Space Access and Awareness: The Future Skyways
A Presentation By Tim Grayson

Imagine operating in space as frequently and easily as we currently can travel through the skies.
Consider this story.
The year is 2015, and the U.S. is getting ready to launch the largest communications satellite ever built.
But this satellite is like none every built before - because it is indeed not yet built!
This is the last of 4 inexpensive launches, containing the satellite bus, on a small, low-cost, expendable launch vehicle.
The antenna assemblies and solar arrays were launched separately as secondary payloads on others' launches and are currently waiting to be mated to the bus.
Once the bus establishes itself in orbit, a robotic spacecraft performs a rendezvous with the drifting pieces of satellite and autonomously wrestles them together.

Meanwhile the integrated Space Situational Awareness System has detected unusual movement of some drifting debris.
The system autonomously cues a highly sensitive, rapid-response sensor to investigate, and it detects some new object separate from the debris and travel on a track that threatens our brand new communications satellite in less then 12 hours!
An alert is sent to the Space Operations Base.
A technician deliberately but calmly pulls a few boxes off a shelf in a depot-like facility and assembles together a mission-tailored inspector spacecraft packaged for launch in less than one hour.
A rapid-response launch platform is sitting outside the assembly building on the tarmac fueled and ready for take-off.
The inspector satellite is loaded on board the launch vehicle, which then scrambles, and in less than 2 hours, the inspector satellite is on orbit.
The inspector satellite is propelled up to the suspicious object by a fast-response orbital transfer system and attempts to characterize it with its extensive suite of imagers and other sensor payloads.
It turns out to be just a panel that had broken off a dead satellite.
Our communications satellite maneuvers just slightly to avoid a potential collision, and with time to spare, this high-value satellite is saved, and an international incident is avoided.

Despite the tremendous capabilities enabled by operating from space, space is still a very difficult place to access and operate within - and equally expensive - far from this vision of aircraft operations.
Once we get to space we face equal challenges knowing what is happening there and how to operate safely, as space becomes a more crowded and hazardous environment, even out at the heights of geostationary orbit.
With your help the DARPA Virtual Space Office is endeavoring to bridge this gap between our present capabilities and our future vision of routine space operations.

DARPA's space legacy is rooted in space access with the development of the main engine of the Saturn V rocket.
DARPA is back in the access business, but just as the mainframe computer has been replaced by the desktop workstation, smaller and cheaper this time are better.

The greatest challenges in access today are cost, timeliness, and flexibility.
Compare space operations to the express air cargo industry.
Cost - Despite some improvement over the years, it still costs about $10,000 / kilogram to launch satellites into space.
We can ship a full container by air for less than a few $100.
Timeliness - To launch a satellite, we need to pick out a rocket early in the satellite design, years in advance, and have the payload delivered for rocket integration 6 months or more before launch.
By air we can drop an express package in a drop-box and have it delivered the next

day.
Flexibility - There are only 3 launch sites available to the US military.
We can ship air cargo from just about any town across the country.

While some of this disparity between space access and analogous air cargo delivery is economic, there remain tremendous technical challenges, as it takes incredible energy to lift a mass outside the bounds of Earth's gravity.
The launch environment in a vehicle that can deliver this kind of energy can be very violent, and it can be extremely harsh on the delicate, complex payload it is carrying aloft.

DARPA has begun to address these issues by developing an airborne launch capability to place micro-satellites and commodity payloads into low earth orbit at any time, any inclination.
By putting the technology focus on the reusable airborne launch platform, this system makes the expendable rocket element very simple, enabling rapid, efficient integration of microsatellite payloads.

DARPA is also working with the US Air Force to develop and demonstrate technologies that will enable radical new global reach missions.
As the U.S. continues to reduce its foreign basing, the new concept of global reach will enable delivery of vital supplies or munitions from the continental U.S. to any place on the planet in under 2 hours.

So what comes next for space access?
Suppose we could design a system with a few hour launch responsiveness capable of lifting much greater payload masses of 500 lb or more to any low earth orbit?
Suppose we could extend the very low-cost expendable launch capabilities being developed to be versatile enough to deliver payloads well over 1000 lbs. into any desired orbit?

While there may be many innovative new paths to achieve these goals, one of the greatest technical challenges that could be addressed for substantial benefit is booster simplicity.
Example approaches to achieve this simplicity and reduce cost could include turbopumps with few parts and light-weight, rapidly manufacturable composite fuel tanks.
Ablative thrust chambers and hybrid (solid/liquid) thrust concepts could provide yet further affordability and performance gains.

Making space easily accessible will also entail system and architecture challenges as well.
We need to design satellite payloads with standard interfaces to take advantage of the responsive booster designs, and we need a depot-like logistics infrastructure to enable truly rapid response.
We need much more flexible and efficient spaceport operations with wider range-safety margins and fewer people.
While not all of these problems are technical, innovative technology can still play a crucial role, with new capabilities such as reconfigurable payloads and autonomous and rapidly deployable range monitoring and operations systems.

While affordable, responsive access to space it a key element to achieving DARPA's vision of versatile spaceway operations, one also needs a flexible, capable operating infrastructure once there.
Suppose satellites could be launched without propellant to save mass and fueled on-orbit with propellant launched separately in a "dumb" commodity vessels?
Suppose a very expensive, very heavy, very complex spacecraft could be launched in pieces over multiple low-cost, small booster launches and then assembled on-orbit to reduce net launch cost and risk?
Suppose highly efficient orbital transfer tugs could move small spacecraft into higher orbits to facilitate microsatellite operations in deep space?

An example of space infrastructure work already underway is space tug technology

that will enable grappling of spacecraft and components that do not have specialized standard interfaces.
More advanced versions of robotic space tugs like these could also be used for spacecraft repositioning, rescue, and retirement maneuvers.
But this is only the beginning.
The entire area of autonomous orbital space infrastructure remains in its infancy and offers limitless opportunities for creative concepts.

One such opportunity is on-orbit assembly, but many challenges lie ahead to make this a reality.
Mission spacecraft designs will need to become modular, if not adaptive or interchangeable.
Sensors and processing algorithms on the robotic spacecraft will need to be able to very accurately distinguish and orient a wide variety of spacecraft structures and components in 6 degrees of freedom.
Manipulators will be needed with greater flexibility, freedom of movement, authority, and control - perhaps even a sense of touch?

Ultimately the goal may lie beyond on-orbit assembly with instead on-orbit manufacturing.
If it is cheaper and lower-risk to lift individual components of a satellite, it may be even more so to lift raw building materials.
Clearly the challenges in this case become extreme, but not insurmountable.
The robotic satellite would need to become a full-fledged factory, capable of processing raw materials into a required structure.
Other approaches could take advantage of as yet to be realized smart materials that could essentially manufacture themselves.
While the future is still uncertain for this technology, the potential gains with respect to the ability to put enormous structures on-orbit are as promising as the challenges are daunting.

Another important aspect of the infrastructure vision is propulsion.
None of the as yet envisioned access solutions can deliver payloads into deep space orbits.
One way to fill this gap could be an orbital transfer tug, which could incorporate grappling with a variety of propulsion technologies.
If such a system existed, a microsatellite could be launched by a low-cost, responsive launch vehicle with only its propellant needed for operational maneuver and then lifted into deep space by a tug.
Conventional chemical propulsion is not likely to be able to support this type of capability, and so there is tremendous opportunity for truly innovative propulsion solutions.

Finally one cannot truly operate in space like we do in the air without knowing what is happening there.
Who in this audience would want to have flown here to this meeting without an air traffic control system?
Space situational awareness poses yet another daunting set of challenges and opportunities.

Fundamentally, space situational awareness involves both the generation and management of information to provide current and accurate answers to the questions:
Where is it?
What is it?
and What is it going to do?
This is becoming an increasingly challenging problem as new satellites are launched, and old satellites break apart and become debris.
Often not much information about on-orbit objects is available, putting the entire discovery burden on the situational awareness system.
Situational awareness must provide exquisite characterization of these enigmas in a timely enough manner that one has the opportunity to evaluate and execute an evasive course of action.

The initial focus of DARPA's space situational awareness sensor development efforts has been on detecting and characterizing objects in deep space from the ground.
Existing programs are developing curved charge-coupled device sensors that will enable telescopes that can detect very small satellites and pieces of debris at geostationary orbit, while at the same time searching the skies over an order of magnitude faster than existing capabilities.
Similarly a new ground-based radar that DARPA is developing in partnership with the Air Force will provide images of satellites in deep space with over an order of magnitude greater resolution than currently attainable even at low altitudes.

The next step is to move to space with our situational awareness capabilities.
Some efforts have already begun to look at microsatellite-based near-field search capability.
Such satellites could escort high-value satellites, providing the last minute warnings of impending conjunctions.
There is still a great need for ideas on how to fill the gap between the ground-based and near-field systems.
Despite the revolutionary performance expected from ground-based systems under development, telescopes on the ground still suffer outages from daylight and weather.
And the types of sensors envisioned for near-field surveillance will inherently be short-range.

A great need exists for a space-based system that has global search performance approaching what can be achieved from the ground.
The challenge is doing this affordably in a responsive spacecraft, perhaps even a microsatellite.
To reach this goal requires advances in technologies such as light-weight optics and smart sensor concepts.
Unlike some of the truly gigantic future astronomy telescopes, a very high-performance SSA telescope could get incredible performance gains from only a 1-m aperture.
Such a telescope is very feasible using novel light-weight optics technologies.
Smart focal plane concepts could allow greater flexibility in SSA satellite operations.
When the system needs to search large areas quickly, the sensor could configure itself for optimal search rates.
If at other times, the ground system is able to pick up much of the search capacity, a smart system could focus on more specific monitoring missions, reconfiguring its sensor to provide higher sensitivity at the sacrifice of some search rate.
Of course such a vision also requires significant advances in automated tasking and automated data correlation and analysis.
The final result would be a seamless space situational awareness architecture providing a near real-time picture of where everything is, much like our air traffic control system.

Finally there remains perhaps the most challenging space situational awareness mission of all, characterization of unknown objects in space.
I have already mentioned the ground-based radar system under development that will provide significant near-real-time imaging capabilities, and other concepts have been considered for drifting characterization satellites that could perform high-fidelity characterization over a long period of time.
But there currently is no way to achieve both the high-fidelity characterization only attainable from a space-based sensor, while at the same time maintaining timeliness.
The tremendous ranges involved make imaging and anything involving weak signals very challenging from stand-off distances, and orbital mechanics constraints create challenges getting to a given satellite in a timely manner using short-range sensors.

We are very excited about any creative solutions to this challenging problem.
Perhaps there are other characterization phenomenologies beyond imagery that can

provide high-fidelity at long range?
An alternative strategy might use a more conventional sensor but take advantage of some type of responsive maneuver system using novel propulsion technology.
Hopefully there are still entirely different approaches that you will discover that will help address this daunting issue.

We have a long way to go until operating in the space-ways becomes as routine as traveling the airways, but we are making progress.
Help us bridge the gap between vision and reality.

Thank You