Satellite System F6

Divide and conquer

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DARPA is looking at a radical new concept that could change forever the way satellites are designed, launched, and used, from LEO to interplanetary space

The Future Fast, Flexible, Fractionated, Free-Flying Spacecraft United by Information Exchange—System F6, for short—would replace large, do-it-all satellites with a cluster of smaller, mission-specific platforms. This plug-and-play network could be updated or have its mission changed by the simple addition of new satellites to the cluster.

"The basic concept is to demonstrate we can take a monolithic spacecraft, irrespective of the mission or size—although it would be targeted at multipayload spacecraft—and decompose that spacecraft into a network of wirelessly linked modules or smaller spacecraft flown in a cluster and networked together, to provide the same or more capability than the monolith," says DARPA program manager and concept creator Owen Brown.

"So this is a not a formation flying exercise, which has been tried in the past," Brown tells *Aerospace America*. "This is flying smaller spacecraft together, each executing a unique function—not only payload or mission functionality, but also infrastructure support. For example, one module could execute the task of data processing while another is performing mission data downlink and another executing the mission of a specific payload. It is plug-and-play, but without the plug."

A radical new approach to launching, operating, and maintaining satellites is under development at DARPA, where breakthrough concepts are the order of the day. The idea involves replacing today's monolithic satellites with clusters of small, wirelessly linked spacecraft, each one providing a unique function. Together their capabilities would equal or exceed those of today's satellites, with far more flexibility—and at lower cost. Simply adding new spacecraft to a cluster could update the network, change a mission, and provide needed infrastructure support.

The fractionation edge

Brown outlined his concept at the Fourth Responsive Space Conference in Los Angeles in April 2006 in a joint paper with Paul Eremenko, an aerospace and defense strategy associate at Booz Allen Hamilton. The presentation touted fractionation as the best approach to developing "responsive space," which they defined as "the capability of space systems to respond rapidly to uncertainty."

In February 2008, DARPA issued one-year System F6 Phase 1 awards to four contractor teams, headed by Orbital Sciences ($13,648,758), Boeing Advanced Network & Space Systems ($12,891,049), Northrop

by J.R. Wilson
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Grumman Space and Mission Systems ($6,159,866), and Lockheed Martin Space Systems ($5,762,781). Contract awards and values were based on what the contractors said they needed to develop the technology and produce the desired results, and on how well DARPA felt the proposals would be achievable and validate those costs.

Orbital is teamed with IBM, JPL, Georgia Institute of Technology, SpaceDev, and Aurora Flight Sciences; Boeing with L3 Communications, Millennium Space Systems, Octant Technologies, and SAIC; Northrop Grumman with Alliant Tech Systems, Aurora Flight Sciences, Juniper Networks, L3 Communications, BAE Systems, Cornell University, JPL, MIT, University of Southern California, and University of Virginia; Lockheed Martin with Aurora Flight Sciences, Colbaugh & Heinsheimer Consulting, Lockheed Martin Integrated and Global Systems, and Vanderbilt University.

"Fractionation is quite a departure in how we do things, from design and procurement through deployment and operations."

Nelson Pedreiro
Director of science and technology
Lockheed Martin Advanced Technology Center

According to DARPA, during the first phase each contractor team will:

•Develop key technologies to enable the fractionated approach. Examples include robust networking, reliable wireless communications, fault-tolerant distributed computing, wireless power transfer, and autonomous cluster navigation.

•Select a space system mission of value to a national security space stakeholder and develop a system design that will accomplish that mission.

•Develop an innovative analytical approach using econometric tools that determine the risk-adjusted cost and value of both a fractionated space system and a monolithic program-of-record with equivalent capability.

•Develop an evolved hardware-in-the-loop test bed that emulate the designed fractionated spacecraft employing a cluster of networked computers.

"We have a significant part of the program, especially Phase 1, developing value-centric design methodology tools—using mathematical tools to answer questions of economics. Each performer is developing methods to help answer the question of what is the value of flexibility, in dollar terms. Flexibility is not a qualitative measure of the goodness of a system; there are methods, based on the fact that flexibility derives its value from spacecraft capability, to allow the performers to place a dollar value on different levels of flexibility that can be built into the system," Brown explains, adding DARPA's intent is to have Phase 1 and Phase 2 as closely aligned as possible.

"The objective of Phase 2 will be to get to a CDR [critical design review] at the end, so we would be ready to build hardware in a DARPA Phase 3 and Phase 4, which would be demonstrating the system on orbit. We haven't specified the length of those phases, just that the goal is to have first launch within four years of program start—February 2012. With the end of each phase, I see the development and output of many tools, and different degrees of knowledge. The glue to this entire concept is the network; so once there is a network, and open source wireless data communications protocols are developed, they will be available to be utilized. So one could imagine the utilization of fractionation could start immediately."

Countering skepticism

Both DARPA and some of the contractors acknowledge that a major obstacle to the ultimate development of operational fractionated satellite clusters is a fairly deep level of skepti-

"In the end, F6 is an important demonstration program, but in many ways [it is] less of a thing and more of a way."

Owen Brown
System F6 program manager
DARPA

cism from the potential user community. In their discussions with possible stakeholders, they have heard concerns about the cost of building multiple satellites, requiring multiple launch vehicles, and whether they can demonstrate the technological capabilities needed for tight cluster navigation and intersatellite sharing of major infrastructure, such as power, data processing, and communications.

Boeing System F6 program manager Randy Rubens says the best response to user skepticism is to demonstrate the value of the system architecture in the form of "resilience to uncertainties"—launch vehicle or spacecraft hardware failures, delays in development of a sensor or payload, changing mission needs, demand for reconfiguration of the formation, or upgrades to the software.

"One thing all the contractors are doing in this phase is to develop the tools and systems engineering processes to really characterize and quantify the effect of those uncertainties on customer value over the life of the program—and then have the capability to influence the design from what you learn from those characterizations," he says. "I like to think of a fractionated system as being greater than the pieces. For example, when you talk about component redundancy, if we are putting up five different modules, we won't have redundant systems on all five modules, because the network architecture enables, in some cases, enough sharing of component capability that it doesn't scale up directly.

"The resilience of the system allows for considering things such as flying a single string module or, in some cases, not putting the same component on every module if it can be shared. You might only put a space-to-ground communications system on one or two modules. With cross-link between spacecraft, you can look at it from a system perspective rather than seeing each spacecraft as a traditional satellite with spacecraft-level redundancy," says Rubens.

A breath of fresh air

Taking a fractionated approach, notes Boeing System F6 business development director Jerry Stenovec, can almost be considered a "technology disrupter"—this is because there is an enhanced tolerance for failure, enabling users to launch new capabilities when only an 80% solution has been acquired, and then add the remaining (and most expensive) 20% gradually as it evolves.

Nelson Pedreiro, director of science and technology at Lockheed Martin's Advanced Technology Center, agrees. "We think it is a breath of fresh air to have such a radical concept that could change how we pursue space systems. Dr. Brown's concept of fractionation offers a lot of flexibility for a gradual deployment of capability into space, especially in terms of repair or replacement of key components. It is a very far-reaching concept, from the point of view of not only operations and deployment, but also development.

> ***"There is an objective skepticism to fractionation that is a bigger obstacle than the technology pillars required to support fractionation."***
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> Randy Rubens
> System F6 program manager
> Boeing Advanced Network and Space Systems

"By fractionating a space system, you actually end up changing the paradigm, even from the design phases, decoupling key system elements and opening the door for parallel development of payloads and spacecraft. With the conventional approach, more often than not, we see particular payloads with very specific requirements that drive requirements for the bus and other payloads, so you get requirements creep. These kinds of interactions are reduced with fractionation. If one payload were delayed, it would not compromise the entire system, and you could have an initial deployment of capability," says Pedreiro.

Progress and possibilities

Some of the key technologies and capabilities required for the System F6 concept already have been demonstrated, such as a navigation system that would enable a cluster of satellites to maintain close positions in orbit autonomously, as occurred in DARPA's recent Orbital Express experiment with the on-orbit rendezvous of two satellites for refueling and maintenance. Others, however, need further

development and proof of viability, such as wireless cluster power-sharing, on-orbit networking, and distributed computing.

"Once you have created an internal spacecraft network, then add on new technologies for wireless capabilities, you then have the capability for fractionation; imagine a centralized power collection element that beams power wirelessly to other network nodes," Brown explains. "The key is flexibility and robustness. Flexibility is the ability of the stakeholder to change or modify the system at any time in the lifecycle—acquisition, launch, operations. Robustness is really the capacity of the system to maintain its intended function in the hostile space environment.

"If an element fails, we fly a microsat with that functionality into the cluster and allow it to become part of the network. That's how we service the system; with a large monolith, we have no recourse today," he notes. With the new approach, says Brown, "we can reconfigure the system, adapt it into new missions by adding new components, new modules. We can incrementally scale the system; if it is a communications system, we could have small modules with transponders and incrementally deploy them as demand increases, giving us a surge capability. If we decompose into a set of smaller modules, we have the capability to launch each of those separately on smaller launch vehicles, which means we have not placed all our eggs in one basket should a launch fail."

"F6 has the potential to be a game-changing event in the history of military space systems, in the same way that the Internet revolutionized data communications."

Gregg Burgess
Vice president for national security systems
Orbital Sciences Advanced Programs Group

Defining factors

Those involved acknowledge that, no matter how successful the DARPA program or even the future of fractionation, not all systems or missions will be fractionated in the same way—and some may not lend themselves to the approach at all. The final approach to each new satellite and mission will depend on a number of factors, including the mission itself, on-orbit lifetime, the degree of security or reliability demanded by the stakeholder, and so on.

"The design methodology trade space will consider a variety of constraints that help shape the outputs, so the value cost and risk will differ with each system. As a result, how you decide to fractionate a system will be very dependent upon what you are trying to do and how long you are trying to do it," Brown says. "However, I think the opportunities for this idea are limitless.

"The key here is the network concept and the fractionation we are hoping to develop. Much as with the Internet, open standards will allow third parties to develop capabilities to plug into the system architecture. That will provide an enormous degree of flexibility for future designers in terms of how they architect their overall system, whether that is LEO, GEO (geostationary Earth orbit), or planetary."

Aiming higher

Stenovec says Boeing believes fractionation can be used beyond Earth orbit.

"I can envision it being applicable with all the various Mars observers in the long term, but we need to mature the technology here first," he says.

Salma Saeed, Lockheed Martin's System F6 program manager, believes that also extends to manned space missions, especially on an interplanetary level.

"You can look at a manned mission in terms of sending one big spacecraft to Mars vs. multiple spacecraft—and it might make sense to send multiples," Saeed says.

"For example, if you want to have staggered development of a Mars camp, it might make sense to have some people and technology arrive first, then others come in later. So you would look at it in terms of how it best makes sense to set up that type of fractionated mission architecture."

Brown, while focusing on development of the basic centerpiece requirements to validate fractionation to the user community (for DARPA, primarily the military), also sees its potential to grow, perhaps beyond anything

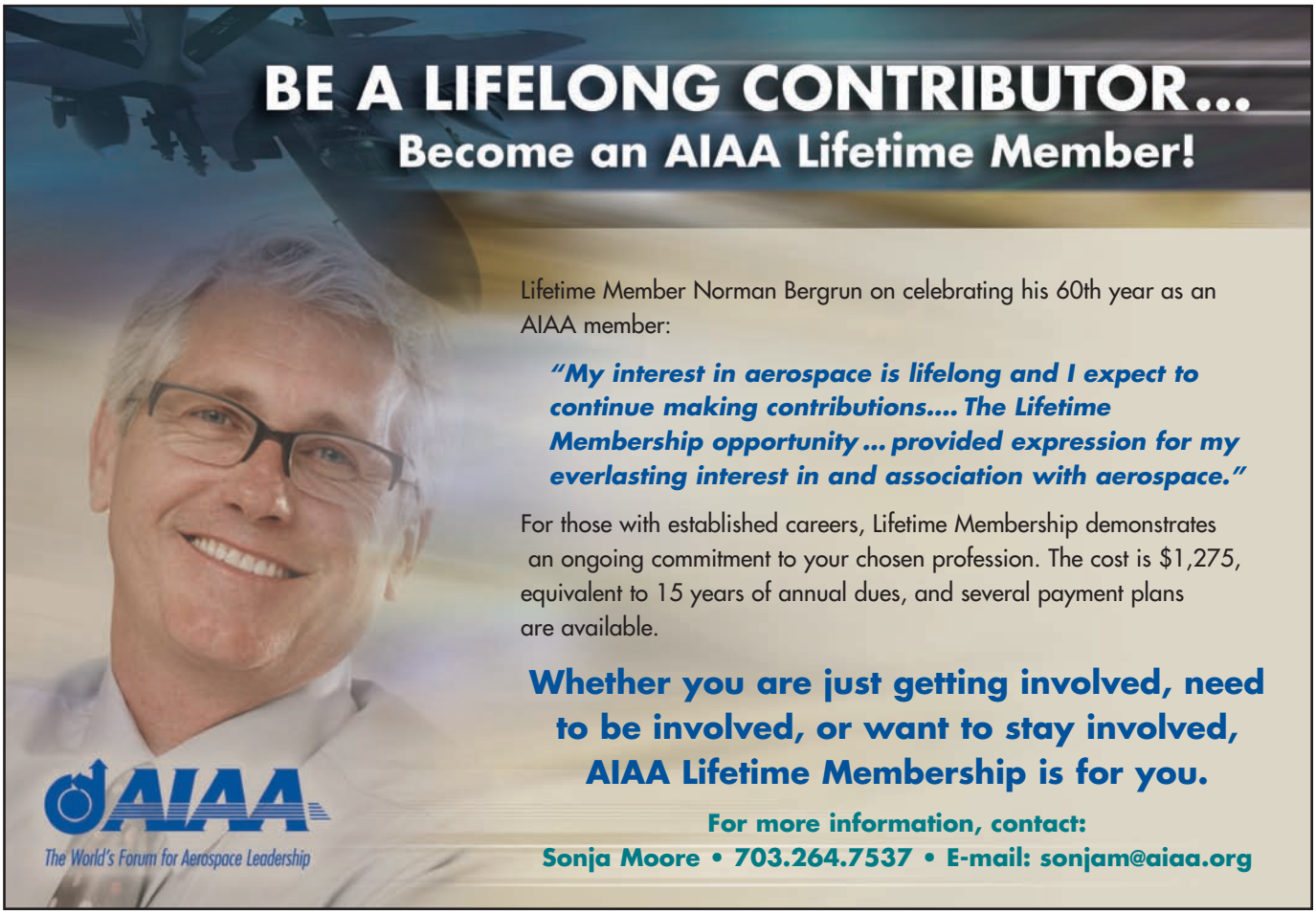
currently imagined, as happened with a previous DARPA creation—ARPANET, better known today as the Internet.

"In the future, if the technologies are proven and there is acceptance of the approach, there may be a blurring in the combining of systems, so there could be sharing of resources between multiple systems. It potentially becomes the next ARPANET, a program focused on sharing of resources between a small number of nodes, but [with] those protocols and standards maturing and gaining wider acceptance, so over time what appears is a very large, worldwide networking system," he explains. "You can imagine this becoming a system of systems, so the question of what is a spacecraft becomes difficult to answer."

In the short term, the contractors believe they can achieve DARPA's goal of launching a functional, proof-of-concept cluster by 2012.

"The F6 concept offers a level of flexibility and robustness unprecedented in space."

Lisa Hill
System F6 program manager
Northrop Grumman Space and Mission Systems

It is uncertain what fractionation may become in the long term if they succeed, but expectations for its evolution are high.

"There are two paradigms for fractionation: fractionation of the system, or fractionation for a service. I think it will start out as fractionation of the system, but we eventually will end up with an infrastructure in desirable orbits and, given the resolution or management of issues of classification, if you are in a good orbit it might be less expensive for a user to just add his satellite to an existing cluster," Rubens concludes. "So I think we will gradually transition into fractionation as a service; that is Dr. Brown's long-term vision for F6."