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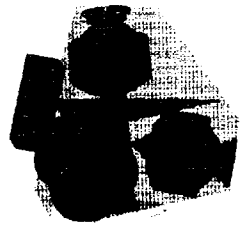

NASA Flywheel System Development

Space Power Workshop
April 4, 2001

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NASA Flywheel System Development Introduction

- **The Aerospace Flywheel Technology Program is a research and technology development program funded by the Cross-Enterprise Technology Development/ Space Base Program, NASA Code R**
- **The Aerospace Flywheel Technology Program is funded and directed out of the Power and On-board Propulsion Thrust Area of the Space Base Program; Thrust Area manager, Mr. Joseph Nainiger NASA GRC**
- **The Aerospace Flywheel Technology Program is jointly managed, supported and sponsored by the Power and Propulsion Office and the Power and On-board Propulsion Technology Division at NASA Glenn Research Center**

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NASA Flywheel System Development Acknowledgements

- Jeff Trudell, NASA Glenn Research Center
- Larry Trase, NASA Glenn Research Center
- Al Kascak, Army Research Laboratory at NASA GRC
- Ralph Jansen, Ohio Aerospace Institute
- Yasser Gowayed, Auburn University

NASA Flywheel System Development Objectives

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- Develop advanced aerospace flywheel component and system technologies to meet NASA's long term mission needs
  - Energy Storage
  - Integrated Power and Attitude Control
  - Power Peaking
- Near term focus on "Century" class flywheels, 300-700 WHr capacity, for mid-sized satellite applications
- Longer term development of flywheels, < 100WHr capacity, for small satellite applications
- Demonstrate flywheel technology goals
  - System Specific Energy (usable) > 20 WHr/Lb (within 5 years), > 100 WHr/Lb long term
  - Cycle Life > 75,000
  - Round Trip efficiency > 90%
  - System Cost Reductions > 25%

Flywheel Development for NASA Missions

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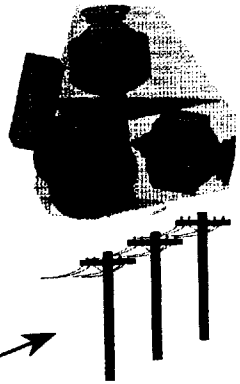
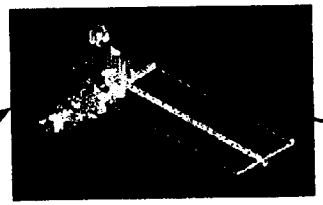


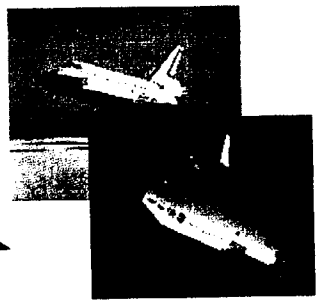
Near-Term

APPLICATIONS

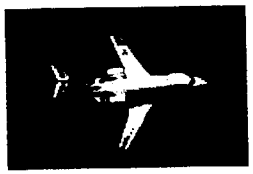
Large Spacecraft (NASA, USAF, industry)



Midsized Spacecraft (NASA, USAF, industry)



Adv. LVs (NASA, industry)

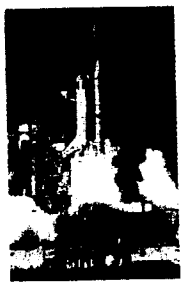


Aircraft (Industry)

UPS (other)

Lunar / Mars (NASA)

Rovers (NASA)



Unique UPS (NASA, other)

Small Spacecraft (NASA, USAF, industry)

Adv. Launch Systems (NASA,industry)

Hybrid & Elec. Vehicles (other)

OTHERS ?

Blue = Energy Storage
Red = Power Peaking

Sooner

WHEN

Later

NASA Flywheel System Development Content

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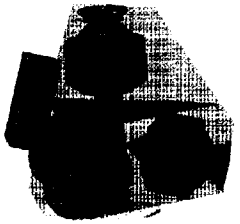
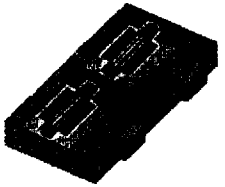




SYSTEM DEVELOPMENT

- FESS 1st Unit Flight on the International Space Station
- AFRL/Honeywell FACETS Ground demo of integrated power and attitude control system (IPACS) – Support AFRL

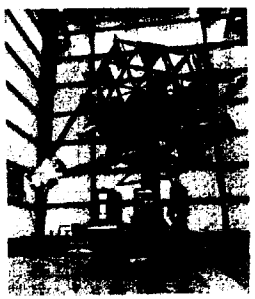
SPACE BASE R&T

- Flywheel Testbed and "Century" Flywheel Development
- Component Technology Research
- Flywheel Rotor Safe-Life Technologies Development

LEVERAGE TECHNOLOGY BASE (Aero & Space)

GOVERNMENT FACILITIES

- Gov't facilities and experts work with industry and academia; Flywheel testbeds, bearing test rigs, electrical test beds, NDE, etc.



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NASA Flywheel System Development Leveraging Programs

- **The Aerospace Flywheel Technology Program augments and leverages NASA Code R Space Base core funding**
  - **Space Act Agreement with AFRL for the FACETS Project and Rotor Safe-Life Technologies**
  - **ISS FESS Project for augmented component testbeds, facilities and technical staff and for Rotor Safe-Life Technologies**
  - **Commercial Space Centers - Centers for Space Power (NASA HQ/GRC)**
  - **NASA and Other NRA's to augment component and system technology development for Space Base core funded program**
  - **NASA SBIR's**
  - **NASA Code Q**
  - **NASA GRC/ARL Aeronautics and internal Programs**

NASA Flywheel System Development Technology Development Strategy

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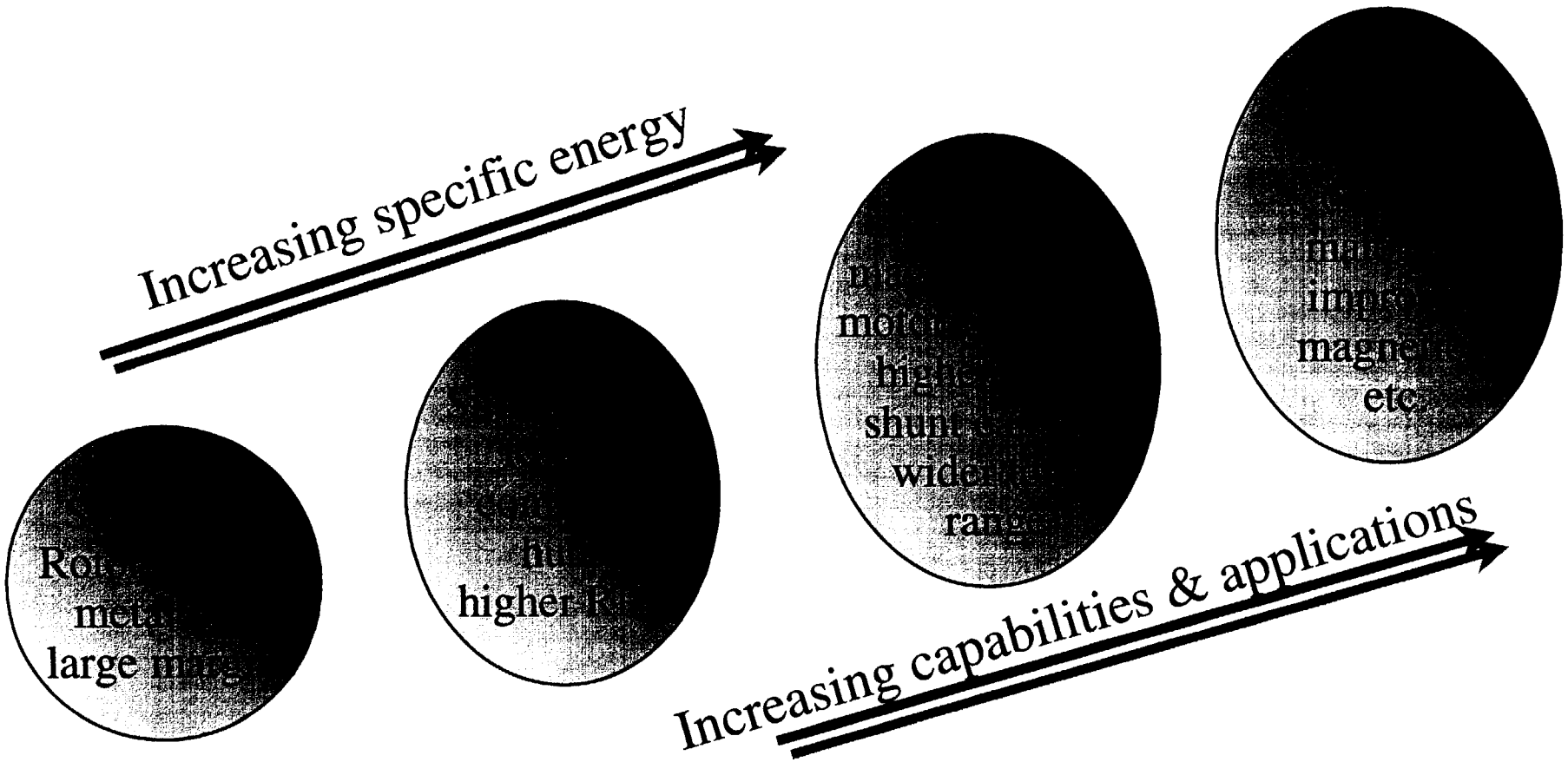

NASA Flywheel System Development
Component Technology Development

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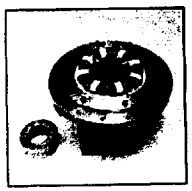
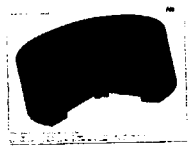
- Magnetic Bearings
  - Advanced Bearing Control
  - Fault Tolerant Actuators
  - Optimized Design
  - Health Monitoring Development
  - Passive (Repulsive) Bearings

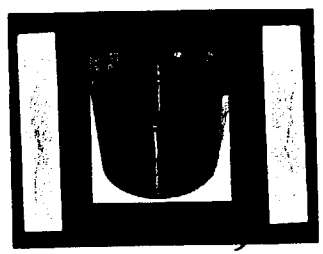


- Power Train
  - Optimized Mtr/Gen Control
  - Advanced Mtr/Gen
  - High Speed Concepts

- Composite Rotors
  - Rotor Safe-Life Technologies
    - Life Prediction Development
    - Material Testing
    - Rotor Cyclic Spin Testing
    - NDE Techniques
    - Standardized Process Development

  - Composite Rotor/Hub Development
  - Century-Class Rotor Design





NASA Flywheel System Development
Component Development Status

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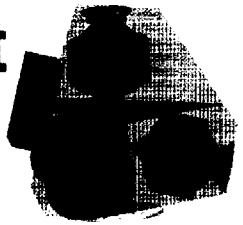
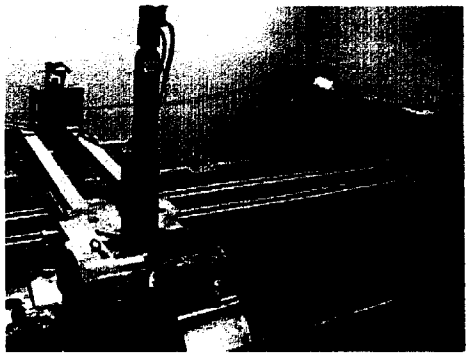
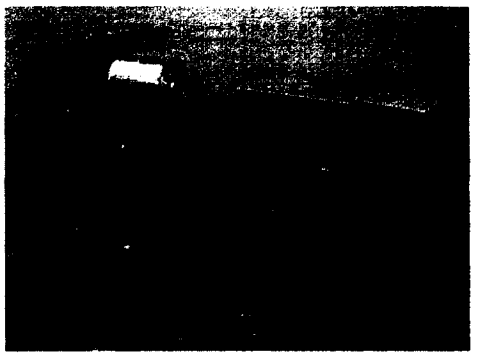


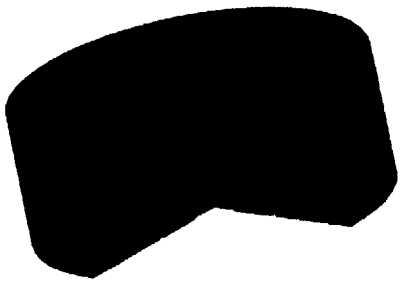
MDC Machine



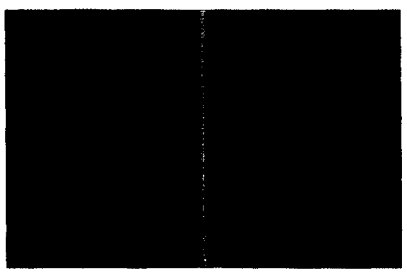
Translation and Rotation Axes



Fiber tensioning system



Concept 1: Box hub



Concept 2: Dome hub

- Preliminary Rotor Designs Complete
- MDC Winding Machine Operational
- Fab and Test MDC Rim – 2001
- Fab and Test Composite Hubs – 2002

Textile Engineering
Auburn University

NASA Flywheel System Development
Component Development Status

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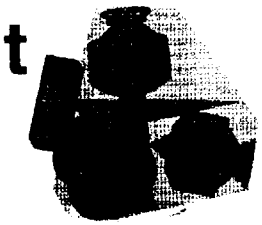
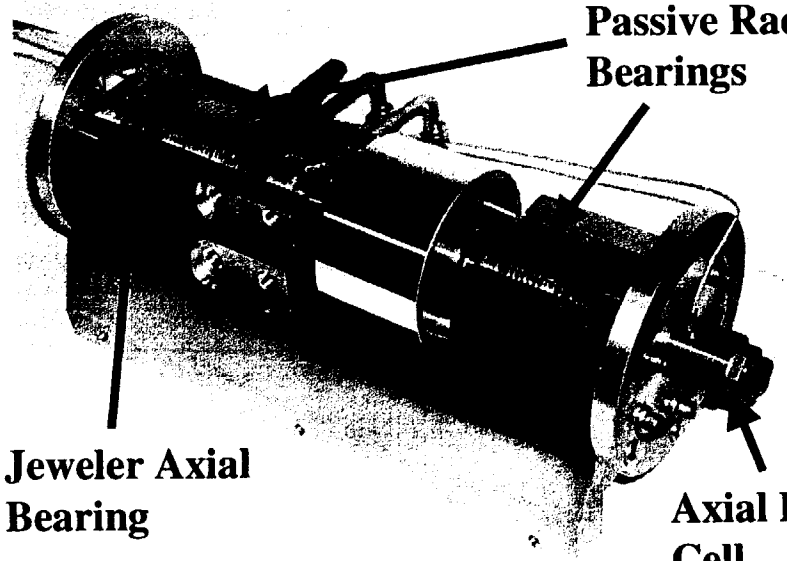


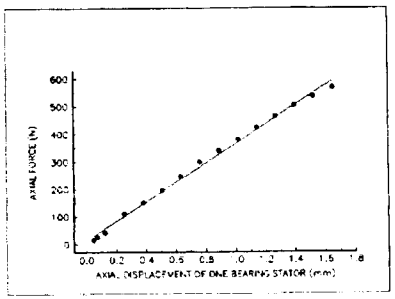
Low Speed Passive Bearing Rig For Concept Evaluation



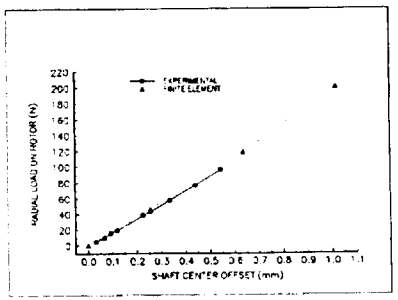
- Air Turbine Drive, < 20,000 RPM
- Analytical tools also evaluated

Next Steps

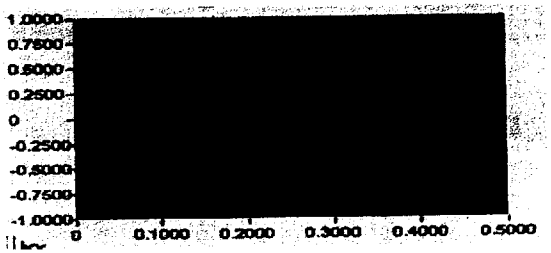
- Install motor drive
- Install active axial bearing



Axial stiffness, 2008 Lb/In.



Radial Stiffness, 1000 Lb/In.



Bearing Damping being measured

NASA Flywheel System Development
Component Development Status

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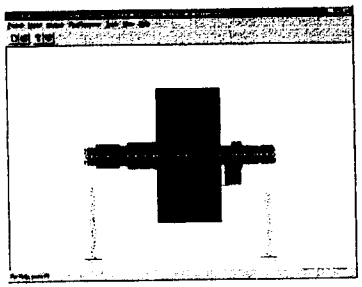
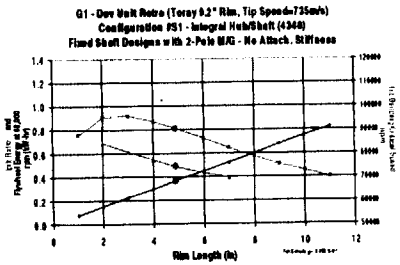
Advanced Rotor Studies

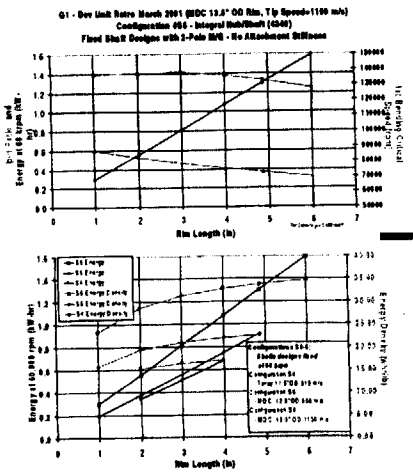
- Rotor Upgrades for Dev 1 and G2
- Passive Bearing Rotors for G2
- High Performance Rotors

Rotor Upgrade Study



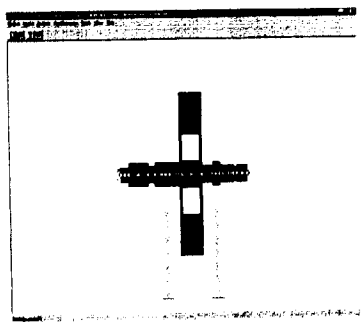


High Performance Rotors For Century Flywheel



- Double Rotor WHr/Lb
- 1100 m/s tip speed
- Composite hubs
- J/I > 1.2
- + Reduce Control/Elect.

Passive Bearing Rotor Concept for G2



NASA Flywheel System Development System Technology Development

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- Objective
  - Demonstrate flywheel system and advanced component technologies that support NASA's mission needs
- Approach
  - A phased implementation of advanced technologies into target system prototype for satellite application
  - Meet the needs of "mid-size" LEO spacecraft (~700 w to ~4 kw) with energy storage requirements of 300-700 whrs
- Accomplishments
  - Flywheel testbed facility operational
  - A flywheel module development unit is under test
- Plans
  - Define mission/satellite requirements and flow down to flywheel system and components in cooperation with mission centers and primes
  - Conduct a two DOF (power/momentum) test on an air table this year

NASA Flywheel System Development
Flywheel System Test Bed

Glenn Research Center

- **Objectives**
  - **Evaluation of integrated systems (single and multiple flywheels)**
  - **Evaluation of advanced component technologies at the flywheel module level**
- **Capabilities**
  - **Integrated with EPS Testbed**
  - **Single module testing with containment**
  - **Two module air table testing (single axis) with containment**
  - **Developmental controls with dSPACE systems**
- **Status**
  - **All basic facility capabilities operational**
  - **Single module testing in progress**
  - **Air table capability currently being installed**
  - **Second flywheel module being designed and fabricated**

NASA Flywheel System Development

Flywheel System Test Bed, Building 333

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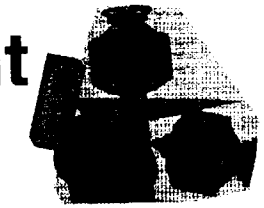

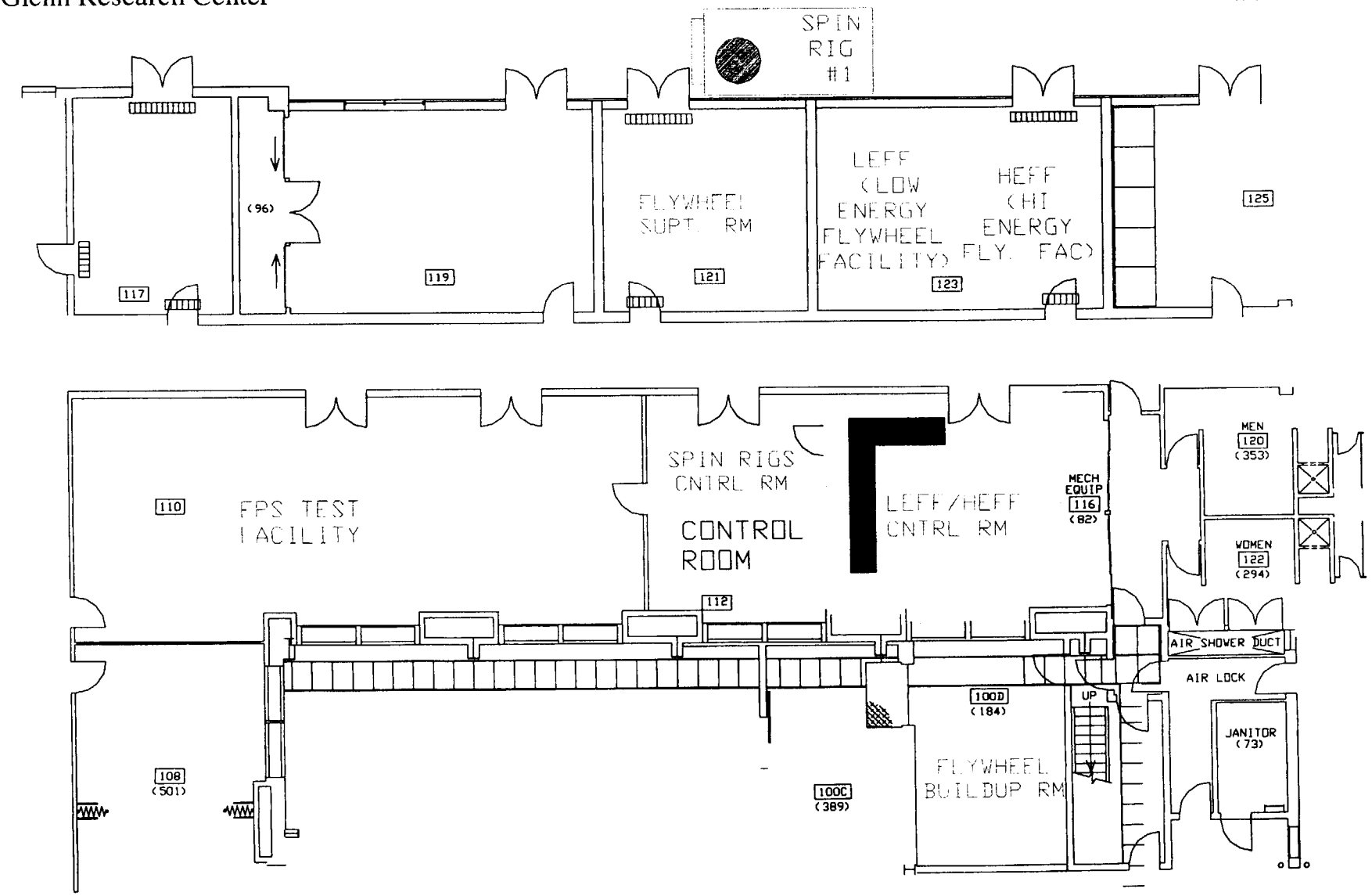

NASA Flywheel System Development

Flywheel System Test Bed – LEFF

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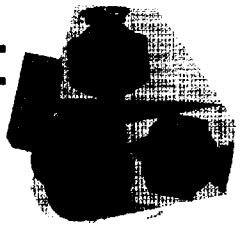
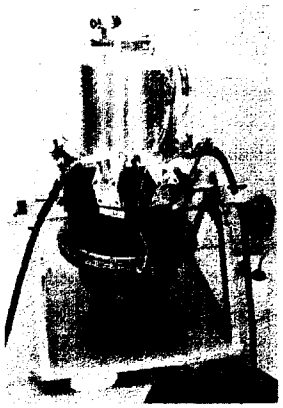
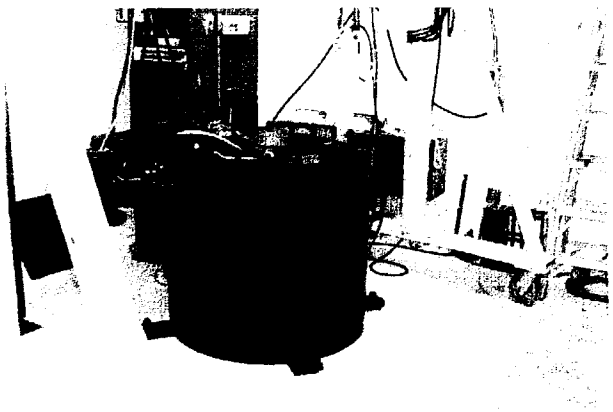


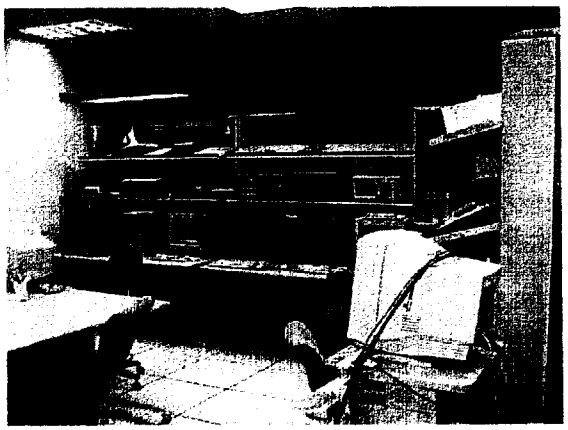


Dev 1 Unit

Dev 1 in Containment Chamber



Containment Chamber



Control Room

NASA Flywheel System Development
Flywheel System Test Bed – Control Systems

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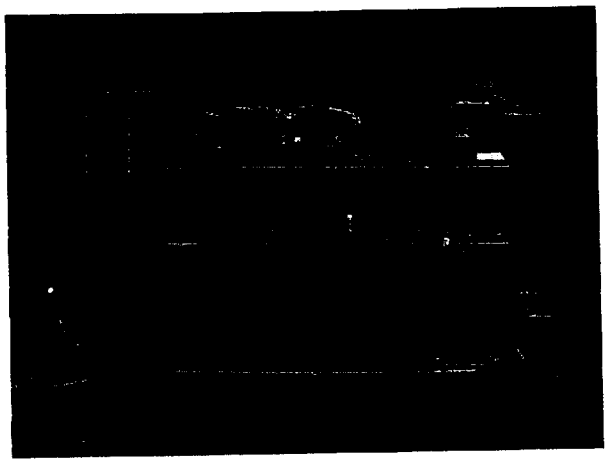
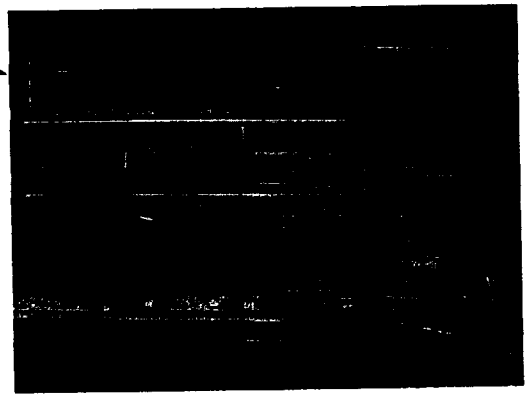
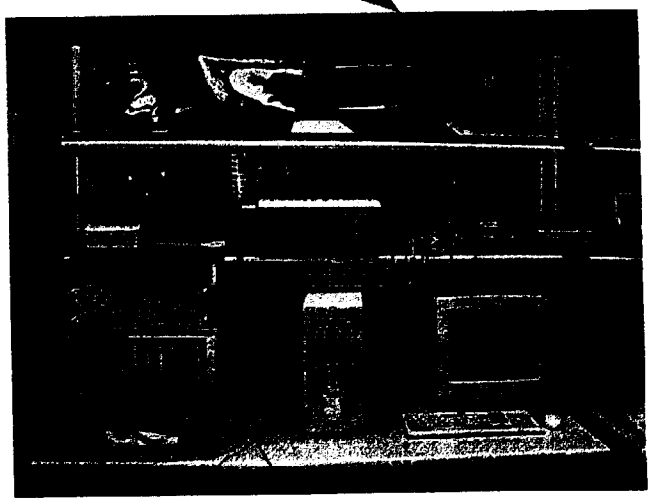


Magnetic Bearing Control



Data Acquisition & ISS Simulation



Motor/Generator Control

NASA Flywheel System Development
Flywheel System Test Bed – Accomplishments

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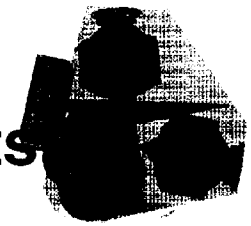

- Implementation of testbed and operation to 20,000 rpm
- Eddy current sensor development
  - Identification and reduction of sensor noise sources
  - Reduced bearing losses (by a factor of 3-4)
- M/G drive control for ISS battery application
  - Charge, to a current set point
  - Discharge, to a regulated voltage
  - Charge Reduction, flywheel regulating bus voltage

NASA Flywheel System Development
Flywheel System Test Bed – Flywheel

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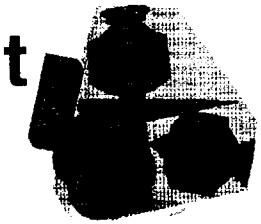
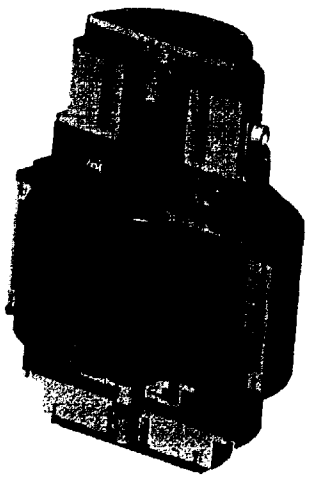


G2 Concept

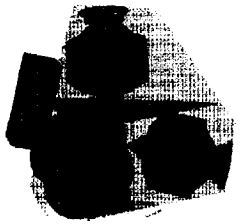


G2 Specifications

- **320 w-hrs useable energy storage**
- **1000 w average charge/discharge power**
- **Speed ratio of 1:3**
- **Maximum operating speed, 60KRPM**
- **Motor/Generator, PM synchronous 2-pole, 3 phase-Y connected**
- **DC Bus voltage, 130V**
- **Magnetic Bearings, homopolar PM bias, 4-pole**

NASA Flywheel System Development

Flywheel System Test Bed – Air Bearing Test



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- **Objectives – Demonstrate single axis attitude control and energy storage system**
- **Configuration – 2 Flywheel modules with 320W-hr each operating with research avionics**
- **Module spec – 60 KRPM maximum operating speed, 130 V DC Bus,**
- **Module upgrades**
  - **D1 – new rotor, new motor/generator**
  - **G2 – all new hardware with improved backup bearing, m/g, m/b, and rotor**
- **Test Plans**
  - **Operation of D1,G2 to 60K RPM individually**
  - **Operation of two modules in torque mode**
  - **Operation of two modules in torque/energy storage mode**

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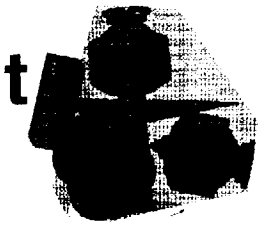
NASA Flywheel System Development Summary



- Develop advanced aerospace flywheel component and system technologies to meet NASA's mission needs
- Near term focus on "Century" class flywheels, 300-700 WHr capacity, for mid-sized satellite applications
- Leveraging other NASA programs and coordinating efforts with AFRL
- Component research and development in magnetic bearings, the power train and composite rotors
- Operational flywheel testbed to conduct advanced components and integrated flywheel systems research and development
- Conduct a phased implementation of advanced technologies into a system prototype for targeted satellite applications
- Conduct a two DOF (power/momentum) test on an air table this year