ASAT-07-08

The Future of Responsive Space

A Summary of the Results and Papers From the 5th Responsive Space Conference

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- Policy Statements
- Operationally Responsive Space Office
- Why is “Responsive Space” Needed?
- What Constitutes Responsive Space
- The Focus of Responsive Space 5
- Summaries from the Panel Discussions and Featured Speakers
- Summaries of Responsive Space 5 Papers by Session
- The Process Continues

Notes:

1. Abbreviated references are included in the form of the last name of the principal author listed in the Responsive Space Conference program and the last four digits of the paper number.

2. Because of last minute paper cancellations, some papers were included in sessions that do not correspond to the session topic.

Policy Statements

- *"Rapidly generate and maintain space superiority and strike capabilities that produce desired war-fighting effects that are there and available when needed."*
  - **Maj. Gen. Tom Taverney**, April 12, 2004

- *"How can we take space and bring it… to the operational and tactical level of war.*

  Launch vehicles that carry 1,000-pound payloads…

  Launch these satellites reliably in hours… put them into orbit over a focused point on the earth.."
  - **Gen. Lance Lord**, Commander, Air Force Space Command

- *"From notification of desire to launch to actual launch 'measured in hours and days, not weeks and months'"*

  "…build a stockpile of small satellites and booster rockets [to be] dispatched very quickly to respond to the combatant commander's needs."
  - **The Hon. Peter B. Teets**, Under Secretary of the Air Force

Policy Statements (Cont'd)

- U.S. Space Transportation Policy January 6, 2005
  - *"The fundamental goal of this policy is to ensure the capability to access and use space in support of national and homeland security, civil, scientific, and economic interests. To achieve this goal, the United States Government shall:…*

    2) *Demonstrate an initial capability for operationally responsive access to and use of space — providing capacity to respond to unexpected loss or degradation of selected capabilities, and/or to provide timely availability of tailored or new capabilities — to support national security requirements*

    5) *Before 2010, the United States shall demonstrate an initial capability for operationally responsive access to and use of space to support national security requirements. In that regard, the Secretary of Defense, in coordination with the Director of Central Intelligence, shall:*

       a) *Develop the requirements and concept of operations for launch vehicles, infrastructure, and spacecraft to provide operationally responsive access to and use of space to support national security, including the ability to provide critical space capabilities in the event of a failure of launch or on-orbit capabilities; and*

       b) *Identify the key modifications to space launch, spacecraft, or ground operations capabilities that will be required to implement an operationally responsive space launch capability."*

- The report setting forth a plan for the acquisition by the DoD of capabilities for ORS just signed on April 19, 2007 and delivered to Congress on April 26*
  - The ORS Office stand-up is this month, with funding to start 10/1/07 – Col. Kevin McLaughlin is the Director, and Lt. Col. George Moretti is the Squadron Commander – funding from FY08 – FY13 is forecast as ~$400M
  - Congressional support is strong, the service labs are heavily investing
  - ORS Definition - Assured space power focused on timely satisfaction of Joint Force Commanders' (JFCs') needs - <u>This is the broadest definition yet presented</u>
    - Space capabilities optimized to meet urgent/unforeseen/emerging needs
      - <u>Reconstitute</u> lost capabilities
      - <u>Augment/Surge</u> existing capabilities
      - <u>Fill Unanticipated Gaps</u> in capabilities
      - <u>Exploit</u> new technical/operational innovations
      - <u>Respond</u> to unforeseen or episodic events
      - <u>Enhance</u> survivability and deterrence
    - Complementing "Big Space," not conflicting with or a replacing it
  - TacSats will be the proving ground

* Extracted from the Keynote presentation by Mr. Joseph Rouge, Associate Director National Security Space Office and from comments from Lt. Col. Carol Welsch, Director of the SMC Space Development Group

Why is "Responsive Space" Needed?

- **Today responsiveness has become critical or at a minimum important**
  - **Military missions** — wars in Iraq and Afghanistan - rapid and continuous battlefield intelligence that's "responsive and flexible" (the quote is from Gen. Tommy Franks assessment of the new strategy for the Iraq war — March 22, 2003)
  - **Disaster monitoring** — tsunami in southeast Asia, hurricane in New Orleans - immediate answers to What, When, Where, and How
  - **Commercial missions** — ground-based (rather than space-based) sparing, 0-g manufacturing based on needs defined today
  - **Science** — observations of transient phenomena; responsive science with tomorrow's experiment based on today's results
  - **Education** — experiments launched while the student is still a student, or at least still in astronautics
  - **Crewed missions** — can we make them safer by having responsive launch available?
  - **<u>However important space assets may be in today's world, they absolutely are not responsive</u>**
    - Apollo went from a dream to landing people on the Moon (including developing the largest rocket ever built) in <u>8 years</u>; now we are talking about a <u>return</u> to the Moon in <u>16 years</u> from an initial statement regarding manned lunar exploration
    - Today, major unmanned programs take well more than a decade, and even small satellite missions can take 5 to 7 years

What Constitutes Responsive Space
Bounding Views

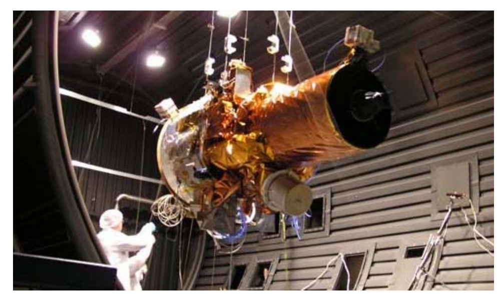
Parameter	View 1 The way to be most responsive is to utilize what is already in space – essentially using strategic assets for tactical applications	View 2 The way to be most responsive is to utilize single function, small satellites/constellations of small satellites
Responsiveness	Already in orbit	Launch on demand - provide information to the end (tactical) user within 24 hours (variation - "6-day spacecraft") of an identified need
Flexibility	Lots of demand on use, so may not be available when needed; possible on-orbit spares provide an additional flexibility dimension	Provide multiple types of data (from different spacecraft) for any location on Earth at any specified future time - match payload(s) to bus/plug-and-play satellite
Cost	Very expensive - $500M to $1B class bus/payload, $100M class launch vehicle, “standing army” required for operations	Total mission cost < $20 million/spacecraft, including launch, spacecraft, payload, and mission operations (allows systems to be built to inventory)
Mission Duration	Has to be long lived to justify cost (5 – 10 years)	Less than 6 months planned mission life - reasonable to launch in response to tactical needs
Size	Large (multiple tons)	Total mass < 1000 lbs, possibly < 500 lbs - reduces both launch and mission operations costs
Functions	Multifunction/multiple sensing instruments (Advocates of this view also have the attitude that little can be accomplished with a single function, small satellite)	1, or at most 2, payloads per spacecraft - allows matching response to the identified need; allows for rapid technology insertions
Orbit	“High” (LEO > 600 km) because of atmospheric drag considerations and lifetime (orbit maintenance propellant issue); or "High" (MEO, HEO, GEO); sensors need to be large/high power to compensate for the high altitude	200 to 400 km altitude - allows better performance from small payloads - instrument 1/4 to 1/2 the size of a comparable resolution instrument at 600 to 800 km [2.4 m optics/Hubble class (~$2.4B and counting) at 800 km provides the same resolution as 0.6 m optics (~$10M recurring) at 200 km]
Vulnerability	Cannot be reconstituted in a finite time period (in a responsive, days, weeks, even months sense), independent of altitude	Somewhat more vulnerable than spacecraft at higher altitudes, but can be replaced quickly; also brings in issue of cost and time for enemy to negate vs. our cost and time to replace; requires companion responsive launch capability

What Constitutes Responsive Space
ORS Tiered Approach

- **Tier-1 (command it)**
  - On-demand with existing assets
  - Minutes to hours

- **Tier-2 (launch/deploy it)**
  - On-call with ready-to-field assets
  - Days to weeks

- **Tier-3 (develop it)**
  - Rapid transition from development to delivery of new or modified capabilities
  - Months (not years)



* Extracted from the Keynote presentation by Mr. Joseph Rouge, Associate Director National Security Space Office

The Focus of Responsive Space 5

- Previous responsive space conferences have focused on the technology and processes to create Responsive Space
- The 2007 Responsive Space Conference expanded the focus to cover three key issues:
  - **Applications** – What are the needs of the war- fighter and civilian users and how can these needs be met?
  - **Implementation** – How do we create demonstration missions and then transition these into an ongoing, robust program of low-cost, responsive missions?
  - **Funding** – What is the current funding status for all of the elements of Responsive Space and how do we create Responsive Funding?

Summaries from the Panel Discussions and Featured Speakers*

- Congressional staffer participants covered a wide range of topics, including:
  - The need for reconstitution capability as a result of the recent Chinese ASAT test
  - Must balance sensors, bus, launch in the ORS process and speed up and reduce the costs of the end-to-end development process (also covered by other speakers)
  - ORS should be disruptive with innovation across the board, with an emphasis on close ties between the developers and operators, including CONOPS and training, cradle to grave (also covered by other speakers)
- BG Neil McCasland, SMC Deputy Commander said from his viewpoint ORS included (also supported by comments later by LTG Robert Kehler, Deputy Commander USSTRATCOM) :
  - Payload design/development, common standard bus development, launch vehicle and range, command and control
  - Quick transition to operational capability is key – the goal is a 50% reduction in cycle time
- Col. Richard White, SMC/XR, added some dimensions to the discussion:
  - Distributed architectures and space situational awareness to increase survivability
  - Standard interfaces to speed up development, integration and test, which includes moving forward on plug and play technology (this capability came up in multiple venues during the conference)

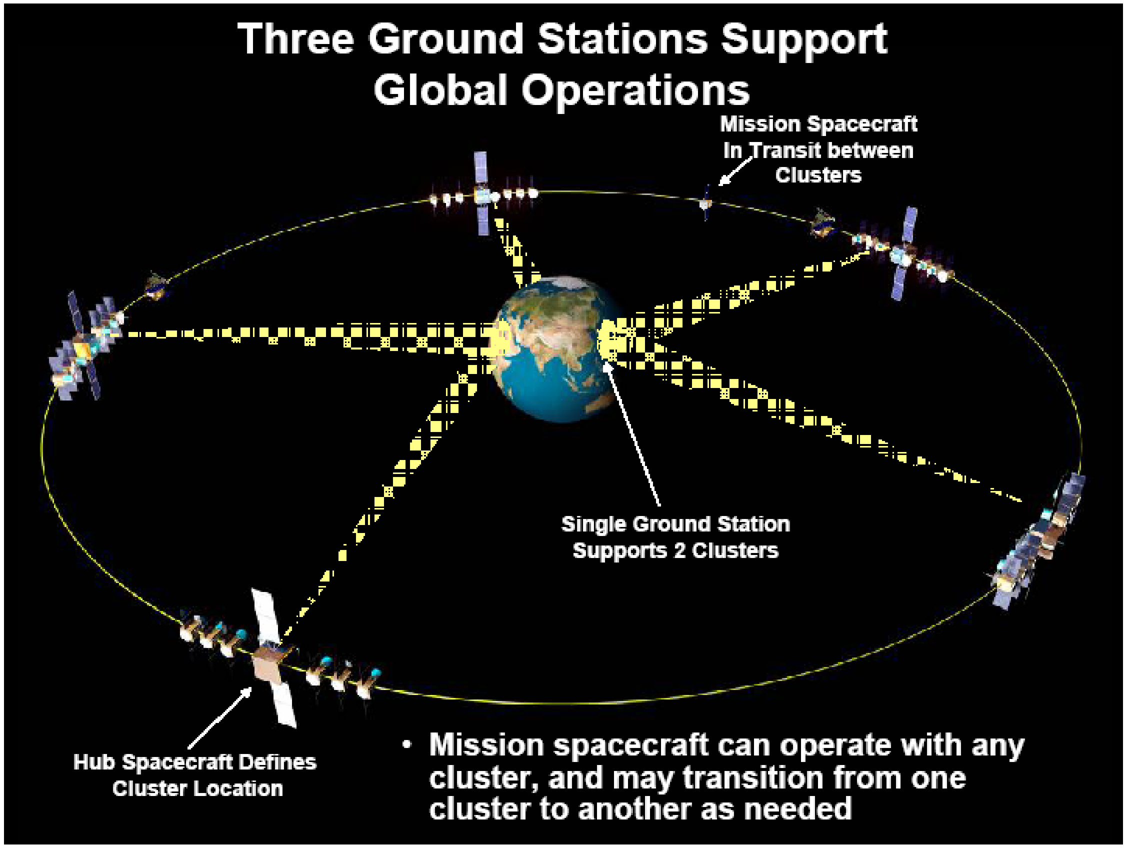
* Not in any particular order

Summaries from the Panel Discussions and Featured Speakers (Cont'd)*

- A common thread pointed to assured communications/communications on the move (voice first, data second) as being the highest priority capability needed across all the military services
  - The Army perspective was get data disseminated in 12 – 20 minutes
  - The Marines are structured to have boots on the ground within 6 hours of an order – also they do not allow themselves to be dependent on GPS
- Other high priority capabilities included navigation and timing (supporting encryption); intelligence, (persistent) surveillance, reconnaissance capability; day/night all weather targeting
- The ability to accommodate failure in exchange for responsiveness also was discussed
  - Change the current 100% or nothing mentality that has driven systems to take 10 years to implement and cost billions of dollars to several years and tens of millions of dollars (even if failures occurred along the way)
  - As a corollary, the 80/20 solution also came up on multiple occasions – 80% of the capability for 20% of the cost
- An overriding comment was that responsive space was much more than just the launch, bus, and payload components, but rather the end-to-end capability to respond rapidly to world events that also included rapid data reduction and rapid dissemination of data in a form useful to the warfighter
- A key comment from the warfighters, especially the Army and Marines, was that size, weight, power were key factors tied to their views of new technology
  - Something that added capability, but also added to what had to be carried was not of interest
  - If a technology replaced multiple functions and either reduced any of the three factors, especially weight, or did not add weight, was of extreme interest

* Not in any particular order

- Approach discussed multiple clusters of geosynchronous orbit satellites (Orndorff, et. al., 1002) - Functionality is split among mission satellites, while common utility functions are concentrated in infrastructure satellites
  - The core of the cluster is the Communications Hub spacecraft
  - Satellites dedicated to specific mission functionality perform the missions of interest
  - Servicing satellite provides both fuel/re-positioning capabilities for cluster members

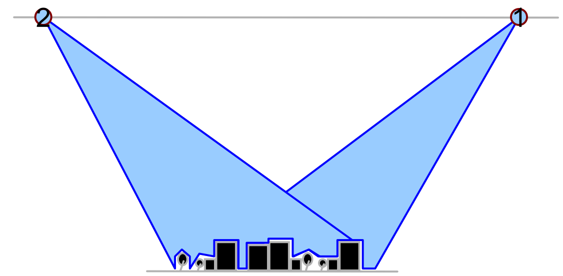


Summaries of Responsive Space 5 Papers by Session
Innovative Architectures and Missions (Cont'd)

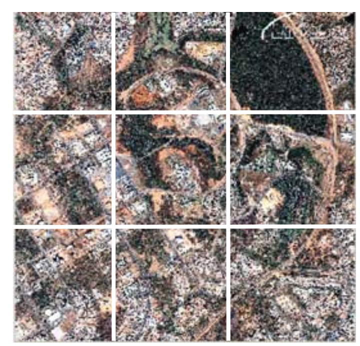
- Surrey Satellite has developed surveillance class satellites – TopSat and Beijing 1, plus RapidEye that is approaching launch (Eves, 1003)
  - Satellites can collect data with multiple sensors at different resolutions over different areas
  - Allows the satellites to be used responsively in different modes, depending upon the nature of the crisis situation/disaster
  - Small satellites agility allows:
    - The use of Ground Motion Compensation modes to collect data over a wider range of illumination conditions
    - A broader range of orbits to be considered, (with consequent implications for revisit rates, and hence responsiveness)
    - Implementation of in-pass stereo and wide-swath imaging modes when required

Single Scene Imaging

Strip Imaging

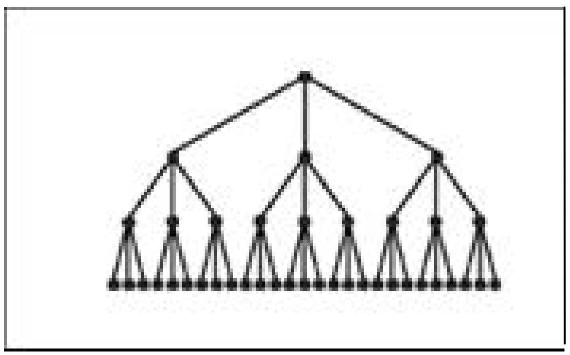


Stereo Mode Imaging

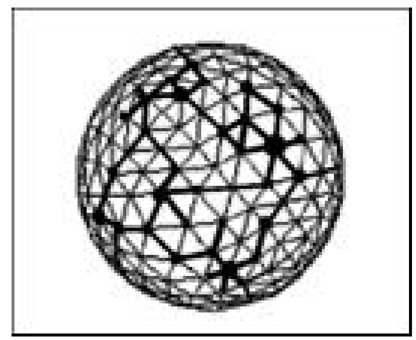


Area Mode Imaging

- Net-Centrics focuses on integrated networking and computing (Janicik, 6005)
  - 4 tenets to implementation in space mission design
    - “Net-ready” the communications segment
    - Utilize unaltered standards (IEEE, ISO, ANSI)
    - Enable IP on space links
    - Incorporate DoD Net-centric systems (Global Information Grid)
  - Many commercial sites demonstrate the power of net-centrics – myspace.com®, ebay®, Google™



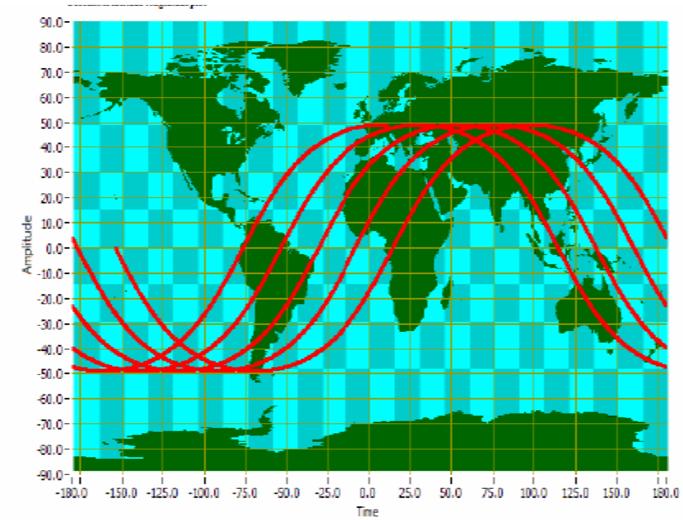
- Traditional “Stovepipe” C2 Hierarchy
- Information flow to end element requires multiple P2P paths and handling along the way



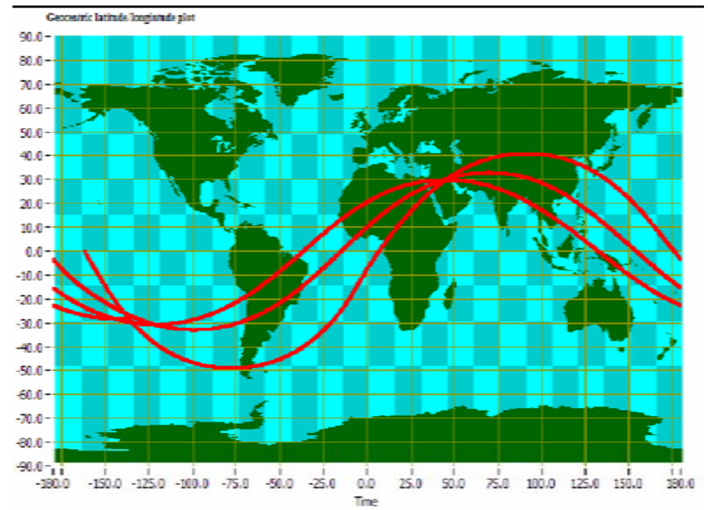
- Efficient networked architecture
- High, medium and low bandwidth and/or processing elements
- Middlemen eliminated via transparent routing

Summaries of Responsive Space 5 Papers by Session
Innovative Architectures and Missions (Cont'd)

- Use of aerodynamic and propulsion assisted maneuvering for orbital transfer vehicles introduces unpredictable reconnaissance via aero-assist maneuvers (Jolley, et. al., 7004, student paper)



Fixed Orbit



Aeroassist Modified Orbit

  - Known fixed orbits - easy for hostile forces to predict the footprint of orbiting platform
  - DoD has long sought a space-plane (Space Shuttle can change inclination only by few tenths of a degree)
  - Craft with high on-orbit agility (waverider) would enable rescue, repair, return, recycling, multiple-objective missions – unpredictable arrival times
    - Uses ~ 1/3 fuel required for all-propulsive maneuver

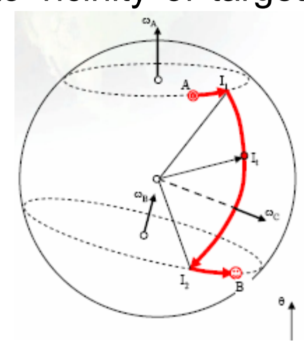
- Paper addresses use of partially continuous Earth coverage via a responsive space constellation (Larrimore, 2001) – accomplished by relaxing persistency requirement to ~ 40 – 50% cumulative dwell
  - Accomplished by determining maximum access inclination from 1 satellite to a given ground target and then building a constellation to provide long access chains
  - Based on a 1994 study by Martin Lo (JPL)
    - Satellite inclination a little greater than target location latitude
    - Two candidate constellations - Walker Delta, "Streets of Coverage"

Target Latitude	Satellite Inclination				
	90.0°	98.6°	53.0°	33.8°	44.5°
40.0°	*26.9*	*27.7*	*43.3*	*31.6*	*40.0*
24.5°	*22.2*	*22.7*	*30.9*	*46.0*	*42.3*
32.0°	*24.3*	*24.7*	*40.4*	*39.8*	*43.9*

- Cumulative dwell is ~ 40-50% of total flight time
  - Several hours of continuous coverage to mid-latitude ground locations
  - Constellations of 6 – 8 satellites – varies depending on orbit, sensor, swath constraints
- Larger with higher altitudes and station mask angles
- Within a few percent of 2 month propagation results

Summaries of Responsive Space 5 Papers by Session
Orbits (Cont'd)

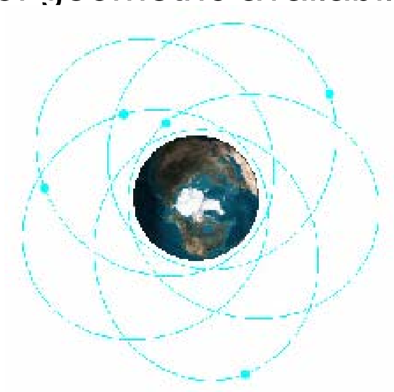
- Use of the appropriate spacecraft slewing/guidance algorithm for Hyper Spectral imagers can drive the overall design of the entire system (Frayman, et. al., 2003)
  - Two types of imaging satellites - body fixed imager (TacSat-3, Hubble Space Telescope), Gimbaled imager
  - Two types of pointing - line of sight (LOS)/Boresight pointing, full attitude/quaternion pointing
  - Paper limited to body fixed imager, but both LOS and quaternion pointing
  - Slewing is the "coarse" action/motion of moving the LOS dynamics/state (direction and rate) from one set of values to another (same applies to quaternion slew)
    - Common approach to slewing is to bring LOS (attitude quaternion) to vicinity of target; then allow a "settling time" so fine controller completes match to target
    - Wasteful of time if slewing can bring LOS to target directly
    - Problem often misstated in terms of slew angle only
      - Inadequate and misleading
      - Implies zero rates at end points
        - Attitude with zero rate referred to as: rest point
        - LOS rates can exceed 1 deg/sec when imaging Earth based targets from moderate altitude



  - **MOST IMPORTANT**: to specify slew it is essential to specify both the attitude and bodyrate at the slew's start and end
  - Three Segment Slew meets practicality objectives flexible, extendable, capable of including further limits and constraints

Orbits (Cont'd)

- TacSat-4 mission orbits are examined in detail for their utility in providing persistent communications (Kantsiper, et. al., 2004)
  - One option is to utilize highly elliptical orbits with 3 (525 X 7,800 km) or 4 hour (525 X 12,000 km) periods that provide long dwell time over a particular region
  - Other orbits examined were "Walker-like" constellations of 3 – 8 satellites and another involving equatorial orbits
  - 5 spacecraft almost always sufficient (An actual theater may not be completely covered by the configurations - performance varies with latitude and longitude
  - The number of spacecraft calculated is minimum required for continuous availability
  - The choice of constellation is driven also by the other mission requirements
    - Analysis only considered geometric availability
    - Multiple manifest and responsiveness may drive toward 2-3 per plane
    - Power generation and storage may drive toward more spacecraft
  - Consideration of geometric availability alone may lead to poor design decisions



- The utility of circular vs. elliptical orbits for persistent communications was examined in some detail (Wertz, 2005)
  - The analysis considered coverage and coverage flexibility, constellation size, ASAT vulnerability, environment, spacecraft and system complexity, failure modes, likely system cost

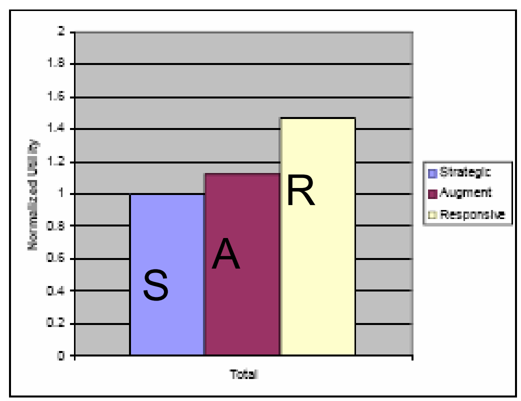
Characteristic	Elliptical (Magic) Orbit	MEO Circular Orbit
Coverage/Satellite	Similar	Similar
Constellation Size	12 – 24 satellites (may be less in some cases)	3 – 6 satellites
ASAT Vulnerability	Moderate – High	Low
Satellite Design Complexity	Complex	Simple
Radiation Environment	High	High (may be able to reduce)
Coverage Flexibility	Moderate (inc. fixed)	High (inc. and altitude variable)
Accessibility	Moderate	Moderate (somewhat less payload mass than Magic orbit with same apogee)
Overall System Cost	Moderate	Low – Moderate

Summaries of Responsive Space 5 Papers by Session
Programmatics

- Can an integrated system of responsive launch and space operations compete with current systems, on a cost and utility basis? (Fram, 3001)
  - Three architectures were developed to analyze the utility of various satellite deployment schemes and how they can benefit the warfighter over a 20 year period involving multiple conflicts – Strategic (Launch on schedule), Augment (Add responsive component to Strategic), Responsive (Launch on demand)
  - Four utility factors, scaled 0 – 1, equally weighted were used
    - Total passes over area of interest
    - Pass quality – look angle and time over target of the pass
    - Sensor quality – type and resolution of the sensor
    - Pass utility – time of the pass – peacetime, pre-conflict, post-conflict or conflict
  - The Responsive architecture had the overall highest value and lowest cost (strategic had the lowest utility/dollar of the 3 architectures)

SDA	Strategic	Augment	Responsive
Cost ($ Billions)	19.880	20.522	12.134

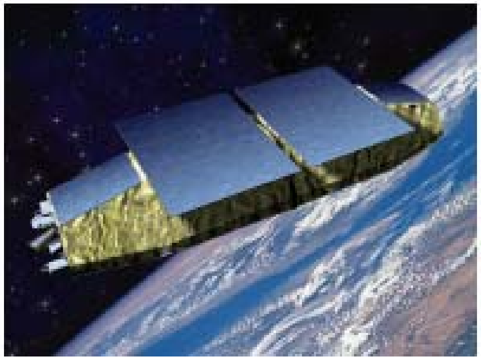
Warfighter Utility



- There is a process in progress to develop ORS/JWS Bus standards that has reached Phase III (Johnson, et. al., 3002)
  - A national systems engineering working group has been established (government, academia, small satellite industrial partners) to develop and maintain bus standards
  - Then design, build, test a prototype bus to demonstrate the standards
  - Bridge the gap between science and technology experiments and operational bus capability
  - Finish by developing an ORS Phase IV transition plan with SMC
  - Mission Requirements and CONOPS
    - Mission envelope and spacecraft support must consider tasking and data dissemination to theater, but limited to theater command level
    - Balance cost and capability/utility (i.e., The 80% capability / 20% cost rule)
    - Spacecraft Bus "Nth-Item" goal <$25M
    - Initial production volume approximately 5 per year, perpetual
    - Spacecraft bus procured in advance of needs and stored in pre-positioned integration facility (depot/war reserve facility)
    - Responsiveness achieved at the mission level - time line from payload/spacecraft bus integration to operational use, including payload integration, launch processing and on-station checkout in less than 7 days
    - Consider architectures that foster "spiral development" for future system improvements
    - Operational Life 1 year
  - Orbits considered – LEO/HEO

- Canada has identified a need for responsive space capability involving increasingly capable small and micro satellites (Bédard, et. al., 3004)
  - Requirement to support intelligence/surveillance, communications, navigation, meteorological, search/rescue
  - Support does not consist of indigenous defense space assets, depends on high levels of cooperation with DoD, depends on commercial sector
  - Canadian definitions of responsive – multi-mission micro/small bus for low cost access to space, scope focused on one mission, 2 – 5 years from requirements definition to operations, \$15M - \$30M/platform including launch, expedite the system life-cycle
  - During last 4 years, effort has seen approval of 2 tech demo missions
    - Near Earth Object Surveillance Satellite (NEOSSat) – space surveillance, launch late 2009, 2 year lifetime/3 year goal, C\$11.5M total cost
      - Near Earth orbit object surveillance
      - High Earth orbit surveillance system
    - Maritime Monitoring and Messaging Microsatellite (M3MSat) – maritime surveillance mission, launch circa 2010, 2 year lifetime/3 year goal, C\$12M total cost
      - Automatic identification system of ships
      - Position heading, time, course speed, rate of turn, cargo

- SSTL is developing a low cost synthetic aperture radar satellite, AstroSAR for military applications, along with civil defense, homeland security, and law enforcement (Eves, 3005)
  - Multi-mode phased-array payload for a 5 year mission costing < $100M; Day/night all weather surveillance of deep/wide areas denied to other surveillance assets used in conjunction with other surveillance assets for cueing; Increased persistence over an optical system; Accelerate the processing, exploitation, dissemination of data to meet operational/tactical timeframes
  - Simplification a focus of the effort – make greater use of the attitude control system that allows reduction in area/complexity of the radar antenna, simplification of the downlink sub-system, no requirement for independent solar array pointing – all lead to cost reduction
  - Use lower inclination orbits (not sun synchronous)
    - Pros - more passes, less predictable pass times, varied view angles, greater payload masses
    - Cons – less predictable lighting conditions, inability to use the satellites for global coverage operations following the period of conflict



Medium Resolution	20km x 1000km @ 3m resolution
Wide Swath	100km x 1000km @ 30m resolution
Maritime Surveillance	900km x 1000km @ 20m resolution

Experimental Modes	Application
Dual pass interferometry	3-D terrain information
Squint mode	Improved target access opportunities
Mitigation of spoof jammers	Protection against CC&D
Crossing node stereo	3-D terrain information
Coherent change detection	Improved exploitation timeliness
Dynamic imaging	Information on moving features
Very high resolution experimental mode	High acuity on specific targets
Ground moving target indication mode	Detection of moving targets

- There are a large number of ORS activities underway that are summarized in terms of their purpose, status, and relationship to each other (Doyne, et. al., 4001) - The first 5 TacSats, the ORS Bus standards initiative, the Virtual Mission Operations Center (VMOC), candidate launch vehicles, operational experimentation status, and the ORS Payload Technology Initiative all are covered
  - TacSats – 1 (RF, visible, IR, comm), 2 (visible, common data link, autonomy, including autonomous orbit control), 3 (hyperspectral imager), 4 (comm on the move, blue force tracking), 5 (TBD payload, plug-and-play)
  - ORS Bus Standards – goal is to provide standards for a block procurement in Phase 4 (See RSC 2005-1006 for additional information)
  - VMOC – see RSC 2007-6001 for more information
  - Launch – TacSats 2-5 on Minotaurs (I, IV); TacSat 1 on Falcon 1; other candidates include Raptor-1 (Pegasus variant), Raptor-2
  - Operations – Tier 1, 2, 3 combinations are discussed
  - Payloads – technology awards have been made in several cost categories – complex ($2 - <$5M), moderate ($0.5 - <$2M), basic (<$0.5M)

- TacSat-2 is in the process of proving the military utility of web enabled space operations (Yee, 4002)
  - A Remote Intelligent Monitoring System (RIMS) was developed that allows access from the web of virtually any aspect of the mission
    - Provides access to trending tools that include automatic graphing to allow instant and easy interpretation of mission information
    - Custom paging of engineers
    - Permitted post-launch recovery of spacecraft commanding that was complicated by local weather that prevented most of the operations team from getting to the operations center
  - If recovery efforts had started just one orbit later, or taken one orbit longer, battery would have fallen to critical level, a potentially unrecoverable situation
  - Web based telemetry & trending allowed us to detect a critical condition and minimized our recovery time
  - International Participation
    - Terma provided star tracker
    - Able to access only tracker data, real time & trended
    - Within 3 days of restoring web telemetry, Terma determined star tracker to be fully functional and meeting nominal performance
  - Utility
    - Highest utility score for ability to allow combatant commander telemetry & command
    - Good utility score for ability to support joint operations across all services
    - Moderately low utility for rapid call-up

- An analysis shows coverage capability of tactical satellites with several different types of payloads to demonstrate that tactical satellites are not necessarily the answer for some tactical missions that are better served by other options (Tomme, 7007)
  - 4 parameters matter for long-term averages in circular orbits – target latitude, satellite inclination, satellite altitude, sensor field of regard
  - SIGINT missions are less restrictive than comm missions that are less restrictive than IMINT missions
  - Results show - passes are short, are very few passes/day, gaps are large, large numbers of satellites are required, costs therefore are high
  - TacSat utility based on 4 space force missions
    - Force application – TacSats appear to be too small to support terrestrial attack from space
    - Support – TacSats appear to require more support than they provide
    - Control - TacSats do not play here; more of a global issue, not a tactical issue
    - Enhancement of battlespace awareness – only tactical mission for which TacSats may be suited
      - Attack warning more of a strategic (i.e., GEO) mission
      - Environmental monitoring – difficult due to mass/altitude restrictions
      - Precision navigation/timing – a MEO mission, primarily strategic
      - ISR – availability - SIGINT/28%, comm/19%, IMINT (3%) – not good
      - Overall timescale mismatch – need minutes, not hours response
    - Overall conclusion – non-orbital assets provide better utility/need force mix

Summaries of Responsive Space 5 Papers by Session
Tactical Satellites (Cont'd)

- The Integrated System Engineering Team (ISET) was established to develop and validate primary interface standards for a class of ORS spacecraft, primarily focused on completing a bus for the TacSat-4 HEO mission (Stadter, et. al., 4004)
  - To date 4 reviews have occurred – SRR, CoDr, PDR, CDR
  - Current status
    - Efforts of the Integrated System Engineering Team have successfully produced extensive trades and well-documented set of standards and interfaces for cost-effective S/C buses of the class of missions considered
    - Validation of a subset of these standards is proceeding through the development of the prototype bus in an open manner that allows government and industry insight into successful implementation approaches and challenging issues that have arisen
    - Because JHU/APL and NRL have led the development of the prototype bus, no proprietary claims have been exercised and any design aspects and techniques are available to the government sponsor for future consideration in industry-supplied operational builds
    - Prototype build of ORS Phase III spacecraft bus to support the TacSat-4 mission is scheduled for completion in April 2008
    - Launch on a Minotaur IV vehicle with a Star 48V fourth stage configuration

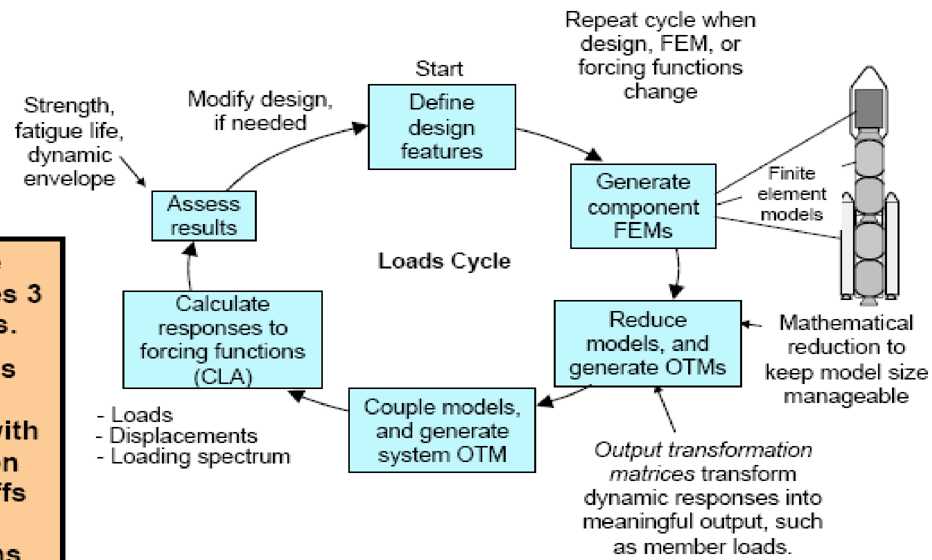
- The Minotaur I demonstrated responsive launch for the TacSat-2 mission (Schoneman, 5002)
  - Rapid launch vehicle build and call-up (<7 Months) - utilized existing long-lead hardware
  - Timed critical operations for ORS baseline - demonstrated 6 day integration (24/7)
  - Stood-by "On Alert" for 5 days while spacecraft issues were resolved and launched When called-up
  - Multiple "firsts" demonstrated while meeting compressed launch integration timeline
    - First Minotaur I mission from Wallops
    - First flight of larger 61 inch diameter Minotaur I fairing
    - Four month integration of NASA Ames GeneSat-1 secondary pico-spacecraft:
    - RocketCam™ onboard video
    - Tightest orbital accuracy requirement to date for Minotaur I

	Orbital Altitude (Apse)		Inclination (deg)
	Insertion	Non-Insertion	
Required:	410 ± 15 km	410 ± 55 km	40.0 ±0.2°
Space Track TLE (Jan 07)	413 km (Δ = + 3 km)	424 km (Δ = +14 km)	40.01° (Δ = 0.01°)

- There is a need to simplify the structural verification process relative to the compatibility of the launch vehicle and payloads in order to accommodate responsive launch (Sarafin, et. al., 5003)

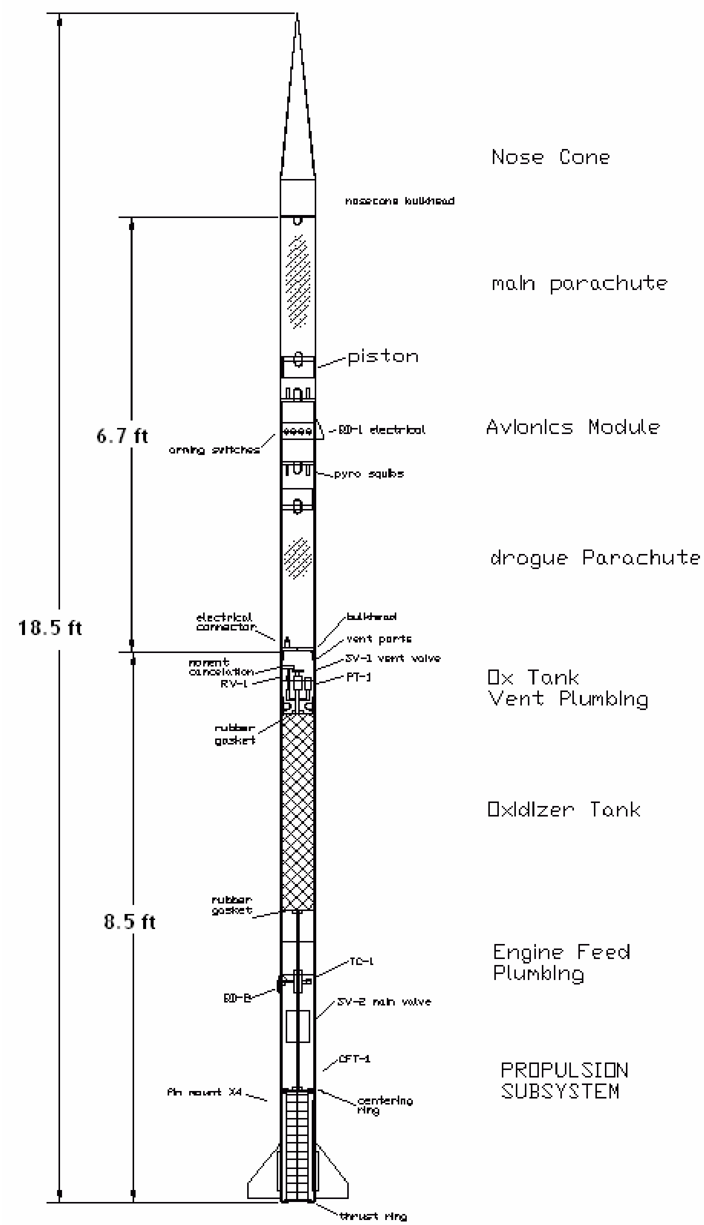
This cycle typically takes 3 to 9 months.

Much of this time is associated with coordination and hand-offs between organizations.



  - Eliminate the need for mission-specific coupled loads analysis (CLA), modal surveys, and exchanging math models between organizations – do variational CLA up front for a range of payload (spacecraft) characteristics and constrain payloads to be within the family analyzed
  - Eliminate the need for review and approval of structural analyses and test plans by mission stakeholders – standardize a simple, effective structural test that is not dependent on analysis
  - Reduce the severity of vibration environments and thus reduce the chances of failure during ground testing (and the mission)
    - Risk from shock can be greatly reduced with a low-shock separation system and a vibration-isolation mounting system)
    - Acoustics not worthwhile for most small spacecraft

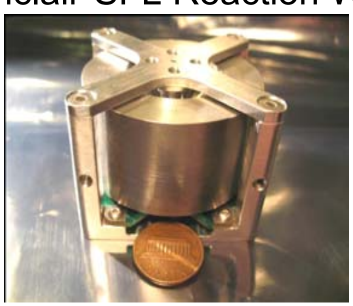
- This paper discussed the technology progress for a small launch vehicle being developed at Purdue University, focusing on the hybrid rocket motor and the recovery system (Droppers, et. al., 5004, student paper)
  - Propulsion:
    - Initially 250 lbf thrust, 90% H_2O_2/HTPB hybrid, blowdown system; later 900 lbf
    - H_2O_2: high density Isp, non-cryogenic, non-toxic, reduces complexity/operations costs
  - Structure:
    - Carbon-fiber composite airframe
    - Aluminum 6061-T6 oxidizer tank
    - Aluminum internal structure
  - Recovery:
    - Dual pyrotechnic parachute deployment (primary/drogue)
    - Redundant recovery system avionics
  - Ground Support Equipment:
    - Remote fill/draining of hydrogen peroxide to and from vehicle
    - Remote control and monitoring of sounding rocket launch operations
  - Guidance and Control
    - Initially G10 fiberglass Fins
    - Liquid injection thrust vector control technology in development



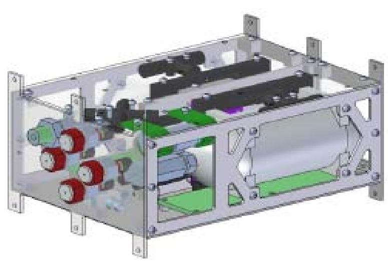
Summaries of Responsive Space 5 Papers by Session
Launch (Cont'd)

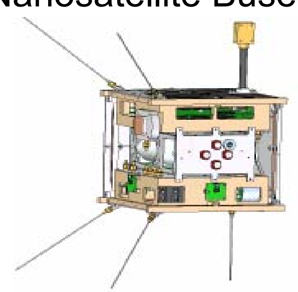
- The Generic Nanosatellite Bus from the University of Toronto Institute for Aerospace Studies meets the common-bus challenge for a wide range of nano-class missions (up to 12 kg and potentially bigger), and provides a platform for state-of-the-art, high-performance applications not previously achievable with nanosatellites (Pranajaya, et. al., 5005)
  - A 20 cm cube
  - One ARM7 housekeeping computer, two ARM7 computers for attitude/propulsion control and payload operations
  - CMOS imagers
  - A power system with triple-Junction cells and lithium-ion batteries
  - Passive thermal control
  - UHF uplink, a 32-256 kbps S-band downlink
  - A 1 arc-min three axis attitude control system consisting of tiny reaction wheels, sun sensors, magnetometer and star tracker
  - A cold-gas propulsion system may also be added
  - Cost effectiveness achieved with commercial components, good design practices, quality assurance, plus focused objectives/requirements

Sinclair-SFL Reaction Wheel



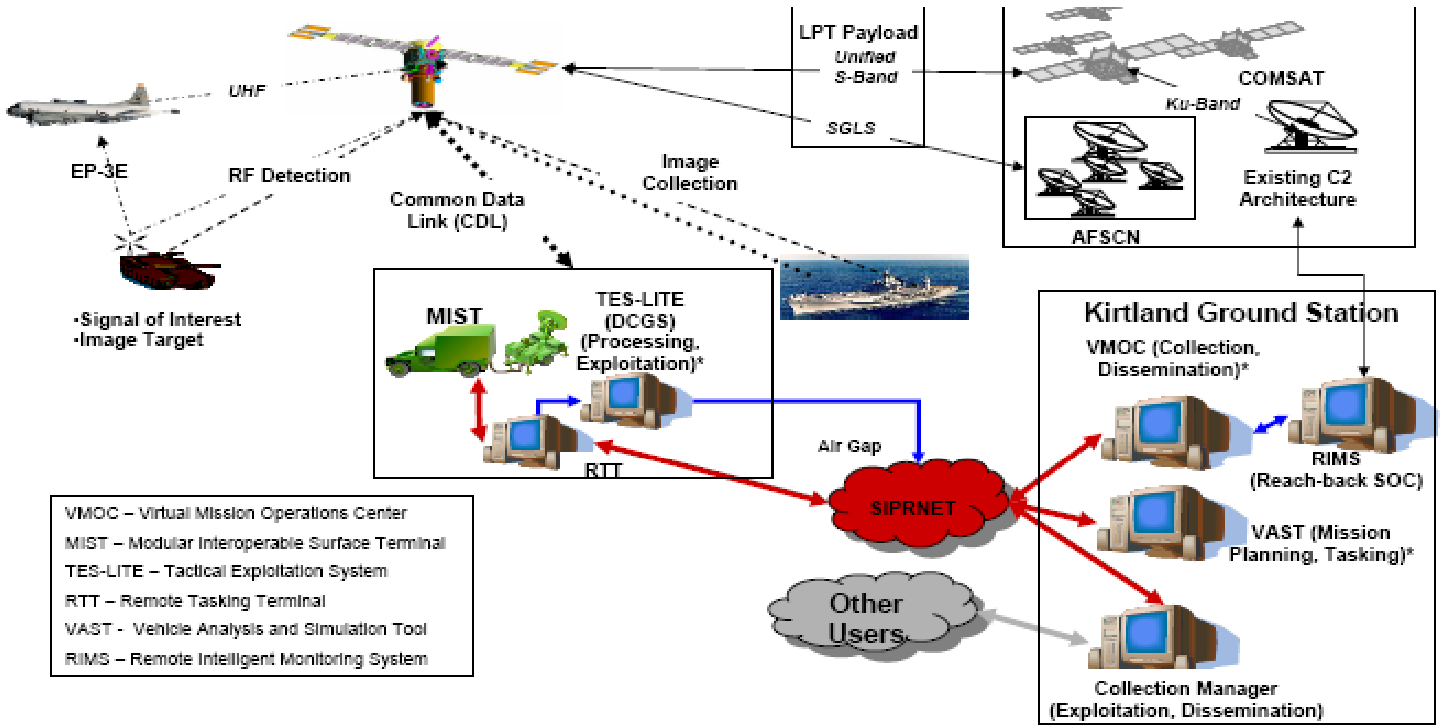
Nanosatellite Buses





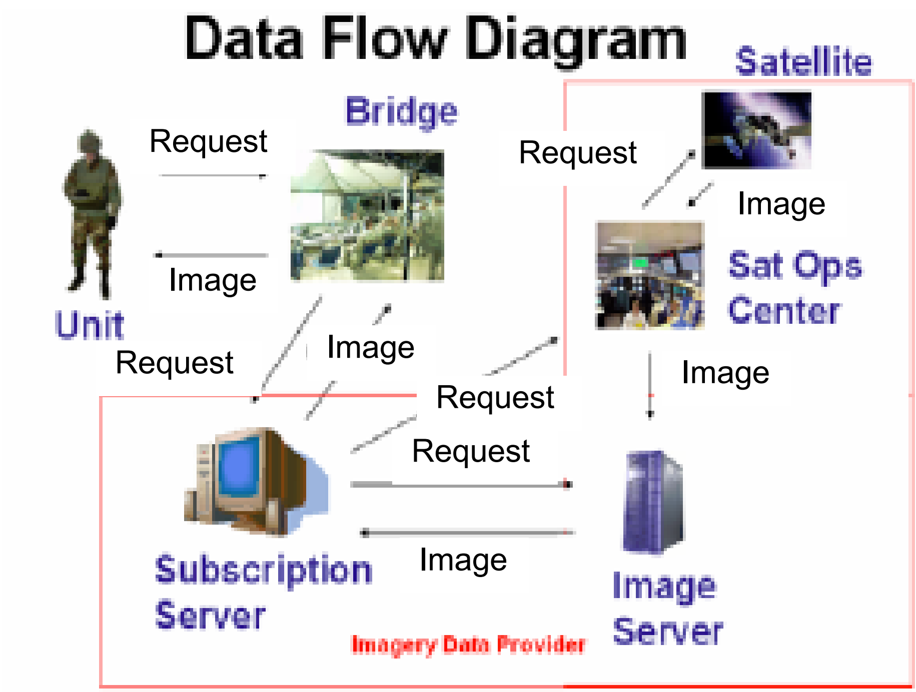
- The Virtual Mission Operations Center permits incremental demonstrations within the relevant operations environment (Miller, et. al., 6001)
  - System of Systems multi-mission planning, command, control, and dissemination of Responsive Space sensor data
  - Payload access to broader numbers of operational users
  - Seamlessly link sensors of various organizations to a broad based community of users for data: tasking, access, and collaboration via web technology
  - Environment for incubating, exploring, and maturing new and relevant web technologies, concepts of operations, and tactics, techniques, and procedures through operational experimentation
  - Bounds the issues and sets the Way Ahead
  - Focused on specific areas of interest within each organization
  - Spydr Terminal Fury (TF) Demonstration
    - MOC Modeled a mature ORS - constellation of 7 satellites
    - Included imagery and RF detection like TacSat-1 and -2
    - Distributed users on web browser
    - Quickly integrated into TF
    - Required no new HW
    - Provided awareness of ORS
    - Training for first adopters
    - Lessons learned
      - Highlighted need for TacSat call-up procedures - establish new policies and procedures for ORS
      - Task priority and apportionment - exercise highlighted need to overwrite lower priorities
      - Evaluating ORS within a traditional exercise like TF - exploration of alternative CONOPS was limited; different metrics needed for ORS than traditional systems

- TacSat-2 represents the first step in taking ORS from an idea to a reality (Finley, et. al., 6002)
  - TacSat-2 Mission Objectives
    - Assess military utility of low-cost ISR satellites & ground stations
    - Evaluate concepts for simplifying and expanding warfighter access to space assets
    - Demonstrate concepts for faster acquisition, responsive launch & operations
    - Accomplish many on-orbit requirements of many non-tactical payloads

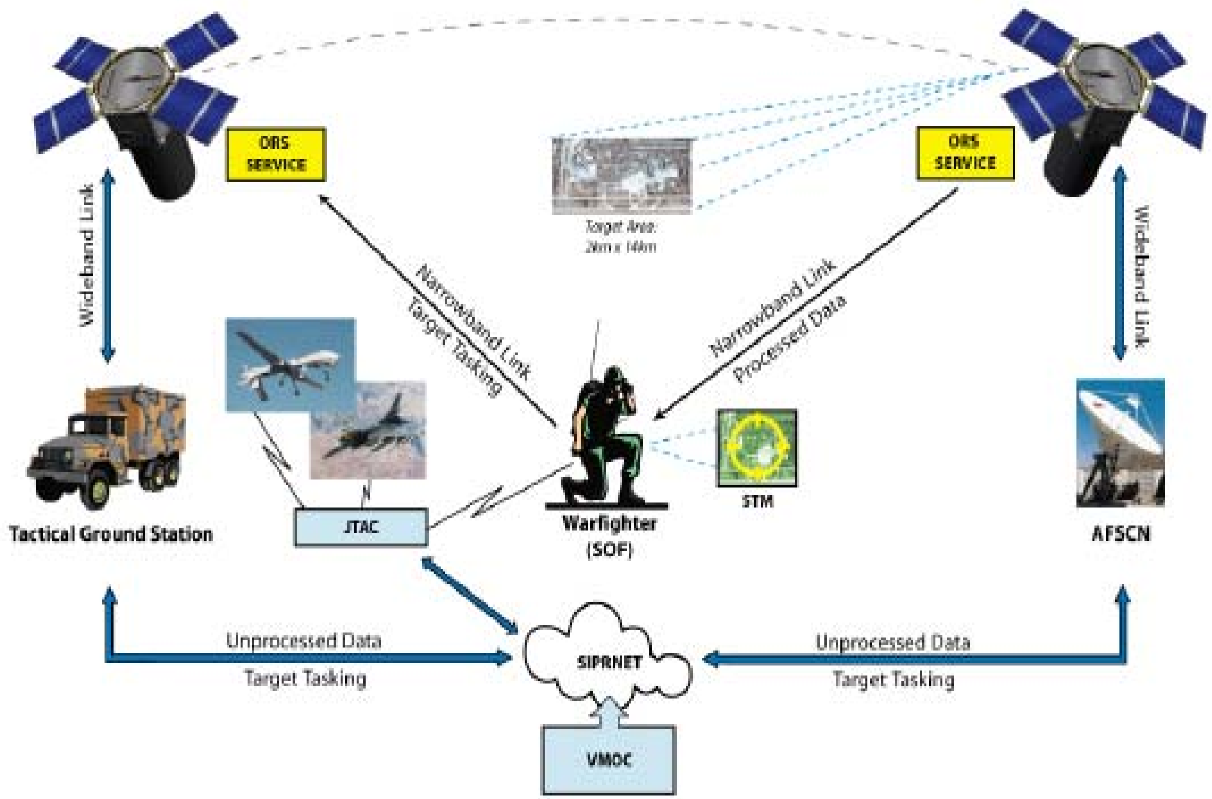


  - **During the RS5 Conference, TacSat-2 was commanded from a remote handheld device at the conference, which resulted in TacSat-2 sending a message to the email of everyone in the conference**

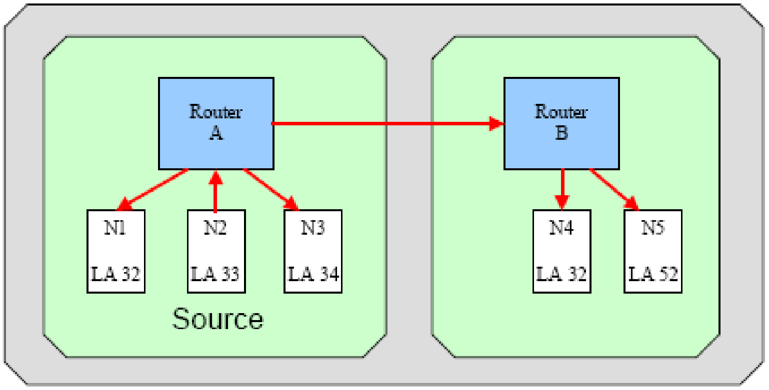
- TheTactical Spacecraft Commanding Service Architecture (TSCSA) effort proposes to develop a system architecture that is warfighter centric and will explore a fundamentally new way to access, task, and receive information from tactical spacecraft assets based on the notion of a distributed, semi-automated planning and scheduling framework built on current web service standards (Yan, et. al., 6003)
  - APL has succeeded in developing and fielding operational strategies and software that work hand in hand to insure maximum utilization of space resources
  - Software enables mission and payload operations staff members to define and publish a capability and command dictionary for each tactical satellite so that warfighters can ingest (via software) a complete understanding of what capabilities are available and how to invoke each one



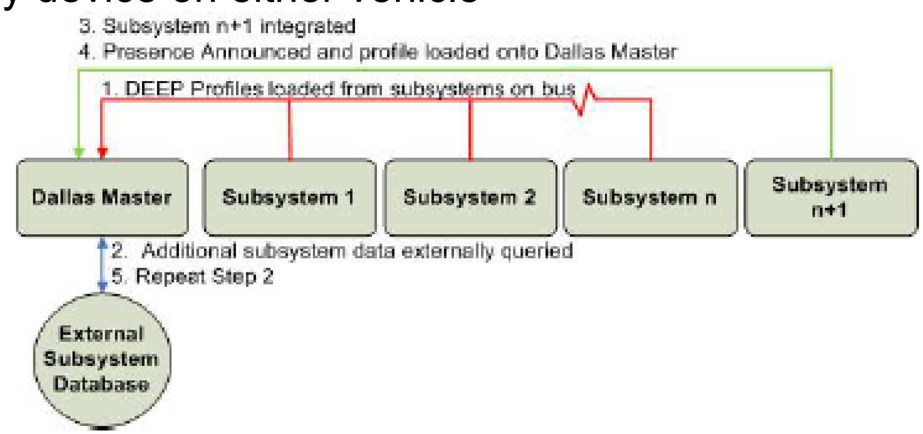
- The Training and Tactical ORS Operations (TATOO) Lab is a computer simulation environment whose purpose is to exercise methods of in-theater tactical satellite tasking for the Warfighter, demonstrate tasking of autonomous ORS satellites, train satellite systems operators, and foster an environment where a standard operational approach can be developed to benefit both the warfighter and operator (Mann, 6004)
  - Training Exercises are meant to show how ORS ideas can streamline the process of requesting and receiving satellite products
  - Stored in a courseware system accessible to the Lab



- Plug and Play utilizing spacewire can aid in achieving responsive space (Klar, et. al., 7001)
  - High speed, low power, designed for space; already a European Space Agency standard based on IEEE 1355 serial standard
  - Used in current & future missions – GOES-R, JWST, Multiscale Magnetospheric Mission
  - SpaceWire has very simple data packet requirements, no standard ARP, broadcast, or higher-level methods
  - SpaceWire would benefit from defined integration with higher-level features (e.g., enables use of IP), automatic configuration, including DHCP
  - Defined broadcast protocol can reduce and balance router load across network (vs. sequential unicast)
  - Goals for spacewire broadcast
    - Broadcast without knowing path to each destination
    - Support existing upper layer protocols or direct use by application
    - Work with existing ESA standard
    - Work with existing COTS SpaceWire hardware
    - Solution could be added to hardware
    - Prevent Loops
  - Messages distributed by sequential unicast to each individual end node



- A protocol exists for the creation of a satellite-wide model paralleling the physical integration of the spacecraft, which allows a stockpile of flight Dallas EEProm Equipment Profile (DEEP) enabled subsystems, ready to be rapidly composed into a functional spacecraft, thus enabling responsive spacecraft by decreasing integration and test time (Rogers-Marcovitz, et. al., 7006)
  - Three elements must be present for the DEEP concept to work
    - A standardized communications bus (Dallas 1-wire bus)
    - A common memory device directly accessible on this bus (1-wire compatible EEPROM device)
    - A common memory structure (hardware profile) across all memory devices
  - The plan is to implement DEEP into the existing Akoya and ONYX satellites
    - Akoya – the host vehicle that provides docking, recharging, ground communications capability
    - ONYX – supports a multispectral imager - provides a testbed for model based anomaly management
    - At the 2006 Conference on Small Satellites, both vehicles were connected via a common power and data wiring harness, allowing one spacecraft to operate any device on either vehicle



The Process Continues

- It is clear to this author that responsive space has become a critical need, and the technologies and infrastructure to support responsive space missions are either available or will be soon
- It is also clear that now it is more a matter of having the necessary will to proceed than anything else for responsive space to become a reality in the very near term
- With the ORS Office officially in existence this month, there is now an official home and a substantial budget to move responsive space forward
  - Schedule*
    - Report to Congress "Plan for ORS" signed by DepSecDef on 19 April
    - Initial ORS Office stand-up in May 2007
    - ORS implementation planning for full-up ORS Office by 1 October 2007
  - Congressional support strong*
  - Service Labs heavily investing*
  - Joint Team still defining ORS roles, missions, capabilities, policies, procedures, personnel & funding - Leveraging ongoing space launch vehicle and TacSat effort*
  - Refining leadership, organization, and program plans*

* Extracted from the Keynote presentation by Mr. Joseph Rouge, Associate Director National Security Space Office