Agile Manufacturing:
Gearing Up to Meet Demand

War has broken out somewhere in the world, and the U.S. becomes involved. Suddenly, all branches of our armed forces need more conventional munitions—and they need them immediately. How can suppliers meet this kind of unpredictable, high-volume demand?

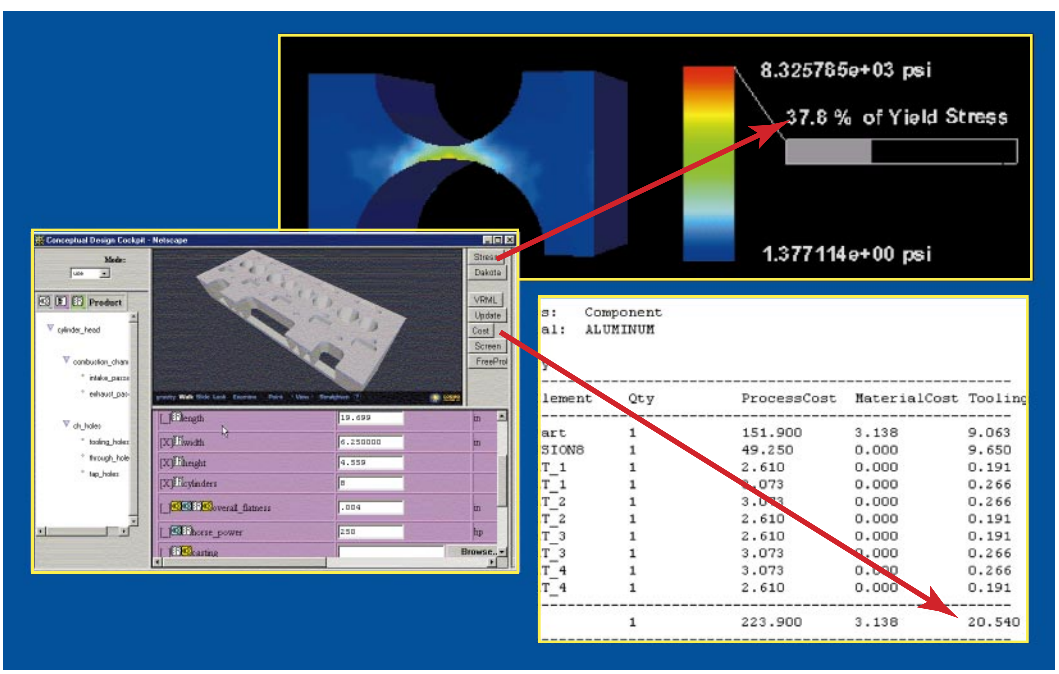
A project under way at Lawrence Livermore aims to help manufacturing companies do just that. Known as Totally Integrated Munitions Enterprise (TIME), it is being funded by the U.S. Army to handle several munitions manufacturing issues. Not only does the Army need to obtain munitions quickly in national emergencies, but munitions productions facilities are being downsized at the same time that a variety of highly complex, “smart” munitions are becoming available. Supplying these munitions on a timely basis while keeping them affordable has become a challenge.

Livermore is one of eight participants in the TIME project. Most other participants, including Raytheon, General Motors Powertrain, Aerojet, and Primex, are in the private sector. Together, project participants are developing and demonstrating a distributed, flexible manufacturing capability that is cost-effective and can be rapidly reconfigured as needs change.

Implementing an integrated manufacturing base means changing a basic practice that is pervasive in manufacturing today. Contractors use subcontractors, who in turn use other subcontractors, and minimal information is shared among them. A contractor typically shares with subcontractors only enough information for the subs to get their job done. But if knowledge, experience, and risk are commonly shared among all partners, so that the manufacturing process can be more widely viewed as a total, integrated process from concept to delivery, then money and time can be saved as quality increases.

Changing the Entire Process

To support this fundamental change, TIME addresses the entire process—from concept to finished product—as a system, integrating design, engineering, manufacturing, administration, and logistics. In the manufacturing industry, this process is called product realization. To facilitate the flow of information



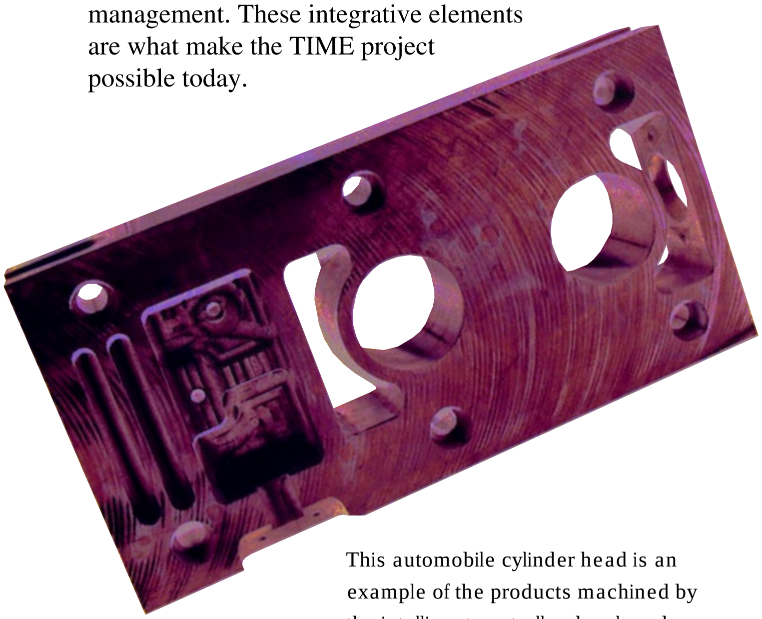
Using Web-based integration manager tools developed by TEAM (Technologies Enabling Agile Manufacturing), a nonspecialist can transparently modify a product design, run cost and product simulations, and produce a tradeoff study.

among various functions, TIME is using a host of Internet-based software tools. Many of these tools were developed during an earlier Department of Energy project known as Technologies Enabling Agile Manufacturing (TEAM). Livermore engineer Bob Burleson was technical manager for TEAM, which started in 1994 and wrapped up work in late 1998. Burleson is technical manager for the TIME project as well.

TEAM's 40 participants were remarkably diverse. Participants from the private sector represented many industries, including aerospace and defense, automotive, machine tools, robotics, consumer electronics, and software. Federal facilities and agencies included Lawrence Livermore, Los Alamos, and Sandia national laboratories, the Oak Ridge Centers for Manufacturing Technology, and the AlliedSignal Kansas City Plant.

The Internet-based software tools developed by TEAM support not only an open flow of information but also modeling of all phases of the work, communication among computing systems for geographically distributed facilities, concurrent engineering and production for teams that may be using different standards, and state-of-the-art methods for controlling manufacturing processes. An integration manager on the World Wide Web pulls together all product realization functions, including product design, process planning, process simulation, and fabrication controls.

Other activities, equal in importance to these software tools, support a generic infrastructure and overall planning and management. These integrative elements are what make the TIME project possible today.



This automobile cylinder head is an example of the products machined by the intelligent controller developed under Lawrence Livermore's leadership.

Manufacturing facilities of TEAM partners served as the proving ground for these models and software tools. The Internet-based tools allowed a large number of facilities to work together quickly and easily. In one instance, project requirements were analyzed at GM in Pontiac, Michigan; design was done collaboratively between a DOE site in Kansas City, Missouri, and Raytheon in Tucson, Arizona; the product analysis was performed at Livermore and ISX Corp in Atlanta, Georgia; DOE sites in Oak Ridge, Tennessee, and Kansas City completed process design; and process simulation was performed by the University of Illinois and a DOE site in Los Alamos, New Mexico. Tradeoff studies between product, process, and resources were performed wherever the product manager happened to be. Then parts were manufactured at GM in Pontiac and inspected at Ford in Dearborn, Michigan.

The real payoff for bringing together these Internet-based tools was in the way they enabled real change. In one instance, a critical machine was down, and the other available machine wasn't as accurate—and even if it were, the entire process design, process simulation, and tradeoff studies would have to be redone. The TEAM project worked across 10 different facilities, making the changeover in less than an hour instead of days or even weeks. That is truly integrated product realization.

Livermore was the leader for development of an intelligent controller for machining products such as the part shown at the left. Machine tools and robots that cut and shape parts for everything from safety pins to computers receive their instructions from a device known as a controller. The controller is programmed to know where to cut, drill, and turn on a particular part and typically serves the machine tool for its entire life. But if a part comes down the conveyor belt slightly crooked, then holes will be drilled at the wrong angle, forcing an inspector to throw that part away. In contrast, an intelligent controller can sense the angle of the part and correct the angle of drilling, reducing waste and saving time and money. An intelligent controller can also be reprogrammed quickly for production of different parts, making it a key player in an agile manufacturing setting. (See also *S&TR*, April 1996, pp. 22–23.)

Meeting Surge Rates and Retrofitting Weapons

The Army was so impressed with the results of the TEAM project and the controller effort that it wanted this collection of tools put to work at its munitions manufacturing facilities. Currently, after having produced a stockpile of m2munitions for potential conflicts, all of these facilities produce munitions at a sustaining rate that just keeps up with the Army's ordinary needs. But the Army also needs facilities to be able to produce at a surge rate, without the necessity of creating a larger stockpile. With agile manufacturing, private companies that manufacture other products could be put to work to produce munitions on short notice. And with agile manufacturing, existing plants could quickly produce entirely new munitions or retrofit “dumb” weapons with new, “smart” features.

Integrated production had already been demonstrated generically, but a demonstration at a munitions manufacturing site was in order. Last fall, the TIME team went to the Scranton Army Munitions Plant in Pennsylvania to show how quickly and easily a manufacturing facility could begin to make something entirely new. There, in just a few days, they were able to produce the part shown on p. 18.

In 2000, another type of demonstration will take place in which production data from a munitions production plant will be used to almost immediately begin production at a nonweapons manufacturing company. The plan is for GM to manufacture components for small grenades using data from Primex, which routinely manufactures these and other conventional weapons. Burleson notes, “This is an almost unheard-of event in the manufacturing world, where proprietary data are zealously protected.”

Work on agile manufacturing to date has focused on material removal processes—milling, drilling, turning, and so on—but agile manufacturing can easily be extended to assembly and other repetitive manufacturing activities.

Tom McWilliams, program leader for the TIME project for the U.S. Army in Picatinny, New Jersey, is enthusiastic about successes to date. “These new control systems could allow existing facilities to change production modes quickly. They could, for example, switch back and forth between ‘dumb’ bullets and ‘smart’ ones, even on a day-to-day basis. Agile manufacturing will give us a flexibility we have not had before.”

—Katie Walter

Key Words: agile manufacturing, machine controller, munitions manufacturing, product realization process, U.S. Army.

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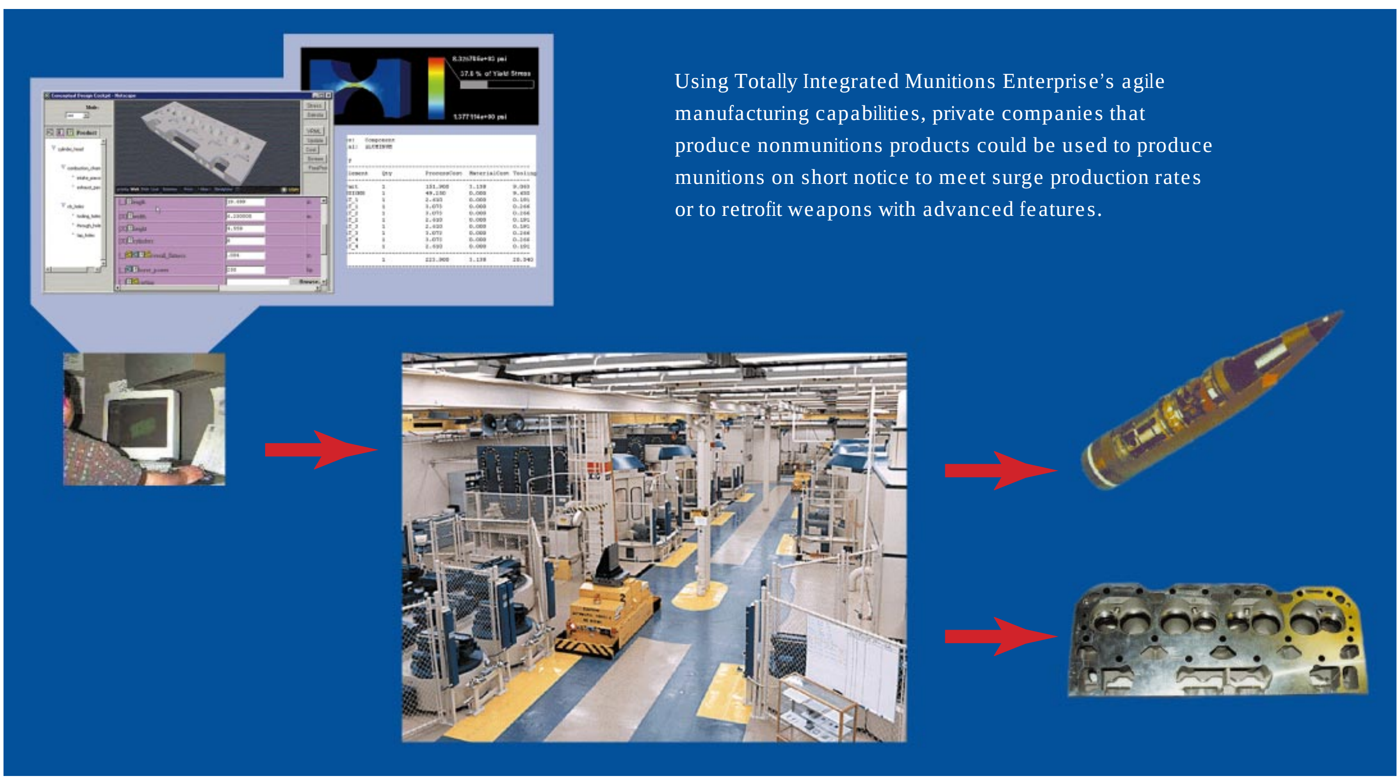


Using Totally Integrated Munitions Enterprise’s agile manufacturing capabilities, private companies that produce nonmunitions products could be used to produce munitions on short notice to meet surge production rates or to retrofit weapons with advanced features.

Bringing Hypersonic Flight Down to Earth

From the doodlings of daVinci and the penned fantasies of Jules Verne to the tangible accomplishments of the Wright brothers and other aviation pioneers, mechanized flight has captured the imagination of humanity through the centuries. Even today, with atmospheric and space flight a reality, there are still aviatory realms to dream about and conquer. Hypersonic flight at speeds 5 to 12 times the speed of sound (Mach 5 to Mach 12) is one such area of interest to the commercial and defense communities.

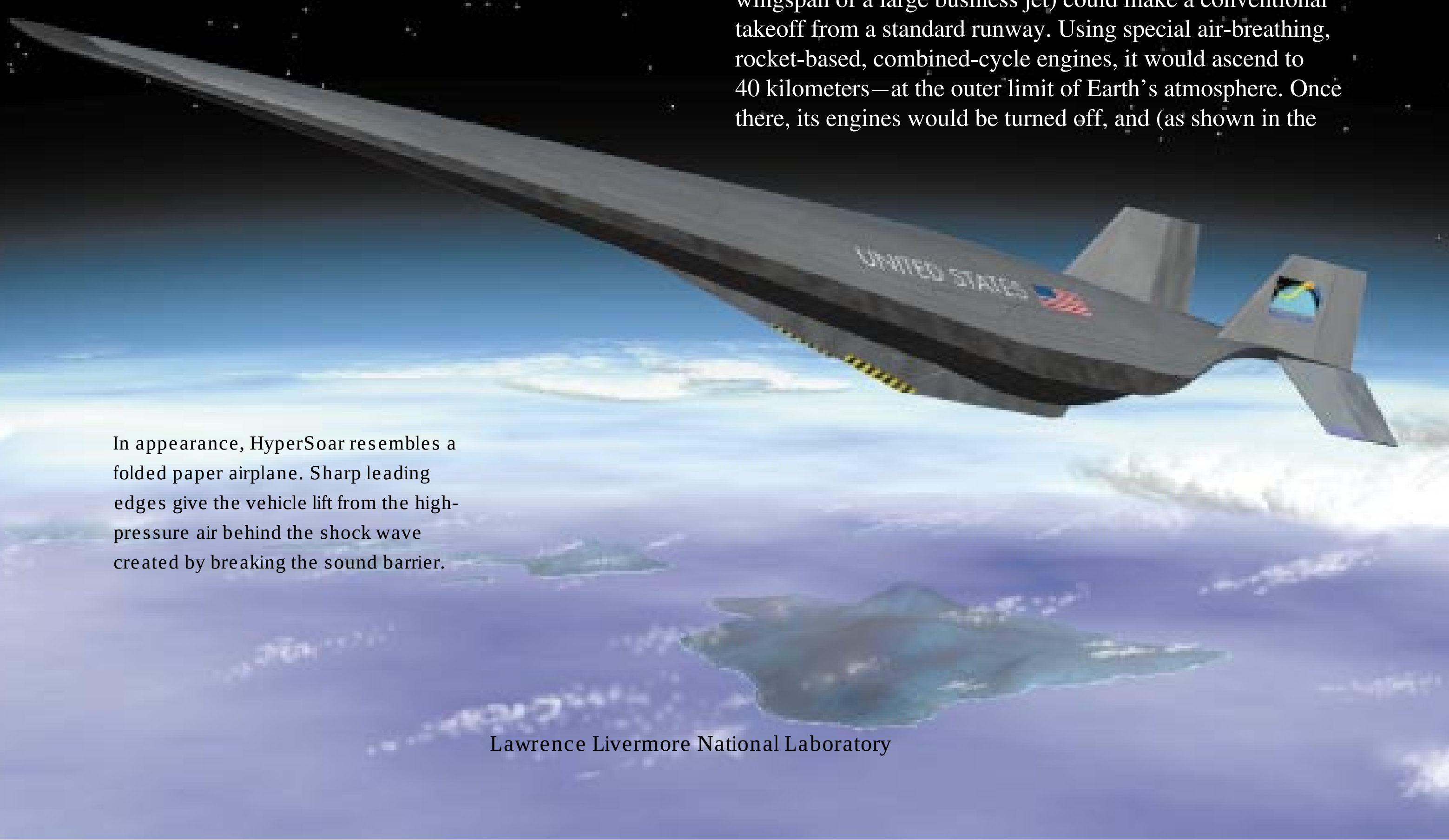
At Lawrence Livermore National Laboratory, aerospace engineer Preston Carter has invented a concept for a next-generation hypersonic aircraft, dubbed HyperSoar, that could fly efficiently, economically, and cleanly.

Flying at Mach 10 (3 kilometers per second), HyperSoar could reach any point on the globe within two hours. (The fastest military plane, the SR-71, flies between Mach 3 and Mach 4, while the commercial Concorde only reaches Mach 2.) HyperSoar would also have twice the fuel efficiency of commercial airliners, be three to five times more efficient in putting satellites in space than today's launch systems, and use liquid hydrogen fuel, which produces simple water vapor when burned.

HyperSoar—a concept-development project funded through Livermore's Physics Directorate and the Laboratory Directed Research and Development Program—could transport people or cargo, strike enemy targets, or help put satellites into space. "The fact that HyperSoar has many potential uses is key," says Carter. "Developing an entirely new aircraft is expensive. However, if there is a large market for such an aircraft, the cost per plane goes down. It's like the difference between a 747 and the Stealth bomber. There are hundreds of Boeing 747s being used by commercial airline companies, airfreight companies, and so on. But the only market for the Stealth is the military, which only needs a few. That's why you'll never see a Stealth being built for much less than they cost today."

Skipping on the Atmosphere

A 25-meter-long HyperSoar aircraft (about as long as the wingspan of a large business jet) could make a conventional takeoff from a standard runway. Using special air-breathing, rocket-based, combined-cycle engines, it would ascend to 40 kilometers—at the outer limit of Earth's atmosphere. Once there, its engines would be turned off, and (as shown in the



In appearance, HyperSoar resembles a folded paper airplane. Sharp leading edges give the vehicle lift from the high-pressure air behind the shock wave created by breaking the sound barrier.

figure below) it would coast up to a high point of 60 kilometers before beginning to fall back down to about 35 kilometers—well inside the atmosphere's upper level. As it descends into denser air, the aircraft would be pushed up by the increased aerodynamic lift. The engines would fire briefly, propelling the plane back into space. Outside the atmosphere, the engines shut off and the process repeats. In this way, HyperSoar would skip off the top layer of the atmosphere every two or so minutes, like a flat rock skittering in slow motion across the surface of a pond.

Inclusive of the time taken and distances covered by the ascent and descent portions of a flight, a trip from Chicago to Tokyo (10,123 kilometers) would involve about 18 skips and 72 minutes, and to travel from Los Angeles to New York (3,978 kilometers) would involve about 5 skips and take 35 minutes. (Both flights require a total of about 2,450 kilometers and 27 minutes for take off and landing.)

By popping regularly out of the atmosphere and using the engines intermittently, HyperSoar would use less fuel and solve a critical problem that plagues other hypersonic aircraft designs—heat.

Beating the Heat

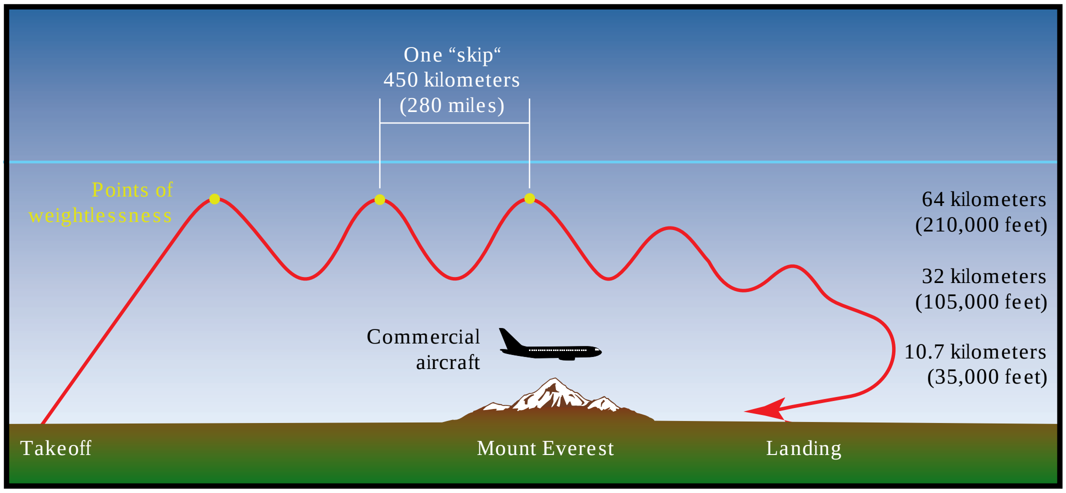
Any object—airplane, spacecraft, asteroid—speeding through the atmosphere will compress and heat the air in front of it. This heat is inevitably absorbed by the surface of the object. "Heat buildup just kills most designs for hypersonic aircraft," Carter said. "The hotter the craft gets, the more material engineers add to the airframe to strengthen and shield it. Also, most other hypersonic concepts have trajectories that are strictly atmospheric, and the only way to get rid of the heat is to dump it into the fuel and then burn the fuel in the engines. The problem is, the faster you fly, the more fuel you must carry as a heat sink. Eventually, you end up carrying a significant amount of fuel just as a heat sink, and the engines end up running fuel-rich, that is, burning up more fuel than they really need. That's wasteful in and of itself. Also, more material and more fuel translate to more weight. After a while, the aircraft can no longer carry a decent cargo."

Because HyperSoar spends nearly two-thirds of its time out of the atmosphere, it can radiate the heat into space. Carter and colleagues at the University of Maryland have analyzed HyperSoar, compared it to other concepts, and found that—thanks to its trajectory and shape—HyperSoar has less heat load on its airframe and consumes less fuel.

From Express Mail to Satellites

"The way HyperSoar blends flight and space access is revolutionary, opening up a world of potential applications," says Carter. Possibilities include using HyperSoar as a freighter, military aircraft, low-cost launcher, and, eventually, a passenger aircraft. According to Carter, HyperSoar would be capable of carrying more weight over longer distances than planes of similar size and mass.

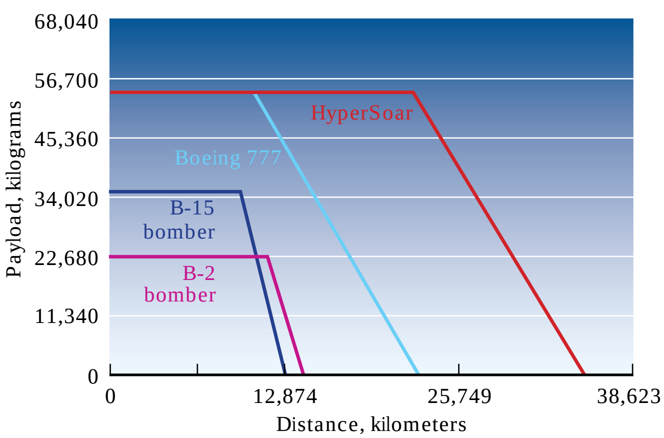
As a freighter, it could make four round-trips to Tokyo daily versus one or less for today's aircraft. This speed would be a boon to the $4-billion-per-year commercial intercontinental package delivery market. "The speed of today's aircraft has limited the growth of this market," says Carter. "The express delivery industry requires central intracontinental hubs that are about two hours' flying time apart. Current technology allows express mail, for instance, to move between these hubs in close to that time. Now, imagine the possibilities if you could fly between Memphis and Singapore in close to two hours." Carter estimates that a HyperSoar aircraft flying express mail between Los Angeles and Tokyo could generate ten times the daily revenue of a similar-size subsonic cargo plane.



HyperSoar's trajectory follows a skipping pattern. Passengers would feel 1.5 times the force of gravity at the bottom of each skip, and weightlessness out in space. The experience would be comparable to being on a swing, although HyperSoar's motion would be 100 times slower.

As a military aircraft, a HyperSoar bomber the size of an F-22 could take off from the U.S. and deliver its payload from an altitude and at a speed that would defy all current defensive measures. It could then return directly to the continental U.S. without refueling and without the need to land at forward bases on foreign soil.

HyperSoar could also be employed as the first stage of a two-stage-to-orbit space launch system. This approach would allow approximately twice the payload-to-orbit as today's expendable launch systems for a given gross takeoff weight. At the high point of its skip, HyperSoar could eject an upper-stage vehicle and its payload into low-Earth orbit. A larger HyperSoar vehicle, the size of a Boeing 777 for example, could handle a 13,700-kilogram payload in addition to the weight of a typical second-stage launcher. At a 255,000-kilogram gross vehicle weight, the HyperSoar would weigh about half as much as the largest Ariane 4 expendable launch vehicle but could carry about 40 percent more payload. Of course, these lower weight-to-payload requirements mean that HyperSoar vehicles will not need to be built as large vehicles but rather as smaller, less expensive ones.



According to its designers, HyperSoar would be capable of carrying more weight over a greater distance than planes of similar size and mass.

Flying the Paper Plane

Even though HyperSoar is still in the "paper airplane" stage, it has garnered interest from organizations as diverse as Federal Express and STRATCOM (the U.S. Air Force Strategic Air Command). HyperSoar has appeared in *Jane's Defence Weekly*, *Aviation Week and Space Technology*, *Scholastic's Weekly Reader*, and daily papers from the *Los Angeles Times* to the *Washington Times* to local newspapers such as the *Valley Times*.

Passenger flight would be one of the last applications to become reality, but it is the one that the media and the public are most interested in. "The public gets very excited about space and air travel," said Carter. "To the general public, HyperSoar looks doable. The technology is nearly there, the concept is proven on paper. The thing now is to make it economically feasible to the defense and commercial communities so HyperSoar can get the funding it needs to take the next step in development."

Carter estimates that about $500 million would be needed to develop the technologies needed and build and test a 16-meter-long flyable unmanned prototype. Lawrence Livermore is positioned to help bring HyperSoar into reality because of its expertise in thermal protection materials, large-scale computational fluid dynamics, ultrahigh pressure testing design, and modeling the environmental effects of high-speed supersonic aircraft.

The question of funding aside, the day when passengers can hop a HyperSoar to London is still a ways off.

"When most people hear about HyperSoar," Carter added, "they immediately think big—building big airplanes to carry lots of passengers or cargo. But that's not economically feasible. I propose building small airplanes to justify the market and then building up from there, according to the need. That's how all the different flight technologies—airplanes, jets, helicopters—got started. It's the way that fledgling technologies like HyperSoar take wing."

—Ann Parker

Key Words: HyperSoar, hypersonic aircraft.

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