AEROSPACE TECHNOLOGY DIRECTORATE

POWER TECHNOLOGY DIVISION

NASA
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NASA/DOD FLIGHT EXPERIMENTS
TECHNICAL INTERCHANGE MEETING
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SOLAR ARRAY MODULE PLASMA INTERACTION EXPERIMENT (SAMPIE)

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Summary

- Space data is badly needed
  - a major obstacle to orbiting HV power systems is Plasma Interactions
  - Ground testing cannot reliably predict on-orbit behavior; space data needed (PIX data is still being analyzed for insight into real space behavior)
  - future designs will rely heavily on computer models, very little space data exists for validation
  - SAMPIE will be the first space experiment to provide data on the performance of various solar cell technologies under identical environmental conditions

Summary (cont)

- Design is highly modular
  - Conceived as "testbed" for emerging solar cell technologies
  - Can be easily repackaged for non-shuttle deployment
- SAMPIE will have a wide ranging impact
  - Technology base will benefit directly from understanding of HV systems behavior in plasma environment
  - Space Station Freedom depending on data return from SAMPIE

SAMPIE was never designed to be SSF specific; BUT recent developments have rendered SAMPIE data critical. (WP-04 is generating CR for plasma contactor, specifically requires SAMPIE's data for contactor optimization)

SAMPIE QUICK SUMMARY

- OAST IN-STEP Shuttle Experiment
- Hitchhiker experiment, Shuttle Payload Bay
- Manifested on OAST-2 in late January, 1994
- Passed CoDR, NAR, Phase 0/1 Safety Review, PDR
- CDR at end of October, 1992
- LEO Plasma Interactions Experiment
- Heritage - SPHINX, PIX, PIX II, VOLT-A
- NASA Lewis experiment, built with in-house contractor (Sverdrup)

Experiment: Objectives

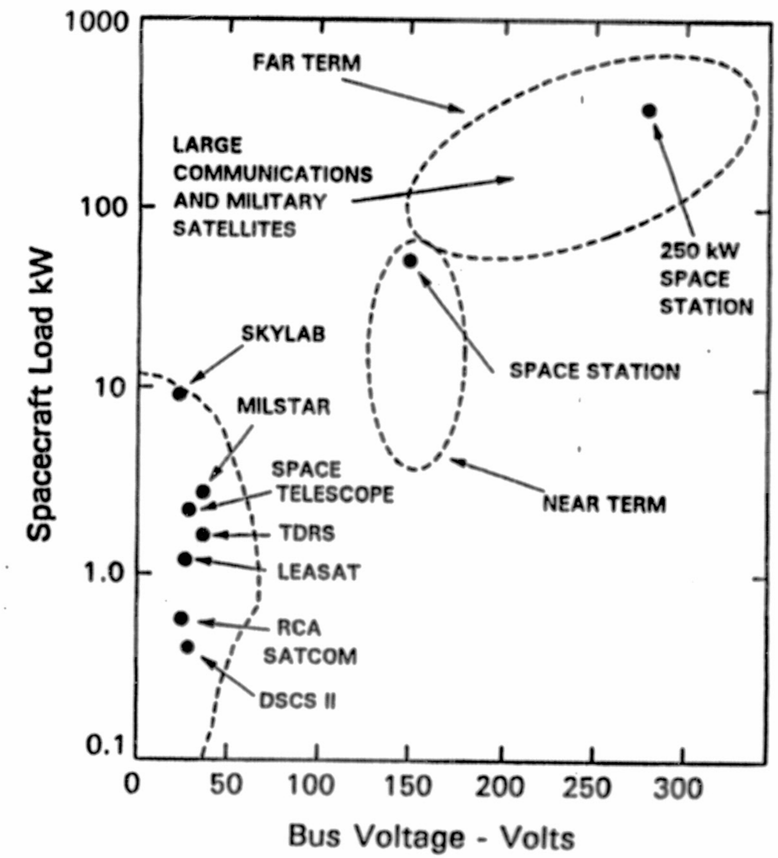
The objective of SAMPIE is to investigate, by means of a shuttle-based space flight experiment and relevant ground-based testing, the arcing and current collection behavior of materials and geometries likely to be exposed to the LEO plasma on High Voltage space power systems, in order to minimize adverse environmental interactions.

Space Power Systems

- **Historically systems were low voltage, < 100 V**
  - Earliest systems used batteries
  - 28 Volt technology inherited from aircraft industry
- **Future systems desire much higher voltage**
  - more efficient, I^2R losses smaller for given $P = IV$
  - less cable mass to orbit
- **Proposed systems range from:**
  - hundreds of volts for SP-100, to
  - thousands of volts for orbit transfer vehicle using solar electric propulsion

TRENDS IN SPACECRAFT POWER

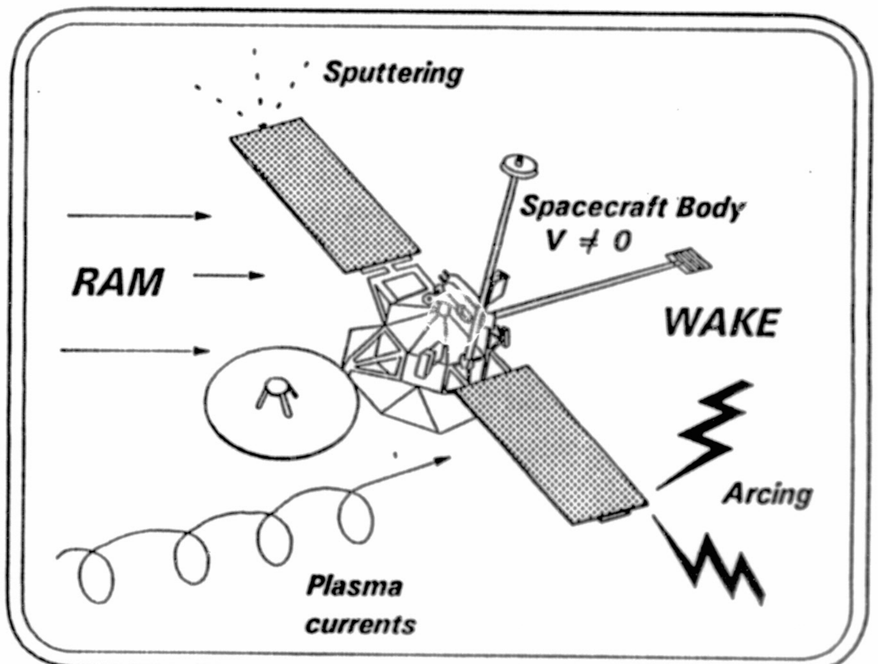
From: Space Vehicle Design
M. D. Griffin
J. R. French



The Problem

High voltage systems immersed in ionospheric plasma will inevitably interact

- **Negative potential → arcing**
  - results in broadband EMI, electrical transients
  - has been known to completely destroy solar arrays in laboratory
  - high energy inbound ions cause sputtering
- **Positive potential → parasitic current drain**
  - even a small pinhole can "snapover", result in large power losses
  - equilibrium current balance determines floating potential of spacecraft



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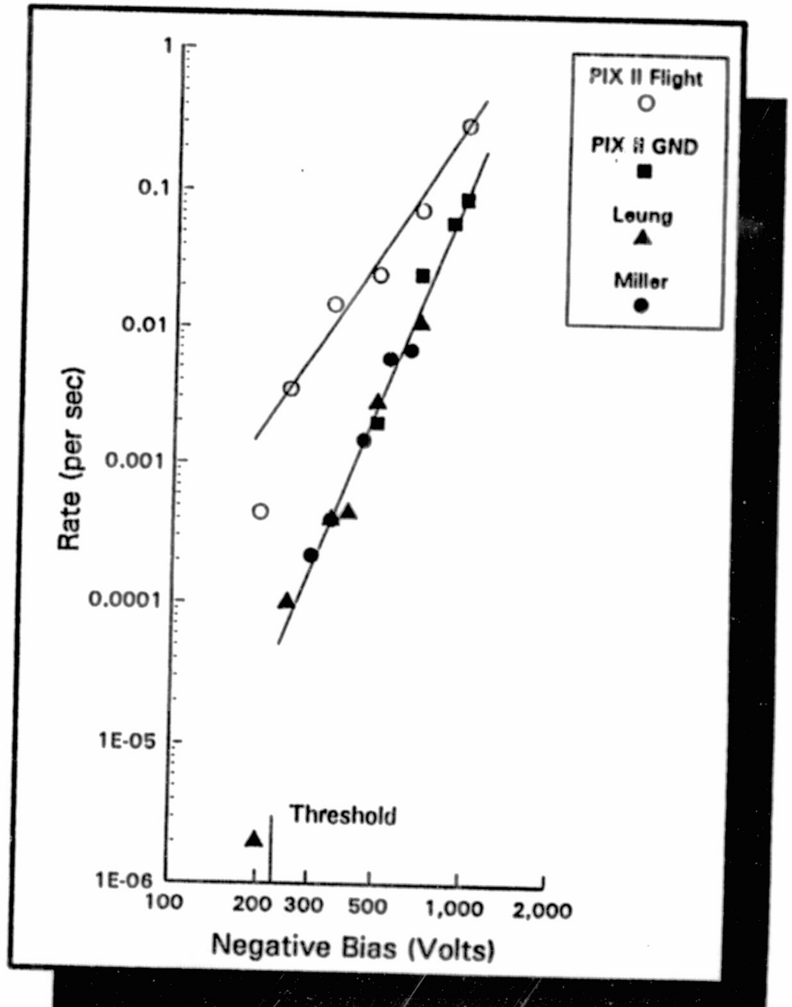
Ground vs Flight

- Ground tests results are always different than flight
- Ground tests cannot reproduce environment

	LEO	Ground
Temp (eV)	.1 - .2	2 - 3
Dominant Ion	O^+	Ar^+
Flow	Mach 20 Ram/Wake	Thermal

- Chamber walls are impossible to compensate for
  - Secondary electron emission occurs from walls
  - SPEAR tests showed discrepancies even with huge Plum Brook chamber



Present Knowledge
Arcing

- Arcing is a negative potential phenomena
  $(M_e << M_{ion})$
- Arcs occur at conductor/insulator junctions, may propagate directly into plasma
- Threshold voltage seems to exist, but
  - different for different materials
  - not predictable from existing theory
  - depends on plasma conditions
- Produce EMI, transients in nearby circuits
  - measured for VOLT-A, may require waiver of shuttle requirements

Present Knowledge Arcing (continued)

- Arc rate depends (in a complicated, poorly understood way) on:
  - voltage
  - ion current
  - materials, principally conductor, some evidence for dependence on properties of nearby insulators
  - plasma conditions
  - geometry

- Arc rate seems independent of array area (number of cells)

- Arc rate/duration depends on:
  - array capacitance ⟶ RC time constant ⟶ duration
  - overall circuit ⟶ how much power available ⟶ strength

Knowledge Gaps; Arcing

- Above mentioned dependencies of rate, threshold, strength, etc. are not quantitative

- Existing knowledge based on behavior of old technology silicon cells. Theoretical framework and emperical scaling laws are not developed sufficiently to predict behavior of new cells.

- Fundamental nature of breakdown and arcing is controversial and poorly understood

- Role of ion energy not clear, ram/wake effect may be critical

Present Knowledge; Current Collection

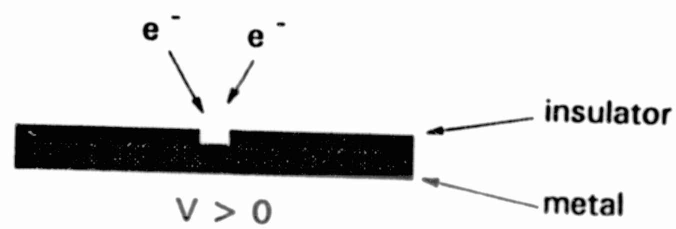
- Parasitic current collection is a positive potential phenomenon

$$M_e << M_{ion}$$

- The major concern is "SNAPOVER"

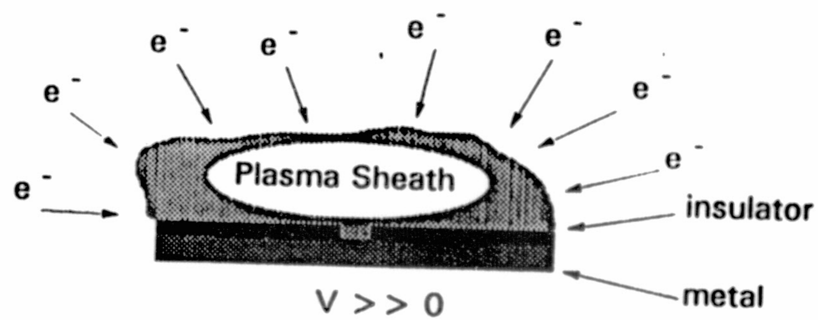
large surfaces collect large current,

small surfaces - small current



BUT

at HV, a very small exposed conductor, e.g. solar cell interconnect or pinhole in insulation can cause plasma sheath to form over large area, entire surface effectively becomes conducting



Knowledge gaps; Current Collection

Physics of sheath formation is poorly understood, when does it form, how big will it be, how conductive, how does it depend on:

- Bias voltage
- material properties (e.g. vapor pressure, work function)
- geometry - appears to be critical, poorly understood
- electron energy, i.e. ram/wake effect

Objectives
(Summary)

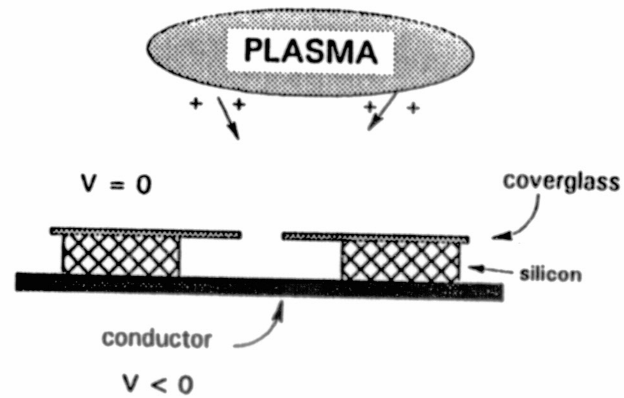
The current selection of experiments for SAMPIE will:

- Directly test plasma interaction effects of several solar cell technologies
  - APSA, Space Station, standard silicon
- Test arc suppression techniques with modified cell arrays
  - Two proposed techniques will get direct space test
- Study basic phenomena underlying Technology challenges
  - Pinhole experiment will study current collection; family of I-V curves will validate NASCAP/LEO, test existing theories
  - Two sets of metal samples will study arcing: family of arc rate vs bias curves will explore effects of material properties
  - Study dielectric breakdown of anodized aluminum
- Provide data for model validation
  - Most of the above will serve this purpose
  - Silicon experiment with "guardrings" for scaling effects
  - Modified SSF cell array with selected edge coating will study current collection

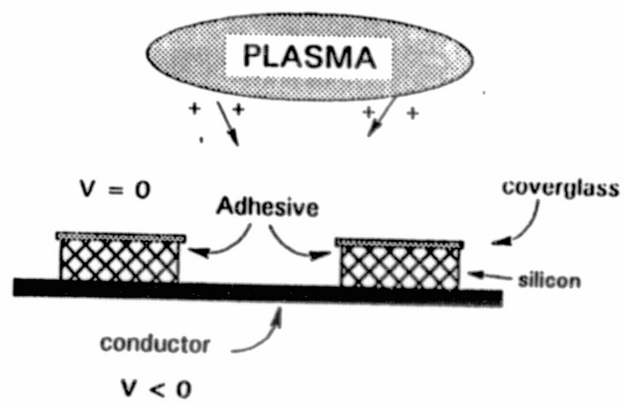
Objectives
(cont)

Two arc mitigation techniques will be explored:

- Extended coverglass:
  - * Coverglass extension shields triple points
  - * Charge buildup on coverglass will help repel inbound plasma ions
  - * NASCAP/LEO will calculate ion motion, sheath formation

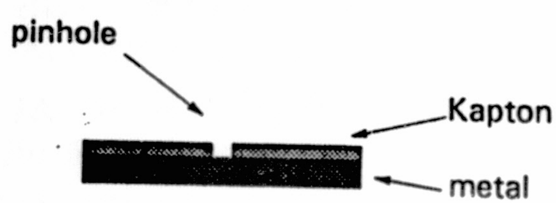


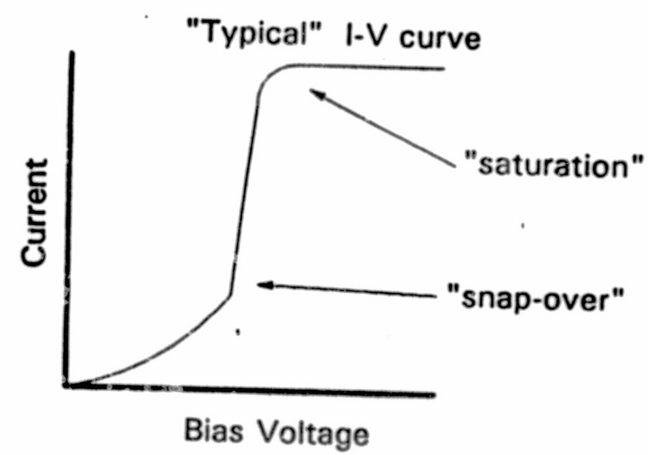
- Special Processing (cleaning)
  - * Researchers at PSI (W. Marinelli et. al.) have been studying arcing under contract from LeRC
  - * Results to date indicate a primary source of arcing is excess coverglass adhesive: proprietary cleaning processes are under development
  - * One cell coupon will be sent to PSI, processed, and returned for flight



Objectives
(cont)

- **Design and fly a controlled experiment studying parasitic current collection**
  - Geometry of solar cells, other flight hardware too complicated
  - Key parameter is pinhole size
  - Use 1 cm metal disks, covered with Kapton, each having a different pinhole





  - Result will be a family of I-V curves
  - Details, including snapover point, can be modeled using NASCAP/LEO, various analytic treatments
  - SAMPIE will fly 6 such pinholes; sizes to be chosen from ground tests, modeling

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Objectives (cont)

Study current collection vs solar cell edge treatments

- Background:
  - Without a plasma contactor, SSF would float -140 V wrt ionosphere as result of current collection.
  - SSF cells average approx 70% cell edge adhesive coverage, 4 mils coverslide overhang.
  - NASCAP/LEO predicts rapid improvement in floating potential as coverage exceeds 90% or overhang exceeds 6 mils.

- Experiment:
  - Need to validate NASCAP/LEO.
  - Use scaled down versions of SSF solar cells.
  - Systematically vary degree of edge coating and overhang. Nominal overhang is 4 mils, so use:

0 mils	3 mils
6 mils	9 mils

Objectives (cont)

- Design and fly, on a space available basis, additional arcing experiments: One currently chosen
  - breakdown from anodized aluminum
    - * alloy and anodization chosen to be space station baseline

- Measure a basic set of Plasma parameters
  - Langmuir probe - plasma density, electron temperature
  - Pressure gauge - background pressure, fast enough to detect thruster firings
  - Sun sensor
  - V-body probe - monitor orbiter potential

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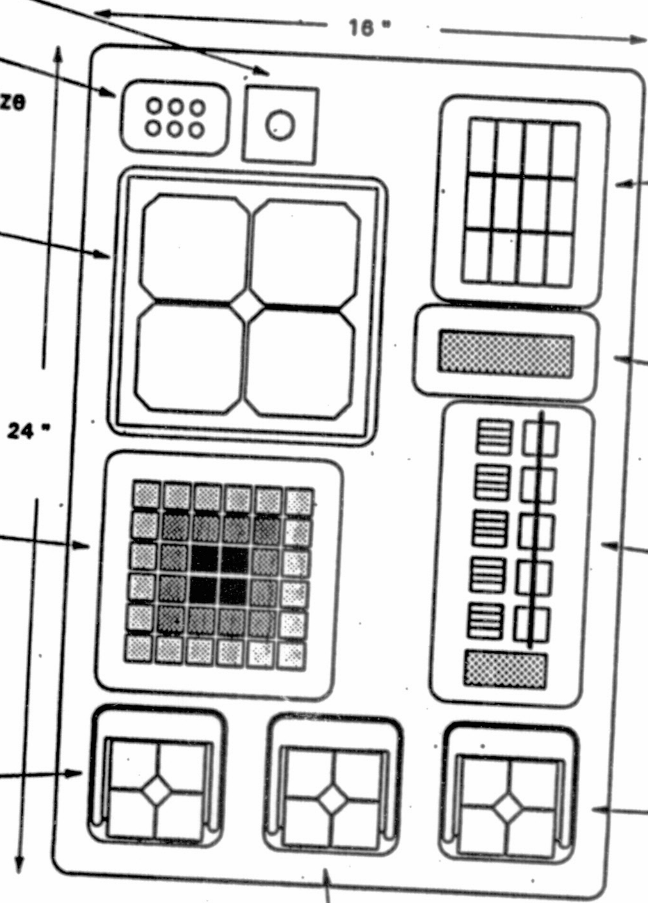
SAMPIE
Experiment Configuration



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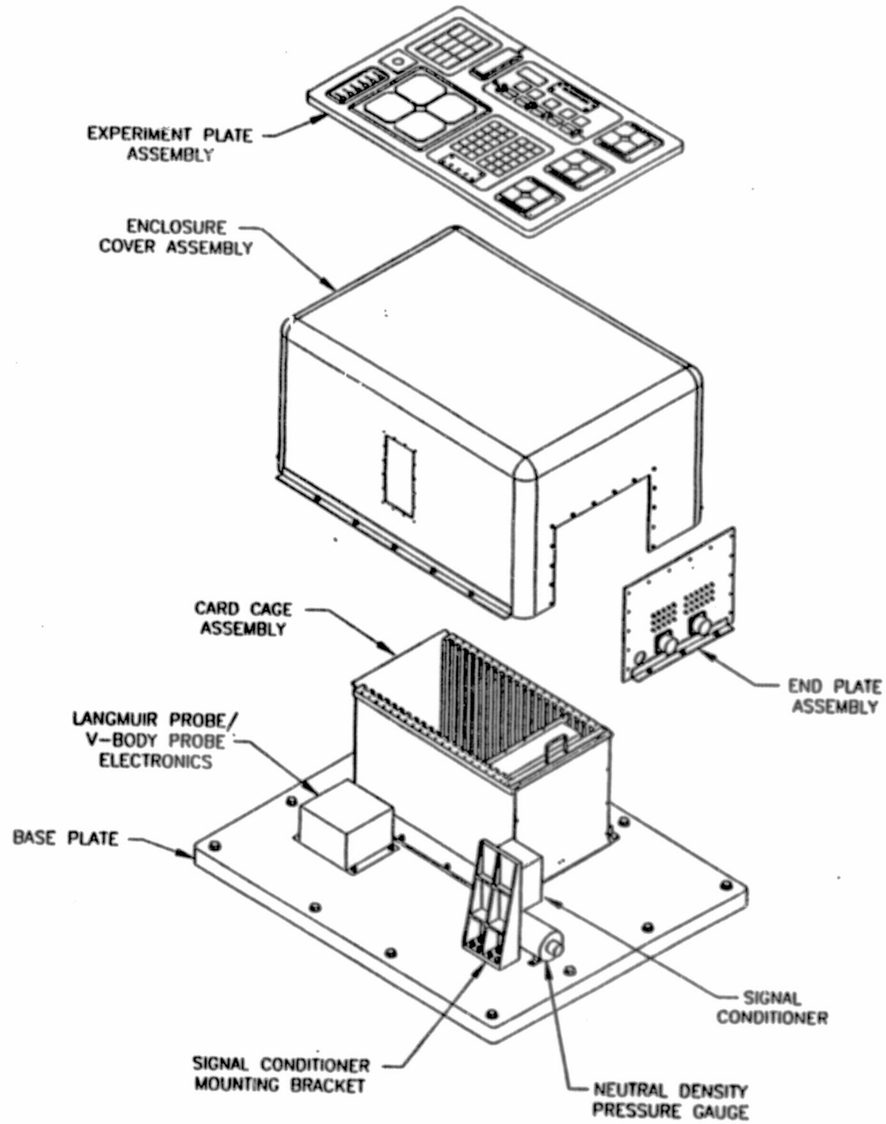
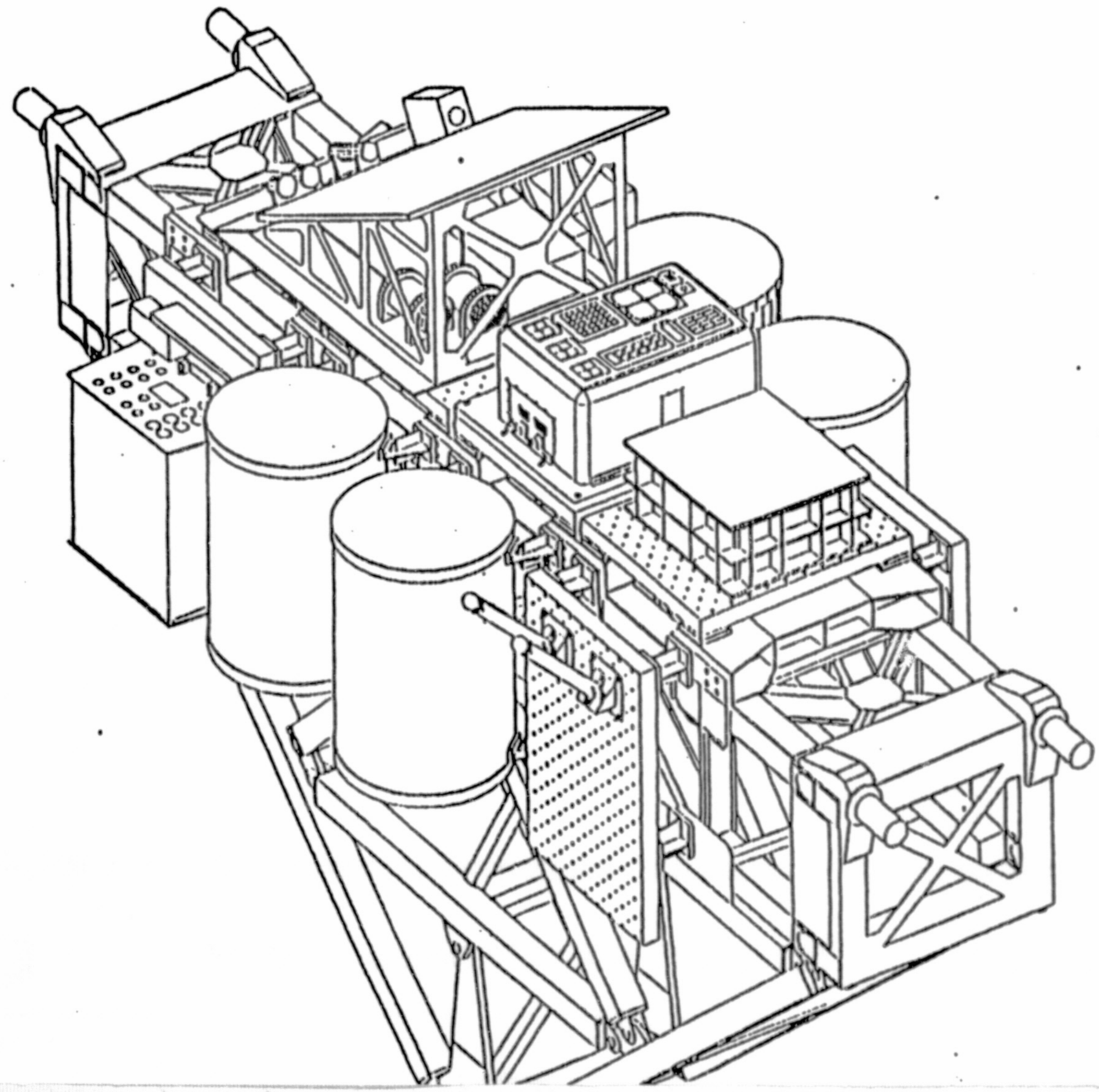
SAMPIE MAJOR COMPONENTS

- BASE PLATE (MPESS MOUNT)
- ENCLOSURE COVER ASSEMBLY
- EXPERIMENT PLATE ASSEMBLY
- CARD CAGE ASSEMBLY
- END PLATE ASSEMBLY
- LANGMUIR PROBE ELECTRONICS
- SIGNAL CONDITIONER
- NEUTRAL PRESSURE GAUGE
- LANGMUIR AND V-BODY PROBES



MAIN ELECTRICAL ASSEMBLY



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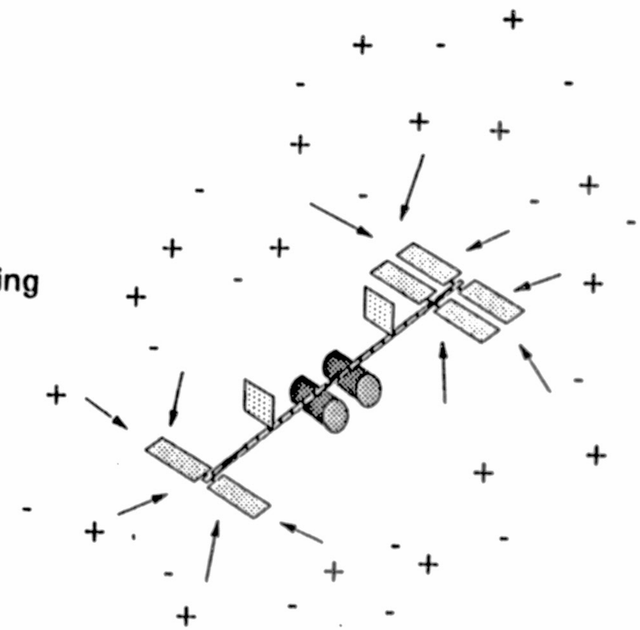
SAMPIE
and
The Plasma Contactor

SAMPIE was designed to study the interaction of HV systems with space plasma

SSF has inadvertantly become an immediate test of these effects

- Current collection by SSF will result in an equilibrium with the station "floating" about -140 volts WRT the ionosphere
- Predictions depend on details of:
  - cell collection characteristics - coverglass overhang, edge coating
  - ion collection by structure
- All predictions follow from modeling
  - NASCAP/LEO
  - Environmental Workbench (EWB)
- Models have only limited validation
  - sounding rockets
  - ground tests



V ~ -140 V

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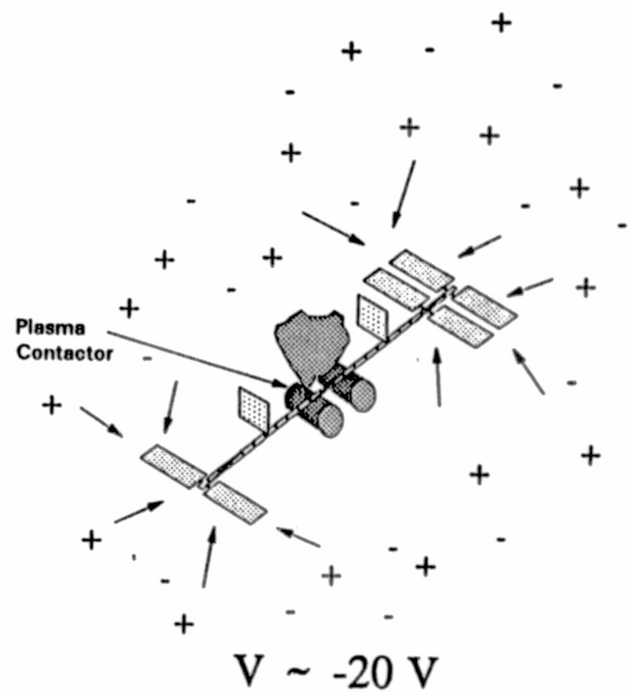
The Plasma Contactor (CONT)

Over the past year, the problem, its implications, and possible design solutions have been studied extensively

- Plasma Contactor selected and baselined
  - Brute force solution, will unquestionably force SSF "near" plasma ground
- Issues:
  - How big should it be?
  - How much EMI will it cause?
  - Where on the structure should it be placed?
- Best guesses based on computer models
- SAMPIE will provide critical data allowing model validation and refinement of contactor design and placement



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