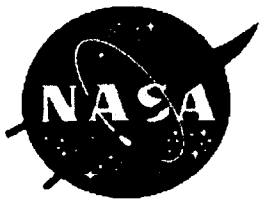
Lithium-Ion Batteries for Aerospace Applications

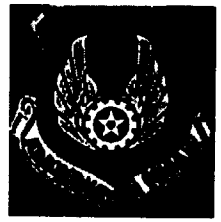
S. Surampudi & G. Halpert
Jet Propulsion Laboratory
Pasadena, CA

R. A . Marsh & R. James
U.S. Air Force Research Laboratory
Dayon, OH/Albuquerque NM

NASA BATTERY WORKSHOP
HUNTSVILLE, AL
October 27-29, 1998



OVERVIEW



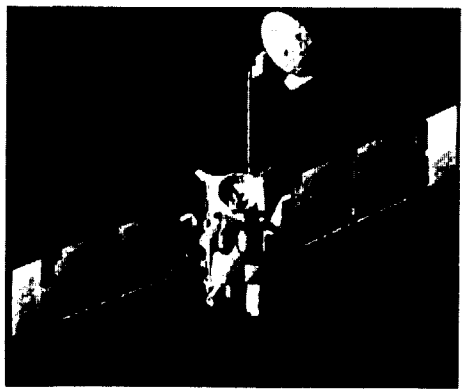
- Program Goals
- NASA Mission Requirements
- AF Mission Requirements
- Potential Near Term Missions
- Management Approach
- Technical Approach
- Program Road Map

PROGRAM OBJECTIVES

- DEVELOP HIGH SPECIFIC ENERGY AND LONG LIFE LITHIUM ION CELLS AND SMART BATTERIES FOR AEROSPACE AND DOD APPLICATIONS.
- ESTABLISH U.S. PRODUCTION SOURCES
- DEMONSTRATE TECHNOLOGY READINESS FOR
  - ROVERS AND LANDERS BY JANUARY 1999
  - LIBRATION POINT MISSIONS BY 2000
  - GEO MISSIONS BY 2001
  - AIRCRAFT BY 2001
  - UAV BY 2003
  - LEO MISSIONS BY 2003

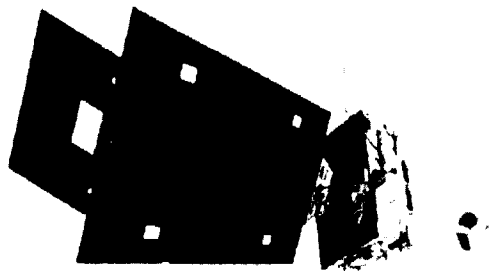
POTENTIAL NASA APPLICATIONS

Planetary Orbiters

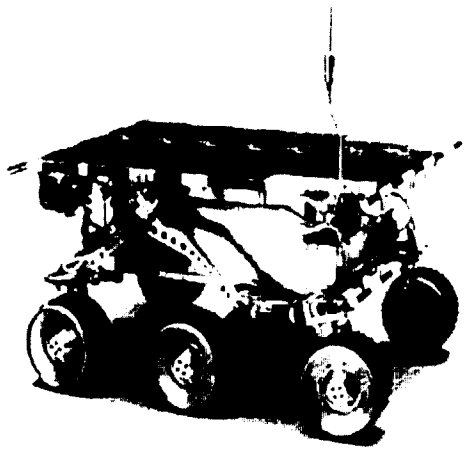


Planetary Lander

GEO Spacecraft

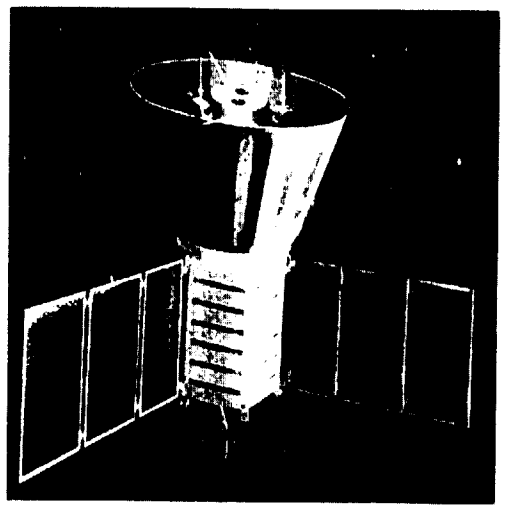


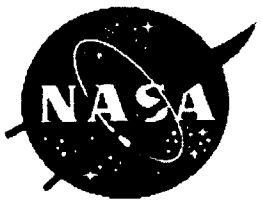
Planetary Rover



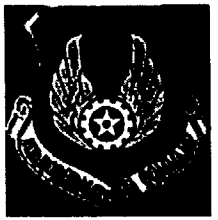
Astronaut Equipment

LEO Spacecraft





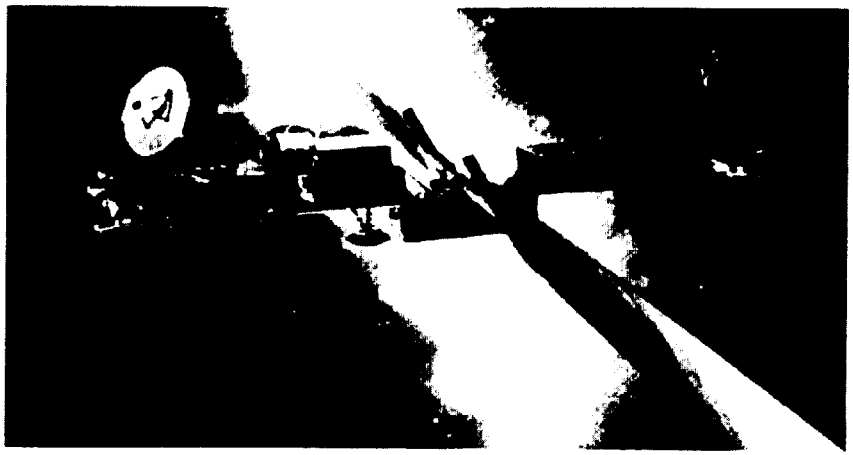
PERFORMANCE REQUIREMENTS



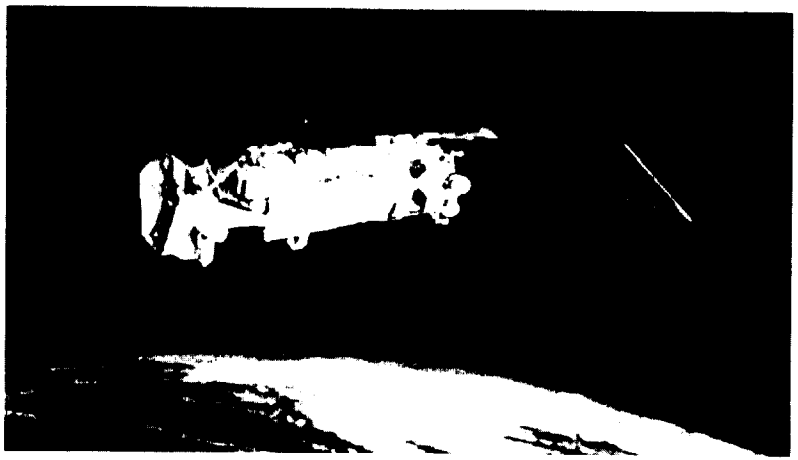
Type	Nominal Voltage (V)	Capacity (Ah)	Temp. Range (°C)	Cycle Life	Dis. Rate Ch. Rate	DOD (%)
Rovers	14	5/7	-30 to +40	>500	C/5-1C C/5-C/3	50
Landers	28	20/25	-20 to +40	>500	C/5 C/2	50
MIDX	28	20	25-30	>100	C/2	50%
GEO	28	20/35	-5 to +30	2000	C/1.6-C/2 C/10-C/20	75
LEO/ ORBITTERS	28	20/35	-5 to +30	30,000	C/2 C/2	>25

POTENTIAL AIR FORCE APPLICATIONS

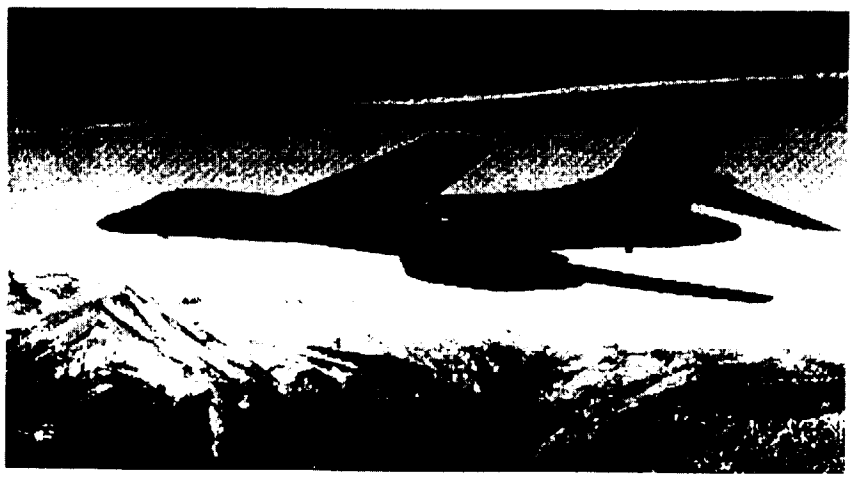
GEO SPACRAFT



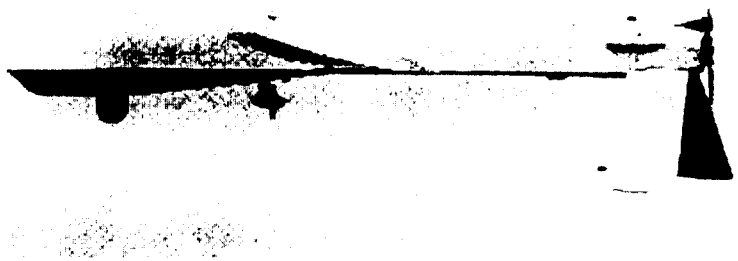
LEO SPACECRAFT



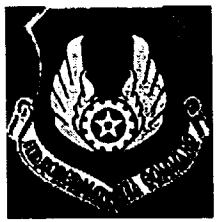
AIR CRAFT



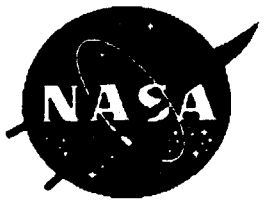
UAV'S

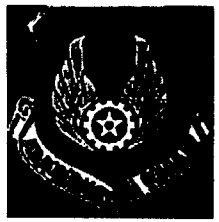


DOD Lithium-Ion Battery Performance Requirements



Type	Operating Voltage	Capacity (Ahr)	Temp. (°C)	Cycle Life	Discharge Rate Charge Rate	% DOD
UAVs	100	200	-40 to +65	1000	C C	50
Aircraft (a)	270	20	-40 to +65	1000	C C	50
Aircraft (b)	270	20	-40 to +65	1000	C C	50
GEO Sats	100	50	-5 to +30	1500	2/3 C C/20	75 (max)
LEO Sats	28	50	-5 to +30	45000	C C/2	25





TECHNOLOGY DRIVERS FOR FOR VARIOUS MISSIONS

MISSION	TECHNOLOGY DRIVER
LANDER/ROVER	LOW TEMP. OPERATION HIGH RATE PULSE CAPABILITY
GEO S/C	TEN-TWENTY YEAR OPERT. LIFE LARGE CAPACITY CELLS (50-200 Ah)
LEO/PLANTERARY S/C	LONG CYCLE LIFE (30,000) MED. CAPACITY CELLS (50 Ah)
AIRCRAFT	LOW TEMP OPERATION HIGH VOLTAGE BATTERIES (270 V)
UAV	LARGE CAPACITY CELLS (200 Ah) HIGH VOLTAGE BATTERIES (100V)

OTHER CHALLENGES: RELIABILITY, SAFETY & COST

POTENTIAL NEAR TERM SPACE MISSIONS/APPLICATIONS

•NASA MISSIONS

•JPL

MARS LANDER AND ROVER -2001

MARS LANDER AND ROVER -2003

MARS SAMPLE RETURN MISSION - 2005

CHAMPOLILON MISSION - 2003

SOLAR PROBE - 2005

•GSFC

SATELITE SERVICING TOOLS

LIBRATION POINT SPACECRAFT (MAP-2000,NGST 2007)

GEO SPACECRAFT(GOES)

LEO SPACECRAFT(EOS)

•AIR FORCE MISSIONS

•GEO

Milsatcom - 2002?

DSP - ?

LEO

SBIRS Low - 2004

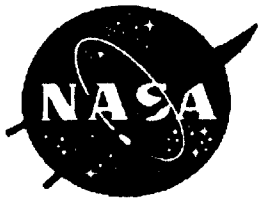
NPOESS - 2007

Surveill. Platforms

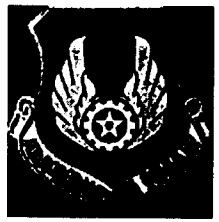
•AIRCRAFT

AVIATION - 2001

UAVs - 2001



MANAGEMENT APPROACH



PARTICIPATING ORGANIZATIONS/AGENCIES INCLUDE: NASA, AIRFORCE, BMDO, JIST.

DEVELOP TWO SOURCES FOR MANUFACTURING CELLS AND BATTERIES

BUILD ON EXISTING COMMERCIAL TECHNOLOGY AND GOVT TECHNOLOGY DEVELOPMENT EFFORTS/PROGRAMS

TEAMING OF UNIVERSITIES, R&D ORGANIZATIONS AND BATTERY MANUFACTURING COMPANIES IS ENCOURAGED

NASA, AIRFORCE, NAVY LABS AND AEROSPACE PRIMES PARTICIPATE IN TECHNOLOGY EVALUATION FOR VARIOUS MISSIONS

TECHNOLOGY APPROACH

DEVELOPADVANCED ELECTRODE MATERIALS AND ELECTROLYTES TO ACHIEVE IMPROVED LOW TEMPERATURE PERFORMANCE AND LONG CYCLE LIFE

OPTIMIZE CELL DESIGN TO IMPROVE SPECIFIC ENERGY, CYCLE LIFE AND SAFETY

ESTABLISH MANUFACTURING PROCESSES TO ENSURE PREDICTABLE PERFORMANCE

DEVELOP AEROSPACE LITHIUM ION CELLS IN 5, 10, 20, 50, AND 200 AH SIZES

DEVELOP BATTERIES IN 28, 100 AND 270 V CONFIGURATIONS

DEVELOP ELECTRONICS FOR SMART BATTERY MANAGEMENT

DEVELOP A PERFORMANCE DATABASE REQUIRED FOR VARIOUS APPLICATIONS

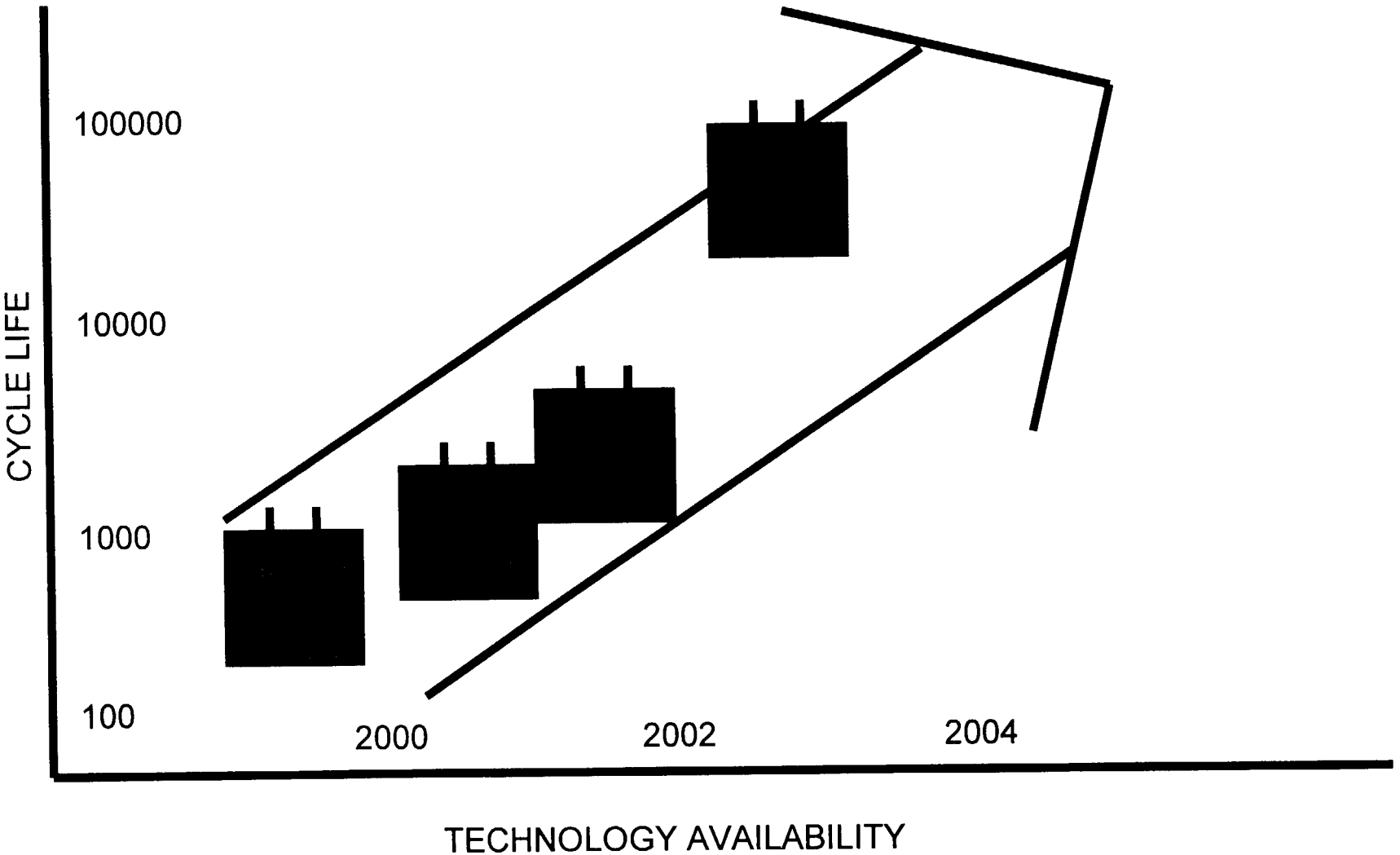
DEMONSTRATE TECHNOLOGY READINESS FOR VARIOUS NASA AND AIR FORCE MISSIONS

FOR OFFICIAL USE ONLY
LI-ION BATTERY DEVELOPMENT PROGRAM
REQUIREMENTS AND DELIVERABLES

Parameter	Supplier B/L	Design 1		Design 2		Design 3		Design 4	Design 5		Cum Total	Cum Cells
		NASA Rovers	NASA Landers	Aircraft (A)	Aircraft (B)	AF GEO	NASA GEO	AF UAVs	AF LEO	NASA LEO/Pl. Orbiter		
Nominal System Voltage	3.5	14	28	270	28	100	28	100	28	28		
EOL Capacity (Ah)	5*	7	20	20	20	50	20	200	50	20		
Temp Range (°C)		-30 to +45	-20 to +45	-40 to +65	-40 to +65	-5 to +30	-5 to +30	-40 to + 65	-5 to +30	-5 to +30		
Life (Cycles)		>500	>500	1,000	1,000	1,500	1,000	1,000	30,000	30,000		
Discharge Rate		C/5 to 1C	C/5 to 1C	C	C	2C/3	2C/3	C	C	C		
Charge Rate		C/5 to C/2	C/5 to C/2	C	C	C/20	C/20	C	C/2	C/2		
DOD (%)		50	50	50	50	75 (max)	75 (max)	50	25	25		
PDR		Feb 99	Oct 98	May 00	May 00	Oct 00	Oct 00	May 00	Oct 00	Oct 00		
1st Generation Cell Del'y (Contract)	Nov 98	May 99	Nov 98	Aug 00	Aug 00	Jan 01	Jan 01	Aug 00	Jan 01	Jan 01		
No. of Cells	30	25	25	20	20	35	25	12	35	40	267	267
CDR		Jun 99	Mar 99	May 01	May 01	Oct 01	Oct 01	May 01	Jun 02	Jun 02		
2nd Generation Cell Del'y (Contract)		Sep 99	Feb 99	Aug 01	Aug 01	Jan 02	Jan 02	Sep 01	Sep 02	Aug 02		
No. of Cells		25	25	20	20	35	25	12	35	40	237	504
"Battery System" Delivery (Contract)		Jul 00	May 99	Apr 02	Apr 02	Jun 02	Jun 02	Jan 02	Feb 03	Feb 03		
No. of Battery Systems		9	2	1	4	2	1	1	2	2	24	
Equivalent Cells		36	16	77	32	58	8	29	16	16	288	792

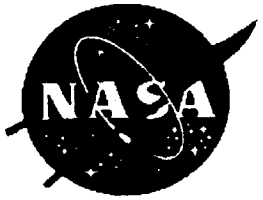
* Whatever the Company baseline cell is but at least 5 Ah

TECHNOLOGY DEMONSTRATION MILESTONES



AEROSPACE LITHIUM-ION BATTERY PROGRAM ROADMAP

TASK	98 99 00 01 02 03 04	GOALS
CHEMISTRY & MATERIALS	LOW TEMP. AND STABLE E'LYTE HIGH CAP. & LONG LIFE ELECTRODES SEPARATOR OC/OD ADDITIVES	IMPROVE - LOW TEMP. PERF. - CYCLE LIFE - OPERATIONAL LIFE
CELL DEVELOPMENT	PROCESS DEV. DESIGN, AND CELL MANUFACTURING 10-20 Ah,500 CYC LT. HR. 200 Ah 40/50 Ah,2000 CYC 30000 CYCLE, 20-50 Ah	EST. MANF. PROCESS OPT. CELL DESIGN FAB. 10-200 Ah CELLS
BATTERY DEVELOPMENT	PROCESS DEV. DESIGN & MANF. LANDER/ROV. UAV/AIRCRAFT GEO S/C LEO, PLANETARY S/C	EST. MANF. PROCESS DEV. SMART BATT. FAB. LANDER, ROVER GEO, LEO S/C, UAV AIRCRAFT BATT.
TESTING & QUALIFICATION	ELECTRICAL PERF., THERMAL, AND SAFETY TESTS 100/50% DOD LEO & GEO LIFE TEST FAILURE MODES & ANALYSIS	EST. DATA BASE DET. FAILURE MODES EST. CHARGE CNTLS DEMON. SAFETY
FLIGHT VALIDATION	LAND/ROVER UAV/AIRCRAFT S/C TOOLS GEO S/C LEO S/C	DEMON. TECH. FOR LANDER, ROVER GEO, LEO S/C, UAV AIRCRAFT MISSIONS

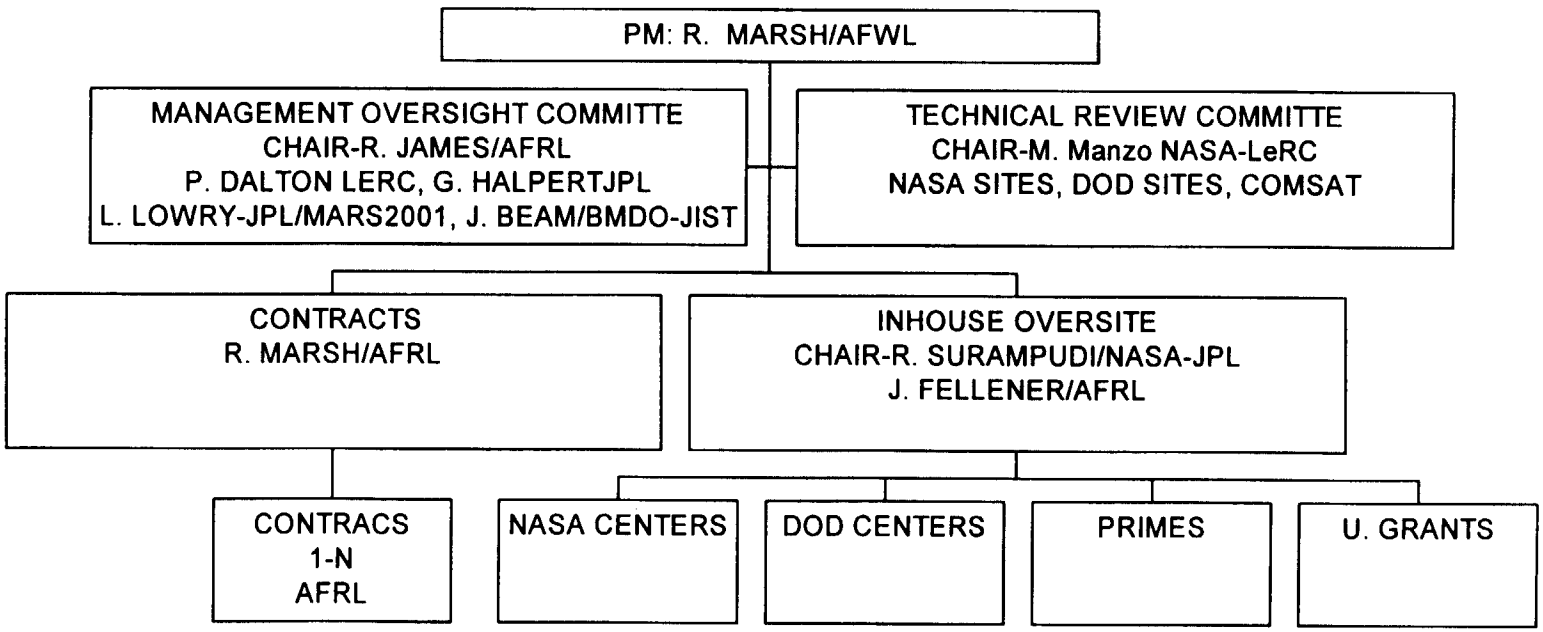


DELIVERABLES

- FIRST GENERATION CELLS
- SECOND GENERATION CELLS
- ENGINEERING MODEL BATTERIES(EM1)
- MANUFACTURING CONTROL DOCUMENTS
- TEST RESULTS
- DESIGN REVIEW DOCUMENTS
- FLIGHT HARDWARE*

* PROCURED THROUGH SEPARATE CONTRACTS BY RESPECTIVE PROJECTS

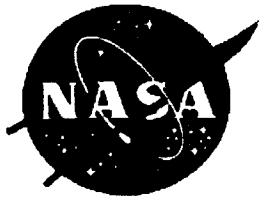
MANAGEMENT STRUCTURE



MISSION REQUIREMENTS

	LANDERS	ROVERS	GEO	LEO/ PLA. ORBITER	S/C TOOLS	LIBRATION POINT S/C
CAPACITY (AH)	20-40	5-10	10, 20, 35	10, 20, 35	3-5 AH	20-25 AH
VOLTAGE (V)	28	28	28-100	28	28	28
DIS. RATE	C/5-1C	C/5-C/2	C/2	C/2-C	C/2	C/2
CYCLE LIFE	> 500 (>60%DOD)	>500 (>60% DOD)	2000 (>75% DOD)	>30,000 (>30% DOD)	>100	50
OPER. TEMP (C)	-40 TO 40	-40 TO 40	-5 TO 30	-5 TO 30	0-50C	25-30
SP. ENERGY (Wh/KG)*	>100	>100	>100	>100	>100	100
ENERGY DENSITY (Wh/l)*	120-160	120-160	120-160	120-160	>80	120-160

* 100% DOD BOL



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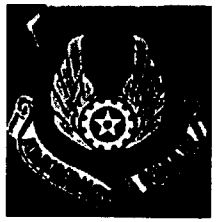

Some of the work described in this paper was performed by the Jet propulsion laboratory, California institute of Technology, under a contract with the National Aeronautics and Space Administration.

MODIFICATIONS TO TASK PLAN

	Revision A	Revision B	Revision C
12/98		150 W System 5 kWh, Nafion Packaged Bat. Charger	
9/99			Generation I 150W,5kWh System USC Membranes 10 kG System Packaged
4/00	150 W System 28V, Packaged 600 Wh	150 W System 5 KwH, 8Kg USC Membrane Packaged	
4/00			Deliver Gen 2 Stack
9/00			Fild Demo Unit with Ball Aerospace