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**AN HISTORICAL SUMMARY AND
PROSPECTS FOR THE FUTURE OF
SPACECRAFT BATTERIES**



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DEVICE RESEARCH AND APPLICATIONS SECTION

**NASA BATTERY WORKSHOP
HUNTSVILLE, ALABAMA
NOVEMBER 18, 1997**

OUTLINE

HISTORICAL EVOLUTION OF BATTERIES IN SPACE
EVOLUTION AND STATUS OF NI-CD AND NI-H₂
PRESENT APPLICATIONS
FUTURE APPLICATIONS
ADVANCED BATTERIES FOR FUTURE MISSIONS

HISTORY OF BATTERIES IN SPACE



APPLICATIONS - FIRST SPACE MISSIONS

1955

10/4/57 SPUTNIK Ag/Zn
1 W FOR 3 WEEKS

12/6/57 VANGUARD Zn/HgO

2/1/58 EXPLORER 1 Zn/HgO
VAN ALLEN RAD BELT

8/7/59 EXPLORER 6 Cyl Ni/Cd
FIRST EARTH PHOTOS

1960

'61-64 RANGERS Pris Ni/Cd
MOON PHOTOS

4/26/62 ARIEL I Pris Ni/Cd
First LEO MISSION

6/23/63 SYNCOM-2 Cyl Ni/Cd
First GEO

1965

5/20/65 APOLLO CM Ag/Zn
LTD CYCLE LIFE

APPLICATIONS - FIRST SPACE MISSIONS

| | | | | |
|-------------|----------|---------------|--------------------|--|
| 1970 | 3/13/71 | IMP 1 | Ag/Cd | NON-MAGNETIC |
| | 6/23/77 | NTS-2 | Ni/H ₂ | 12 HOUR POLAR |
| | 9/23/77 | AF | Ni/H ₂ | LEO |
| 1980 | 2/14/80 | SOLAR MAX | Ni/Cd | STANDARD BATTERY |
| | 5/19/83 | INTELSAT V | Ni/H ₂ | GEO |
| | 4/4/83 | STS-3 | Li-BCX | ASTRONAUT EQUIPMENT |
| | 4/7/84 | LDEF | LITHIUM & OTHERS | EXPOSURE TO SPACE |
| | 10/18/89 | GALILEO HOURS | Li/SO ₂ | WITH THERMAL BATTERY FOR JUPITER PROBE |
| 1990 | | | | |

APPLICATIONS - FIRST SPACE MISSIONS

| | | | |
|------|---------|--------------------------------------|-----------------------|
| 1990 | 4/25/90 | HST NASA LEO | Ni/H ₂ |
| | 6/10/90 | LEASAT Super Ni/Cd | GEO |
| | 1/25/94 | CLEMENTINE LUNAR MAPPING | SPV Ni/H ₂ |
| | 1/25/94 | TUBSAT-B STORE MESSAGES | 2 Cell CPV |
| 1995 | 5/1995 | CENTAUR 28V, 250AH LAUNCH VEHICLE | Li-SOCl ₂ |
| | 5/5/97 | IRIDIUM-1 LEO 34 TO DATE | 50Ah SPV |
| | NOV 97 | FLIGHT EXP WAKESHIELD | Na/S |
| 2000 | | | |



**EVOLUTION OF
NI-CD BATTERIES
IN SPACE**

NI-CD SPACE BATTERY EVOLUTION

| | 1958-69 | 1970-79 | 1980-89 | 1990-97 |
|----------------------|---|---|---|--|
| Technology | 3-6 Ah Cells Pellon GTM Seals | 5-20 Ah Cells Teflonation Ceramic Seals NASA Std Cells | NASA 50 Ah E-I Process Lt Wt Designs Passivation | Super Ni-Cds Pellon 2536 |
| Performance | 2-5% DOD < 1000 cycles Leaks Const. I Charge | 10-20% DOD NASA VT | >10 Years GEO 40K Cycles LEO | 'MATURE' |
| Manufacturers | Gould Gulton Saft Sonotone | EPI G.E.. Gulton Saft | EPI G.E../Gates Saft Sanyo | EPI Hughes Saft Sanyo Acme |



**EVOLUTION OF
NI-H₂ BATTERIES
IN SPACE**



NI-H₂ SPACE BATTERY EVOLUTION

| | 1958-69 | 1970-79 | 1980-89 | 1990-97 |
|---------------|---------|---|---------------------------------------|--------------------------------|
| Technology | | 35-50 Ah IPV E-I Aq. Process Back to Back(C) Recirculating(AF) | E-I Alc. Process 100 Ah | CPV & SPV 120 Ah 26% KOH |
| Performance | | LEO 25% DOD 2000 Cycles Polar 40% DOD 5 years | 40K Cycles LEO 10 YEARS GEO | 50-100K LEO CYCLES |
| Manufacturers | | EPI Yardney ERC SAFT GE | EPI Hughes JCI Saft Gates | EPI Hughes JCI Saft |

KEY EVENTS IN SPACE BATTERY HISTORY

| | 1958-69 | 1970-79 | 1980-89 | 1990-97 |
|-------------------------|---|---------------------------------|--|---|
| NI-CD | '59 EXPLORER-6 (CYLINDRICAL) '62 ARIEL-1 LEO (PRISMATIC) '63 SYNCOM2 GEO | | '80 SOLAR MAX NASA 20 AH STD '82 LANDSAT -D STD 50 Ah | '90 LEASAT GEO SUPER NI-CD |
| NI-H₂ | | '77 NTS-2 & AF FIRST IPV USE | INTELSAT 5 IPV GEO | '90 HUBBLE IPV '94 CLEMENTINE SPV '94 TUBSAT CPV |
| LITHIUM | | | '83 STS- LI-BCX '89 GALILEO Li-SO ₂ | '95 CENTAUR '96 PATHFINDER |

**NASA MISSIONS
TODAY**





NEAR TERM NASA MISSIONS - GSFC

| <u>LAUNCH DATE</u> | <u>MISSION NAME</u> | <u>MISSION TYPE</u> | <u>NO. BATS</u> | <u>NO CELLS/BAT</u> | <u>CELL CAPACITY</u> | <u>CELL TYPE</u> |
|--------------------|---------------------|---------------------|-----------------|---------------------|----------------------|--------------------------------|
| 11/97 | TRMM | LEO | 2 | 22 | 50Ah | EPI-SUPER NI-CD |
| 12/97 | TRACE/SMEX | LEO/SS | 1 | 22 | 9Ah | EPI- SUPER NI-CD |
| ?/97 | ACE | LIBATION | 1 | 18 | 12Ah | NI-CD |
| 5/98 | LANDSAT-7 | LEO | 2 | 17 | 50Ah | EPI - AXIAL Ni-H ₂ |
| 6/98 | EOS-AM | LEO | 2 | 54 | 50Ah | EPI-RE Ni-H ₂ |
| 7/98 | GOES-L | GEO | 2 | 28 | 12Ah | GATES / SAFT NI-CD |
| 9/98 | WIRE/SMEX | LEO | 1 | 22 | 9Ah | EPI-SUPER NI-CD |
| ?/99 | IMAGE | LEO | 1 | 22 | 21Ah | CS SUPER NI-CD |
| ?/00 | MAP | FULL SUN | 1 | 11/2CELL | 23Ah | CPV EPI-J RE NI-H ₂ |



NEAR TERM NASA MISSIONS - JPL

| <u>LAUNCH DATE</u> | <u>MISSION NAME</u> | <u>MISSION TYPE</u> | <u>NO. BATS</u> | <u>NO CELLS/BAT</u> | <u>CELL CAPACITY</u> | <u>CELL TYPE</u> |
|--------------------|---------------------|---------------------|-----------------|---------------------|----------------------|---------------------------------|
| 1996 | MGS | MARS ORB | 2 | 11/2CELL | 23Ah | CPV EPI-J RE NI-H ₂ |
| 1996 | MPF | LANDER | 1 | 18 | 40Ah | AG/ZN RECHARGE |
| 1996 | MPF | ROVER | 3 | 3 | 12Ah | LI-SOCL ₂ 'D' |
| 1997 | CASSINI | PROBE | 3 | 13 | 8Ah | LI-SO ₂ |
| 1998 | NEW MIL DS-1 | | 1 | 11/2CELL | 12Ah | SAME AS MSTI-3 |
| 1998 | NEW MIL DS-2 | | 2 | 4 | 2Ah | LI-SOCL ₂ FLAT PLATE |
| 1998 | MARS SURVEYOR/98 | | 2 | 11/2CELL | 16Ah | NI-H ₂ |
| 1999 | STARDUST | | 2 | 11/2CELL | 16Ah | NI-H ₂ |
| 1999 | STARDUST SAMP. RET | | 3 | 13 | 8AH | LI-SO ₂ |



NEAR TERM NASA MISSIONS - MSFC

| <u>LAUNCH DATE</u> | <u>MISSION NAME</u> | <u>MISSION TYPE</u> | <u>NO. BATS</u> | <u>NO CELLS/BAT</u> | <u>CELL CAPACITY</u> | <u>CELL TYPE</u> |
|--------------------|---------------------|---------------------|-----------------|---------------------|----------------------|---------------------------|
| 1998 | AXAF | LEO | 3 | 22 CELLS | 40 Ah | EPI IPV NI-H ₂ |

1997 NASA Aerospace Battery Workshop

-17-

General / Ni-Cd / Ni-MH Battery Session

**THE FUTURE OF
BATTERIES IN SPACE**



POTENTIAL NASA SPACE MISSIONS / APPLICATIONS

NASA MISSIONS

JPL

MARS LANDER AND ROVER -2001
MARS LANDER AND ROVER -2003
MARS SAMPLE RETURN MISSION - 2005
CHAMPOLION MISSION - 2003
SOLAR PROBE - 2005

GSFC

SATELLITE SERVICING TOOLS
LIBATION POINT SPACRAFT
(MAP-2000,NGST 2007)
GEO SPACECRAFT(GOES)
LEO SPACECRAFT(EOS)

JSC

SHUTTLE APPLICATIONS

AIR FORCE MISSIONS

LEO

NPOESS -2007
Surveill. Platforms
SBIRS Low

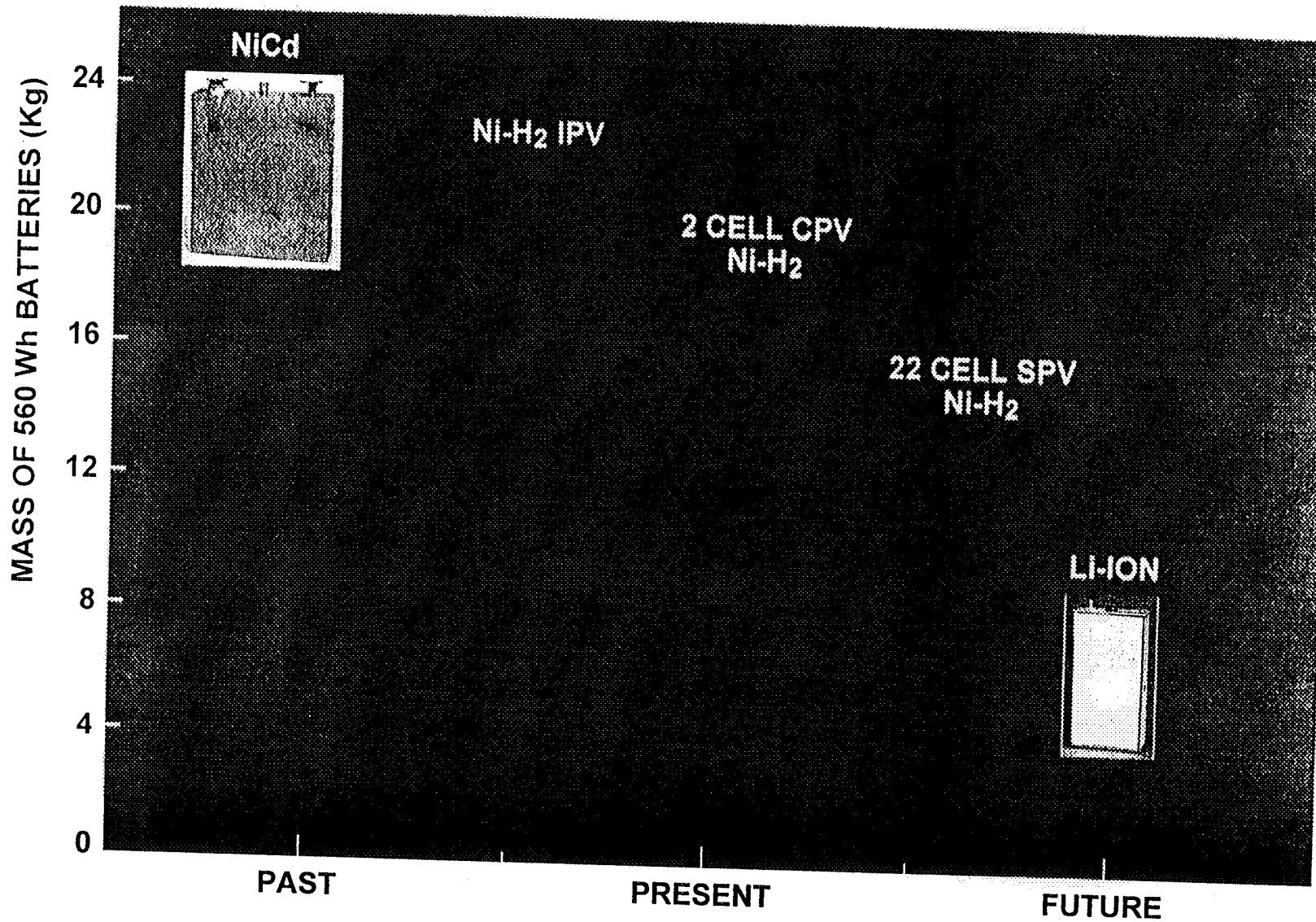
GEO

Milsatcom - 2002
DSP

AIRCRAFT

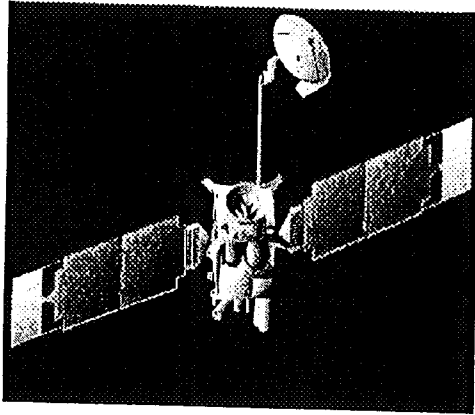
AVIATION 2001
UAVs- 2002

EVOLUTION OF FLIGHT BATTERIES

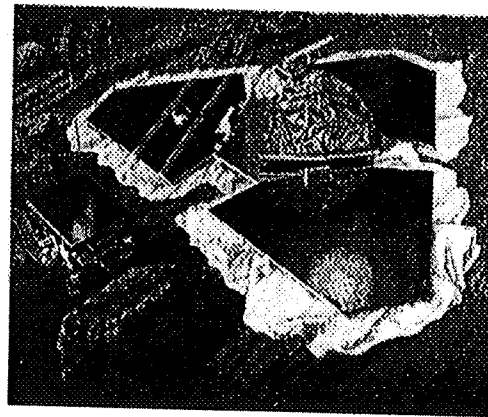


POTENTIAL NASA APPLICATIONS

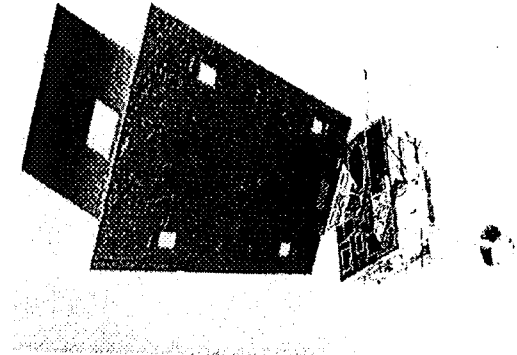
Planetary Orbiters



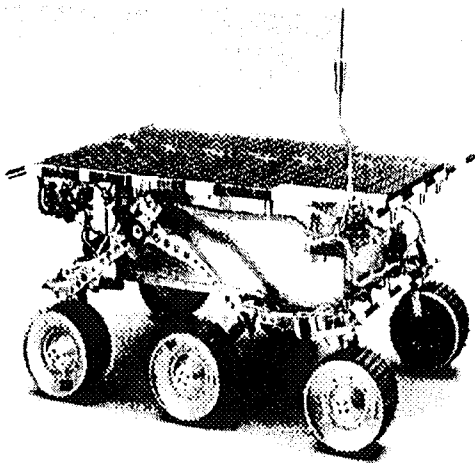
Planetary Lander



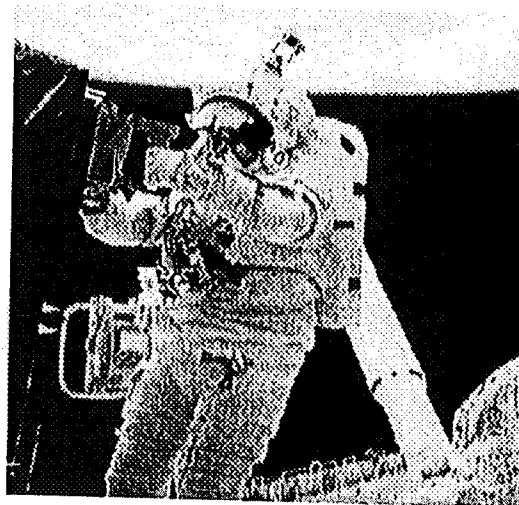
GEO Spacecraft



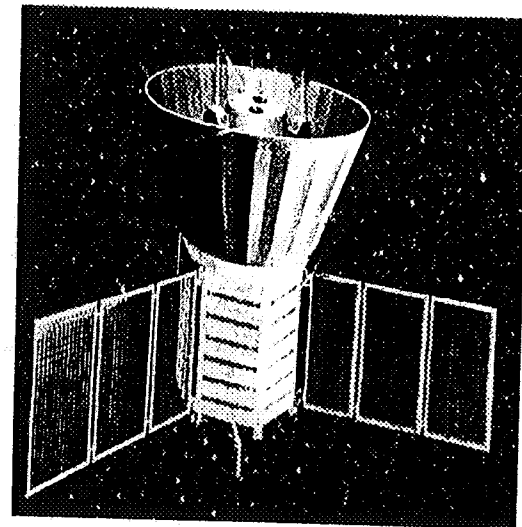
Planetary Rover



Astronaut Equipment



LEO Spacecraft



TECHNOLOGY PROGRESSION

2003

28-270V
10-100 Ah
100 Wh/kg
2000 GEO &
30,000 LEO
CYCLES

1996

1-20 Ah Cells
100 Wh/kg
500 cycles

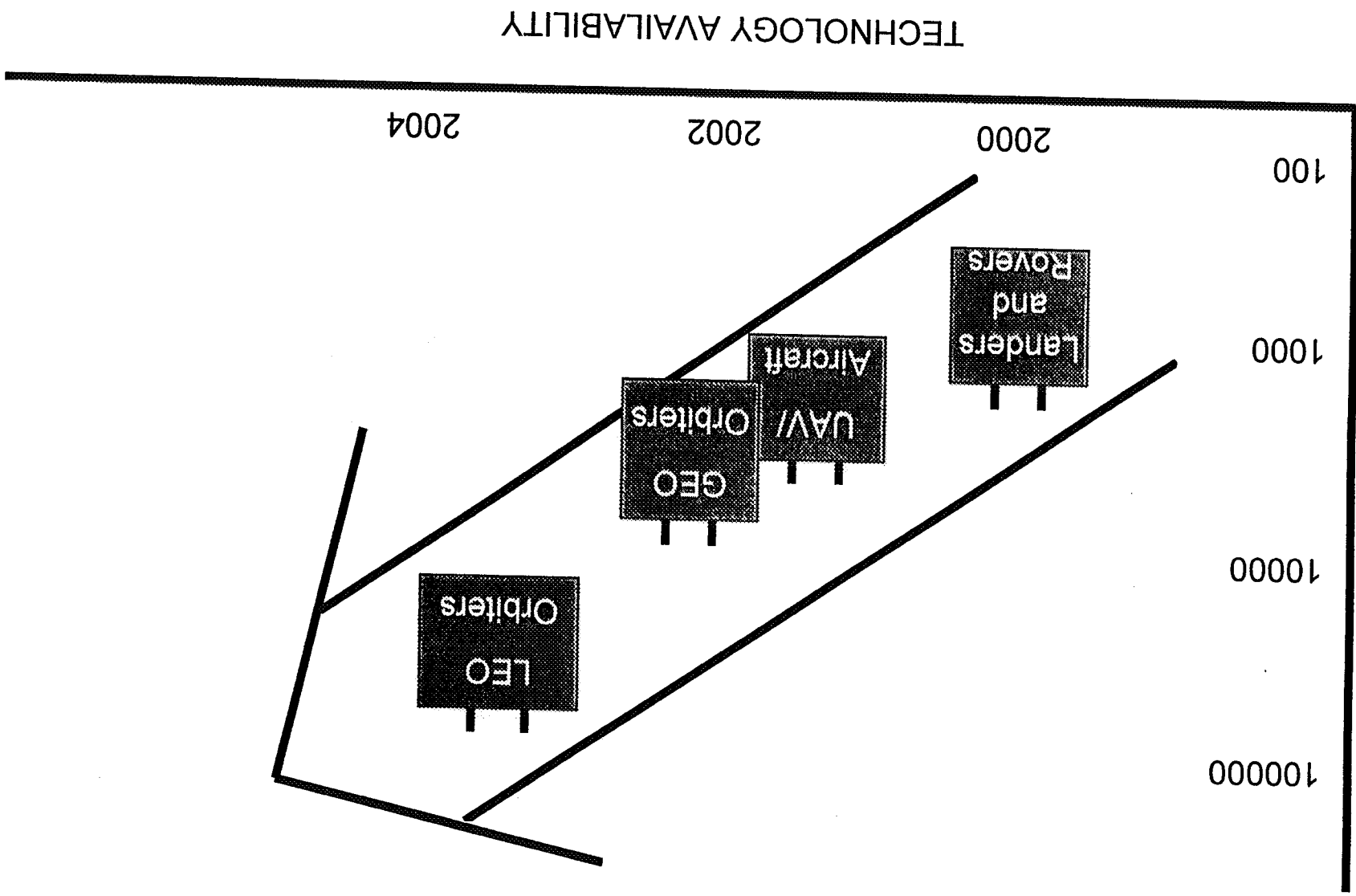
LONG LIFE
Cell Design
Battery Design
Manufacturing
Database
Charge Control

1992

100 mAh
< 200 cycles

Anode Mat.
Electrolyte
Cat. Mat.
Separator
Binder

TECHNOLOGY DEMONSTRATION MILESTONES





**PROGRAM OBJECTIVES
OF NASA / AF L-ION PROGRAM**

- DEVELOP ADVANCED LITHIUM ION CELLS AND SMART BATTERIES FOR AEROSPACE AND DOD APPLICATIONS
- ESTABLISH U.S. PRODUCTION SOURCES
- DEMONSTRATE TECHNOLOGY READINESS FOR:
 - SATELLITE SERVICING TOOLS BY 1999
 - ROVERS AND LANDERS BY 2000
 - LIBATION POINT MISSIONS BY 2000
 - GEO MISSIONS BY 2001
 - MILITARY TERRESTRIAL APPLICATIONS BY 2001
 - LEO MISSIONS BY 2003



TECHNOLOGY CHOICES FOR FUTURE MISSIONS

NEAR TERM (>2000):

LI-ION LIQUID ORGANIC ELECTROLYTE CELLS

- 1-20Ah CELL SIZES
- >1000 CYCLES
- SUPERIOR LOW TEMPERATURE PERFORMANCE
- COMMERCIAL APPLICATIONS USE
- LEVERAGE OF FUNDS SEVERAL PROGRAMS

LONG TERM MISSIONS (>2007)

LI - ION POLYMER

- HIGHER SPECIFIC ENERGY
- ADAPTABILITY TO SEVERAL CONFIGURATIONS

TECHNOLOGY APPROACH TO NASA / AF LI-ION PROGRAM

DEVELOP ADVANCED ELECTRODE MATERIALS AND ELECTROLYTES TO
ACHIEVE IMPROVED LOW TEMP. PERFORMANCE AND LONG CYCLE LIFE

OPTIMIZE CELL DESIGN TO IMPROVE SPEC. ENERGY, CYCLE LIFE AND
SAFETY

ESTABLISH MANUFACTURING PROCESSES TO ENSURE PREDICTABLE
PERFORMANCE

DEVELOP AEROSPACE LITHIUM ION CELLS IN 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 FOR VARIOUS APPLICATIONS

DEMONSTRATE TECHNOLOGY READINESS FOR VARIOUS NASA AND AIR
FORCE MISSIONS

SUMMARY

THIS PAPER INCLUDED:

A CHRONOLOGICAL HISTORY OF BATTERY FLIGHT FROM 1959 TO THE PRESENT

A LIST OF THE NEAR TERM FLIGHT MISSIONS FROM 1997-2000

A PLAN FOR AN INTERAGENCY (NASA / AF) PROGRAM TO DEVELOP LI-ION BATTERIES FOR PLANETARY, AVIATION, LEO AND GEO MISSIONS FROM 2000-2003