Space System Vulnerability to Orbital Debris Penetration

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NASA/MSFC

A Poster Presentation
to the
ADPA/NSIA/AIAA

Aircraft Survivability Conference

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October 21-23, 1997

National Aeronautics and Space Administration
George C. Marshall Space Flight Center

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Space System Survivability
Meteoroid/Orbital Debris Impact

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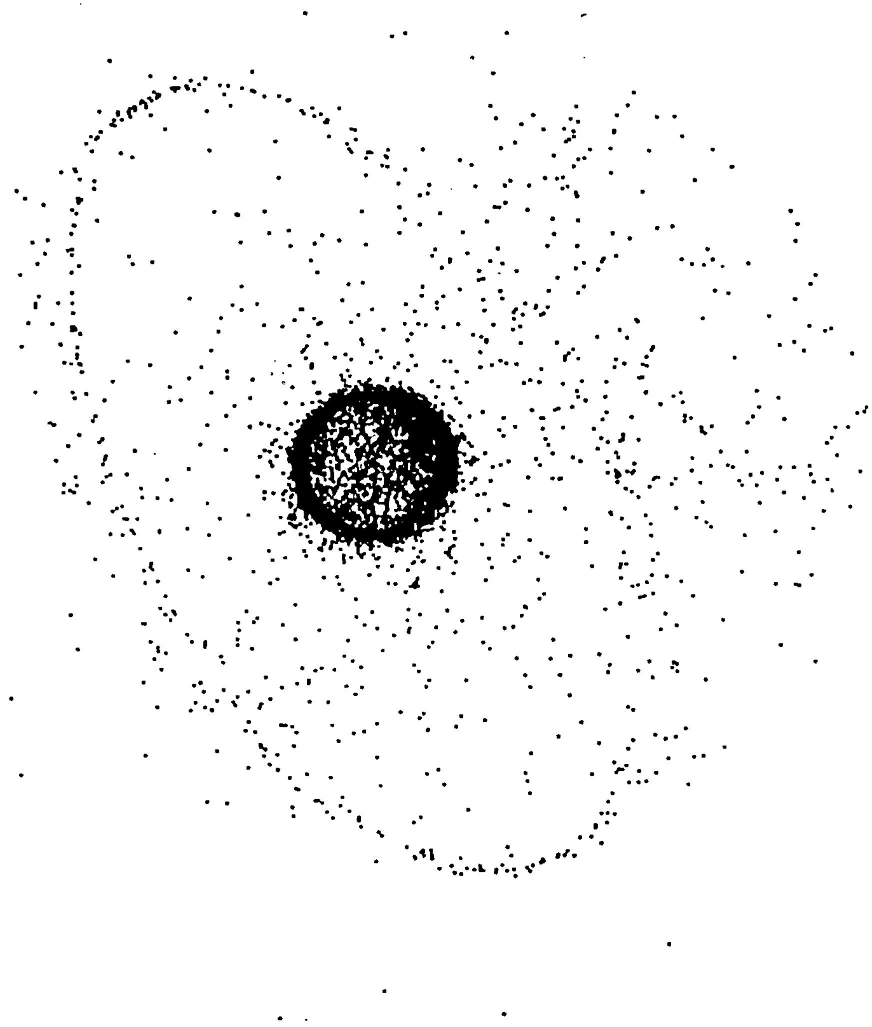
- **Orbital debris (space junk) has grown explosively over the last four decades.**
  - Now over 2,000,000 kg of mass in low earth orbit (LEO--up to 2000 km) vs. 70 kg of meteoric material.
  - 100,000 LEO objects over 1 cm diameter.
  - Average crossing (impact) velocity of orbital debris--8.7 km/sec.
  - Approxiamtely 70% aluminum, 30% plastic, steel, copper wiring, etc.



- **Probability of impact increases with exposure area and time.**
  - International Space Station has over 1000 square meters of exposed area and a design life of 15 years.
  - LEO satellite constellations (Iridium) have large cumulative exposed areas and exposure times.
- **Orbital Debris is highly directional--approaching from the "front" and "sides" of a stable LEO spacecraft.**

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ORBITAL DEBRIS RISK MITIGATION

For a single impact,* $$P_{loss} = P_{impact} \times P_{\frac{penetration}{impact}} \times P_{\frac{loss}{penetration}}$$

Reduce P_{impact}

- Environmental Definition

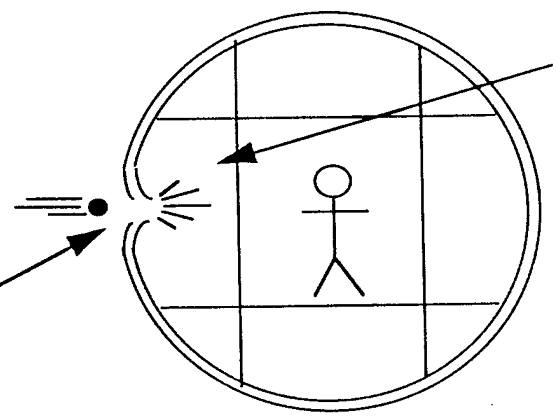
→ **Debris Reduction, Tracking, & Avoidance**

Reduce $P_{penetration/impact}$

- Penetration
- Ricochet
- Spallation

→ **Augmented Shields and Materials**

Analysis Tool: BUMPER



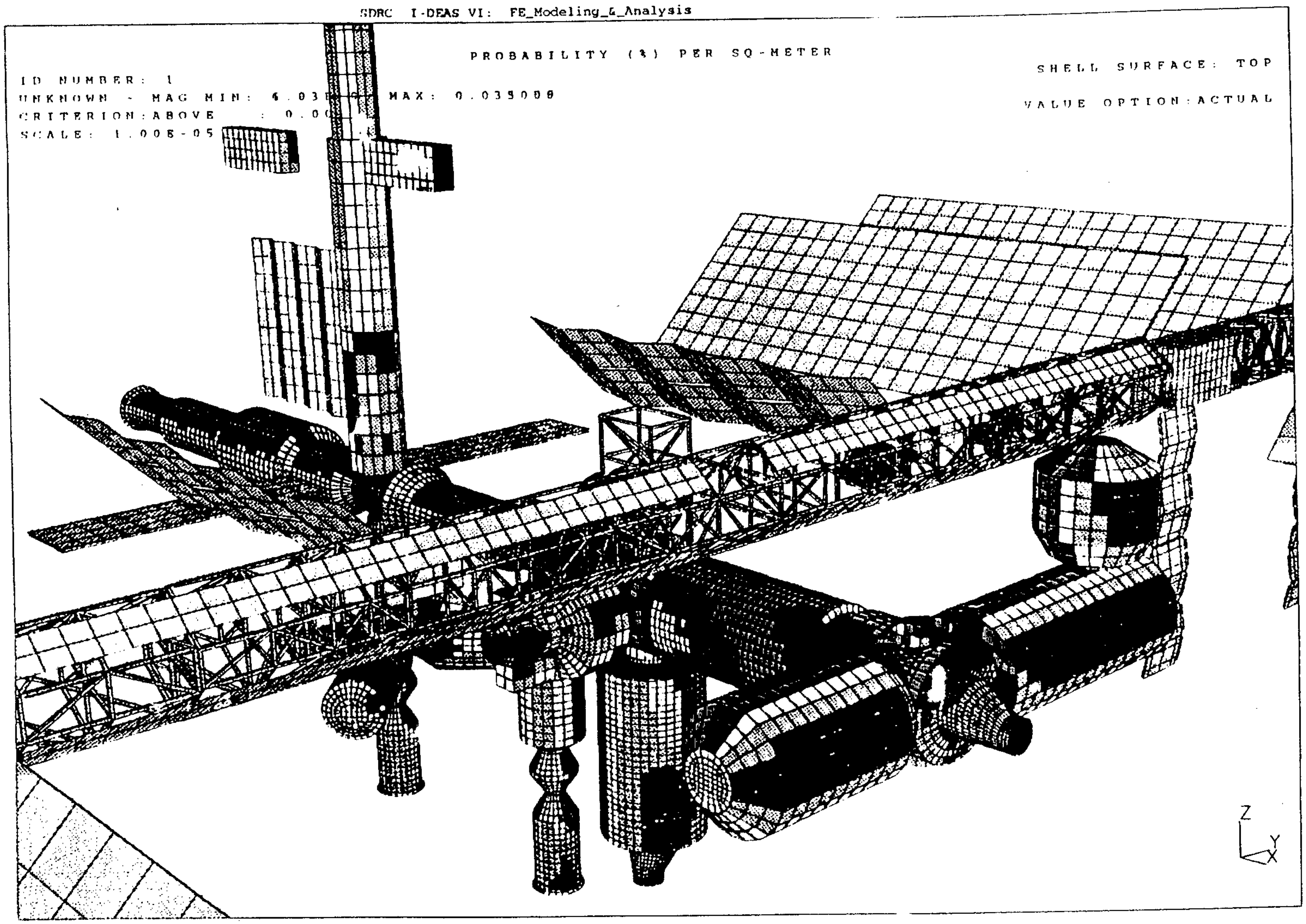
Reduce $P_{loss/penetration}$

- Critical Cracking
- Thrust Hazard
- Critical Equipment Loss
- Injury Loss
- Hypoxia
- Critical Module Depressurization

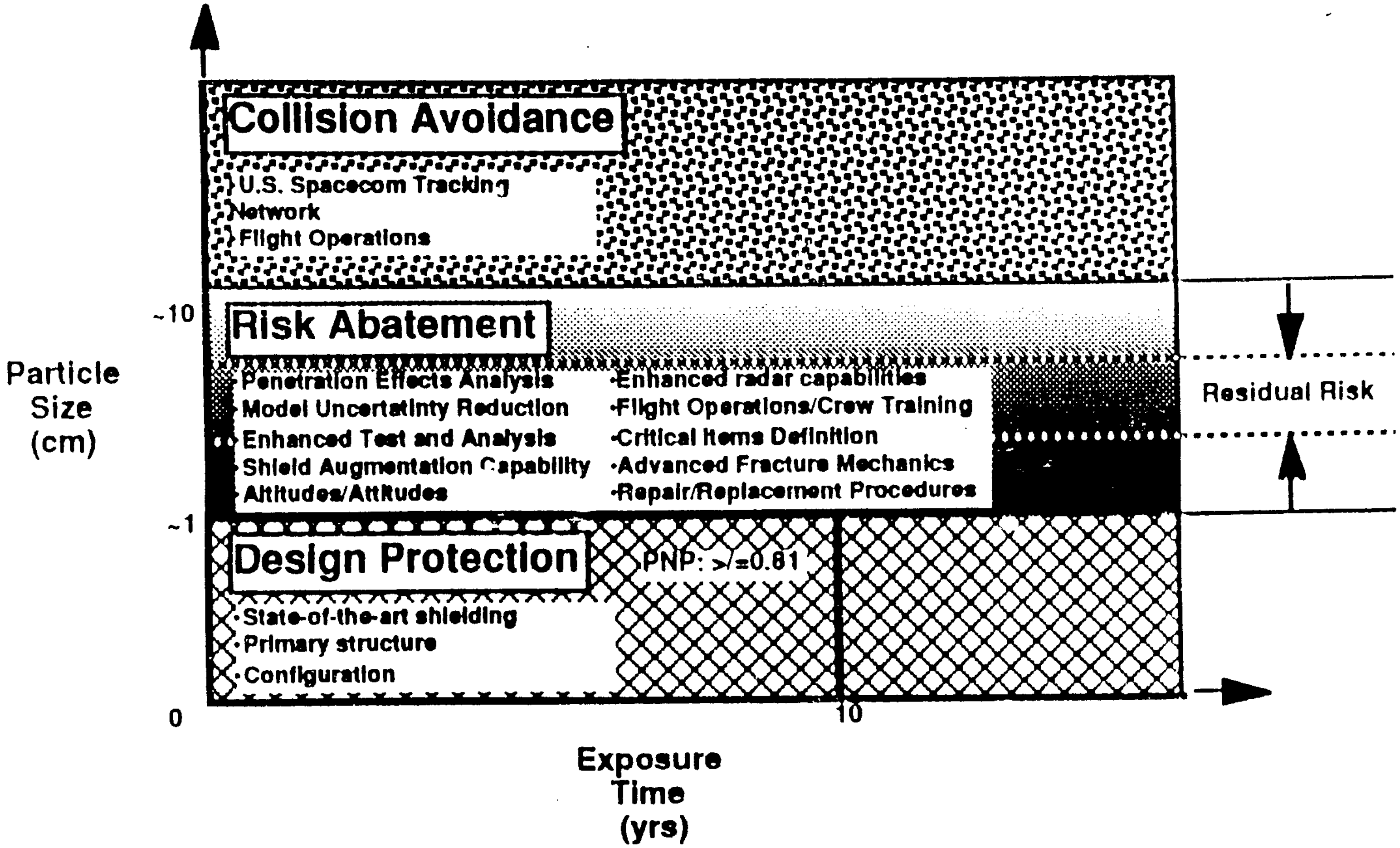
→ **Modify Design and Ops:**
- Equipment Locations
- Hatches Open/Closed
- Crew Position in Modules
- Sealing/Repair Strategies
- Internal Spall Blanket

Analysis Tool: MSCSurv
(Manned Spacecraft Crew Survivability)

* Probability of loss due to one or more impacts = $P_{loss} = 1 - \exp(-N_{impacts} \times P_{penetration/impact} \times P_{loss/pen})$.



Probability of Orbital Debris Impact
Highest Probability Areas in Red



M/OD Strategic Plan

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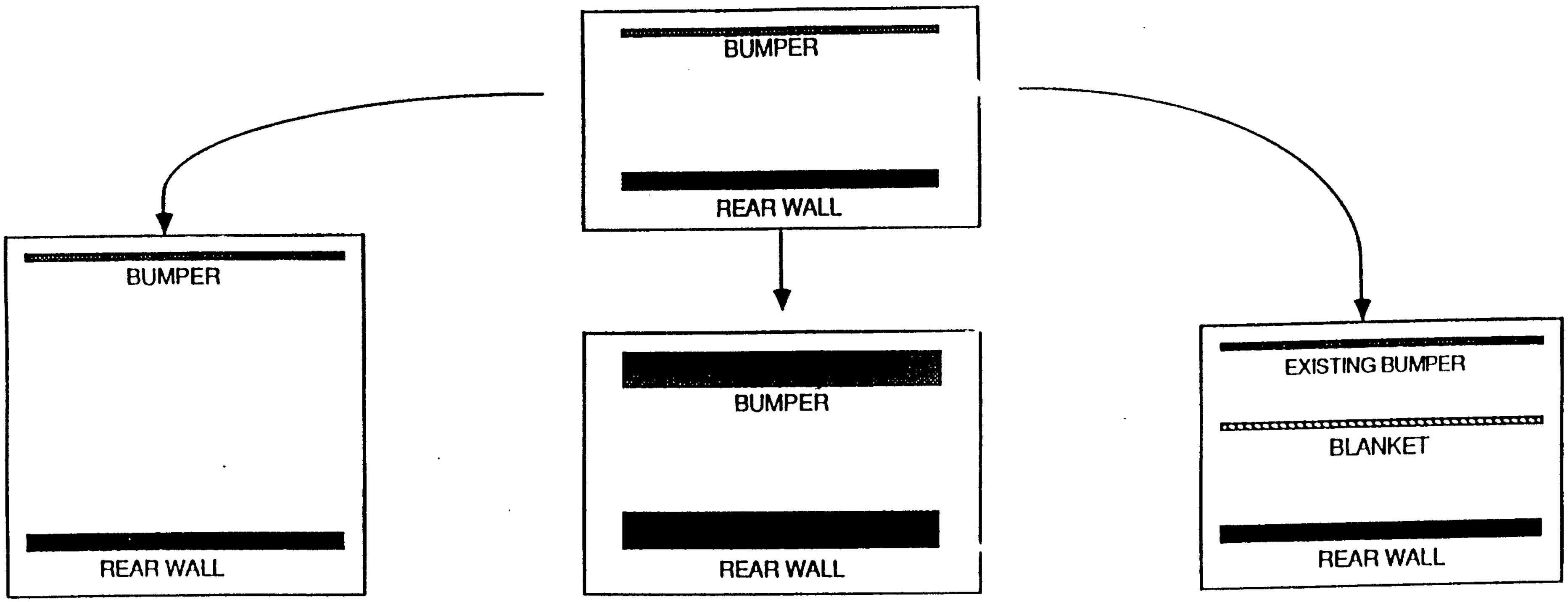
SPACECRAFT SURVIVABILITY IN THE ORBITAL DEBRIS ENVIRONMENT

NASA

J. Williamsen
May 25, 1993

THREE WAYS TO IMPROVE BASELINE SHIELDING



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LONGER STANDOFF

- MOST WEIGHT EFFICIENT
- DIFFICULT TO PACKAGE INTO ORBITER

THICKER BUMPER AND WALL

- LEAST WEIGHT EFFICIENT
- EASIEST TO IMPLEMENT

ADD LAYERS OF MATERIALS

- MODERATELY EFFICIENT
- POSSIBLE TO IMPLEMENT ON EXISTING DESIGN

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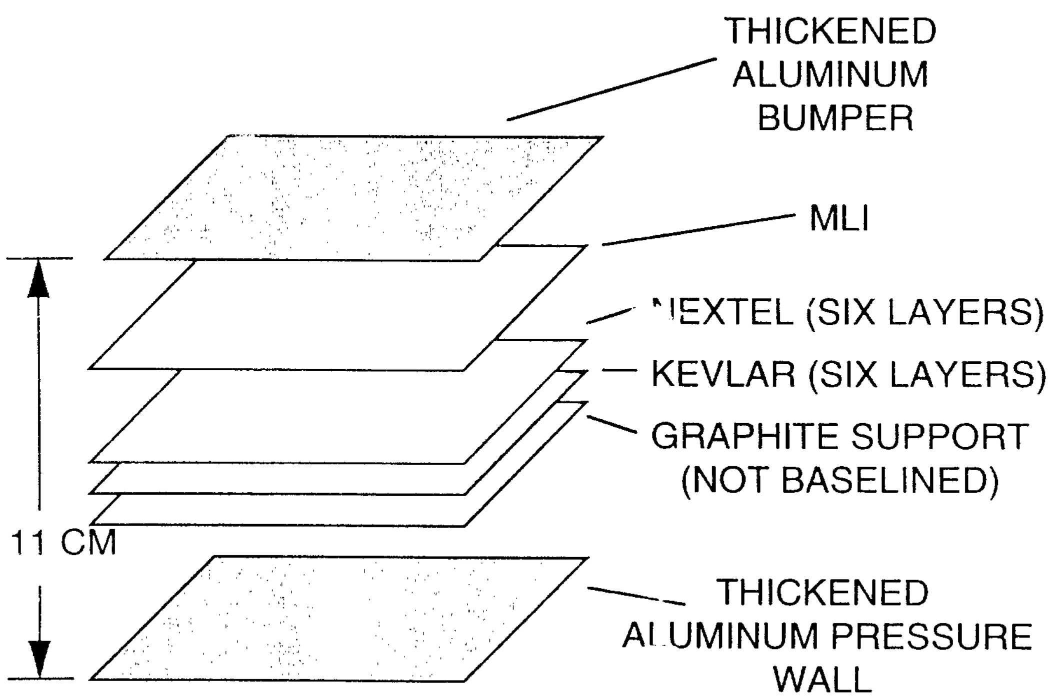
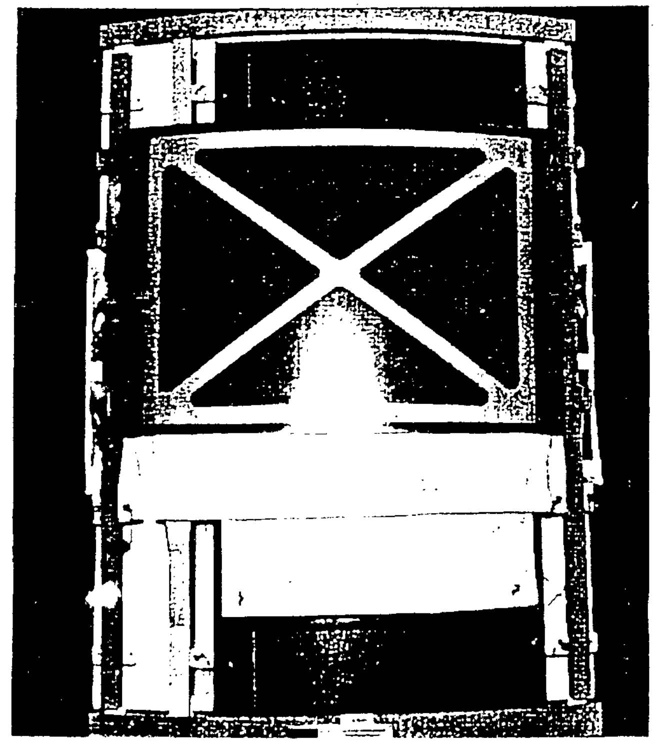
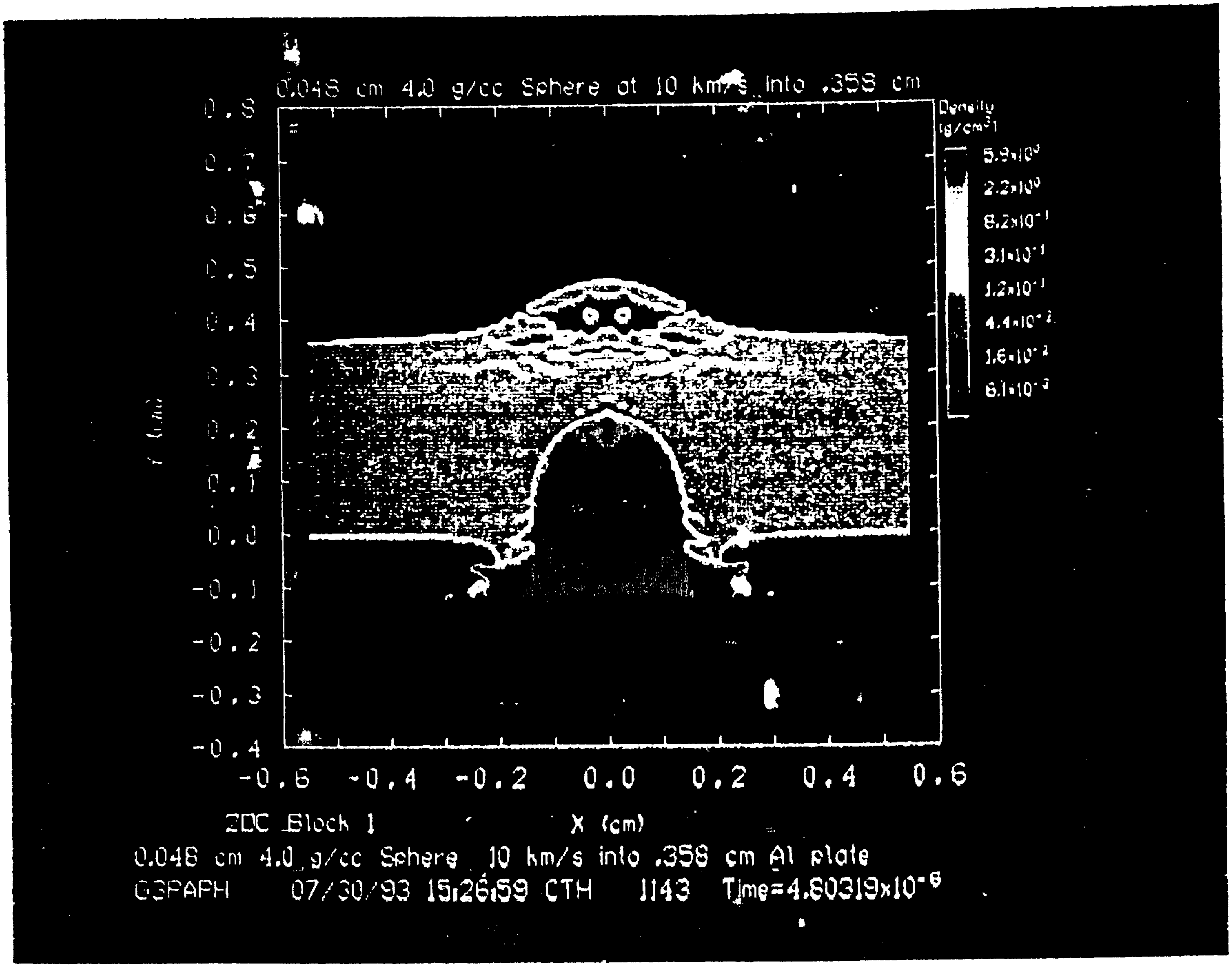
ENHANCED MANNED MODULE SHIELDING





- **IN-HOUSE NASA DEVELOPMENT (WITH JSC) FOR USE IN U.S. LAB, HAB, AIRLOCK.**
- **DEFEATS 10X MORE MASSIVE PARTICLES (ON AVERAGE)THAN BASELINE SHIELD.**
- **NOW PLANNED FOR USE ON NASDA, ESA MODULES. RSA ALSO EXAMINING USE FOR FGB.**

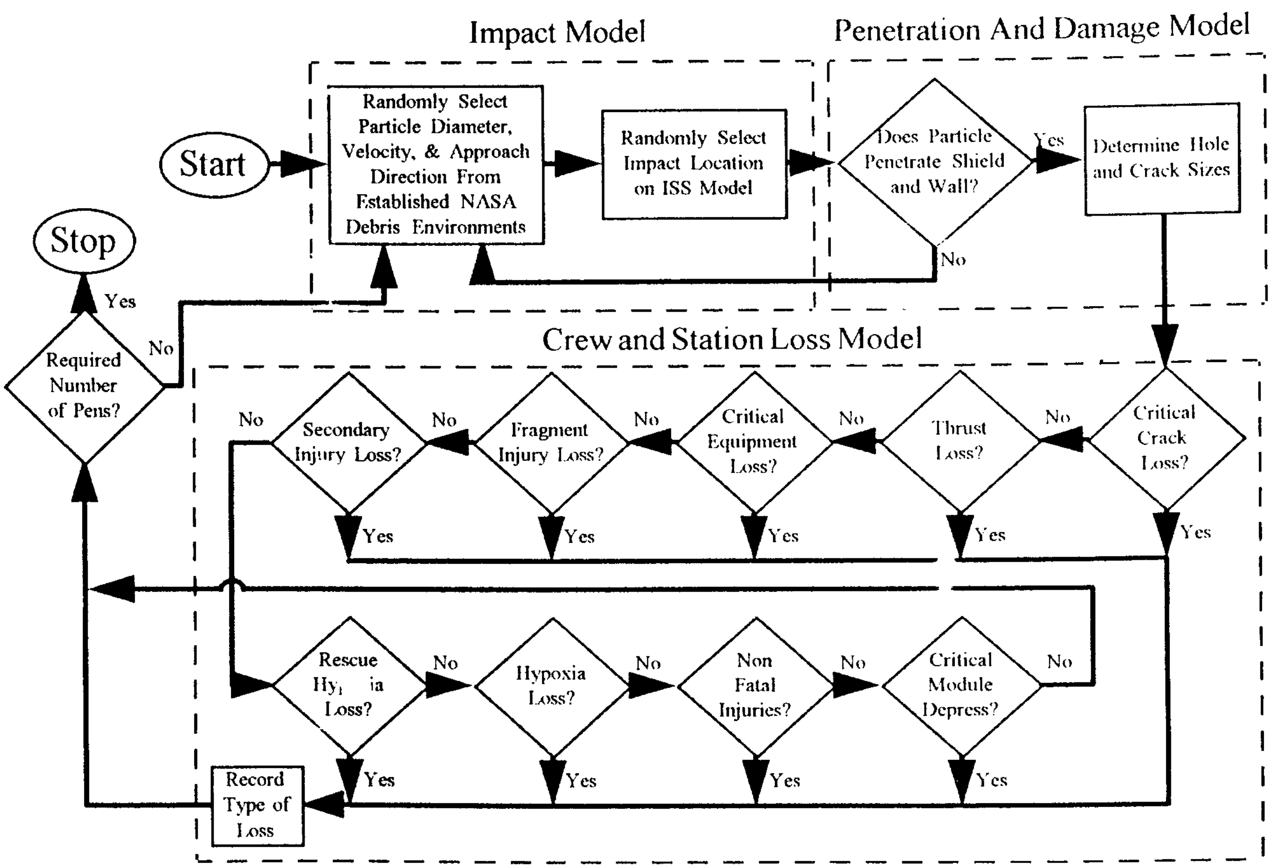

0.048 cm 4.0 g/cc Sphere at 10 km/s Into .358 cm
Density (g/cm³)
5.9×10^0
2.2×10^0
8.2×10^-1
3.1×10^-1
1.2×10^-1
4.4×10^-2
1.6×10^-2
6.1×10^-3
Y (cm)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
2DC Block 1
X (cm)
0.048 cm 4.0 g/cc Sphere 10 km/s into .358 cm Al plate
G3PAPH 07/30/93 15:26:59 CTH 1143 Time=4.80319×10^-6

Marshall Space Flight Center
Structures and Dynamics Laboratory

MSCSurv Flow Chart

J. Williamsen
17 March 1997

The Manned Spacecraft Crew Survivability (MSCSurv) computer program computes the probability of critical failure following orbital debris penetration.



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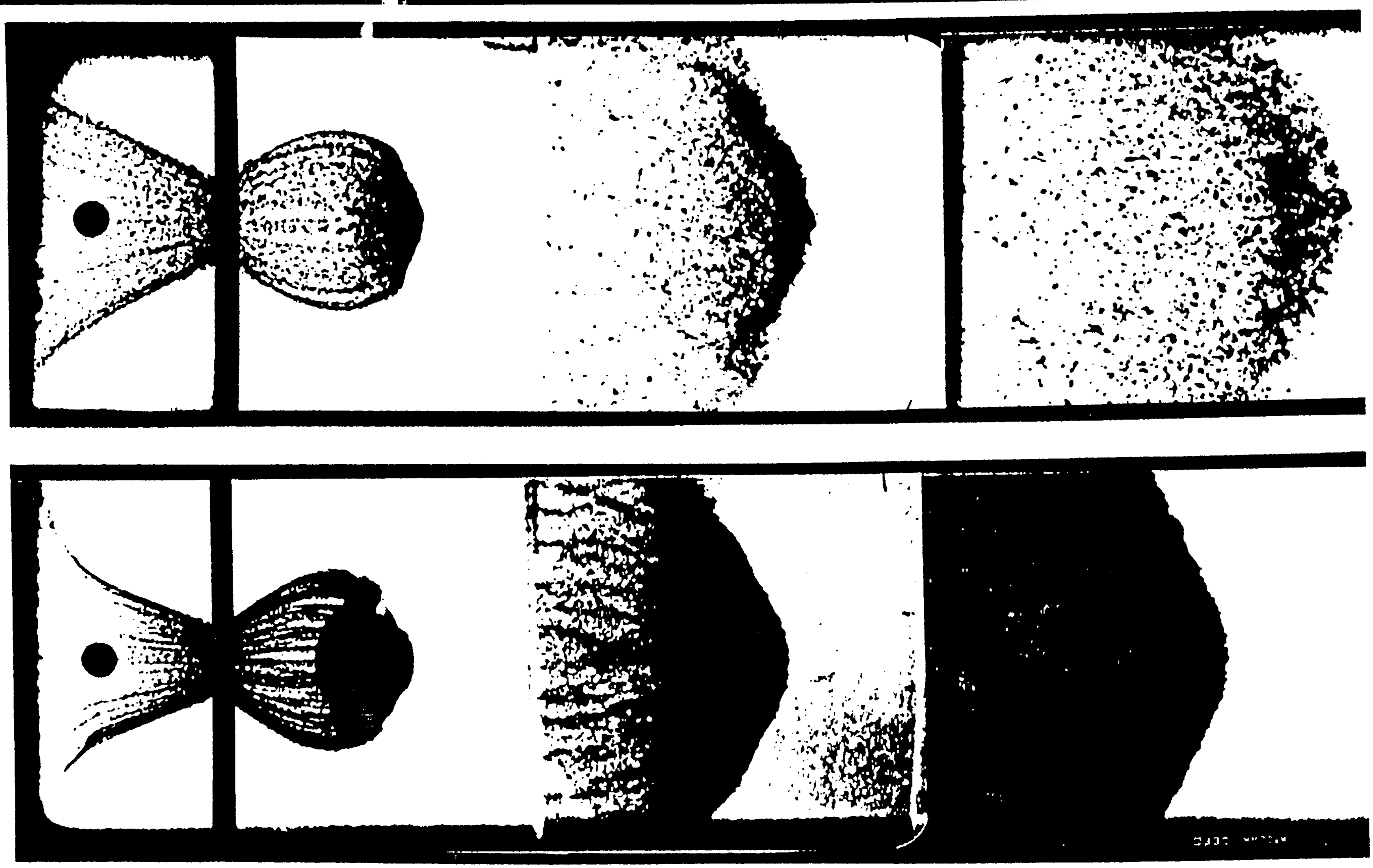
RADIOGRAPHS OF PROJECTILE/TARGET DEBRIS CLOUDS FOR 7 AND 11 km/s IMPACTS



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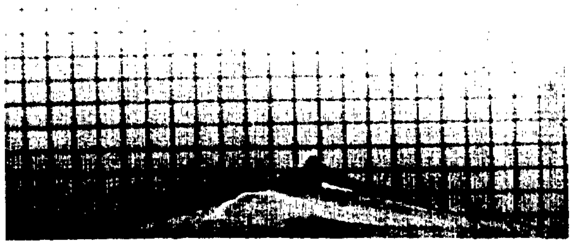
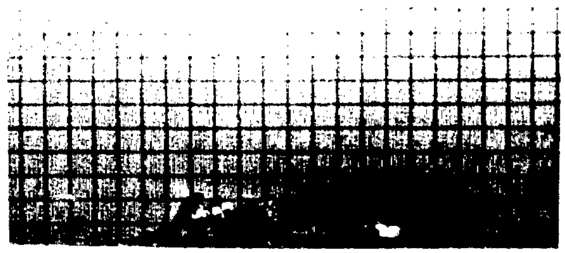
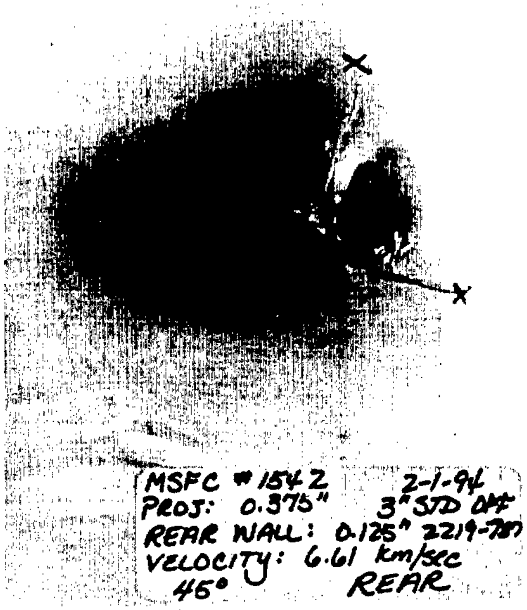
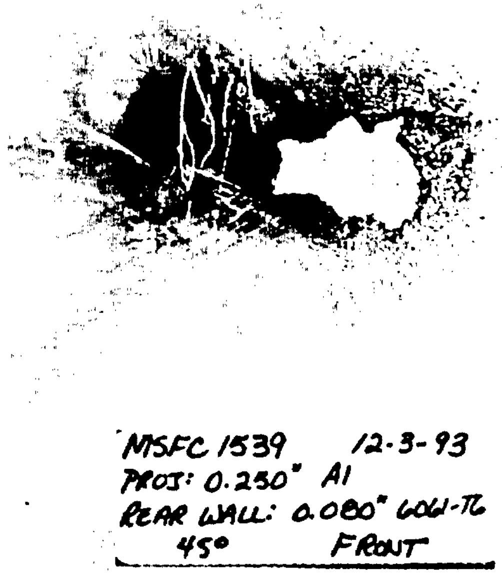
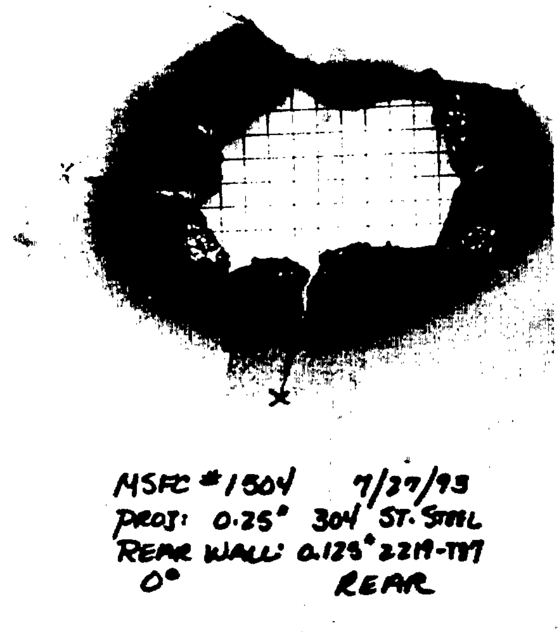
Space Station Pressure Wall Holes Following Hypervelocity Penetration









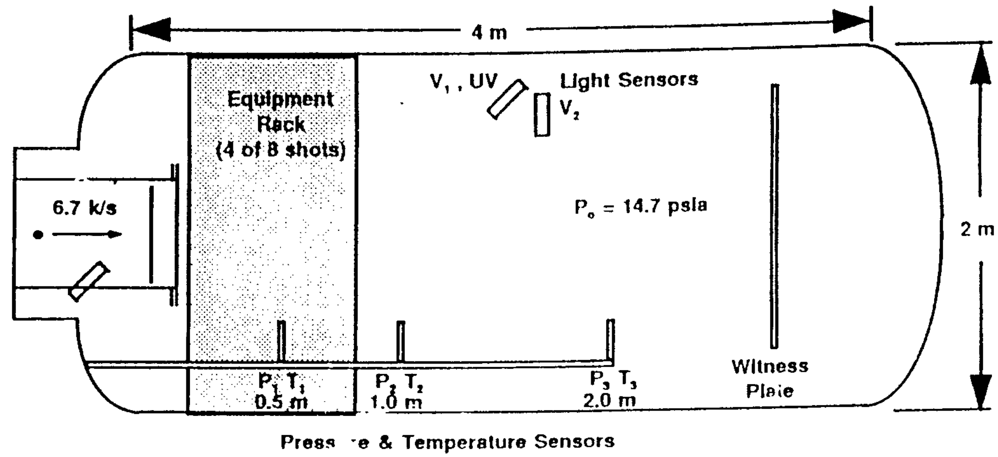


Manned Module Internal Effects Following A Penetration

MSFC - University of Alabama in Huntsville

- Eight tests measuring:
  - Overpressure
  - Flash Intensity
  - Temperature rise
  - Fragment dispersion.
- Determines effects of:
  - Projectile energy
  - Shield type
  - Internal equipment
  - Spall blankets

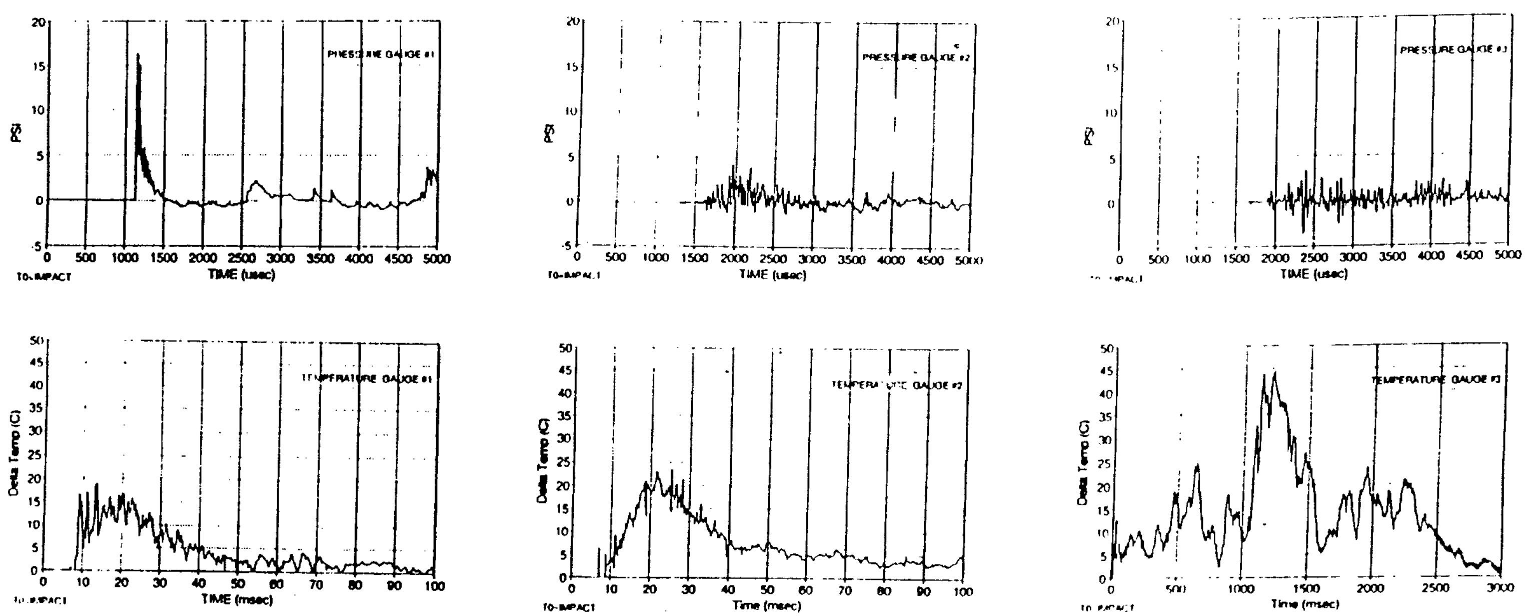
  on hazard levels experienced by crew members.



Overpressure

Test #1 7/18/94
Dia = 0.52 in.
Vel = 6.7 k/s
U.S. Lab Whipple Shield
No Internal Equipment

Temperature Rise



Thrust Hazard

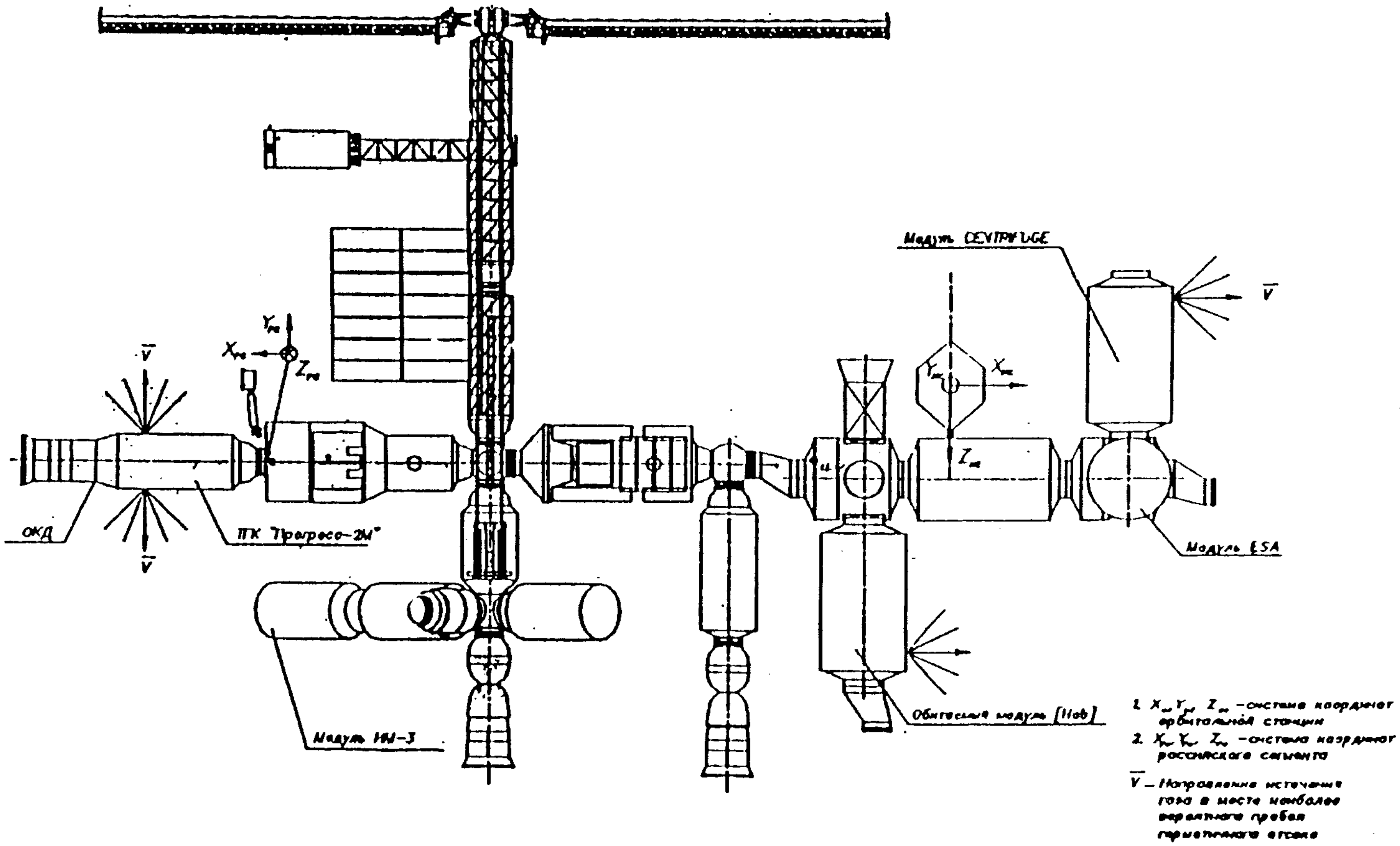


РИС.1

Critical Thrust Impact Locations
International Space Station Module Cluster

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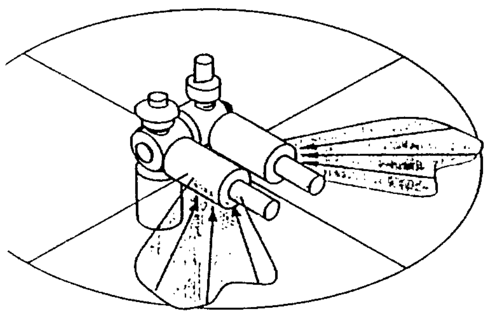
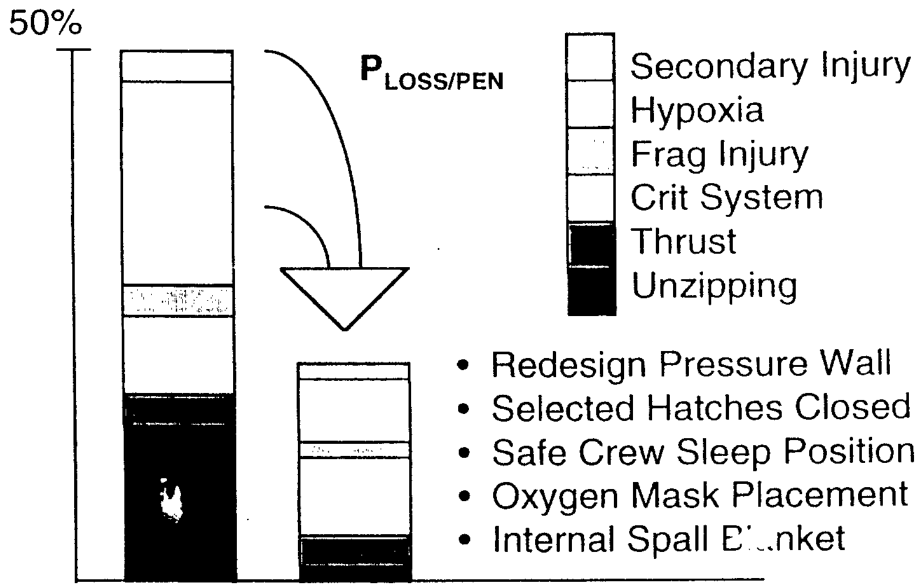
MINIMIZING SPACECRAFT OR CREW LOSS FOLLOWING PENETRATION

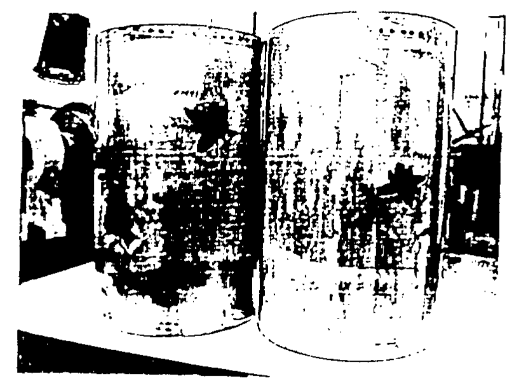


Environment Models



- Redesign Pressure Wall
- Selected Hatches Closed
- Safe Crew Sleep Position
- Oxygen Mask Placement
- Internal Spall Blanket

Baseline Improved Ops and Equipment

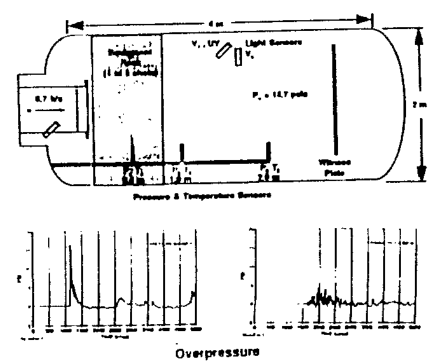


Damage Prediction

Fracture Analysis

Manned Spacecraft and Crew Survivability (MSCSurv) Computer Simulation

- **Developed and Run at MSFC for:**
  - **Space Station Flight Operations (JSC)**
  - **Astronaut Office**
  - **ESA, NASDA, RSA**



Specialized Tests

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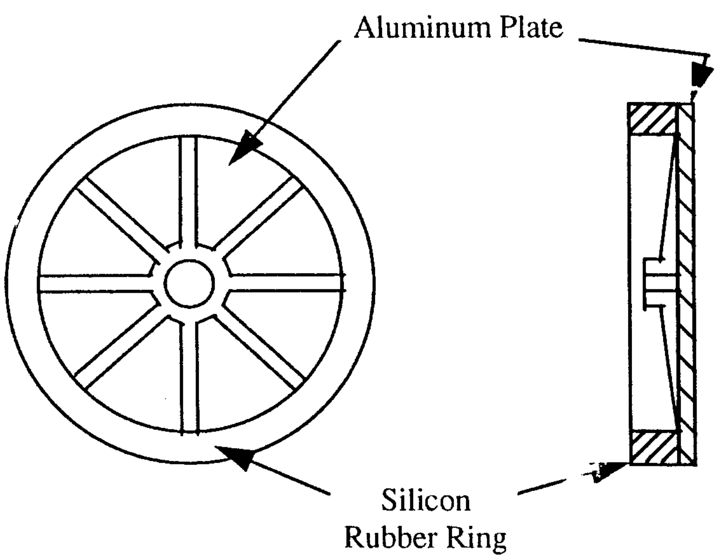
International Space Station
Kit for External Repair of Module Impacts
from Meteoroids and Orbital Debris

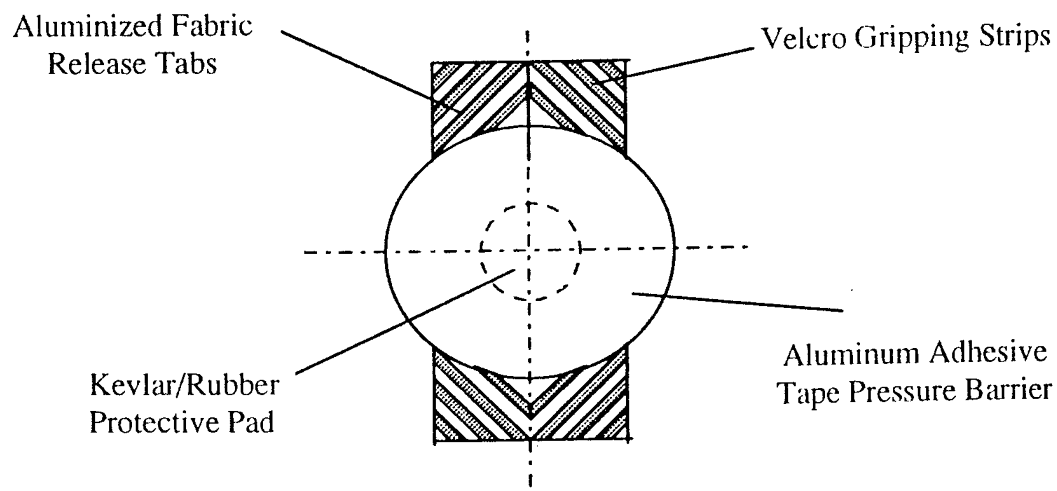
J. Williamsen
10 June 1997

Existing Internal Patch Types

Rigid Internal Repair Patch



Flexible Internal Repair Patch



Original KERMIt Patch Concept

External Adhesive Pressure Wall Patch

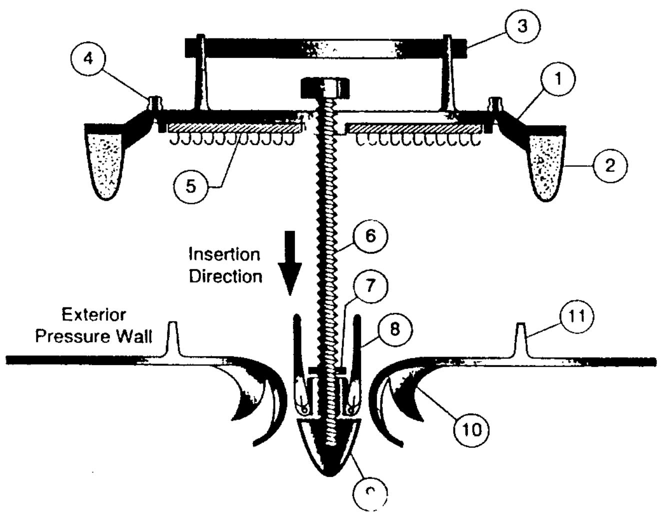


Figure 1. Patch probe inserted into hole.

Items

1. Patch Frame
2. Flexible Outer Seal
3. EVA Handle(s)
4. Adhesive Sealant zirc
5. Adhesive Interface Plate
6. Threaded Probe
7. Jam Nut
8. Spring-loaded Sprag Assembly (Collapsed Position)
9. Probe Tip
10. Damaged Pressure Wall with internal petals
11. Exterior structural feature (Grid) on Pressure Wall

1A-2810

External Adhesive Pressure Wall Patch

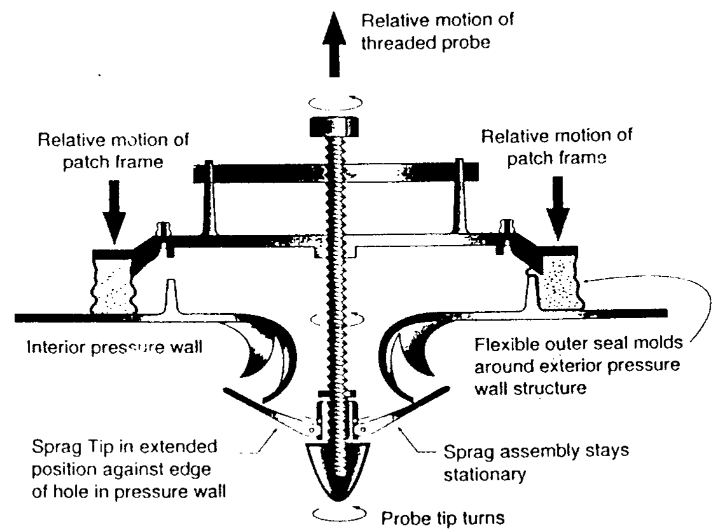


Figure 2. Patch lowered against exterior pressure wall.

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Original KERMIt Patch Concept

External Adhesive Pressure W~" Patch

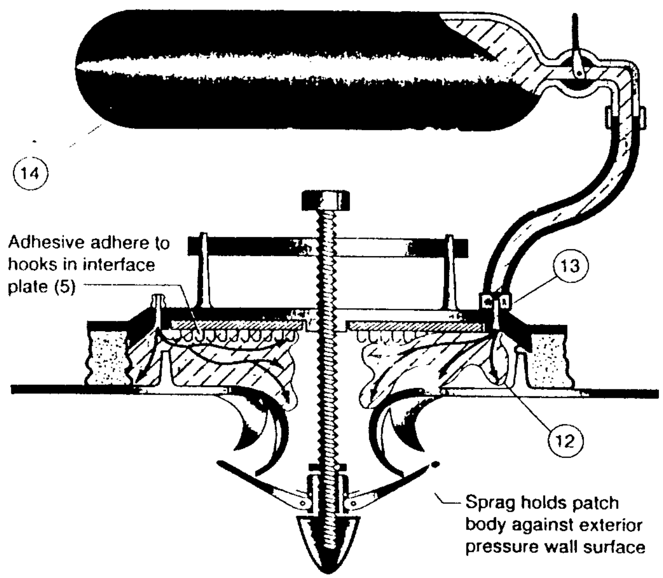

Figure 3. Patch body filled with adhesive sealant.

12. Liquid adhesive sealant
13. Flexible connection to patch zirc (4)
14. Adhesive sealant reservoir

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Exter,.al Adhesive Pressure Wall Patch

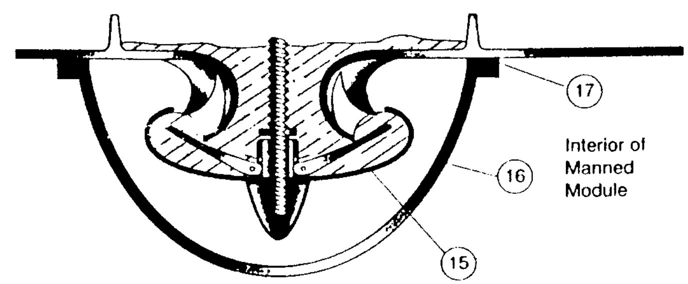

Figure 4. Optional internal seal components.

Items

15. Optional **flexible cap** over sprag assembly to contain liquid adhesive
16. **ınternal cover assembly** placed over sprag assembly following module re-pressurization to engure seal
17 ıternal cover seal (adhesive)

1A-2821