N95-20504

BMDO PHOTOVOLTAICS PROGRAM OVERVIEW

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Outline

BMDO advanced solar array program overview
Brilliant Eyes type satellites
Electric propulsion
BMDO photovoltaic programs
Why concentrators?
Ioffee concentrator and cell development
Entech linear mini-dome concentrators
Flight test update/plans
Conclusions

BMDO Advanced Solar Array Program Overview

Primary need is for a better power source for Brilliant Eyes type satellites

Lightweight and low cost systems are also needed to enhance BMDO electric propulsion programs

Cooperation with other government agencies is important to address broader needs and leverage capabilities

- **NASA Lewis Research Center**
- **Phillips Laboratory**
- **Others**

Commercial spin-offs to improve U.S. competitiveness in the global marketplace are also important

Brilliant Eyes Program Overview

BMDO Program for a low orbit constellation of satellites for surveillance and tracking of ballistic missiles for theater and national defense missions

Program is managed by the Air Force Space and Missiles Center for BMDO

Competition ongoing to select prime contractor

- Rockwell and TRW selected from four original contractors last year
- Source selection in progress to select one contractor to build the first two satellites
- Both contractor's programs will be continued for a later downselect for the full satellite constellation

First flight ~1997

Brilliant Eyes Type System Constellation Specs

Altitude <2000 km, high inclination & low inclination rings

In lower end of VanAllen radiation belts

Constellation of 10 to 40 satellites

Deployed on an MLV, multiple satellites per launch

Emphasis on achieving mission objectives at minimum cost

Conservative approach to non-critical satellite components

Brilliant Eyes Type System Spacecraft Specs

500 kg goal

1 kW solar arrays for 500 W of orbital average power onboard (end of life)

5-7+ year lifetime

Rad hard parts required

Applications of Electric Propulsion

Initial orbit positioning - primary application, major fuel savings at a cost of weeks extra time for the deployment

- Extra satellites/launch vehicle (major $ savings)

or

- Extra margin in launch mass (risk reduction)

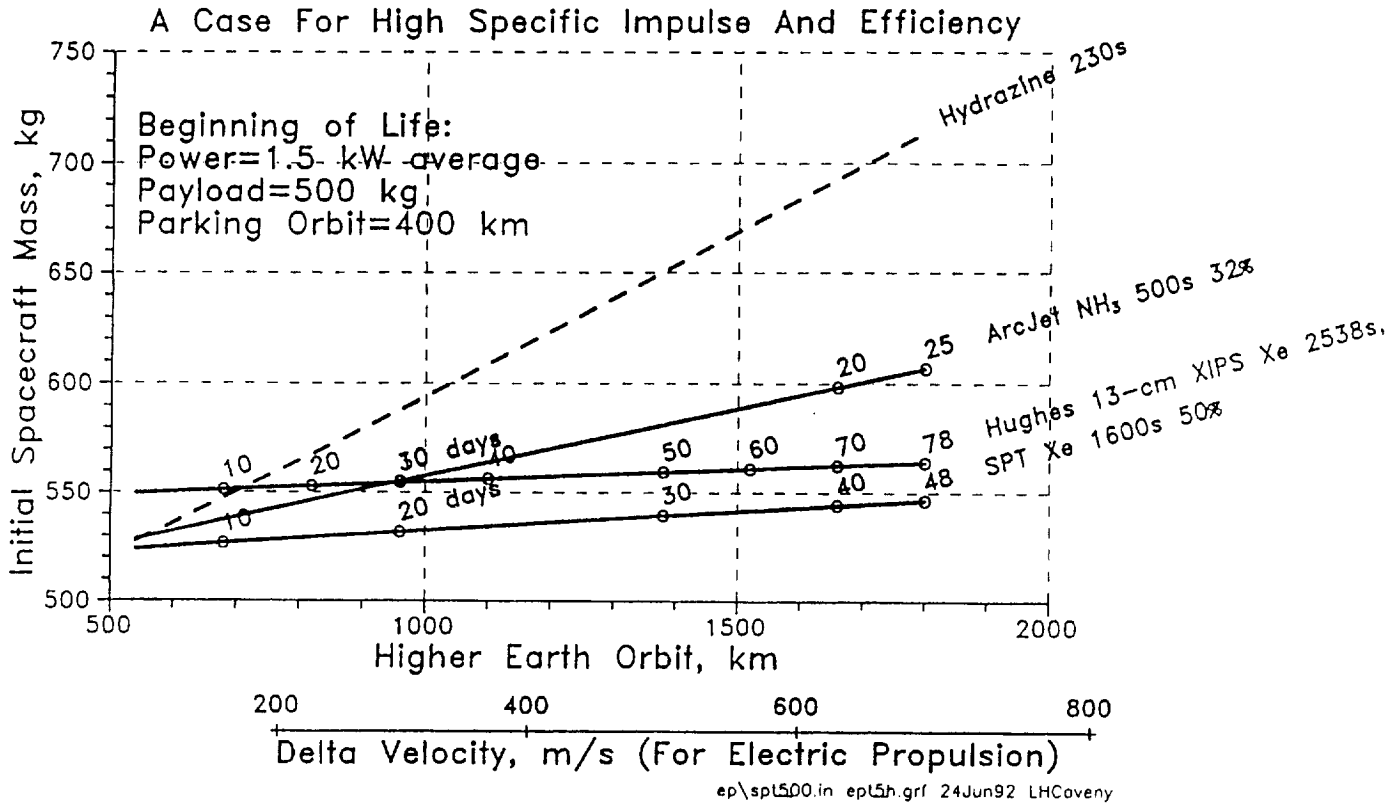
Strategic maneuvers and repositioning

Orbital maintenance

Deorbit satellite at end of life

Primary Drawback of EP is longer trip times for positioning and maneuvers - More solar array power (if affordable and mass efficient) helps a lot

BRILLIANT EYES
EARTH ORBIT TRANSFER



BMDO Photovoltaics Programs

Concentrator Solar Arrays

- **Entech linear refractive concentrator**
- **Ioffee reflective and refractive concentrators and cells**
- **NASA Lewis agent for program management**

Multiple-band-gap planar arrays

- **Phillips Laboratory agent for program management**

Other SBIR programs

Flight tests to demonstrate technology maturity

Why Concentrators?

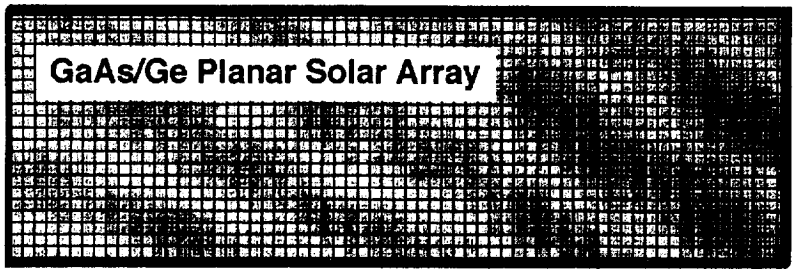
Concentrator solar arrays provide a pathway to major advances in satellite solar array parameters of interest

- Cost 2X lower than planar silicon
- Specific power of 100 W/kg or better - even for small satellites
- Very small penalty for incorporating radiation resistance

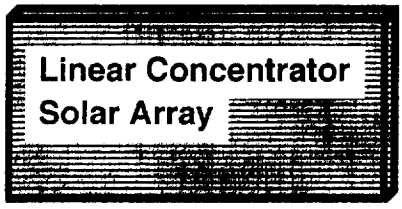
Technology development over the last decade has resulted in concentrator designs that are practical to integrate onto satellites

- Linear concentrators only require one critical axis for sun pointing
- Sun acceptance angles have been increased by nearly an order of magnitude
- Innovative optics designs allow low cost manufacturing approaches

Solar Array Technology Comparison for Brilliant Eyes Type Satellites



Array Specs:
1278 W (EOL)
2131 W (BOL)
12 m^2
42 kg
$6.39M (est.)



Array Specs:
1278 W (EOL)
1406 W (BOL)
4.5 m^2
18 kg
$0.84M (projected)

(note: drawings to scale)

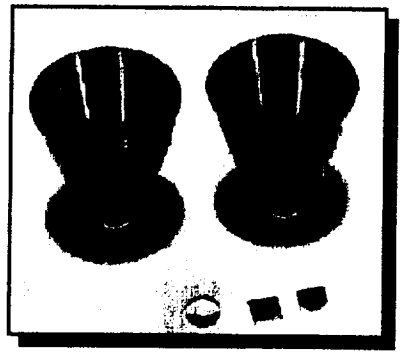
Ioffee Concentrator and Cell Development

Mirrored and flat fresnel concentrator array development

- Linear version of reflective concentrator now being developed
- Four fresnel modules being prepared for flight test

Advanced tandem and multi-junction solar cells

- GaAs/InGaAs
- GaAs/AlGaAs

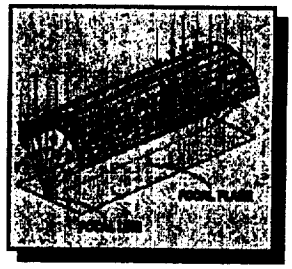


Array goals are:

- 300 W/m2
- 100 W/kg
- 30% efficiency

Entech Linear Concentrator Technology Description

Concentrator solar arrays to provide power to satellites



Single axis convex fresnel concentrator concept

Technology nearing maturity for satellites

- Materials, cells, and lenses already space flight tested
- 2 axis mini dome concentrator module being prepared for launch on PASP+
- One axis version of concentrator ground demonstrated

Performance of arrays provides many operational benefits

- Efficiency = 1.5 x GaAs
- Recurring Cost = 0.3 to 0.5 x Si
- Array specific power = 1.5 to 2.5 x APSA for small arrays
- Radiation tolerance same as InP

Flight Test Update/Plans

Lear Jet concentrator module performance tests

LDCE-4, -5: Materials experiment, limited AO exposure

EOIM III: Small area lens materials and cells

Wakeshield (MATLAB-1): Materials experiment and two mini dome lenses (AO performance testing of lens coatings)

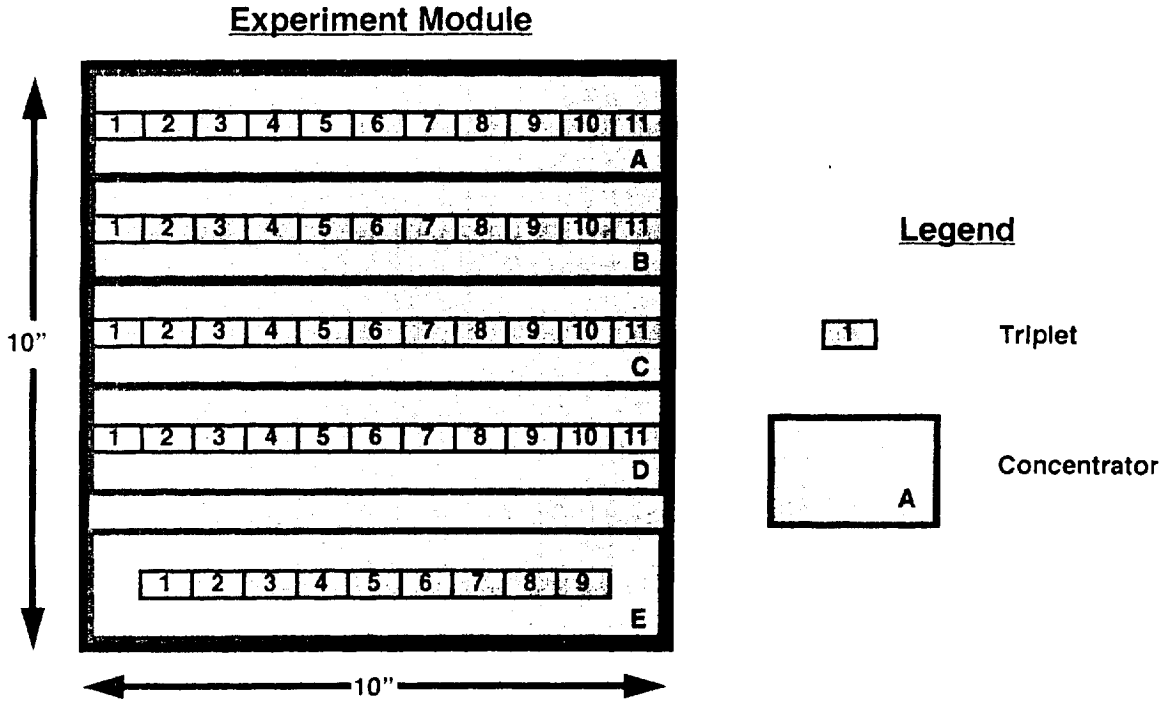
PASP-plus: First active experiment of advanced refractive concentrator array technology, long duration (1-3 yrs.), radiation damage, and high voltage plasma interaction

STRV-2: In planning stages, first active experiment of one axis concentrator module

Molniya flight experiment: 1995 test of four 16 element Ioffee fresnel concentrators

C-SAVE: Planned 1997 flight demonstration of a 1 to 1.5 kW linear concentrator array

STRV-2 Experiment Layout



Molniya Concentrator Flight Experiment

Flight test of four Ioffee concentrator modules

- **Flat fresnel concentrators**
- **16 element modules**
- **Tandem solar cells**

Mounted on outer wall of a Molniya communications satellite

Launch planned in summer 1995 on a Molniya launch vehicle from Baikanour

Molniya orbit provides high radiation environment

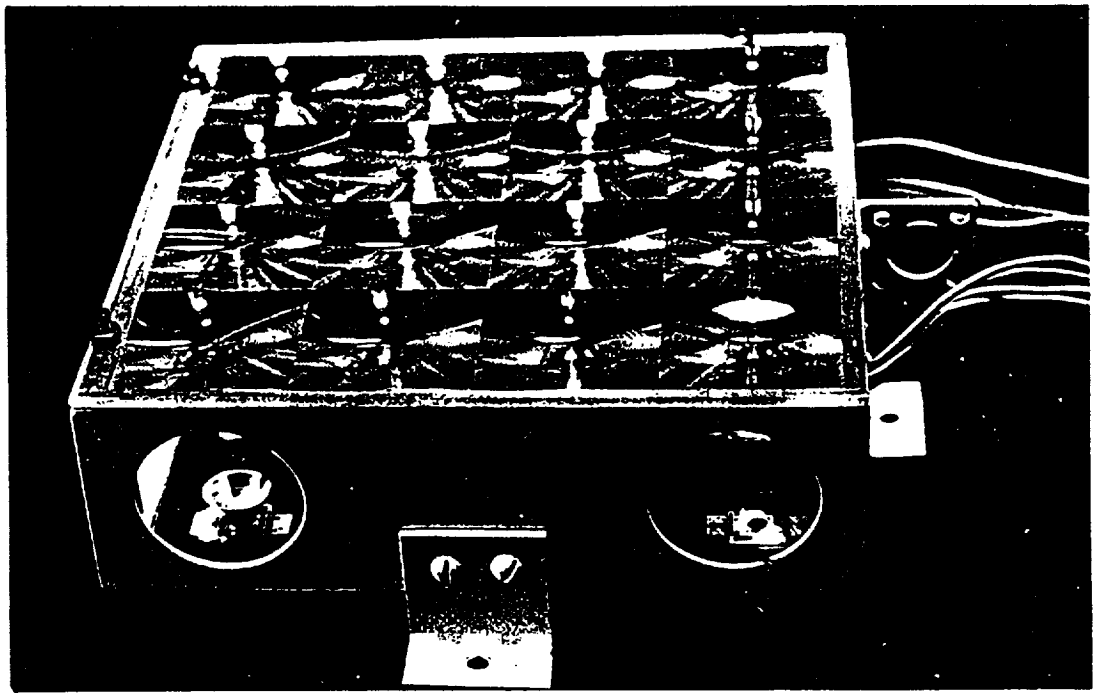
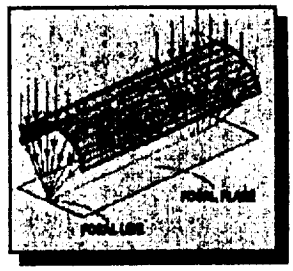


Photo of Fresnel lens concentrator panel on the basis of 16 modules (input photoactive square 100 cm^2).

C-SAVE Concept

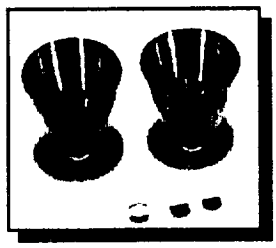
Objective

- Demonstrate and quantitatively measure the performance of a linear photovoltaic concentrator array
  - ✓ Array pointing
  - ✓ Off-axis tracking
  - ✓ Thermal distortion effects
- Space qualify concentrator solar arrays



Description

- Two solar arrays sized to approximately 500 w each (1 kw EOL total) - each array will be 1.5 m^2
  - ✓ Either reflective or refractive optics
  - ✓ Sunlight focused onto a strip of high efficiency, multi-band gap photovoltaic cells
- Arrays will be deployed in space and will track the sun in one axis (when the experiment is operating)



Conclusions

Concentrator solar arrays provide significant benefits to future BMDO missions

- Low cost
- Light weight
- Radiation resistant

BMDO approach is to develop flight test modules and arrays to demonstrate technology maturity

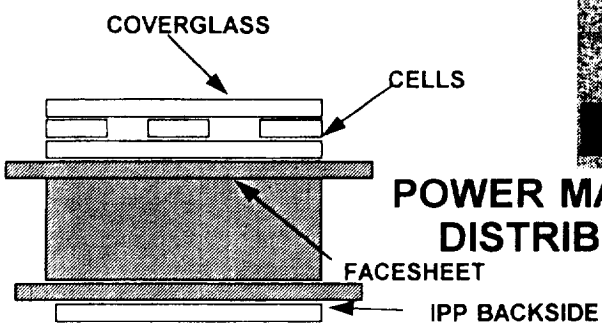
Space concentrator arrays will provide significant cost and mass advantages to a range of commercial satellite programs

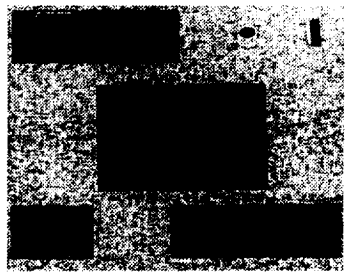
AIR FORCE ACTIVITIES IN SPACE PHOTOVOLTAIC POWER SYSTEM TECHNOLOGY

Kelly Gaffney
U.S. Air Force
Kirtland AFB, New Mexico

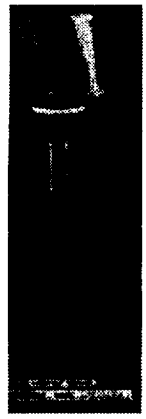
TECHNOLOGY FOCUS

PHOTOVOLTAICS





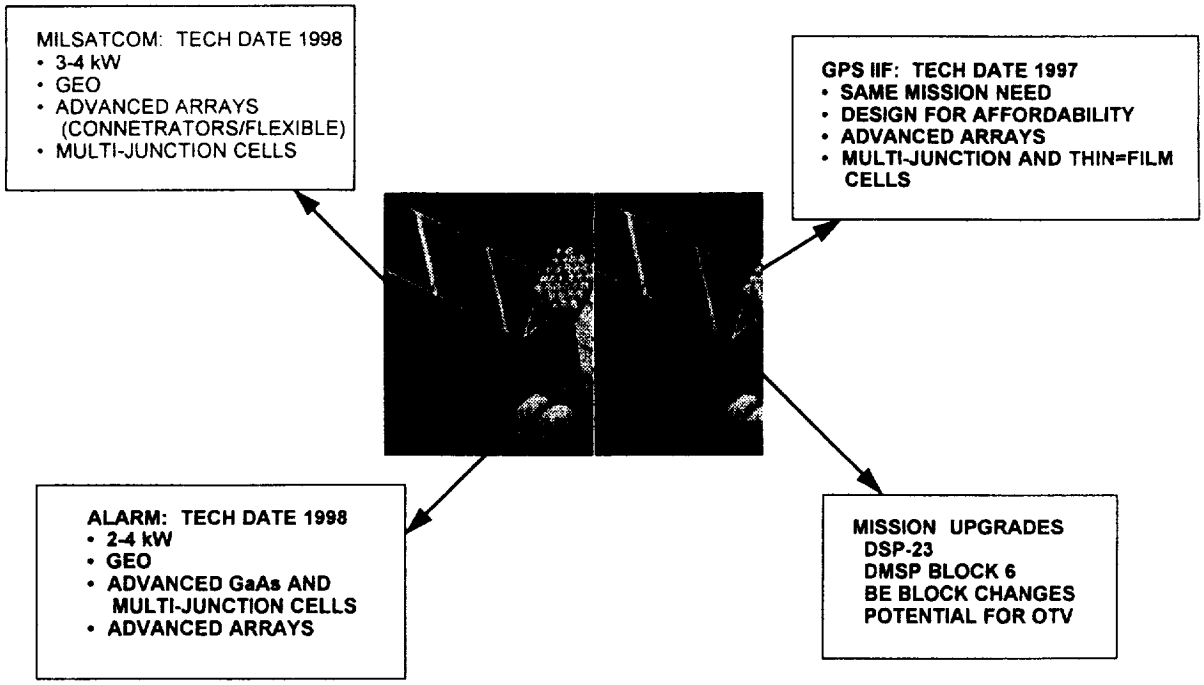
POWER MANAGEMENT AND DISTRIBUTION



ENERGY STORAGE

FULL TECHNOLOGY LIFE CYCLE DEVELOPMENT
HIGH RISK/HIGH PAYOFF
NEAR TERM SOLUTIONS
MARKET AND USER DRIVEN

NEW AIR FORCE SATELLITES FOR THE YEAR 2000

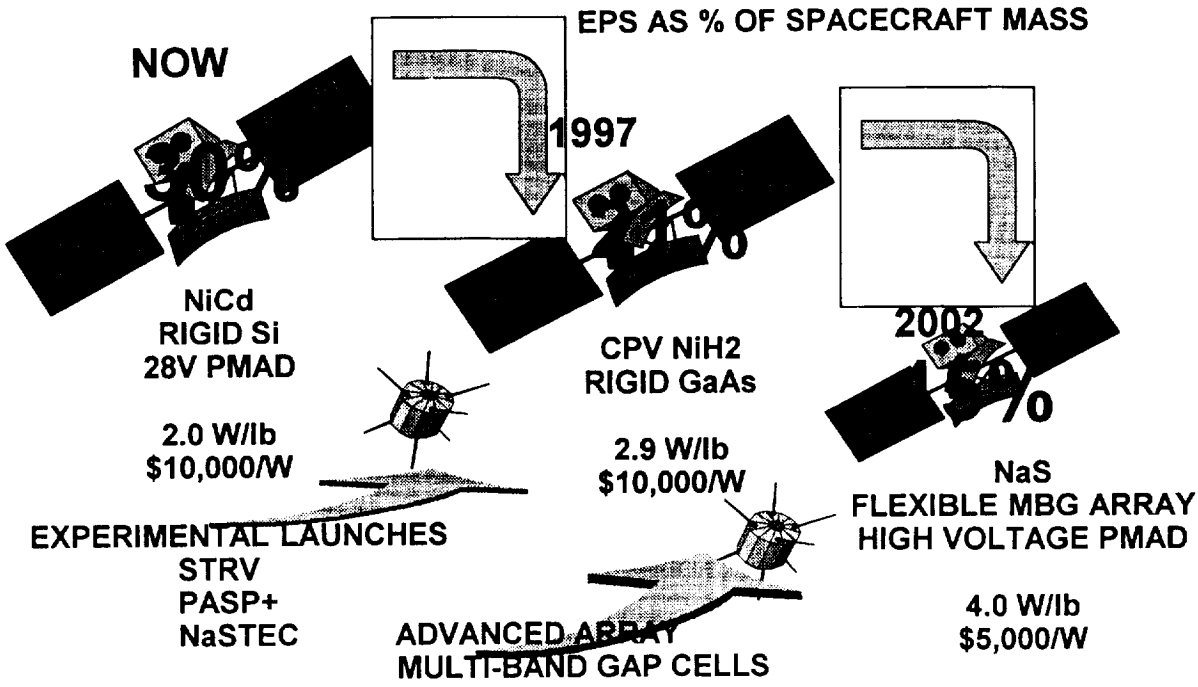


TECHNOLOGY CHALLENGES

SATELLITE/LAUNCH POWER TECHNOLOGY DRIVERS

LAUNCH VEHICLE	SATELLITE
ARRAY VOLUME (150W/M2)	NEED FOR MORE POWER
BATTERY/ARRAY MASS (15-25% OF SATELLITE MASS)	SOLAR CELL COST ($1000/W)
SATELLITE LIFETIMES (NiCd BATTERIES--3 YEARS IN LEO) (SOLAR CELL DEGRADATION)	POWER SYSTEM MODULARITY & STANDARDIZATION .
PRIMARY BATTERY PERFORMANCE (10% OF LAUNCH PROBLEMS)	COMPONENT RELIABILITY (LATCHING RELAYS, BYPASS SWITCHES, ETC)

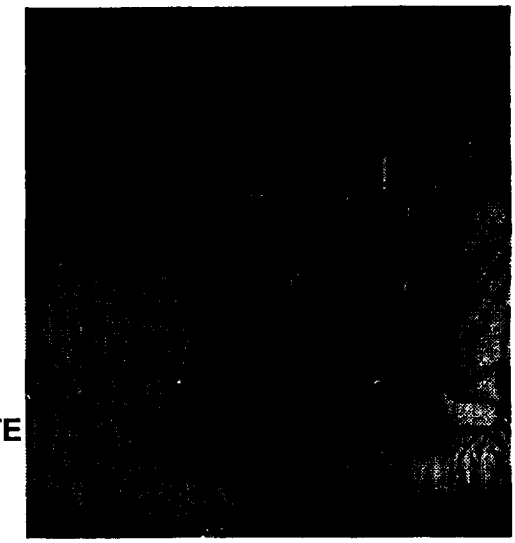
SYSTEM BENEFITS FROM TECHNOLOGY



TECHNOLOGY OPTIONS/BENEFITS

PHOTOVOLTAICS TECHNOLOGY IMPROVEMENTS

STATE OF THE ART: GaAs RIGID ARRAYS
18% EFFICIENT CELLS
50W/KG BOL, 250W/M2 BOL
STOWAGE PROBLEM



ADVANCED POWER OPTIONS:

LOW RISK: GaInP/GaAs/Ge RIGID ARRAY
27% EFFICIENT CELLS
85W/KG BOL, 400 W/M2 BOL
LESS OF A STOWAGE PROBLEM

MEDIUM RISK: CIS AND CdTe THIN FILM CELLS
12% EFFICIENCY, RAD-HARD
40% LIGHTER, LESS SUBSTRATE
SIGNIFICANTLY LOWER COST

MEDIUM RISK: ADVANCED FLEXIBLE BLANKET
OR CONCENTRATOR ARRAY
100-150W/KG BOL
SOME HAVE STOWAGE VOLUMES
OF 0.15M3

PHOTOVOLTAICS
TECHNOLOGY OPTIONS/BENEFITS

GaAs CELL IMPROVEMENTS:

PREMISE: ULTRA LIGHTWEIGHT GaAs SOLAR CELL BY INCORPORATING LIGHT-TRAPPING FEATURES ON THE BACK OF THE CELL. HIGH CURRENTS CAN BE OBTAINED WITH A VERY THIN LAYER OF MATERIAL. GOAL IS A 24.5% CELL AT 1 SUN AMO

SUCCESS:
- IMPROVED LPE GROWTH LAYERS--2CM X 4CM CELL
- OPTIMIZED ANTI-REFLECTIVE COATING
- INCORPORATED LIGHT TRAPPING STRUCTURE TO THICK CELLS

FUTURE PLANS:
- CHOOSE METAL FOR USE IN BACK CONTACT
- IMPROVE FABRICATION PROCESS

BENEFITS:
- VERY LIGHT, HIGH EFFICIENCY GaAs
- GOOD RADIATION TOLERANCE BECAUSE OF THIN DEVICE STRUCTURE

PHOTOVOLTAICS
TECHNOLOGY OPTIONS/BENEFITS

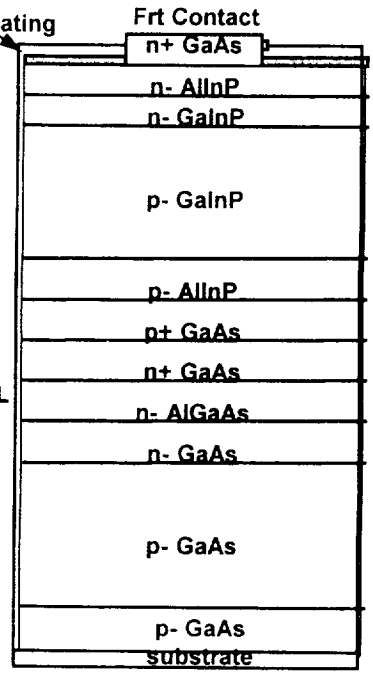
MULTI-JUNCTION SOLAR CELL:

PREMISE: DEVELOP 25% EFFICIENT, MONOLITHIC, MULTI JUNCTION SOLAR CELLS. CELLS SHOULD BE TWO-TERMINAL, STANDARD SIZE AND COST NO MORE PER WATT THAN GaAs

SUCCESS:
- 24.6% EFFICIENT, TWO JUNCTION GaInP/GaAs CELL DEVELOPED
- READY FOR FLIGHT TEST ON MIGHTYSAT
- 26.7% EFFICIENT GaInP/GaAs/Ge , 2 BY 2cm LAB CELL READY BY CHRISTMAS

FUTURE PLANS:
- THREE YEAR PLAN TO IMPROVE RELIABILITY/YIELD OF TANDEM CELL COLLABORATE WITH MANTECH AND NASA TO DEVELOP 6 BY 6, HIGH BATCH PRODUCTION
- GROUND AND RADIATION TESTING IN LATE 1996
- FLIGHT QUALIFICATION IN EARLY 1997

BENEFITS:
- 35-40% REDUCTION IN WEIGHT OVER GaAs
- 40% REDUCTION IN ARRAY CROSS-SECTIONAL AREA FOR LAUNCH
- COSTS SIMILAR TO GaAs



PHOTOVOLTAICS
TECHNOLOGY OPTIONS/BENEFITS

...-FILM SOLAR CELLS

PREMISE: DEVELOP HIGH EFFICIENCY (12-15%), LARGE AREA DEPOSITION THIN-FILM PHOTOVOLTAIC DEVICES. FOCUS IS ON CIS AND CdTe

SUCCESS:
- DEPOSITION OF CIS ON 4 X 4 IN SUBSTRATE
- 12% CIS CELLS IN SMALL SIZES
- DEVELOPMENT OF 10% CIS ON 24 CM X 24 CM FLEXIBLE METAL FOIL BY DEC

FUTURE PLANS:
NEW PROGRAM TO DEVELOP REEL-TO-REEL DEPOSITION ON FLEXIBLE SUBSTRATES IN THE 12-15% RANGE

BENEFITS:
- SIGNIFICANT COST REDUCTIONS OVER CRYSTALLINE CELLS
- 30-40% ARRAY WEIGHT REDUCTION
- REDUCED STOWAGE VOLUME FOR ARRAY

PHOTOVOLTAICS
TECHNOLOGY OPTIONS/BENEFITS

ADVANCED FLEXIBLE BLANKET ARRAY:

PREMISE: TO DEVELOP AND FLIGHT QUALIFY TWO FOLD-OUT ARRAYS WITH AT LEAST 150W/Kg EFFICIENCY, 0.15m3 STOWAGE VOLUME AND SYSTEM LEVEL COSTS OF LESS THAN $500/W IN 1-3 KW POWER RANGE

SUCCESS: AWARDING OF TWO SEPARATE CONTRACTS
- ROLL-OUT FLEXIBLE BALNKET USING CIS THIN-FILM CELLS AND SHAPE MEMORY CONTROL
- RIGID, COMPOSITE, FOLD-OUT ARRAY USING ANGLED MIRRORS FOR SUN CONCENTRATION

FUTURE PLANS:
- DEVELOP AND FABRICATE ARRAYS
- FLIGHT TEST IN 1998
- POTENTIAL INTEREST BY POST-1999 SATELLITES

BENEFITS:
- 3-FOLD INCREASE IN ARRAY EFFICIENCY
- SIGNIFICANT DECREASE IN ARRAY STOWAGE VOLUME
- 50% COST SAVINGS ON ARRAY PROCUREMENTS

PHOTOVOLTAICS
TECHNOLOGY OPTIONS/BENEFITS

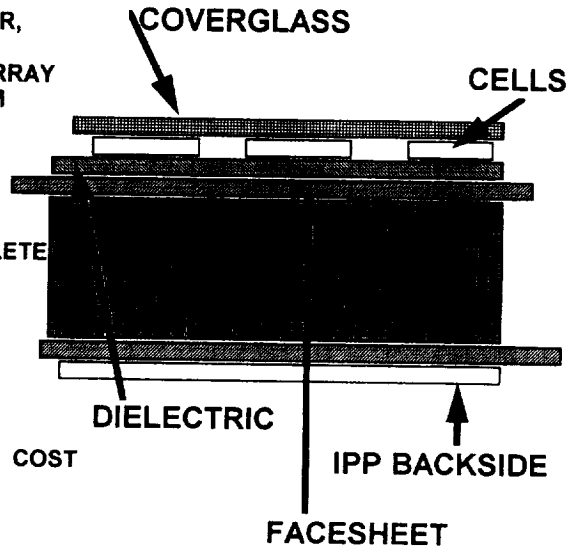
INTEGRATED POWER SYSTEM: LOW RISK

PREMISE: TO DEVELOP AND DEMONSTRATE A MODULAR, STANDARDIZED POWER SYSTEM ARCHITECTURE USING SHUNT REGULATION MOUNTED TO THE GaAs SOLAR ARRAY USING A HYBRID PATCH AND RESISTOR STRIP. SYSTEM IS ABLE TO ACCOMADATE GROWTH BETWEEN 100W -- 5KW WITH MINIMAL REDESIGN.

SUCCESSES:
- PANEL DEVELOPMENT COMPLETE
- PRELIMINARY GROUND TESTING OF COUPONS COMPLETE
- FLIGHT TEST PROGRAM IN PLACE

FUTURE PLANS:
- FLIGHT TEST ON STP MISSION IN LATE 1995

BENEFITS
- MODULAR, STANDARD ARCHITECTURE MEANS LESS REDESIGN AND MINIMUM REQUALIFICATION: LOWER COST
- LESS SYSTEM WEIGHT: 12 W/KG
- BETTER THERMAL CONTROL



PHOTOVOLTAICS
FLIGHT EXPERIMENTS: NEW STARTS

LABSAT

FLIGHT TEST HIGH EFFICIENCY DUAL JUNCTION CELLS AND TRIPLE JUNCTION CELLS ON COMPOSITE SUBSTRATES

HARDWARE DELIVERY DATE: 30 SEP 1995

CONDUCT DESIGN ANALYSIS FOR FUTURE LABSAT POWER SYSTEM UPGRADES

UoSAT

COOPERATIVE EFFORT WITH UK, NASA, NRL, BMDO TO FLIGHT TEST POWER SYSTEM COMPONENTS

PROBABLE AF EXPERIMENTS INCLUDE NaS LONG-TERM FLIGHT TEST, ADVANCED ARRAY DEMO, TRIPLE JUNCTION SOLAR CELL FLIGHT

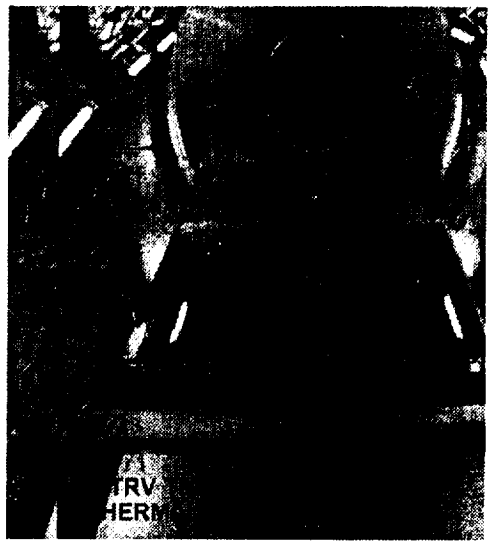
LAUNCH DATE IS JUN 1996

PHOTOVOLTAICS
FLIGHT EXPERIMENTS

STRV 1B

FLIGHT TEST OF ADVANCED CELL TECHNOLOGIES. PRIMARY POWER PANELS ARE GaAs, 5.5MIL MANTECH CELLS. EXPERIMENTAL PANELS HAVE 20 DIFFERENT EMERGING CELL TYPES

PANELS WILL BE TESTED OVER THREE MISSION FOR ELECTRICAL PERFORMANCE ANND RADIATION RESISTANCE.



PASP+

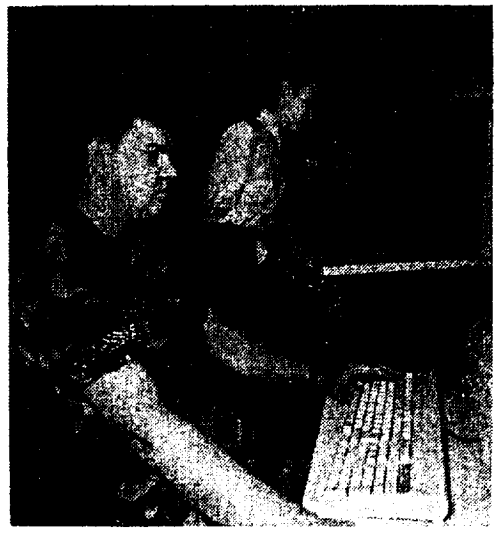
FLIGHT TEST OF 12 ADVANCED ARRAY DESIGNS: FLEXIBLE BLANKETS, CONCENTRATORS, THIN-FILMS

ARRAYS WILL BE TESTED FOR ENVIRONMENTAL AND PLASMA INTERACTIONS, HIGH VOLTAGE PERFORMANCE AND ELECTRICAL PERFORMANCE

LABORATORY PROGRAM

SOLAR CELL ASSESSMENT

- FULL LABORATORY CAPABILITY TO CONDUCT MECHANICAL AND ELECTRICAL TESTING OF SOLAR CELLS
- RADIATION DEGRADATION TESTING AT UK DRA HARWELL FACILITY
- SOLAR CELL DATABASE TESTING WILL START THIS YEAR (12 CELLS ALREADY IDENTIFIED--TANDEM, THIN-FILMS, GaAs, ADVANCED Si)
- DATABASE WILL BE OPEN TO ALL
- WILL TEST ANY CELLS UPON SPO REQUEST AT NO COST



CONCLUSIONS

NEW AIR FORCE SYSTEMS ARE COMING ON LINE BY THE TURN OF THE CENTURY: LIFE CYCLE COST WILL BE THE BIG DRIVER

POWER TECHNOLOGIES AS BOTH COST AND WEIGHT REDUCTION TOOLS ARE OF INTENSE INTEREST TO OUR CUSTOMERS

TECHNOLOGY TRANSITION PATH FOR TANDEM CELLS AND ADVANCED ARRAYS IS IN PLACE

LABORATORY WILL CONTINUE ON THE PATH TO LIGHTER, CHEAPER CELL AND ARRAY TECHNOLOGIES

NEW PROGRAM INITIATIVES TO WATCH FOR: TANDEM CELL MANTECH, ADVANCED THIN-FILM CELL DEVELOPMENT, TANDEM CELL FLIGHT TEST SOLAR CELL ASSESSMENT, RENEWED INTEREST IN ARRAYS FOR OTV