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CONFIGURATION TRADES FOR A SPACE OBJECT SURVEILLANCE FENCE

18th Space Control Conference

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Objective

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- To Clarify Basic Concepts Regarding Space Surveillance Fences
- We Will Look at
  - Mission and Requirements
  - Ways and Means to Meet the Mission
  - RF Concepts and Waveforms
  - Microwave Sensor Concepts
- Our Measures of Merit (MoMs) are
  - Meeting the Mission
  - Cost
    - » Initial non-recurring
    - » O&M and life cycle costs
  - Risk
    - » Performance
    - » Cost
    - » Schedule

Mission and Requirements

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- Mission Derived from Multiple Sources
  - USSPACECOM -- NORAD Catalog Support, Debris Monitoring
  - AFSPACECOM, Army -- Support Space Order of Battle
  - NAVSPACECOM -- Support Fleet Needs
  - Chambered Round
  - NASA -- Safety
    - » International Space Station (ISS)
    - » Space Shuttle
    - » Other Spacecraft
- Requirements
  - Catalog Maintenance
    - » See Most Objects Twice a Day
    - » Object Sizes 0.3 Meters and Larger
    - » Very High Probability of Intercept on First Pass
  - Debris Monitoring -- Count Objects Down to 1 cm in Size

Mission to 2010 Time Frame

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- Increase in Number of Objects
  - Current VHF Fence “sees”
    - » 45 Objects per Minute (1994)
    - » 70% of Catalog Objects
    - » 100% of LEO Objects with Inclination Over 33 Degrees
    - » 150 Objects Seen by No Other Sensor
    - » Source: NAVSPACECOM /N32 Brief, 25 June 1994, available at http://www.fas.org/spp/military/program/track/navspace.htm
  - Number of Objects
    - » Has Increased Linearly Since 1960
    - » Object Flux Projected to Remain Steady Through 2020
- Coming Change in Mission
  - Space Shuttle Protection -- Threshold Probability for Serious Damage per Mission is Now 0.5%
  - International Space Station (ISS) Protection -- Equivalent Exposure in 1 Year on Station to All Space Shuttle Missions to Date

Historical Number of Object Versus Time

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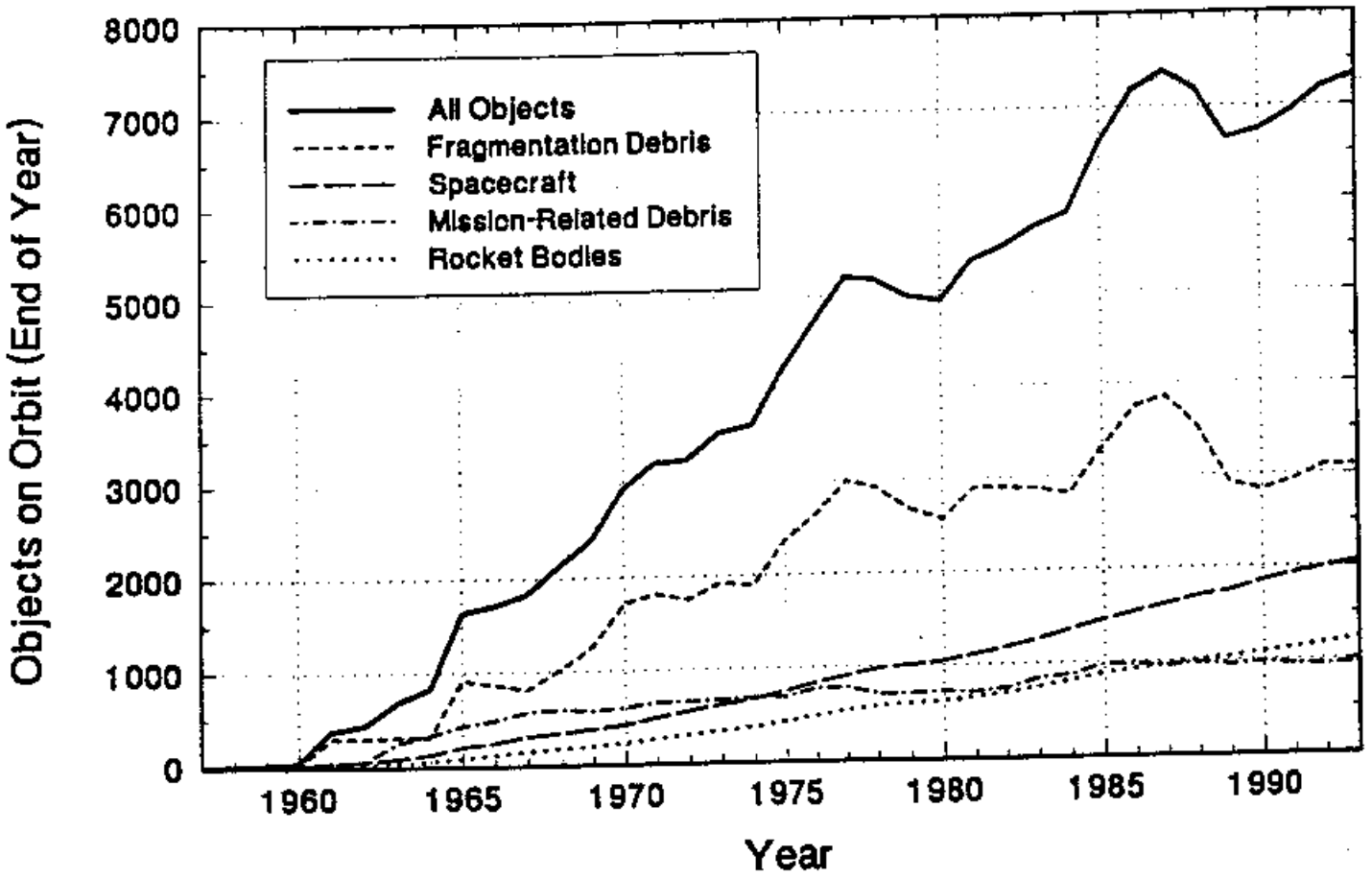

From "Orbital Debris"
Page 20

18th Space Control Conference, Configuration Trades for a Space Object Surveillance Fence, J.K. Beard, Slide 5

Projected Future Cross Sectional Object Flux
in Objects per Square Meter per Year

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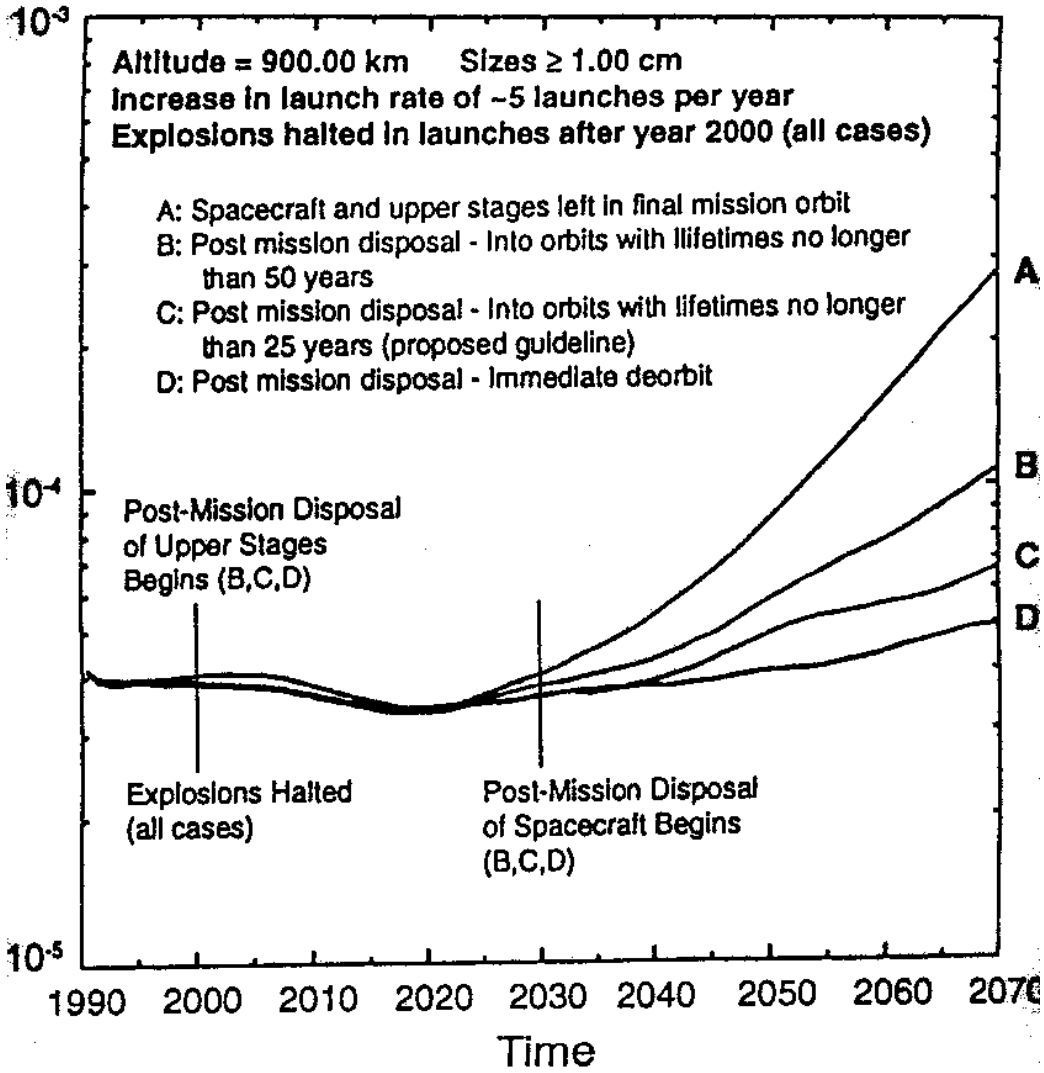

From "Orbital Debris" Page 171, from "The NASA debris handbook," J.P. Loftus, NRC Committee on Space Debris Workshop, 18 November 1993.

Computer Depiction of NAVSPACECOM Catalog December 15, 1993

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December, 1993 Cover Graphic from “Orbital Debris.” Objects are enlarged to make them visible on the scale of this graphic. Fresh graphic courtesy Kaman Sciences

Ways and Means to Meet the Mission First Cut

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- Sensor Candidates in Order of Practicality
  - Ground Based
    - » Retain Existing VHF Surveillance Radar -- Insufficient Sensitivity for 1 cm Debris
    - » New Active RF -- Requires X Band for 1 cm Debris
    - » EO/IR -- Not All Weather
    - » Laser Radar -- Not All Weather
  - Space Based -- All Require Expensive Constellations
    - » Active RF -- No Practical Power Source
    - » Laser Radar -- No Practical Power Source or Fan Beam
    - » Passive EO/IR -- Sensitivity and Aperture Size Issues
- The First Cut -- Feasibility, Cost, Risk, Technology Availability
  - New Active RF
  - Retain Existing VHF Surveillance Radar
  - Combination of New and Old

Requirements Flowdown

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- Sensitivity -- Generally Match Existing Capability
  - 1 Square Meter -- To 10,000 nmi (18,500 km) Slant Range
  - 0.1 Square Meter (30 cm objects) -- To 2,000 nmi (3700 km) Slant Range
  - New Debris Capability: 1 cm -- To 850 nmi (1500 km) Slant Range
- See Everything Twice a Day Without Cueing with High Probability
  - Stationary Fan Beam CW Search Fence
  - Search Fence Must Be 22.5 Degrees Wide
    - » A 90 Minute Orbit Will Be Detected Every Time
    - » Fence Will Cross Every Orbit Every 12 Hours
- Produce Orbital Elements on First Pass
  - Compute 6 Numbers
  - Needs Modulated Waveform or Triangulating/Interferometric Multiple Receivers
- See Smaller Debris
  - 30 cm Airy Region Limit Requires Frequency Over 150 MHz
  - 1 cm Airy Region Limit Requires Frequency Over 4.8 GHz

Principal Cost Trade Issues -- Antennas

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- Large Antennas Drive Cost of Current VHF Fence
  - High Altitude Receiver Sites at Elephant Butte, NM and Hawkinsville, GA are Antenna Cost Driver
    - » High Cost of Large Number of Open Air Dipoles
    - » Design Life Cycle Ends About 2002
  - Main Transmitter at Kickapoo Lake, TX
    - » Two Miles of Open Air Dipoles
    - » Large Number of Solid State HPA Modules that Use Custom Transistors
    - » HPA Transistor Buy Runs Out in 2005
- Antenna Size Versus Wavelength
  - Radar Equation Drives Receiver Antenna Effective Area
  - Antenna Can Become Simpler at X Band
  - Wavelength Remains Significant Factor

Other Cost Trade Issues

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- Initial Transmitter Cost
- Power Cost
  - Current State of the Art DC to RF Efficiency is 25% $\pm$ 5%
  - No Strong Effect from Frequency
  - No Strong Effect from Technology or Size of Transmitter
- System Considerations
  - Phase Matching
    - » Accuracy is in Wavelengths
    - » Antenna Sizes are in Wavelengths
    - » No Strong Effect with Frequency
  - Data Processing Requirements
    - » Increase Rapidly with Frequency
    - » Antenna and Transmitter Costs are Far Larger than Computer Costs

Bandwidth Requirements

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- Orbital Dynamics are the Driver
  - Highly Elliptical Orbits Mean Up to 11180 Meters per Second Velocities
  - Clear Bandwidth Requirements are $1.49 \cdot 10^{-4}$ Times Center Frequency
  - Each Transmitter Requires its Own Band
  - Overlap in Higher Doppler Regions Allowed
- Clear Bandwidth Allocation per Transmitter
  - 30 kHz Used by Existing 216.98 MHz Fence
  - Low Power Transmitters at Jordan Lake, AL and Gila River, AZ are Offset by 30 kHz to Mitigate Ambiguities
  - 447 kHz Clear Band Required at 3 GHz
  - 716 kHz Clear Band Required at 4.8 GHz
- Bottom Line
  - Allocations of Large Absolutely Clear Bands Very Difficult at X Band
  - Compromise
    - » Get a 1 MHz to 1.5 MHz Frequency Band Allocation as Needed
    - » Software to Handle High Density of Small Objects Also Handles Remaining Spurs in the Band

Second Cut

- Active RF System
  - Uncued Fixed Fan Beam for High Probability of Intercept
  - Short Dwell Time
- Waveform
  - Unmodulated CW
    - » Blind Speeds and Ranges Drive Toward Receive While Transmit
    - » Ambiguities in Dense Environment and High Probability of Intercept
      - CW Waveform Resolves Multiple Returns Using Doppler
      - Unmodulated CW Avoids Doppler Ambiguities
  - Pulsed Concepts
    - » No Sufficient Investment to Date -- Unknown Potential
- Detection System
  - One Transmitter
  - One or More Receivers
- Orbital Element Measurement
  - CW Waveform Needs Two or More Receivers for Triangulation
  - Optional Auxiliary System for Verification and Track

Concepts

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- Detection
  - Unmodulated CW
    - » Fan Beam Transmit
    - » Unmodulated CW Waveform
    - » S Band Allocation Now Underway -- Gives Up 1 cm Debris Sensitivity
    - » One or More Receivers
  - Pulsed RF -- Single Site?
- Verification and Track
  - All Weather Solution
    - » Association on Next Pass
      - Not Compliant -- 90 Minutes to Get 6 Numbers
      - Requires Very High Association Probability
    - » Auxiliary RF Sensors
      - Done with Existing VHF System Using Other Space Track Sensors
    - » Triangulation with Two or More Receivers
  - High Capability
    - » Auxiliary EO/IR Sensor -- Previously Suggested (N00612-94-D-8401)
    - » 1 Meter Reflector Provides Track Capability at Low Cost per Site
    - » Pulsed RF?

Strengths of Microwave Concepts

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- Low Risk
  - Scaling of Existing Concept
    - » Improvement of Sensitivity and Accuracy Over Existing VHF System
    - » If VHF System Meets Mission then Microwave System Will Meet Mission
  - All System Functions Consistent with 2000 Start-Up Date
- Improved Accuracy
  - Detected Objects are in Far Field -- Higher Angle Accuracy
  - Range Rate Resolution Increases with Frequency for a Given Dwell
  - Additional Data Available from Chirp at Microwave Frequencies (Toward the 6th Number)
- Simpler Siting -- Smaller Antennas
- Lower Life Cycle Cost
  - Smaller Antennas Allow Radomes for Longer Antenna Replacement Cycle
  - Newer Transmitter Design with Lower Maintenance Costs

Issues of Microwave Concepts

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- Frequency Allocation
  - Residual Spurs in Clear Band May Be OK
  - Clear Band of 750 kHz to 1.5 MHz Should be Do-able
- Operation of Co-Located Receiver in Rain
  - Some Transmitter Power Scattered into Receiver by Heavy Weather
  - Receiver Can Have Dynamic Range/Spur Issue
  - Complex Spurs May Defeat Ambiguity Resolution in Dense Environments
- Processing and Communication Architecture -- Data Flow Questions
- Obtaining Six Orbital Elements on First Pass
  - Requires Triangulation from Multiple Receiver Detections
  - Multiple Receiver Sites Impacts Cost
  - Data Fusion is Part of Architecture Issue
  - Pulsed RF Concepts May Get Six Orbital Elements with Single Site
- Obtaining 22.5 Degrees with Single Transmitter at Low Altitudes
- Alternative of Pulsed RF Concept Not Yet Defined

Keep Some or All of VHF Capability?

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- Investments Required To Keep Part or All of Existing VHF Capability
  - Redesign Receiver Antennas for Lower Cost and Longer Life Cycle
  - Redesign Transmitter for Lower Support Costs
- Strengths of Keeping Some or All of Existing VHF Capability
  - Sensor, Processing, Data Flow Architecture, and Frequency Allocation In Place
  - Meets Mission
  - Expandability Proven
  - Existing Off-line Anomalous Detection Analysis
  - Mitigates Schedule Risk of Microwave Sensor
  - Can Complement Microwave Sensor and Relax Requirements, Reduce Cost
- Weaknesses
  - Antenna Replacement Remains Major Cost Driver
  - Still Requires Second Pass or Other Sensors for 6 Orbital Elements
  - Debris Threat -- New Microwave System Still Must See 1 cm Debris at 600 km Altitude With Reduced Cost Offset

Next Steps

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- Reexamine Mission, Requirements, and CONOPS
  - Consider All Users, Present and Prospective
    - » New Sensor Capabilities will Change Multiple User's CONOPS
    - » NASA Requirement for Detecting 1 cm Debris May Drive Wavelength
    - » Siting Flexibility May Allow New Applications of Microwave Fence Technology
      - OCONUS Sites
      - Quick Response to New Siting Requirements
      - Tactical Use -- TBM Fences
  - Consider Mixes of Sensors
    - » Single Receiver
    - » Auxiliary EO/IR Sensor
    - » Multiple Receivers
    - » Other Space Track Sensors
    - » Auxiliary RF Sensors
    - » Continuing Use of All or Part of Existing VHF System (Loss of Some Cost Offset?)
- Develop Detailed Alternatives for
  - Sensor Configurations -- X Band, Pulsed Concepts, Auxiliary Sensors
  - Data Processing and Data Flow Architectures

Mission and Threat References

- "Space Systems Threat Environment Description (TED) (U)," DST-2660F-722-93, 29 October 1993 (USSPACECOM Document)
- "Mission and Functions of the Naval Space Surveillance System," OPNAV Instruction 5450.206, Department of the Navy, CNO, OP-943, 22 June 1981
- "Satellite Detection and Reconnaissance Defense (U)," Operational Requirement No. AD-01503, CNO OP-761 or Ser 0014P76, 31 December 1959
- "Space Surveillance Requirements (U)," Headquarters US. Space Command, Peterson AFB, CO, 30 August 1995
- "Operational Requirements Document or the Naval Space Command Surveillance System (U), (DRAFT)" NAVSPACECOM, 21 November 1995
- "Next Generation NAVSPACECOM Space Surveillance Concept," Final Report, NAVSPACECOM Contract N00612-94-D-8401, 07 March 1996.

Space Surveillance Web Sites

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- Government Agencies
  - USSPACECOM
    - » http://www.peterson.af.mil/usspace/
  - AFSPACECOM
    - » http://www.spacecom.af.mil/hqafspc/index.htm
  - NAVSPACECOM
    - » http://www.navspace.navy.mil/
- Current UHF System
  - http://www.zilker.net/~crossley/NAVSPASUR/how.html
  - http://www.fas.org/spp/military/program/track/spasur_at.htm
- USSPACECOM Catalog
  - http://www.peterson.af.mil/usspace/satcat.htm
- National Academy of Science
  - http://www.NAS.edu/
- Federation of American Scientists
  - http://www.fas.org/spp/military/program/track/

Debris Web Sites

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- Unclassified Catalog (GSFC Bulletin Board)
  - http://oigsysop.atsc.allied.com/scripts/foxweb.dll/app01?
- NASA - Johnson Space Center Space Debris Site
  - http://sn-callisto.jsc.nasa.gov/
- Aerospace Corporation Space Debris Site
  - http://www.aero.org/cords/sdbasics.html
- Full text of “Orbital Debris, A Technical Assessment,” National Research Council, ISBN 0-309-05125-8, National Academy Press (1995) in HTML
  - http://books.nap.edu/books/0309051258/html/index.html
- Full text of “Protecting the Space Shuttle from Meteoroids and Orbital Debris,” National Research Council, ISBN 0-309-05988-7, National Academy Press (1997) in HTML
  - http://books.nap.edu/html/shuttle/
  - http://www.nap.edu/books/0309059887/html/index.html
- Collection of Debris Links
  - http://pr.erau.edu/%7Emadler/research/debris_links.html