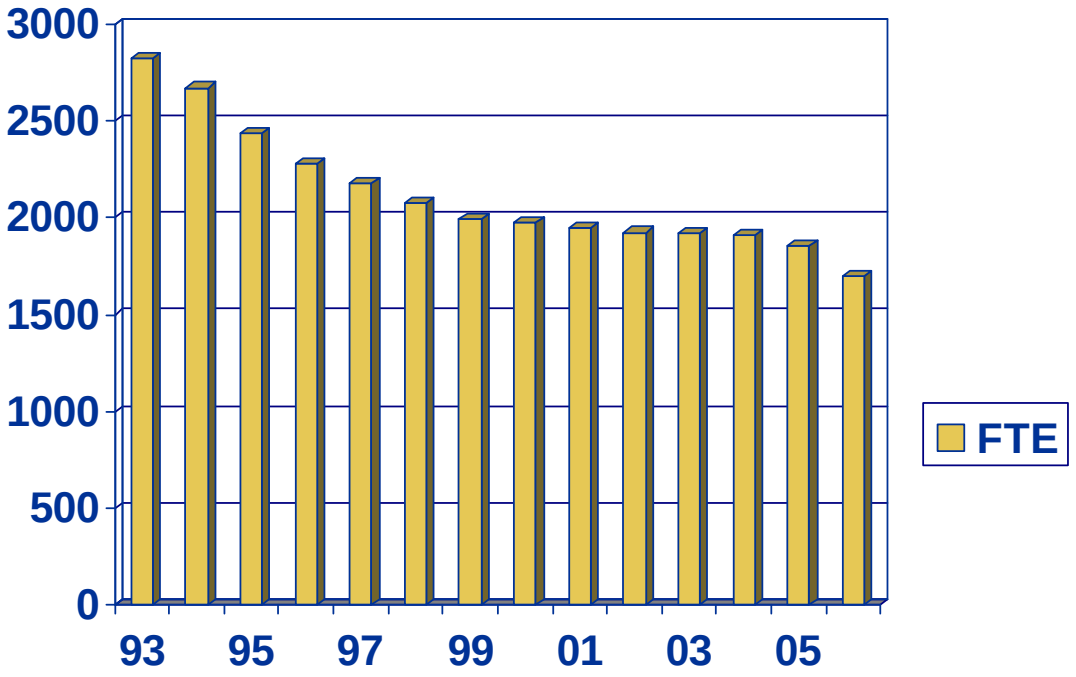
- 75% of workforce charges their time directly to the technical mission
- 67% of scientists and engineers have advanced degrees, 25% with earned Ph.D's

Administrative and Clerical

Scientists and Engineers

Skilled Craftsman





Mission and Product Lines

- Glenn Research Center is a NASA Field Center with the top priority to support the Agency's four **missions**:
  - Space Exploration
  - Space Operations
  - Earth and Space Science
  - Aeronautics
- GRC's major **product lines** of power, propulsion, and communications are critical to achieving the Agency's future objectives.

Competencies and Partnerships

- The **competencies** required to produce technologies for these major product lines are well aligned with priority national objectives.
- GRC will aggressively look to form **partnerships and seek new business opportunities** that fit the following criteria:
  - GRC competencies are required and the proposed effort will either maintain or strengthen those competencies.
  - The business case is positive for both our partner and GRC.

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**)	2 detailed charts in Appendix
Communications	Antenna Test Facility, Communications Testbed, 35 R&D labs	5 detailed charts in Appendix
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. 6 detailed charts in Appendix
Instrumentation, Controls, Electronics	31 R&D Labs, Clean Rooms (p 33**)	3 detailed charts in Appendix
Materials	142 R&D Labs, Large Multi-Axial Fatigue Facility (p 32**)	5 detailed charts in Appendix

** Facilities Brochure
http://www.nasa.gov/centers/glenn/testfacilities/

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, BioTech 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**)	3 detailed charts in Appendix
Systems Analysis	World-Class Aerospace Analysis Tools	
Systems Engineering	Development and Verification Labs	
Thermal Energy Conversion	Power Systems Facility	Includes power

** Facilities Brochure
http://www.nasa.gov/centers/glenn/testfacilities/

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

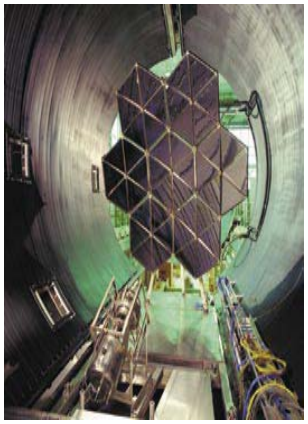
- Power Management & Distribution
- Pipelines

Cross Cutting Competencies

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

Selected Energy Related Labs and Facilities

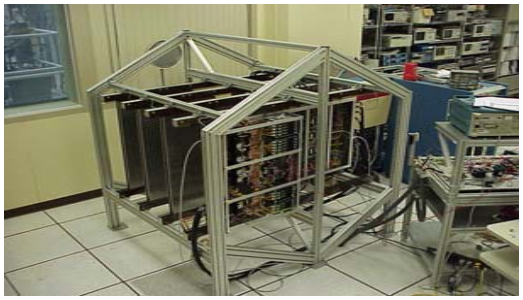
Spirit/Opportunity Rover



Solar concentrator

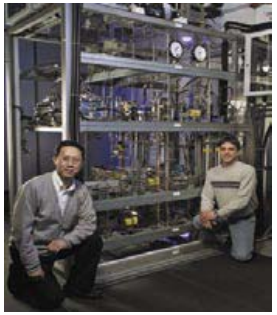
Space power facility

Fuel cells test lab



Advanced electric power test-bed

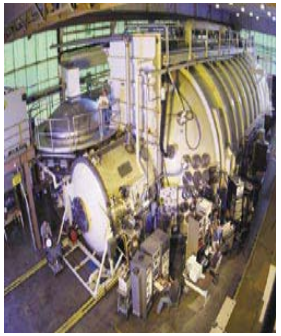
Fuel cell and electrolyzer in regenerative fuel cell rig



Regenerative fuel cell rig

Instrumentation and controls lab

10 x 10 wind tunnel



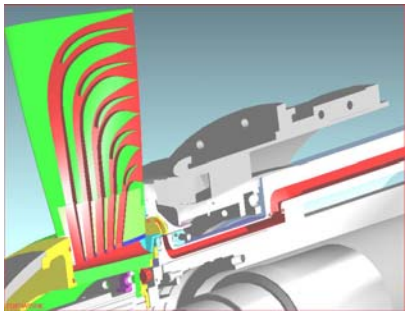
Solar simulator

Slush Hydrogen and densification

Acoustics

Description

- Fundamental and applied research for engine noise reduction
- Noise prediction methods for turbofans
- Source diagnostic methods
- Supporting subsonic, supersonic, and rotorcraft propulsion



Fan trailing edge blowing

Facilities/Labs

- Wind Tunnel (9'x15')
- Fan test lab
- AeroAcoustic Propulsion Laboratory
  - Nozzle acoustic test rig
  - Small hot jet acoustic 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
- New emphasis on fan noise associated with space applications

Jet noise flow diagnostics

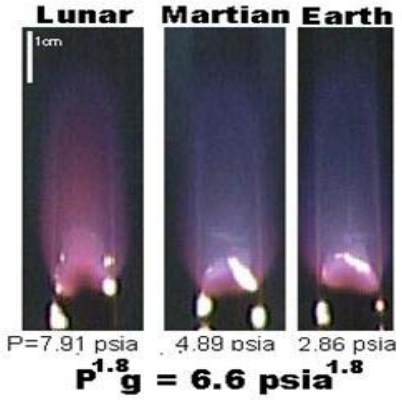
Accomplishments

- Quantified 1-3 decibel (dB) fan noise reduction from new concepts such as trailing edge blowing, over the rotor treatment, and variable area nozzles (2005/2006)
- Predicted and verified 2-3 dB jet noise reduction from offset and chevron nozzles (2005)
- Developed time-domain fan noise prediction method and improved jet noise prediction code (2005/2006)
- Engine noise data base for Honeywell Tech 7000 turbofan (2006)

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

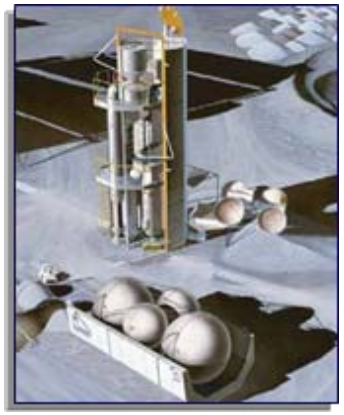


Material flammability testing

Particulate emissions from B-52 bomber

Focus Areas

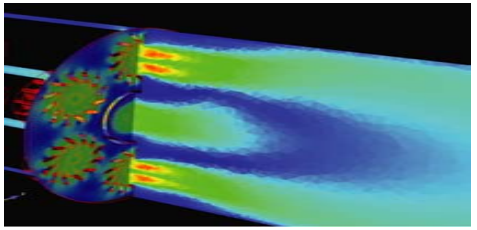
- Combustion diagnostics development and validation experiments
- Combustion Computational Fluid Dynamics code validation experiments
- Low emissions combustion
- Particulates / particle measurements
- Active combustion control
- Alternative fuels
- Combustion physics
- Fire safety



Lunar in-situ resource utilization facility

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

Accomplishments

- 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 distribution units
- Advanced power components
- Switches/converters
- Capacitors/magnetics
- 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, Integrated Solar Upper Stage (Air Force)
- Demonstrated integrated momentum and power control with flywheel system operating at 60,000 rpm

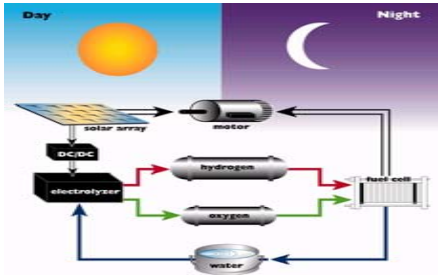
Electrochemistry-Physics

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 low temperature operations 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 (-75 °C to +200 °C)



Regenerative 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
- System modeling and analysis
- Technology validation, mission operations

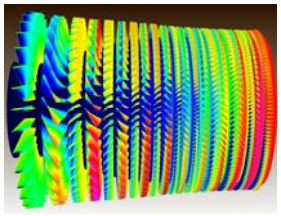
Accomplishments

- Gemini, Apollo, and Shuttle fuel cell technology Development 1960's - 1970's)
- Fuel cell demonstration scientific balloons; Helios (2001)
- Program with DoD for lithium-ion batteries for Mars Exploration Rover (2002)
- Evaluated battery technologies for Space Station and Electric Auxiliary Power Unit replacement for Shuttle (2000)
- 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)
- Conducted Lithium-Ion verification test program (2001)

Fluids, CFD and Turbomachinery

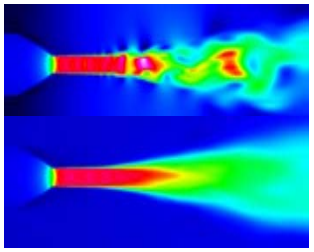
Description

- 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, operability efficiency and turbine cooling capabilities
- Explore the fundamental principles of physics and chemistry through research in the unique natural laboratory of space



RANS and LES simulation of compressors

Thrust vector control



Instantaneous

Time-Averaged

Large eddy simulation of mach 1.4

Facilities/Labs/Tools

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

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)

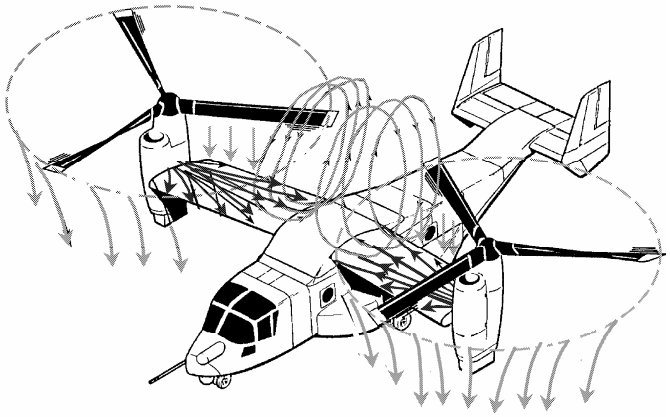
THE NATIONAL CENTER FOR MICROGRAVITY RESEARCH
NCMR
FLUIDS AND COMBUSTION

Accomplishments

- Mach 2.4 external compression inlet concept developed (2005)
- Offset stream nozzle technology validated with CFD tools, utilizing state-of-the-art turbulence models for jet flows, and experimental database (2006)
- Aerodynamic testing of a highly loaded multi-stage axial compressor with 4.5 pressure ratio (2006)
- Developed Large Eddy Simulation technique for turbomachinery flow analysis. (2005)
- Tip gap aerodynamic and heat transfer measurements in transonic turbine cascade (2004)
- Completed performance tests of wave rotor (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

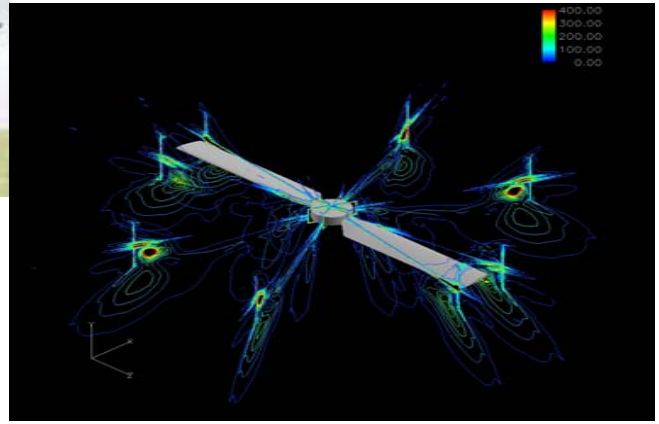
Rotary-wing-specific issues

- 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.

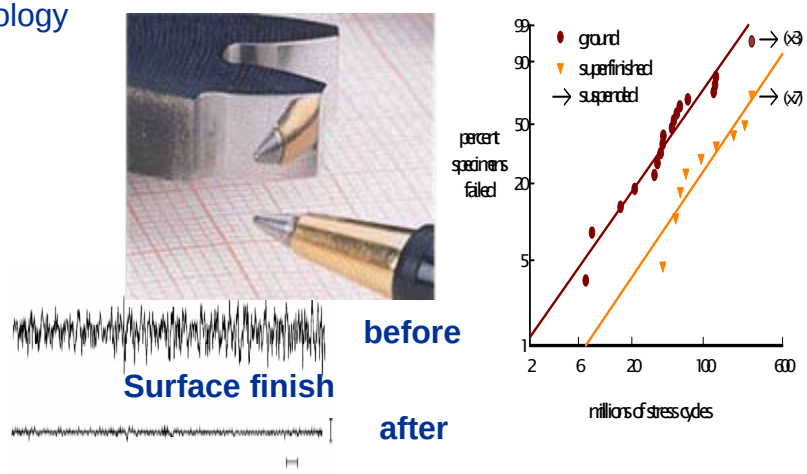
Mod-5B 3.2 MW (100 m diameter) wind turbines in the state of Hawaii was the largest in the world.

Mechanical Components and Lubrication

Description

- Drive system technology
- Gears and bearings
- Fundamentals of lubrication (tribology)

Gear surface fatigue life increased by 4 X by superfinishing process



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

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

Accomplishments

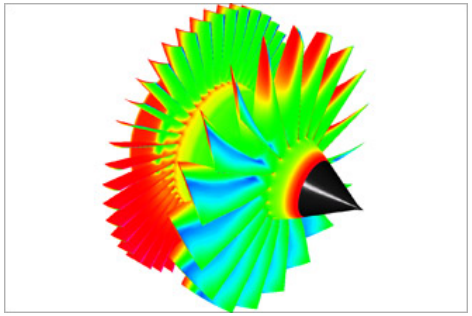
- High speed gearing windage and performance assessment (2006)
- Advanced gear material contact and bending fatigue testing completed (2006)
- Advanced lubricant developed for extended loss-of-lube operation of gears (2005)
- Superfinished gear surface fatigue life testing completed (2004)
- Diagnostic tool developed for gear contact fatigue use data fusion and fuzzy logic (2003)
- Gear crack propagation methodology developed for thin rimmed gears

Modeling, Simulation, and Visualization

Description

- Design and analysis of component and system operations
- Support design of new technologies
- Provide detailed understanding of experimental data

3D iced inlet simulation



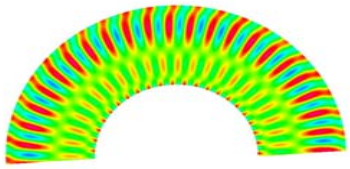
3D engine simulation

Facilities/Labs/Tools

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

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



Noise analysis

Accomplishments

- Numerical Propulsion System Simulator reduces analysis time by 55% (2001)
- TURBO-AE used by Air Force and 20 companies (1995 to present)
- Significant engine noise reduction achieved utilizing GRC codes (15 unique codes)
- 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)
- LEWICE 2D/3D (LEWis ICE accretion program) utilized by industry to design more efficient aircraft deicing systems for safe operations (2006)
- Virtual treadmill collaborations with Cleveland Clinic for astronaut health monitoring (2004)
- SIZER enables preliminary vehicle synthesis, sizing and scaling functionality for mission planners and requirements analysis

Photovoltaics

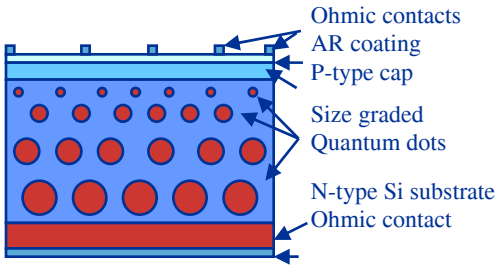
Description

- Materials growth
- Device fabrication
- Measurement / characterization of cells and arrays
- Modeling / measurement of plasma interactions with high voltage arrays
- High power / light weight systems for space applications

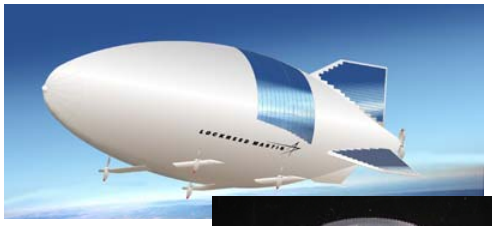
Novel deployable arrays for space applications

Facilities/Labs

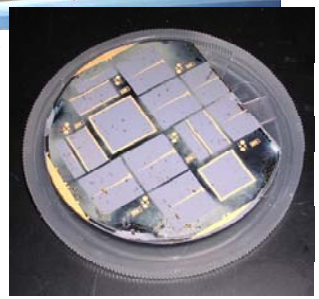
- Several chemical vapor deposition reactors
- Plasma interactions facility
- Lear jet calibration platform
- Electron microscopy facilities
  - Atomic force microscopy
  - Scanning tunneling optical resonance



Nano-photovoltaics



High efficiency flexible arrays



Focus Areas

- Polycrystalline thin film III-V photovoltacis
- 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

Accomplishments

- 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)

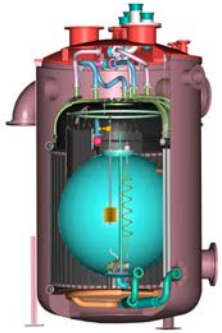
Propellant Systems

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
- Develop the technology to subcool cryogenic propellants to increase density, improve vehicle performance, eliminate boil-off

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)



Long duration storage

Slush Hydrogen and densification

Insulation

Focus Areas

- Mass gauging (optical, radio frequency, and compression bellows)
- Single phase flow propellant management devices
- Advanced insulation and active cooling concepts
- Hydrogen densification

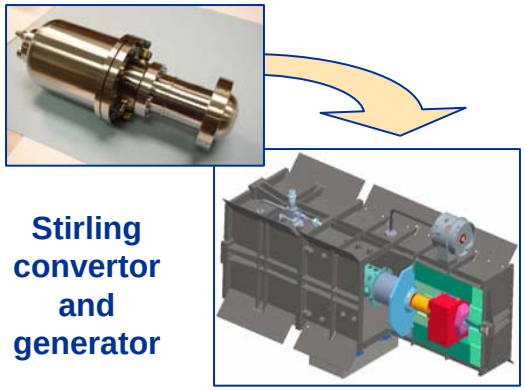
Accomplishments

- >200,000 gallons slush liquid Hydrogen produced (1988-1994)
- First ever zero boil-off concept feasibility demonstration with hydrogen (1998)
- Liquid acquisition device fundamental performance with cryogens: (liquid Nitrogen–1999), (liquid Hydrogen- 2000),(liquid Oxygen–2005), (liquid Methane–2006)
- Radio frequency mass gauge demonstration in oxygen (2006)
- Captive firing/mission simulation of complete Delta 3 oxygen/hydrogen upper stage (1998)

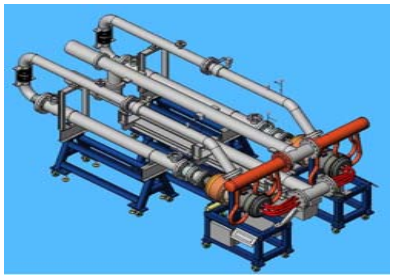
Thermal Energy Conversion

Description

- Thermal energy conversion
- Dynamic power: Brayton, Rankine and Stirling
- Fission and isotope power generation (partner with DOE)
- Radiator system development
- Modeling and conceptual Design
- System performance modeling
- End-to-end system testing



Stirling convertor and generator



Dual closed-Brayton test loop

Facilities/Labs

- Brayton and alternator facility
- Heat pipe laboratory
- Stirling research laboratory
  - Ambient test stand (6)
  - Thermal vacuum facility (small)
- Large thermal-vacuum facility(24mx 8m)
  - Solar simulator
  - Integrated end-to-end testing
- Lunar power management and distribution facility
- Polymer composites laboratory
- High temperature creep Lab

Focus Areas

- Brayton and Stirling energy conversion
- Heat rejection systems
- Electrical controllers
- Power management and distribution
- Reactor and isotope heat sources (partner with DOE)
- Component development: polymer composites, alternators, heat exchangers, composites, magnets
- High temperature materials
- Reliability and endurance testing

High temperature water heat pipe lab

Accomplishments

- Over 90,000 continuous hours of operation (24/7) on eight 100 watts electric Stirling convertors (2006)
- Demo of high efficiency ~40% Stirling convertor (2006)
- Demo of 50 kilowatts Brayton alternator test unit (2006)
- Demo of 30 kilowatts dual closed Brayton test system (2006)
- Long-term life testing at 230 ºC titanium-water heat pipes (2006)
- Demo of 230 ºC polymer-matrix composite radiator panels (2006)

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

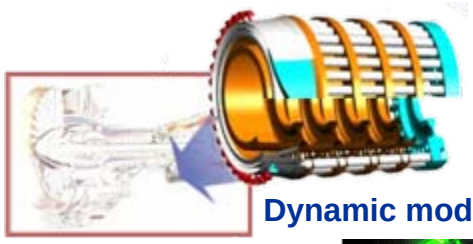
Instrumentation, Controls and Electronics

Description

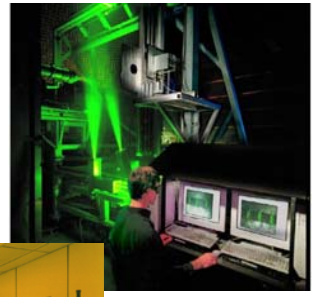
- Sensor development for harsh environments
- Optical instrumentation and NDE
- Controls and dynamics
- Design, development and testing for space flight instrumentation
- Digital circuit board design and analysis for aerospace
- Electronics for cryogenic environment
- Intercalated graphite conductors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

Focus Areas

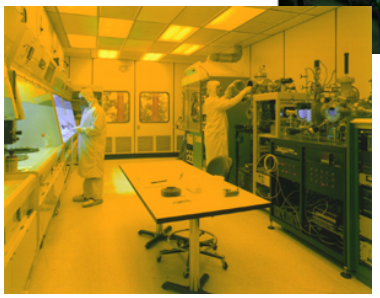
- Intelligent control and propulsion health monitoring and physics-based modeling
- Optical flow path measurements
- NDE methods development
- Silicon Carbide based electronic devices and MicroElectroMechanical Systems (MEMS)
- Robotics technology development
- Crew Exploration Vehicle avionics
- Crew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



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)

Accomplishments

- 1400 ºC temperature sensitive paint sensor
- Zero false alarm fire detection system demonstrated (R&D 100 Award) (2005)
- High temperature (600°C) Silicon Carbide pressure transducer demonstrated (2006)
- Portable unit for metabolic analysis demonstration (2006)

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)

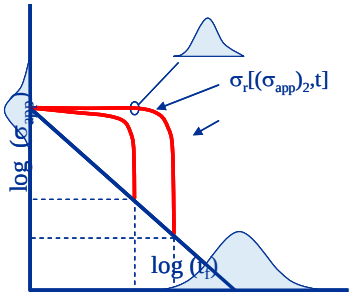
Ceramic matrix composite vane with environmental barrier coating

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 thermomechanical and subcomponent test facilities encompassing a wide range of temperature, environmental, and load regimes
- Atmospheric and high pressure burner rigs

Focus Areas

- Aerospace propulsion materials (metals, polymers, ceramics, coatings, composities) 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



Probabilistic life prediction model

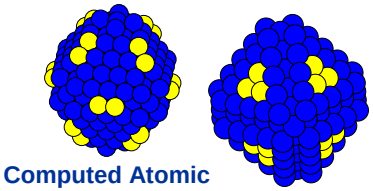
Accomplishments

- 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)
- Integrated multiscale Micromechanics Analysis Code (2005)
- Advanced probabilistic structural analysis tool (2005)

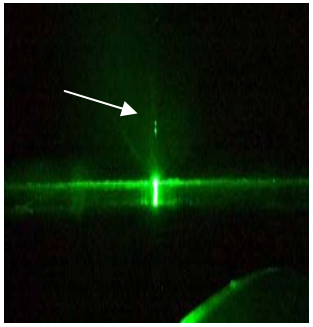
Nanotechnology

Description

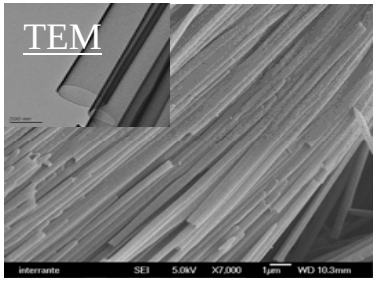
- Modeling - atomistic computational alloy design
- Nanomaterials - synthesis of Boron Nitride, Metal Oxide, Carbon-nanotubes and smart polymeric materials for high temperature and harsh environment use
- Nanophotonics - optical trapping for device manipulation and fabrication
  - quantum dots/optical 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



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

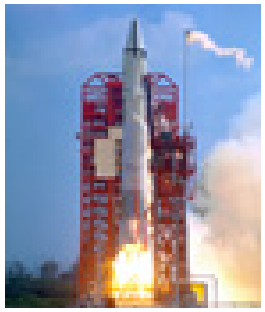
Focus Areas

- 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

Accomplishments

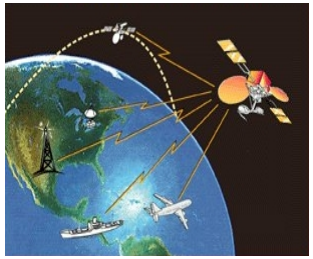
- Calculation of free surface energetics of nanoparticles (2004)
- Demonstrated Boron Nitride nanotube composite with superior hydrogen storage (2006)
- Detected Hydrogen with Tin Oxide electrospun nanofibers (2006)
- Experimentally verified a light propagation model for predicting light scattering from 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)

Program/Project Management



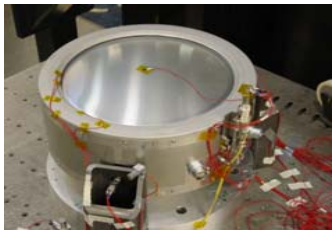
Centaur Launch Vehicles

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



Communications

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



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

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

Structures

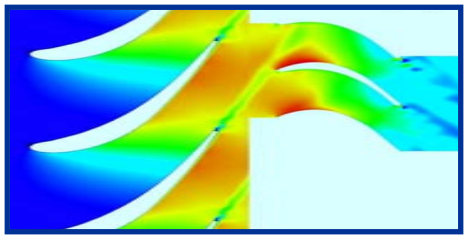
Description

- Fluid-structure interaction
- Impact mechanics and energy absorbing structures
- Predicting and verifying structural dynamics responses, loads, vibration, acoustic, and shock environments for flight structures
- 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

Ballistic impact lab

Facilities/Labs

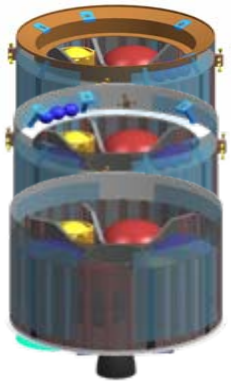
- Aeroelastic and structural testing in supersonic and low-speed wind tunnels
- Ballistic impact test facility
- Structural statics and dynamics labs
- Acoustic testing lab



Fluid-structure interaction modeling

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



Service Module study

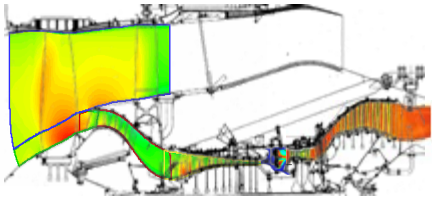
Accomplishments

- 3-D Navier-Stokes TURBO aeroelastic code developed and validated (2005)
- 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



Aeropropulsion

Lunar Lander

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)

Focus Areas

- Architecture studies
- Space mission operations
- System trade studies
- Program support
  - Requirement definitions
  - Analytical analysis
  - Independent verification and validation
  - Metrics, earned valued
- Independent reviews
- Assess technologies
  - Gaps, benefits
- Methods development

Rocket propulsion

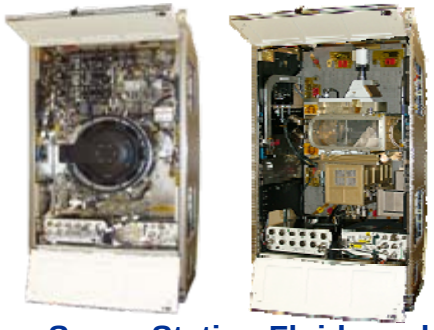
Accomplishments

- Green propellant thermal cycle evaluation (2006)
- International Space Station vacuum power design (2006)
- Flight Performance Systems Integration Group (2006)
- Analysis of Crew Exploration Vehicle/Crew Launch (2006)
- Vehicle power and trajectory (2006)
- Lunar Surface Access Module designs (2006)
- Lunar surface power architecture (2006)
- Cargo launch vehicle design (2006)
- Engineering based cost analysis (2006)
- Proposal development and evaluation (2006)
- Delta 3 oxygen/hydrogen upper stage historical repository of data (2006)

Systems Engineering

Description

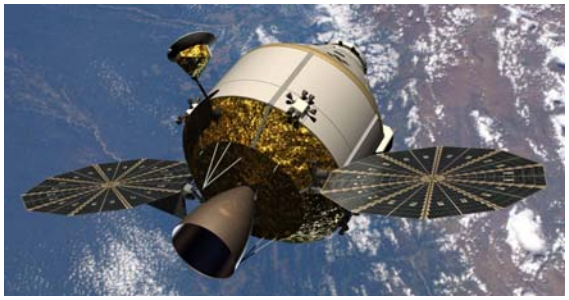
- Development and maintenance of systems engineering processes
- Application of systems engineering processes at a system level
- Technical management of systems



Space Station Fluids and Combustion Facility

Facilities/Labs/Tools

- Commercial software codes:
  - DOORS®
  - Cradle®



Crew Exploration Vehicle

Crew Exploration Vehicle

Crew Launch Vehicle

Delta-III Vehicle in B-2 facility

Focus Areas

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

Accomplishments

- Successful development, integration and operations of microgravity experiments on shuttle and station (1992-present)
- 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)
- Accelerated training program for new systems engineers (2006)

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 NREL to contribute to our country's emerging needs in energy.

Partnership Contact

- We look forward to exploring potential partnerships with your organization.

- To continue our partnership exploration, please contact:
  Dr. Robert J. Shaw
  Chief, Business Development and Partnership Office
  Phone: (216) 977-7135
  Email: robert.j.shaw@nasa.gov

- Glenn Research Center Websites
  - **Business Development and Partnership Office**
    - http://newbusiness.grc.nasa.gov
  - **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