Orbital Debris

Space Hazards: Natural & Human-made

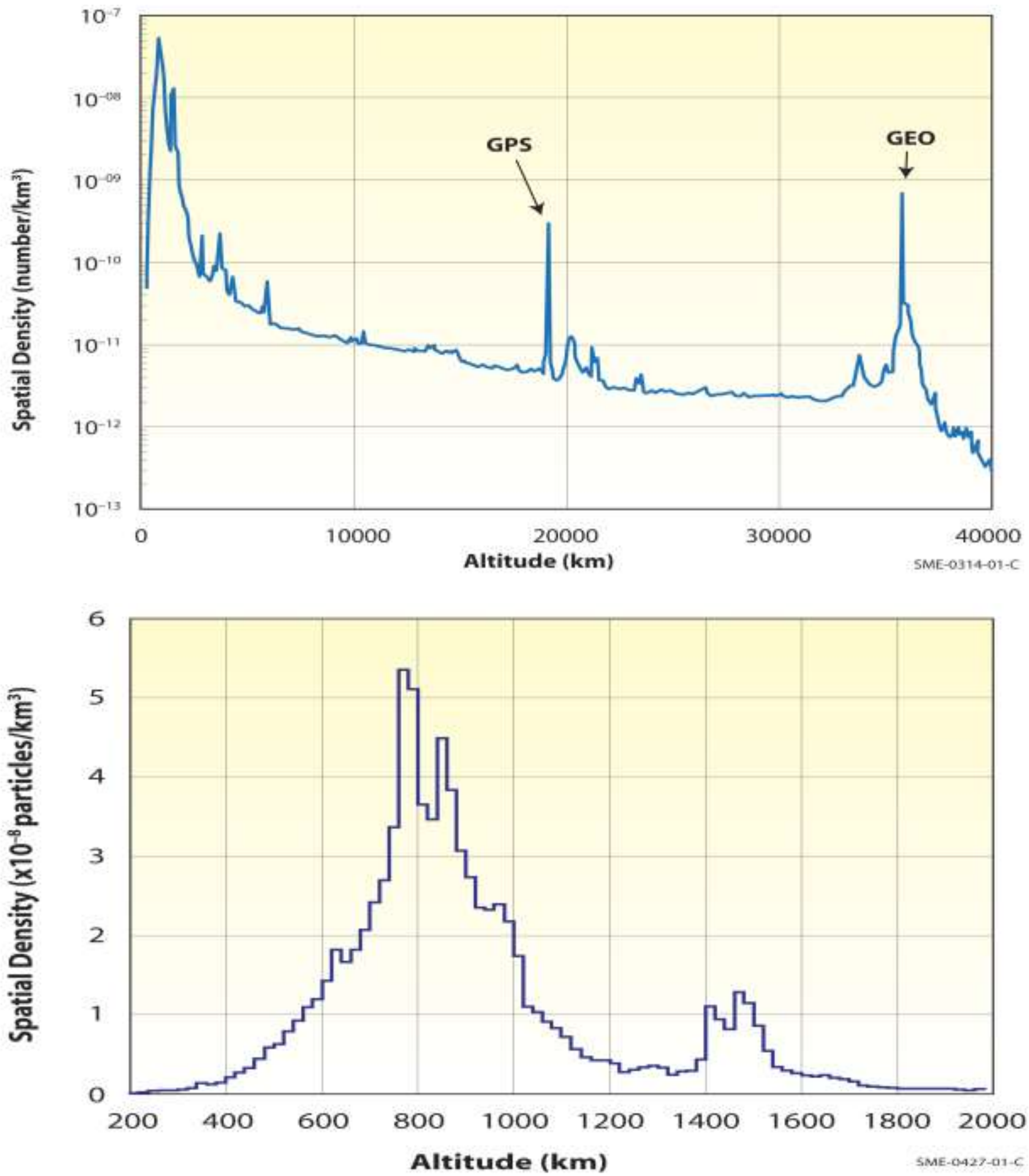
- **Micro-meteoroids**

- **Space hardware**

- **Space junk is now one of the principle threats to orbital satellite systems, on which we depend for a multitude of essential services: from meteorology to the global transport of goods and passengers.**

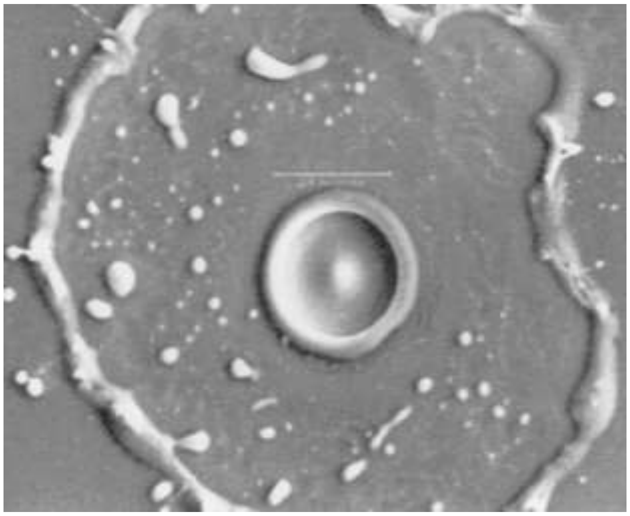
- **It is estimated that more than 700 000 dangerous debris objects are in Earth orbit and have the potential to damage or destroy operational satellites. For many missions, the risk of losing a mission through the impact of space debris is considered to be the third highest risk, after the launch and deployment risks.**

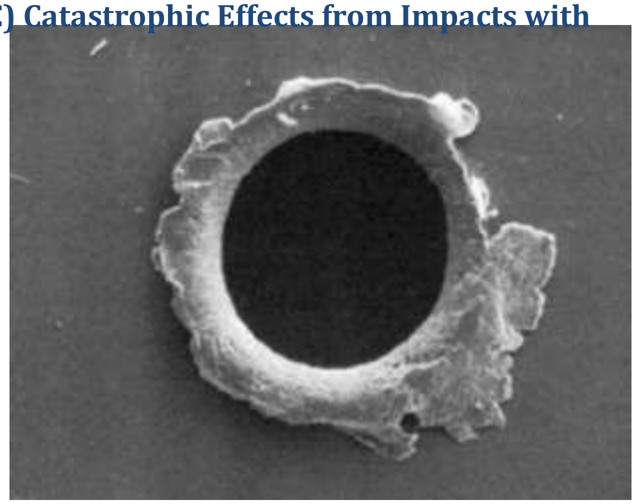
- **In order to avoid the consequences of space debris, we need to know where the debris objects are, which means developing technologies related to surveillance radars and telescopes.**



(A) Spatial Density Values of All Catalogued Objects for January 2011, (B) Spatial Density Values of All Catalogued Objects for January 2011 (LEO Only). Densities in GEO are approximately 10 times less than in LEO. The probability of a spacecraft getting hit by something big is small, while the chance of getting hit by something small is big. See text for discussion.

Fig. 7-24. (A) Erosion, (B) Penetration, and (C) Catastrophic Effects from Impacts with Debris. (Courtesy of NASA)





Debris Tracking in the US:

- **Strategic Command (STRATCOM) tracks orbital objects (larger than ~10cm dia)**

- **The JSpOC maintains the catalog of all artificial Earth-orbiting objects, charts preset positions for orbital flight safety, and predicts objects reentering the Earth's atmosphere. Currently, the JSpOC tracks more than 16,000 objects orbiting Earth. About 5 percent of those being tracked are functioning payloads or satellites, 8 percent are rocket bodies, and about 87 percent are debris and/or inactive satellites.**

- **Phased-array radars can maintain tracks on multiple satellites simultaneously and scan large areas of space in a fraction of a second. These radars have no moving mechanical parts – electronic beam-steering**

- **Conventional radars use moveable tracking antennas or fixed detection and tracking antennas. A tracking antenna steers a narrow beam of energy toward a satellite and uses the returned energy to compute the location of the satellite and to follow the satellite's motion to collect more data.**

- **Electro-Optical Sensors consist of telescopes linked to video cameras and computers.**

- **Space Based Sensors have the ability to detect debris, spacecraft, or other distant space objects without interference from weather, atmosphere, or time of day. Space based sensors use optical or infrared sensors which either scan, or quickly focus between targets without having to expend time and fuel to reposition the entire spacecraft.**


Stratcomm radar antenna system

Country or Organization	Payloads	Rocket Bodies & Debris	Total
China	98	3395	3493
CIS	1406	4600	6006
ESA	39	44	83
France	49	426	475
India	41	133	174
Japan	113	76	189
USA	1124	3701	4825
Other	479	115	594
TOTAL	3349	12490	15839

As of 2010

Common Name	Year of Breakup	Altitude of Breakup	Catalogued Debris	Tracked Debris in Orbit	Cause of Breakup
Fengyun-1C	2007	850 km	2841	2756	Intentional Collision
Cosmos 2251	2009	790 km	1267	1215	Accidental Collision
STEP 2 Rocket Body	1996	625 km	713	63	Accidental Explosion
Iridium 33	2009	790 km	521	498	Accidental Collision
Cosmos 2421	2008	410 km	509	18	Unknown
SPOT 1 Rocket Body	1986	805 km	492	33	Accidental Explosion
OV 2-1/LCS 2 Rocket Body	1965	740 km	473	36	Accidental Explosion
Nimbus 4 Rocket Body	1970	1075 km	374	248	Accidental Explosion
TES Rocket Body	2001	670 km	370	116	Accidental Explosion
CBERS 1 Rocket Body	2000	740 km	343	189	Accidental Explosion
		TOTAL	7903	5172	©2011 Microcosm Inc.

Top ten, as of 2010

Spacecraft	Maneuver Date	Object Avoided
TDRS 3	27 January	Proton rocket body
ISS	22 March	CZ-4 rocket body debris
Cloudsat	23 April	Cosmos 2251 debris
EO-1	11 May	Zenit rocket body debris
ISS	17 July	Proton rocket body debris
Space Shuttle	10 September	ISS debris
*PARASOL (France)**	29 September	Fengyun-1C debris
Aqua	25 November	Fengyun-1C debris
Landsat 7	11 December	Formosat 3D

* Operating in NASA-led Earth observation network

Avoidance maneuvers in just 2009

NASA/TM–2009–214785

Handbook for Designing MMOD Protection

Astromaterials Research and Exploration Science Directorate
Human Exploration Science Office
NASA Johnson Space Center

MMOD Protection Design Process:

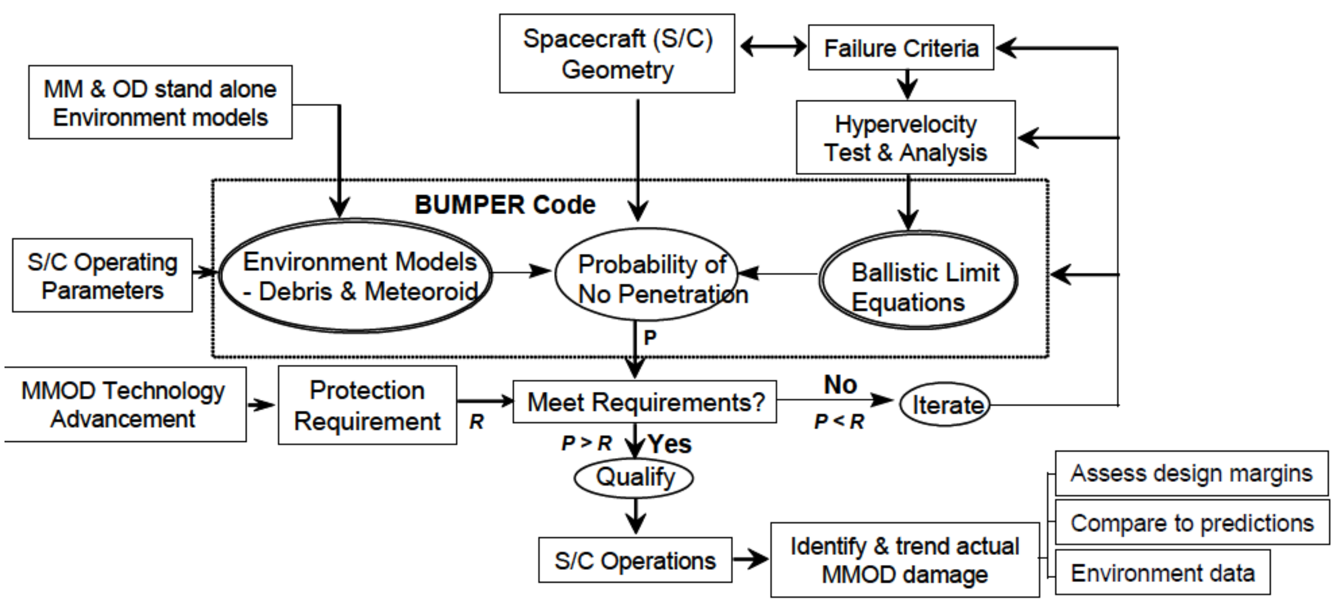
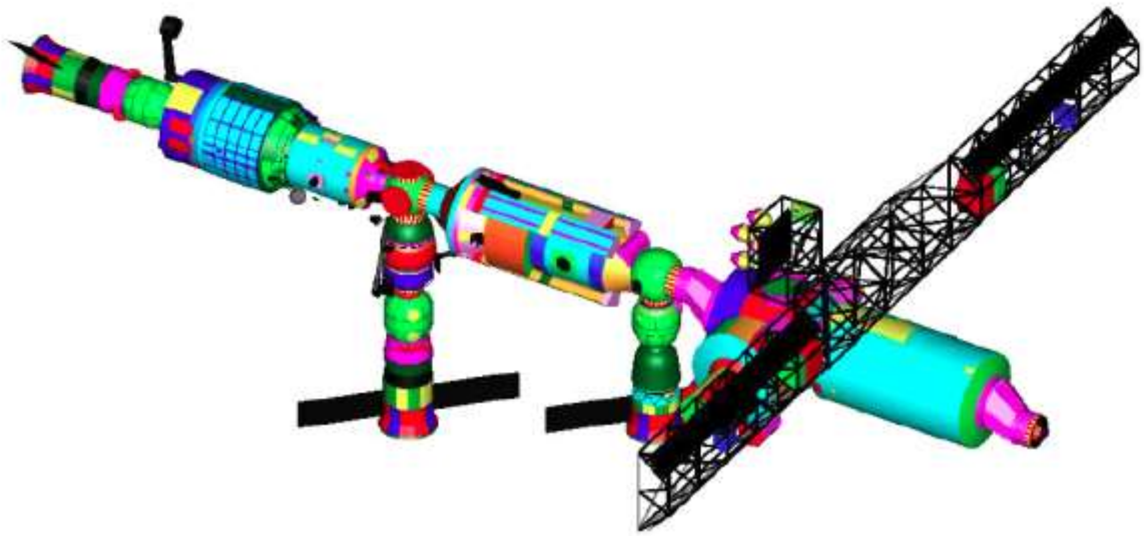


Figure 2-1. Process to evaluate and design MMOD protection.

Spacecraft Geometry Model:

The large number of different shields on the ISS is partly a reflection of the directionality of the MMOD environment. For a spacecraft with fixed orientation relative to the velocity direction, the front (ram surface) and sides of a spacecraft are more exposed to orbital debris impact while the front, sides, and top (zenith) are more exposed to micro-meteoroid impact. More robust shielding, which is more capable from MMOD protection standpoint, is located where MMOD impact rates are highest.



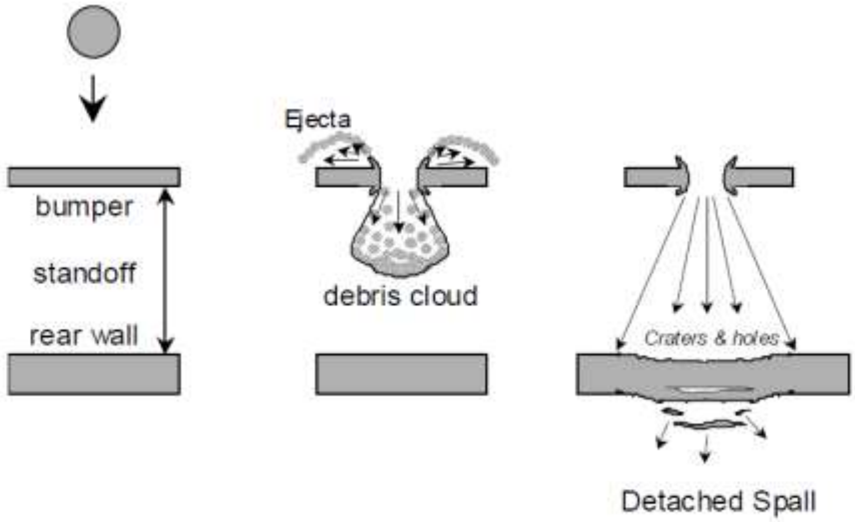
Failure Criteria:

Table 2-1. Damage Modes and Failure Criteria for Space Station Elements

Critical Elements & Components	TPS Damage	Spall or Perforation of Pressure Shell or last layer of shielding	Damage exceeding allowables to Pressure Vessel	Uncontrolled Depressurization	Catastrophic Rupture	Detonation or Deflagration
Crew Modules		X		X	X	
Windows		X*		X	X	
Pressure vessels			X	X	X	
Propellant tanks			X		X	X
Control moment gyros		X			X	
Cargo transfer vehicles		X	X	X	X	X
Crew transfer vehicles	X	X	X	X	X	X

*Window failure criteria is detached spall from redundant pressure pane (which is exterior of primary pressure pane).

Spacecraft Debris Protection: "Whipple Shield"

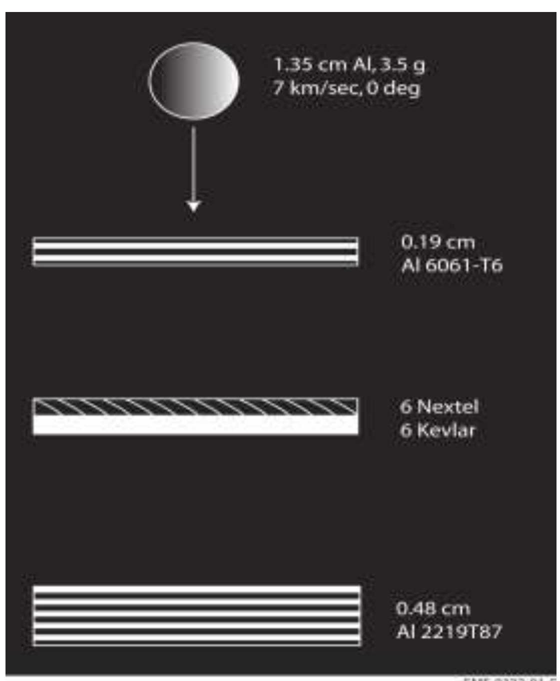


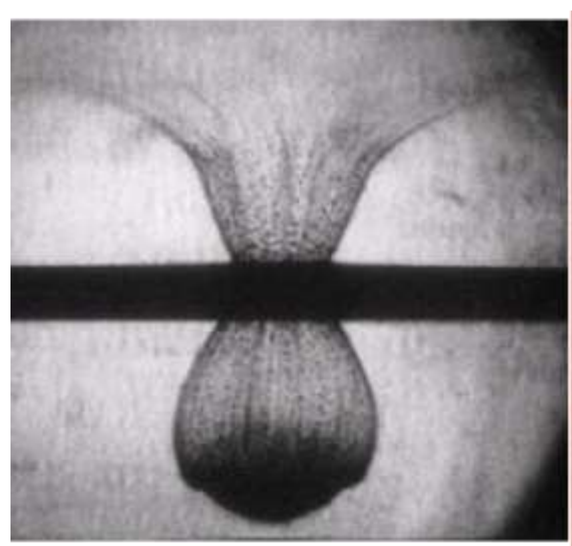
a) Whipple shields consist of a bumper, standoff (gap or spacing), and rear wall.

b) Hypervelocity impacts will generate a cloud of bumper and projectile debris that can contain solid fragments, liquid, and vapor particles.

c) The rear wall must survive the fragments and debris cloud impulsive loading. It could fail by perforation from solid fragments, spall, or tear and petal from the impulsive loading.

Figure 1-1. Whipple shield schematic.





Stuffed Whipple Shield on ISS

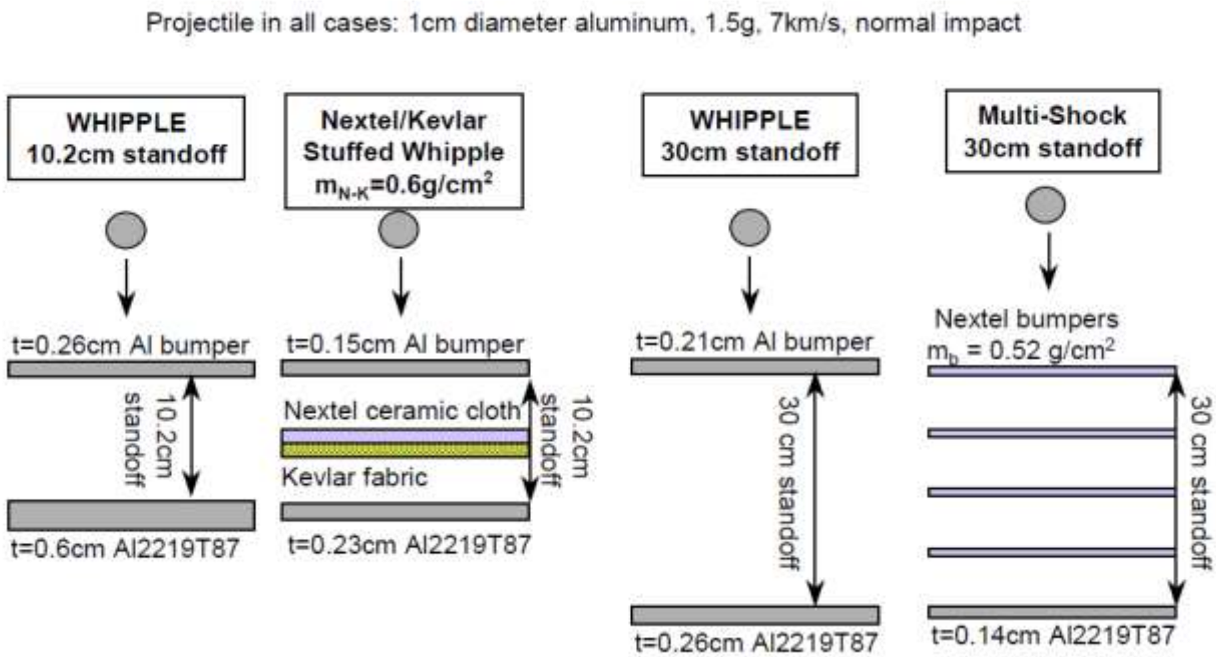


Table 2-7. MMOD Protection Requirements for Various Spacecraft

Spacecraft	Environments Considered	Required PNP
Apollo Command and Service Module	Meteoroids	0.995 per 8.3-day mission
Apollo Lunar Lander Module	Meteoroids	0.995 per mission
Skylab Module	Meteoroids	0.995 per 8-month mission
Spacelab Module	Meteoroids	0.999 for 7-day mission
Space Shuttle Orbiter vehicle	Meteoroids and Orbital Debris	0.995 per mission (for damage resulting in LOCV)[1]
Hubble Space Telescope	Meteoroids and Orbital Debris	0.95 for 2 years
International Space Station	Meteoroids and Orbital Debris	0.98 to 0.998 per critical element over 10 years

Equations for Designing MMOD Shields

- **Design equations: initial design to meet requirement**

- **Performance equations: verify that requirements have been met**

- **Example: Single-Wall Shielding with Aluminum Shield**

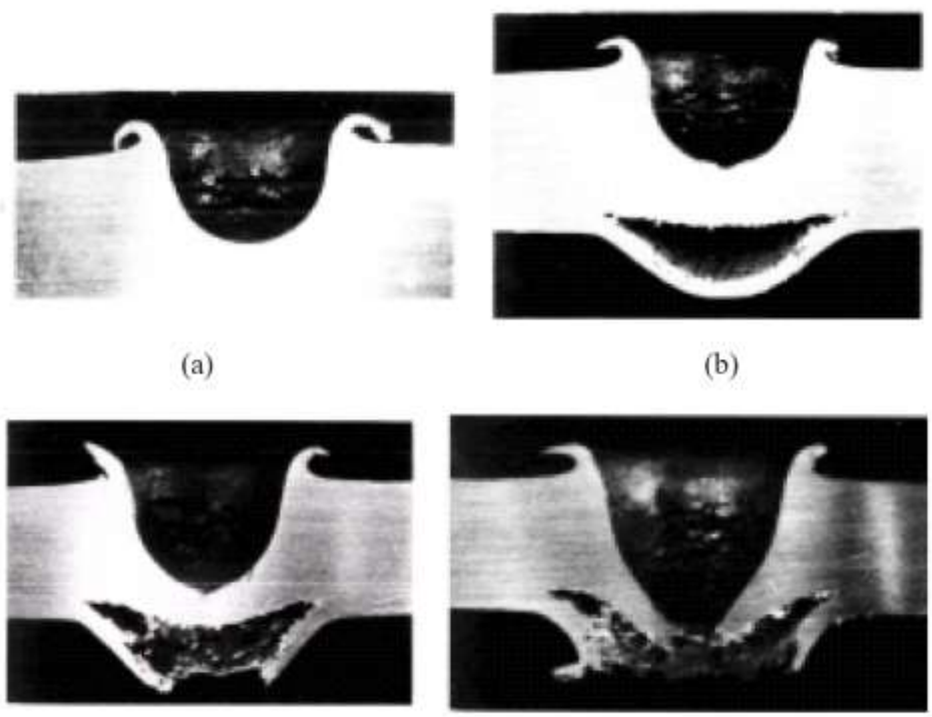
- **Design eqn for penetration depth:**

Speed of sound in materials:

Medium	Vel (m/s)
Aluminum, shear - longitudinal wave	3100 - 6400
Beryllium	12890
Brass	3475
Brick	4176
Concrete	3200 - 3600
Copper	4600
Cork	366 - 518
Diamond	12000
Glass	3962
Glass, Pyrex	5640
Gold	3240
Granite	5950
Hardwood	3962
Iron	5130
Lead	1960 - 2160
Lucite	2680
Rubber, butyl	1830
Rubber	40 - 150
Silver	3650
Steel	6100
Steel, stainless	5790
Titanium	6070

To prevent incipient spall:	$t \geq 3\ P_\infty$	(4-3)
To prevent detached spall:	$t \geq 2.2\ P_\infty$	(4-4)
To prevent perforation:	$t \geq 1.8\ P_\infty$	(4-5)

Impact Physics:



(a) (b) (c) (d)

Figure 4-2. HVI damage modes in aluminum: (a) craters in semi-infinite targets; (b) attached spall; (c) detached spall; and (d) complete penetration or perforation of the target. Impact damage from soda-lime glass projectiles into Al 1100 targets at 5.9 km/s; target thickness to projectile diameter ratio are: (a) t/d = 10, (b) t/d = 4, (c) t/d = 3.4, (d) t/d = 3 [26].

Performance Equation: