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OPINION

Why it's time to reach for full reusability

Now that SpaceX has vividly demonstrated the promise of reusability in space launch, it's time to revive the goal of aircraft-like reusability of launch vehicles. Eugene A. Ustinov and Philip I. Moynihan, both formerly of NASA, make the case and present a concept.

BY EUGENE A. USTINOV AND PHILIP I. MOYNIHAN

Even before Sputnik was launched, the fertile imaginations of the public and futurists alike widely believed that once space-borne with artificial satellites, humankind would quickly progress toward human spaceflight to the moon, Mars and Venus, all across the solar system, even to the stars. We assumed that the chemical rockets that opened the way to space would give way to nuclear and then to thermonuclear propulsion systems. The theoretical estimates of performance of nuclear and thermonuclear propulsion looked very promising. It was also widely believed that the corresponding technologies would be available soon, and the same generations that witnessed launch of the first Earth satellites would see rapid progress toward deep space flight not only by probes, but also by humans. It appeared natural that orbital space operations would assume only a minor fraction of all space operations, in a way similar to how the early seafaring navigation of coastal waters gave way to navigation of the high seas.

This didn't happen. Now, more than six decades after Sputnik, the space operations are almost exclusively limited to low-Earth orbit. Humans paid merely six brief visits to the moon and have sent a few tens of robotic missions to the moon and planets — most notably Mars and Venus. But the overwhelming majority of missions (only a tiny fraction of them having crews) were sent to the lower- and higher-Earth orbits.

What happened? Why did early expectations not materialize? Why in contrast to the rapid development of aviation throughout the 20th century has space flight stagnated essentially where it terminated a few decades ago when the first semi-reusable crewed spacecraft, the space shuttle orbiters, were launched? Conceptually, we've seen little development since the early 1980s.

Unrealistic expectations

The expectation that chemical rockets would soon give way to nuclear and thermonuclear rockets turned out to be unrealistic. It appears that chemical propulsion remains the only feasible option for the present time and the foreseeable future. The modern expendable rockets, the ancestors of customized missiles that provided a quick solution for space access in the late '50s and early '60s, remain the only practical means of delivery to space. Expendable is the key word. Prior to SpaceX's recovery of first stages in recent years, these vehicles, each costing many millions of dollars, were piecewise thrown away on their way to space. Until SpaceX revealed that the cost of a payload launched into low-Earth orbit may be possible for less than $2,700 per kilogram or for less than $7,500 per kilogram when launched into geosynchronous orbit, only those customers who can afford to pay $20,000 or more per kilogram of delivered goods can pay for conventional transportation.

The end of the Cold War spelled the end of an era of practically unlimited funding for space exploration. The large, well-established aerospace companies are still supplying expendable rockets and are developing new ones. And their cost per unit never substantially decreases. The principal reason why costs remain constant or continue to increase is that whatever innovations are engaged, the launch vehicles are still thrown away after a single use. Imagine a transcontinental airliner scrapped after each flight. Could you imagine that any forthcoming innovations could ever eventually reduce the cost of a flight on such a non-reusable airliner to anything near the current ticket price? That's not very likely.

So, launch vehicle reusability is the only practical cost-effective option. Why then, well over half a century into the spacefaring era and with the exception of SpaceX's evolutionary first step, does reusability — specifically of the launch stage — remain primarily a technical dream? Like all revolutionary concepts, it requires considerable investment.

Competing for funding

There is one point necessary to mention. In our opinion, the destiny of reusable space launch vehicles was marred by the premature attempt to use the Earth's atmosphere in two ways simultaneously: as a support for aero assist with wings providing supplemental lift and as a supply of oxidizer (atmospheric oxygen) for jet propulsion. Hypersonic air-breathing propulsion turned out to be a technology area that was too difficult to be mastered simultaneously with reusable ascent/re-entry vehicle design. The ill-fated National Aerospace Plane, or NASP, project clearly demonstrated the limitations of the usability of that aspect. Our conclusion: At least for the time being, the choice of a reusable launch vehicle should be a rocket plane, not a hypersonic air-breathing jet plane.

As an initial consideration, the physics of an air-breathing reusable first stage imposes substantial payload restriction. In order to generate the required greater thrust necessitated by a heavier payload, an air-breather must have a larger intake duct in order to ingest more oxygen for the greater combustion demanded. And the ability to take in more oxygen increases directly with the first power of velocity. Meanwhile, the thrust required to overcome the increasing aerodynamic drag as the aircraft accelerates increases with the square of velocity. This combination of oxygen demand and overcoming drag sets a practical upper limit on payload size.

There is another point one must also consider. Single stage to orbit was another idea that turned out to be technically unrealistic to pursue with

A SpaceX Falcon 9 carrying the company's Crew Dragon spacecraft is launched in 2020 from NASA's Kennedy Space Center in Florida.
SpaceX

▲ **The first stage** of a SpaceX Falcon 9 rocket is brought back to Florida on a drone ship after a 2020 launch from NASA's Kennedy Space Center in Florida.
Melissa Lawton

The capability of SpaceX to fully recover and reuse the first stage of a rocket demonstrates only one part of the potential value of reusability.

existing chemical propulsion. The propellant required for even the best-performing engines leaves less than 10% of the takeoff weight for both the payload and structure. This is very challenging technologically and economically unattractive. Two stages to orbit appears to be the only viable option.

Combined with the uncertainties of competing concepts and their unknown futures, the potential investors are understandably hesitant to direct their capital toward development of reusable vehicles.

The success of recovering and reusing launch stages demonstrated by SpaceX is definitely a significant accomplishment and a much-needed, long-awaited first step in the right direction. But the engineering complexity cannot be overstated, albeit there are resulting overall cost savings wrought by this achievement. The continued application of this method will bring down the costs of future launch operations. Although this effort represents an evolutionary step toward reusability, what is really needed to significantly reduce launch costs is a revolutionary step. The capability of SpaceX to fully recover and reuse the first stage of a rocket demonstrates only one part of the potential value of reusability. The launches are still constrained to dedicated rocket launch facilities, and the recoveries of the launch stages are limited to highly specialized procedures and landing pads.

Also, the SpaceX concept involves a purely bal-

A one-third scale model of the National Aerospace Plane was tested in the Transonic Dynamics Tunnel circa 1992 at NASA's Langley Research Center in Virginia. A full-scale model was never built.

NASA

listic first stage. Once the launch stack reaches the staging velocity and the second stage is released, the first stage must perform two maneuvers: 1) to decelerate from staging velocity to zero and 2) to hover back to the launch site — both requiring the budgeting of a predetermined quantity of propellant. For comparison, the first stage of the rocket plane launch vehicle would make a nonpowered U-turn followed by a glide back to the launch site.

The Pegasus concept of carrying a space-borne payload to low-Earth orbit with a first stage comprising a conventional aircraft is a cost-effective approach also. The first-stage aircraft is undeniably reusable, as it can operate from any conventional airport. However, the application of a conventional aircraft for the first stage, as with Pegasus, limits the size of the orbital delivery to a fairly small payload.

Operating from an airport

A rocket plane, which is in essence a fixed-wing rocket, would be a natural means of using the aero assist of the Earth's atmosphere en route to orbit, while simultaneously enabling operations from any conventional airport. Aerodynamic lift developed by the wings can help compensate for the vehicle weight and thus reduce gravity losses, a major component of energy budget of the launch vehicle. Aerodynamic lift is instrumental during the entry and descent phase too. The space shuttle flights demonstrated that aspect every time a vehicle returned from orbit.

For operations from conventional airports, the initial wing loading of the stack of two launch stages needs to be complemented by a winged pre-stage to enable the takeoff from conventional-length runways at airspeeds of a conventional airliner. Two U.S. patents granted to Eugene, one in 2012, "Non-powered, aero-assisted pre-stage for ballistic rockets and aero-assisted flight vehicles," and in 2013, "Aero-assisted pre-stage for ballistic rockets and aero-assisted flight vehicles," suggest how this could be done. The first describes a nonpowered version, which, of course, would be easier to implement. The second describes an aero-assisted (winged) pre-stage that would be powered, which substantially eases the propellant budget of the launch vehicle.

We strongly recommend that a government organization such as NASA or the U.S. Defense Department, as well as interested private corporations, such as SpaceX or Northrop Grumman, which now owns the Pegasus rockets, conduct feasibility studies of the rocket plane as a launch vehicle. The referenced patents can be taken as a point of departure for this effort. Such feasibility studies could involve a detailed analysis of the rocket-plane concept, followed by a proof-of-concept suborbital flight demonstration. Suborbital flights could function as the intermediate goal toward final acceptance of the rocket plane as a truly low-cost launch-vehicle option. ★

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