The Commercial Space Advancement through Venture and Operations (CSAVO) Initiative

(January 2020 - April 2020)

Design Challenge: Airport Management and Planning

Team Members:

Graduate Students - Cooper Burleson, Jack Green, Jason Endsley

Number of Graduate Students: 3

Number of Undergraduate Students: 0

Advisor's Name: Mary E. Johnson, Ph.D.

Name of University: Purdue University

Executive Summary

In this proposal, a team of three Graduate Students from Purdue University's School of Aviation and Transportation Technology sets out to answer the ACRP's Request for Proposal in the ACRP Airport Design Competition specifically for Challenge IV: Airport Management and planning. The team responds to the prompt of "Creative approaches to airport revenue generation for general aviation airports." In this proposal, the team describes the process, risk, cost, benefits, and sustainability impacts of adapting existing general aviation airports to incorporate entry level spaceport operations, without the need for a full FAA-CST spaceport license. The team introduces their novel approach entitled the Commercial Space Advancement through Venture and Operations (CSAVO) Initiative that they have developed, which aims to guide general aviation airports looking to generate additional revenue towards traditional spaceport operations that do not require lengthy and costly licensing through the FAA. Through the implementation of low-cost test cells in medium to high-need areas, GA airports that follow the guidance of CSAVO will be able to introduce space industry activities such as rocket engine testing into areas that did not previously have access to such an industry. Upon conducting several different types of analysis including a cost benefit ratio analysis, a risk analysis, and a sustainability analysis, the team is able to conclude and show that this idea is not only a feasible idea, but also a profitable and impactful one. While there are many GA airports which could adopt the initiative, the team has gone a step further and selected five airports which they feel would be the very best fits for the initiative. These airports, as listed by the team, will be able to reap all the economic, social, and sustainability impacts that come with such a venture.

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1. Problem Statement and Background

In the last four decades, there has been a decline in the amount of aviation activity at general aviation (GA) airports due to a lack of funding / economic shifts, a lack of the general populous' interest, and fundamental changes in the GA and other aerospace markets (Federal Aviation Administration, 2014). There have been several attempts to study this situation on both the federal and private levels. *The General Aviation Airports: A National Asse*t (ASSET) report was spearheaded by the Federal Aviation Administration (FAA) and sought to reclassify all existing GA airports into new categories, showcasing their utilization. Private organizations, such as the Aircraft Operators and Pilots Association (AOPA) have also sought to study this trend of under and lowering utilization, reaching similar conclusions as the FAA. The AOPA discussed in their *State of General Aviation* from 2019 that GA has still not recovered from the 2012 drop off in annual GA flights, and while the numbers have seen a slow rise since 2014, the number of annual flights will not recover to pre-2012 numbers for some time (AOPA, 2019). This drop in utilization has led to a loss of revenue in many GA airport communities in the last half decade and will continue, if predictions hold, through 2030 (Moore, 2014). These trends of underutilization and lost revenue on both the federal and private level have led many to wonder if there are alternative paths through which GA airports could begin to recoup these losses.

One newer market which has come into vogue in the public's opinion in the past two decades is the space operations / commercial space market. While aviation has seen a decline in revenue the past few decades, the commercial space market has seen a drastic increase in revenue generation, topping out at an "estimated $339 billion generated in revenue by 2030" (George, 2019, p. 183). Of course, several venture savvy airports and organizations have caught on to the potential revenue that could be generated from this market. As of April 2020, eight airports have made a conversion to either a full-time spaceport or a dual use air/space port (Burleson, C. and Kozak, B., 2020). These spaceports / airports can be seen below in *Table 1*.

Table 1: Converted Licensed Spaceports (Burleson, C. and Kozak, B., 2020, pg. 8)

Name of Launch Site	Previous Name	Founding	Spaceport Approval
Colorado Air & Space Port	Front Range Airport	1984	August 17, 2018
Wallops Flight Facility	Wallops Flight Facility	1945	December 18th, 2002
Oklahoma Space Industry Development Authority	Clinton-Sherman Air Force Base	1942	June 12th, 2006
Cape Canaveral Air Force Station	Cape Kennedy Air Force Station	1940	July 1st, 2010
Ellington Airport	Ellington Airfield	1917	June 26th, 2015
Cecil Field	Naval Air Station Cecil Field	1941	January 6th, 2015
Midland International Air and Space Port	Midland International Airport	1927	September 15th, 2014
Mojave Air & Space Port	Civilian Aerospace Test Center	1935	June 17th, 2004

Each of these above air/space ports have seen a dramatic increase in spaceport operations taking place on the grounds since their respective approval dates. These operations included full scale launches, as seen at the likes of the famous Cape Canaveral Air Force Station, to small experimental testing grounds at Midland International Air and Spaceport. While each site is unique in terms of operation and operations performed there, each has seen an increase in business opportunity and generated revenue since their conversion (Burleson, C. and Kozak, B., 2020). As such, these sites have seen new venues for revenue generation open, which were previously unavailable due to the lack of space industry designated space at their locations; however, even with these airports standing as examples of successful conversion and revenue generation, many GA airports view space / commercial space operations to be outside of their operating parameters. Many GA airports believe that full scale spaceport operations are only suited for large non-GA airports, or not suited for airports at all. This sentiment stems from the fact that securing a spaceport license through the FAA can take years and cost millions to the investing airport (Burleson, C. and Kozak, B., 2020). As a result, many GA do not give the space industry's market a second thought, yet there is still revenue to be generated in the commercial space market, even without a FAA spaceport license.

Due to the increase in existing and predicted revenue generation in the commercial space market, it is not hard to connect the dots showing that the commercial space market is a segment of the aerospace industry worth paying attention to. While specifically launch and landing operations are heavily regulated by the FAA, most other aspects of the commercial space market are not. The building and firing of test engines, for example, are not under the jurisdiction of the FAA or FAA-CST, but rather under the jurisdiction of the municipality where the tests are conducted. While the vehicles themselves flown by private space industry are under the regulation and licensing of the FAA, the on-site maintenance and MRO operations of those vehicles are not. In fact, there are a multitude of "spaceport operations "that any private company or entity can undertake, including a GA airport. These "spaceport operations" do not require any changes to the current relationship with the FAA, and rather only affect the people at the airport and local governing entities.

Therefore, this design team proposes an innovative approach and analyses for GA airports to consider when evaluating opportunities to participate in commercial space. This approach is called The Commercial Space Advancement through Venture and Operations (CSAVO) Initiative. Its goal is to form a set of introductory guidelines and analysis for any GA airport who is interested in generating additional revenue through commercial space operations without the need to invest millions into becoming a fully licensed spaceport launch facility. The team has created these guidelines in response to the ACRP 2019-2020 Design Competition, with the intent of responding to the Airport Management and Planning Challenge. These guidelines will include the basics for creating, maintaining, and marketing space-engine test sites of GA airport grounds, as well as notes for forming lasting business partnerships with commercial space focused private companies and universities, and even analysis tools with which GA airports can assess if The CSAVO Initiative is right for their community and operation.

2. Literature Review

2.1 Regional Planning of Commercial Spaceports

Shove, Christopher. (2002). *Regional Planning of Commercial Spaceports, Journal of the American Planning Association*, 68:1, 85-95. Retrieved from: DOI: https://www.tandfonline.com/doi/pdf/10.1080/01944360208977193?needAccess=true

In this article, Chris Shove, the vice president and director of the Florida Space Research Foundation, asserts that there are several ancillary services that would become pertinent activities in the creation and maintenance of spaceports and sites looking to partake in spaceport operations. In his piece published in 2002, Shove describes that:

> "Commercial spaceports can also provide many ancillary services, such as public works infrastructure including roads, water and sewer systems, and electricity; public safety including police, fire, and launch safety from the launch pad to orbit; spacecraft maintenance and storage facilities; business support services such as business incubators, offices and research/development laboratories, restaurants, and retail space; and education and tourism facilities" (Shove, 2002, p. 86).

These ancillary activities would demonstrate benefits based on their subsequent revenue stream, providing economic advantages to the spaceport / airport and their communities. This paper describes that the removal of spaceport operations, such as the halt of spaceport services in the Kennedy Space Center after the Challenger accident, too have large impacts on the economic wellbeing of the surrounding areas. Shove postulates that the reason for this impact is due to the integrated development of a spaceport and its local area creating a “spaceport community” which have almost all brought economic benefits to their communities.

Shove goes on to suggest that the issues that might be of concern in the development of spaceports include insurance, public safety, and monopolistic tendencies. To resolve these, Shove writes that coordination between government agencies, local, and state government as well as private owners should be prioritized. The cooperation is specified between regulations that relate to public safety or the environment, the use of federal facilities for spaceport operations, funding and or grants for business partnerships, and private/public policy coordination.

Finally, Shove alludes to the fact that spaceports can have long-term developmental impacts on the corresponding region, specifically within the realms of environmental impact, population growth, economic prosperity, economic diversity, and property usage. Each of these impacts is interconnected with positive and negative connotations; however, it is generally stated by Shove that spaceports bring with them an influx of positive benefits. Environmentally, it is said that endangered species in the proximity of the spaceport could see an upset balance of their ecosystem due to the spaceport. Shove addresses this as states that, “The National Environmental Protection Act (NEPA) requires careful mediation of development related to endangered species” (Shove, 2002, p. 93). Additionally, the toxicity of fuels involved with spaceports are inspiring groups to develop solutions, such as a leak drainage system, that could mitigate spaceport environmental impacts. Similarly, heavy funding and development is being poured into developing spacecraft that do not utilize environmentally hazardous fuels, to lower the environmental impact of launches.

In closing, Shove draws attention to how commercial spaceports have a regional scope, and as such, development of spaceport and spaceport operations demand a substantial amount of regional and municipal consensus for both building and consultation. Like this, accredited commercial spaceports are forced to have active relationships with the Federal Aviation Administration (FAA) under the U.S. Department of Transportation (DOT) in order to obtain a spaceport active launch license. Consequently, Shove alludes that both federal and regional / municipal government coordination of funding and policy is a must for any organization looking to create or maintain a commercial spaceport.

<u>2.2 State Spaceports - If You Build It, Will They Come?</u>

Finger, George, et al. (2012). *State Spaceports - If You Build It, Will They Come?, American Institute of Aeronautics and Astronautics.* Retrieved from: https://arc.aiaa.org/doi/pdf/10.2514/6.2007-9921.

In this article, George Finger, an independent researcher, and his team compare the challenges between the construction of different types of spaceports. The various types of spaceports discussed in the article include: spaceports funded and developed by state-based or sponsored organizations looking to bring aerospace companies to their controlling regions, spaceports funded by privately-financed space entities, and individual or standalone launch sites and facilities which are created and maintained by federal agencies for specific federal launch programs.

The article describes and compares how each of the types of spaceports are or will be organized. This organization is largely based on the sites needs and functions once full-time operations begin. One example of a state-run spaceport launching government-funded missions, privately funded missions, and major-operational is Cape Canaveral's Kennedy Space Center (KSC). Finger approves of the current management, organization, and structure of KSC and asserts that any future state-run launch sites should resemble the current infrastructure of KSC. A trait which Finger suggests as the most important trait for future state-run sites include proximity to the ocean for easy discard of stages without the worry of endangering surrounding wildlife, people, or communities. Additionally, Finger comments suggest that KSC and other military-based operations have the added benefit of being defendable if the site is to also run military operations. Finally, Finger work seems to comment that KSC's proximity to the equator allows for the easiest launch into most launch azimuths, and notes how that too is an alluring quality for any future launch sites.

The above mentioned qualities; however, may not prove to be as important in privately serving spaceports. Finger and his team discuss how entrepreneurial (private) operators serving orbital flights are set to develop more reusable rockets in the coming decade, making ocean recovery undesirable. Similarly, military protection may be obsolete, excessive, or even intrusive to a privately run spaceport, based on the type of missions being run. Finger goes on to suggest that while equatorial launch sites do have certain benefits, non-coastal and non-equatorial options allow for higher elevation launches, increasing launch efficiency due to atmospheric changes.

Moving forward, Finger suggests that entrepreneurial suborbital flights specialized for space tourism serve a different set of standards. This includes that these sites rely less on the importance of launch location, due to the suborbital nature of the flight. Finger seems to go on to describe additionally that "because this is a business enterprise, all expense and revenue sources must be integrated into the enterprise. The site may need to include related training facilities, entertainment facilities, themed hotels, restaurants and the like" (Finger, et al., 2012, p. 3). This assertion carries the implication that the surrounding communities would need to support the

spaceport's economic needs, but that in return, the surrounding region would also experience the benefits of the increased revenue due to the new introduced space industry's existence.
Finger then concludes this portion of the article by stating that "Newly developing Spaceports need to be more responsive to the needs of the entrepreneurial operators in order to increase their success in attracting them to their Spaceport" (Finger, et al., 2012, p. 5).

The article closes with a discussion of what prospective spaceports might expect when being developed and implemented. Finger and his team break down these expectations into three main groups, with the third having four subcategories, which can be seen below in *Table 2*.

Table 2: Developing Spaceport Expectations (Finger, et al., 2012, p. 5-6)

Expectation	Description
Financial / Competitive Cost Structure:	The Spaceport's cost structure must allow the Entrepreneurial operator to evaluate the business case without a large fee and operate in an ongoing manner to make a profit. The pricing structure needs to be less costly than any other Spaceport option for that non-traditional user.
Responsive Scheduling:	The Spaceport must commit and provide operational infrastructure on a schedule which is responsive to the business plan needs of the Entrepreneurial user. The schedule must allow the user to launch on desired dates/times without a concern for postponement or cancellation due to other overriding launches.
Technical - Siting:	The Spaceport would likely be in a large, mostly uninhabited area within the US at a relatively high elevation which would be licensed and regulated through the FAA rather than controlled by a Federal launch range (e.g. central US desert). Aviation flight corridors should not interfere with the Spaceport's airspace because they can impact the flexibility of the launch schedule. Even remote sites can be limited due to aircraft overflight restrictions.
Technical - Site Layout:	Operational areas would include runway(s) for horizontal take offs and horizontal landings; large, relatively smooth landing zones (up to a mile in diameter) for parachute landings; hardened concrete pads for vertical powered landings; small concrete pads for rail guided launches, and larger vertical launch pads with exhaust ducts and vehicle specific adapters. Sites may want to provide the flexibility to support testing vehicles of a variety of types and scales.
Technical - Streamlined and Independent Range Operations:	Operations will be managed in such a way as to support launches on demand by the non-traditional operators.

2.3 General Aviation Airports: A National Asset

Federal Aviation Administration. (2012). *General Aviation Airports: A National Asset, Federal Aviation Administration*. Retrieved from https://www.faa.gov/airports/planning_capacity/ga_study/media/2012assetreport.pdf

This report is the result of a 2 year study conducted from 2010 to 2012 by the Federal Aviation Administration (FAA) and includes information pertaining to General Aviation (GA) airports, their classification, GA airport use/operations, the importance of GA airport, and a catalog of classified and unclassified GA airports. The FAA asserts that GA serves many purposes and supports activities such as emergency response, law enforcement/national security operations, disaster relief, as well as other GA activities. GA airports are spread all over the United States servicing local communities and beyond each with their own unique roles and operations.

In order to better categorize the wider spread of GA airports, the FAA developed four categories of which all GA airports can be easily identified. These four categories include: National, Regional, Local, and Basic. The FAA has placed 84 airports in the National category, 467 airports in the Regional category, 1,236 airports in the Local category, and 668 in the Basic category. There were also 497 additional airports that the FAA could not place into one of these four categories. One example of a type of airport that could not be categorized include old/decommissioned military airports that were converted to GA airports. The team writing this report noted that these airports are important as military airports could have extra potential for dual use operation due to their size and infrastructure. The team will be able to use this article as well as the newly defined categories to help in identifying airports in the United States with significant potential for dual use airport and space related operations.

3. Problem Solving Approach

In order to address the issue of generating revenue for GA airports, the team set out to devise an approach that would allow GA airports to tap into and participate in the commercial space economy without the need for a large upfront investment. Similarly, the team strove to discuss and inspect ideas that need little FAA and government oversight, due to the added pressure and cost usually associated with such products. As such, the team decided prior to brainstorming potential spaceport operations that only approaches which did not require a full spaceport operator or spaceport facility license from the FAA would be eligible. Instead, airports which choose to participate in spaceport operations outlined by The CSAVO Initiative will only deal with local zoning and municipality laws, rather than the full spectrum of FAA licenses and regulations. With these boundaries set, the team began brainstorming their problem-solving approach.

Throughout the brainstorming process, several ideas were introduced that could have stood as viable options for this entry into the space industry guideline but were ultimately ruled out. These ideas included a potential license for solely horizontal spacecraft operations, the construction of full-scale spacecraft testing facilities, MRO and other maintenance operations for spacecraft, and testing / flying simulations for new and experimental spacecraft. Unfortunately, the primary issue with each of these ideas was their scope. All had a very high upfront cost, and while they could make an airport money back over a long period of time, the team felt that the potential risk of a space economy failing to establish in an airport’s selected area would result in many GA airports opting out. Though the above ideas failed to meet all the team's needs, one idea proved viable as the main pursuit of the CSAVO Initiative: Rocket Engine Test Cells (RETCs).

After trimming away the expensive and unattainable ideas that had arisen during brainstorming, the team decided to seek out a plan which would create space operations at a GA airport for the lowest cost possible. The result was RETCs. With a suitable company, entity, or university looking to work in the field of rocket engines,, a reorganization of existing airport rules and regulations, and only a few thousand dollars in investment, RETCs will offer GA airports with no prior experience in commercial space operations the chance to enter into an ever evolving and expanding space economy. Additionally, by also outlining a set of guidelines for the construction and maintenance of these test cells (found in section 4.1), as well as developing a model for which a GA airport could use to determine the going rate at which they might rent or lease the test cells to potential customers (found in section 4.4), the team feels that pursuing RETCs as the primary focus of CSAVO will result in the widest variety of GA airports adopting the idea.

4. Technical Descriptions

The RETCs being developed as part of the initiative are designed with the intent that any GA airport in the country may take part in their construction. As such, the cost is intentionally left low by the team and the decision to use better or more advanced, expensive equipment is up to the airport themselves. It is important to state here and elsewhere however, that low cost does not correlate to unsafe. These technical guidelines will address the proper safety guidelines that must be met, in order to ensure the safety of all involved parties.

4.1 Test Cell Cost and Construction

The premise of this design is to create a test cell for potential companies and universities in which they could test a small to medium size rocket engine. As such the team has opted to use pre-existing fabrications in order to limit cost and save on build time. A list of needed materials for a single test cell can be found below in *Table 3*.

Table 3: RETC Item List

Item	Description	Cost	Source
Excavator	Rented for a day. Used to dig out two ditches in which the storage container is placed.	$1,282 (daily)	(United Rentals, 2020)
Storage Container 20’	Placed next to each other partially underground and act as the test cell and control room. 2 needed.	$1,400 (each)	(Onsight Storage Solutions, 2020)
Fuel Tank 420 Gallon	A double-wall 420-gallon horizontal tank that can hold two products. Used to hold fuel and oxidizer.	$3,884	(Eagle Tanks, 2008)
High-Pressure Piping 1” diameter	High tolerance piping that connects both sides and sources from the tank to the test cell. 4310 aluminum with a 1” diameter.	$6.75 (/foot)	(Aircraft Spruce, 2020)
Various High-Pressure Fittings and Valves	A misc. category of high-pressure valves and fittings which connect the engine and the fuel tanks outside. 60,000 psi.	$500	(High Pressure Equipment, 2020)
LED Lights	Overhead lights in both the cell and control room to provide light.	$128.95 (each)	(Home Depot, 2020)

It should be noted that by creating more than one cell, some of the above costs may not be charged more than once. For example, if a GA airport wished to scale this model from one to five test cells, the cost of renting an excavator would stay the same, and not incur additional cost to the airport for subsequent RETC. It is also assumed that all power needed to operate the lights and any future technology that will be installed into the cell by its renters can be supplied by the airport itself, and no additional generator would be needed. A simple drawing of what a RETC’s layout would look like is included below in *Figure 1*.

It will be important to ensure that the system itself is safe for rocket engine operations. This is ensured by creating blast mounds between potential explosive sites, in order to mitigate damage if an unscheduled rapid disassembly were to take place. While a full work up of explosive siting is found in section 4.2, it should be noted here that a minimum of a three foot barrier between the two containers and a minimum of a ten foot barrier between the fuel tank and the test cell is required when designing and constructing a RETC.

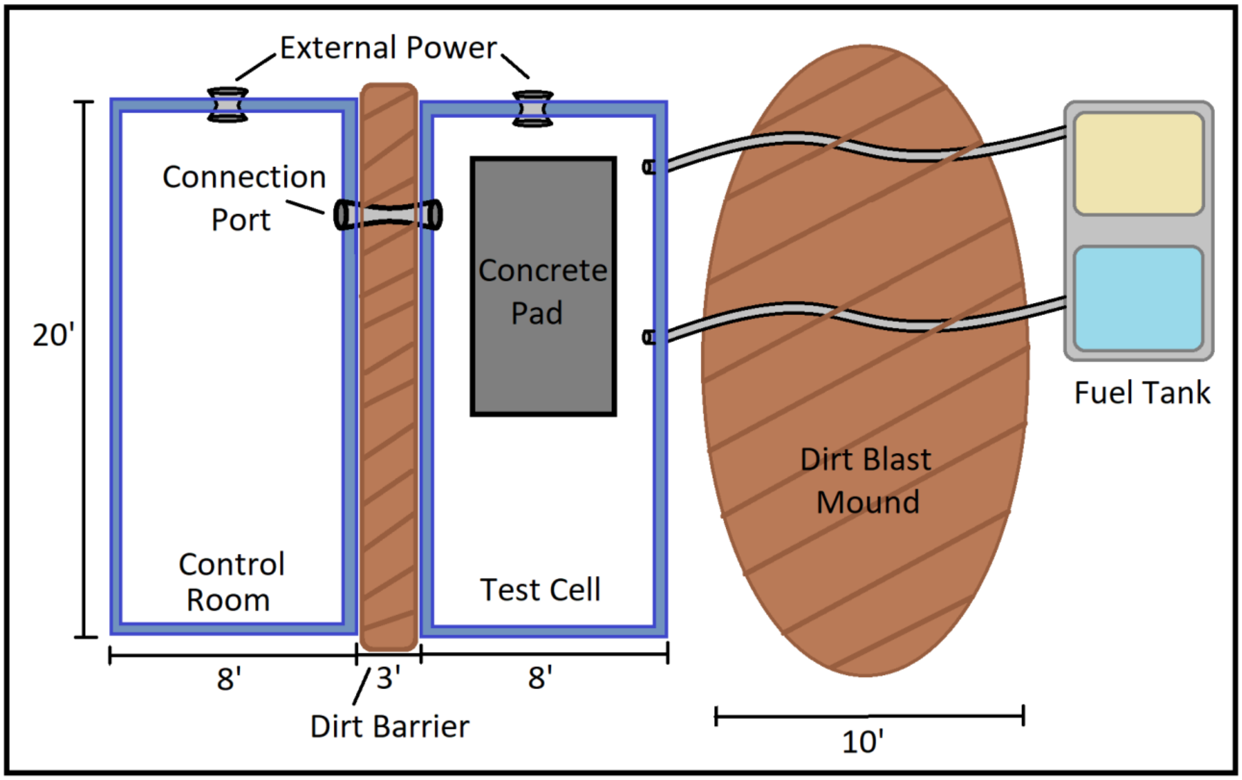


Figure 1: RETC Bird's Eye View Diagram

Assuming that the excavator was only needed for one day, the fuel tank was placed near the test cells, (explosive siting requirements are located in section 4.3) allowing for only 100 feet of piping needed, and that 2 LED lights were purchased and wired so that both containers met OSHA guidelines of 10 foot candles in a workspace (OSHA, 1974), the item cost to construct one RETC would be $9,632. Further, it is then assumed that each additional RETC after the first would cost an additional $4,466 if additional fuel tanks were not required. While this is no small amount by itself, when compared to the millions spent on test cells across the country, and when coupled with the fact that such a cost could be recouped through rent / leasing, this number becomes much more palatable.

4.2 Test Cell Location

Due to the potentially dangerous nature of rocket engine testing, great care must be taken when deciding on placement for an RETC. The most important consideration that must be taken is the placement of the fuel tank in regard to other buildings and high population density areas at the airport. While the test cell does not have any direct oversight from the FAA and other aerospace bodies, it is the goal of the team to follow FAA and other federal recommendations wherever possible. As such, the team and CSAVO will be observing and following explosive siting regulations outlined in *DESR 6055.09 Edition 1* (DESR, 2019). Outlined by the United States Department of Defense (DOD) in Volume 4 of *DESR 6055.09 Edition 1* in the section titled “QD Criteria For Airfields And Heliports, Piers And Wharfs, And Specific Facilities,” the DOD lays out distancing and siting rules when placing fuel tanks at an airport. The FAA and all FAA spaceports follow these regulations as well, and so CSAVO will be no different.

In regards to placing the fuel tank / tanks for the RETCs, the following regulations must be met: Fuels chosen must be weighed and converted to US pounds (lbs.), this weight must be compared to the figures list below, and the distances given based off of weight must be followed with no exception. This is to ensure the safety of all persons in and around the airport as well around the tanks and RETCs themselves. Defined as Quality Distances (QDs), the first QD that is needed is the distance the tank must be from areas in which aircraft are stored and not in use. These distances are derived from the base weight of the fuel in pounds being used per 1 gallon.

Table 4: DOD QD for Stored and Parked Aircraft (DOD, 2019, p. 175)

NEWQD	Distance from Specific Targets
(lbs.)	(ft)
50	111
70	124
100	139
150	159

The next number that must be assessed is the QD to active runways. This number is assessed based off the total weight of fuel located in the stored tank, rather than just by a single gallon. Similarly, to before, one must calculate the total weight of all fuel in the 420-gallon tank to determine at what distance this tank must be placed from an active runway. The values needed can be found in *Table 4 and 5*.

Table 5: DOD QD for Active Runways (DOD, 2019, p.120)

NEWQD	Front	Side	Rear
(lbs.)	(ft)	(ft)	(ft)
1000	1250	1250	1250
1500	1250	1250	1250
2000	1250	1250	1250
3000	1250	1250	1250
500	1250	1250	1250

An example of these calculations is included below. For this example, the team assumes that a commercial space entity is using the full fuel tank to house both Liquid Oxygen (LOX) and Liquid Hydrogen (LH_2), two of the most common liquid rocket fuels, in equal parts. The weight of 1 gallon of LOX is 9.52 pounds, while the weight of 1 gallon of LH_2 is 14.1 pounds. The weight of 210 gallons of LOX is 1,999.434 pounds, while the weight of 210 gallons of LH_2

is 2,961.476 pounds. Using *Figure 2* and *Figure 3*, one can assess that due to LH_2's higher single gallon weight, the tank may not be placed within 111 feet of any non-active aircraft parking areas. By adding the two weights to get 3,160.91 pounds total in the tank, one can use *Figure 3* to see that the tank may not be within 1,250 feet in any direction of an active runway.

While using these siting requirements is important when determining where the tanks should not be placed, it only partially helps narrow down where the RETCs should themselves be placed. In order to determine this, the team suggests the following, based on conversations with current airport managers and directors. These numbers do not supersede DESR 6055.09.

Table 6: CSAVO QD Recommendations

Object to Maintain Distance From:	**RETC Quality Distance:**
Hanger	500 ft
Unpaved Road	550 ft
Paved Road	800 ft
Taxiway	600 ft
Pedestrian Walkway	900 ft
Office Building	1,250 ft
Inactive Runway	1,250 ft
Active Runway	1,500 ft

5. Safety Risk Assessment

5.1 Risk Assessment and FMEA

Defined by the Merriam-Webster Dictionary as an action "to protect against failure, breakage, or accident," safety is a state in which a thing, person, or organization strives to ensure that all parts of a process will not inflict lasting damage on other things, persons, or organizations if a failure state were to occur (Merriam-Webster, 2020, p. 1). In the CSAVO Initiative, the team strives to do just that. Through the use of risk assessment, as well as the development of a SMS plan, the team aims to create safety guidelines that will allow for the safe operation of test cells and GA airports as they become symbiotic parts in an airports ecosystem.

As outlined by the FAA in Advisory Circular 150/5200-37, Safety Risk Management (SRM) can be broken down into five phases. These phases are as follows:

- Phase 1 - Describe the System
- Phase 2 - Identify the Hazards
- Phase 3 - Determine the Risk
- Phase 4 - Assess and Analyze the Risk
- Phase 5 - Treat the Risk (i.e., mitigate, monitor, and track)

(Federal Aviation Administration, 2007, p. 9).

In addition to the above steps, a severity matrix is included as part of Phase 4, which will help the team assess potential risks that arise from introducing CSAVO into a GA airports ecosystem by measuring and comparing the risk's severity and likelihood of occurring. This figure is seen below as *Figure 4*.

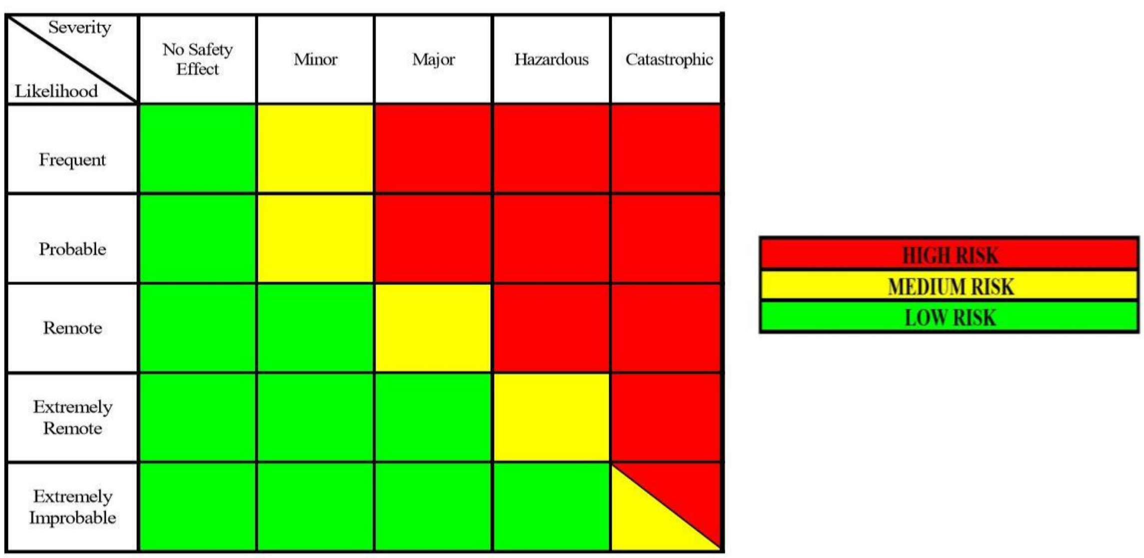


Figure 4: SRM Predictive Risk Matrix (Federal Aviation Administration, 2007, p.12).

By introducing new rocket engine test cells into an already potentially dangerous environment, there will no doubt be a rise in potential hazards. These hazards, which have been discussed and ranked using the below FMEA, were derived as a result of both team and industry expert discussion.

FMEA Form

Process/Product Name: GA Airport RETCs
Responsible: GA Airports, CSAVO
Prepared By: Jason Endsley, Cooper Burleson, Jack Green
FMEA Date (Orig.): 10-Mar
(Rev.): 4

Process Step/Input	Potential Failure Mode	Potential Failure Effects	SEVERITY (1 - 10)	Potential Causes	OCCURRENCE (1 - 10)	Current Controls	DETECTION (1 - 10)	RPN
What is the process step, change or feature under investigation?	In what ways could the step, change or feature go wrong?	What is the impact on the customer if this failure is not prevented or corrected?		What causes the step, change or feature to go wrong? (how could it occur?)		What controls exist that either prevent or detect the failure?		
The storage of exotic test fuels.	The fuels could explode while being stored.	Loss of the RETC and or fuel tank.	10	CSAVO guidlines are not followed.	4	Valve regulators and routine checks of fuel tank.	7	280
The firing of a rocket engine near an active runway.	FOD could be spread onto the runway.	Aircraft may take FOD damage.	7	Airport places test site exhasut facing the runway.	4	Orienting RETCs away from runaways and populated areas.	9	252
	A place could be hit by the exhaust.	Aircract may take exhaust damage.	9	Airport places test site exhasut facing the runway.	2	Orienting RETCs away from runaways and populated areas.	9	162
Environmental impact of rocket exhaust on the airport's surrounding.	Fumes from toxic fuels are transmitted into the air.	Airport may be held liable for harmful emissions.	8	Airport does not follow CSAVO guidlines on emmissions handling.	6	CSAVO and FAA regualtions outline proper emmisions handling procedures.	6	288
	Toxic lquid by products enter into the water system.	Airport may be held liable for harmful water conditions.	8	Airport does not utilize the pre-existing waste managment system for byproduct disposal.	4	CSAVO and FAA regualtions outline proper waste handling procedures.	6	192
Public opinion due to increased noise pollution.	High noise levels during testing lead to local complaints.	Airport may face public scrutiny.	5	Airports does not orient RETCs away from densly populated areas or use sound barriers of any kind.	9	Alert the public before any major tests.	4	180

Figure 5: CSAVO FMEA

The scales used in order to select these severity, occurrence, and detection numbers can be seen below in *Figure 6*. They were derived using the ASQ's model for FMEA design.

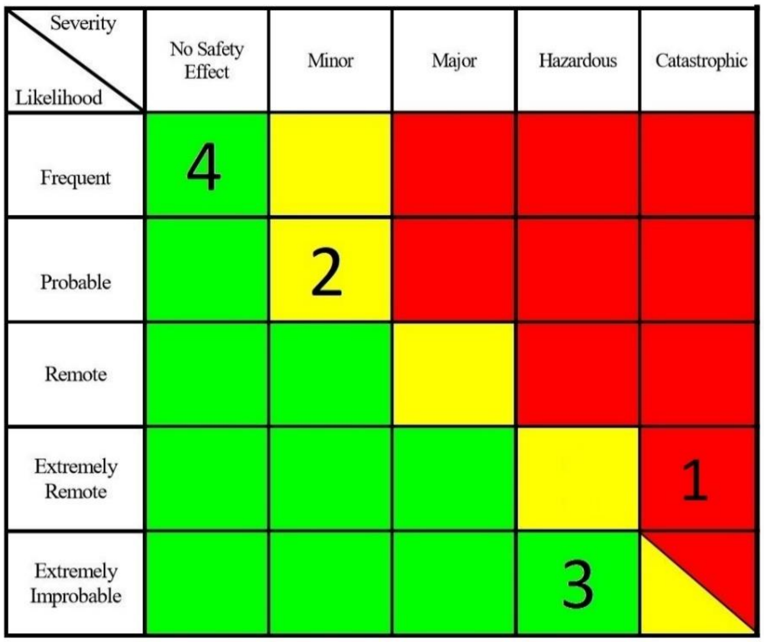
Severity Scale		
Effect	**Criteria: Severity of Effect**	**Ranking**
Hazardous - Without Warning	May expose client to loss, harm or major disruption - failure will occur **without** warning	10
Hazardous - With Warning	May expose client to loss, harm or major disruption - failure will occur **with** warning	9
Very High	Major disruption of service involving client interaction, resulting in either associate re-work or inconvenience to client	8
High	Minor disruption of service involving client interaction and resulting in either associate re-work or inconvenience to clients	7
Moderate	Major disruption of service not involving client interaction and resulting in either associate re-work or inconvenience to clients	6
Low	Minor disruption of service not involving client interaction and resulting in either associate re-work or inconvenience to clients	5
Very Low	Minor disruption of service involving client interaction that does not result in either associate re-work or inconvenience to clients	4
Minor	Minor disruption of service not involving client interaction and does not result in either associate re-work or inconvenience to clients	3
Very Minor	No disruption of service noticed by the client in any capacity and does not result in either associate re-work or inconvenience to clients	2
None	No Effect	1

Occurrence Scale			
Probability of Failure	**Time Period**	**Per Item Failure Rates**	**Ranking**
Very High: Failure is almost inevitable	More than once per day	>= 1 in 2	10
	Once every 3-4 days	1 in 3	9
High: Generally associated with processes similar to previous processes that have often failed	Once every week	1 in 8	8
	Once every month	1in 20	7
Moderate: Generally associated with processes similar to previous processes which have experienced occasional failures, but not in major proportions	Once every 3 months	1 in 80	6
	Once every 6 months	1 in 400	5
	Once a year	1 in 800	4
Low: Isolated failures associated with similar processes	Once every 1 - 3 years	1 in 1,500	3
Very Low: Only isolated failures associated with almost identical processes	Once every 3 - 6 years	1 in 3,000	2
Remote: Failure is unlikely. No failures associated with almost identical processes	Once Every 7+ Years	1 in 6000	1

Detection Scale		
Detection	**Criteria: Likelihood the existence of a defect will be detected by process controls before next or subsequent process, -OR- before exposure to a client**	**Ranking**
Almost Impossible	No known controls available to detect failure mode	1
Very Remote	Very remote likelihood current controls will detect failure mode	2
Remote	Remote likelihood current controls will detect failure mode	3
Very Low	Very low likelihood current controls will detect failure mode	4
Low	Low likelihood current controls will detect failure mode	5
Moderate	Moderate likelihood current controls will detect failure mode	6
Moderately High	Moderately high likelihood current controls will detect failure mode	7
High	High likelihood current controls will detect failure mode	8
Very High	Very high likelihood current controls will detect failure mode	9
Almost Certain	Current controls almost certain to detect the failure mode. Reliable detection controls are known with similar processes.	10

Figure 6: FMEA Scales (American Society for Quality, 2018).

The team's model of introducing test cells into GA airports raises four major hazard concerns. These concerns include: (1) The storage of exotic test fuels, (2) the firing of a rocket engine near an active runway, (3) potential environmental impact of rocket exhaust on the airport's surrounding environment, and (4) public opinion due to increased noise pollution. Each of these hazards has been over laid on the FAA's Predictive Risk Matrix in *Figure 6* below:



Potential Hazards:

1) The storage of exotic test fuels leading to an explosion.
2) The firing of a rocket engine near an active runway.
3) Potential environmental impact of rocket exhaust on the airport's surrounding environment.
4) Public opinion due to increased noise pollution.

Figure 7: CSAVO Predictive Risk Matrix

While each hazard does range from no effect on safety to having a potentially hazardous effect on the airport, it should be noted that these severities levels were decided upon if CSAVO guidelines were not followed. If the CSAVO SMS Plan is incorporated into the GA Airport's already existing plan, then the severity of each of the hazards could be reduced.

5.2 CSAVO SMS Plan

In order to ensure the success of any airport attempting to follow CSAVO, a Safety Management System (SMS) must be developed. According to the Federal Flight Administration, a SMS should “integrate modern safety risk management and safety assurance concepts into repeatable, proactive systems” (Federal Flight Administration, 2016, ¶. 2). There are four components to a successful SMS which are “Safety Policy, Safety Assurance, Safety Risk Management, and Safety Promotion” (Federal Flight Administration, 2016, p. 4). The Safety Policy is the first step to creating a SMS, as this step helps identify goals, objectives, methods, processes, and improves current processes. The SRM is a structured approach to identifying and controlling the potential safety hazards (Section 5.1). The Safety Risk Management (SRM) will help the airport identify risks associated with the process or system for the next part of a SMS, Safety Assurance. Safety Assurance is a useful tool for evaluating how current risk management strategies are working and could help identify better ways to mitigate known hazards or possibly discover previously unknown hazards. Safety Assurance can utilize audits, data analysis, employee reports, or several other methods to obtain information related to Safety Assurance. This will allow the airport to ensure they are meeting FAA policies, local municipality laws and ordinances, or any other safety related regulations. Furthermore, this information will help identify weak areas of the SMS and highlight the need for improved safety practices in those areas. The last component of a SMS is Safety Promotion, which is the most proactive part of an SMS. Safety Promotion includes safety training for employees, improving safety awareness, requiring an active role in safety for all employees, and overall promoting safety in all work areas. The SRM and Safety Assurance components work in tandem to identify risks and then implement the needed risk mitigation strategies.

FAA Order 3900.19C is a very good starting point for the Safety Policy, as this order handles nearly all aspects of Occupational Safety and Health (OSH). This order lays out the basic requirements for workplace safety policies. A notable chapter in this FAA order is Chapter 15:

Toxic and Hazardous Substances (Federal Aviation Administration[3], 2019). This chapter covers Hazard Communication (HAZCOM) Training, which is important because hazardous fuels as well as other chemicals may be stored and used in the airport facility for rocket engine testing. This also raises the concerns for emergency responses, as first responders will also require additional training to deal with these new hazards. By adopting FAA Order 3900.19C, the building blocks will be in place for a comprehensive OSH Policy. Through information gained from the Safety Assurance part of the SMS, more specific policies can be added to increase the overall safety of The CSAVO Initiative.

An example of Safety Risk Management for The CSAVO Initiative is provided above. The SRM above can be adapted and changed to better fit the specific airport that is considering these changes, as the airport may have additional concerns on top of the ones listed in the paper. By utilizing the same methodology as above, the airport will be able to identify, analyze, and possibly control the other identified hazards.

In order to ensure the continual effectiveness of the SMS, the airport and/or test cell operators must collect data that can be analyzed. As mentioned above, a system should be in place that allows employees to report safety concerns or workplace hazards. Audits (either performed internally or through a third party) as well as employee interviews are another useful tool to gather information that may prove to be useful for improving the Safety Management System in place. The FMEA and Risk Matrix are just two of several useful Lean Six Sigma tools for assessing safety.

Lastly is Safety Promotion, which may be most effective as it involves several proactive safety measures. Anybody who may work in or around the test cell needs to have proper training to ensure a safe environment. Several training courses would be encouraged for anyone working in or near the test cell such as; Lockout/Tagout (LOTO) training, Personal Protective Equipment (PPE) training, as well as other training required and/or recommended under FAA Order 3900.19C such as HAZCOM training. As mentioned above, first responders would also need additional training. Aircraft Rescue and Fire Fighting (ARFF) would need to update their training standards, because the fuels and other chemicals used in rocket engines may require different equipment or techniques to safely contain. Depending on the newly introduced chemicals several changes may be needed such as new fire extinguishers installed around the test cell, specialized fire retardant for firefighter response, additional PPE for first responders, as well as updated emergency evacuation plans. The FAA website on Aircraft Rescue and Firefighting (ARFF) provides 16 related Advisory Circulars pertaining to ARFF that may help guide the airport in determining the required changes (Federal Aviation Administration[1], 2019). While the new training and equipment will incur cost, these proactive measures will be significantly less expensive than paying for damages retroactively.

5.3 Cost/Benefit Analysis

Costs and benefits considered for this analysis include the entities described in detail in the previous sections; however, additional costs and benefits unforeseen by the scope of this design may have an impact on the final cost quantities. More conservative estimates could include metrics involving changing requirement levels, budget shortcomings, schedule slippage, and technical issues that may occur during the design and build of a RETC. For the purpose of this design, the cost analysis would be conducted over a three-phase implementation approach. These three phases allow for an in-depth investigation into each of the phases, including a better understanding of the costs, expenses, and priorities of each phase. Further cost analysis would be conducted as the project continues and the RETC development moves away from the concept study phase.

The first phase is the combined alpha and beta research and development. While each the alpha and beta R&D is considered a separate step in the integration of the design, their research and development characteristics give similarities in types of costs and expenses expected. Potential quantitative costs come from the expended labor on developing, implementing, and maintaining the described operations. While economically a community-wide impact could be determined, the specific impacts that the implementation of the RETC operations themselves will be considered more in depth. For Phase I, cost focus would be placed on the research and development of facilities involved with successful RETC operation. Labor costs for alpha research and development are shown in *Table 7* below.

Table 7: Costs analysis for alpha research and development for design proposal

Cost Analysis - Alpha Research and Development for CSAVO							
Costs to Airport				Costs to Contracted Companies			
Entity	Rate ($/hr.)	Quantity (hours)	Subtotal	Entity	Rate ($/hr.)	Quantity (hours)	Subtotal
Student	$50	140	$7,000		$0	0	$0
Faculty Advisor	$100	50	$5,000		$0	0	$0
Total			**$12,000**	**Total**			**$0**
Combined Total	**$12,000**						

The example of the beta research and development costs that might be considered in this design is shown below in *Table 7*. Labor costs would include the potential engineers and analysts hired to begin the implementation of the design. In addition to this, potential travel and material expenses are worth considering. The summary here is an example of what could be seen;

however, this does give a good representation of what would be expected for this particular spaceport design.

Table 8: Beta Research and Development Labor and Expense Costs

Cost Analysis - Beta Research and Development for Pilot Implementation of CSAVO							
Costs to Airport				Costs to Contracted Companies			
Entity	Rate ($/hr.)	Quantity (hours)	Subtotal	Entity	Rate ($/hr.)	Quantity (hours)	Subtotal
Engineering Contractor	$100	320	$32,000	Site Scout	$70	120	$8,400
Airport Authority Manager	$120	320	$38,400				
Airport Authority Engineer	$100	320	$32,000				
Graduate Student Research	$50	240	$36,000				
Total			**$138,400**	**Total**			**$8,400**
Combined Total	**$146,800**						

In Phase II, the preliminary testing and implementation of a potentially scaled-down version of the full-scale design is completed. This concept could allow for a step-by-step integration that gives the local community a chance to build a support system for the coming infrastructure. Typical cost factors in this stage of development historically include the formation or building of a “launch pad deck, flame deflector, launch service building, launch mount, umbilical tower, lightning protection system, launch rail, propellant systems, water systems, high pressure gas systems, facilities entities such as power, lighting, data, and communications, vehicle processing, various transporters and ground support equipment, and finally emergency egress” (Gulliver, 2014, p. 1). With the development of the CSAVO test cell system, this cost can be greatly reduced. Costs typically seen in the development of a major spaceport can be split between two entities; the airports which will house the spaceport operations, and the contractors or launch customers that will supply launch materials necessary for their missions. The airport will be responsible for the initial development cost, for example the building of the test cell. However, the launch customers would be able to rent the facilities, in addition to fronting the developmental cost for new launch facilities.

The step-by-step approach could also allow for changes of the design to be made as a result of what is seen on the preliminary test site. A table showing the potential costs for the operations conducted in Phase II is shown below.

Table 9: Operational Labor and Expense Costs for Phase 2

Cost Analysis - Phase II Demo Spaceport Integration for CSAVO							
Costs to Airport				Costs to Contracted Companies			
Entity	Rate	Quantity	Subtotal	Entity	Rate	Quantity	Subtotal
Airport Authority Manager	$120/hr.	8000 (hrs.)	$960,000	Engineer (x2)	$100/hr.	3200 (hrs.)	$320,000
Airport Authority Engineer	$100/hr.	3200 (hrs.)	$320,000	Contracted Workers (x10)	$30/hr.	8000 (hrs.)	$240,000
Initial Test Cell	$9,700	1	$9,700	Law/Policy Advisory	$250	800 (hrs.)	$200,000
Power and Support Systems	$75,000	1	$75,000	New Facilities	$3,000,000	2	$6,000,000
				Storage	$500,000	3	$1,500,000
Total			**$1,364,700**	**Total**			**$8,260,000**
Combined Total	**$9,624,700**						

The third and final phase is the full-scale implementation of the design into the chosen area. This would include expenses ranging from new construction of additional test cells, to the development and testing of spaceport operations that would be seen with a full-scale design.

Table 10: Combined costs and expenses for phase III

Cost Analysis - Phase III Full-Scale Implementation of CSAVO							
Costs to Airport				Costs to Contracted Companies			
Entity	Rate ($/hr.)	Quantity	Subtotal	Entity	Rate ($)	Quantity	Subtotal
Airport Authority Manager	$120	6000 (hrs.)	$720,000	New Launch Facilities	$3,500,000/yr.	2	$7,000,000
Additional Test Cells	$4,500	1	$4,500	Rent/Use Cost of facilities	$106,000/yr.	2	$212,000
Airport Authority Engineer	$100	2800 (hrs.)	$280,000	Storage Cost	$750,000/yr.	3	$2,250,000
Spaceport Grounds Staff	$200	6000 (hrs.)	$1,200,000	Engineer (x2)	$100/hr.	2800 (hrs.)	$280,000
				Contracted Workers (x10)	$30/hr.	6000 (hrs.)	$180,000
				Law Practice	$250/hr.	800 (hrs.)	$200,000
Total			**$2,204,500**	**Total**			**$10,122,000**
Combined Total	**$12,326,500**						

The grand total of the full design-to-production effort is shown in the table below. The costs involved in supporting spaceport operations are not small, however with the suggestions made within the CSAVO initiative, it is possible that these costs be greatly reduced for both the aspiring spaceport, and the launch customers it will service.

Table 11: Grand total for all three phases of the CSAVO initiative

Grand Total Cost for CSAVO		
	Airport Grand Total Estimate	Contractor Grand Total Estimate
Phase I - Alpha & Beta Research and Development	$150,400	$8,400
Phase II - Demo Site Implementation	$1,364,700	$8,260,000
Phase III - Full-Scale Implementation	$2,204,500	$10,122,000
Grand Total Estimate	**$3,719,600**	**$18,390,400**
Combined Total	**$22,110,000**	

While costs remain a critical part of understanding the design, the potential benefits of this approach are promising. Benefits include the availability of spaceport operations to a greater area, reducing the cost of storage, transport, and materials that are typically seen in the limited spaceport market faced today. Currently, operational availability is limited to the few locations where spaceports exist. The expansion of spaceport operations into more reachable communities allows for certain activities to be completed without the burden of travel time, travel cost, and material shipment that would exist when subjected to testing at one of the few pre-existing locations. In addition to the increased availability, local communities could see economic growth for their communities, with an influx of jobs stemming from the resulting spaceport. The benefit analysis table provides a short estimate of the monetary benefits CSAVO would provide.

Table 12: Benefit Analysis Table for Three-Phase CSAVO Initiative

Benefit Analysis for CSAVO Initiative		
	Noted Benefit	Benefit ($)
Phase I	Development not requiring company/big money input	$2,500,000
Phase II	Demo site reduces regulation/licensing costs	$5,000,000
Phase III	Test cell and CSAVO development from existing airport	$150,000,000
Total Benefit	**$157,500,000**	
Total Cost	**$22,110,000**	

Typical landscape rental at an operating spaceport place test cell space rental at $8,000 per month, totaling just over $100,000 per year when including utilities. This would be paid by a launch customer to the supporting airport, ensuring an income for each test cell to be rented out. This does not include the additional income from facility usage such as material and vehicle storage. The infrastructure and expenses that are required for successful spaceport operation come with extreme costs that are not easily met. Existing ground-up spaceport integration is estimated to cost in the $200 million range (Gulliver, 2014). However, without the need for spaceport entities that typically cost the most to develop (including extended runways, terminals, and training facilities) operating a spaceport from existing infrastructure reduces both cost and man-hours attached to the spaceport design.

5.4 Sustainability Assessment

Defined by the FAA as “Actions [which] reduce environmental impacts, help maintain high, stable levels of economic growth, [and or] help achieve ‘social progress’, [sustainability is] a broad set of actions that ensure organizational goals are achieved in a way that's consistent with the needs and values of the local community” (Federal Aviation Administration [2], 2019, ¶. 1). As such, the CSAVO Initiative will aim to do just that. By guiding, to the best of its abilities, airports in ways to reduce environmental impact of spaceport operations, outlining ventures which could generate revenue for years to come, and by setting the foundation for lasting social connections both on a local and global level, the CSAVO Initiative aims to fall in line perfectly with the FAA’s definition of sustainability.

In order to assess whether the CSAVO Initiative does fall in line with this definition, the goals of the Initiative were organized by a globally recognized measurement. The EONS mode and approach was used by the team in order to analyze the sustainability impacts these kinds of spaceport activities would have on the chosen airport and its surrounding community and area. EONS was chosen as the analysis mode because it incorporates most of the ideas of the Triple Bottom Line, another popular form of sustainability measurement, but focuses more on operational efficiency. Similarly, EONS is the main model used by the FAA in its sustainability designs and processes. Seeing as this proposal will rely heavily on the FAA’s rules and guidelines and similar CFR codes, it was agreed upon by the team that following their EONS model would yield the best chance of success. By focusing on this approach, the sustainability analysis will not only focus on the basics of sustainability but will go deeper and consider the impacts on economic growth, protection of the environment, ethical corporate practices, and the efficiency of the operation. A tabled overview of CSAVO's Sustainability Goals, and their positive and negative impacts can when placed in EONS categories, can be seen below:

Table 13: CSAVO Sustainability Goals

EONS Sustainability Model - CSAVO Goals							
Economy		Operational		Natural Resources		Social	
↑	Generate revenue by leasing out test sites and hanger space to space industry companies.	↓	Create guidelines for exotic fuel handling, use, emergency exposure and disposal.	↓	Store exotic fuel types on airport property.	↑	Form partnerships with either space industry startups or nearby university engineering programs.
↑	Increase the amount of high-wage jobs at the airport through space industry companies.	↓	Create guidelines for runway usage while engine testing is occurring.	↓	Coordinate fuel delivery and storage with a space industry company or entity.	↓	Create guidance rules and Bonds with the local municipality due to increased noise during engine test fires.
↓	Build test cells in a remote part of the airport facility.	↓	Create Explosive Siting guidelines following 14 CFR 420 Appendix E.	↑	Design means of measuring emissions to ensure that the local area is not too negatively impacted by testing.	↑	Brand and market spaceport operations in order to increase tourism at the airport and local area.

As seen above, the goals involved within the CSAVO Initiative all have positive and negative effects that correlate to the arrows next to each box. For example, while [Generating revenue by leasing out test sites and hanger space to space industry companies] has a positive trend within the economy tab, due to the fact that generating money would be a positive outcome for an airport adopting CSAVO guidelines, [Build test cells in a remote part of the airport facility] has a negative trend due to the fact that this would cost the airport some amount of initial investment. The reason for each trend can be found below in Table 12.

Table 14: CSAVO EONS Breakdown

Actions	**EONS**	**Trend**	**Reason**
Generate revenue by leasing out test sites and hanger space to space industry companies.	E	↑	The generation of revenue will have a positive economic effect on the airport. By leasing out hanger, RETC, and land space to commercial space companies, an airport will be able to recoup the cost of the initial RETC investment. This will have a positive long-term effect on the airport.
Increase the amount of high-wage jobs at the airport through space industry companies.	E	↑	The action will have a positive economic effect on both the airport and the local community. Due to the increase in high wage jobs in the airport, other industries too will see a rise in revenue generation, as each new job at the airport will be adding money back into the local economy.
Build test cells in a remote part of the airport facility.	E	↓	The action will have a negative economic effect due to the initial investment of $9,631.80 for the first RETC and the subsequent investment of $4,465.80 for each following RETC.
Create guidelines for exotic fuel handling, use, emergency exposure and disposal.	O	↑	This action will have a positive organizational effect as a new job will be created to oversee the creating and adhering to the new guidelines. If an airport already has similar guidelines in place, they may be changed retroactively to allow the RETCs to be a part of their guidance.
Create guidelines for runway usage while engine testing is occurring.	O	↓	This action will more than likely have a negative organizational impact as these guidelines will more than likely limit the time in which aircraft can take off from one of more runways.
Follow Explosive Siting guidelines following DESR 6055.09.	O	↓	This action will have a negative organization effect as it will add a new task to the airport’s facilities manager. If an airport already has similar guidelines in place, they may be changed retroactively to allow the RETCs to be a part of their guidance.
Store exotic fuel types on airport property.	N	↓	This action will have a negative natural resource impact as toxic and potentially dangerous chemicals will be introduced and stored at the airport.
Coordinate fuel delivery and storage with a space industry company / entity.	N	↑	This action will have a positive natural resources impact as the coordination between the space entity and the airport may result in a lesser amount of fuel or toxic material being needed to be brought in. Shared resources can lower overall need.

Design means of measuring emissions to ensure that the local area is not too negatively impacted by testing.	N	↑	This action will have a positive natural resources impact as it will keep the airport and space entities alike accountable for how and when they burn their exotic fuels. Through aerial and ground / water tests, the airport will be able to report accurately if the RETC testing is actively impacting the environment.
Form partnerships with either space industry startups or nearby university engineering programs.	S	↑	This action will have a positive societal impact as it will foster connections within the airport's community. These partnerships may lead to greater and grander investments down the line.
Create guidance rules with the local municipality due to increased noise during engine test fires.	S	↓	This action will have a negative societal impact as it will undoubtedly run into some social backlash during its inception. In the long run however, these guidelines will lay the groundwork for the airport to operate RETCs within the parameters outlined by the local authority.
Brand and market spaceport operations in order to increase tourism at the airport and local area.	S	↑	This action will have a positive societal impact as it will introduce space tourism into the local economy. Small ventures at first may prove fruitful and be scaled up to full scale attractions if both the airport and space entities take interest.

6. Interaction with Airport Operators

6.1 Interviews of Airport Operators

Adam Baxmeyer, the current airport manager at Purdue University's Airport (KLAF), played an important role in helping the team understand what would incentivize a GA airport to adopt the guidelines of a project like the CSAVO Initiative. During the course of a two part interview, Adam described how it would be important for any program looking to sell itself to GA airports, to make sure to highlight in what ways the program would increase revenue in categories that appealed most to GA airports. While landing and parking fees do generate some revenue, the team learned from Mr. Baxmeyer that the best way to generate long term revenue and gain the interest of prospective airports was to focus on land leasing and long-term hanger rentals. This allowed the team to narrow its scope down to which kinds of services CSAVO could provide for prospective clients. All ideas that came from this discussion were a result of the team's personal understanding of the interview.

6.2 Interviews of Space Industry Experts

Andrew Nelson, currently the FAA policy advisor to Spaceport Camden in Camden, Georgia as they attempt to gain their spaceport license from the FAA, played a pivotal role in helping guide this proposal. Throughout three different interviews, two in person and one over the phone, Nelson helped in determining which kinds of spaceport operations can and cannot be conducted for little to no initial investment. He discussed how acquiring a full spaceport license from the FAA was a costly and time-consuming venture and warned that if a GA airport did not have a well-funded backer for such a venture, then it would be practically impossible for a GA airport to acquire a license. This caused a major shift in the writing of the CSAVO Initiative Guidelines. Nelson would go on in later interviews to identify that test cells designed to test experimental rocket engines for either space industry startups, universities, and or government contractors would be a low up-front cost means of getting an airport in spaceport operations. From these talks, the team was able to devise a series of ideas that would go on to form the basis for CSAVO. All ideas that came from this discussion were a result of the team's personal understanding of the interview.

7. Impact

The Airport Cooperative Research Program helps bring new and innovative ideas to the National Airspace System Infrastructure. The ACRP Request for Proposal was very concise and informative, which allowed our team to easily address the competition needs. This competition gives students a chance to explore ideas that may not be directly applicable to their previous education experience, which is an incredible opportunity to learn about related topics and apply them to background knowledge. These new ideas can help make airports more useful to the National Airspace System, as ideas such as the CSAVO Initiative allow airports to expand their services to incorporate emerging technologies to generate additional revenue. The ACRP competition gives students a chance to learn about and possibly utilize these new technologies to improve current operations, or in this case, use current technology to help generate additional revenue for an airport in a new manner. By encouraging students to think outside the box, it allows completely novel ideas to be generated. However, this also requires students to engage with industry experts to get professional opinions on these emerging ideas. The CSAVO Initiative is a novel idea to help generate revenue and is an avenue to generate significant interest in engineering and technology fields at airports. Rocket engine testing requires highly trained and skilled individuals. This initiative would help make highly qualified individuals more interested in working at smaller airports which could bring high paying and high skilled jobs into communities that may not have had them previously.

Before an airport can implement CSAVO they must first identify if this is a viable option for revenue generation based on that airport's location, size, and other related factors. If it is found to be a viable option, the airport must get permission from local municipalities and any other regulating agencies that may have an objection to conducting these operations. At this point the airport must obtain funding via internal and/or external sources, and then begin planning for the location, required materials, construction, and other related aspects for the test cell. Most of the funding would come from external sources, which reduces the risk as well as the financial burden of the CSAVO Initiative on the airport. Developing a Safety Management System is a very important step in preparing the test cell, as the safety of workers must be a priority from the early planning stages. Once the cell is constructed and ready for use, it can be leased to universities or companies. We estimate that the space could be leased for roughly $8,000 per month, which comes to $96,000 a year just to lease the space. The company or university leasing the cell would also have to pay the utilities, which are estimated to be around $10,000 for the year. This brings the total revenue potential to $106,000 a year. The increasing need for test cells in the growing aerospace industry, alongside the lowered potential risk for the airport, makes this an affordable and viable business venture to generate additional revenue for the airport that has a high potential of being successful.

8. Conclusion

The implementation of the team's CSAVO Initiative at any GA airport with the capacity to support such space operations is desirable from an economic, sustainable, organizational, and social standpoint. The team's case studies and analyses showcase that these claims are true, and that CSAVO will have a lasting impact in each of the above-mentioned categories. Through a low cost investment that pays for itself within the first month and a half of operation, CSAVO aims to be a profitable experience for the airport overseeing the operation, but also to bring outside investment and economic interest into the airport's surrounding community. By investing in one's local economy, a CSAVO airport will become the beacon for space research in its area. Although the RETC will introduce more exotic fuels into the local ecosystem, a CSAVO airport will be able to safely and accurately measure and control their emissions and waste management. Finally, through the introduction of small scale space operations into areas that lack any sort of access to space technology, CSAVO aims to allow the rapid expansion and growth of not only the GA airport investing into the initiative, but into the greater space economy as a whole.

Appendix

Appendix A - List of Complete Contact Information

Name: Mr. Cooper Grant Burleson
Email: cburleso@purdue.edu

Name: Mr. Jason Endsley
Email: jendsle@purdue.edu

Name: Mr. Jack Green
Email: green248@purdue.edu

Name: Dr. Mary E. Johnson
Email: mejohnson@purdue.edu

Appendix B - Description of University

"Purdue University is a vast laboratory for discovery. The university is known not only for science, technology, engineering, and math programs, but also for our imagination, ingenuity, and innovation. It is a place where those who seek an education come to make their ideas real — especially when those transformative discoveries lead to scientific, technological, social, or humanitarian impact.

Founded in 1869 in West Lafayette, Indiana, the university proudly serves its state as well as the nation and the world. Academically, Purdue's role as a major research institution is supported by top-ranking disciplines in pharmacy, business, engineering, and agriculture. More than 39,000 students are enrolled here. All 50 states and 130 countries are represented. Add about 950 student organizations and Big Ten Boilermaker athletics, and you get a college atmosphere that's without a rival" (Purdue University[1], 2019, p.1).

"Purdue University's School of Aviation and Transportation Technology, one of six departments and schools in the Purdue Polytechnic Institute, is recognized worldwide as a leader in aviation education. All seven of Purdue's Aviation and Transportation Technology undergraduate majors are world-class educational programs" (Purdue University[2], 2019, p. 2).

"The mission of the School of Aviation and Transportation Technology is to prepare the next generation of leaders and change agents for the transportation sector. The School of Aviation and Transportation Technology will be the recognized global leader in aviation technology education through excellence in faculty, students, curricula, laboratories, and mutually beneficial partnerships" (Purdue University[3], 2019, p.1).

Appendix C - Description of non-University Partners

For this project, there were no non-university partners.

Appendix E - Evaluation of Educational Experience

Students - Cooper, Jack, and Jason

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

Yes. The team agrees that this competition did provide both a meaningful and fulfilling learning experience for all persons involved. While everyone on the team had previously submitted a proposal of some kind for either academic or personal pursuits, no one on the team had ever attempted to respond to an RFP while all working remotely. This was of course not the case at the beginning of the semester; however, as both our university and the world reacted to COVID-19, the way in which our work was performed on this response changed drastically.

2. What challenges did you and/or your team encounter in undertaking the Competition? How did you overcome them?

The whole team feels that we gained a full understanding of the pain and benefits that online cooperation on a large-scale project takes on as it moves through development. Switching from in person meetings to online only post COVID was by far the biggest challenge that the team faced; however, we still made it to the finish line. We all feel that we have all learned much more from this experience attempting to complete the response before the self-imposed April deadline while simultaneously working remotely, than we would have if this kind of challenge had not been put on us.

3. Describe the process you or your team used for developing your hypothesis.

At its core, the team wanted to bring the space industry into the competition. Even before the team had sat down and looked at the various categories in which the ACRP had challenges, the team knew that we wanted to develop something related to space operations. While the original hypothesis would change from the gargantuan task of securing GA airports FAA Spaceport Licenses, a costly and timely endeavor, to what is now the CSAVO Initiative, still that thread of space remains. Once we had reorganized down to a more manageable feat of introducing testing sites into GA airport land, we set out to ensure that all airports who wished to follow CSAVO guidelines could. The result was an initiative that was cheap and set the stage for later term development in the space sector.

4. Was participation by industry in the project appropriate, meaningful, and useful? Why or why not?

Yes. Participation by industry was paramount in the final product that is CSAVO. It was both industry experts that helped the team realize that our initial goals were far too lofty and would never truly generate a profit for the GA airports. As a result, the pivot to low-cost ventures was a direct result from our conversations with industry heads. It is therefore the opinion of the team that participation of industry was most definitely appropriate, meaningful, and very useful in our pursuit to respond to the ACRP's RFP.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

The team feels that perhaps the best learned skill from this whole endeavor, as mentioned above, was working on a large-scale project remotely. The ability to develop, orchestrate, and deliver a 40 pages response to an RFP all while working across multiple time-zones led to the development of useful skills which will benefit us all in the workforce and beyond. Similarly, the knowledge gained while working on this project will also hold future worth. The ins and outs of spaceport licensing, the regulatory aspects of aerospace engines testing, and the ability to write and respond to RFPs all will be knowledge that we take with us into our futures.

Faculty – Dr. Johnson:

l. Describe the value of the educational experience for your student(s) participating in this competition submission.

Spaceports as a way to improve the economic sustainability of airports across the country. This idea was so different from what we had done before, that the students were not sure I would let them use that topic. Surprise! With team members from very different undergraduate educational backgrounds, this team succeeded under trying circumstances in the world and at Purdue. For students in my aviation sustainability course, this competition has great value primarily due to the challenges and topics coming from real airports, the interactions with industry experts, and the structure of the project report being a proposal in response to the competition guidelines that mirror a request for proposals. This competition encourages the students to do deep dives into not only what to do to improve airports, but also to quantify the risks, costs, and for my students, to describe the impact that these projects may have on airport sustainability. One key to the educational value of the experience is the interactions with industry experts from airports, airlines, and consultants. The students have had much fewer interactions due to the stresses placed on the air transportation system since late January. When the industry interactions did occur, this energized the team as they realized that these airport challenges are truly important and that with some tweaking or changes, their proposed solution may become a better solution.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

Yes. This group used data collection and analysis, and heavy use of federal and state regulations to propose ways that airports become engaged in the expanding world of commercial space, even if the airport did not want to allow take-off and landing due to increased expenses, regulations, and capital funding needed to improve the airport. This is a graduate level applied aviation sustainability course where the airport improvement projects are evaluated on the sustainability analysis, risk analysis, and benefit/cost analysis.

3. What challenges did the students face and overcome?

This group first faced the challenge of figuring out what is a spaceport, how are they regulated, what are ways that airports can participate while not allowing both take-off and landing. The next challenge was finding experts to speak with and find data. There are Spaceports now in the US, but there are not many. Data is also limited, especially compared to the vast amounts of data for Part 121 operations and the commercial airports. The corona virus also changed the way the team communicated with each other, me, and the industry experts. The students overcame these challenges and produced a high-quality project. I am very proud of them.

4. Would you use this competition as an educational vehicle in the future? Why or why not?

Yes. This competition inspires students to learn more deeply, to seek out regulations and guidance, to read the available literature, and to learn how to learn - skills needed for the rest of their careers.

5. Are there changes to the competition that you would suggest for future years?

Yes, consider including a sustainability analysis as a required section of the report and not requiring the paper copies of the report to be sent.

Appendix F - Work Cited

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