SURVIVABILITY ANALYSIS

OF A SMALL SATELLITE CONSTELLATION

Edward A. S. Hanlon

Ensign, United States Navy

Space in the News

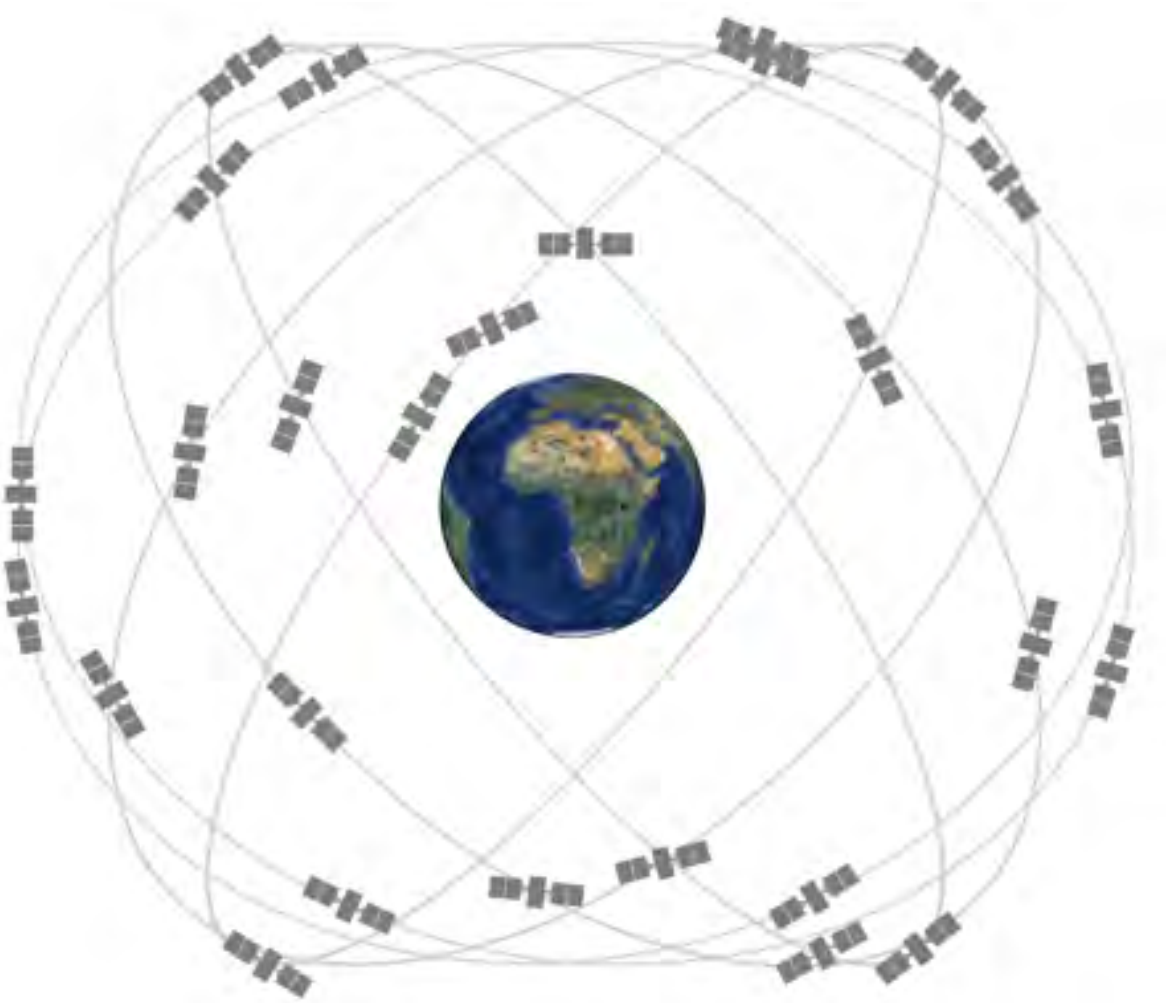
There's a New Cold **War** Brewing in **Space**
Bloomberg - Mar 21, 2018
Even before Trump's comments, the Defense Department was under orders to formulate a "concept of operations" document for **space war** fighting, due this June. That exercise will help to inform how the government develops and acquires new space capabilities, Air Force General John Hyten, commander ...

Space War Is "Absolutely Inevitable," Researchers Say
Inverse - 7 hours ago
"It is absolutely inevitable that we will see conflict move into space," **space war** expert Michael Schmitt told the Guardian on Sunday. Schmitt, a professor of public international law at the University of Exeter, is part of an international consortium of law, military, and space experts who have developed the ...

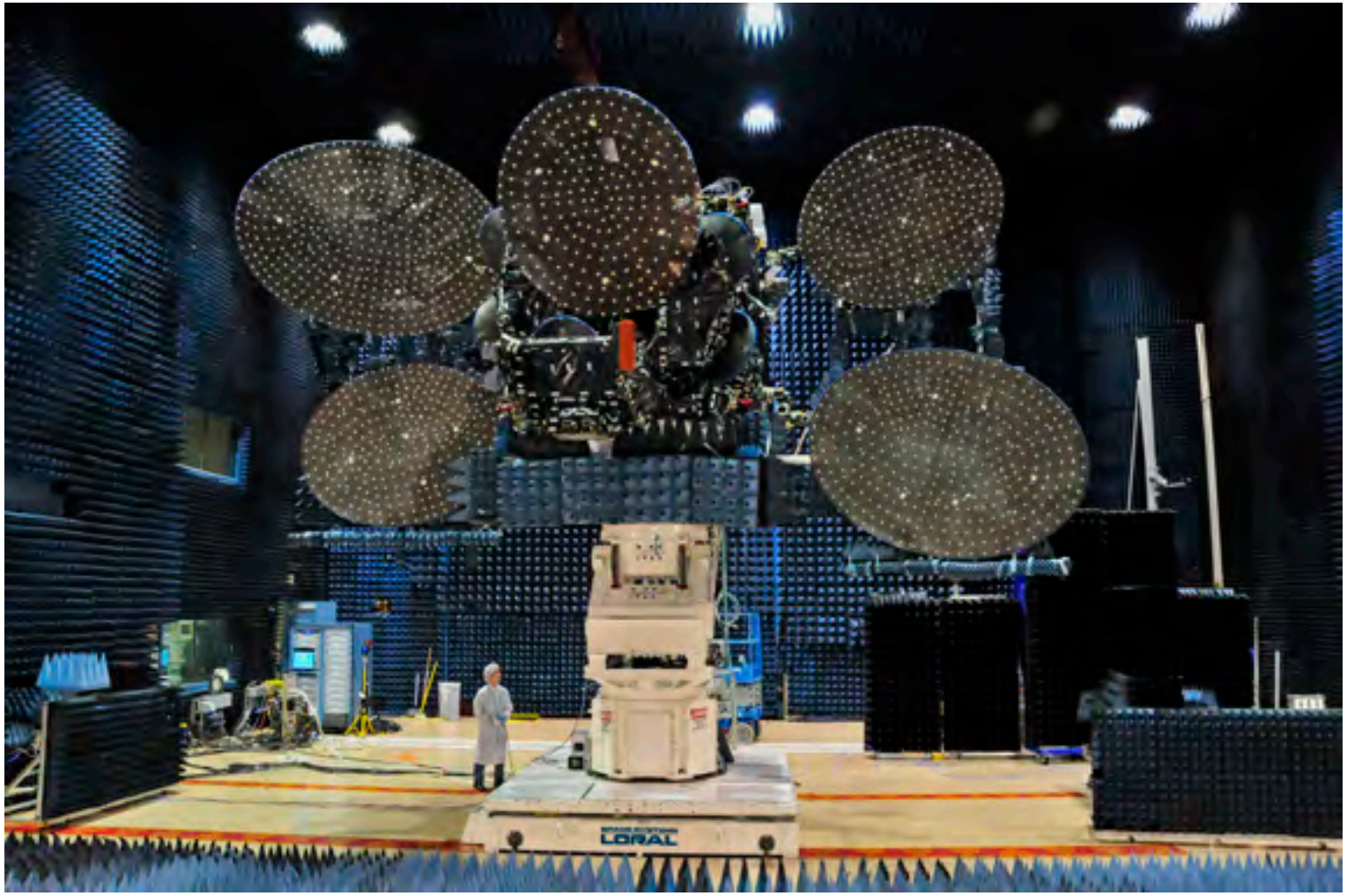
'It's going to happen': is the world ready for **war** in **space**?
Highly Cited - The Guardian - 22 hours ago

World should prepare for military conflict in outer **space**, experts warn
ABC Online - Apr 9, 2018
... secretary of the Air Force, Heather Wilson, declared America must start to prepare for the possibility of armed conflict in outer **space**. US President Donald Trump also recently called for a dedicated US military **space** force. "My new national strategy for **space** recognises that **space** is a **war**-fighting domain, ...

Space is Important



Space is Vulnerable



Space is Contested

In any conflict, space will be contested – and we haven't always assumed that in the past. There's been a change in culture – a change in planning and training going on in the United States military because we cannot take space dominance for granted.

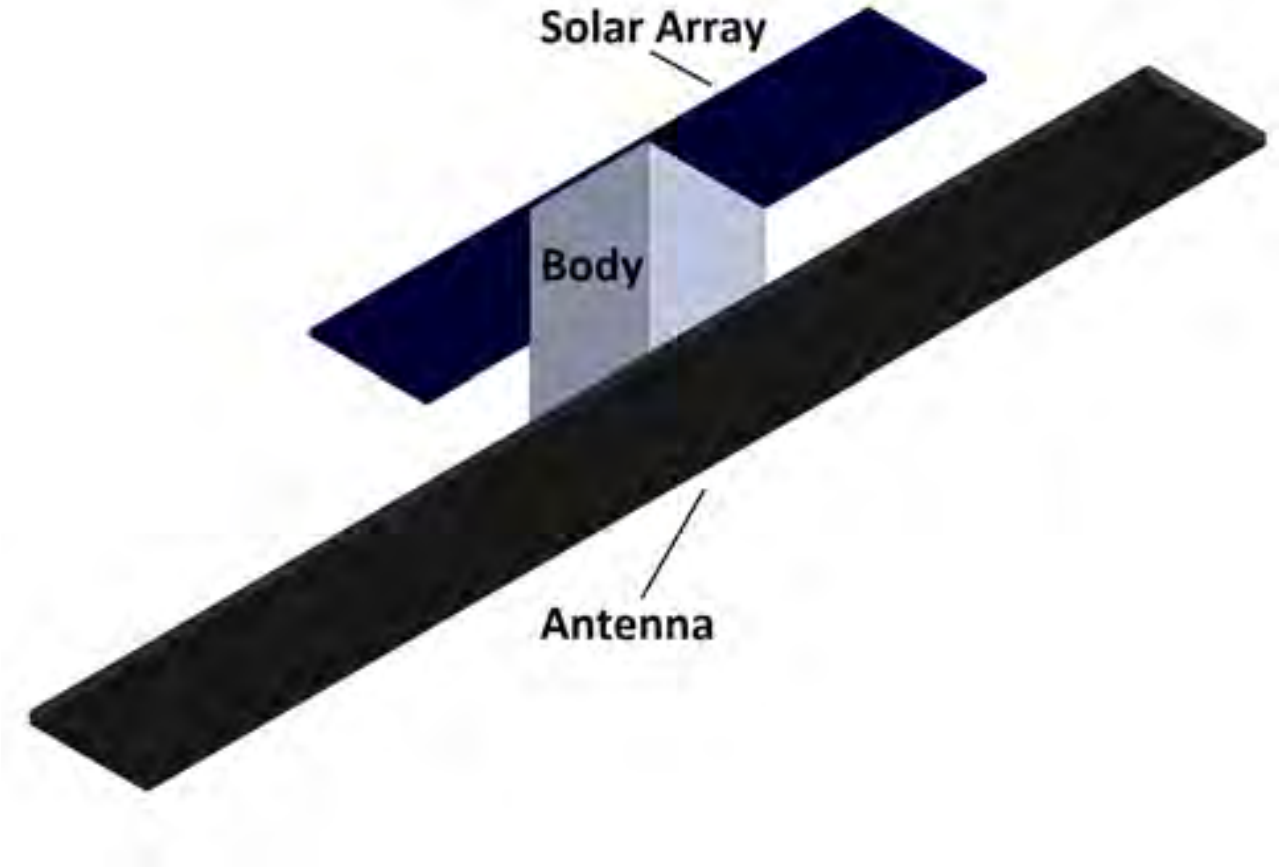
– U.S. Secretary of the Air Force, Heather Wilson

Small Satellites

SmallSat Advantages

1) *Small*: <500 kg, effectively no larger than a washing machine.
2) *Inexpensive*: Typically orders of magnitude cheaper than full size spacecraft.
3) *Quick*: High risk tolerance and small physical size accelerates design and construction process.
4) *Replaceable*: Low cost and access to launch provide easy replacement for lost capability.
5) *High Risk Tolerance*: Acceptable to lose spacecraft.

Example



Survivability

Definition of Survivability

Combat survivability is the capability of a craft to ***avoid*** *or* ***withstand*** *a* ***man-made*** *hostile environment.*
– Robert E. Ball

Components of Survivability

Susceptibility (Avoid)

- The inability of a craft to avoid enemy threats.

Vulnerability (Withstand)

- The inability of a craft to withstand the effects of threats.

$$P_k = P_h P_{k|h}$$

Process

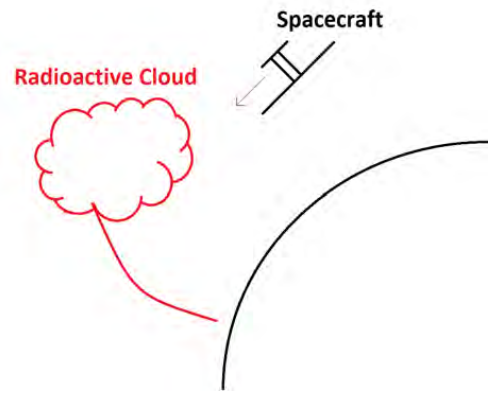
1) *Threat Analysis*
2) *Vulnerability Analysis*
3) *Susceptibility Analysis*
4) *Opportunities for Improvement*

Threat Analysis

Types of Space Threats

1) *Deception*: Target reports incorrect information.
2) *Disruption*: Target's capability temporarily degraded.
3) *Denial*: Target's capability temporarily disabled.
4) *Degradation*: Target's capability degraded irreparably.
5) *Destruction*: Complete loss of target spacecraft.

Indiscriminate



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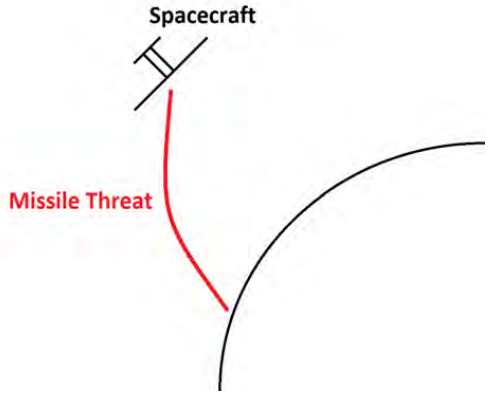
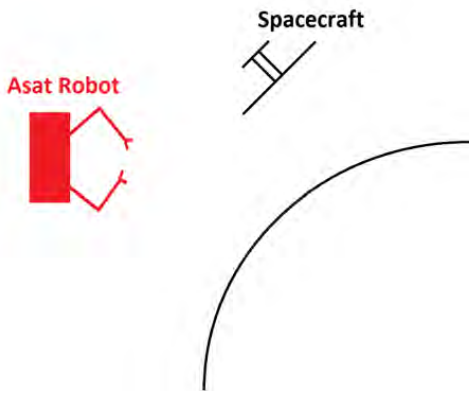


Co-orbital



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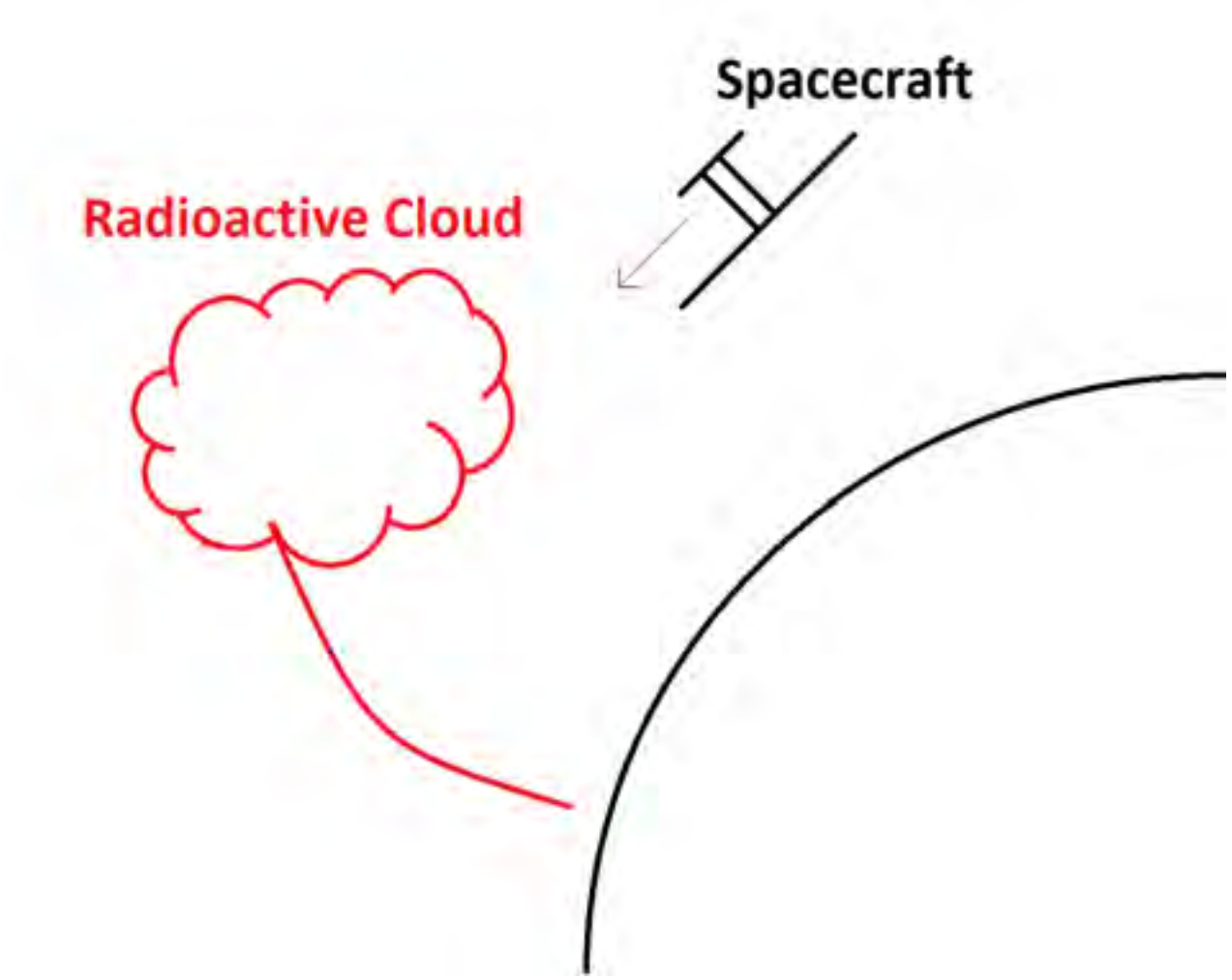
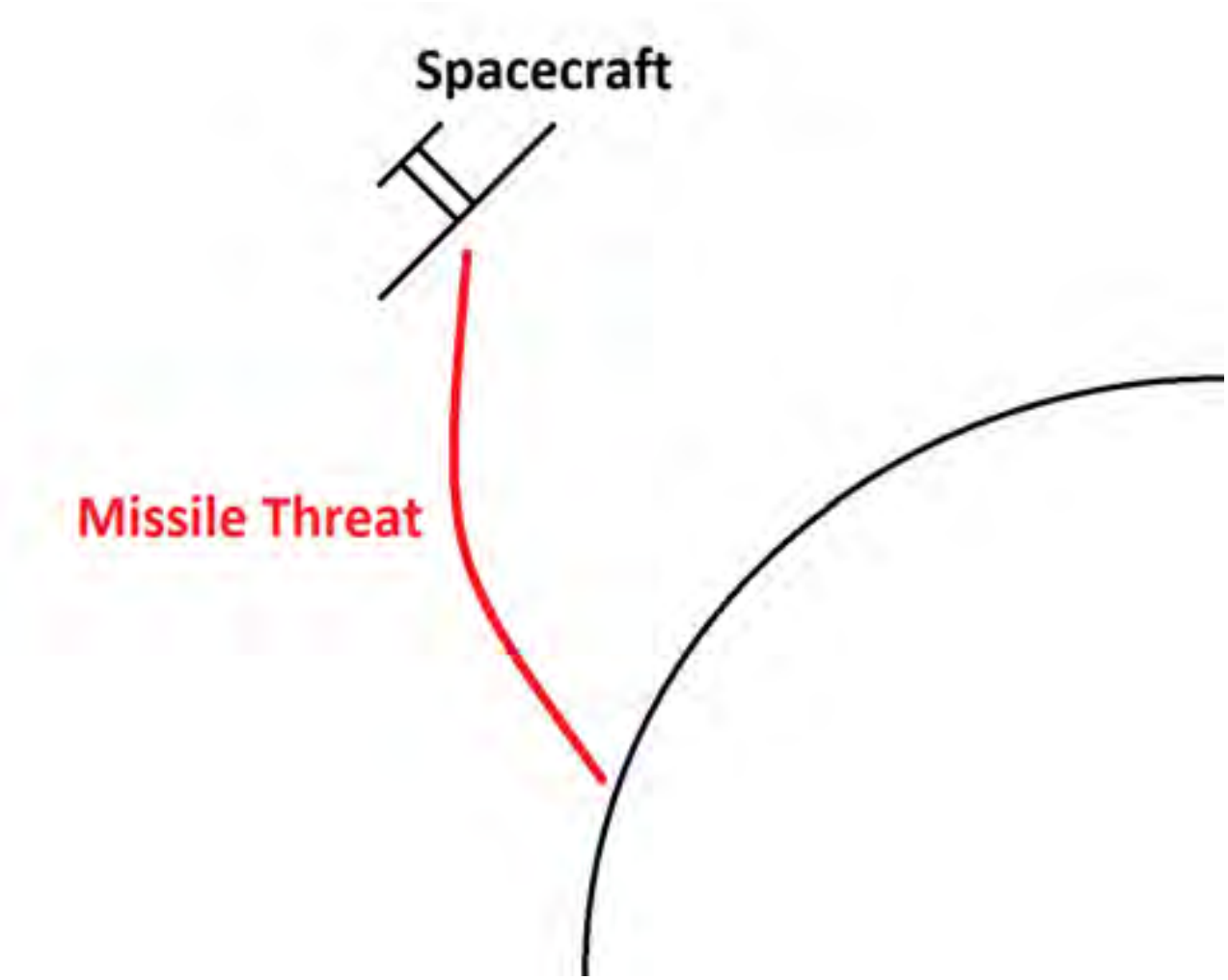


Indiscriminate

List of spacefaring countries.

Country	Satellites	Nuclear
United States	1551	Y
Russia	1497	Y
China	251	Y
Japan	168	N
India	84	Y
France	69	Y
Israel	17	N
North Korea	8	Y
Iran	1	N

Directed



Directed Examples

United States:

- *Historic*: ASM-135 Air Launched direct ascent anti-satellite missile. Demonstrated in 1985.
- *SM-3 Missile*: Successfully destroyed a satellite in low earth orbit in 2008.

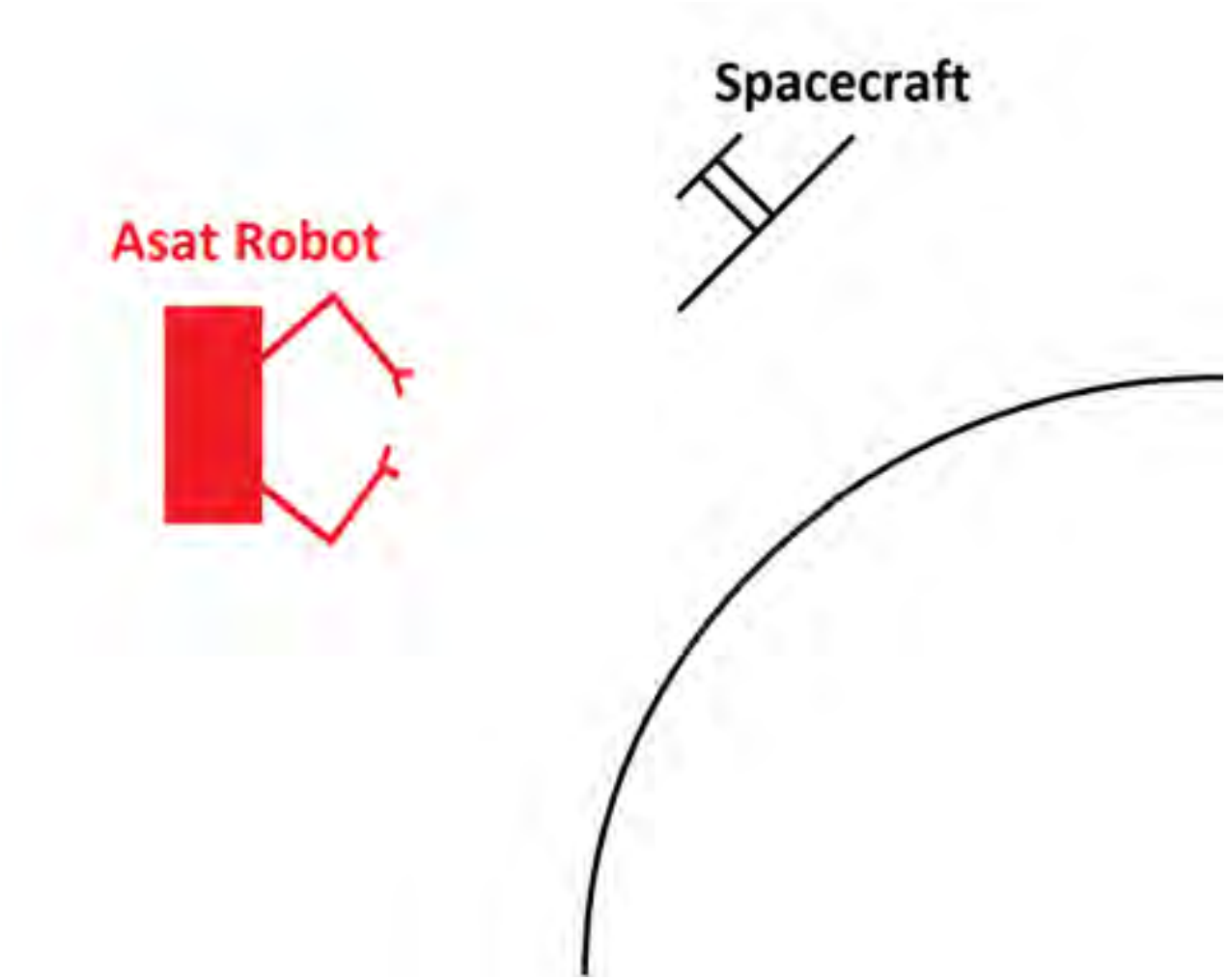
Russia:

- *Nudol LEO*: A direct ascent anti-satellite missile.
- *Kontakt LEO*: An air launched direct ascent anti-satellite missile.
- *S-500 LEO*: A BMD system with secondary applications as an anti-satellite missile.

China:

- *SC-19 LEO*: First tested in 2005, used in the 2007 ASat demonstration.
- *Unnamed GEO*: Hypothesized to have been tested in 2013.

Co-orbital



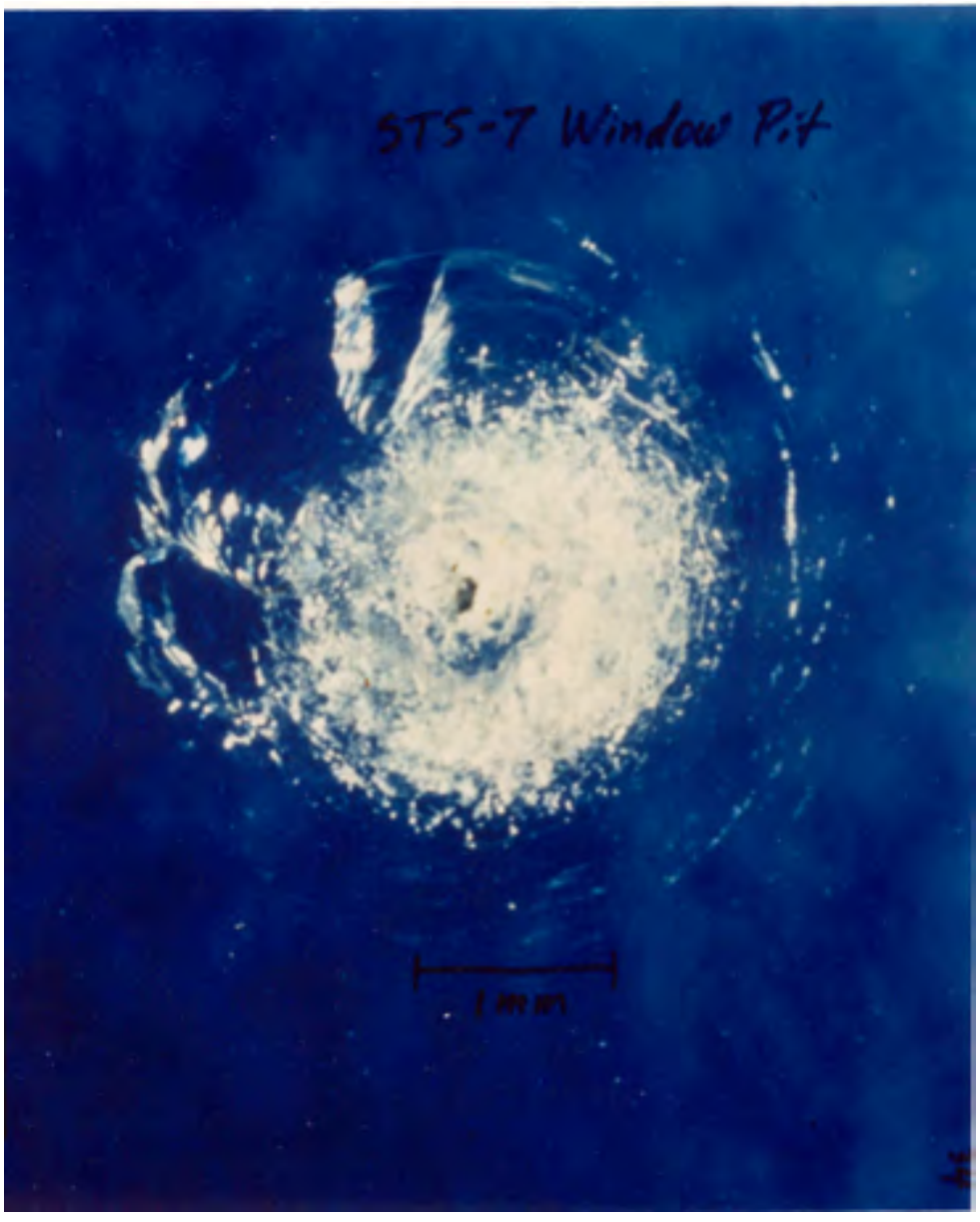
Co-orbital Examples

Dual-use Technology

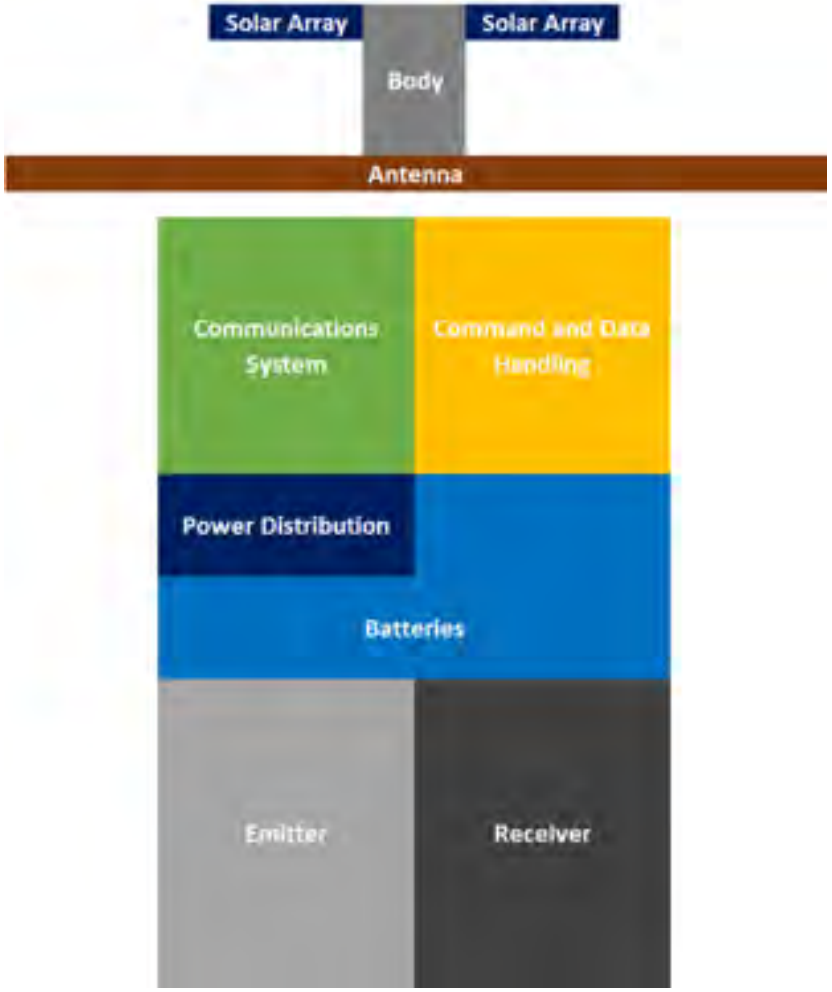
- Any spacecraft capable of rendezvous can be hazardous.
- Significant government, industry and educational investigation.
  - Satellite Servicing
  - Orbital Debris Mitigation
  - Formation Flight
  - On-orbit Construction
- Ultimately must be governed by action, not design characteristic.

Vulnerability Analysis

Impacts



Component Location



Vunerability

Spacecraft are very vulnerable to most threats:

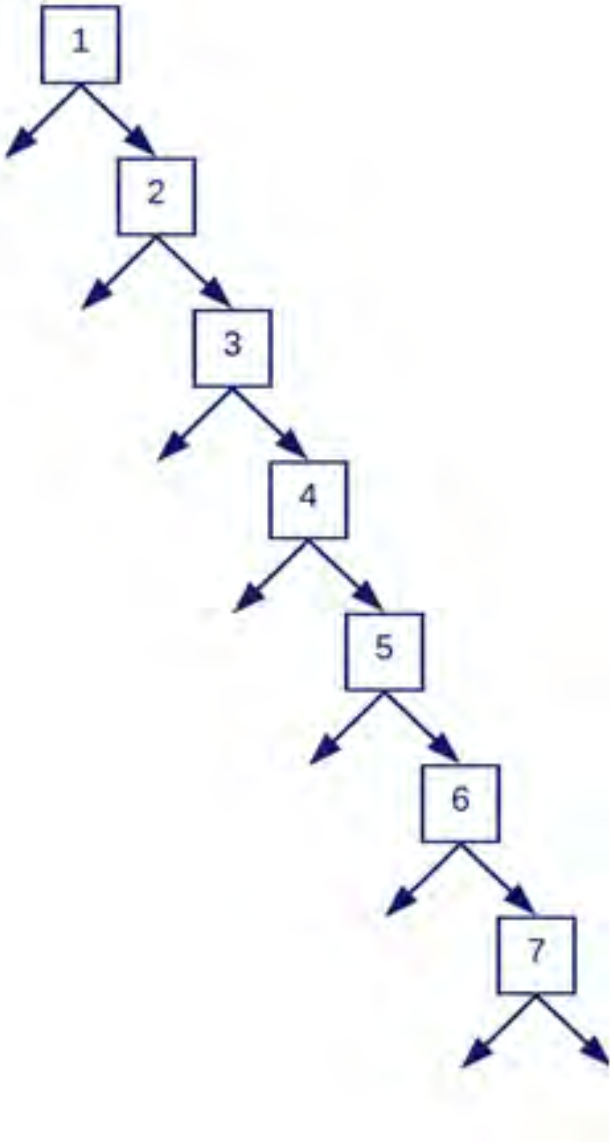
- *Missiles*: Any impact to the spacecraft will most probably be fatal.
  - $P_{K|H} = 1$
- *Robots*: Any contact with the spacecraft can certainly be fatal.
  - $P_{K|H} = 1$
- *Radiation*: Spacecraft are hardened against radiation and EMPs, as they face them in their natural environment. Any increase in ambient radiation will proportionally decrease the lifetime of the system.
  - $P_{K|H} = 0.3$

Vulnerability Summary

Component	Indiscriminate	Directed	Co-Orbital
C&DH	Y	Y	Y
Comms	Y	Y	Y
ADCS	Y	Y	Y
EPS	Y	Y	Y
Frame	N	Y	Y
Antenna	N	Y	Y
Solar	Y	Y	Y

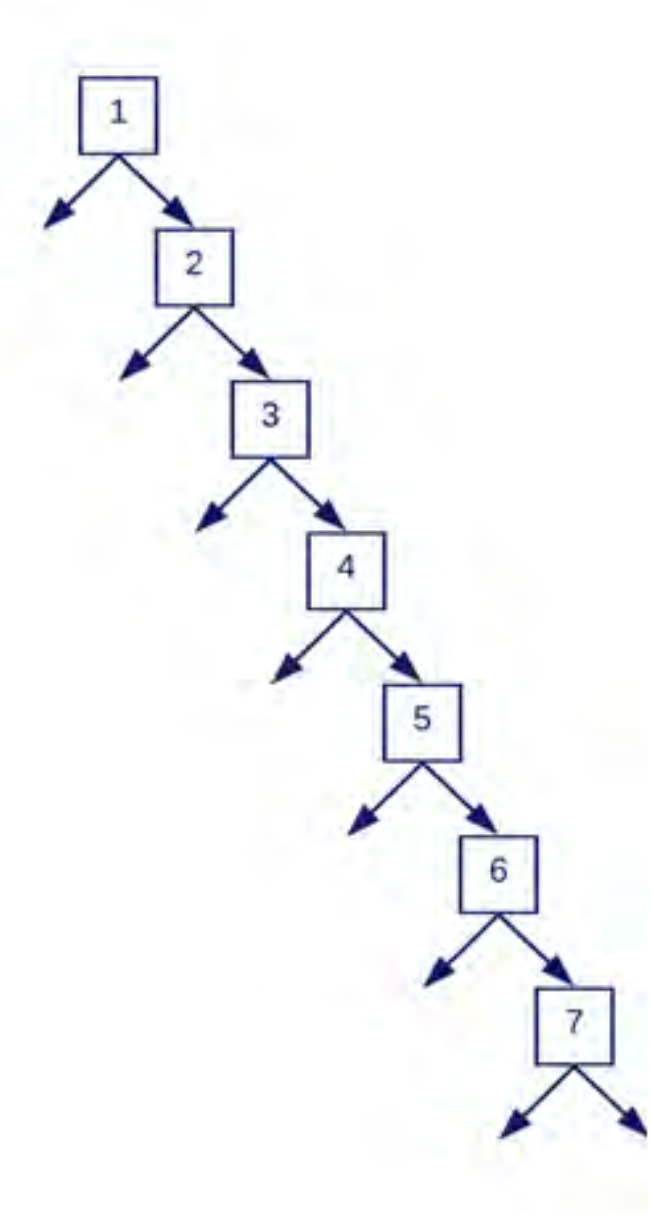
Susceptibility Analysis

Indiscriminate



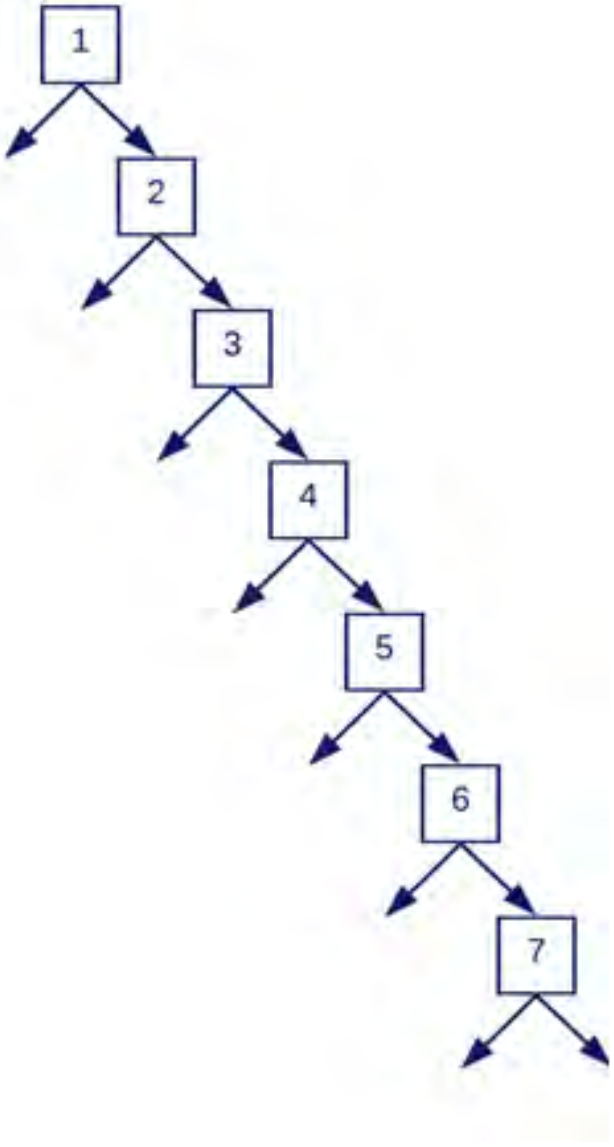
#	Essential Event
1	Enemy determines that space assets are in use.
2	Enemy willing to deny space to all users – including potential allies.
3	Enemy determines what optimal altitude is for deployment.
4	Missile motor functions.
5	Missile guidance system functions.
6	Warhead operates correctly.
7	Spacecraft flies into radiation.

Directed



#	Essential Event
1	Enemy determines that space assets are in use.
2	Spacecraft detected by ground.
3	Enemy determines spacecraft orbit and optimal location for interception.
4	Missile motor functions.
5	Missile guided to location the space-craft is expected to arrive.
6	Warhead intercepts satellite.
7	Impactor or fragments hit spacecraft.

Co-orbital



#	Essential Event
1	Enemy determines that space assets are in use.
2	Spacecraft detected by ground.
3	Enemy determines the spacecraft orbit and the optimal location for co-orbital interception.
4	Enemy tasks orbiting asset.
5	Enemy asset enters same orbit.
6	Orbiter intercepts satellite.
7	Orbiter disables spacecraft.

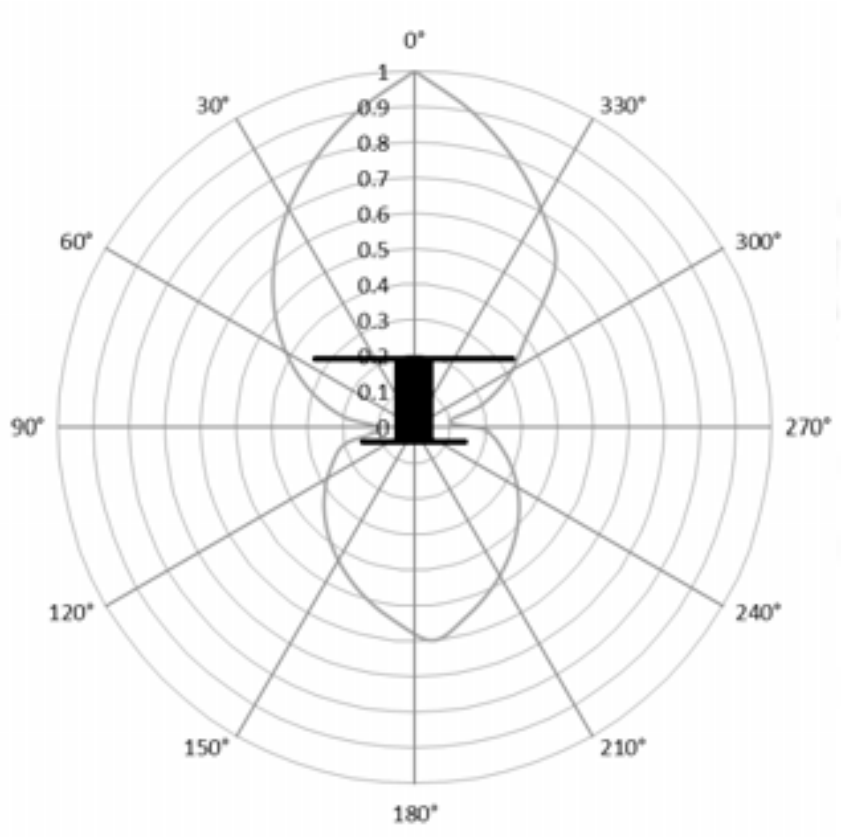
Opportunities for Improvement

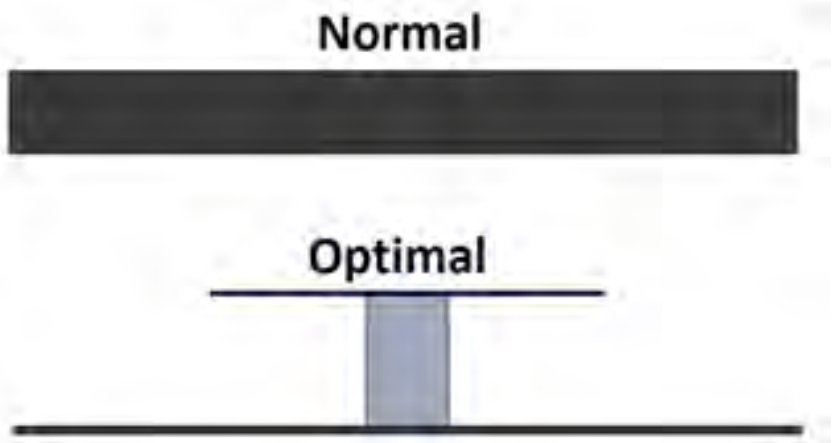
Factors

Driving design parameters:

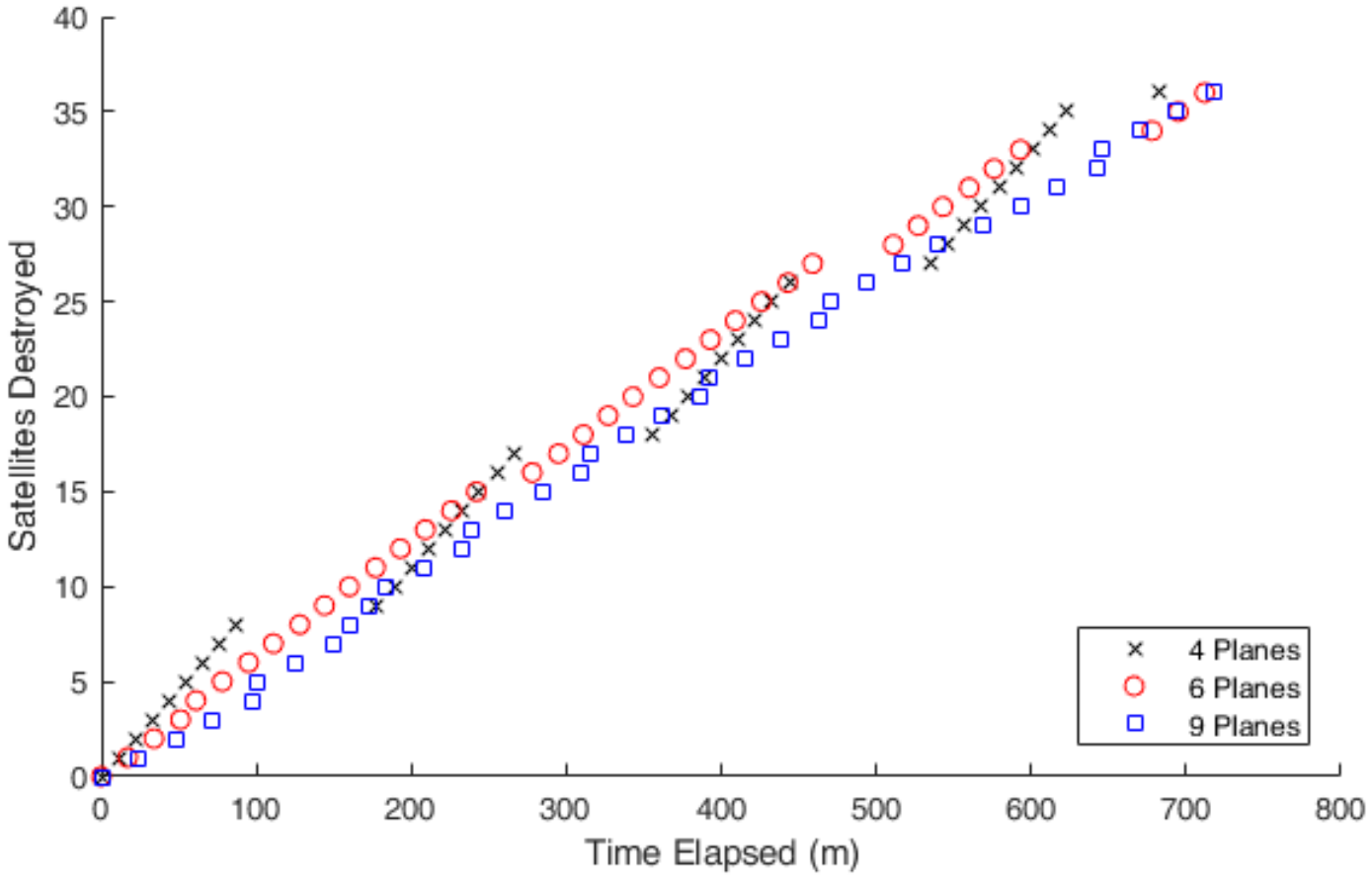
- Spacecraft's detectability.
  - Electro-optics
  - Radar
  - Infared
- Orbit Design.
  - Altitude
  - Planes
- Ability to detect and deter aggression.
  - Attribution
  - Response

Detectability



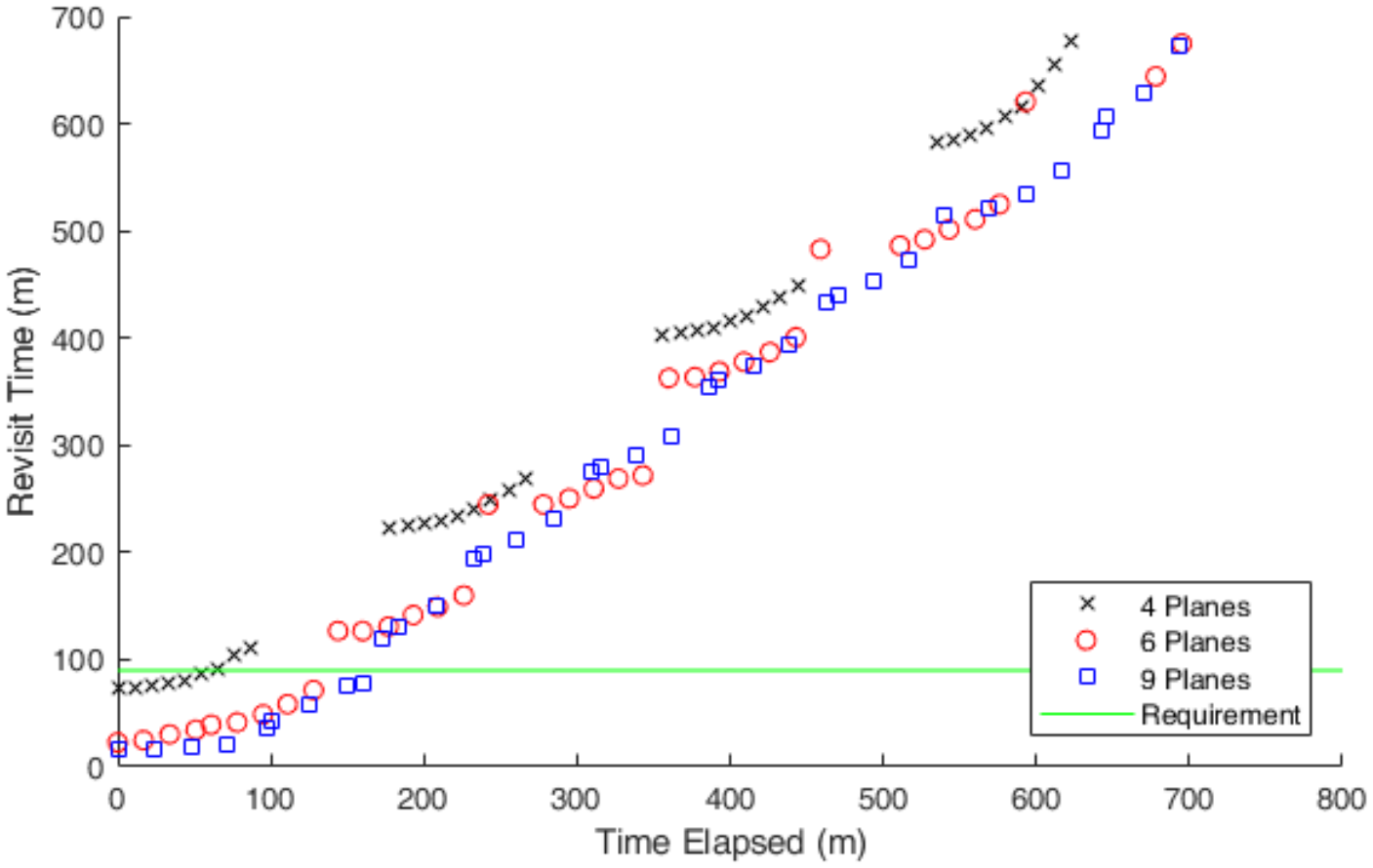


Orbit



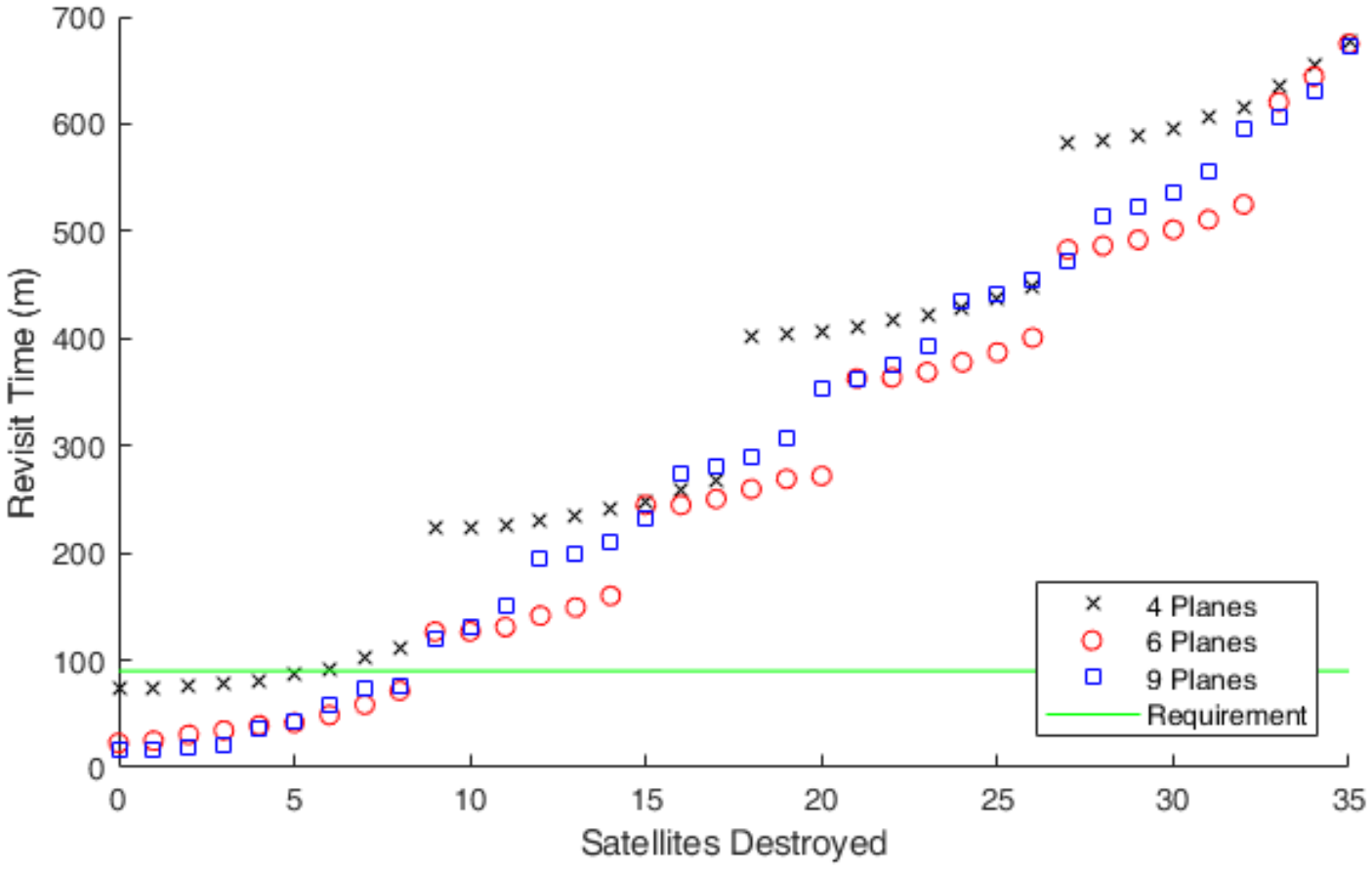
Spacecraft destroyed vs time.

Orbit



System revisit time compared to the engagement time.

Orbit



System revisit time vs number of spacecraft destroyed.

STK Results

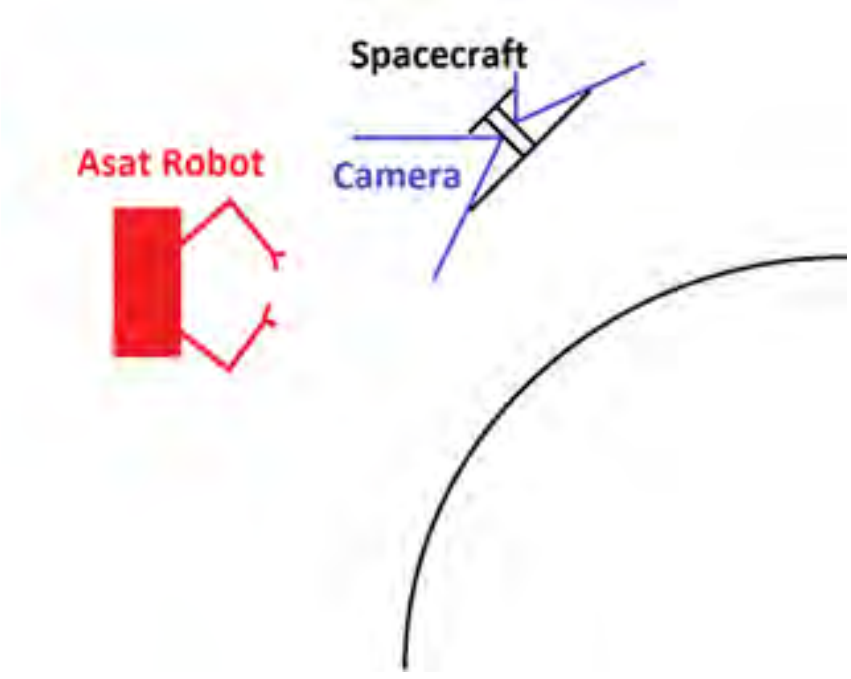
STK orbital analysis result.

Planes	Cost ($M)	Initial (min)	(S.C.)	(Time)
4	40	73	5	55
6	60	23	8	144
9	90	17	8	173

Deterence

Space Situational Awareness:

- *Across Domain*:
  Identify and track hostile actors.
- *On-board*:
  Distinguish between natural and hostile action.
- *Design*:
  Protect ground service ports.



Defensive Systems
Established Policy

Conclusion

Conclusion

A recommended constellation consists of spacecraft that are:

- Deployed in six orbit planes.
- Programmed with radar cross section reduction maneuvers in the event of anticipated hostile action.
- Equipped with a system of situational awareness cameras.

Even with SmallSat, it is still worth considering survivability as part of the design.

- Lower cost does not mean the capability is less important.
- Access to effective ASat weapons will only increase.
- Small changes can have an effect.

Principal advantage over large satellites:

- Distributed costs.
- Easy replenishment.
- Unusual orbit configurations.

Further Reading:

- *Threats*: Global Counterspace Capabilities: An Open Source Assessment, Secure World Foundation, April 2018
- *Survivability*: Fundamentals of Aircraft Combat Survivability Analysis and Design

Questions?

Edward Hanlon
eahanlon@nps.edu
443-775-0241