TacSat-4

I&T, Launch Processing, and Early Flight Operations Experience

26th Small Satellite Conference

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Topics

• TacSat-4 Mission Overview
• Integration & Testing
• Launch Processing & Launch Vehicle
• Early Flight Operations
• Ground Systems
• End Users Results
• Lessons Learned
TacSat-4 Mission Overview

• TacSat-4 mission’s is to advance technologies & augment SATCOM
• New technologies used for: antennas, thermal systems, bus standards, highly automated ground C2, VMOC mission planning, new battery, new launch vehicle configuration
• Capability augments national SATCOM with up to 5 Legacy UHF channels…
  ➢ Near global access (but not continuous) including Arctic circle
• Year-1 Military Utility Assessment & Experimentation
  ➢ ORS Leading JMUAs including DHS/USCG
  ➢ Navy MUA in Trident Warrior 2012
  ➢ International Trials via TTRDP
• Years-2 & 3 Operations
TacSat-4 Orbit and Global Coverage

Maximum Hours per Day for a Given Location

A Given Location Typically Sees 3 Passes per Day Averaging 2 hours each Pass

Approximate footprint for US centered pass ("hand drawn" to show scale)

TacSat-4
~12,000km Apogee & 63.4° inc.

GEOs ~36,000km @ Equator
TacSat-4 Spacecraft – Bus and Payload

TacSat-4 “COMMx” Payload
10 Channels of UHF

Spacecraft Bus Prototype for ORS Standards
Integration and Testing

- The bus and payload were maintained as two separate programs through all of the design and integration, and most of the testing phases.
- Parallel integration paths for the bus electronics, propulsion subsystem, and wire harness were utilized to reduce the time required for integration.
- A lot of payload in a small volume + mission CONOPS
  - Drove need for an active thermal control system for the payload
  - Complicated integration, system level testing, and troubleshooting efforts due to the highly integrated nature of the design.
- The payload antenna mechanism was qualified at the subsystem (antenna) level which simplified the ground support equipment & testing, and reduced program costs.
- Thorough integrated payload testing, particularly EMI/EMC testing, was important to ensure self-compatibility. A potential for self-interference was identified and corrected during this testing.
• Bus and payload shipped in separate containers and integrated at launch site after separate post-ship functional testing
  ➢ Core SV launch processing team consisted of 8 people, maximum of 20
• Kodiak facilities and personnel were great
  ➢ Small, dedicated team
  ➢ Small complex & single launch pad, so focus is on your mission only
• LV personnel quote: “Best (easiest) satellite we ever launched”
  ➢ Simple (mechanical only) interface with launch vehicle
  ➢ No SV umbilical therefore no battery charging or telemetry
  ➢ Launched powered off
• New Minotaur IV+ launch vehicle configuration is now flight proven
  ➢ Thrust vector control Star 48 motor for 4th stage
Launch Vehicle and Kodiak Launch Site

TacSat-4: Providing Communications and Enabling ORS

Minotaur IV+ Rocket

Launched: 27 Sept 2011

Kodiak Launch Complex
Highly Automated C2 & VMOC Mission Planning are Working Well

- Blossom Point Tracking Facility
- 1st US Space Systems Ground Station - 1956
- Flexible for S&T/R&D
- Robust for Operations

Automated Command & Control after Checkout (C2)

Highly Automated Mission Planning and Scheduling Tool

Additional details in next presentation:
“VMOC Automated Mission Planning Now in Operations”
Early Flight Operations: First Rev

- TacSat-4: Providing Communications and Enabling ORS

- TacSat-4

- Early Flight Operations: First Rev

- Shuttlecock
- Anomaly Mnvr S/A C/O
- Apogee (L+2:28)
- Nominal Mnvr
- LV-Sep (L+0:28)
- AD Enable (L+0:33)
- Perigee (L+0:32)
- HULA LOS
- POGO AOS (L+2:30)
- LION AOS (L+1:44)
- REEF AOS (L+0:59)
- Check-Out Burn
- ISP
- RC-RW
- SA Deploy (+Y)
- SA Deploy (-Y)
- Vent OL Thrust RC-AJ
- ISCheck-Out Out Burn
- RC-AJ
- RC-RW
Early Flight Operations: the Good


Spacecraft Bus, Most of Payload, and New Launch Capability

- Bus used to develop & test new quick response standards, i.e. enabled streamlined launch processing.
- New technologies used for: antenna, battery, flight software automation, thermal, ODTML in HEO
- New launch vehicle capacity, orbit, & facility

BP Command & Control and VMOC Mission Planning

- State-of-the-Art capabilities & automation … working well

User Experimentation & Eval.

See later slides
Early Flight Operations: the Problems

RF interference (EMI)

• Several of the initially assigned downlinks were noisy. Noisy frequencies were identified and are being replaced.

Loop Heat Pipe

• Worked nominally for ~2 months then reduced performance. Exact cause cannot be fully determined.
• Limits to ≤ 5 channels (specific to tasking)

EFFECT: These items are limiting TacSat-4 to 5 channel bird.
Early Flight Operations: the Interesting

- Protons dominate Inner Belt
  - Monitoring the environment with Air Force’s CEASE and Solar Cell Experiments
  - CEASE Measurements show Levels an Order of Magnitude Higher than Predicted
  - Solar Cell Experiment degrading faster than Predicted
  - TacSat-4 Arrays being measured monthly
  - Mitigation strategy developed to take advantage of directional dependency
- Electrons dominate Outer Belt
  - CEASE Measurements show Levels an Order of Magnitude Lower than Predicted
User Experimentation & Military Utility Evaluation is Well Underway

- **JMU A Report coming out in August**
- **Army SMDC Battle Lab**
  - Execution lead for ORS JMU A Evaluation
  - Focus on Communications-On-The-Move (COTM) and VMOC Mission Planning Systems
  - Evaluations conducted for multiple legacy radios and antenna configurations
  - Testing & report completed
- **US Coast Guard**
  - Ship & Helicopter use especially at high latitudes
- **Submarine Community**
  - Testing at NUWC completed in January and Feb
  - BCA-LANT & BAC-PAC Antenna Installs for AOR Use
  - LANT and PAC testing in Late Summer & Fall 2012
- **Navy’s Trident Warrior 2012 done in June**
  - Navy Ship, Sub, and Marines participating
  - International participation with UK & Canada
  - Official MUA in Nov 2012, Quick Look in August
- **Naval Special Warfare Center, Coronado**
  - In addition to UHF SATCOM, they have interest in UHF Blue Force Tracking / Friendly Force Tracking for training in US
- **International Participation by UK & Canada**
  - via TTRDP & Trident Warrior-12

NUWC “Sub” & USS Olympia for TW-12

COTM testing in mountainous area (pikes peak)

1/6/12 USCG Cutter Healy breaks ice around the Russian-flagged tanker Renda 250 miles south of Nome.

Tri-Lateral Technology Research & Development Program
End Users Results: Summary Performance

- Supports SATCOM for All SATCOM Radios and SATCOM Antennas Tested
- Independent SPAWAR testing also confirms TacSat-4 supports standard / legacy SATCOM equipment including Omni antennas
- Downlink – Comparable to current SATCOM Capability
  - Excellent results with User SATCOM antennas, Humvee X-wings, sub equipment, ships, etc.
  - Intermittent with NON-SATCOM antennas like whip and baton antennas
  - ~25% success with non-SATCOM whips
  - ~75% success with tuned whips
  - Expected better but had radio noise figure error in link budget
- Uplink – Very strong, can receive low power radio transmissions
  - Can extend battery life and, in some cases, can reduce probability of detection
Lessons Learned: Mission Capability

- UHF SATCOM has been realized in this small satellite size and class of mission.
  - The SATCOM capability works well with strong signal strength and low bit-error-rate results.

- The 4 hour HEO has proven valuable by providing “long dwell” capability for a small satellite class of mission.
  - The primary User limit with a single satellite is the lack of continuous (24-7) service; however, this orbit scales well in terms of adding two or three more satellites for full coverage of many, selected areas. One negative still being characterized is that this orbit is seeing higher radiation levels (especially protons) than the models predicted.

- A new Minotaur IV+ capability has been developed and successfully validated. It is now a vehicle configuration available with increased payload mass and/or orbit altitude.
Lessons Learned: Bus Standardization

• Developing useful standards and interface documentation for standardized buses and payloads requires significant up front systems engineering effort including design, analysis, and validation.

• Standardized designs are not optimized designs. For example, the standardized bus prototype used for TacSat-4 was not optimized for SATCOM. As such, its design included many requirements that the TacSat-4 mission did not need for its SATCOM mission.

• The “launch powered off” standard required extra design and verification work for the electrical power system, but it provides real benefits at the launch range. Specifically, it eliminated procedures and simplified the launch countdown. The cost was increased design complexity and risk especially in the spacecraft and early orbit operations.

• An adiabatic thermal interface between the spacecraft bus and a primary payload places excessive burden on the payload and underutilizes straight-forward spacecraft thermal capabilities. Note: The matured bus standards do NOT specify an adiabatic interface.
Lessons Learned: Mission & Ground Ops

• Mission operations can be complicated, require significant advanced planning and coordination. The use of mission dress rehearsals with both hardware and process simulators was essential.

• Mission simulators can be expensive to develop and implement, but typically pay for themselves in the long run.

• Automated ground station operations are essential for cost effective mission operations. They reduce operator errors by doing proven procedures automatically, letting operators focus on the actives people are better at such as trending, preventing, and resolving operational problems.

• As the mission and ground operations team encounter and resolve on-orbit problems, the resolutions are add to the automated operations in the form of new procedures or constraints. The result is increasingly robust automated operations as time goes by & operations experience increases.

• Ground C2 & VMOC Mission Planning Automation are working very well for TacSat-4
Lessons Learned: Launch Processing

• Kodiak facilities and personnel were great
  – Small, dedicated team
  – Small complex & single launch pad, so focus is on your mission only

• LV personnel quote: “Best (easiest) satellite we ever launched”
  – Simple (mechanical only) interface with launch vehicle
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• TacSat-4 launch was “mixed” with many others causing delays
  – Mission priority delayed launch multiple times. Need to resolve else will often be the case even with theoretically separate launch teams, funding, ranges, etc.

• To achieve very short timelines launch would require….
  – To shorten processing time at the launch site the LV must be stacked and either ready for launch, or require minimal processing.
  – The spacecraft buses and payloads must be checked out when they first arrive at the launch depot, and the mission team must trust that the bus and payload are still good when call up occurs, or rely on a quick test to verify.
ADDITIONAL INFORMATION

• “VMOC Automated Mission Planning Now in Operations”, European Space Agency 4S Symposium, June 2012.

• “ORS Phase 3 (TacSat-4) 30 Ah Li-Ion Battery”, Space Power Workshop 2012

• “Innovative COMMS”, C4ISR Journal, June 2011

• “TacSat-4, Advanced UHF SATCOM,” European Space Agency 4S Symposium, June 2010.


• “Design and Analysis of The Thermal Control System for The TacSat-4 Spacecraft, COMMx Payload,” International Two-Phase Thermal Control Technology Workshop, October, 2009.