**Slide 1: Introduction**

* **Title:** Space Debris Removal Satellite Constellation Design
* **Subtitle:** Ensuring Safe and Sustainable Space Operations
* **Introduction:**
  + "This presentation outlines the design approach for a constellation of satellites dedicated to active space debris removal. Our aim is to enhance the long-term sustainability of space activities by addressing critical debris issues while implementing best practices from the Orbital Debris Mitigation Standard Practices (ODMSP)."

**Slide 2: Mission Overview**

* **Objective:**
  + "Deploy a constellation of satellites to systematically identify, capture, and deorbit debris, focusing on high-risk regions in low Earth orbit (LEO)."
* **Mission Goals:**
  + "1. Debris Reduction: Actively remove 10% of priority debris items annually. 2. Risk Mitigation: Reduce collision risk for operational satellites. 3. Technology Demonstration: Validate debris capture and deorbit technologies."

**Slide 3: Work Breakdown Structure (WBS)**

* Definition:
  + "This structured breakdown details the essential tasks required to implement a satellite constellation for active debris removal, ensuring mission objectives are met efficiently."
* **Components:**

**1.** **Constellation Design: Focuses on defining mission requirements, optimizing satellite orbits, and designing communication networks to support debris interception.**

* System Engineering: Define mission requirements and constraints, develop architectural designs, and conduct trade studies.
* Orbital Mechanics: Determine optimal orbits for debris interception using trajectory analysis.
* Network Architecture: Design a robust communication network for inter-satellite and ground communication.

**2.** **Manufacturing: Involves building satellite hardware, integrating sensors for debris detection, and ensuring subsystem compatibility during assembly.**

* Satellite Fabrication: Develop custom frames and enclosures capable of housing all necessary systems securely.
* Sensor Integration: Equip satellites with sensors for debris detection and characterization.
* Assembly & Integration: Integrate subsystems, ensuring mechanical, thermal, and electrical compatibility.

**3. Ground Systems: Establishes communication links and control protocols to manage satellite operations and support autonomous decision-making.**

* Communication Infrastructure: Establish reliable uplink and downlink capabilities, integrating with existing ground station networks.
* Control Systems: Develop command and control protocols for satellite operations, including autonomous decision-making support.

**4. Testing and Validation: Conducts comprehensive subsystem tests and mission simulations to verify performance, accuracy, and capture strategies.**

* Subsystem Testing: Conduct unit and integration tests on propulsion, navigation, and capture mechanisms.
* Mission Simulations: Execute simulated missions to validate capture strategies and navigation accuracy.

**5. Deployment and Operations: Manages launch logistics, integrates with global tracking systems, and performs debris capture and deorbit operations.**

* Launch Planning: Coordinate launch schedules, vehicle selection, and deployment strategies.
* Debris Tracking: Integrate with global debris tracking networks to maintain updated situational awareness.
* Removal Operations: Execute planned capture and deorbit operations, utilizing coordinated maneuvers to optimize efficiency.
* Detail:
  + "Each component involves detailed tasks, such as subsystem prototyping (modeling and testing capture devices), detailed interface testing (validating communications and control systems), and integration of algorithms for real-time autonomous operations. This structured approach ensures that each satellite functions effectively within the broader debris removal mission."

The content provides a clear breakdown of the key elements needed for a constellation focused on debris removal, referencing typical processes and elements that might be emphasized in comprehensive resources like SMAD. It's designed to communicate effectively on a slide while inviting deeper exploration into each stage for stakeholders interested in specifics.

**Slide 4: Concept of Operations (ConOps)**

**Deployment to Orbit**

* The constellation will be launched via the SpaceX Rideshare Program, leveraging its Falcon 9 Transporter missions to ensure cost-effective and frequent deployment.
* Satellites will be initially deployed into a 500 km Sun-synchronous orbit (SSO), optimizing coverage for global debris tracking.
* After deployment, each satellite will perform a series of orbital maneuvers using onboard propulsion to lower its altitude into an operational Low Earth Orbit (LEO) between 400-450 km, balancing mission longevity with debris capture efficiency.

**Operational Phase (10-Year Mission)**

1. Scanning & Identification:
   * The satellite will use onboard radar and optical sensors to scan and track orbital debris.
   * Advanced algorithms will analyze debris size, trajectory, and collision risk.
   * Targets will be prioritized based on mass, velocity, and potential impact to active space assets.
2. Debris Capture:
   * Once a target is identified, the satellite will conduct a rendezvous maneuver to align with the debris.
   * Capture mechanisms such as robotic arms, nets, or electrodynamic tethers will secure debris for controlled disposal.
3. Deorbiting Process:
   * Using onboard propulsion, the satellite will perform a controlled deorbit burn, lowering both the debris and itself into a trajectory ensuring atmospheric re-entry.
   * For larger debris, the system will release it into a decay orbit where atmospheric drag will facilitate a natural burn-up.

**End-of-Life & Decommissioning**

* After a 10-year operational period, satellites will either:
  + Self-deorbit using remaining propulsion to ensure compliance with the Orbital Debris Mitigation Standard Practices (ODMSP).
  + Transition into a graveyard orbit if deorbit is not immediately feasible.

**Slide 5: Orbit Design**

* **Initial Orbit:**
  + **Altitude (500-800 km Range):**
    - This range is ideal because most debris in **Low Earth Orbit (LEO)** is concentrated here, particularly from defunct satellites, upper stages, and collision fragments.
    - **500 km** is favorable for easier **deorbiting** due to increased atmospheric drag. **800 km** offers **wider coverage** but requires more fuel to remove debris.
    - By staying within this altitude range, you balance **accessibility** to debris and **fuel efficiency** for both capture and deorbiting.
  + **Inclination (82-98 degrees):**
    - This range encompasses **polar and Sun-synchronous orbits (SSO)** where much of the debris exists due to **Earth observation, remote sensing, and scientific missions**.
    - Limiting your focus to debris with the **same inclination** simplifies rendezvous maneuvers because the **relative inclination difference** is small or zero, reducing **ΔV** requirements for plane changes (which are fuel-intensive).
    - For **Sun-synchronous orbits (~97.4°)**, your satellite can maintain a constant Sun angle, providing consistent lighting conditions for **debris detection**.
* **Maneuver Plans:**
  + **Dynamic Orbital Adjustments:**
    - Your satellites will use **small ΔV burns** to modify **semi-major axis** (altitude) and **true anomaly** (position along the orbit) to approach debris.
    - Since the inclination is fixed, **in-plane maneuvers** (raising/lowering altitude) are the most efficient, using either:
      * **Hohmann Transfers** for altitude changes.
      * **Phasing Maneuvers** to synchronize with debris by adjusting the satellite’s orbit period.
  + **Micro-Maneuvers for Collision Avoidance:**
    - Satellites can execute precise, small burns for **conjunction avoidance**, ensuring compliance with collision risk management standards.
    - These burns can also **fine-tune** the approach to the debris without significant fuel penalties, especially in the same inclination plane.
* **Debris Capture Strategy**
  + Same inclination targeting
    - Restricting to debris in the same inclination minimizes the need for costly **plane changes**.
    - You can perform **co-orbital rendezvous**, where you only adjust altitude and relative position, which requires much less ΔV.
    - This allows for **multiple debris captures** within the same orbital plane, increasing mission efficiency.
  + Capture
    - **Netting or Harpoons** for large, stable debris.
    - **Electromagnetic tethers** or **contactless manipulation** for small or fragile debris.
    - **Drag augmentation** to speed up natural deorbiting for non-captured items.
* Deorbiting Process
  + After capturing debris, the satellite will execute a **retrograde burn** to lower its perigee into the **denser atmosphere** (typically below 300 km) for rapid re-entry.
  + For large debris, a **passive drag device** (e.g., an inflatable sail) could assist in ensuring it burns up safely.
  + Maintaining the **same inclination** during deorbit simplifies the trajectory calculation and reduces the risk of creating secondary debris.

**Slide 6: Volume, Mass, Power, and Cost (VMPC) Budgets**

* **Volume Budget:**
  + "Each satellite designed for compactness, fits within a microsatellite platform (approx. 50 cm x 50 cm x 50 cm) to reduce launch costs."
* **Mass Budget:**
  + "Total mass per satellite: 100 kg, structured as:
    - Capture Mechanism: 30 kg
    - Propulsion and Power: 40 kg
    - Avionics and Communication: 30 kg"
* **Power Budget:**
  + "150 watts generated via deployable solar arrays, with peak use reserved for capture operations and communication bursts."
* **Cost Budget (Components):**
  + "Each satellite costs approximately 1million,comprisingcapturetech(1*million*,*comprisingcapturetech*(300k), propulsion (400k),andsensors/communication(400*k*),*andsensors*/*communication*(300k)."

|  |  |
| --- | --- |
| **Subsystem** | **Volume (cm^3)** |
| **Bus** | 25,000 |
| **Capture Mechanism** | 15,000 |
| Capture Unit | 10,000 |
| Sensors and Cameras | 5,000 |
| **Propulsion System** | 15,000 |
| Propulsion Units | 10,000 |
| Fuel Tanks | 5,000 |
| **Avionics and Communication** | 20,000 |
| Onboard Computer | 5,000 |
| Sensors | 10,000 |
| S-Band | 5,000 |
| **Total** | **125,000** |

|  |  |  |
| --- | --- | --- |
| **Component** | **Mass (kg)** | **Percentage of Total Mass** |
| **Satellite Bus** | **25** | **25** |
| Structure | 18 |  |
| Thermal Control | 7 |  |
| **Capture Mechanism** | **30** | **30** |
| **Propulsion and Power** | **30** | **30** |
| Power System | 12 |  |
| Propulsion System | 18 |  |
| **Avionics and Communication** | **15** | **15** |
| ADCS | 6 |  |
| Onboard computer | 6 |  |
| S-Band | 3 |  |
| **Total** | **100** | **100** |

|  |  |
| --- | --- |
| **Power System** | **Power Consumption (W)** |
| Solar Arrays | 80 |
| Batteries | 20 |
| Power Management | 20 |
| Propulsion System | 30 |
| **Total Power Cost** | **150** |

|  |  |
| --- | --- |
| **Subsystem** | **Cost ($)** |
| **Bus** | **120,000** |
| **Capture Mechanism** | **250,000** |
| Capture Unit | 75,000 |
| Sensors and Cameras | 5,000 |
| **Propulsion and Power** | **350,000** |
| Fuel and Propellant | 40,000 |
| Propulsion Units | 180,000 |
| Power System (Solar Arrays and Battery) | 130,000 |
| **Avionics and Communication** | **280,000** |
| Onboard Computer | 90,000 |
| ADCS | 100,000 |
| S-Band | 5,000 |
| **Total** | **1,000,000** |

|  |  |
| --- | --- |
| **Additional Cost** | **Cost ($)** |
| Labor and Assembly | 2,000,000 |
| Testing and Validation | 2,000,000 |
| Operation and Communications | 1,500,000 |
| Contingency | 50,000 |
| Rideshare | 650,000 |
| **Total Cost** | **6,200,000** |

**Slide 7: Comprehensive Cost Budget**

* **Components Plus Additional Costs:**
  + "Total mission cost projected at $50 million:
    - Satellite fabrication and components: $10 million
    - Launch services: $30 million
    - Ground system development: $5 million
    - Operations and data analysis over mission life: $5 million"
* **Financial Planning:**
  + "Contingency reserves set at 15% to accommodate unforeseen technical challenges or market variations."

**Slide 8: Design Considerations for Debris Mitigation**

* **ODMSP Integration:**
  + "Our design is deeply aligned with ODMSP as we proactively reduce debris.
    - Minimize any secondary debris during operations by using controlled capture and deorbit methods.
    - Ensure operational protocols limit risk of collision and accidental explosions."
* **Technological Innovations:**
  + "Innovations include adaptive navigation systems for high-dexterity debris capture and AI-driven decision-making for synchronous satellite cooperation."

**Slide 9: Challenges and Risks**

* **Identification:**
  + "Challenges and risks include:
    - High precision required for capture operations.
    - Coordinating maneuvers in increasingly congested space regions.
    - Ensuring reliability and durability of capture systems during orbit lifetime."
* **Mitigation Strategies:**
  + "Strategies involve:
    - Incremental testing and validation of capture and deorbit techniques.
    - Use of machine learning to enhance autonomous decision-making.
    - Developing robust communication and coordination frameworks across the constellation."

**Slide 10: Conclusion**

* **Summary:**
  + "Our constellation project strategically addresses the growing issue of space debris with innovative technologies and rigorous adherence to international mitigation practices."
* **Future Outlook:**
  + "We anticipate scaling the constellation and improving technology post-mission to address medium Earth orbits (MEO) and expand to include broader international collaboration."
* **Q&A:**
  + "Thank you. Please direct your questions or requests for further information to [Contact Information]."