Hearing of the Senate Committee on Defense Appropriations

"National Security Space Launch Programs"

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Thank you, Chairman Durbin, Ranking Member Cochran, members of the committee, for providing an opportunity to discuss the important topic of national security space launch programs, and in particular, the Evolved Expendable Launch Vehicle Program which is central to maintaining assured access to space for the Department of Defense.

The Evolved Expendable Launch Vehicle (EELV) program as it exists today is the result of technical, economic, and policy decisions made over several decades. After the loss of the Space Shuttle *Challenger* in 1986, the Reagan Administration limited the Shuttle to flying only those payloads that required its unique capabilities. Additional launch failures and subsequent decisions in the 1990s led to the creation of the EELV program and the Atlas V and Delta IV launch vehicles to meet U.S. national security needs for expendable vehicles. Boeing and Lockheed Martin formed United Launch Alliance (ULA) in 2006 at the behest of the government in an effort to reduce duplicative costs in separate launch vehicle programs.

In late 2012, the Department of Defense (DoD) announced that it would invite competition for its EELV-class payloads beginning in 2015. The Air Force would proceed with a "block buy" of up to 36 "launch cores" from United Launch Alliance while competing up to 14 cores from potential new U.S. entrants such as SpaceX. The Air Force separately signed a contract with SpaceX for two launches in 2014 and 2015 to support the certification process for Space X's Falcon 9 v1.1 vehicle. The criteria for certification are set forward in a Launch Services New Entrant Certification Guide. There are several potential ways to achieve certification, through combinations of successful flights and/or detailed analyses showing compliance with Air Force requirements.

Current Issues and Policies

Fiscal constraints, rising launch costs, limited demand, and strict government requirements have combined to create a complex, on-going debate about the role of competition in the procurement of EELV-class launch services by the DoD. Private companies, whether Boeing, Lockheed, or potentially SpaceX, Orbital, and other companies yet to emerge must provide these services as the Air Force does not own and operate its own launch vehicles in contrast to its ownership and operation of air cargo transports. The government clearly has an interest in getting the most value for the taxpayer dollar while at the same time requiring a high degree of mission assurance given the criticality of national security payloads. The government also has an interest in understanding the implications of its purchasing decisions on the U.S. aerospace industrial base.

Due to the size and scope of DoD launch purchases and the requirement to use U.S. suppliers, DoD decisions have a major impact on the U.S. space launch industrial base. National space policy calls for maintaining assured access to space, with the DoD having the largest share of this responsibility. NASA and commercial providers also require assured access to space and they too are concerned about the U.S. launch industrial base. However, they purchase the best available launch services meeting individual mission needs, with NASA limited to U.S. suppliers unless specifically exempted, and commercial satellite firms purchasing the best globally available launch services, unless limited by export controls or other regulations.

DoD, NASA, and commercial satellite firms all rely on the same industrial base such that decisions made in one U.S. sector nearly always affect others, often in unanticipated ways. The DoD decision to end the use of the Delta II launch vehicle meant that fixed costs that had been shared by DoD and NASA now fell completely on NASA. This increased the cost to NASA and made the Delta II uneconomic for a large class of science missions that had relied upon it for many years. Similarly, the retirement of the Space Shuttle together with the cancellation of the follow-on Constellation program by NASA ended the sharing of certain fixed costs with DoD and drove up the cost of solid and liquid rocket propulsion systems, including those used by EELVs.

The 2013 National Space Transportation Policy does not specifically address the EELV program. Rather, it directs the Secretary of Defense to: "Ensure, to the maximum extent practicable, the availability of at least two U.S. space transportation vehicle families capable of reliably launching national security payloads". This condition is met today by the existence of the Atlas V and Delta IV, and in the future may (or may not) include SpaceX, Orbital, or even NASA's Space Launch System. There is no requirement that these vehicle families be privately owned, although that is at present the most plausible assumption.

U.S. national policy addresses the space launch industry base by stating that the health the industrial base, broadly defined, is a consideration that goes beyond the needs of any specific mission in awarding contracts or setting the parameters of competition. Specifically, the policy states that:

> "To promote a healthy and efficient United States Government and private sector space transportation industrial base, departments and agencies shall:
> - Make space transportation policy and programmatic decisions in a manner that considers the health of the U.S. space transportation industrial base; and

- Pursue measures such as public-private partnerships and other innovative acquisition approaches that promote affordability, industry planning, and competitive capabilities, infrastructure, and workforce."

It should be noted that the policy includes both government and private sector industrial bases, although in practice is it difficult to clearly separate the two. The only government-led launch system development at present is the Space Launch System, and even in that case private contractors are doing the work in commercial as well as government facilities. With regard to private sector competition for government contracts, the policy states that:

> "U.S. commercial space transportation capabilities that demonstrate the ability to launch payloads reliably will be allowed to compete for United States Government missions *on a level playing field, consistent with established interagency new entrant certification criteria*. Any changes to these new entrant criteria shall be coordinated with the Assistant to the President and National Security Advisor and Assistant to the President for Science and Technology and Director of the Office of Science and Technology Policy before they may take effect." [Emphasis added]

I have emphasized to the phrase "level playing field" as the determination of just what this means is central to the question of competition going forward. Policy alone cannot answer the dilemma of how industrial base and competition objectives should be traded so as to assure the existence of at least two "U.S. space transportation vehicle families capable of reliably launching national security payloads." The judgment as to what constitutes acceptable reliability is left to the DoD and the Air Force. I will briefly address three primary factors that are driving possible trade-offs and the uncertainties around them: market structure, mission assurance needs, and options for reducing launch costs.

Structure of the Launch Market

Given that private firms provide U.S. launch services, how many launch providers can the market sustain? It should be recalled that ULA was formed because launch demand, U.S. and foreign, was inadequate to sustain two independent competing launch providers with separate infrastructures. The structure and size of the market has not changed in the last decade; U.S. government demand has remained flat at best. There has not been growth on the commercial side for EELV- class payloads, although there has been an increase in small "nanosats" and "cubesats."

Historically, the demand for space transportation has often been overestimated, whether from projections in the early 1980s of the need for 24 Shuttle flights per year, or the 1990s expectations of hundreds of small satellites for mobile satellite services. Virtually all of those "big LEO" and "little LEO" systems disappeared or went bankrupt in the face of the rapid expansion of ground-based cellular communications. In 2013, the FAA's commercial space transportation advisory committee (COMSTAC) predicted a small increase in commercial launches in 2014 and 2015, followed by a decline to a relatively steady state for the rest of the decade.

Mass tourism to orbit, not just suborbital flights, would be a “game changer” in terms of bringing significant new commercial demand to the space transportation market. In the government civil sector, the market for transportation of cargo and crew to the International Space Station is quite modest however, a U.S. commitment to human lunar exploration, with procurement of private launchers to deliver cargo to the Moon, could greatly strengthen demand for U.S. launchers. Both tourism and lunar logistics would occur outside of the DoD budget, and thus would have the potential to benefit DoD, but it is unknown when, if ever, either new source of demand might occur.

The recently successful SpaceX launches of communication satellites are a case in point, taking back market share from European and Russian providers that had largely driven the United States out of international competitions. A shift in demand toward the United States would, of course, drive up costs for competitors in Europe and Russia, who would have less demand for their services. This would also create partial disincentives for new countries seeking to develop launch capabilities and offset some of their costs through export of launch services. In this way, U.S. pricing power can be a barrier to entry for developing space launchers.

While the success of the SpaceX Falcon and, more recently, Orbital’s Antares launcher is welcome, it should be kept in mind that governments, not private industry, drive much of global launch demand. Most foreign government launch opportunities are inaccessible to U.S. launch providers, just as U.S. government launch opportunities are inaccessible to foreign launch providers. In general, competition is a good thing. However, the launch market is not a classic one of "many buyers and many sellers," but is instead characterized by very thin demand, few suppliers, and multiple government-driven industrial polices (U.S., European, Russian, Chinese, Indian, and Japanese). Major spacefaring countries have shown a willingness to retain their launch autonomy, even if it makes no commercial sense.

In space transportation, price is among several factors, such as schedule, reliability, and risk that affect demand. In conventional markets, falling prices create increased demand. Space launch demand has, however, proven to be remarkably flat over a very wide range of prices. Past studies have estimated that launch prices would have to fall to a few hundred dollars per pound, from the thousands of dollars per pound levels of today, to induce new demand, notably in space tourism. A consequence of flat demand is that a lower cost supplier, able and willing to offer a lower price, can displace a higher priced incumbent. However, once accomplished, the new supplier has every incentive to raise prices to gain revenue and profit margin. The buyer does not necessarily benefit from lower prices once a new set of suppliers is established. Said another way, the prices experienced by buyers in a thin market, with flat demand and high barriers to entry, generally do not drop after the exit of the former incumbent.

The attainment of lower launch costs and hence lower prices with present-day expendable launchers can create disincentives to the private development of new reusable launchers. As expendable prices drop, the economic break-even point for investing in reusable launch systems increases; that is, more flights of the reusable system are required to "pay back" the investment in its development. This is an especially difficult barrier given current and foreseeable launch markets, where demand is essentially flat. Thus, new reusable launch vehicle technology resulting in dramatically lower operational costs would seem to be out the reach of private development. It is not the availability of capital but rather the lack of an attractive business case that is the problem.

High prices and low volumes characterize today's launch market such that industry revenue is maximized when demand is (nearly) linear with prices. If prices were to be cut by half and volume only doubles, total revenue would be constant.
This creates a classic market failure in that there is no market incentive to invest. The space launch market thus has some similarity to other historical transportation technologies, from canals and railroads to automobiles and airplanes. Faced with these issues in the past, the government has taken action to overcome "market failure," with incentives that move the market to prices at which demand is capable of driving prices lower rather than higher. Thus, the early transcontinental railroads profited from the sale of former federal land, not the operation of the railroads themselves. The air transportation system enabled by government support for airports and the air traffic control system benefits the economy as a whole far more than it does the airline owners and operators.

The point of these examples is that space launch is a strategic national capability that serves public as well as private objectives. Despite its criticality, however, the economic structure of today's space launch market results in a classic "market failure" that justifies government intervention. However the purpose, degree, and scope of that intervention is a subject of debate, as we will discuss.

Mission Assurance and the Cost of Failure

Launch vehicles are a means to an end, the reliable placement of payload into space. The loss of a national security payload is unlike a commercial loss in which an insurance payout can compensate for the loss. The cost of failure in the national security arena is tremendous, in terms of direct hardware losses, failure investigations and corrective measures, replanning and rebuilding, delayed mission capabilities, and indirect loss of national and international confidence. The stakes are even higher, of course, where human life is concerned.

The EELV program has an excellent reliability record, with 68 successful launches since 2002. Launch vehicle reliability records, whether for Atlas, Delta, Titan, Soyuz, Proton, Long March, Zenit or Ariane, develop over time. A launch vehicle may be designed to be reliable, and the tools of probabilistic risk assessments can help predict relative reliabilities among different designs. But it is only with accumulated flight experience over time that one can actually know what the reliability of a vehicle is. This is a challenge for developing vehicles in which the configuration of the vehicle may be changing from flight to flight. The actual flight heritage and confidence of individual subsystems, such as engines, electrical, guidance, and separation devices, can vary substantially in a vehicle that appears outwardly unchanged.

If mission assurance is critical and the costs of failure are high, it makes sense to be willing to incur additional costs to assure launch vehicle reliability – and to want to have actual flights to prove that reliability. The current Air Force approach of requiring combinations of either demonstrated performance or documentation is a reasonable one for giving new entrants an opportunity while protecting national security interests. That said, the United States incurs considerable cost to ensure that it can place national security payloads reliably into space, with extensive documentation requirements, audits, and inspections, not only of technical matters but of financial and business processes as well. Do all of these additional costs add value for the government? What are the cost/risk/benefit trade-offs of doing something different?

Government oversight is costly, but reliance on the private sector when commercial demand is very thin is also risky. During the defense reforms of the 1990s, the government stopped requiring its standards for radiation-hardened electronics, assuming an experienced industry could and would apply more cost efficient commercial standards. Government needs proved to be both unique and limited, such that there was little economic incentive to meet government standards in the much larger commercial markets. The result was a series of costly failures in government programs that necessitated rebuilding, at public expense, an industrial capability that had withered.

I am not saying that we should accept less reliability for lower launch prices; or that some level of failure in space is acceptable. It is difficult to identify a viable product or service that thrives with low reliability. However, there is suggestive evidence that the cost of government-driven mission assurance and current Federal Acquisition Regulations (FAR) increase costs by factors of 3-5 times, not just 20-30%.[1] Thus debate should be about the cost of assuring reliability and whether than can be accomplished in a more cost-effective way.

The traditional FAR process is not inherently dysfunctional – nothing in the FAR requires government program managers to act inefficiently. Unfortunately, the penalties imposed on government managers who try to expedite development by tailoring the application of FAR processes can be so severe that, in practice, most

[1]Comparison of actual private costs to development costs predicted by government cost models have indicated wide gaps in some cases of small launch vehicles, communications satellites, and cargo aircraft. The data are sparse however as few direct public-private product analogues exist.

persons in authority will not take the risk. The typical government acquisition cycle is structured with far more emphasis on eliminating any possible cause of failure, than achieving success in a timely and cost-effective manner. In reality, the cost of broken hardware and the required rework can easily be less onerous in the long run than the cost and schedule overruns that so typically plague government procurement. But cost and schedule overruns, as long as they are in some sense "moderate," e.g., factors of two or less, are not considered to be "failures," whereas broken hardware emphatically is.

As a result, government procurement can become so dysfunctional that innovative approaches such as NASA Space Act Agreements are sought out for use in situations well beyond their originally intended sphere of applicability. The DoD and intelligence communities have their own "other transactional authorities" which can be used in place of FAR-based procurements, and have at times sought their own approaches to operating more efficiently in performing critical missions, such as classification and the establishment of special programs under DARPA or the Strategic Defense Initiative Organization.

Expedited approaches to Federal acquisition are structured so as to sacrifice a certain amount of formal, documented accountability for the expenditure of public funds in exchange for significantly expedited results obtained at substantially lower cost. While this has worked extremely well in particular cases, it remains broadly true that public funds must be carefully accounted for, and the government must be a "smart buyer" on behalf of the taxpayer. Experiences with programs such as the Future Imagery Architecture demonstrate the consequences of agencies having inadequate internal skills and capacities to oversee major program acquisitions.

This raises a key but widely misunderstood point: much of what has been labeled "commercial space transportation" at NASA in recent years is really just innovative contracting with new contractors. It is, largely, *not* private capital being put at risk to compete in private markets; the arrangements involved might far more accurately be described as "private-public partnerships." There is nothing inherently wrong with such arrangements, but we should use accurate terminology in describing them, and we should require that in exchange for the public funds that are advanced, the government benefits accordingly. For example, the development of two new cargo suppliers for the International Space Station – Falcon 9 and Antares – has been a success. The DoD may thus be in a position to benefit from the capabilities of SpaceX and Orbital that NASA has helped to develop with its innovative combination of public money and private talent.

By all observations, the new private entities are intensely focused on reducing costs, and this includes the cost of compliance with government regulations that are now imposed on United Launch Alliance. If a private entity can demonstrate reliability without traditional levels of government oversight, it could have a sizable cost advantage. This then raises the question of whether the government will allow one set of rules for so-called "new entrants" and a different set for incumbents. Looking forward to the potential 14-core competition, the question for the government will be what costs it wishes to impose on suppliers of national security space launch services, and whether those rules are applied on a "level playing field" as called for in U.S. policy.

Reducing Launch Costs

How does one actually reduce launch costs? Clearly, anyone with deep pockets can reduce launch *prices*—e.g., sovereign nations, wealthy entrepreneurs or philanthropists—but how can the actual *cost* of launches be cut? The rocket equation and propulsion mass fractions are as unforgiving as private capital markets. Process improvements, in design, production, and operations can help, such as vertical component integration, horizontal payload processing, and streamlined launch checkout and operations. However the amount of "touch labor" required per pound of launch vehicle is stable across a wide range of masses, so improvements tend to be of marginal, not break-through, benefit.

Increasing production volume through large buys can achieve economies of scale. However, without new demand, large buys are not sustainable without government support. As mentioned earlier, demand is relatively flat, so there are limits to the size of buys that could be justified. Launch costs might be made cheaper if some lower level of reliability could be traded for cost, but no payload owner would want to use them. Large-scale space tourism is only possible at levels of reliability and safety even greater than what we have today.

Various teams are exploring how existing engines such as the RS-68, RS-25, and even the old Saturn V F-1, could be manufactured more efficiently. The production line for Merlin engines at SpaceX is very large, with 10 engines being used on each Falcon 9 flight. This helps build operational experience more rapidly than if using a fewer number of more powerful engines. Whether this multi-engine approach is reliable and executable as flight rates increase remains to be seen.

New concepts such as reusable "flyback" boosters that return expensive elements (propulsion, avionics) for re-use are promising. Electric propulsion for in-space movement of satellites is developing rapidly. During the government shutdown last year, a space electric propulsion conference was held at my university. It attracted about 400 participants, U.S. and foreign, industry and academia. Commercial satellite companies are moving to take advantage of electric propulsion. This could have great impact on the commercial launch markets, as a dedicated upper stage would no longer be needed to place a satellite in its final orbit. I am speculating, but a two-stage vehicle with a reusable first stage could be a serious competitor in that future world.

New technology seems to be the long-term answer, in particular, advanced propulsion with much higher specific impulse, than current chemical propulsion. DARPA has pioneered work in high energy density materials that may the potential to dramatically increase the performance of chemical rockets. DARPA also does not seem to think that re-engineering existing engine designs will enable major cost reductions. Instead, they are looking at reusable systems such as two-stage to orbit concepts. Single-stage to orbit vehicles using air-breathing engines still look to be beyond the state-of-the-art. As mentioned earlier, the economic break-even point for reusable launch vehicles is greater than for expendable launchers. Assuming expendable launch prices do decline, this will make the economic case for reusable more challenging without dramatic technology advancements. Thus investments in new space launch R&D are likely going to have to come from the government, not private industry.

Concluding Observations

The United States and the DoD in particular need to decide how it best assures the existence of at least two "U.S. space transportation vehicle families capable of reliably launching national security payloads." In doing so, the DoD has to be mindful of the overriding need for mission assurance, fiscal constraints, and the need for a U.S. industrial base that can assure access to space for all payloads.

In this context, industry competition is a tool, not an end in itself. Depending on its terms and conditions, competition can result in meeting DoD needs at lower cost or failing to meet those needs and merely shifting costs to other accounts. The EELV program as managed by ULA today represents high degree of experience and capability that are vital to assuring access to space for all national security needs. As a potential competitor for national security launches, SpaceX is innovative, real, and brings an intense focus on cost control while meeting customer launch needs.

How will any new entrant, do in the future? Only repeatable, configuration-controlled flight experience will tell. The Launch Services New Entrant Certification Guide is a thoughtful and prudent approach that is being applied to SpaceX and should be to any candidate new entrant. The more difficult question is what comes after a new entrant is certified. Will current FAR-based procurements be used, or will the DoD procure future services in a more commercial-like manner, perhaps paying for additional specific services not required by private sector customers?

Will incumbents and new entrants, with very different histories, compete under the same rules? And, whether they do or do not, what may be said about the rules themselves? Do today's rules appropriately reflect the nearly 60 years of lessons learned in space transportation? I do not know the answers to these questions, and I suspect no one else does either at this time. In this connection, I am reminded of the comment made some years ago by Wayne Hale, former Space Shuttle Flight Director and, later, Program Manager – "I am not sure I know how to make space transportation more reliable, but I do know how to make it more expensive."

In the end, the policy issue is not one of SpaceX and other potential new entrants versus ULA as much as it is one of deciding what the role of the DoD should be, and what are the government's policy requirements. Should we be trying to:

- Get the lowest price for reliable transportation to orbit for a particular mission?
- Get the lowest price for all national security missions?
- Get the lowest price for all government-funded missions?
- Assure access to space for all needs with a U.S. industrial base at least cost?

The last question is a consequence of the fact that a space launch industrial base meeting all government needs, civil as well as national security, cannot presently be sustained by private market demand. Thus, a significant degree of government support will be necessary for the foreseeable future.

Reliability and readiness have been the top priorities for national security launches. Given the importance of national security missions, what is the most cost-effective way for the DoD to assure mission success? Can mission assurance be achieved at lower cost than the way we do it today? This certainly seems plausible, but careful thought needs to be given as to what responsibilities and capabilities ought to remain within the government. Will the government have the authority to order a stand-down of a vehicle family in the event of a failure? Are agencies willing to relax or modify their use of cost-accounting rules and other FAR-based requirements for all launch service providers? In short, how much is the government willing to pay for "process" in addition to "performance"?

Defense acquisition reform is a much larger topic than the present hearing, but nonetheless bears directly upon the present case. Thus, the question of how best to acquire space launch services may provide an opportunity for pilot-testing some forms of regulatory relief, as opposed to direct subsidies. The government could pay separately for non-commercial processes and deliverables, rather than having all such costs bundled into the launch cost or company overhead as is done at present. The government may still pay more for its launches than a commercial buyer would, but the costs drivers would be more visible and accountable and would more easily allow cost-benefit trades to be performed.

Most critically, the United States needs to ensure that its space policies, programs, and budgets are in alignment, since to do otherwise is to invite failure. The first consideration for any policy choice and implementing approach is that it be clearly stated and adequately funded – with clear priorities on which requirements, schedules, and goals will be relaxed if resources or regulatory relief are not forthcoming.

Thank you for your attention. I would be happy to answer any questions you might have.

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Prior to NASA, Dr. Pace was the Assistant Director for Space and Aeronautics in the White House Office of Science and Technology Policy (OSTP). From 1993-2000, Dr. Pace worked for the RAND Corporation's Science and Technology Policy Institute (STPI). From 1990 to 1993, Dr. Pace served as the Deputy Director and Acting Director of the Office of Space Commerce, in the Office of the Deputy Secretary of the Department of Commerce. He received a Bachelor of Science degree in Physics from Harvey Mudd College in 1980; Masters degrees in Aeronautics & Astronautics and Technology & Policy from the Massachusetts Institute of Technology in 1982; and a Doctorate in Policy Analysis from the RAND Graduate School in 1989.

Dr. Pace received the NASA Outstanding Leadership Medal in 2008, the US Department of State's Group Superior Honor Award, *GPS Interagency Team*, in 2005, and the NASA Group Achievement Award, *Columbia Accident Rapid Reaction Team*, in 2004. He has been a member of the US Delegation to the World Radiocommunication Conferences in 1997, 2000, 2003, and 2007. He was also a member of the US Delegation to the Asia-Pacific Economic Cooperation Telecommunications Working Group, 1997-2000. He is a past member of the Earth Studies Committee, Space Studies Board, National Research Council and the Commercial Activities Subcommittee, NASA Advisory Council. Dr. Pace is a currently a member of the Board of Trustees, Universities Space Research Association, a Corresponding Member of the International Academy of Astronautics, and a member of the Board of Governors of the National Space Society.