CENTER FOR SPACE POLICY AND STRATEGY

AUGUST 2023

STRIKING A BALANCE BETWEEN SAFETY AND SCRUBS

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Summary

Rapidly growing demand for space launches increases the impact of launch scrubs and holds. Commercial launch providers and consumers of launch services are seeking greater efficiency in launch operations to maximize profits, but, with launches from the Space Force's Eastern Range in 2023 projected to be nearly triple that in 2021,[1] cascading disruption is likely to be the new normal. Commercial aviation also suffers when canceled launches result in additional airspace closures. Avoiding unnecessary canceled launches would save resources and help maintain crucial launch campaign schedules. However, dated weather sensors and methods result in some weather-related scrubs, which are unnecessary. This paper presents a short-term solution for improving the ability of space launch ranges to meet the growing demand by addressing the third leading cause of launch cancellations. The solution is to update weather-related policies and allow commercial mobile alternatives to fixed-range infrastructure. For example, mobile sensors could mitigate the need for some costly range improvements and be replicated and/or reused across the country to standardize and supplement environmental sensing capabilities at U.S. ranges and spaceports. An airborne sensing platform could potentially provide additional surveillance services, such as ensuring that no unauthorized aircraft or vessel enter the launch keep-out areas, or could perform debris characterization, imaging the launch vehicle during ascent to evaluate performance and analyze mishaps.

Introduction

Unprecedented space sector growth, combined with increased launch activity and the transformation of the industry to an increasingly commercial enterprise, is now compelling U.S. space launch ranges to think and operate differently. Profit-driven commercial launch customers will need flexible, efficient, and responsive services and infrastructure to meet their schedules and business needs. One step toward reaching these goals is to use on-demand mobile airborne platforms to monitor and predict the weather more accurately. Improved weather forecasting will result in fewer costly launch delays ("holds") or cancellations ("scrubs").

This paper provides an overview of launch ranges and spaceports and the key services they provide. It then focuses on the issue of increasing launch tempo and the resulting reduced tolerance for holds and scrubs, providing a potential solution using on-demand mobile airborne platforms. Finally, recommendations are provided.

Ranges and Spaceports

For safety and mission assurance, rocket launches require special restricted areas called "ranges" to protect people and assets in the launch area and under the trajectory of the rocket. Just like an airport, these launch ranges include areas for takeoff and landing, radars and sensing facilities, and trained personnel to ensure the safety of flight and mitigate hazards for surrounding communities.

Among other capabilities, ranges include a network of instrumentation to track rockets, provide telemetry, collect imagery, and assess weather data. The range's operations control center is the central node for flight safety, weather assessment, scheduling, and instrumentation data analysis. "Go" or "no go" launch decisions often hinge on weather conditions. Forecasters and launch weather officers rely on balloons, radars, electric field mills, and other ground-based sensors to generate key weather data for launch weather predictions. One of the major causes of launch holds and scrubs is the potential of hazardous weather events, such as triggered lightning,[2] which is an electric discharge induced by the presence of a launch vehicle while in a large ambient electric field.

Launch ranges, such as the Eastern Range (Kennedy Space Center and Cape Canaveral Space Force Station, Florida), Western Range (Vandenberg Space Force Base, California), and Wallops Flight Facility in Virginia are federally owned and operated. In addition to the federal ranges, many commercial spaceports exist with Federal Aviation Administration (FAA) licenses. Spaceports are commonly funded by tenant leases and landing fees, so they often rely on federal funding for major infrastructure projects, which is a lengthy process that greatly limits spaceport near-term capacity-building and modernization. Other sites are set aside for "exclusive use" for commercial launch system developers. Figure 1 is the official FAA map for locations and types of ranges and spaceports in the United States as well as launch/reentry sites. The three federal sites shown in orange are the Eastern Range, the Western Range, and Wallops Flight Facility.[3]

What's included in launch infrastructure?

- Launch pads
- Vehicle processing facilities
- Propellant storage tanks
- Radars
- Communications networks
- Command and control systems
- Human capital
- Maintenance

The FAA licenses sites for horizontal launch, vertical launch, both horizontal and vertical launch, and reentry in eight states. Issuance of a launch vehicle operator license is contingent on meeting FAA requirements for safety, risk, and financial responsibility. This places limitations on launches and requires steps to curb environmental effects. For example, at SpaceX's Boca Chica spaceport, launches are not allowed on 18 identified holidays and are limited to no more than five weekends per year, among other measures to minimize community and wildlife effects.[4] Therefore, minimizing scrubs and holds from this spaceport would mitigate the risk of extended delays such as waiting a whole weekend after a Friday scrub to attempt a launch.

The Increasing Launch Tempo

The number of orbital launches has been increasing with the rate of increase accelerating in recent years. This is due to the commercial launch activity required to populate proliferated low Earth orbiting satellite constellations such as Starlink and OneWeb. Completing these large constellations will require a consistent launch campaign spanning

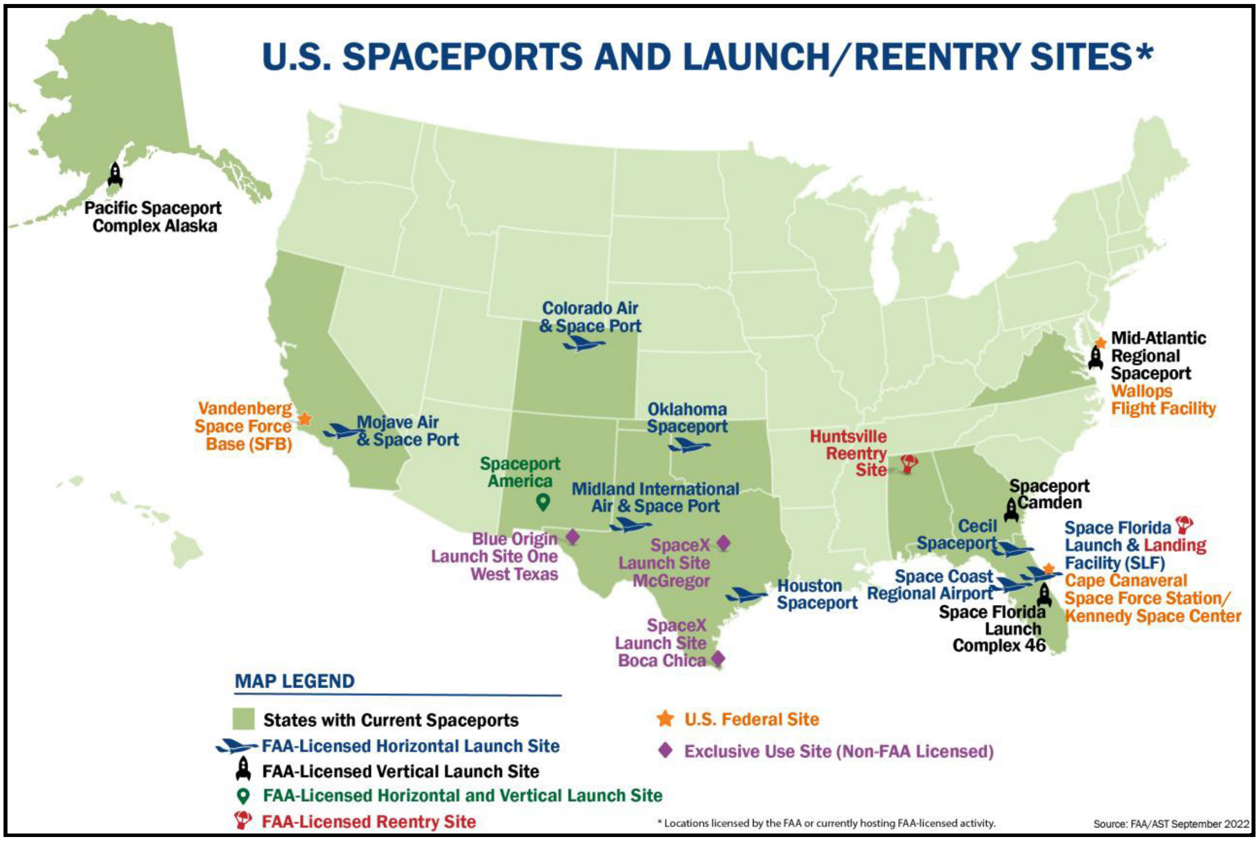


Figure 1: U.S. spaceports and launch/reentry sites. *Source: Federal Aviation Administration Office of Commercial Space Transportation (FAA/AST)*

many years and a robust and reliable range infrastructure to support it. In addition to Starlink and OneWeb, many other commercial constellations exist in various stages of development, deployment, and operations.[5] The number of satellites already approved is over 20,000, so an increasing number of launches will be needed per year to deploy these satellites.

In 2021, the Eastern Range successfully launched 45 orbital rockets and broke the standing record of 29, set in 1966.[6] Then again, in 2022, the Eastern Range beat that record with SpaceX alone having launched 57 rockets by the end of the year.[7] The Eastern Range is experiencing an unprecedented number of launches per month with 87 launches predicted in 2023.[8] This tempo makes the entire launch schedule highly susceptible to delays because any slight delay or scrub upsets the entire schedule that follows. These launch delays affect financial profitability for both the range and commercial customers, whether in the form of repetitive launch fees for support of Eastern Range services or delayed commercial satellite operator revenues and profits because of a stalled fully operational satellite constellation.

What's Holding Up Progress?

The aging Eastern and Western Ranges have been showing signs of stress trying to meet the increased demand. Although improvements have been made, many of the facilities need renovation or replacement. This has been recognized by the United States Space Force (USSF) since 2019 with the initiation of the Range of the Future[9] (now called Spaceport of the Future[10]) effort. Spaceport of the Future lays out a plan to commercialize management and operations of both the Eastern and Western Ranges, while still ensuring that national security needs can be met. While the long-term solutions offered by updating to USSF Spaceport of the Future and by making Congressional changes to the U.S. Commercial Space Launch Act (CSLA)[11] are considered, other short-term solutions can be put in place that could improve launch throughput, as proposed in this paper.

Why were there no major infrastructure updates to the Eastern or Western Ranges when commercial launches flourished? Historically, the CSLA does not allow the Department of Defense to charge fees to commercial launchers to cover indirect costs of maintenance, sustainment, modernization of range support equipment, or even range services. Even if there is an innovative advantage and willingness on the part of the commercial customer to pay for desired range enhancements, CSLA restricts them. This is an obvious missed opportunity when one considers the moderate growth of national security launches, which determines range improvements budgets, as compared to the enormous growth of commercial launches.

Potential Short-Term Solution

Many external and internal factors cause launch delays, but what is certain is that any increase in the sheer number of launches will amplify the potential for launch delays or scrubs (see Figure 2). "The results [of The Aerospace Corporation's analysis of non-geostationary orbits satellites (NGSO) constellation deployment launch capacity shortfall estimates] suggest that even if only a quarter of the NGSO plans come to fruition, current launch service providers will be tasked at maximum proven capacity."[12] When the Federal Communications Commission (FCC) approves a proposed constellation, the race is on to meet the FCC's 6-year and 9-year deployment milestones, which dictates the deployment of 50 percent of their satellites within 6 years of license approval and 100 percent within 9 years. Therefore, launch delays can be devastating since constellation performance and viability depend heavily on the number of operational satellites in orbit.

Figure 3 provides a notional forecast for launches on the Eastern Range for the next 10 years. It illustrates the maximum expected launches, and the possible launches given scrubs and delays to varying degrees.

Launch weather officers evaluate data from multiple sensors and decide if the lightning launch commit criteria (LLCC) is safely within the parameters to proceed. Currently, meteorological data is based on radar reflectivity, high-altitude balloons, visual observations, cloud data, and ground-based electric field mills. A main risk factor addressed by commit criteria is triggered lightning, explained in Figure 4.

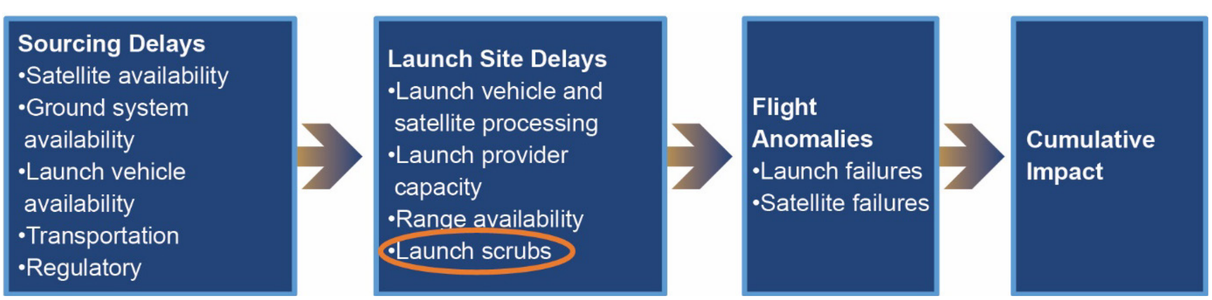
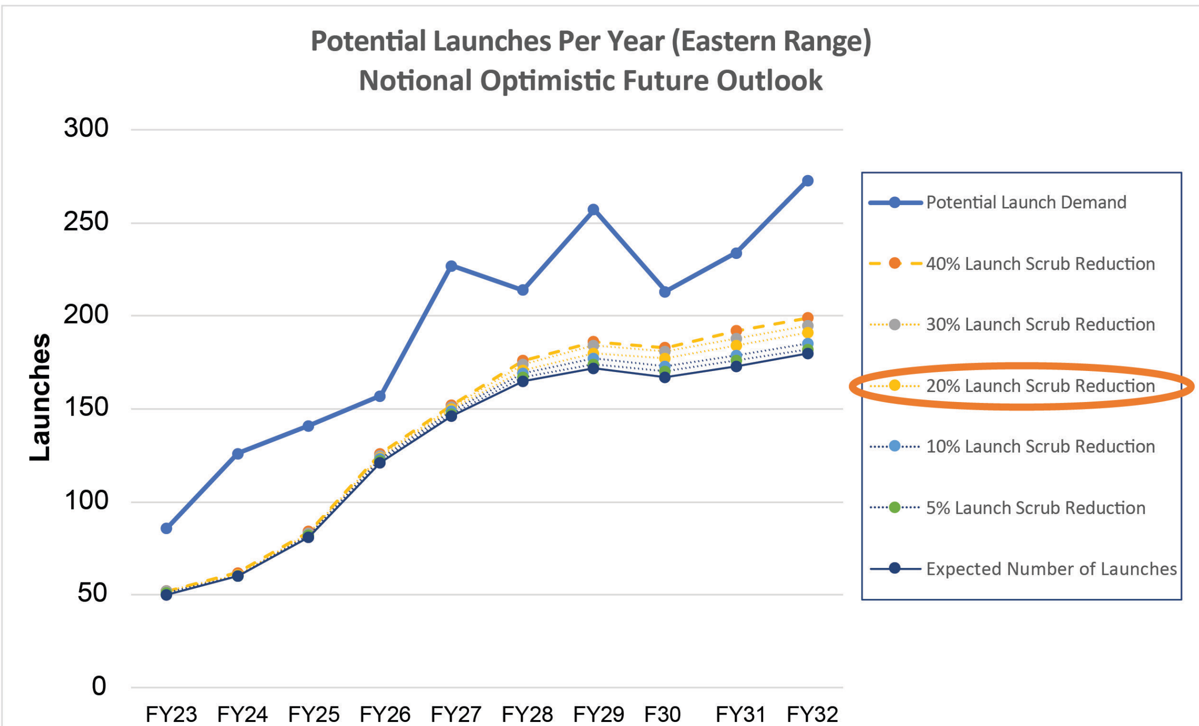


Figure 2: Launch delay risks.



The **top curve** is based on an optimistic set of assumptions, including the FCC approving all proposed satellites, and they are deployed within the 9-year time frame as required by the FCC. Civil and national security launches are included in this notional forecast of planned launches. However, these are a relatively small subset compared to the number of commercial launches.

The bottom curve indicates the number of expected launches after considering all sources of launch delay risks, such as launch site, launch vehicle availability, and launch scrubs.

The dotted curves above the bottom curve represent the expected number of launches given reductions in launch scrub probability, as shown in the legend. This family of curves was created using The Aerospace Corporation's Assured Space Access Model (ASAM), which is a discrete event simulation of launch ranges, including the Eastern Range. The 20 percent launch scrub reduction effect is highlighted since that is the potential benefit for the Range in a Box solution described below. Courtesy of Grant Cates 2022

Figure 3: Potential launches per year from the Eastern Range—notional optimistic future outlook.

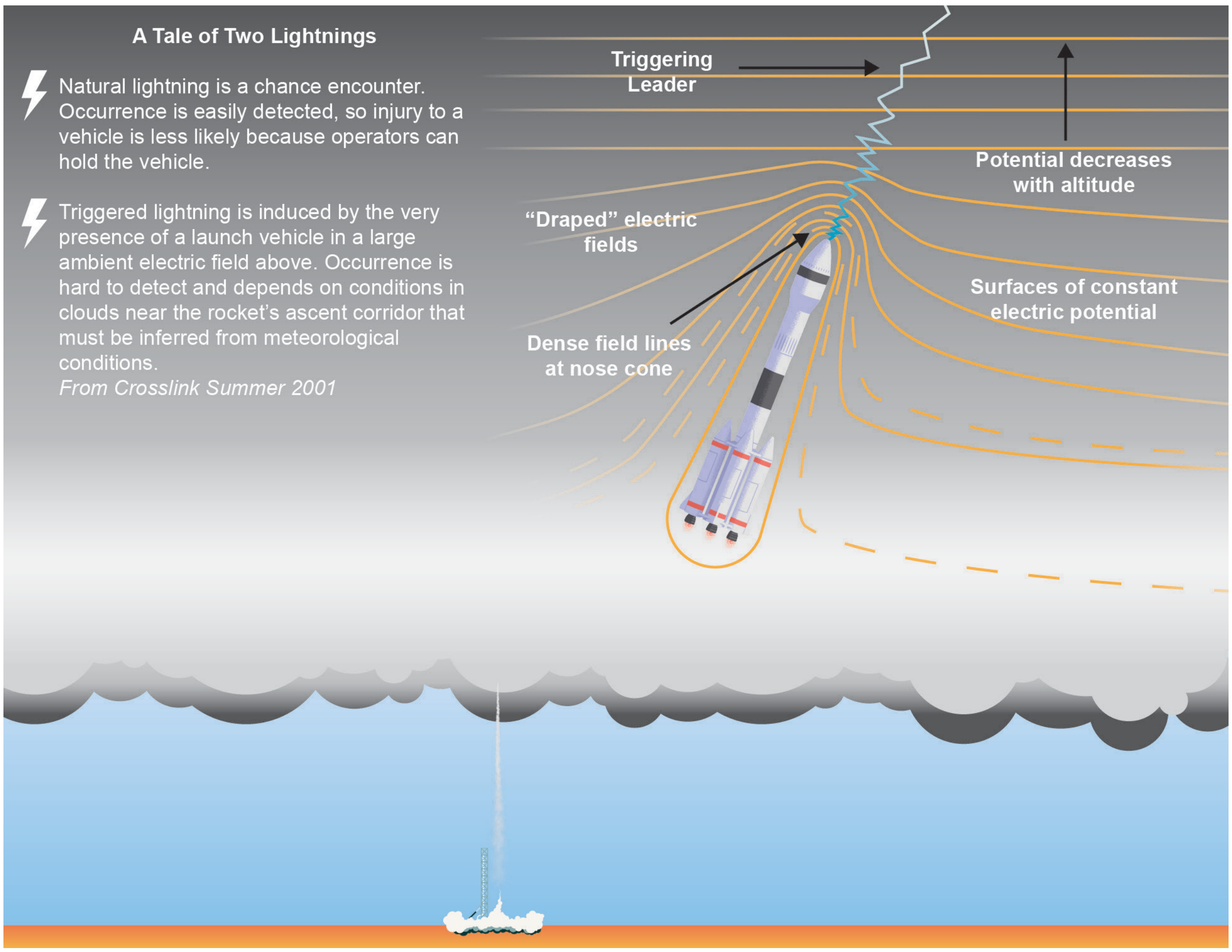


Figure 4: Natural lightning vs. triggered lightning. *Source: The Aerospace Corporation,* Crosslink, *2001*

Rules related to lightning commit criteria are determined by the Lightning Advisory Panel, consisting of top American scientists in the field of atmospheric electricity and related disciplines, including cloud physics. This panel has stated in the past, specifically for mitigation of the risk of triggered lightning: "We want the record to show that we believe the best way to ensure safety from atmospheric electricity hazards, and also to improve launch availability, is to use an instrumented aircraft in conjunction with the ground-based field mill network to measure electric field environment and its time development along and near the flight path."[1,13] A NASA publication from 2004 states, "Weather is the single greatest cause for launch delays and scrubs, and about 30 percent of weather delays are related to lightning avoidance rules."[14] More recently, a 2010 study determined that direct measurement of cloud electrical fields, microphysical content, and reflectivity could mean up to 20 percent of LLCC violations could be avoided, meaning fewer unnecessary holds and scrubs.[15]

> Like hurricane hunters requiring data inside a hurricane, the most accurate sensing for electric fields is an airborne platform located in the projected trajectory of the launch vehicle.

Today's new technologies and business models have made this type of airborne, in situ, direct sensing more affordable and useful for improving overall launch tempo. The Lightning Advisory Panel is updating the official airborne field mill LLCC rules from 1988. In 2017, the panel developed updated commit criteria precursor rules to support a comprehensive demonstration of airborne in situ direct sensing system of systems to collect data to improve lightning prediction (Project ULTRA 2017[15] based on airborne field mill sensing derived from a 2003 precursor demonstration[16]). Currently, the Lightning Advisory Panel would need more in situ cloud measurement data to determine safety parameters. Should these rules be adopted, the official updated commit criteria would provide the commercial and government launch weather officers with expert guidelines on how to interpret and apply the data provided by an airborne platform.

> ***"With the number of space launches and supported mission partners growing every year, we are continually looking for efficiencies in our operations to maintain the quality of weather support that our government and commercial partners have come to expect."***
>
> —Capt. Zachary Daniels
> Joint METOC Officer for the 45th WS[17]

Even though LLCC related to factors like wind, temperature, ice, precipitation, and dense clouds can affect launch criteria evaluations, the LLCC related to triggered lightning are among the leading causes of holds and scrubs. Data compiled by The Aerospace Corporation for the Eastern Range (Figure 5) shows that triggered lightning-related launch scrubs in 2020 were second only to vehicle and recovery-related scrubs. When considering only weather-related scrubs, triggered lightning

[1]Statement made by meteorological experts J.C. Willett, R. L. Walterschield, E. P. Krider, H. C. Koons, and D. Rust

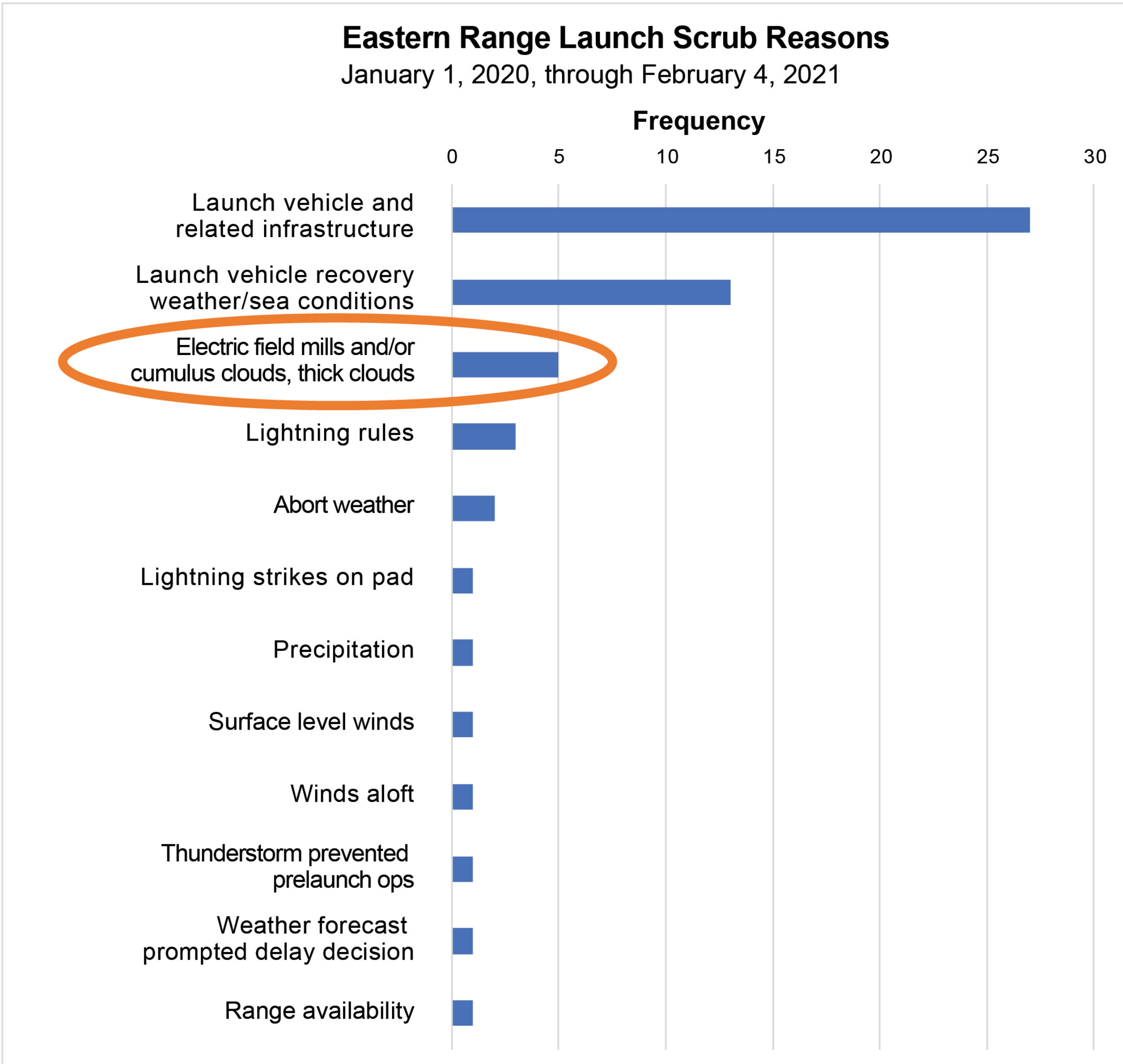


Figure 5: Causes for Eastern Range launch scrubs from January 1, 2020, to February 4, 2021. *LLCC rules related to large ambient electric fields that can induce electric discharge in the presence of a launch vehicle are circled in orange. Note that this recent data supports the potential 20 percent increase in launch tempo predicated by Project ULTRA.*[15]

conditions coupled with the current rules accounted for 19 percent of the scrubs for the 13-month period represented in Figure 5, which is consistent with the ULTRA test results. Refining the criteria would greatly affect the highlighted scrub frequency. (See "Natural and Triggered Lightning Flight Commit Criteria"[2] for a detailed description).

Enhancing weather sensing technology, specifically for triggered lightning, is potentially a near-term, affordable option for increasing the overall launch tempo at U.S. federal ranges.

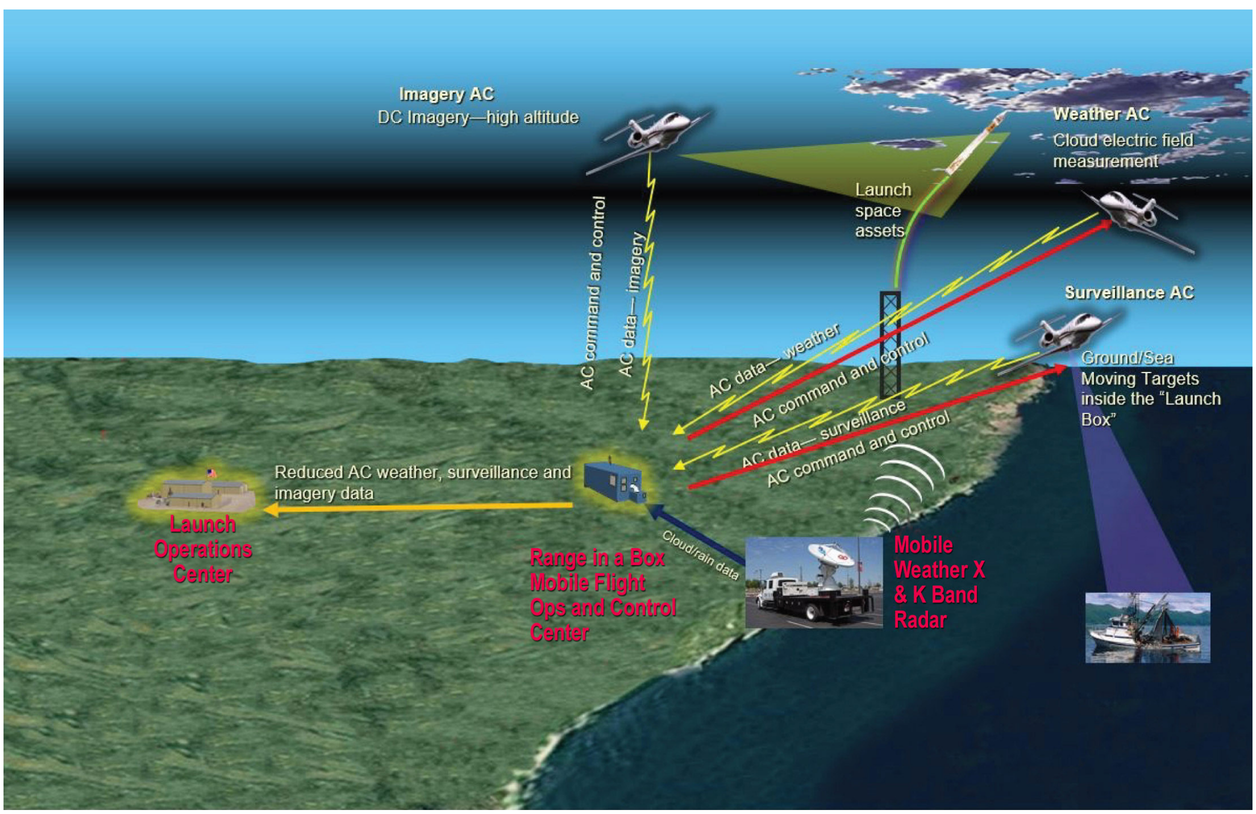
A system of systems based on the demonstrated Project ULTRA[15] is a potential short-term solution for improving the ability of space launch ranges to meet growing launch demand by updating weather-related policies and sensing technologies. One such solution could be a *Range in a Box*, comprising:

- A transportable self-contained range weather radar system.
- A trailer/mobile ground station functioning as a control center, where instrumentation data is received and organized (to avoid costly integration into operation centers).
- Jet aircraft or unmanned aerial vehicles (UAV) that are fully instrumented to record and downlink in realtime launch site atmospheric data as well as imagery.

Range in a Box

Using an airborne solution like *Range in a Box* enables data collection on cloud electrification that is correlated to other instruments' data and high-resolution radar returns, allowing users to develop predictive models for triggered lightning. Such an airborne system could be part of a mobile systems-of-systems commercial pay-per-launch alternative to infrastructure-related weather assessments, imagery collections of ascending rockets, and surveillance of exclusion areas.

To better understand *Range in a Box* from an operational context perspective, see Figure 6.



AC = AIRCRAFT

Figure 6: Range in a Box.

The radar for *Range in a Box* is an X-band dual-polarized radar, which provides high-resolution weather imagery as compared to C-band used for Doppler weather and S-band used for lightning evaluations at the Eastern Range, for example.

The ground station for *Range in a Box* can incorporate data from the airborne field mill, the radar, and other publicly available data, as well as ascent imagery for debris characterization, for example. The mobility of the ground station means that the launch site could surge occupancy on an as-needed basis. The ground station could have user-friendly displays that allow launch weather officers (or other stakeholders) to evaluate the LLCC in realtime during launch operations.

The airborne platform for the *Range in a Box* can be equipped with additional instruments and sensors for a variety of services, such as an electro-optical/infrared gimballed camera for ascent imagery (for example, debris characterization) and small synthetic aperture radar for surveillance of the launch box (since unauthorized boats, or aircraft in the launch box can cause a launch abort). This airborne platform must be able to sample the clouds fast enough to satisfy the requirements of the launch criteria, be able to withstand potential lightning strikes, and warm its wings to avoid icing.

> ***"We want to be able to create a range where anybody who wants to bring their own equipment can plug-and-play."***
>
> —Col. Tony Mastalir
> Former 30 SW Commander[18]

Based on the research we have done, there are a number of benefits to be realized by employing a short-term solution for in situ airborne sensing like *Range in a Box*. These include the ease of deployment as the system is mobile and containerized. It would also be possible for commercial entities to pay by the launch within the current legal framework imposed by the Commercial Space Launch Act. Fixed ground sensors suffer corrosion and sometimes destruction. A system such as this would avoid those hazards. The data collected could be correlated to improve weather modeling predictions, which would lead to more reliable radar-based electrical cloud potential detection in the future. Improved assessment of triggered lightning would allow launch schedules to be tightened, thus making an incremental improvement in launch tempo. Finally, a *Range in a Box* implementation would enable additional range-related sensing like stratospheric wind profile collection, debris characterization imagery, launch box surveillance, and telemetry relay.

Conclusion and Recommendations

With improved sensing technology and updated policies, the U.S. can improve cost and schedule efficiencies on the federal launch ranges. Using an airborne weather sensing platform would improve data accuracy and speed, thus allowing for tighter launch criteria, and would provide more launch opportunities on the range. An airborne sensing platform would also deliver additional value through services such as *Range in a Box* surveillance and debris characterization. These improvements can also be used to bolster U.S. spaceports by providing them with an innovative mobile sensor platform and updated U.S. policies from which to operate. Although the reduction in launch scrubs and holds would be incremental through implementation of such a system, it is a step in the right direction. Reducing launch scrubs translates into increased launch range throughput capacity. The benefit increases as congestion on federal ranges increases.

The following recommendations are meant to provide short-term, immediately implementable solutions and do not include or address other long-term efforts to change legislation, such as the Commercial Space Launch Act, or address range and spaceport needs (for example, Spaceport/ Range of the Future).

The U.S. government should consider granting approval, funding, and incentives for commercial entities to operate a mobile system-of-systems infrastructure solution as described above, potentially on a pay-per-launch model. These systems would be able to carry multiple payloads to support not only weather sensing but also provide other surveillance data in the launch box as well as debris characterization and mishap imagery using high-speed cameras and other instrumentation. In support of this recommendation, authorization and support of commercial integration prototyping of mobile infrastructure solutions to be used at spaceports and on federal ranges is needed. This would allow for the authorization and flight planning during launch operations, badging access to federal ranges for contractors, FCC frequency allocations, and other supporting infrastructures such as parking and power for the mobile command centers.

To enable finalization of updated Airborne Field Mill LLCC rules and launch weather officer procedures, a follow-on demonstration of a Project ULTRA-like system at either the Eastern Range or the Western Range would provide the data and information that the Lightning Advisory Panel needs. To enhance the accuracy of weather models used to determine launch decisions, a unified government repository for the data from such demonstrations coupled with additional data collected by commercial entities providing similar services could be established. Finally, organizations like the University Corporation for Atmospheric Research could be encouraged and incentivized to use the data repository to refine atmospheric models. This would lead to an end goal of needing only radar information to determine triggered lightning risks during a launch vehicle flight.

The ability to reduce holds and scrubs resulting from induced lightning is a good first step but is only a small part of a broad ranging solution space. While short-term, immediately implementable solutions can help mitigate the risk of cascading launch delays on increasingly crowded space ranges, a need still exists for long-term efforts to update legislation, such as the Commercial Space Launch Act, and for updated policies and strategies and resource allocation to address range and spaceport needs, for example, Spaceport/Range of the Future.

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