The X-30 National Aerospace Plane is out front in a broad jump to new technologies—but there is one problem in the way.

Technology Hits the Cost Barrier

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'A major challenge for us lies in finding ways to acquire the capabilities that we will need without incurring the very high costs that we have today. That isn't asking for magic. It's just recognizing that cost has become a major part of the technology equation.

"As our cost dilemma becomes stronger and stronger, we are being forced to become more creative in coping with it. Technology itself is going to have to provide some solutions. We are coming to understand that we have to reshape the way we work technology."

So says Dr. Robert W. Selden, Chief Scientist of the Air Force, in sizing up the service's state of affairs in science and technology. Ranging in his discussion through such R&D arenas as aircraft, spacecraft, computers, lasers, radars, and electronic combat, Dr. Selden sees high promise for future Air Force systems.

He warns, however, that R&D may be robbed of its potential by the prohibitive expense of bringing it to fruition. The costs of the technologies and of the systems for which they are destined may turn out to be unacceptably high unless the Air Force does a better job of restraining them, the Chief Scientist says.

Dr. Selden cites the National Aerospace Plane (NASP) as a good example of a future system that "offers great capabilities but involves complex technologies that likely will be very expensive." Those technologies "challenge us, as we think through the capabilities that they will bring, to devise ways of doing them that are smarter than we've done before."

The Chief Scientist wryly adds: "We can't be under any illusions that we're going to find out how to make a Piper Cub do the jobs that we want the NASP to do."

In the NASP program, directed by USAF and involving NASA, the Navy, and the Defense Advanced Research Projects Agency (DARPA), General Dynamics, McDonnell Douglas, and Rockwell International are in competition to develop technologies for the X-30 experimental aircraft that is expected to be ready for flight in the early to mid-1990s.

Rocketdyne and Pratt & Whitney are developing the highly advanced engines that the X-30 will require for flight at speeds ranging from subsonic to hypersonic.

The overarching purpose of the NASP project is to develop so-called "single-stage-to-orbit" flying machines capable of taking off from runways, climbing into space, flying there and in the air, and landing on runways. Many military and civilian uses are foreseen for such aircraft/spacecraft.

Tough technological challenges must be mastered in such developmental arenas as flight dynamics, propulsion, materials, and in integrating the X-30 system. "A major part of the whole process of doing the engineering for large, complex systems like the National Aerospace Plane is looking really hard at how to accomplish it with the resources that are expected to be available over a given period of time," Dr. Selden says.

"We are dealing with systems and technologies that are easy to envision but, because of their cost and expense, very difficult to realize."

The Cost of Technology

In this context, he sees the US military science and technology community as having arrived at a crossroads.

"We have come to the place where we are dealing with systems and technologies that are easy to envision but, because of their complexities and expense, very difficult to realize."

Several years ago, Norman R. Augustine, now the chairman and chief executive officer of Martin Marietta Corp., predicted only somewhat facetiously that in another fifty years or so the Pentagon would be able to afford only one airplane per year if defense budgets and costs of airplanes continued to grow at the sharply diverging respective rates of recent times.

Of this, Dr. Selden says, "We know that we'll never get to that point—to where one airplane costs ten billion dollars—because we also know that we'd change the way we do business long before we ever got there. Our whole acquisition system would change. It would have to."

He points out that the Air Force's Advanced Tactical Fighter program presents "a major technology challenge and a major problem of cost containment" and is "an example of where costs and technical capabilities are really coming to the crunch stage."

But the ATF program is not wholly germane to Dr. Selden's espousal of new ways of approaching technology to restrain its costs, he says, because "it is too far along" and "will likely not be as different as some of our future systems will have to be.

"The ATF isn't in the same technology-development position that the NASP is in," he claims. "NASP needs a set of major breakthroughs in a whole variety of different technologies, whereas a very capable ATF is much closer to being realizable."

Even so, Dr. Selden sees the ATF program as forcing the Air Force to "exercise a great deal of discipline to try to work through the problems" of integrating top-of-the-line technologies in a fighter to make it do what it will need to do at an affordable price.

In this regard, the ATF program serves as "a stepping-stone" for USAF's science and engineering communities as they move to cope with the much tougher cost-cum-technology conundrums to be expected in developing systems well beyond the ATF.

Meanwhile, Dr. Selden asserts, "I'm optimistic that all the problems and challenges of the ATF program will work themselves out."

As Chief Scientist of the Air Force, Dr. Selden reports directly to Chief of Staff Gen. Larry D. Welch and is his advisor on matters relating to Air Force science and technology. Dr. Selden is a member of the steering committee of the Air Force Scientific Advisory Board. He meets regularly with Gen. Bernard P. Randolph, Commander of Air Force Systems Command, which operates Air Force laboratories, and with John J. Welch, Assistant Secretary of the Air Force for Acquisition, who in 1969–70 held the position that Dr. Selden now occupies.

A graduate of Pomona College, Calif., and holder of a master of science degree and a doctorate in physics, both from the University of Wisconsin, Dr. Selden worked at the Lawrence Livermore National Laboratory from 1965 to 1979 on projects ranging from the development of nuclear warheads to the physics of nuclear weapons.

He left the Livermore laboratory

to become leader of the Applied Theoretical Physics Division at Los Alamos National Laboratory, N. M. He subsequently served at Los Alamos as deputy associate director for strategic defense research and as associate director for theoretical and computational physics, managing four laboratory divisions.

In 1986, Dr. Selden became the first director of the newly established Los Alamos National Laboratory Center for National Security Studies. It was created to conduct research in broad areas relevant to national security, with emphasis on the relationship between policy and technology.

The Challenge of Space

Dr. Selden sees space and hypersonic flight, both of which the NASP program involves, as "areas of great potential and of major technological challenge for USAF."

He declares: "In our use of space today, and in our thoughts about how we'll use it, we are in about the same stage as we were with aircraft before World War II. Our space technology and uses of space are going to develop in many, many ways that we don't envision in detail today. The technologies represented by the NASP development are ones that, over time, will contribute to revolutionizing our thoughts about how we use space.

"The ability to fly from the ground directly into space—and relatively cheaply—is going to change our whole concept about space. In part, it will continue to be a corridor that we'll pass through. But it will also be a place where, if we can get there much more easily and less expensively, we will go much more often."

From the NASP program, Dr. Selden declares, "single-stage-to-orbit flight will be the real payoff, the thing that will revolutionize our use of space."

Here again, though, the Chief Scientist emphasizes that the going will be difficult. "We wouldn't need a big research program if we knew we could build a propulsion system that could do the job."

He describes the NASP-to-be as "an engine with wings on it," and adds: "The airplane that will fly into space will not look anything like the space shuttle. The shuttle does come back from space and flies in the atmosphere at hypersonic speeds. So we have the benefit of a number of actual trials at such speeds.

"But we know that the shuttle will not take off from a runway and go into space. It can't fly up there by itself. That's the really hard part. That's the big problem. The shuttle has a big slingshot. So the key thing for us now is to develop the slingshot as part of the airplane, the NASP."

A crucial element of the NASP program has to do with the development of scramjets—supersonic combustion ramjets—envisioned as the craft's means of hypersonic flight at up to twenty-five times the speed of sound. Such work is having its ups and downs, but remains encouraging, Dr. Selden says.

This is true of the entire NASP program, he adds. "We're pushing the state of the art, and we absolutely cannot have all successes. But there are excellent teams in Air Force laboratories and in industry that are developing some exciting new technologies, and they will ultimately succeed."

Quite apart from its promise of wondrous flying machines, "NASP is one of our more important science and technology programs because it's pulling along so many technologies that will be really important by the middle of the next century or, with good luck, long before that," Dr. Selden asserts.

Hide-and-Seek

The NASP program aside, among technologies that he identifies as currently crucial are those for avoiding or foiling detection, as in stealth aircraft, missiles, and electronic countermeasures, and those for detection, as in radar and other sorts of sensors.

Stealth and countermeasures technologies are in a continuous race with sensor technologies, the Chief Scientist says. In any game of hide-and-seek, he notes, "the advantage at first goes to the person who is hiding, who gets to choose the time and place and camouflage." This will be the case in the stealth-sensors race "for some time, maybe a decade or two, depending on the investment in detection technology," he predicts.

It seems obvious that crews of stealth aircraft need to be careful about using active radar, which could give away the game if its signals are detected. It is said that no surface-to-air missile radar in use anywhere in the world today is capable of spotting the Air Force's B-2 Stealth bomber until it is too late to do anything about it.

In view of these impacts that low-observable technologies have on both offensive and defensive radars, is it possible that stealthy flying machines will make radar obsolete?

"Not at all," Dr. Selden asserts, "but radar systems will become much more sophisticated. To avoid electronic countermeasures, we're already into systems where we don't just turn on a continuous, single-frequency radar beam and have it do its thing. We turn it on in a pulsed fashion—on and off, perhaps irregularly.

"We also have it hop around at various frequencies so there will be blips all over the map, and we do this in accordance with patterns that require large-scale computing for us to know what we're going to send out and what we expect to receive back [from the radar]."

How can such radar be thwarted? "If you want to interfere with that process, then you have to build machinery that listens to it, figures out what's going on, and decides how to counter it—all in real time.

"If anybody wonders why we're having so much trouble today in the arena of electronic combat, that ought to explain it. Electronic combat has entered a new era. . . . The technology of computing and the technology of the electronic systems that generate these signals and receive them is changing faster today than we can put systems into production. It's a revolution."

Dr. Selden says that it takes "about five years for full generational changes" in electronics technologies today—"and since when have we been able to design, build, produce, and put into the field any kind of system within five years?"

Increasing Complexity

The Chief Scientist also claims that the problems of developing, fielding, and countering modern military technologies are more complex than they used to be. They are expanding, in effect, geometrically rather than arithmetically.

For example: "We're getting to the place where it isn't enough just to make airplanes fly faster than the other side's, because the other airplane has now changed its capabilities, perhaps with longer-range detection systems and weapons, or in the way it flies.

"A very different kind of thing is happening now. We have to use high-speed computing, and we have to design systems that will be responsive to what we're seeing and will see in this electromagnetic world. And to be able to change the capabilities of systems after they're built. *That's* the real challenge.

"We're moving into an electromagnetic environment now that is way beyond what was envisioned two decades ago."

Dr. Selden makes the point that military science and technology is still more a matter of step-by-step progress than of dramatic breakthroughs. Nonetheless, such progress these days is the stuff of several revolutions in R&D.

For example, he says, "the laser revolution has been several decades in the making and is now upon us. The revolution isn't in the 'death ray' aspect of lasers, it's in communications and sensors."

Take laser radar, for instance. The Chief Scientist explains that it "is hard to do, but it's coming. Its resolution of images will be very different, very high."

In the atmosphere, laser radar will have problems common to all optical systems: seeing through clouds, water vapor, smoke, and anything else that confounds eyesight. But laser radar should be in its element in space.

Out there, says Dr. Selden, laser radar "will be a very big deal. It will be able to look out over long distances and resolve very small images." He also sees laser radar's extraordinarily narrow beams as highly advantageous "for tactical applications, where you're below the weather and are able to use automated systems to look up at, home in on, and get high resolution on particular kinds of things."

Unlike the more futuristic laser radars, laser communications systems are already upon us, Dr. Selden says. "They're impressive just because of the greatly increased data rates they are capable of providing. In space or in optical fibers, they're highly directional and harder to interfere with—to jam—than anything in the radio and microwave regimes."

"We're moving into an electromagnetic environment now that is way beyond what was envisioned two decades ago."

The Heart of the Revolution

Dr. Selden claims that computational prowess, provided by computers that now operate at prodigious speeds and that will get even faster, is the key to all kingdoms in the world of modern military technologies and systems.

Computers are at the heart of a technology revolution in military electronics that has been taking place for two decades or so, and that has by no means run its course, he contends.

Dr. Selden positions this revolution "in an intermediate time period before aerospace planes, space stations, flights to Mars, and things like that occur."

The Chief Scientist points out that high-speed computers pervade "all technologies for the propagation of electromagnetic energy in command control communications and intelligence [C^3I], electronic combat, sensors, the whole spectrum.

"There isn't a modern radar system that doesn't have computation built into it. There isn't a sensor system today that doesn't have a computer program for doing data analysis and [image] reconstruction. Almost all our high-speed communications systems involve computer processing, from simple concepts, like multiplexing, to data compression."

Then there are the farther-out scientific fancies, such as antimatter propulsion. Dr. Selden regards research on antimatter by the Air Force, other government agencies, and the private sector as "a very exciting effort of basic physics that relates to the nature of matter itself—how it's put together and how it works."

But the Chief Scientist parts company with researchers who claim that breakthroughs in antimatter propulsion, as in space travel, may be relatively near.

"We're a long, long way from thinking about practical application of antimatter as a propulsion system, death ray, or anything else," Dr. Selden says. "But the potential is certainly there. Antimatter could eventually be a very big energy source."

Regardless of whether or when antimatter research pays off, the Air Force should stay with it, Dr. Selden claims. "I think it's very important that the Air Force is involved in some cutting-edge research activities in areas that are relevant to long-term Air Force needs. A very small investment keeps us involved with some of the best people in the academic research community," he said.

Fundamental to the Future

Dr. Selden claims that USAF's leadership has no reservations about the importance of research and exploratory development and has its heart in fostering science and technology as fundamental to the service's future.

"The Air Force is historically the service that depends the most on technology," he asserts. "Flying is itself a technological invention. Everything that happens in the Air Force has something to do with technology.

"This is widely recognized by every one of the senior leaders of the Air Force. There is a long-term understanding of, and commitment to, science and technology on the part of the Air Force.

"So the issue today isn't really one of the importance of science and technology. The issue is how to make the hard decisions about increments in the science and technology budget, one way or the other.

"Those are really hard decisions. We have to make them as we go."

He continues: "In times of tight budgets, there is, historically, a dilemma for those programs that are longer-term and that don't have direct day-to-day relevance. Sure, there is a lot of budget pressure on the science and technology base, and, as this increases, [the base] will take some hits. But there is also the recognition that, as we move into a period when we must reduce the size of our forces, the technological edge will become even more important.

"Even though the science and technology base is only a very small fraction—one to two percent—of the Air Force budget, it is the most visible and important element of its size in the budget. So there's no disposition to mistreat it just because it's small."

"The Air Force is historically the service that depends the most on technology. Flying is itself a technological invention."

Science and the Air Force

Dr. Selden became Chief Scientist of the Air Force last August. He is the latest in a long line of scientists who have come to the post, from outside the Air Force for the most part, since it was created in 1956.

The average tenure of each Chief Scientist has been about three years. The Air Force's intention in setting up the senior management position was that it be filled "on a temporary basis of a few years" by each occupant, Dr. Selden says.

The post had its origins in the Scientific Advisory Group created by Gen. Henry H. "Hap" Arnold, Chief of the US Army Air Forces, and Theodore von Kármán, its first director, after World War II. On December 15, 1945, that group, which later evolved into the Air Force Scientific Advisory Board, issued a report called "Toward New Horizons," which laid the foundation for the separate US Air Force and for the scientific and technological directions that the service would take.

The report was the forerunner of Air Force Systems Command's 1964 Project Forecast report and 1986 Project Forecast II report on choice technologies and systems foreseen for USAF at those times.

"Toward New Horizons" was pegged in great measure to an axiom that General Arnold had expressed in a letter to Dr. von Kármán more than a year earlier, as follows:

"It is a fundamental principle of American democracy that personnel casualties are distasteful. We will continue to fight mechanical rather than manpower wars."

This set the stage for USAF's never-ending pursuit of technological advantage over adversaries, Dr. Selden says.

"A Marvelous Job"

The scientists and engineers who worked on the "Toward New Horizons" study "did a marvelous job of looking at major technology issues out in time," in Dr. Selden's opinion. He recalls the study having dealt with such then-futuristic concepts as supersonic aircraft, unmanned aircraft, G-loadings that would tax human tolerance, and global navigation and communications systems, all of which and more have come to pass.

Dr. Selden tips his cap to the Air Force laboratories, which are operated by Air Force Systems Command, as being "centers of excellence on a variety of topics" and "keepers of the corporate [Air Force] sense of long-term direction in science and technology."

The Chief Scientist claims that "the Air Force laboratory system is better than it gets credit for in some external views of it" but acknowledges "some problems" that USAF has identified, is analyzing, and is intent on solving.

He regularly visits and works with the Air Force laboratories and spends as much time as he can in the US and overseas with the operational commands. "I need to have an understanding of how the operational Air Force works and a sense of how technology is actually used—of what it looks like out there—not just theory."

Dr. Selden cautions that "not everything we do has an end application as a piece of hardware. There are 'people' priorities too."

He sees himself as "a part of the relationship between the Air Force and the academic world at large. That's what the whole Air Force laboratory system does, and the Air Force Office of Scientific Research, but I do it too, often in the role of spokesman for the Chief of Staff.

"It is important for the Air Force to stay in touch with people in the academic world who are outside of the Air Force community. We're all in this together. Having some of the preeminent technical people in the world concerned with problems that the Air Force has to work on and solve within the next few decades requires that we recognize some work in basic science that now seems unrelated, at face value, to the Air Force." ■