AIRSPACE INTEGRATION IN AN ERA OF GROWING LAUNCH OPERATIONS

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Accommodating space launches in the National Airspace System (NAS) is burdensome, but at historical launch rates it is manageable. However, it is expected that launch rates will increase substantially, with the preponderance of that increase coming from commercial customers. This will require better integration of space launch activities in the NAS. This paper presents the issues and highlights potential conflicts between the "space side" and the "air side" that may call for intervention from high-level decisionmakers.

Background

"Space launch" is a broad category, covering orbital launch of satellites, suborbital launch of payloads (and soon tourists), vertical launch of rockets, horizontal launch of aircraft carrying rockets, flyback of boosters, etc. There are even emerging concepts involving catapults (SpinLaunch) and evacuated tubes (the Thor launch system from 8 Rivers) being proposed for space launch. Therefore, any methods to increase space launch integration into the NAS will not be one size fits all. For example, processes (filing a flight plan) and technology (such as Automatic Dependent Surveillance-Broadcast, or ADS-B) could prove feasible for better integrating suborbital space tourism flights (which has been likened to "suborbital aviation") into the NAS but prove infeasible for rockets launching satellites to orbit.

This paper focuses primarily on vertical launch of rockets to orbit, which is likely the hardest space launch modality to integrate into the NAS for a few reasons:

- Vertical launches of rockets generally occur from fixed launch sites, which limits flexibility. A system such as Northrop Grumman's Pegasus or Virgin Orbit's LauncherOne, carried aloft by an aircraft to a location where the rocket is dropped and launched for its flight to orbit, has a degree of freedom to choose a drop location to minimize impact to the NAS (within mission requirements). Similarly, ABL Space Systems is developing a ground-based launch system that could potentially be deployed to locations that also minimize such impact. That being said, these launch systems are relatively "small" and generally do not present a growing trend for orbital launch .

- The fixed site in the United States with the greatest space launch activity—the combined Cape Canaveral Air Force Station (CCAFS) and Kennedy Space Center (KSC) in Florida—affects airspace heavily traveled by commercial aviation.

- Space launch to orbit results in a larger "footprint" compared to suborbital systems. The instantaneous impact point track (where a rocket would land on the ground if its thrust were terminated during flight) for an orbital launch system extends from the launch site to the point where the system achieves orbital velocity (over 17,000 miles per hour). This track is thousands of miles long, whereas suborbital systems have a much shorter impact point track.

- The reliability of suborbital space tourism vehicles is anticipated to be higher than that of space launch systems. The demonstrated reliability percentage of launch-to-orbit systems is in the mid-to-high 90s, while suborbital space tourism systems are striving for (and should achieve) much greater reliability.

Current Process

To date, space launch has been *accommodated* in the NAS rather than *integrated*. That is, a launch operator determines a launch day and time based on mission needs and secures a launch window from the relevant range authorities, regardless of the impact on the NAS. (There are some exceptions for certain holiday periods, but, generally, impact on the NAS is not a consideration for space launch operators.) Hazard areas are identified by the launch provider and reported to range safety authorities; the Federal Aviation Administration (FAA) issues a notice to airmen (NOTAM), defining Special Activity Airspaces (SAAs) to alert aircraft pilots of potential hazards due to launch activities (such as flight of the launch vehicle itself, hardware jettisoned from the launch vehicle, or debris in the event of vehicle breakup/explosion). These hazard areas can cover the airspace over many hundreds of square miles and last for substantial periods of time (hours), again depending on mission needs.

The Changing Launch Landscape

The kind of accommodation described above is burdensome, but, at launch rates of approximately 20 per year (from CCAFS, for example), it is manageable. In addition, most space launches have historically been for government customers, so acceptance of this process by other users of the NAS has had an aspect of "for the greater good." It is anticipated, however, that launch rates could increase substantially, with the preponderance of that increase accommodating commercial customers (see Figure 1). This increase speaks for the need of better integration of space launch activities in the NAS.

In addition to the potential increase in launch cadence, there are efforts underway to shorten the readiness timelines for launch systems to achieve a "responsive" launch capability. Recent efforts along these lines include the Defense Advanced Research Projects Agency (DARPA) Launch Challenge and the Rapid Space Launch Initiative (RSLI) from the Air Force's Space and Missile Systems Center. An outcome of such schedule compression has implications for the existing process. NOTAMs are often published well in advance of space launches, which provides planning time by other users of the NAS. As the ability improves for launch operators to provide "responsive" launch, the lead time available for providing NOTAMs will decrease.

While the focus of this paper is orbital space launch, it should be noted that there are a dozen FAA-licensed spaceports in the United States, only a few of which are currently active but more are being proposed and developed. The "infrastructure" for more spaceflight is getting in place, pointing to an expectation of increased demand on usage of the NAS, not only for orbital launch from CCAFS.

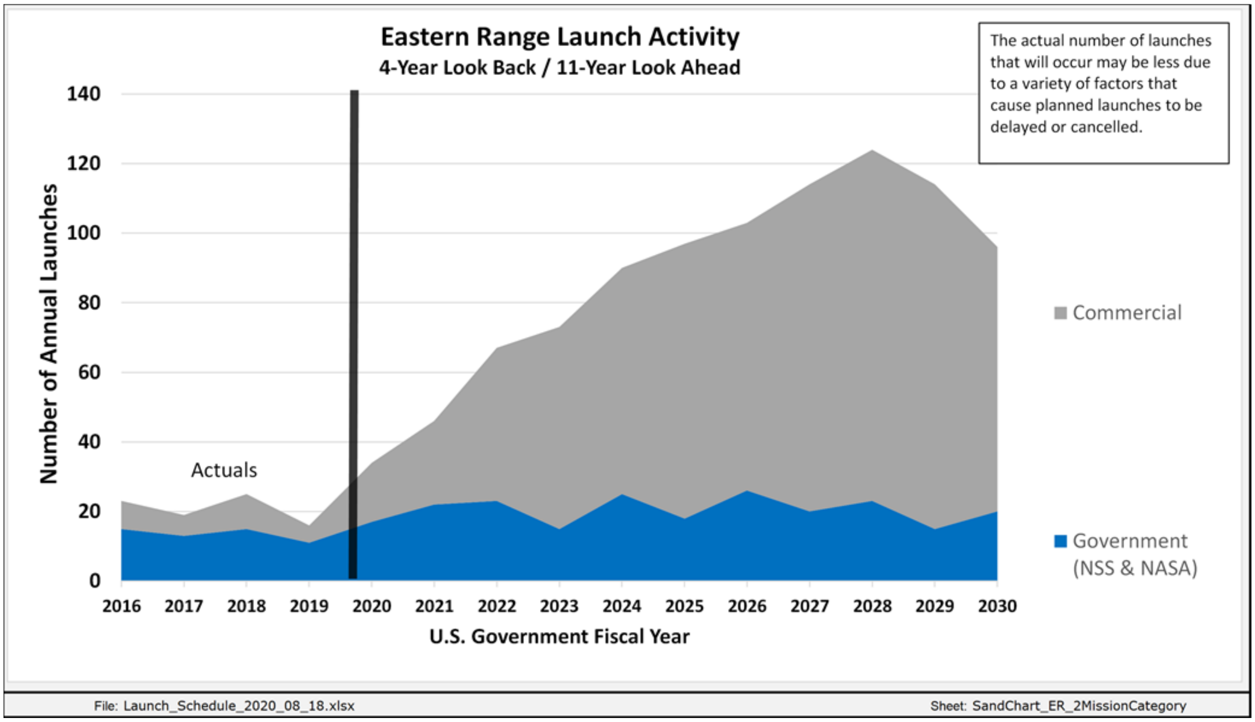

Figure 1: Eastern Range Launch Activity. *Derived from several data sources as of August 18, 2020, in particular Federal Communications Commission (FCC) filings for planned satellites, which telegraph a large potential increase in future launch rates. A description of the methodology used to derive this upper-bound launch demand can be found in the paper by Grant Cates et al.,* Launch Uncertainty: Implications for Large Constellations *(The Aerospace Corporation, Center for Space Policy and Strategy, November 2018).*

Considerations in Integrating Space Launch into the NAS

The process described above (segregating airspace for space launch activities) has a history dating back to the early days of spaceflight and is a valid risk management approach that has successfully protected the uninvolved public from space launch mishaps. Integration of space launch into the NAS must maintain this excellent safety record, protecting not only people on the ground but also users of the NAS. Any integration strategy must recognize characteristics of orbital space launch that constrain the solution space. This is particularly relevant given the existing infrastructure and operational procedures involved with managing use of the NAS. These characteristics fall into the broad categories of launch timing, launch system reliability, and launch trajectories.

Launch Timing. An obvious way to minimize the impact of space launch on the NAS would be to limit space launch opportunities to times when the affected portions of the NAS are relatively unused, perhaps between 1:00 a.m. and 4:00 a.m. local time. Such an "integration" of orbital space launch into the NAS is more procedural than technical; that is, it would follow the current process.

This sort of accommodation is not possible since launch times are not determined arbitrarily but are calculated to meet very specific needs. Launch times are driven by mission requirements with limited flexibility to move them into time frames with less air traffic. For example, launches of cargo or crew to the International Space Station (ISS) must launch at a specific time on a given day to rendezvous with the station (an "instantaneous launch window"). Similarly, satellites often have a specific time they need to reach their orbital destination for phasing with other satellites or to meet other mission needs. Generally, launch vehicles have limited ability to accommodate a suboptimal launch time. Therefore, an integration strategy of limiting space launch to "quiet" times in the NAS is not achievable since orbit mechanics generally dictate launch times for orbital space launch.

A feasible option might be to limit the duration of launch windows. Launch providers generally plan for the longest launch window possible within their capabilities and mission requirements in order to have the greatest likelihood of launching if issues arise during the launch countdown. For this reason, certain launches might have launch windows that are hours long, which obviously have a greater impact on the NAS than an instantaneous launch window. This area is ripe for study to determine where air and space equities can both be accommodated, determining the tradeoff of launch window duration versus the probability of successfully launching and the impacts on air traffic. It's important to realize that this is not just a "scheduling" issue; there can be significant cost considerations on the part of the launch provider and satellite payload for a missed launch opportunity.

Launch System Reliability. *Aerospace* is used to describe both air and space activities. There are certainly great similarities: many companies service both the air and space markets; advanced materials and technology are used in both; there is overlap in many technical skills used for both; etc. It is easy, therefore, to view space launch rockets as something akin to just "bigger airplanes." Even a first-cut engineering look might lead one to believe in a near-equivalence of airplanes and rockets in terms of expected reliability; a large passenger jet is roughly the same size as a medium-lift space launch rocket, and both expend roughly the same amount of energy in carrying out their missions.

However, other considerations drive expected reliability for the two systems to be much more different than their apparent similarity. A simple thought experiment provides some insight into why orbital space launch rockets would be less reliable than aircraft. Regarding the energy expended in carrying out their missions, an international aircraft flight might take 10 hours whereas a space launch mission might take 12 minutes to reach low Earth orbit. This reframes the comparison as a *power* consideration, not an *energy* consideration—rockets are at least tens of times more powerful than aircraft per pound (using admittedly simplistic "thought experiment" values). This has sometimes been described as "the tyranny of the rocket equation"; when the mass of a rocket is increased, the amount of fuel required increases exponentially, so it is unattractive to beef up rockets for higher reliability.

In addition, rockets are, in general, single-use items (though this is changing as some launch systems have successfully incorporated reusable elements). A system designed to survive its operating environment once obviously will be less physically robust than one required to survive thousands (or even tens of thousands) of times, even considering periodic maintenance. It remains to be seen how "design for reuse" will affect the reliability of launch vehicle hardware, but given that the number of intended reuses of systems flying or in development is in the tens of uses one would not expect an increase in reliability of orders of magnitude.

These considerations lead one to see notionally that space launch rockets would be inherently less reliable than aircraft—a lighter, more powerful machine would be expected to be less reliable than a more robust, less powerful machine. And the result of this thought experiment is substantiated by the actual flight record (the aforementioned demonstrated reliability of space launch systems being in the mid-90-percent range) and the reliability expectations of those responsible for acquiring launch services.

As an example, the probability of "loss-of-crew" that NASA's Commercial Crew Program levies on its commercial providers is 1 in 270, with a greater risk of "loss-of-mission" of 1 in 60. For comparison, FAA Advisory Circular (AC) 25.1309-1A describes aircraft target levels of safety being an average probability per flight hour for catastrophic failure conditions of 1×10^{-9}; that is, functionally not anticipated to occur during the entire operational life of an aircraft type. While the numbers laid out here are not directly comparable (one being a risk per mission and the other being a risk rate per hour), the difference in the orders of magnitude is striking and shows the very different design philosophies of aircraft and rockets. Given this, rockets cannot be treated just like aircraft in the NAS as normal operations assume a high level of intrinsic reliability of the craft.

Launch Trajectories. To reach orbit, space launch systems are required to put their payload up 100 miles or more with enough horizonal velocity to remain in orbit. The "up" is the easier part of the problem, requiring a few thousand miles per hour; the harder part is the approximate 17,000 miles per hour to be added horizontally. At the thrust levels available for rockets, it takes hundreds of miles for that horizontal velocity to be achieved. In addition, the down range distance the vehicle would travel if the thrust were terminated extends for thousands of miles, which results in SAAs covering very large areas (see Figure 2).

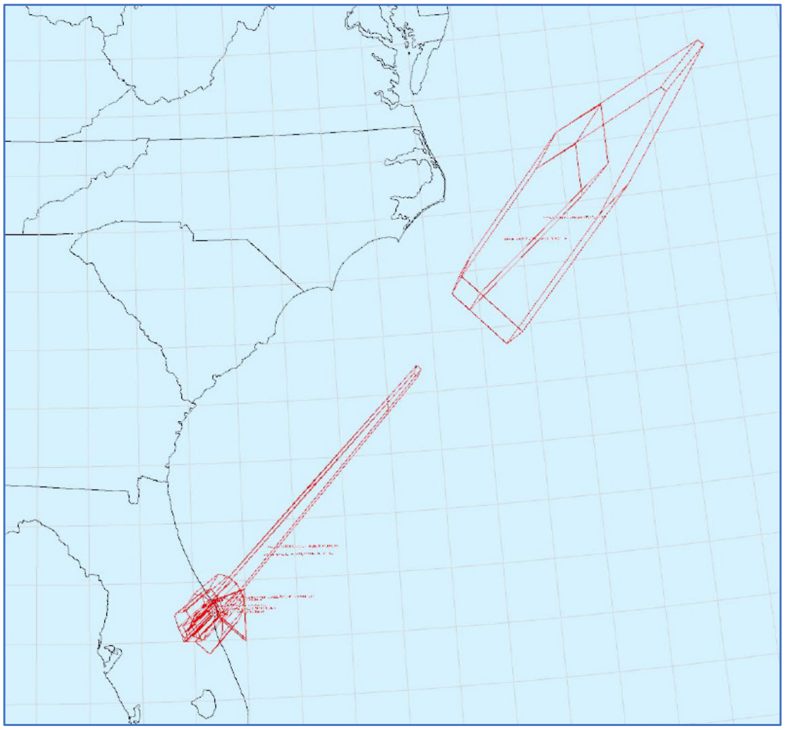

Figure 2: The SAAs for a SpaceX Falcon 9 launch on March 1, 2013.
From the FAA report, "SpaceX Falcon 9/Dragon Operations NAS Impact and Operational Analysis."

Further, to maximize performance to orbit, hardware is often jettisoned from launch vehicles during ascent when no longer needed (for example, payload fairings that are not needed once the air is sufficiently thin, depleted solid rocket motor casings, etc.). These jettisoned bodies travel down through the NAS.

A further consideration involving space launch rockets is that they are not controllable in that they cannot react to situations that would require evasion to avoid a collision. They are, of course, guided by control laws to reach their orbital destination, but they cannot sense any other users of the NAS. Aviation use of the NAS presumes a level of ability to react to changing conditions in the NAS to maintain safety; short of self-destruction, rockets do not generally have this ability.

Where Does This Leave Us?

Given the physical characteristics described above, which pose barriers to space launch rockets achieving the level of reliability expected of aircraft using the NAS, it would appear that integration of space launch into the NAS would be virtually impossible; for all real purposes, one must assume that a rocket will fail during flight. The current process of segregating airspace to protect against such a failure has worked for decades, but the anticipated increase of launch rates necessitates improvements to this concept of operations to minimize the impact on the NAS. While total integration of space launch rockets as "just another user" of the NAS would appear to be impossible given the differences in the systems, improvements can be made in the areas of situational awareness, data exchange, and automation to minimize the impact of space launch on the NAS.

One area in need of improvement is data sharing between launch providers and the managers of the NAS. The current process to "release" the SAAs created for space launch relies on manual operations; that is, relevant air traffic control authorities monitor whether a launch has occurred, the launch has been scrubbed for the day, or the launch time has been delayed to later in the launch window, etc. They then use existing communication capabilities to effect airspace management changes. The FAA's Space Data Integrator (SDI) project aims to automate much of this process (see the fact sheet on the FAA website). By incorporating information directly from launch providers into the air traffic control system, SAAs can be released more expeditiously. Such increase in situational awareness would improve the coordination of space launch activities with other users of the NAS. And while operational integration of orbital space launch into the NAS might never be fully possible, there is no reason why full data integration cannot occur. Indeed, any operational integration is predicated on data integration, so any advancement will require this and should be advocated to decisionmakers and pursued.

Existing technology (such as ADS-B) employed by such users of the NAS should be investigated for potential use in orbital space launch. While some characteristics of orbital space launch might be outside the operating range of such technology (due to rockets' speed, acceleration, altitude, etc.), assessments should be made to determine how such technology could facilitate space launch integration into the NAS, and promising research lines should be pursued.

The SAAs presented in Figure 2 make certain assumptions about failure modes and debris generation. While safety of the NAS users is paramount, it is conceivable that such failure and debris modeling might be *too* conservative; that is, larger areas than necessary might be segregated for orbital space launch. Given that there is essentially no cost to using conservative assumptions in such analyses, since impact on the NAS is not a consideration, erring on the side of safety is to be expected. Research into evaluating and improving such modeling might bear fruit in reducing both the area and time affected by such segregation. For example, high-altitude aircraft with high-quality optics (such as NASA's WB-57 aircraft with its DyNAMITE imagery system) could carry out observation campaigns of launch vehicle hardware jettisoned during flight. This would provide data to anchor and validate modeling, potentially allowing the size of SAAs to be reduced while maintaining equivalent levels of safety.

Carrying out such an imagery campaign (as an example) brings up the consideration of the cost of such research activities versus the potential benefit of reduced impact on the NAS. Aircraft users of the NAS are currently incurring costs due to space launch, in time and fuel spent avoiding SAAs. What is an acceptable expenditure to reduce SAAs by, say, 50 percent in area and time span, and what is the anticipated benefit to other users of the NAS? Who would shoulder the cost of such activities? Such questions point to the critical part of integration of space launch in the NAS: continuing dialogue between all the stakeholders, representing both air and space. As mentioned earlier, increasing space launch integration into the NAS will not be one-size-fits-all due to the different modalities of space launch. In fact, some of the categories of space launch (such as suborbital tourism launches) might have more in common with commercial aircraft operators and have similar equities with which they would be concerned. For this reason, representatives of all spaceflight modalities should be included in any discussions regarding integrating space access into the NAS.

While not a space launch concern, spaceflight often includes reentry of space hardware, both intentional and random. Unless the hardware is "designed for demise" as it reenters the atmosphere, it will transit the NAS and become another user with its own set of integration challenges. If the proliferated LEO constellations described in FCC filings come to fruition, the number of reentries could greatly increase. Given this, any discussions of integrating space access into the NAS should include relevant satellite operators whose systems could potentially enter the NAS from above.

This paper focuses on the technical considerations in integrating space launch into the NAS without addressing other mechanisms to foster integration. For example, given that the NAS is a resource with competing claims from the "air side" and the "space side," one idea would be for users to explicitly pay for its use. For space launch, this might be a fee paid to the FAA for each launch attempt. This fee could be determined based on the area of the NAS affected, duration of usage, etc. With "skin in the game," launch providers would be motivated to minimize their impact on the NAS. Such nontechnical mechanisms to foster integration should certainly be investigated by all stakeholders.

Conclusion

In 1949, the 81st U.S. Congress promulgated the first launch safety policy: "From a safety standpoint, [launch vehicles] will be no more dangerous than conventional airplanes flying overhead." This guiding principle has resulted in the safe regime we enjoy today (codified in Air Force and FAA regulations, AFSPCMAN 91-710 and 14 CFR Part 400, respectively), at the increasing expense of affecting other NAS users. While the technical characteristics of orbital space launch make full integration into the NAS challenging, there are avenues of investigation that could reduce the impact of orbital space launch on the NAS.

About the Author

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