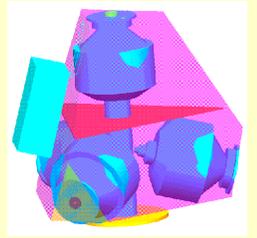




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# NASA Flywheel System Development

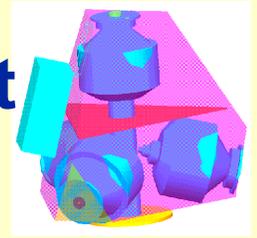
*Space Power Workshop  
April 4, 2001*

Kerry McLallin  
(216) 433-5389  
kerry.l.mclallin@grc.nasa.gov



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# NASA Flywheel System Development Introduction

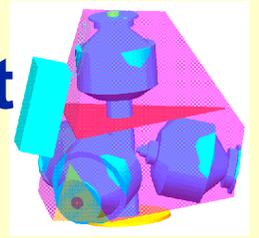


- **The Aerospace Flywheel Technology Program is a research and technology development program funded by the Cross-Enterprise Technology Development/ Space Base Program, NASA Code R**
- **The Aerospace Flywheel Technology Program is funded and directed out of the Power and On-board Propulsion Thrust 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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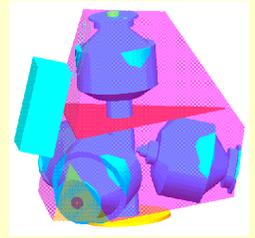
# NASA Flywheel System Development Acknowledgements



- **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



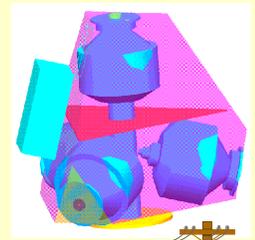
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- **Develop advanced aerospace flywheel component and system technologies to meet NASA's long term mission needs**
  - **Energy Storage**
  - **Integrated Power and Attitude Control**
  - **Power Peaking**
- **Near term focus on "Century" class flywheels, 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

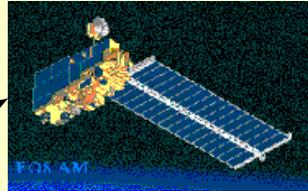
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Near-Term

APPLICATIONS

Large Spacecraft  
(NASA, USAF, industry)



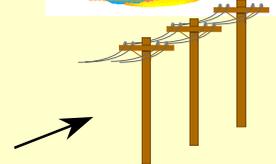
Mid-sized Spacecraft  
(NASA, USAF, industry)



Adv. LVs  
(NASA, industry)



Aircraft (Industry)



UPS (other)



Lunar / Mars  
(NASA)



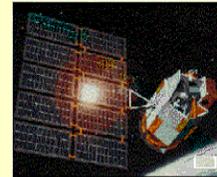
Rovers  
(NASA)



Hybrid & Elec.  
Vehicles (other)



Unique  
UPS (NASA, other)



Small  
Spacecraft  
(NASA, USAF, industry)



Adv. Launch  
Systems  
(NASA, industry)

OTHERS ?

Blue = Energy Storage  
Red = Power Peaking

Sooner

WHEN

Later





# NASA Flywheel System Development Content

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## SYSTEM DEVELOPMENT

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

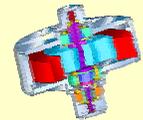
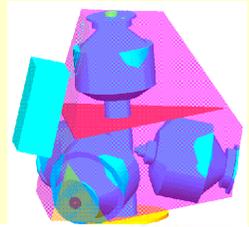
## SPACE BASE R&T

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

## LEVERAGE TECHNOLOGY BASE (Aero & Space)

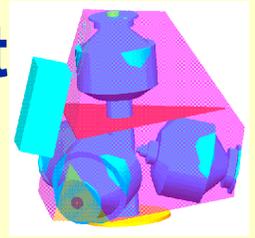
## GOVERNMENT FACILITIES

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





# NASA Flywheel System Development Leveraging Programs

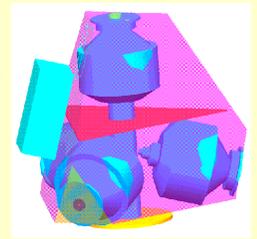


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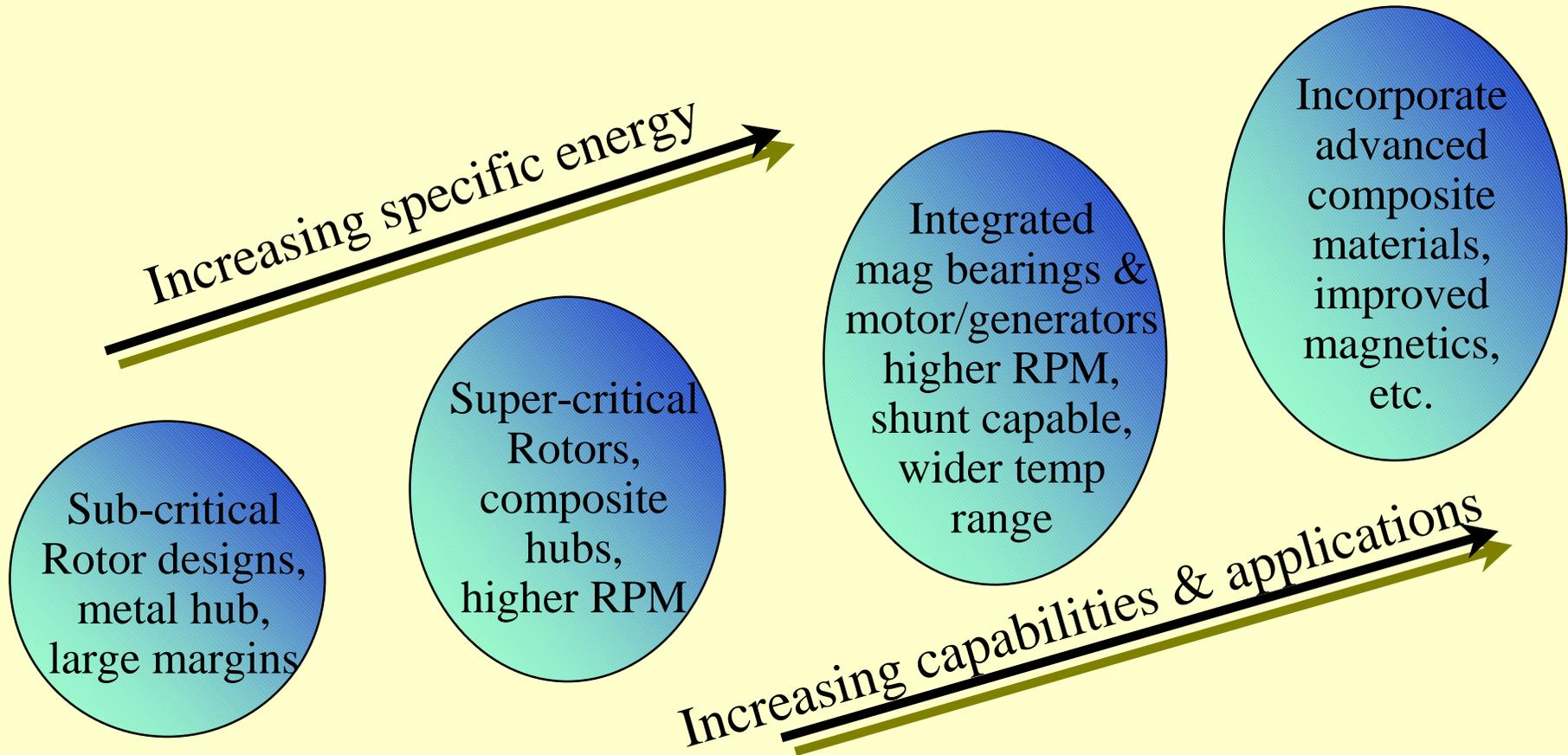
- **The Aerospace Flywheel Technology Program augments and leverages NASA Code R Space Base core funding**
  - **Space Act Agreement with AFRL for the FACETS Project and Rotor Safe-Life Technologies**
  - **ISS FESS Project for augmented component testbeds, facilities and technical staff and for Rotor 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

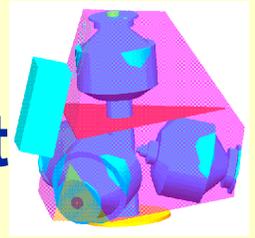


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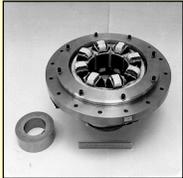


# NASA Flywheel System Development Component Technology Development



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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**

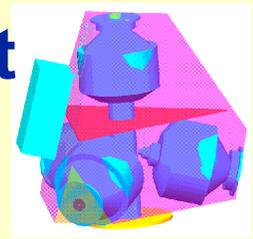


- **Composite Rotors**
  - **Rotor Safe-Life Technologies**
    - **Life Prediction Development**
    - **Material Testing**
    - **Rotor Cyclic Spin Testing**
    - **NDE Techniques**
    - **Standardized Process Development**
  - **Composite Rotor/Hub Development**
  - **Century-Class Rotor Design**





# NASA Flywheel System Development Component Development Status



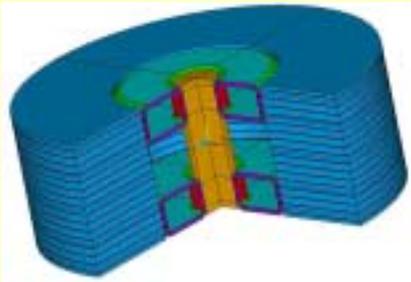
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## MDC Machine

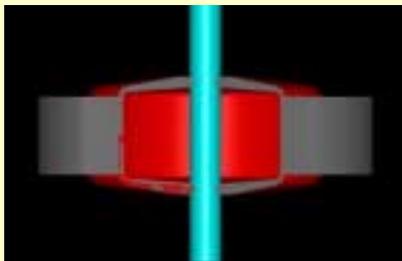


Translation and Rotation Axes

Fiber tensioning system



Concept 1: Box hub



Concept 2: Dome hub

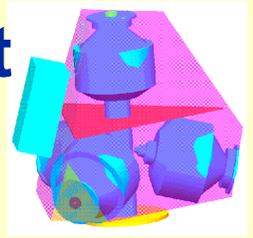
- Preliminary Rotor Designs Complete
- MDC Winding Machine Operational
- Fab and Test MDC Rim – 2001
- Fab and Test Composite Hubs – 2002

Textile Engineering  
Auburn University



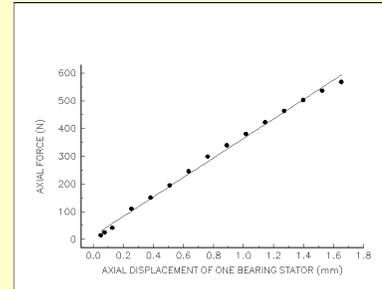
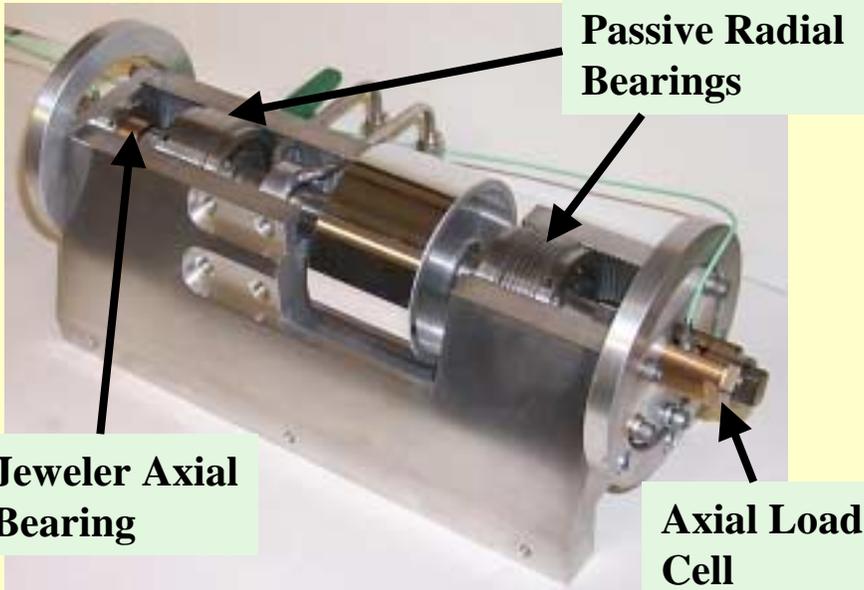


# NASA Flywheel System Development Component Development Status

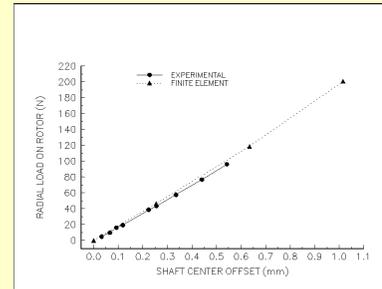


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## Low Speed Passive Bearing Rig For Concept Evaluation



**Axial stiffness,  
2008 Lb/In.**

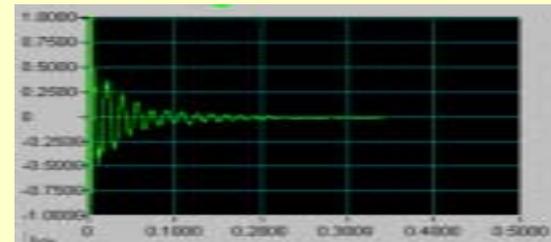


**Radial Stiffness,  
1000 Lb/In.**

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

### Next Steps

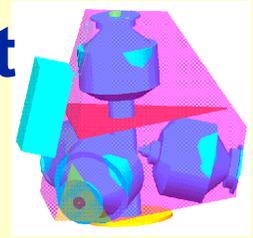
- Install motor drive
- Install active axial bearing



**Bearing Damping being measured**



# NASA Flywheel System Development Component Development Status

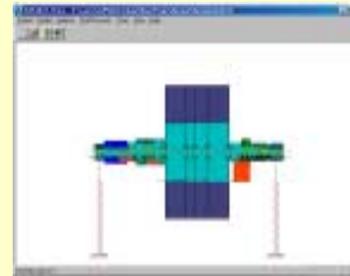


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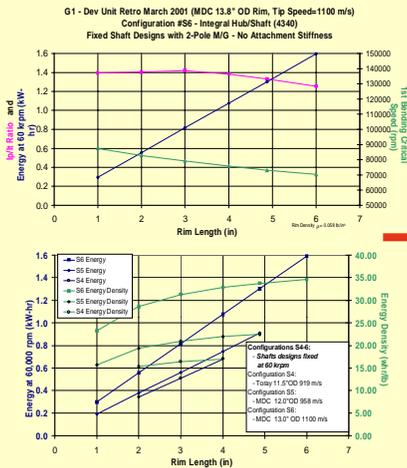
## Advanced Rotor Studies

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

## Rotor Upgrade Study

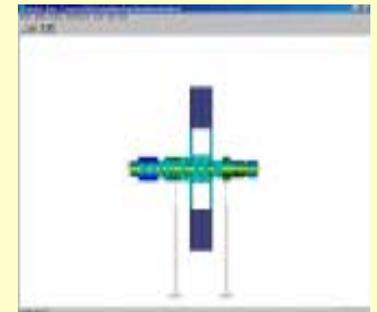


## High Performance Rotors For Century Flywheel



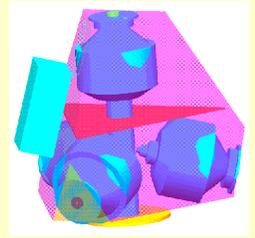
- Double Rotor WHr/Lb
- 1100 m/s tip speed
- Composite hubs
- $J/I > 1.2$
- + Reduce Control/Elect.

## Passive Bearing Rotor Concept for G2





# NASA Flywheel System Development System Technology Development

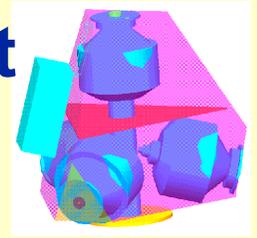


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- **Objective**
  - **Demonstrate flywheel system and advanced component technologies that support NASA's mission needs**
- **Approach**
  - **A phased implementation of advanced technologies into target system prototype for satellite application**
  - **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



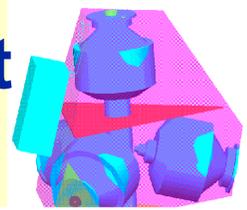
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- **Objectives**
  - **Evaluation of integrated systems (single and multiple flywheels)**
  - **Evaluation of advanced component technologies at the flywheel module level**
- **Capabilities**
  - **Integrated with EPS Testbed**
  - **Single module 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**

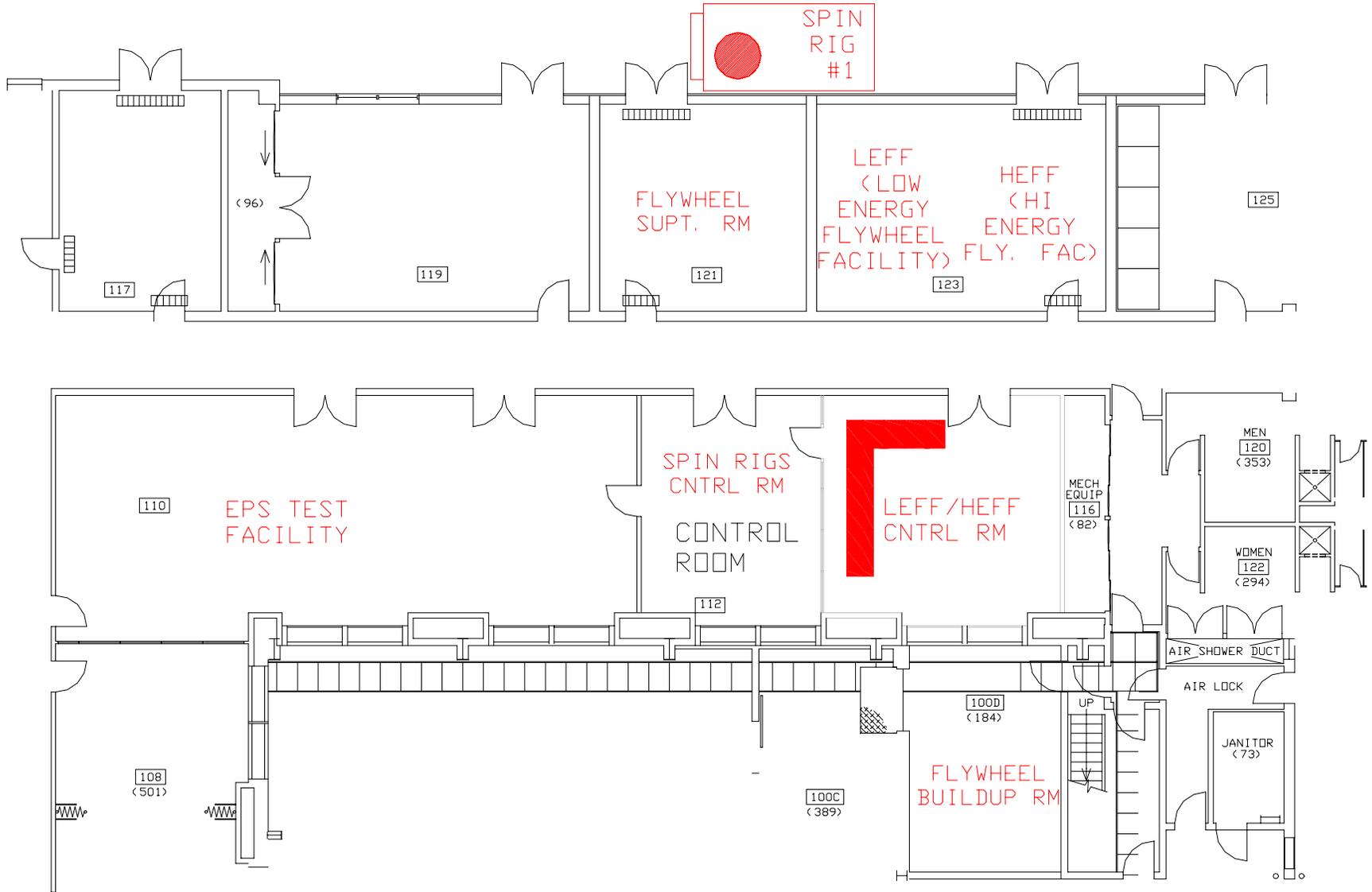


# NASA Flywheel System Development

## Flywheel System Test Bed, Building 333



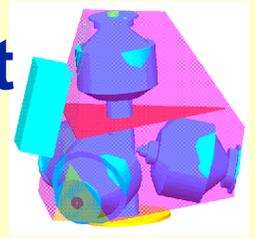
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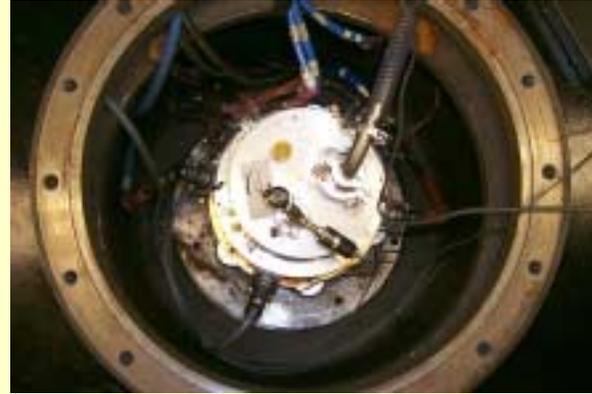


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# NASA Flywheel System Development Flywheel System Test Bed – LEFF



**Dev 1 Unit**



**Dev 1 in Containment Chamber**



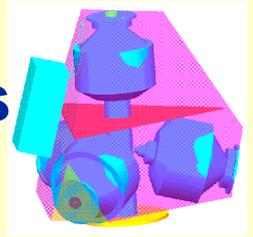
**Containment Chamber**



**Control Room**



# NASA Flywheel System Development Flywheel System Test Bed – Control Systems



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Magnetic Bearing  
Control



Data Acquisition  
& ISS Simulation

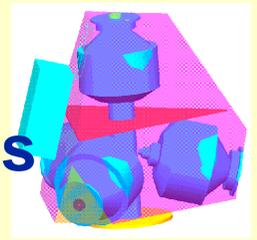


Motor/Generator  
Control



# NASA Flywheel System Development

## Flywheel System Test Bed – Accomplishments



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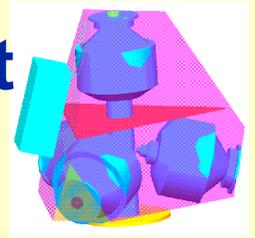
- **Implementation of testbed and operation to 20,000 rpm**
- **Eddy current sensor development**
  - **Identification and reduction of sensor noise sources**
  - **Reduced bearing losses (by a factor of 3-4)**
- **M/G drive control for ISS battery application**
  - **Charge, to a current set point**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



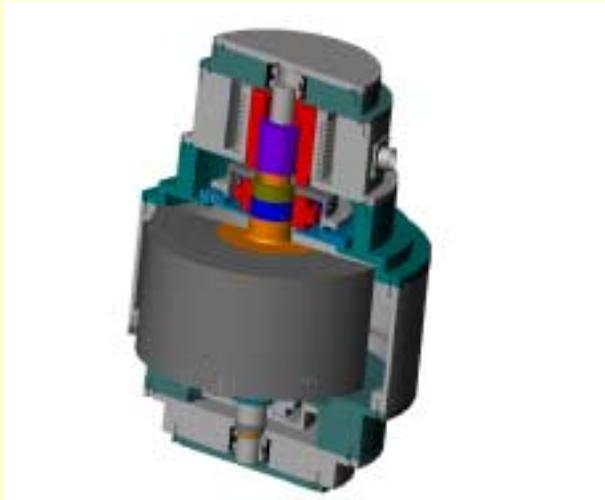
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# NASA Flywheel System Development

## Flywheel System Test Bed – Flywheel



### G2 Concept



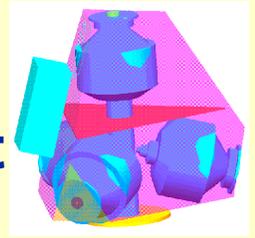
### G2 Specifications

- **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



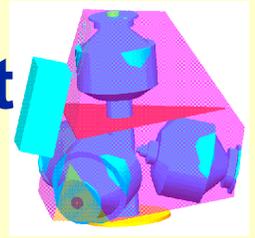
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- **Objectives – Demonstrate single axis attitude control and energy storage system**
- **Configuration – 2 Flywheel modules with 320W-hr each operating with research avionics**
- **Module spec – 60 KRPM maximum operating speed, 130 V DC Bus,**
- **Module 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**