Racing Toward Becoming Operationally Responsive in Space

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Abstract

The US Air Force Research Laboratory (AFRL) is currently supporting the joint Operationally Responsive Space (ORS) program with two aggressive research space programs. The goal of the ORS program is to improve the responsiveness of space capabilities to meet national security requirements. ORS systems aim to provide operational space capabilities as well as flexibility and responsiveness to the theater that do not exist today. ORS communication, navigation, and Intelligence, Surveillance and Reconnaissance (ISR) satellites are being designed to rapidly meet near term space needs of in-theater tactical forces by supporting contingency operations, such as increased communication bandwidth, and ISR imagery over the theater for a limited period to support air, ground, and naval force missions. This paper will discuss how AFRL/RHA is supporting the ORS effort and describe the hardware and software being developed with a particular focus on the Satellite Design Tool (SDT).

In an effort to further support the evolution of ORS technologies with Warfighter's involvement, Star Technologies Corp recently started coordinating the integration of the TATOO Laboratory with a satellite robotics test bed. Accessible via the TATOO Lab, the robotics test bed will be used to demonstrate and evaluate leading edge satellite technologies, such as Guidance Navigation and Control, attitude control, formation flying, and plug-and-play electronics. The test bed will consist of a Mission Control Center with wireless control and telemetry, an exceptionally flat and smooth floor area, and two robotic satellite simulators equipped with "next generation" plug-and-play hardware.

Introduction

AFRL's Space Vehicles Directorate together with the Scientific Simulation, Inc. was the first to create the Plug-and-play (PnP) satellite design for rapid construction through modular components that encompass the structural panels, as well as the guidance and health/status components. Expansion of the PnP technology is currently being led by AFRL's Human Effectiveness Directorate and Star Technologies Corp. by pushing the boundaries of mobile hardware and software technology through developing the "Training and Tactical ORS Operations (TATOO)" Laboratory located in Great Falls, VA. The TATOO Laboratory provides a computer-based simulation environment directed at improving Warfighters' space capability responsiveness by delivering the means to create and exercise methods of in-theater tactical satellite tasking for and by the Warfighter.

The Air Force Research Laboratory/ Human Effectiveness Division (AFRL/RHA) and Star Technologies Corporation are continuing to push the boundaries of mobile hardware and software technology through the development of the team's "Training and Tactical ORS (Operationally Responsive Space) Operations (TATOO)" Laboratory located in Great Falls, Virginia (Fig 1). The TATOO Laboratory provides a computer-based simulation environment directed at improving Warfighters' space capability responsiveness by delivering the means to create and exercise methods of in-theater tactical satellite tasking for and by the Warfighter.

Fig. 1. TATOO Laboratory

The current approach of delivering satellite information to the Warfighter through the Virtual Mission Operations Center (VMOC) is deemed inadequate on the modern battlefield. However, through collaboration with the United States Special Operations Command (SOCOM) and the Air Force Special Operations Command (AFSOC), the TATOO team is addressing select AFSOC space-technology deficiencies. Some focal areas include: providing direct tasking satellite software, developing training material, procedures for the Warfighter and satellite systems operators and conducting ORS training sessions. The technological underpinnings of this newly-developed technology will be the ease with which allow Special Operations Forces (SOF) personnel to model ORS satellite processes, and directly task the satellites for communications and sensor data in operationally relevant timeframes (Fig 2).
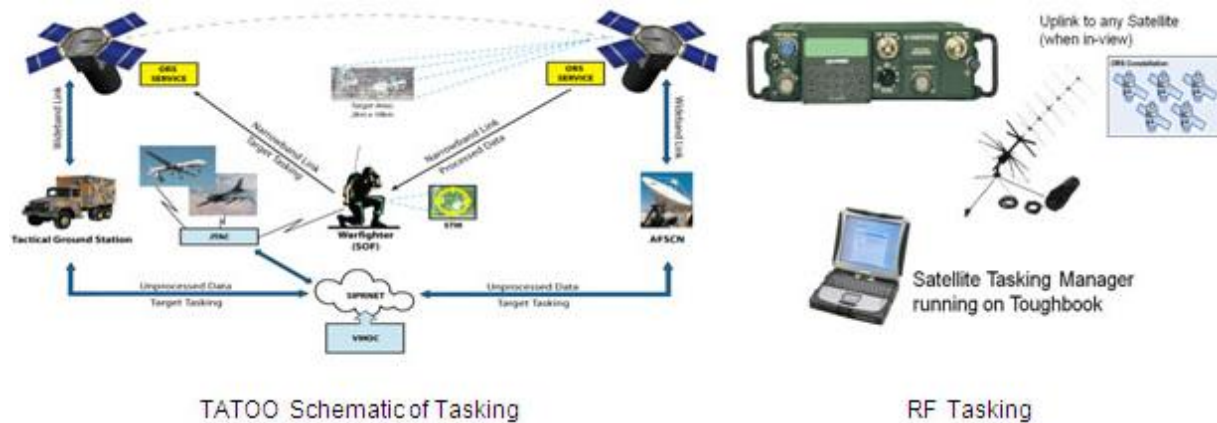
Fig. 2. Tasking Schematic

ORS, according to the Department of Defense, is a subset of space activities focused on timely satisfaction of the urgent needs of the Joint Force Commanders (JFCs) for improving the responsiveness of space capabilities to meet national security requirements. ORS communication, navigation, and Intelligence, Surveillance and Reconnaissance (ISR) satellites are designed to rapidly meet near term space needs of in-theater tactical forces by supporting contingency operations, such as increased communication bandwidth, and ISR imagery over the theater for a limited period to support air, ground, and naval force missions [1].

The TATOO Laboratory builds on concepts that tie in directly with the operational side of ORS by using realistic training and simulation to support the development and evaluation of ORS specific Concept of Operations (CONOPS) approaches, along with the training and evaluation of those CONOPS implementations for in-theater tasking, image collection, and data retrieval from Tactical Satellites (TacSats). The Laboratory fosters an environment for improving existing ORS tactical CONOPS through the development, demonstration, and assessment of realistic training for autonomous satellite tasking, scheduling, interface, and data retrieval for TacSats owned by In-Theater Commanders.

For training exercises, the team utilizes its Spacecraft Design Tool (SDT) to emulate ORS satellites and to provide an environment for rapid prototyping of spacecraft using true plug-n-play components, environments, and subsystems. SDT is AFRL's high fidelity dynamic spacecraft 6 degree-of-freedom (6DOF) simulation software used inside its Responsive Space Testbed that offers both simulation and real-time data display capabilities, including attitude (Fig 3). The simulation tool is a component based architecture designed after Microsoft's .NET framework. The software can load an array of component models for rapid Responsive Space satellite and TacSat2 design, including sensors, actuators, electrical, propulsion, and attitude determination and control systems (ADACS). It can integrate with virtually any external program, including MATLAB and other thermal, structural and optics modeling tools. The SDT also provides Real-time messaging that allows distributed Satellite Systems Operators (SSOs), who are certified in satellite tasking, to address each ORS satellite via a TCP/IP port, replicate aspects of proposed ORS operations, and communicate to each ORS Satellite Activity Manager the autonomous state-of-health activities and battery-life status of each satellite. The Satellite Activity Manager is the mechanism on-board each satellite that reconciles Warfighter requests received by the SDT.
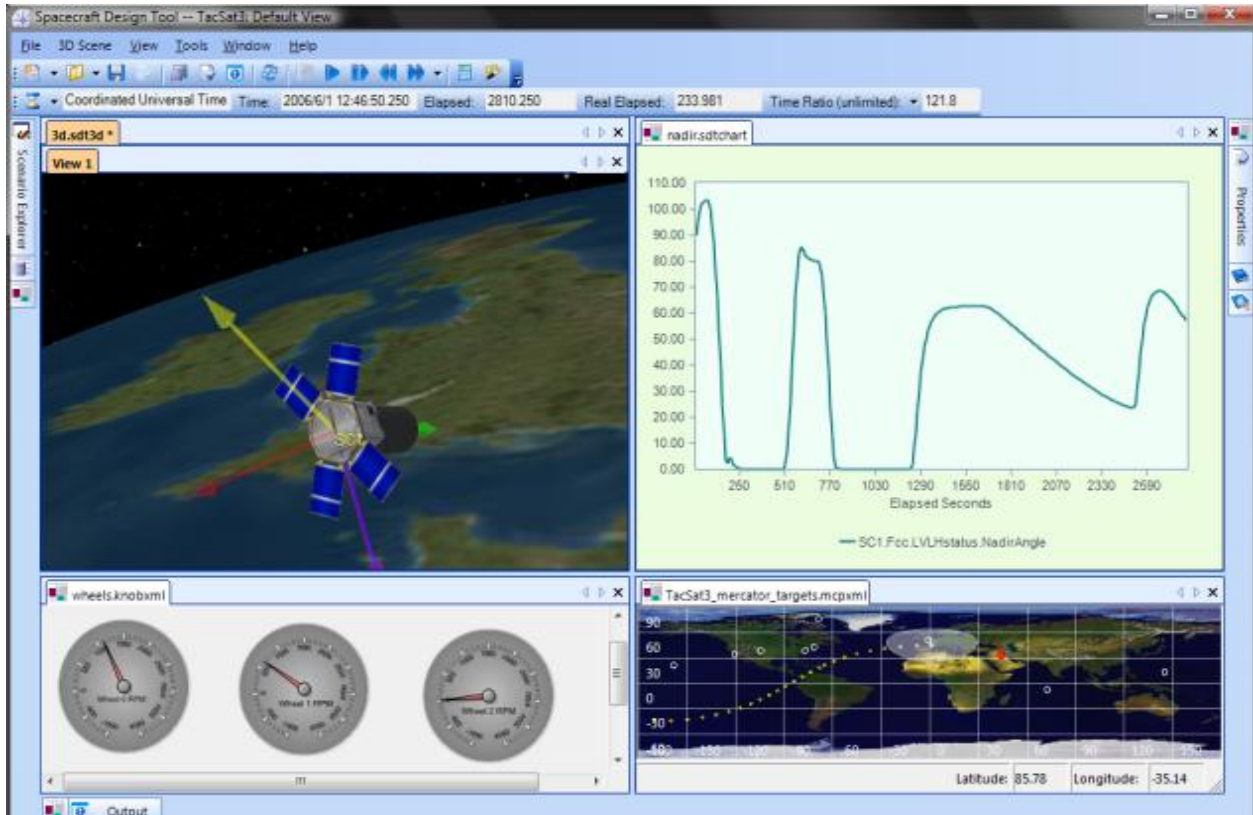
Fig. 3. Spacecraft Design Tool

Within this plug-and-play framework, the user can also run 3D interactive training exercises focused on modeling and experimenting with ORS constellation sizes, allowing users to understand the resulting effects on the timeliness on meeting battlefield requests. SSOs can also experiment and publish different orbits to the SDT using Analytic Graphic, Inc's Satellite Tool Kit (STK) with coverage module, a commercial-off-the-shelf (COTs) software tool for satellite designers and space mission planners that performs all of the calculations for the trajectory and attitude of spacecraft around the Earth and other celestial bodies. The orbital information provided by the STK software enables SSOs to prepare for the launch of new ORS satellites and permits users at the VMOC node to visualize how ORS satellites can quickly assist in mission needs, from the Warfighter applications to satellites.

The TATOO Lab also supports the advancement of Tactical Ground Station Mission Operations; Tactical Operations for Mission Tasking and Scheduling; Tactical Mission Data Retrieval; and Warfighter Support Systems. Through the use of ESRI's Geographic Information Systems (GIS) based tools (currently ArcView and FalconView), combined with Star's Satellite Tasking Manager (STM) plug-in, the Warfighter and theater commander in the theater node can view a projected ground trace of each ORS satellite over a location with their expected pass time, current tasking load, and capabilities. STM is a revolutionary advancement in satellite tasking, providing users a point and click interface designed to simplify the process of requesting and receiving satellite products; the plug-in, accessed via a toolbar button in ArcMap and FalconView, provides a mapping and annotating functionality, giving users the ability to create and model the processes that are used to request a collection, and accordingly, determine the best choice asset for given ORS requirements. Working with the ORS Service and Targeting component on-board each satellite in the ORS constellation, the ground terminal- STM, is able to task any satellite in a given constellation; move tasking requests from satellite to satellite to meet constraints (i.e. date, time, location, angle, and cloud cover); track satellite tasking loads and priorities; supervise slew rates; and monitor the availability of ORS assets [2].

Using a propagator, the ORS Service periodically returns an almanac to the connected STM, to update users in the event that requests are moved, expected housekeeping times are adjusted, and/or satellite locations and capabilities have changed. With this information, SOF personnel can determine which satellites do not meet their constraints and avoid conflicts due to overlapping task requests. In the event of multiple Warfighters sending out task requests to the same ORS satellites, a request can be published to a commander, who can view the requests and select the optimal tasking. Additionally, a commander can authorize a Warfighter to have complete control over a designated time slot.

A typical scenario for a PnPSat1 or Tactical Ground station request entails a user connecting a Toughbook to a PRC-117 military radio transmitting 9600bps or a Secret Internet Protocol Router Network (SIPRNet) connection. The user then opens FalconView and ArcMap to select a coordinate set to represent an area of interest on a map, and if needed informs the STM of additional constraints such as date, time of day, look angle, and current cloud cover. When a satellite is in view, the user is alerted by the ORS Service and asked to authenticate with the satellite by sending a username and password. Next, the satellite compares this against a list, and once authenticated proceeds with transmitting a text-based message to the Warfighter containing the satellite's expected pass time, current tasking load, and capabilities to the STM through a TLE (two-line elements) file that represents the satellite's orbit. The STM interprets the message and creates symbols to represent the satellite's ground trace on a map using FalconView and ArcMap's GIS-based drawing tools. The user can then determine which satellite is best suited to meet operational requirements, and eventually prepare and send a tasking request directed through a RF or a SIPRNet connection to a specific satellite in-view within an ORS constellation. If the satellite can perform the task in the same pass, the product is downloaded as soon as available, however if the satellite cannot perform the task in the same pass and/or there are insufficient ORS assets, then the user is alerted by the STM as to when the product can be retrieved.

The STM not only offers solid task-management support to meet operational objectives, it also offers the possibility of High Performance On Orbit Computing (HPOOC) for the Warfighter's software, and image processing algorithms envisioned for AFRL's Plug-n-Play satellite effort. The STM possesses enterprise-class features that allow for the high-speed transmission of high-resolution imagery using SIPRNet for both tasking and product retrieval. Receiving imagery is also available via RF satellite communication, however due to the 9600bps transmission limit, the imagery product has to be received in multiple tries and pieced together with the STM. Nevertheless, the Warfighter can use the imagery to compare it against the Image Product Library (IPL), which is a repository of images saved from prior ORS Satellite collections. If needed, a Warfighter can request a Reachback and have personnel operating at the VMOC node to analyze the imagery, annotate, and publish it to the IPL so that the theater can later access it.

Standard operational approach for satellite tasking is proceeding in AFRL's Plug-n-Play satellite effort; the company's use of COTs hardware coupled with a PRC-117 military radio and SIPRNet connection is eliminating current decision-making and distribution delays. The integration of these technologies allows for timely and clear information and decisions to be passed to every level of command. The TATOO framework is a network-centric state-of-the-art solution that delivers Blue Force Tracking information directly to all air and surface in garrison, in transit, deployed, and executing forces. More importantly, the configuration provides the means for SOF and conventional operations to reduce complex spacecraft configurations by delivering the key channels to receive, process, display, and distribute space derived-data and products directly into platforms and austere operating locations. The proposed technology is streamlining satellite tasking, spanning mission capture to deployment, still, STAR Technologies has continued to expand the breadth of its support for ORS Services through its new robotic Satellite Simulation Test Bed (SSTB) development.

In an effort to further support the evolution of ORS technologies with Warfighter's involvement, Star recently coordinated with subcontractor Andrews Space on integrating the TATOO Laboratory with Andrew's SSTB located just south of Seattle, Washington. Accessible via the TATOO Lab, the SSTB was used to demonstrate

and evaluate leading edge satellite technologies, such as Guidance Navigation and Control, attitude control, formation flying, and plug-and-play electronics. The test bed will consist of a Mission Control Center with wireless control and telemetry, an exceptionally flat and smooth floor area, and two robotic satellite simulators equipped with "next generation" plug-and-play hardware.

The two rechargeable battery operated satellite simulators are equipped with a GPS simulator, a wireless modem for IEEE 802.11 LAN systems, a cold gas reaction control system, reaction wheels, control movement gyros, rate gyros, a pneumatic vertical piston, and air bearing surfaces and joints to achieve the required 6DOF (rotations and translations) needed for testing and training (Fig 4). The lightweight satellites will also incorporate an intelligent Space USB (SPA-A) plug-and-play software architecture with Satellite Data Model (SDM) and xTEDs flight software. The SDM is a side-ware system that will provide fault-tolerant plug-and-play features, such as a Data Manager, Sensor Manager, Task Manager, and a Process Manager. The SDM will allow components to register their own data requests and xTEDS (a XML description of characteristics of spacecraft hardware and software) to the network, in addition to providing components with a producer that most closely matches their data needs and formats. Following this design paradigm, it is anticipated that the fusion of technology will significantly improve satellite data sharing capabilities, space-derived products, and Warfighters' access and use of commercial communications satellite transponders. Moreover, the robotic models are expected to greatly enhance satellite integration, resulting in increase ability for mission planners, C2, ISR and executing forces to receive, process, and disseminate accurate, timely, and manageable information.
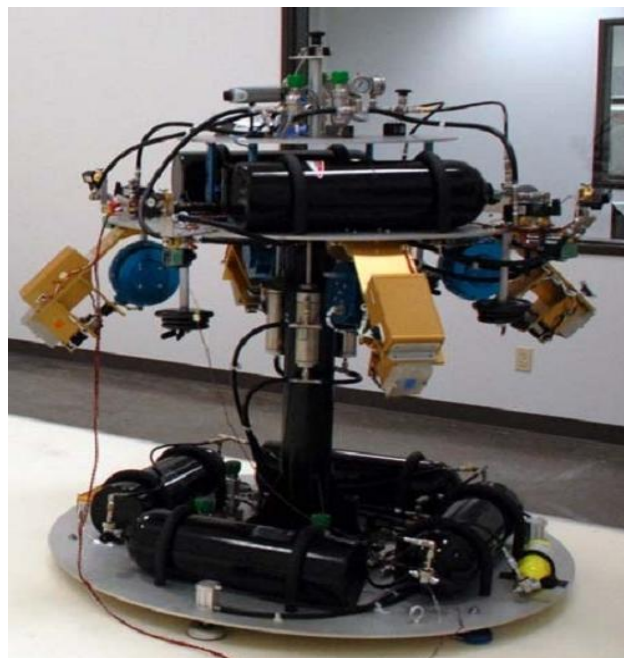

Fig. 4. Robotic Satellite Simulator

In May of 2009 a demonstration was conducted by Star Technologies and Andrews Space Inc that utilized the Satellite Simulation Test Bed and the TATOO Laboratory which performed a mission over North America. Inside the test bed, the team conducted a functional demonstration and experiment with simulated Warfighter-satellite interactions. Using the Spacecraft Design Tool, users in the MCC were able to supervise and control the robotic satellites and their product delivery. In an isolated section of the facility, the one robotic simulator traversed the large self-leveling epoxy floor space on high pressure air bearings to approximate the frictionless movement in space and was able to deliver simulated satellite products to team members located at the remote TATOO Laboratory in Great Falls Virginia. The MCC also included several distributed cameras for satellite observations,

and a suite of computers and monitors connected over the internet to the TATOO Ground Station to replicate a remote real-time training capability. The long-term expectation is that the architecture and integration of the two facilities will rectify the current outmoded controller workstations, minimize the footprint for processing and displaying space-derived information and deliver space information and products to deployed locations.

Overall, the demonstration produced a solid benchmark for further development and system refinement. It also showed the potential for a sound approach to satellite specialty training that will assist ground force personnel in preparation of satellite tasking and resource decisions across all field conditions at different security levels. We are pleased to report that the successes of the TATOO program will be carried forward into further development by the Space Vehicles Directorate of AFRL. It is the hope that products developed through the TATOO program will advance the plug-and-play satellite concept and ultimately equip warfighters with a pedigree space control system that will enable precision and efficacy needed for the successful operation of advanced satellite systems.

References

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