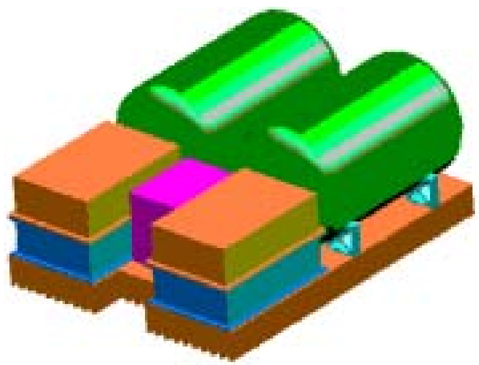
Flywheel Rotor Safe-Life Certification

Lewis Research Center

Aerospace Flywheels Workshop

October 8, 1998

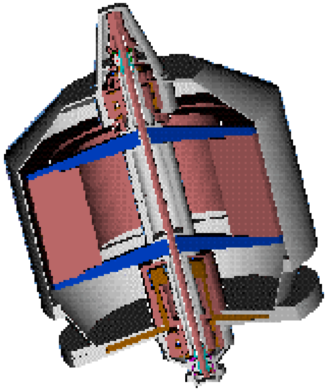
Kevin Konno



Agenda

Lewis Research Center

- Background
- Flywheel Rotor Safe-Life (FRSL) Program
  - Objectives
  - Scope
  - Phase 0 tasks
- ACESE
  - Overview
  - Certification program description
- Summary



Background

Lewis Research Center

- “Safe-Life” (i.e., no containment) recognized as advantageous for FES for many reasons: weight savings from abatement of “unnecessary” containment, greater reliability against failure, greater probability of longer service life.
- Test methods for demonstrating safe-life designs for flywheel rotors have not been established.
- Existing test facilities are not well suited for all anticipated tests (esp. LCF)
- ***Community concurred at the NASA/USAF Aerospace Flywheel Workshop, Sept 1997
- Government led sponsor team identified

- Rotors must be certified, i.e., quantitatively evaluated (thru appropriate tests) and established for flight readiness, for any space application.

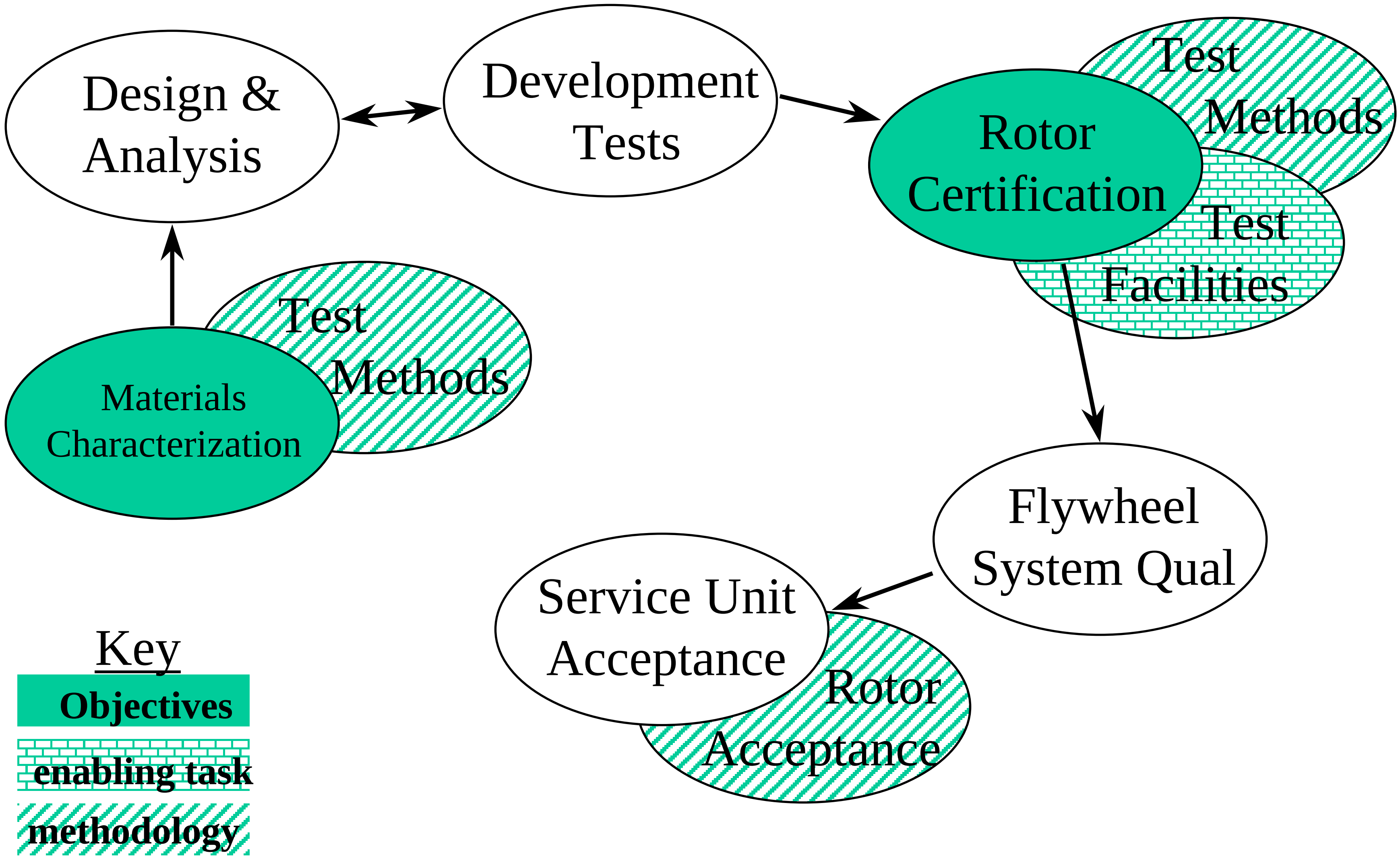
FRSL Rotor Safe-life Objectives

Lewis Research Center

- Define a standard man-rated flywheel qualification process for high-performance applications (space and terrestrial) using a safe-life approach for rotor certification that is accepted by the user community.
- Provide innovative life-cycle test methods, NDE, and facilities.
- Certify one rotor per participating vendor via this process to enable near-term use of flywheels (subsequent rotor certifications to be vendor responsibility).
- Define path to full unit qualification & acceptance (actual unit qual. to be vendor or user responsibility).
- Provide a basis for sustaining the certification process after program completion.

FRSL Program Scope

Lewis Research Center

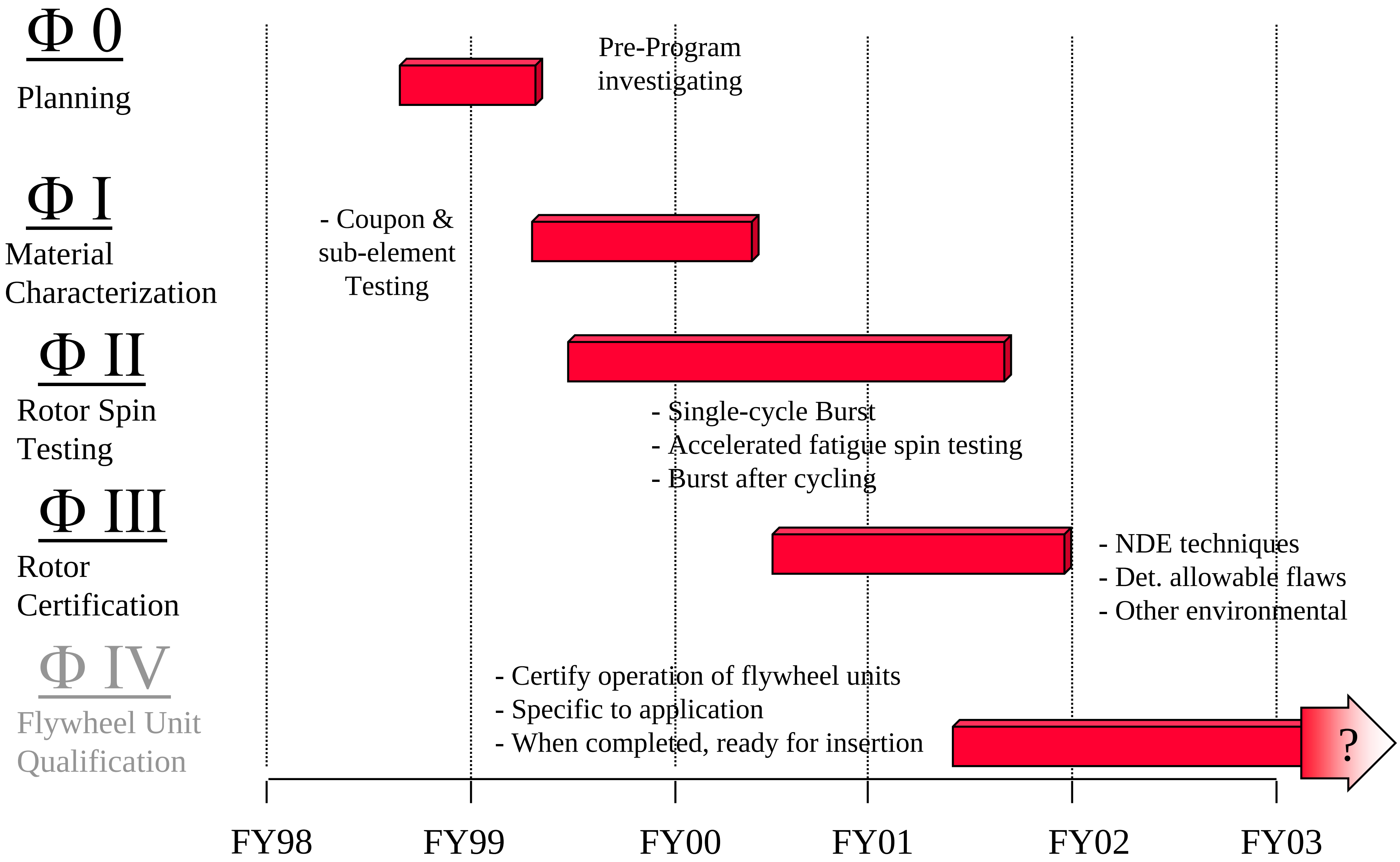


FRSL Players & Roles

Lewis Research Center

Players	Role
Gov't sponsors (USAF/AFRL, NASA LeRC, DARPA, DOT, DOE)	Co-fund, manage & coordinate, provide tech assistance & facilities
Other Gov't (other customers, e.g., USAF, JSC)	Flywheel committee membership: Oversight & concurrence
Industry (customers & vendors)	Design & fab of test and flight articles, test facilities, co-fund
Other (FAA, aero industry)	Flywheel committee membership: Oversight & lessons learned

Phased Project Concept



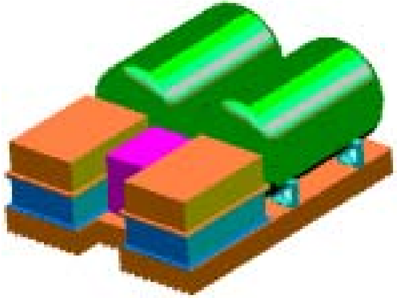
FRSL Phase 0 Tasks

- Investigate technologies needed to complete phases 1-4.
- Resource survey of existing technology in test facilities, analysis capability, materials database, design heritage, etc. beneficial to FRSL Program.
- Define specific new technology development needed to complete the objectives of the FRSL Program.
- Document results.

ACESE Overview

Lewis Research Center

- Attitude Control and Energy Storage Experiment (ACESE) incorporates dual, counter rotating 1.2 kW-hr rotors as experiment which, if successful, would be long term replacement for Nickel-Hydrogen batteries on ISS.
- Launch date set at early 2002.
- Johnson Space Center (JSC) ISS Payload Safety Review Panel (PSRP) will be reviewing ACESE hardware. Well-established process for certifying spaceflight hardware.
- High speed, energy composite rotating structures heretofore unseen by JSC ISS PSRP.



ACESE Rotor Certification Outline

- The Rotor Certification (RC) Plan is organized around a building block analysis/test matrix utilizing:
  - Probabilistic computational analysis techniques to identify the materials characteristics and design allowables for metallic hub/ composite filament-wound rim flywheels, accounting for 1)service, transport environmental extremes, 2)fabrication and process variances.
  - Verification of the materials characterization/design allowables thru sufficient small-scale coupon and sub-element tests.
  - Detailed finite element analysis of the final ACESE rotor design to identify probable failure modes and margins of safety.
  - Full scale rotor testing to verify all structural requirements.
  - Quality Control Plan to insure quality flight hardware.

DRAFT

ACESE Rotor Cert. Plan - Materials Design Allowables- Tests

Lewis Research Center

Test type	Test article type	QUANTITY OF TEST SPECIMENS						Cost per test ($)	Total cost ($)	Comments:
		Room temp.			High temp.					
		Lot 1	Lot 2	Lot 3	Lot 1	Lot 2	Lot 3			
STRAND TENSILE-FIBER & RESIN	LAMINATE	5	5	5	5	5	5		4400	STRENGTH & MODULUS
HOOP TENSILE (N.O.L. SPLIT D, OR HYDROBURST)	SUB-ELEMENT	10	10	10	3	3	3		6000	- STRENGTH & MOD. COST BASED ON N.O.L. SPLIT D TEST
TRANSVERSE TENSION	DOGBONE/ HR-GLASS	5	5	5	1	1	1		3500	- STRENGTH & MODULUS
TRANSVERSE COMPRESSION	COUPON	5	5	5	1	1	1		4400	THICK BLOCK CUT OUT OF FILAMENT WOUND RING
TRANSVERSE SHEAR	COUPON	5	5	5	1	1	1		6300	- STRENGTH & MODULUS- ISOPESCU NOTCHED SPECIMEN
TRANSVERSE FLEXURE STRENGTH	COUPON	5	5	5	1	1	1		2200	
FATIGUE	COUPON	5	5	5	1	1	1	$75 setup	$6 per hour	RESIDUAL STRENGTH, STIFFNESS AFTER 4 SERVICE LIVES; FULL S-N CURVE
CREEP - LOSS OF PRELOAD DUE TO THERMAL & AGE EFFECTS	COUPON /RING	5	5	5	5	5	5	$75 setup	$1 per hour	COMPRESSIVE PRELOAD NORMAL TO FIBER DIRECTION
RESIN PROPERTIES DUE TO EXPOSURE TO: VACUUM(1E-X TORR- OUTGASSING), ATOMIC O_2, RADIATION, IONIZING RADIATION(PER SSP 30512), RELATIVE HUMIDITY(30-50%), PLASMA(PER SSP 30420, 30425),	COUPON	5	5	5	1	1	1		TBD	DATABASE PROBABLY EXISTING; TBD TESTING NEEDED
DYNAMIC MECH. ANALYSIS	COUPON	5	5	5	1	1	1	500	7500	RESIN STIFFNESS VS TEMP.
SUB-SCALE SPIN FAILURE	SUB-ELEMENT	3	3	3				2000 + 2000	24000 + 24000	ISOLATE HIGH STRESS AREAS ON SUB-LENGTH PART (FULL OD, ID AS FLIGHT
RESIDUAL STRAIN	SUB-ELEMENT	1	1	1	1	1	1	1500	7500	

ACESE Rotor Cert. Plan- Rotor Level Verifications

DRAFT

Lewis Research Center

Analysis type	**CRITERIA**	**S.F./ACCEPTANCE LEVEL**	**Reliability (%)**
LAUNCH/LANDING RELATED:			
FEA ATP VIBRATION (BASED ON 1σ LEVELS)	1 σ, 3 σ RANDOM VIBS (SEE TABLE 5)	LIMITS S.F.=2.0 ON S_U(BASED ON 3 σ LEVEL)	99.999
FEA STATIC ACCEL.	SEE TABLE 6	S.F. =2.0 ON S_U	99.999
ON ORBIT RELATED:			
FEA MAX. OPERATING SPEED (INCLUDING ALL OPERATING, ENVIRONMENTAL EXTREMES E.G. GYROSCOPIC AND THERMAL EFFECTS)	105% NORMAL OPER. SPEED	S.F. 2.0 ON S_U USING 99% ALLOWABLES	99.999
FEA PROOF TEST SPEED	110% MAX. OPER. SPEED (PER SSP 30559)	S.F. 1.2 ON S_U	99.9
FEA FAILURE EVENT SPEED	EITHER BENIGN OR FULL ROTOR TEAROUT	> 142% OF MAX. OPERATING SPEED	N/A
SAFE LIFE ANALYSIS (OR TEST)	PER SSP 30558, 30559, NASA FLAGRO (& COMPOSITES ALTERNATIVE CODE); LOADING SPECTRUM FROM: GROUND HANDLING, ATP VIBRATION, 50K CYCLES OPERATING LOAD, LAUNCH (PER “GODDARD SPECTRUM)	4 SERVICE LIVES	99.99 (AT ONE SERVICE LIFE)
ALLOWABLE DEFECT SIZE	PER SSP 30558, 30559; COMPOSITE: TBD ANAL. METHOD METALLICS: FLAGRO/NASGRO	TBD SIZE CRACKLIKE FLAW OR SMALLER ALLOWED THRU FRACTURE MECH. ANAL. OR TEST	N/A
ROTOR STIFFNESS, RESONANCES	AXIAL, LATERAL, & GYRO FOR STATIC CASE AND FOR CENT. STIFFENING CASE	TBD	N/A

Lewis Research Center

ACESE Rotor Cert. Plan - Rotor Verifications, Cont.

Test type	Test article type	Test article quantity	Cost per test ($)	Total cost ($)	Comments:
RANDOM VIBRATION	QUAL ROTOR, ACCEPTANCE ROTORS(FLIGHT)	2 QUAL., 2 ACC.	TBD	TBD	PER TABLE 5, 6 (COULD BE DONE @ SYSTEM LEVEL IN LIEU OF ROTOR LEVEL)
PROOF TEST	ALL FLIGHT UNITS	2	TBD	TBD	110% MAX. OPER. SPEED(MOS)
BALANCE CHANGES & MOMENT OF INERTIA	ALL FLIGHT UNITS	2	TBD	TBD	TBD CYCLES @110% MOS
FAILURE EVENT SPEED	NONFLIGHT	3	20,000	60,000	>142% MAX. OPER. SPEED IF NON-FAIL SAFE CONDITION
LOW CYCLE FATIGUE	NONFLIGHT	3	20,000	60,000	4 X SERVICE LIFE= 50000 CYCLES (CYCLE = 30%M.O.P.-100% - 30%)
ROTOR SIGNATURE (MODES)	1 FLIGHT UNIT	1	TBD	TBD	STATIC CASE – COMPARE TO MODEL(COULD BE DONE AT SYSTEM LEVEL IN LIEU OF ROTOR LEVEL TESTS)
NON DESTRUCTIVE EVAL	VARIOUS	VARIOUS	TBD	TBD	CT BEFORE AND AFTER PROOF TESTING, BURST TESTS, LCF AND HCF TESTS(SEE PROCESS CONTROLS SECTION)

Rotor Safe-life Efforts Summary

Lewis Research Center

- ACESE
  - A specific design with specific energy storage goal, packaging constraints, environmental issues inherent to LEO, ISS applications.
  - Status: Phase A completed, SDR held (4/98), PDR scheduled 10/98.
- FRSL
  - Broader goals relevant to applications in terrestrial and aerospace regimes.
  - Fosters new technology, facilities economically.
  - Synergistic coordination of activities with DARPA Containment Program.
  - Combined Government/industry effort gives best opportunity for success.
  - Status: Rotor certification workshop held (2/98), Phase 0 kickoff meeting held (9/98), UT CEM work on Phase 0 currently being done.
- Flywheels will not become accepted until their safety and lifetime are proven and their reliability quantified!