Aerospace Technology Gaps and the U.S. Space Force

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Agenda

Executive Summary

Research Objectives/Methodology

USSF Mission/Goals

In-Space Propulsion

Satellite Communications

Conclusion/Recommendations
Executive Summary

• In this presentation, we will be analyzing the needs for the future of the U.S. Space Force.
  – how the aerospace industry can develop to fulfill those needs

• We have developed a methodology that initially identified the present and future technology gaps for the Space Force.
  – After recognizing gaps in current technology, our motivation was to find how the aerospace industry is planning to advance
  – Our research encompassed two specific aerospace technologies that are vital for the Space Force
Research
Objectives/Methodology
Approach and Outcomes

● Identify the strategic objectives of the USSF
  ○ From Space Force Documentation

● Create a methodology to best determine technology gaps
  ○ Critical evaluation of available/conceptual technology in a chosen discipline
  ○ Tested on the following fields:
    ■ In-Space Propulsion
    ■ Satellite Communications

● Provide USSF with recommendations
Methodology

1. Derive USSF Objectives
   • From global trends & USSF documentation
2. Create Hypothesized Mission Profiles
   • Thought exercise to help relate USSF objectives to current technology
3. Infer Technology Needs
4. Research and Analyze Current/Emerging Technology
5. Synthesize the individual capability/need mismatches between steps (3) and (4) into technology gaps
USSF Missions/Goals
Global Trends

• Post Cold War: international collaboration in the space domain (ex. ISS)
  – This period appears to be ending
  – Trending toward factionalism
• Russian government still has strong presence in space
• China’s influence is spreading across Asia
  – Rapid development of in-space capabilities
• Potential Chinese-Russian cooperation
• Competition between US, Russia, and China on in-space activities is likely.
Space Force Objectives*

- Space Superiority
- Space Domain Awareness
- Space Support to Operations
- Space Mobility and Logistics
- Information Mobility

*Document: Comprehensive Plan for the Organizational Structure of the U.S. Space Force
Hypothesized Mission Profiles

• Protect USSF space assets from hostile threats
  – Kinetic, Laser, Electronic, Cyber Warfare
  – May require rapid response
• Initiating in space offensive maneuvers
  – Blind, disable, or even destroy a target spacecraft
• Planetary and non-planetary surveillance
• Transportation of crews and equipment to, from, and across cislunar space
  – Generally requires larger spacecraft
• Defend commercial/private spacecraft
  – Preserve freedom of action/ensure in-space safety
In-Space Propulsion
General Requirements

1. Impulsive Maneuvers
   • Required thrust dependant on a spacecraft’s mass
   • Essential for offensive/defensive maneuvers, transportation

2. Attitude Controls/Orbital Maintenance
   • Attitude control important to complete in-space missions
     – Note: Attitude Control can be done with reaction wheels
   • Orbital maintenance required to correct prevent orbital drift

3. Longevity
   • Spacecraft’s lifespan exceed its mission length (10+ years)
   • Fuel requirements often a limiting factor

4. Deorbiting Ability
   • Necessary to prevent accumulation of space debris
Technology

Chemical Propulsion
• Typically used on medium/large spacecraft
  – Well-understood, flight-demonstrated
• Capable of high thrust, but comparatively low $I_{sp}$

Electric Propulsion
• Often used for small spacecraft and deep-space missions
  – Some methods are well understood (HETs)
  – Currently lots of innovation in this field
• High $I_{sp}$, but intense power requirements limit thrust

Nuclear Propulsion
• Use of fission/radioisotopes to (in)directly provide thrust
  – Early stages of development
• Nuclear Thermal: high $I_{sp}$ and thrust for in-space applications
• Nuclear Electric: used in conjunction with electric propulsion
Thrust

- Higher thrust leads to faster maneuvering
- Larger mass -> lower acceleration

Specific Impulse ($I_{sp}$)

- Increases thrust by increasing exhaust velocity
- Higher $I_{sp}$ leads to less fuel consumption
Fulfillment of Individual Needs

1. Impulsive Maneuvers (Met)
   - Variety of chemical propulsion technologies (bipropellants) meet this need
   - Small spacecraft can use electric propulsion
   - Nuclear Thermal a great option with development, high $I_{sp}$

2. Attitude Control/Orbital Maintenance (Met)
   - Monopropellants, cold gas, electric propulsion are effective options

3. Longevity (Met)
   - Reducing fuel consumption (increasing $I_{sp}$) is key
     - High $I_{sp}$ electric systems such as HETs and Gridded Ion are great solutions
   - Nuclear Propulsion also offers impressive $I_{sp}$

4. Deorbiting Ability (Met)
   - Aerodynamic Drag, Electrodynamic tethers can be used in cislunar space
     - Uncontrolled Solution
   - Electric propulsion systems also an excellent, controllable option
Synthesis of Needs

1. Impulsive Maneuvers & Longevity (Not Met)
   - Electric Propulsion meets both needs for small spacecraft
   - Larger spacecraft generally require chemical propulsion
     - Requires in-space refueling
   - Nuclear Thermal is a potential future solution

2. Attitude Controls/Orbital Maintenance & Longevity (Met)
   - Electric propulsion fulfills this need; chemical propulsion does not
     - Low thrust requirement means these systems can be very efficient

Takeaway: the lack of high thrust, high $I_{sp}$ solutions is the most significant propulsion technology gap the USSF is facing.
Satellite Communications
General Requirements

1. Security and Confidentiality
   • Prevent access to information

2. Information Mobility
   • Reliability of transmissions
   • Rapid timing of transmissions
   • Ability to respond to threats swiftly and seamlessly

3. Resiliency
   • Maintain communications in all operating environments
   • Diversified and proliferated satellite communication capabilities
Technology

RF Communication
• Conventional method of SATCOM
• Responsible for majority of communications today

Optical Communication
• Newer, promising method of SATCOM

Data Processing
• Set of technologies responsible for sending, receiving, and interpreting communications
Fulfillment of Individual Needs

1. Security and Confidentiality (Met)
   • Current technology like Protected Tactical Waveform offers secure communication capabilities
   • Could be improved with innovation in quantum cryptography

2. Information Mobility (Not Met)
   • An ever increasing demand for bandwidth requires improvements upon conventional RF technology to combat spectrum congestion
   • With further development, optical communication and the use of higher frequency bands could meet requirement

3. Resiliency (Not Met)
   • MILSATCOM currently relies on a small number of large multipurpose satellites
   • Disaggregation could meet requirement by providing redundancy and target diversity
Synthesis of Needs

1. Security and Confidentiality/Information Mobility (Not Met)
   • Protected communication is currently very limited in capacity
   • Optical communications are more secure than RF communications and more readily deployed

Takeaway: The lack of widespread protected communications is a significant problem facing the USSF
Conclusion/Recommendations
Summary: Propulsion

Conclusions

• Modern technology adequate to fulfill most USSF objectives
• Large spacecraft limited by fuel requirements

Recommendations

• Focus on small spacecraft development in the short term
  – Can meet our longevity requirement via electric propulsion
• Invest in Nuclear Thermal Propulsion research
  – Eventually large spacecraft will be necessary
  – Even with nuclear propulsion, in-space refueling will eventually be necessary
Summary: Communications

Conclusions
• RF spectrum congestion and increasing bandwidth demands pose big problem
• Advancements in optical communications or higher frequency bands are necessary to meet requirements
• Older space systems that prioritize size and capability are high-value, easily identifiable targets

Recommendations
• Focus attention on development of antenna technology to cover new frequency bands (including optical frequencies)
  – Cost, power consumption, miniaturization, efficiency
  – Promising techs include metamaterial, 3D-printed, and fractal antennas
• Implement disaggregation sooner rather than later
  – Redundancy, target diversity
Learning Outcomes

During Research:

• More involved in current events regarding space policy
• Understanding the urgency of space security
• Assessing applications of aerospace technologies to Space Force needs
• Forming hypotheses and utilizing documentation to develop an informed viewpoint

Follow-Up:

• Continue to stay updated with current events
• Apply this research method to other technologies
• Applying knowledge to our aerospace careers
• Using what we learned as motivation for our studies
• Informing others and seeking knowledge from professionals
Thank you!

Questions, comments, concerns?
Discussion

We are writing a research paper which covers these points in more detail.

• What technology is the aerospace industry lacking on the most? What developments need to be made with that technology?
• What research methods would help our analysis?
• Are there any resources you would recommend for learning more about the needs of the Space Force?
• What are some emerging threats that the aerospace industry has not begun to address yet?