Welcome to the

2nd

Aerospace Flywheel Workshop

7-6 October 1998
Air Force Research Laboratory

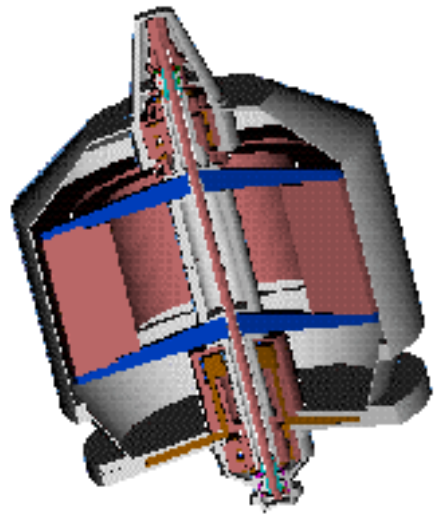
National Aeronautics and
Space Administration
Lewis Research Center

Sponsored by

Air Force Research Laboratory
Phillips Research Site

Workshop Objectives

- Inform & Receive Feedback
- Communicate & Coordinate
- Promote Technical Interchange
- Network



Overview of the AFRL/NASA Flywheel Program

"Advanced Energy Storage for NASA and USAF missions"

NASA Lewis Research Center
David Christopher

AFRL
Dr. Jerry Fausz

NASA/USAF Aerospace Flywheel Workshop
7 October 1998

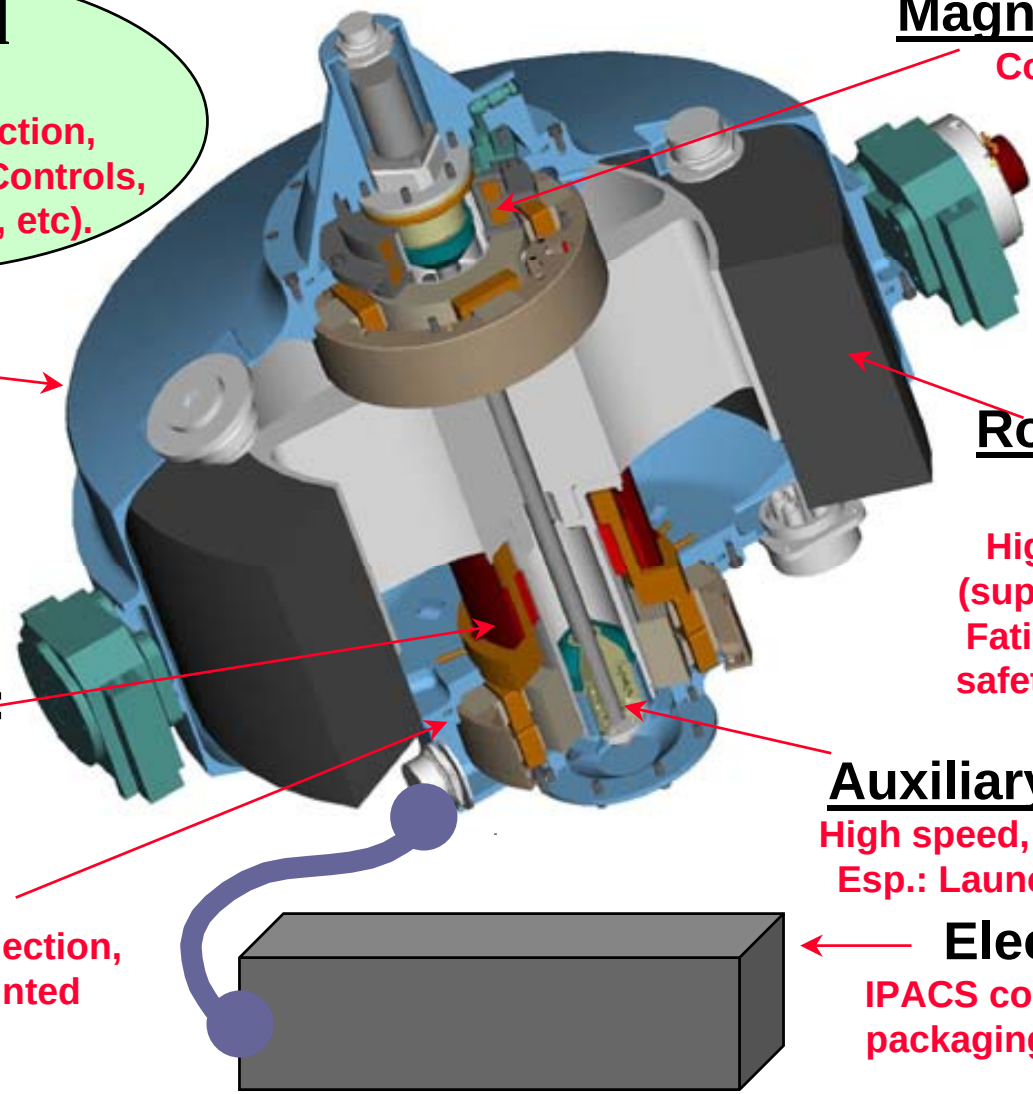
Outline

- Introductory remarks
- Applications and Roadmaps
- USAF/NASA Program Structure
  - Flywheel Systems
  - Base Research & Technology Efforts
- Looking ahead
- Concluding Remarks

Space Flywheel Components and Challenges

Flywheel System:
Component interaction, Space environment, Controls, (micrometeoroids, etc).

Magnetic Bearings:
Controls & losses are the key risk areas, also fault tolerance & design for IPACS



Enclosure:
lightweight but stiff, spacecraft mechanical and thermal interface

Rotor (Rim, Hub Shaft):
High specific energy (super critical design?), Fatigue Life & "creep", safety W/O containment

Motor/Generator:
Reliability, efficiency

Auxiliary Bearings:
High speed, high impact, life
Esp.: Launch environment

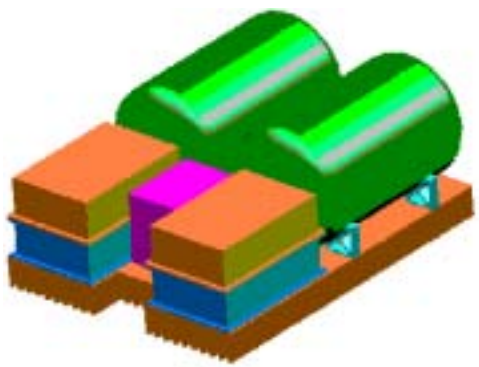
Thermal:
passive heat rejection,
Esp.: Gimbal mounted concepts

Electronics:
IPACS control algorithms, packaging for lightweight

Flywheel Energy Systems

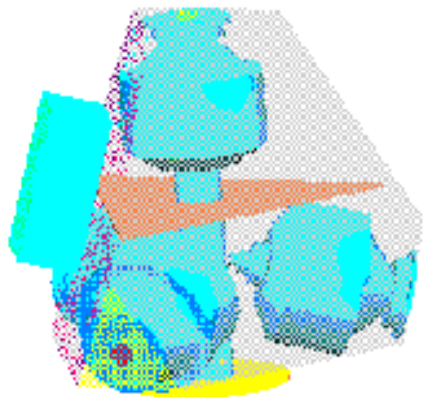
Flywheel Energy Storage (FES)

- 2, counter-rotating Flywheels
- Energy storage
- Replace some Power Mangmnt And Distribution (PMAD) functions



Integrated Power & Attitude Control System (IPACS)

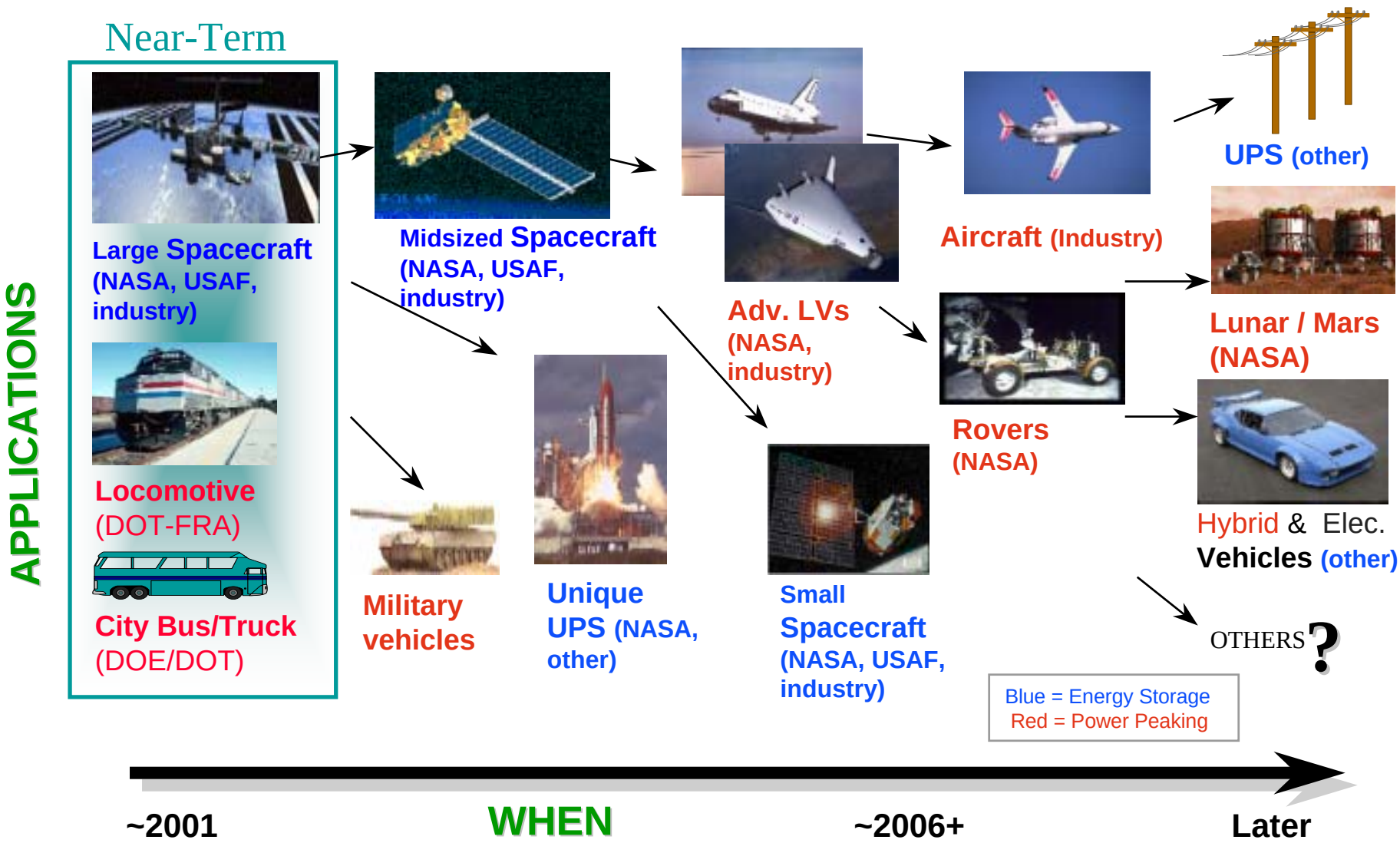
- Array of ≥ 2 FWs
- Energy storage & Attitude control torque
- Replace some PMAD



E.g., A Tetrahedral Arrangement of 4 FWs, or 4 pairs of FWs

Applications and Roadmaps

Near-Term and Far-Term Applications



Put
“Satellite Market Growth Chart”
HERE

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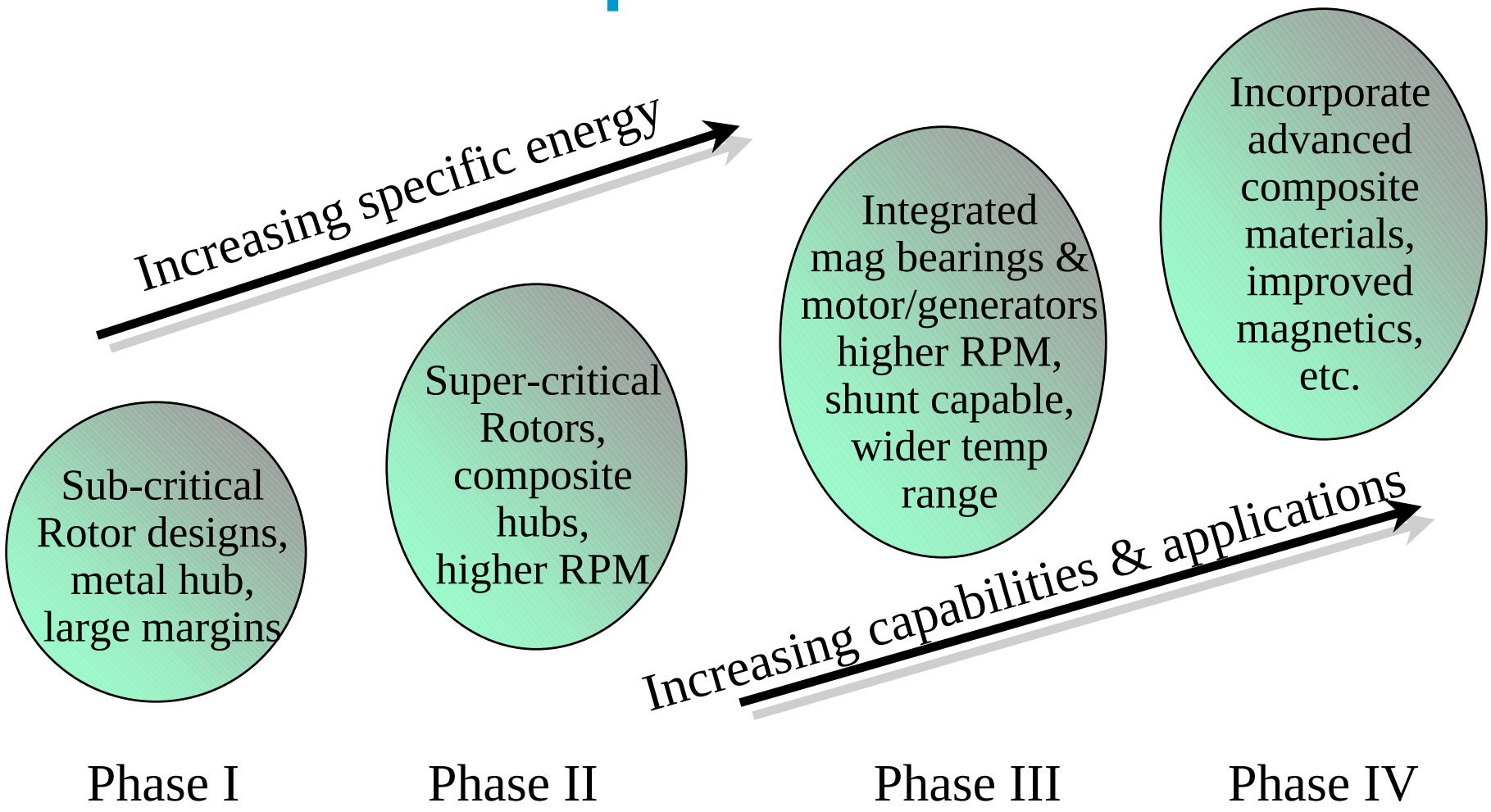
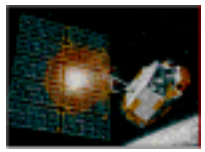
Flywheel Technology Development Phases

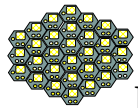


Like Batteries, No one size fits all

Small (<500W)



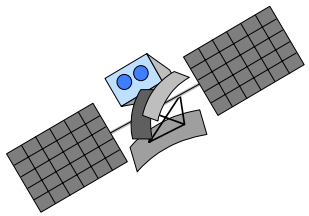
NASA Explorer, New Millenium, & Discovery Classes



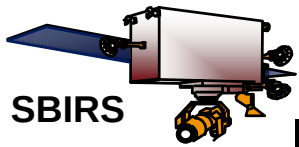
Military Micro Sats

Small Rovers

Medium (2-5KW)

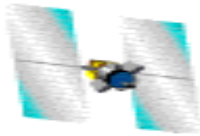


Discover II/ Starlite



SBIRS

NPOESS

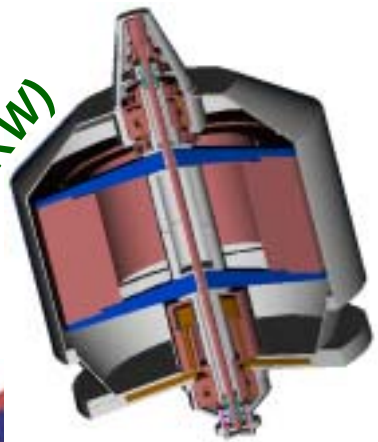


GPS II

Medium Size Surveillance

RLV

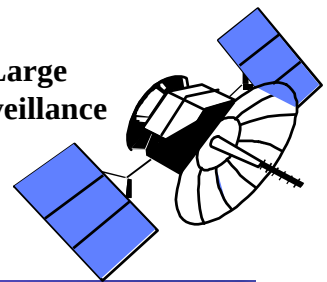
Large (>10KW)

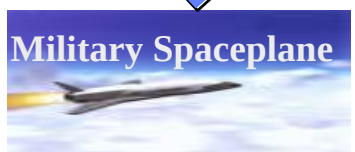


ISS

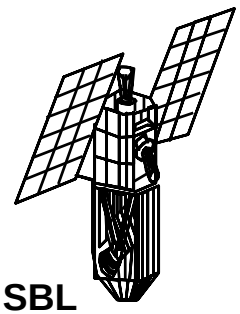
SBR

Large Surveillance





Military Spaceplane



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Technology Roadmap

ACESE

1st Flight Demo (Designed as a foundation)

Insert multi-Kwhr Rotor

Reduced length rotor; down-sized bearings & motor-gen.

FESU for ISS

Build off of ACESE experience

FES & IPACS

multi-Kwhr Flywheel

Mid-size flywheel

Small flywheels

Power peaking flywheel

Develop products w/ flight heritage

DoD Missions: SBR, SBIRS-Low, etc.

Other NASA: Earth Science, Moon/Mars

Commercial: LEO comm sats, etc.

Adv. RLV, Aero

Deploy technology to benefit missions

Establish a Presence → **Expand the Horizons** → **Develop the Frontiers**

Technology Metrics/Goals

Metric	Existing Battery Systems**	Flywheel SOA*	Flywheel Goals
Effective, Usable Specific Energy (SE) in LEO	< 3 Whr/lb	~10 Whr/lb	>20 Whr/lb
Cycle life (at above SE levels)	~30,000	TBD (estimated at 50,000)	>75,000
Energy Storage (turn around) Efficiency	68-80%	85%	>90%
Cost	$0.5-3M	Comparable	> 25% reduction

* Based on laboratory units extrapolated to flight configuration. Current TRL ~ 4.3-5.3

** Includes associated hardware (e.g., battery regulator)

AFRL/NASA Program Structure

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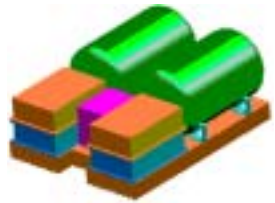
3 Legs of the NASA/USAF Program



SYSTEM DEVELOPMENT: *Guides Base R&T*

- USFS Development Flywheels (medium)
- FARE, Inc small OCR flywheel (small)
- Flight experiment on the International Space Station (ISS) in 2001 (large)
- Ground demo of integrated power and attitude control system (IPACS)
- Various studies

BASE R&T: *Supports System Development*

- Component technology research
  - bearing systems
  - rotors
  - electronics
- Participation in the Rotor Safe Life Technologies P

GOVERNMENT FACILITIES: *Enables/Enhances System and R&T Work*

- Gov't facilities and experts work with industry and academia
  - flywheel develop lab, bearing test rigs, electrical test beds, NDE, etc.
  - Leverage Technology Base (Aero & Space)

National Aerospace Flywheel Program Players

DOT/DOE | Navy/Army | DARPA | Terrestrial Flywheels | NIST

Other USAF

USAF AFRL — **NASA LeRC**

Other NASA

Flywheel Vendors

- American Flywheel Systems
- FARE
- USFS

Primes

- TRW
- Boeing
- Hughes

Other Businesses

- Applied Mat'l Tech., Inc
- Dow-UT
- Aerospace Corp
- Foster Miller
- Test Devices
- Allied Signal
- Mohawk Innovative Tech., Inc
- The Bearing Consultnts
- PreMag Inc

Academia/ Labs

- Ook Ridge Nat'l Lab
- Univ MD
- Air Force Institute of Tech
- Univ VA
- Univ TX
- Auburn
- VA Tech
- TX A&M
- Penn St

System Developments

Large flywheels (≥1,000 Whr)

Mid-sized flywheels (100-<1,000 Whr)

Small flywheels (< 100 Whr)

Energy Systems

Attitude Control & Energy Storage Experiment (ACESE)

Objective

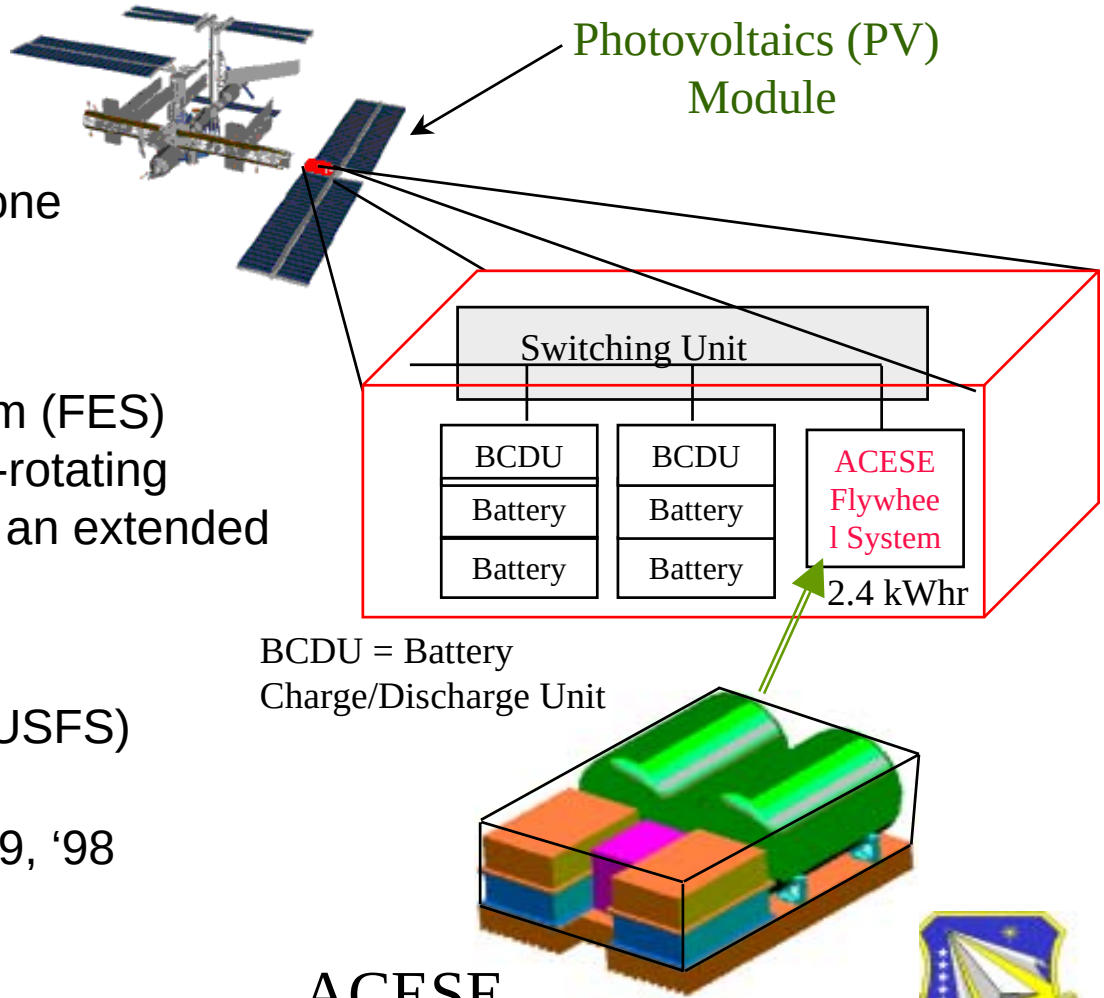
- Demonstrate flywheel energy storage, power delivery, and one axis of attitude control torque

Approach

- Deploy flywheel energy system (FES) consisting of a pair of counter-rotating flywheel units and operate for an extended period of time (~1yr)

Status

- CA w/ industry team (Boeing,USFS)
- SDR completed Spring 98
- PDR split from Oct 20 - Nov 19, '98
- Deploy 2002



ACESE

Engineering Model Flywheel Energy Storage (FES) System

Objective

- Build and lab test a FES system to gain experience w/ energy storage & single axis torque control as a foundation for mid-size wheel development

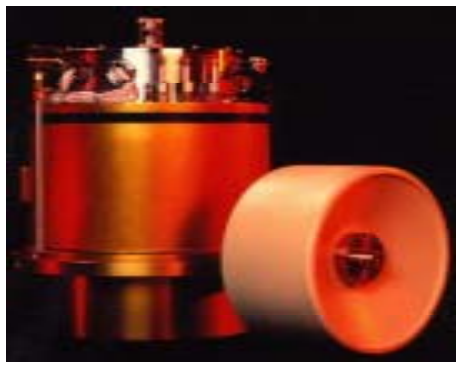
Approach

U.S. Flywheels subcontract w/ TRW

- ~ 500 Whr, ~ 20 Whr/lb rotor
- Filament wound rim, metal hub
- 2 wheel system
- Magnetic & mechanical bearings
- Coordinated w/ DARPA effort

Plans

- Hardware to support ACESE development
- Demo of FES in the lab



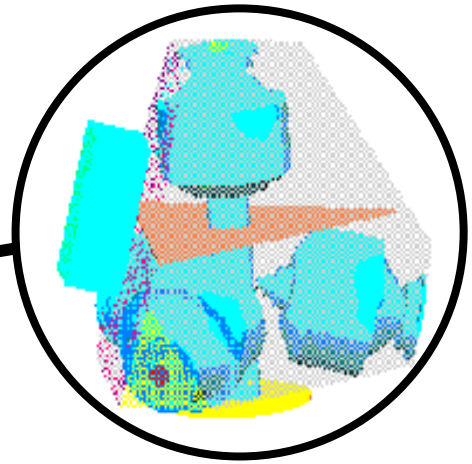
Status

- Units are assembled and in test at USFS.
- Hardware upgrades in progress

Flywheel Integrated Power and Attitude Control System (IPACS) Ground Test Bed

Objective

- Develop, demonstrate, and foster user confidence in flywheel IPACS technology (system-level simultaneous energy storage and three-axis attitude control)



Approach

- Procure hardware for IPACS ground demonstration on ASTREX testbed under BAA 98-01
- Test IPACS on ASTREX to user-specific requirements
- Establish follow-on flight demonstration

Status

- BAA proposal deadline 30 Sept 98
- Proposal evaluation begins 14 Oct 98
- Program kickoff anticipated Jan 99

Open Core Rotor (OCR) Flywheel

Objective

- Research feasibility of alternate, shaft-less configuration as a foundation for small wheel development (<200 WHr)

Approach

- Phase I & II SBIR with FARE, Inc.
- Work teaming for Phase III
- Aggressive Goals to maximize lessons learned:
  - Single wheel lab demo system
  - 50 Whr (goal)
  - Filament wound cylindrical rotor
- Builds upon U of Md work

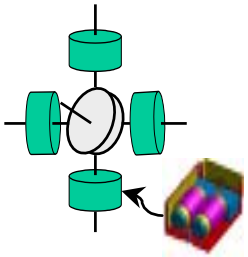
Key Challenges

- High RPM mag bearing & motor/generator
- Packaging

Status

- Unit assembled
- Limited operation demonstrated.
- 2 year effort started in Jan 1997.

Base Research & Technology

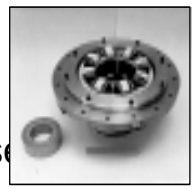


Base R&T Efforts

System Research

- Uof MD Open Core Rotors (OCR)
- AFIT f/w system tool
- DARPA Starlite & SBR solar thermal studies
- LeRC Analyses & Modeling
- GSFC SBIR w/ AFS
- FMEA/FTA

Magnetic Bearings



- Tex A&M Mag Bearing Rese
- Univ of VA Mag Bearing Research
- MiTi Bearings
- PreMag Reaction Wheel Mag Bearings
- Tests at NASA

Composite Rotors

- Rotor safe-life program
- AMT Rotor and HMS
- Health Monitoring
- Dow-UT Polar Weave Rotor
- Auburn Work
- ORNL Composites and Test
- Univ of Texas Composites
- Foster-Miller Rotor
- LeRC composite tests and structural dynamics analyses
- Century-class rotor design
- DARPA Safety Program

Concluding Remarks

- Space Energy Storage is a growing Market & FES / IPACS are ideal to fill this need:
  - Growing interest by projects
- Exciting developments planned in 1999:
  - Rotor Safe-Life Project
  - ACESE critical design
  - Initiate procurement of an IPACS test bed
  - More testing!: e.g, Phase 4 of the DARPA effort, etc., etc.
- Technology efforts will increasingly focus on smaller flywheels
  - Many missions need “century class” flywheels (100’s of whrs)
  - Component advances necessary for smaller wheels also benefit larger wheels
- Look for a NASA Research Announcement (NRA) opportunity for component technologies to enable/enhance smaller flywheels and IPACS