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Transitioning Traditional Aviation Weather Instruction to a Space Launch Weather Support Course: Operational Considerations

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Introduction

Weather support to space launch operations, while similar to that for traditional aviation, presents significant additional challenges that are not addressed in traditional aviation weather classes. Guinn and Rader (2012) examined the topics covered in meteorology courses supporting 22 different accredited professional flight B.S. degree programs and found the primary focus to be largely on general aviation hazards (*e.g.,* icing, turbulence, thunderstorms) and aviation products *(e.g.,* AIRMETS, SIGMETS). None of the schools examined listed weather support to space-launch operations as a topic area in their course descriptions. However, with the burgeoning commercial space industry projected to produce between $300 million and $1.6 billion in revenue over the next several years (Tauri Group, 2012), the need for universities to be able to educate commercial space operators and future meteorologists on the weather and environmental impacts on space-launch operations becomes increasingly important. At Embry-Riddle Aeronautical University, Daytona Beach (ERAUDB) the projected growth in the commercial space industry has led to the advent of a new degree program, Commercial Space Operations (CSO), and created the need to modify and extend traditional aviation weather instruction to include space-launch weather requirements. While traditional aviation weather instruction does overlap with that for space-launch weather support, it does not cover the full-spectrum of impacts that both CSO and meteorology students need to master for successful careers in the industry.

To address this challenge, ERAUDB, with guidance from the 45th Weather Squadron at Patrick Air Force Base, is working to modify their curriculum to include weather support to space-launch operations, utilizing the new suborbital space flight simulator (SSFS) and lab, a recent initiative of the Department of Applied Aviation Sciences. This paper reviews current aviation weather coursework offered at ERAUDB and explores the operational considerations of transitioning traditional aviation weather instruction to a suborbital and orbital space flight weather support curriculum. These considerations include: more stringent spacecraft and system weather sensitivities, triggered lightning, triboelectrification, vertical distribution of winds within *and* above the troposphere, and space weather impacts. We also discuss potential uses of simulations to create experiential learning opportunities for students, as well as some of the limitations and challenges of using simulations in place of real-world exercises. The goal is to initiate a conversation on improving weather education and training for students seeking operations or meteorological careers in the commercial space industry.

Background

ERAUDB currently offers three undergraduate courses covering various topics in aviation meteorology. These include a traditional aviation weather course, an advanced course focused on weather for commercial air transport pilots, and lastly, an interdisciplinary course that provides real-time operational weather support to an air race. The courses and desired learning outcomes are discussed below.

Aviation Weather Course

The "Aviation Weather" course is the first aviation-focused meteorology course students take following an introductory survey course in meteorology. The focus is primarily on private-pilot and instrument-rated pilot concerns with a course goal of increasing basic meteorological knowledge directly related to the identification and mitigation of aviation weather hazards affecting safety of flight. Students are exposed to the meteorological theory as well as the practical application of products offered by the Aviation Weather Center. Core topics include: instrument meteorological conditions, convective weather, aircraft icing, wind shear, and turbulence. Ancillary topics, such as space weather and volcanic ash also are briefly introduced. The course requires students to evaluate a variety of weather analysis and forecast products to make safer operational decisions. The course culminates with a discussion and exercise on proper weather flight planning requiring students to safely evaluate weather hazards for a multi-leg, cross-country flight.

Weather for Commercial Air Transport Course

The "Weather for Commercial Air Transport" course shifts the instructional focus from private and instrument pilot topics to topics more specific to commercial air transport, which are beneficial for students seeking eventual FAA certification as Airline Transport Pilots (ATPs). These include: high-level (FL180 to FL400) hazards and products, airborne weather radar, international weather service products and providers, as well as global aviation climatology. Space weather impacts on communications, navigation and transpolar flight are expanded along with expanded discussions on volcanic ash impacts to safe flight. This course culminates with a multi-leg, transoceanic flight plan using industry-standard flight-planning software. The students must not only create a flight plan, but they must also explain their meteorological reasoning for the chosen route of flight.

Air Race Classic Weather Support Course (Experimental).

The "Air Race Classic Weather Support" course is designed to offer interdisciplinary, experiential learning opportunities for meteorology majors and minors as well as aeronautical science (professional pilot) majors and those pursuing their FAA dispatch certification. The educational focus is on providing operational weather support for an actual air race with the goal of identifying the best flight levels and departure times to gain the greatest tailwinds (or to minimize headwinds) while maintaining VFR during daylight-only flight. The aeronautical science students possess knowledge of aircraft performance (rates of climb, service ceilings, etc.) and national airspace, while meteorology majors typically bring a strong command of weather pattern recognition and product interpretation to the course. Collaboration among the different student groups under the supervision of experienced aviation forecasters helps build and expand the skillsets of each to provide effective flight routes and altitudes to maintain safety while minimizing transit times.

Weather Topics Required for Sub-Orbital Space Launch Support

While the traditional aviation weather courses provide knowledge about impacts on horizontal flight in the troposphere, they do not cover the weather and other environmental impacts on sub-orbital aircraft during vertical flight through the troposphere, stratosphere, and mesosphere. In addition to the flight phase, weather also has a tremendous impact on pre- and post-launch operations, which can differ significantly from traditional aviation support. These operations include: the transport of the launch vehicle to the launch pad, the movement of explosives, toxic chemical and fuel operations, and vehicle recovery operations. These weather and environmental concerns should be included in a curriculum that seeks to be relevant for those pursuing degrees in CSO, as well as meteorology majors desiring to provide space-launch support. Here we highlight some of the key topics that should be included in a curriculum supporting space-launch operations. These weather topics include: increased wind sensitivities, space weather impacts, triggered lightning, triboelectrification, and vertical distribution of winds within *and* above the troposphere.

Increased Wind Sensitivities

Because orbital and reusable sub-orbital aircraft typically land unpowered, they are far more susceptible to wind direction and speed than conventional aircraft. For example, the space shuttle required 15 knots or less crosswind during the day and 12 knots or less during night landings. (NASA KSC, 2003) These are approximately equal to the cross wind thresholds of small general-aviation aircraft, such as a Cessna 172 (Cessna, 1998). Comparatively, larger commercial aircraft, such as Boeing 757, have demonstrated crosswind landing thresholds of 36 knots. Because of the greater sensitivity to winds, meteorologists supporting space-launch operations must be more acutely aware of observed and forecasted wind conditions over a much narrower window of acceptable thresholds.

Space Weather Impacts

Space weather typically refers to highly accelerated particle and electromagnetic radiation from the Sun (or other stars), its interaction with Earth's atmosphere and magnetic fields and the impacts of this interaction on our technological systems and health. Space weather is a concern for conventional aviation operations mostly on polar flight routes. It can adversely affect spacecraft in several ways. Collisions with low-energy charged particles (electrons) during solar events can cause spacecraft surface and bulk charging resulting in damage to electronic components, while collisions with high-energy particles (protons) can cause even more significant damage to computer memory (NOAA SPC, 2010). Solar events can also lead to elevated risk of particle radiation exposure to pilots and crew traveling at high altitudes (NOAA SPC, 2010) and latitudes. Also, geomagnetic storms increase the density of the thermosphere, resulting in unexpected drag, and potentially causing a space vehicle to slow or even change orbit (NOAA SPC, 2010). Meteorologists providing services to space-launch operations must understand the space weather environment and provide information to customers concerning solar events, such as solar flares and coronal mass ejections that may potentially cause a space weather constraint violation. For this reason, students need to understand potential space weather impacts to commercial space operations and be able to translate and interpret products from NOAA's Space Weather Prediction Center.

Triggered or Induced Lightning

While natural lightning poses a threat to both terrestrial aviation and space launch operations, vehicle-triggered lightning is a far greater risk for orbital and suborbital vehicles. Natural lightning monitoring and avoidance is well-covered in most aviation weather courses (Guinn and Radar, 2012); however, weather instruction for space-launch operations must also include techniques for monitoring and assessing the risk of triggered lightning. Instructors need to ensure students are closely familiar with the Code of Federal Regulation (CFR) Title 14, Part 417 (CFR, 2015) which addresses launch safety. Specifically, Part 117, Appendix G details the natural and triggered launch commit criteria, which must be met before a launch can be initiated. Using the CFR (2015) launch commit criteria as a guide would require the students to become proficient in cloud identification to determine the cloud types, thicknesses, and temperatures that are indicative of increased risk of triggered lightning. In addition, weather radar analysis techniques taught in traditional aviation weather to identify areas of intense precipitation and convective weather would need to be expanded to include analysis of more advanced radar information such as maximum radar reflectivity (MRR) data (NASA LAP, 2014) and volume-averaged, height-integrated radar reflectivity (VAHIRR) data (Bauman, 2008) to determine the potential for induced lightning (CFR, 2015). Further, students would require an increased knowledge of basic electrical fields and the ability to evaluate data from atmospheric-electrification sensor data, such as field mills, to determine the potential for lightning strikes.

Triboelectrification

In addition to triggered lightning, students must also understand the concept of triboelectrification (or frictional charging) and the impact it has on safe operations. Triboelectrification refers to charge build-up and subsequent discharge on a vehicle during the launch. The charge build-up occurs when the vehicle passes through regions of cloud containing ice crystals at speeds slow enough to prevent the ice from melting (NASA, 1974). If the charge build-up becomes significant enough, discharges may occur, damaging electrical systems, communications equipment, or possibly the vehicle itself (NASA, 1974; Winters *et al.*, 2011). In rare instances launches may be canceled or delayed (Winters *et al*, 2011). Although triboelectrification also occurs in commercial aviation, these charges are readily dissipated through static wicks on aircraft (Bergqvist, 2013).

Vertical Wind Analysis

Upper-level winds, while important to terrestrial aviation support for forecasting wind shear and turbulence, become even more critical for supporting sub-orbital launches. For NASA Space Shuttle operations, for example, the vertical wind information was used to generate the steering commands on the launch vehicle during take-off and determining the resulting aerodynamic loads the vehicle would experience in flight (NASA, 2010). In addition, the winds help determine the direction, speed and development of upstream clouds that may lead to cloud electrification concerns discussed above (NASA, 2010). Other sub-orbital flights would likely have similar constraints during ascent. Weather courses focused on space-launch support would therefore require more thorough training on vertical wind analysis to support these flights.

Vision for an Interdisciplinary Space-Launch Weather Curriculum

During the past year, ERAUDB has developed a Sub-orbital Space Flight Simulator (SSFS) complete with a separate room housing a mock Mission Control Center (MCC). Although simulations of launches do not currently incorporate weather data into the scenario, we envision an interdisciplinary use of the MCC that would include a full suite of personnel including air traffic management, safety, and meteorology in addition to the launch control officer. Simulations could include real-time weather data feeds from satellite, radar, and numerical models as well as space weather information and products from the NWS Space Weather Prediction Center. Previous-weather scenarios could also be selected and fed to the weather terminal for the meteorology student to make launch commit criteria decisions, which would then be relayed to the launch operations officer.

The curriculum would be experiential in nature, similar to the Air Race Classic course, allowing students to role-play and make go-no decisions based on information injected into the launch scenario. Students would need to communicate carefully any information affecting their respective areas of responsibility; however, everyone would require a basic knowledge of each MCC station's roles and requirements. Furthermore, pre-launch operations could also be incorporated into the scenario leading up to launch day. Thus, the meteorologist in training would need to evaluate the weather forecasts to provide the best timeframe for successful launch criteria. The end goal would be to educate meteorologists and commercial space operators on the full-spectrum of weather support to space-launch operations.

Challenges and Limitations

A current limitation to expanding a meteorology curriculum to address space launch operations is the lack of electrical field data for the students to practice warning for triggered lightning. It is unlikely most schools have access to field mill instruments to measure the electrical field potential for assessing lightning risk, such as currently used by the Air Force to support space-launch operations at Kennedy Space Center. In addition, unlike the Air Race Classic course, there would be no real-world student support to an actual space launch due to the significantly greater risks involved. All environmental weather support would need to be accomplished through simulated launches. However, while this does limit the realism of the support, it is also beneficial in that it allows for far greater frequency of operational support experiences for students. That is, simulations can be conducted multiple times per year with many different weather scenarios, while the air race only occurs once per year with no opportunity to modify the weather conditions.

Summary and Conclusions

With the growth of commercial space operations in industry as well as academia, the need for educating both future commercial space operators and meteorologists on the weather and environmental impacts on space launch operations is becoming more urgent. While many aviation and aerospace-focused universities offer significant training and coursework in weather support to traditional aviation operations, none offer operations-focused curriculum on space-launch weather support. ERAUDB is seeking to create a curriculum that incorporates known environmental impacts to space-launch operations based on current and past support to space shuttle and other rocket launch operations conducted by the 45th Weather Squadron at Patrick Air Force Base, as well as FAA published space launch commit criteria. The goal is to expose students to the impacts of weather on space-launch operations and exploit simulation equipment to create experiential learning opportunities for students studying both meteorology as well as commercial space operations. The end goal will be to produce career-ready students for a rapidly growing new industry.

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