2019-2020 ACRP UNIVERSITY DESIGN COMPETITION

Aircraft Portable Stair and Accessible Loader (PSAL)

(January 2020 – April 2020)

Design Challenge: Airport Operation and Maintenance: Challenge K.

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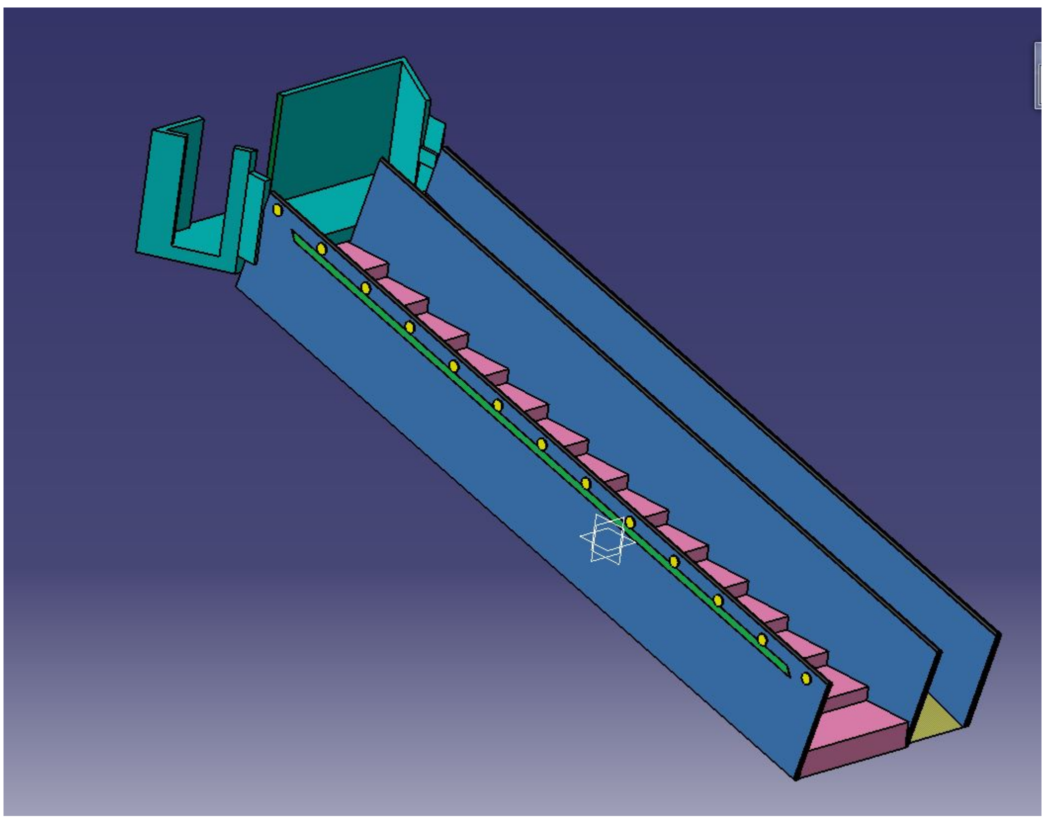

CAD credit: Yuwei He

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Executive Summary

This report presents an innovative solution to the ACRP University Design Challenge 2019-2020, specifically in the Airport Operation and Maintenance Challenge. The team's solution addresses challenge K: "Operation and maintenance procedures to enhance sustainability and resilience at airports". Enplaning and deplaning of aircrafts is one of the highest frequency functions for air carriers to operate and for passengers to participate in; limited resources are targeted at it. There are many incidents at airports that leave passengers injured and, in some cases, result in the loss of life when using aircraft stairs. Many low risk incident reports go unfiled industry wide.

Addressing the root causes of high-risk events will provide enhanced sustainability and resilience at airports, as showcased in the safety risk assessment, cost-benefit analysis, and sustainability assessment in this project. Additional benefits to the innovative design are providing portable stairs that meet the ever growing and expanding narrow body fleet, which would provide advantages to airports serving a wide range of carriers and aircraft styles in a single day of operations. The conceptual design presented has a benefit/ cost ratio of 1.81. It provides a solution to better serve the wide range of airport customers. The team addresses safety concerns of passengers boarding aircraft via stairs while complying with the Americans with Disabilities Act (ADA), Federal Aviation Administration (FAA), and Occupational Safety and Health Administration (OSHA) regulations and providing a positive customer service experience to passengers.

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Problem Statement and Background

Problem Statement

Enplaning and deplaning of aircraft is one of the highest frequency functions for air carriers to operate and for passengers to participate in; limited resources are targeted at it. There are many airport incidents that leave passengers injured and, in some cases, result in the loss of life when using aircraft stairs. Many low risk incident reports go unfiled industry wide. This report presents an innovative solution to the portable aircraft stairs that addresses these concerns.

In addition to the important safety requirements, there is an ever-growing need for sustainable, resilient, and portable aircraft stairs that are operational at all sized airports serving a wide range of aircraft types. These stairs would also increase efficiency and safety measures. The demand for these aircraft stairs is created by operational root causes ranging from airport capacity, unplanned diversions, size of operations, and passenger injuries.

Another challenge facing airports and air carriers is the storage of aircraft stairs. There is limited real estate on the ramp and the stairs need to be placed in a location where it is easily accessible to meet the demands of on-time performance. With fewer stair types, there is less demand on ramp real estate and the airport may serve multiple aircraft types. This is especially important during unusually high demand or emergency operations.

Background

Traditional portable aircraft stairs relieve certain operational pain points, but these existing stairs units do not address all safety concerns. Major events related to portable aircraft stairs occur infrequently but the severity of the outcomes of these events lead to hospitalization and even fatalities. An example of this is on "July of 2010, a 61-year-old woman slipped while disembarking a plane using portable stair in Cancun, Mexico. The woman lost her balance on the seventh step and fell to the bottom of the stairs. She hit her head and died from the sustained injury" (Daily Mail Reporter, 2010). Nor does the traditional stairs unit address storage limitations faced at many airports. Figure 1 shows passengers deplaning with their luggage in hand.

Photo Credits: Ashley Rader

Figure 1 - *Passengers Enplaning with Luggage via Attached Stairs*

Summary of Literature Review

Evolution of Passenger Boarding Equipment

"In 1997, the FAA mandated new regulations requiring easier, more dignified access to commercial aircraft" (Keith, 2009, para. 1). The boarding equipment was initially introduced targeting to benefit passengers with special needs as well as every single passenger. The first ramp prototype included a 15-foot, straight platform with an approximate 15 to 19 degree slope that went from the ground to the aircraft door (Keith, 2009). In the late 1990s, four regional airlines, SkyWest, Horizon, America West and Comair, brought a standardization of regional express ramp. Some safety features were added to accommodate different models of CRJs and replacing the ramp material with aluminum to reduce weight (Keith, 2009).

To customize different carriers' need, Horizon became the first airline not allowing passengers to use the stairs on a CRJ. In 2004, SkyWest developed a swinging type ramp called the "swinging gate ramp" (Keith, 2009, para. 4). The SGR is designed for a "drive in - pushback" operation and allow passengers to board and deplane without traversing aircraft steps. The height and degree of slope both can be customized based on the needs of the airport or airline customers (Keith, 2009). The SGR can be set at the CRJ 700/900 height due to the length of the upper bridge; and for the CRJ 200 and ERJ 135/145 due to the lower height without changing settings (Keith, 2009). This helps to eliminate any need for hydraulic lifts and saves time to deploy Ground Service Equipment (GSE). However, not every airport can use a swinging gate ramp or jetway even now, especially smaller airports.

Aircraft Boarding Requirements

Chapter 2 of the *Advisory Circular (AC) number 150/5220-21C* outlines the requirements and standards that are regulated by the Federal Aviation Administration (FAA) which include recommendations for aircraft boarding (enplaning and deplaning) from the following (FAA, 2012).

- Society of Automotive Engineers (SAE) *Aerospace Recommended Practice (ARP) 1247, General Requirements for Aerospace Ground Support Equipment (Motorized and Non-motorized)*
- U.S. Access Board's *Technical Assistance for ADA Accessibility Guidelines (ADAAG) for Transportation Vehicles*

- ADA and Architectural Barriers Act (ABA) *Accessibility Guidelines for Buildings and Facilities (U.S. Access Board, 2004)*.

These requirements and standards listed in the AC are minimum requirements that shall be executed and enforced. The AC also addresses Human Factors components in addressing the need to have:

> "all boarding equipment must be easily operated by personnel possessing no special skills and given minimum training on the equipment. Operation must also be easily accomplished by personnel within the range of anthropomorphic sizes, as defined by the 5th percentile Asian female on the lower limit, to the 95th percentile Caucasian male, on the upper limit. Unless otherwise specified, and wherever applicable, the standards of Federal Aviation Administration (FAA) HF-STD-001 must be followed" (FAA, 2012, p. 3).

General design requirements address a range of items such as platform size with space clearance, flooring, gaps and change of levels, handrails, ramps, loading capacity and installation and acceptance standards.

Existing Solutions

The team found several passenger boarding stair types used by general aviation and commercial airports. The existing solutions focus on having stairs that are compact and that make it possible to fit different aircraft in the airport operation. However, the current stairs have areas that may be improved for safety, sustainability concerns, and ground maintenance. Three existing solutions are explored in this section.

The AS228 Aircraft Boarding Staircase by LIFT-A-LOFT Corp. (LIFT-A-LOFT, n.d.)

The AS228 aircraft boarding staircase can be mounted on a heavy-duty truck. The stairs are mounted to the truck and can be retracted and extended. This solution focus on having the stairs to be able to fit multiple different fleet of aircraft and the stairs to be stored easily. One significant drawback for this solution is that the stairs will be left outside and will be exposed to extreme weather and UV lights which can lead to rust and corrosion. The truck that the stairs are mounted onto also run on gasoline, which does not meet the airport sustainability goal.

FrontBull Ambulift by Bulmor Industries GmbH (Bulmor Industries GmbH, n.d.)

The FrontBull Ambulift is a compact electrically driven passenger boarding vehicle that is designed to meet the needs of regional and small airports. The stairs are stored inside the vehicle to protect the passenger boarding stairs from getting damaged from the extreme weather or other foreign damage. This solution reduces the mobility for passenger boarding, improves the sustainability, and makes the boarding process more environmentally friendly. However, this solution can be costly. The amount of space the unit occupies on the ramp depends on the aircraft types serviced.

PS-813PAR Towable Passenger Stairway by Stinar Corp. (Stinar, 2017)

This is another popular aircraft boarding stair. It is not attached to any vehicle and it can fit with different aircraft types. The stairway height can be adjusted by the hydraulic power pack on the stair. The structure of the stair frame is fully aluminum to secure the stability and make the stairs free from corrosion. The stairs itself is not attached to any vehicle and it can be easily connected to a tug or other type truck that can possibly hold the load and the weight to the stairs.

Safety Reports on Existing Stair Solutions

During our research, our team wanted to find the most common ways that passengers are injured during boarding and deplaning. Falls on the boarding stairs have potential to be serious. Examples of different kinds of common hazards include elevation differences between the stair/platform and the aircraft door and excessive horizontal gaps between the platform and the aircraft door threshold (Lykins, 2019). This is typically associated with trapping feet and losses of balance. Another common problem experienced with boarding using aircraft stairs is variation in the stairs themselves (Lykins, 2019). Our brains work by automatically learning and recording the distance of each step; if one step has a distance that is off, a tripping hazard is created (DiPietro, 2018). Finally, there are hazards associated with the railing of the stairs. The railings sometimes have the bottom open, leading to a space where a child or a person's cane could fit though or get the passengers foot caught. Often the rails are lower than they should be to accommodate the varying height of humans' centers of gravity. With all these hazards, it is easier to understand that injuries happen, sometimes even death.

There have been multiple incident reports with aircraft boarding stairs through the years. It is difficult to quantify the number of incidents per year because they often go unreported by passengers and airlines. From the team's research it is estimated that around 2 fatal accidents occur per year (Lykins, 2019).

At London Stansted Airport in August 2010, a child fell between the guardrail and the stair surface platform. The child, Olga, reached the top of the stairs, then turned to her mother which had her hand full, and leaned back. Olga lost her balance then fell through the guardrail gap from the top of the stairs (Press Association, 2010). There were four previous reports of similar incidents with children and portable aircraft stairs. This led to the issuing of a special airworthiness information bulletin, the release of safety bulletins, and revision of the Boeing 737 flight attendant manual (FAA Safety Bulletin NM-07-47, 2010).

In July of 2010, a 61-year-old woman slipped while disembarking a plane using portable stair in Cancun, Mexico. The woman lost her balance on the seventh step and fell to the bottom of the stairs. She hit her head and died from the sustained injury (Daily Mail Reporter, 2010). More recently, on June 24th, 2017 an elderly man died from fall related injuries after deplaning using portable aircraft stairs at Ben Gurion Airport in Israel. The man, who was in his 90s, struggled with balancing his baggage while descending the stairs, fell then hit his head (Staff, 2017).

Similarly, on May 26th, 2017, a turbo-prop aircraft landed at Cork Airport in Ireland. After the aircraft had taxied to its gate, the portable stairs were brought to the aircraft. A woman fell from the top step to the ground and sustained several serious injuries including head injuries and a broken shoulder (Air Accident Investigation Unit Ireland, 2017). An investigation was conducted that pointed out "the time a passenger spends on the steps is a time of higher risk of injury than the remainder of their flight" (English, 2017). The article also pointed out that it is hard to assess the full extent of injuries caused by falls on portable aircraft stairs because not all causes have been reported by the passenger, airline, or airport.

Problem Solving Approach

To choose the design requirements our group wished to pursue, we used our interactions with industry experts, the individual expertise of the team members, and discussions with our peers in class. Two of the team members have an FAA Airframe & Powerplant certificate, and have experience at our airport KLAF, with stairs and other units. Another member has experience with safety from a major airline and at an airport. That combined helped us determine our design criteria using the literature review. These criteria helped us decide which improvements to make to a commercially available aircraft stair unit.

The team felt that the biggest opportunity for design improvements is to attempt to mitigate the likelihood or severity of potential accidents. Portable aircraft boarding stairs have been linked with passengers suffering serious injuries and even death. Passengers are required to carry their luggage using the portable stairs that may already feel small or unstable. This may lead to passengers falling, losing their balance and injuring themselves and others. Another major pitfall of portable stairs is that they are not easily handicap accessible. The elderly passenger population, handicapped passengers, and parents with strollers and young children are forced to a haul their walkers, wheelchairs, and strollers up the portable stairs, and in some cases must wait for a special wheelchair loader to be brought over to the aircraft to load the passenger.

After deciding on criteria for improvements, we use a table to indicate the initial design needs and wants, and the categories we wanted to focus on. The design needs and wants are depicted in Table 1.

Table 1

Design Needs and Wants for Portable Aircraft Stairs

Design Needs and Wants		Reference
Safety	Must improve on safety by lowering the severity and frequency of accidents linked to portable stairs.	FAA Advisory Circular 150/5200-37
Weight	Should be kept light so the solution can still be mobile.	Team's Want based on equipment needs for mobility
Cost	Must show obvious benefits despite cost and have an inexpensive acquisition cost.	ACRP Cost-Benefit Analysis
Sustainability	Must improve on the environmental impact of the original design's energy consumption, operational impact by being more accessible and quicker in operations, economic impacts by saving time on turnarounds, thus opening more gates, and finally social impacts by eliminating potential for injury or death.	EONS Framework Evaluation EPA
Federal Regulations	Must meet all OSHA, ADA, and FAA Requirements for boarding and de-boarding an aircraft.	OSHA, ADA, FAA Advisory Circular (AC) number 150/5220-21C
Visible	Be visible on the ramps to all personnel, ground equipment, and aircraft to mitigate the likelihood that something would run into and damage the stair unit or cause injury.	Team's Want
Accessible	Be accessible to all type of passengers and accommodate passenger baggage	FAA HF-STD-001
Fleet - Type	Be able to service a large portion of the narrow-body fleet type served by the airport.	Team and airport manager's want
Time	Must not take longer to enplane and deplane passengers than the current design of attachable chair design.	Team's Want

Pugh Matrix: Choosing a Design

To potentially keep the design cost and production cost lower, the group first needed to choose an existing base design of Portable Aircraft Stairs to improve. For this, we used three criteria: the widely used stair design, stairs with a potential for improvement, and stairs with reported safety incidents. Finally, we wanted to choose a design that would be most likely to help our group achieve the design improvements that address the criteria. The team needed to focus on different ways of addressing the accessibility issue. We came up with many ideas, but we had to choose the most feasible and sensible improvement approaches.

Again, our design needs and wants came into play and we had to decide on ways we wanted to achieve each requirement. We came up with a few base designs that had potential for improvement to address the issues we decided to focus on. The Pugh Matrix seen in Table 2 was used to help the team to decide which design concepts were better, neutral or worse than each other, in accordance with our design criteria.

Table 2

Pugh Matrix - Improved Design Concept

		Concepts		
		Large, Multi-part Boarding Ramp	Scissor-Lift Type vehicle	Portable Stairs with Built in Belt Loader
Criteria	Safety	Baseline	-	+
	Weight		-	-
	Cost		N	+
	Sustainability		N	+
	Federal Regs.		N	N
	Visible		N	N
	Accessible		N	+
	Fleet - Type		+	+
	Time		-	+
	Sum of Positive	0	1	6
	Sum of Neutral	0	5	2
	Sum of Negative	0	3	1

Through utilizing the Pugh Matrix, we were able to see a clear forerunner for our base design. The idea of a set of portable stairs mounted on a tug/ truck (as commonly seen around airports) with a built-in belt loader attachment had the most positive impacts on our criteria with only one negative impact from the baseline design. The common stair design can be seen in Figure 2 and a common baggage loader can be seen in Figure 3.

Photo credits: Ashley Rader

Figure 2 - *Example of one type of Portable Aircraft Stairs*

Photo credits: Ashley Rader

Figure 3 - *An Example of One Type of Baggage Loader with Stroller and Car Seat*

From the Pugh matrix the group was able to choose the aircraft portable stair and accessible loader, which the team elected to call PSAL. This idea incorporated both the traditional stair design with a belt loader to accommodate baggage in one unit. Details of the design ratings thought the Pugh matrix are explained in this section and a discussion of design criteria is presented.

Aircraft Portable Stair and Accessible Loader (PSAL)

Safety: The group believed the belt loader design had the biggest potential for improvement of safety. Not only did the team want to raise the handrails, fill in the bottom guardrail, and improve visibility; but also, the addition of the belt loader means that passengers can have their hands free of the baggage as they board the aircraft.

- This gave a positive rating.

Weight: The Belt Loader design would have a weight similar to a large-multipart boarding ramp but less than a hydraulic type scissor lift vehicle. We believe the PSAL solution would weight more than the base portable stair unit. However, due to the Covid-19 pandemic, our access was restricted to CAD programs and we were not able to conduct a weight analysis. Based on our experience at KLAF, the team believed that although the PSAL would be a heavier solution, it would still be a mobile solution.

- This led to the only rating that was negative.

Cost: Although the solution may have a higher initial acquisition cost than other solutions, it would offer a cost-benefit analysis that had obvious benefits over solutions.

- This led to a positive rating.

Sustainability: The belt loader/ truck can be run by electric power and alternative fuels. The operations would run quicker and smoother and be able to serve all types of people and airports. The benefits of the solution far outweigh the costs, and the large increase in safety improves the social impact of the unit.

- The led to a positive rating.

Federal Regulations: This criterion is to meet all OSHA, FAA and ADA requirements for boarding and de-boarding an aircraft gave a neutral rating across the board because we would be able to meet the requirements on all designs.

- This led to a neutral rating.

Visible: The team wanted to add lights to the final solution regardless of base solutions to improve safety and make it more visible. The lights that would be added would be powered by small solar panels, much like lights typically found in a garden. This ensures that they are not too expensive, and not too bright to where they would bother pilots.

- This again gave a neutral rating.

Accessible: One of the largest areas we wanted to address was the accessibility of the design. This includes being accessible for older passengers with walkers and wheelchairs, handicap passengers, and accessible for passengers with children and strollers/ car seats. For this, the belt loader gave big improvement.

- This led to a positive rating.

Fleet-Type: The belt loader would be able to serve a wider fleet-type because it would be adjustable, unlike the multi-part ramp which is set to be one size and not adjustable.

- This also gave a positive rating.

Time: The belt loader takes less time to set up than the multi-section ramp and would take less time to load all the passengers than a scissor-lift type of vehicle.

- This led to a positive rating.

Safety Risk Assessment

The FAA intends to implement the use of Safety Management System (SMS) at U.S. airports to complement existing airport safety regulations in 14 CFR Part 139 (FAA, 2013). FAA defines Safety Management System (SMS) as "the formal, top-down business-like approach to managing safety risk. It includes systematic procedures, practices, and policies for the management of safety (including safety risk management, safety policy, safety assurance, and safety promotion)" (FAA, 2019, p.1).

A risk is the chance of loss or injury measured in terms of severity and probability. The FAA *Advisory Circular 150/5200-37* suggests using a predictive risk matrix to assess and analyze the risks, as shown in Table 3. The likelihood and severity are evaluated separately and divided into five levels respectively. Based on the assumption that risk is the product of likelihood and severity, a final score is provided in each category to evaluate the risk level. The safety matrix classifies all potential hazards into three risk levels in general based on the final score: low risk, medium risk and high risk (Timmons, 2016).

Table 3

Predictive Risk Matrix (based on Advisory Circular 150/5200-37)

Low Risk: 0-4.99 Medium Risk: 5-10 High Risk: 11-20	**Severity**	**No Safety Effect**	**Minor**	**Major**	**Hazardous**	**Catastrophic**
Likelihood	Level	1	2	3	4	5
Extremely Improbable	1	1	2	3	4	5
Remote	2	2	4	6	8	10
Probable	3	3	6	9	12	15
Frequent	4	4	8	12	16	20

While the aircraft portable stair and accessible loader (PSAL) is designed to improve the safety of passenger boarding and deboarding procedures, latent hazards still exist and bring considerable risks. Some notable situations are listed in Table 4, such as falling luggage on loader, slippery steps on stair, and human errors. Most of the situations result in low risks.

Table 4

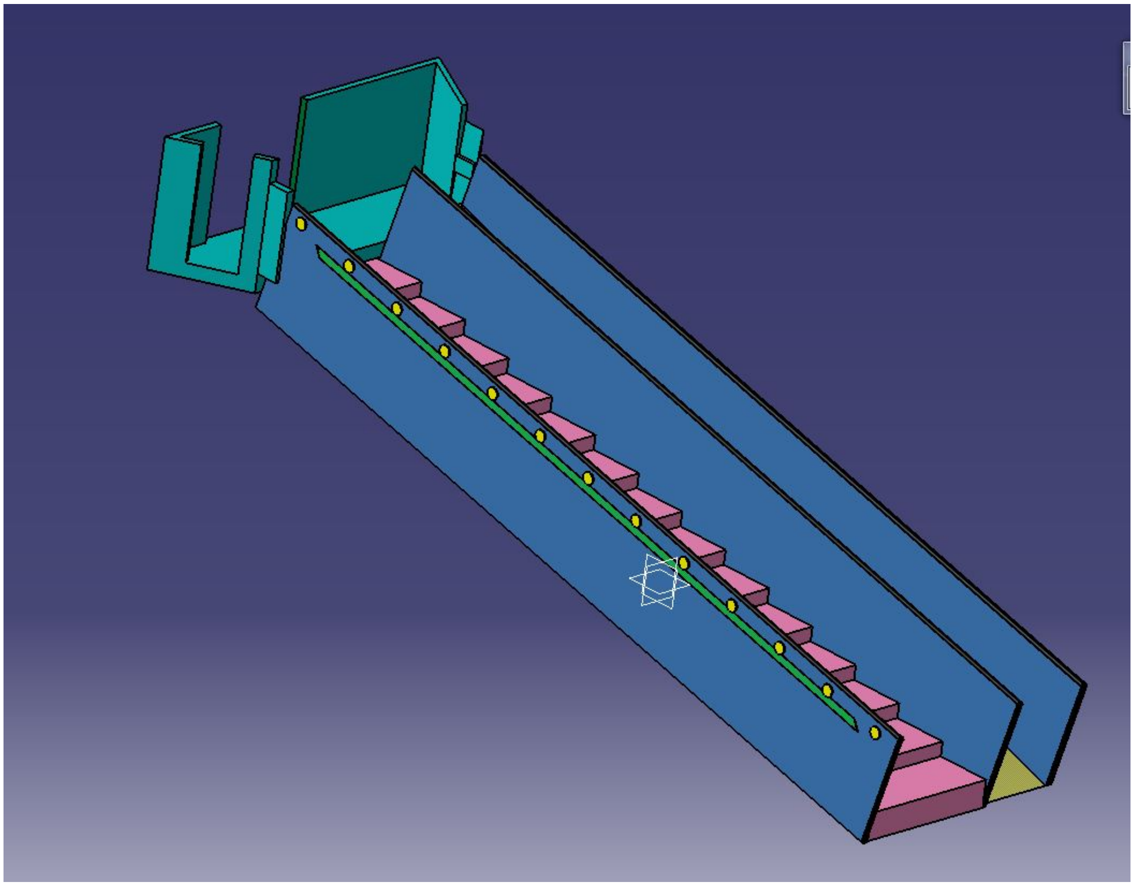
List of Potential Risk Assessment

Situation		Likelihood	Severity	Risk	Possible Solutions
1	Poor lighting	1	2	2	Add small lights on the handrail powered by solar panels
2	Falling luggage on loader	1	2	2	Have the truck driver or an assistant control the belt speed
3	Slippery steps on stair	2	2	4	Use caution signs when operating in wet condition
4	Disorder on luggage pickup near the aircraft door	2	2	4	Posit an assistant on boarding platform to help luggage pickup
5	Power outage	1	5	5	Backup power
6	Impact of weather on operations, such as strong winds, snow conditions	2	4	8	Follow the stair design limits and decide if operates in severe weather
7	Human errors including poor maintenance or incorrect operation	3	4	12	Regular training and maintenance

Note. Scores for likelihood, severity, and risk level are evaluated according to Table 3.

Description of Idea

Our proposed solution is the aircraft portable stair and accessible loader (PSAL) shown in Figure 4. The main changes made in the proposed design compared to traditional aircraft stairs are to address passenger safety, airport operations, and aviation sustainability.



CAD Design: Yuwei He

Figure 4 – *Proposed Solution, the Aircraft Portable Stair and Accessible Loader (PSAL)*

The stairs are to be designed based on the OSHA, ADA, and FAA standards for basic aircraft boarding procedure requirement and the safety standards as shown in Table 1. The stairs will be able to board passengers along with passenger's carry-on baggage at the same time. The design is to widen and separate the traditional stairs in half and have one side for passenger boarding and the other side as a conveyor belt. This is to give the passengers a hands-free experience while boarding the aircraft so they can hold the railing, focus on climbing the stairs, balance better, and tend to children if needed.

The conveyor belt is designed to be attached to the boarding stairs so that passengers can easily pick up their carry-on items from the conveyor belt. The conveyor belt also provides convenience to those who have large carry-on items like strollers, car seats and musical instruments, and for people who require special accommodation like wheelchairs, walkers and crutches. Additionally, one ramp agent or equipment operator can be available on the boarding platform to assist passengers with boarding the aircraft and picking up their baggage from the conveyor belt. However, this is not a necessary labor input if cost is a major concern in depending on the airport and different operations. Figure 5 provides a front view of the stairs to better see the platform. Based on the information found during our literature review, the stairs will all have the same dimensions.

CAD Design: Yuwei He

Figure 5 – *Aircraft Portable Stair and Accessible Loader, Front View*

These stairs would be mounted on a vehicle that is converted to electric or alternative fuel to support towing and the belt loader. This lowers the emissions of the unit and makes it more sustainable.

The portable aircraft boarding stairs will be able to fit all the narrow body fleet. PSAL is designed to be flex-fit and fit with a wide fleet type. This allows for airports to only need one unit to service any narrow-body aircraft type, save space on the ramp, and provide easier storage of the PSAL unit. This design feature is useful in a lot of airport operations.

To increase safety and visibility; small, solar-powered lights and reflective strips were installed on the PSAL unit. This addition especially aids passengers during night boarding and making the unit visible to all airport personnel mitigating the likelihood of the unit being hit. The solar-powered lights are similar to the solar pathway lights you may see in a garden, meaning they are very compact, lightweight, inexpensive and durable. They are on the outside of the railing so passengers cannot touch the panels and hurt themselves or damage the lights. Lastly, the lights would not be so brength, that they bothered pilots on the flight deck or personnel operating other equipment in the area.

A few final design features to note is that the stairs and belt loader are separated by a solid guardrail to decrease the likelihood of passenger injuries. To avoid the need for variable speed or a bottleneck at the top of the stairs with baggage, an operator can be added to assist with the baggage and belt loader, or a manual control can be used to vary the speed of the loader by trained airport ground personnel. The stairs are equipped with traction aid to prevent passengers slipping and the stairs have slots to allow for water-run off during bad weather. The boarding platform is enlarged compared to traditional stairs, so it gives passengers more room especially when the previous passengers are still looking for their seats. The boarding platform also accommodates the ADA compliant handicap door at the top.

Industry Experts

The team interacted with four industry experts related to portable aircraft stairs. Most of the meetings were 20-45 minutes in length. These interactions ranged along different milestone points throughout the project incorporating feedback throughout the process. The team contacted the following experts:

- Adam Baxmeyer, C.M – Airport Manager at Purdue University (KLAF)
- Angela Hawk – Alaska Airlines Manager of Ground Service Equipment (GSE)
- Jeff Pittard –President of Purdue Aviation (FBO)
- Dr. Stewart Schreckengast – Graduate Faculty Member at Purdue University

Industry Experts Background Information

Each industry experts brought a large amount of information from various perspectives of the aviation industry. Which created a holistic review to the assessment of the portable aircraft stairs and accessible loader.

Adam Baxmeyer, C.M.

Mr. Baxmeyer is the airport operations manager for Purdue University Airport (KLAF). As a Purdue alumnus, he has also been the Deputy Director of Operations and Facilities for Bloomington Normal Airport Authority and the Airport Operations Supervisor for Cherry Capital Airport (Purdue University Archives, n.d.).

Jeff Pittard

Mr. Jeff Pittard is President of Purdue Aviation LLC, which is a full-service Fixed Base Operation (FBO). They provide fuel sales, aircraft maintenance, flight training, aircraft rental and aircraft sales (Purdue Aviation LLC, n.d.). With over three decades of experience, Mr. Pittard has been exposed to it all in the general aviation community.

Stewart Schreckengast, PhD, FRAeS

"Dr. Schreckengast is a member of the Graduate Faculty of Purdue University and the University of South Australia. He conducts undergraduate and graduate courses in aviation safety and security, along with applied research in airport development, safety management and multi-modal security programs. In addition to his extensive knowledge of FAA regulations for airport development and safety management, he has assisted in the development and implementation of International Civil Aviation Organization (ICAO) Annexes 1, 6, 8, 11, 13, 14, 17 and 19. He has extensive experience as a facilitator in workshops for Airport Inspections, Safety Management Systems and Security through symposiums and training conducted for MITRE/CAASD, ICAO, FAA, University of South Australia and Purdue University" (Purdue University, 2019).

Design Feedback

The information that we received from our industry experts aligned with the Advisory Circular on aircraft boarding equipment, focusing primarily on the passenger's exposure and functionality with the aircraft stairs themselves. A constant theme throughout the interviews were:

- ADA compliance
- Impacts of climate conditions on the stairs and accessible loader with enplaning and deplaning passengers at various airport locations

- Efficiency and injury reduction projected with the use of the accessible loader for passenger bags.

In general, the industry experts interviewed agreed that the proposal of the portable aircraft stairs and accessible loader addresses the safety concerns outline in the problem statement of this report.

The majority of the feedback was addressing more in-depth explanation of how the ADA compliant equipment (e.g. aisle chair wheelchairs) currently in use at airports would be complementary to the portable aircraft stairs design itself. The team considered the compliance pieces of ADA regulations but added user experience for the passengers and employees, and cost into the analysis before making alterations to the design. Ultimately with the input from our industry experts, the design incorporates a door/ solid gate on the side of the stairs (figure 4) to allow easy access to disable passenger lifts of various kinds. The door/solid gate will eliminate the need for airports or air carriers buying additional equipment to utilize the portable aircraft stairs and accessible loader. The stairs are also complementary to non –lifts design that would be able to utilize the stairs for equipment such as the aisle chair wheelchairs being manually lifted onto the aircraft.

The industry experts expressed that such a design would be useful in industry in several different situations and they believed it would positively impact the safety of passengers while enplaning and deplaning.

Projected Impacts of Design

The target market for the portable aircraft stairs and accessible loader is any sized airport that includes ground loading operations for a narrow-body aircraft fleet such as but not limited to Gulfstream jets, Leer jets, King Air jets, Embraer jets, and Canadair jets, as well as smaller Boeing and Airbus aircraft. With the stairs having limited adjustability to conform to the needs and compliance of enplaning and deplaning passengers for multiple sized aircraft, these stairs provide airports the availability to better accommodate the ever-changing needs of its customers (airlines, charters, etc.) in scenarios such as:

- Diversions
- Over-flow parking
- Limited gate space

Features embedded into the stair design provide additional benefits such as reduction of passenger injuries and equipment damage. Also, with the reduction of needed equipment provides additional ramp space and can provide increase operational efficiencies with the ability to dual board or reduce aircraft turn times by streaming the overall process.

- Reduction in passenger injuries

Utilizing the conveyor belt minimizes the need to carry the passengers' personal item up or down the stairs, freeing the passenger's hands to better use the railing and its safety features. With the additional lighting to make the stairs more visible during night operations or certain weather scenarios.

- Reduction in equipment damage

The stairs eliminate the need to have multiple stairs for the narrow-body fleet this will provide crews more experience and exposure to a signal piece of equipment.

- Additional ramp storage

With the need of having multiple aircraft stairs for a the narrow-body aircraft fleet eliminated, this will provide additional storage to the airport that could be used for other needs.

Project Meets ACRP Goals

The proposed project meets ACRP goals to improve airport operations. By improving on and the synergizing of existing aircraft portable stair, and the proposed concept design greatly improves the operational efficiency, safety and sustainability at airports of all sizes that serve a wide range of aircraft types.

Stairs and loaders used by airports serve as a significant bridge to connect ground service and the aircraft. Many studies have been conducted in recent years to optimize the passenger travel experience in airports. However, very few works focused on the boarding experience. As mentioned above, there were multiple safety incidents reported every year regarding boarding with existing portable stairs. The proposed new design improves safety, accessibility and many other functions aiming to help more passengers have a more efficient and convenient boarding experience.

This competition raised the teams’ awareness of airport problems. We talked to a wide range of airport professionals and through these interactions were able to get a glimpse at the wide range of problem solving they do in their jobs. There are benefits and career opportunities the team had not previously considered in the aviation and airport industry. The team’s awareness was generated to the benefits ACRP offers airport operations and infrastructure (ACRP Guidelines, 2019-2020).

Cost Benefit Analysis

For this project, a cost-benefit analysis is performed in order to have a complete estimation of the impact of the proposed design. The cost in this project is divided into two major components: tangible cost and intangible cost.

Benefits of the projects include increase revenue, reduce environmental impact, cost savings and in this case to reduce the number of incidents, injuries, and fatalities. The cost and benefit analysis are performed based on the guidelines from the ACRP (ACRP Guidelines, 2019-2020; Byers, 2016). The cost analysis includes two phases of development, the alpha and the Beta with Alpha being the first phase and beta is the second (Byers, 2016). After the design is completed, the intention is to license the stairs design to a certified aircraft stair provider. This provider would sell the aircraft stairs to airports and pay royalties to the designers.

Costs (Table 5, 6, & 7)

In the alpha stage, the CAD model development has the most significant amount because the designer had to come up with the original design followed by the standards and aircraft boarding stairs requirements. In table 5, the team estimated the cost of concept development if we were paid employees. The development cost is $8,600 which is shown in table 5.

Table 5: Portable Stair Concept Development

Item	Rate	Quantity	Subtotal	Notes
Labor- University Design Team				
Student efforts	$20	160	$3,200	4 Graduate students - 40 hours input
Concept CAD Modeling	$50	30	$1,500	CAD Modeling, GD&T
Safety expert	$33	20	$660	Safety requirement on airport operation
Faculty advisor	$100	30	$3,000	Project advisor
Miscellaneous	$300	-	$300	
Subtotal		**240**	**$8,660**	

The second stage (Beta) focused on the prototype development and intellectual property protection, see table 6. The conceptual sketch must be transformed into a full engineering design and tested as needed. Prototype building is necessary to conduct test and to demonstrate to potential licensees, this includes purchasing the materials needed for building the prototype and the manufacturing craftsmen labor costs. The design team plans to seek intellectual property protection to potentially license the design to a certified aircraft stairs provider. This stage is estimated cost $162,050. See table 6.

Table 6: Prototype Development

Item	Rate	Quantity (hr.)	Subtotal	Notes
Applied Academic Research	$50	-	$125,000	4 Graduate students (50%) Faculty advisor (10%). Prototype development
CAD Modeling	$50	200	$10,000	Building prototype from the concept development with detailed GD&T
Estimated Physical Prototype Construction	$40	500	$20,000	Physical prototype construction, including materials, labor cost and inspection
Safety Expert	$33	50	$1,650	Safety requirement on airport boarding stairs operation and prototype inspection
Local Travel	$100	-	$100	Local airport visits
Intellectual property protection	$5,000	-	$5,000	Intent to license this stair unit to existing manufacturers of similar units
Miscellaneous hardware and specifications	$300	-	$300	
Subtotal		**750**	**$162,050**	

In table 7, the cost to the airport to purchase and operate the stairs for a 10-year period are presented. The airport would purchase the stairs from an aircraft stair provider for $45,000, with a 10-year cost estimated total at $224,275. This cost includes the stairs product, one-year warranty, initial operating training and retraining, maintenance, and fuel.

Table 7: Airport Acquisition, Operation & Maintenance (per year) of One Stair Unit				
Item	Rate	Quantity	Subtotal	Notes
Labor - Airport Operator's Personnel & Stair Technical Support Agent				
Stair unit purchase price (Retail price)	$45,000	1	$45,000	Acquisition of one unit
Year 1 technical training material	$100	1	$100	Obtain the technical material and create training manual
Initial training cost per hour	$35	150	$5,250	Initial operation training for airport personnel
Year 1 scheduled maintenance	$1,000	-	-	Maintenance is covered under warranty on year 1
Year 1 Subtotal			**$50,350**	
Recurring training per hour	$35	75	$2,625	Training per year for 10 operators
Airport trainer cost	$50	10	$500	
Technical support agent	$800	1	$800	Air, lodging, local transportation, meals and other miscellaneous
Technical training material	$100	4	$400	Equipment training
Year power and alternative fuel supply	$6,000	1	$6,000	Estimated from (US DOE, 2017)
Yearly Maintenance and inspections year 2-10	$1,000	9	$9,000	
Recurring years subtotal			**$19,325**	**Per Year**
Year 2-10 Subtotal			**$173,925**	
10 Year total cost to airport			**$224,275**	

Benefits (Table 8)

On a daily basis, the use of the stairs will relax passengers and make boarding go smoother but may only impact gate turn-around-time a negligible amount. Additional studies using the prototype would need to be done to understand its impact on gate turn-around-time. The benefits to the airport are largely intangible, until the unthinkable happens. The thought behind the benefits to airports is the benefit in preventing the unthinkable. Benefits to the airport are shown in table 8. The main idea is that the proposed stairs have the potential to reduce injury accidents, fatality and aircraft damage. The value of a life is estimated to be $955,000, while an injury and aircraft damage are valued at $230,000 (Byers, 2016). For example, if the stairs reduce the probability by 10% of having fatal injury over a 10 year period then the prevention benefit is estimated at $95,500, [One fatality is $955,000 x 10%].This estimate is based on resources provided in the ACRP competition website (Byers, 2016). See table 8.

Table 8: Prevention Benefits to the Airport

Item	Benefits	Notes
Reduces probability by 10% of having one injury accident in 10 year	$9,550	Estimated by $955,000*10% divided by 10 years
Reduces probability by 10% of having one aircraft damaged in each of 10 years	$23,000	Estimated by $230,000*10%, for each year
Other benefits	$8,000	More gates leased; more landing fee revenue, less ramp space needed
Year 1 Subtotal	**$40,550**	
Ten-Year Total Benefit	**$405,500**	**Year 1* 10 year**
Ten-Year Total Cost	**$224,275**	
Benefit/ Cost Ratio	**1.81**	

One of the main benefits for the proposed concept is to improve the safety operation for ground ramp operation. Safety is the most critical concern for the Aviation industry. There are fewer accidents in the aviation industry compared to other forms of transportation. For the proposed concept, the idea focused on the safety improvement and better boarding efficiency. Better boarding efficiency can reduce gate turn-around-time, which could lead to increase airport capacity. The proposed design concept would potentially increase the airport revenue by increasing the ability to have more landings. The compact design of the stairs will reduce the need for ramp space, which could be used for other purposes that can possibly generate more revenue.

The benefit/ cost ratio is 1.81 which means the benefit of the proposed idea outweigh the cost. The safety analysis shows that we have made potential safety improvements.

Sustainability Assessment

The aviation industry has been evolving rapidly since the advent of flight. Since then, the industry has been on the frontlines of innovation and technology. There is a constant drive for the new and improved and for the faster and more advanced. One area that has experienced a great change is in the focus on sustainability. With this push, several key areas have risen in aviation sustainability. These key areas are commonly categorized as economic, operation, natural resources, and social sustainability. The EONS framework model come from the Sustainability Aviation Guidance Association (SAGA, 2015). SAGA bases their definition of sustainability by the Brundtland Commission, such as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland Commission, 1987). EONS is the framework used by the Federal Aviation

Administration on their Airport Sustainability website (FAA, 2019), and by the Airports Council International – North America (ACI-NA, 2020).

The sustainability analysis is integrated by comparing how the current base stair design and our stair design improves on each aspect of EONS. We expect to see the biggest improvements in Operation, Natural Resources, and Social by improving on the environmental impact, the lifecycle of the product and safety. The sustainability assessment includes safety in the Social aspect of the EONS model.

Sustainability Assessment

Economic

- PSAL allows for wider variety of aircraft to be served by the airport. This will increase the value of the airport to the community and bring more business to an airport.
- With the decrease in turnaround time, the airport can acquire more landing fees and gate leases.

Operations

- Operations will be improved by increasing the accessibility of the portable stair design. This includes being handicap accessible, accessible for older passengers with walkers and wheelchairs, and accessible for parents with children and strollers/ car seats.
- The new design will take less time to load all passenger on the aircraft making the operations run smoother and quicker.
- The design allows for a shorter amount of time needed for boarding an aircraft. That lowers turnaround time, and the time needed by employees to load the aircraft.

Natural Resources (Environmental)

- The belt loader/ truck can be powered by electric and alternative fuels to reduce the effect of emissions on the environment.
- The lights on the unit are solar-powered, lightweight, and durable.

Social

- The increase in visibility with the addition of lights to the final design improve social sustainability through making them safer for passengers using the stairs.
- There will also be a huge improvement of safety by raising the handrails and by using a solid panel below guardrail.
- The last improvement to the social impacts of sustainability and passenger safety incudes this biggest change to the design that addresses the addition of the belt loader meaning that passengers can have their hands free of baggage during loading.

Conclusion

In this design project, the proposed Aircraft Portable Stair and Accessible Loader (PSAL) is presented for the ACRP challenge "Operation and maintenance procedures to enhance sustainability and resilience at airports". One innovation of PSAL is that the combined Portable Stair and Accessible Loader would create a safer, more efficient and sustainable boarding experience not only for elderly passenger population, handicapped passengers, mothers with strollers and young children, but also for all passenger who have carry-on luggage during travel. With PSAL, passengers can be "hands free" when boarding the aircraft and pay extra attention to walking up the stairs.

The PSAL will greatly help many types of airports in many different operations. PSAL offers many benefits and improvements to operations through diversions, over-flow parking, opening limited gate space, reduction in passenger injuries, reduction in equipment damage, opening additional ramp space, and enhancing airport sustainability and resilience. PSAL allows flights to have quicker loading and unloading operations leading to quicker turn arounds times. The quicker turnaround times allow airports to conduct for gate leases and collect more landing fees. Through the cost-benefit analysis PSAL boasted a higher ten-year benefit over the ten-year cost that gave a benefit/ cost ratio of 1.81.

The team talked to several industry experts whose experience cover airport operations, airport management, as well as aviation safety management, and received great feedback to review the initial design. In addition, the team analyzed the design with a Safety Risk Assessment, a Cost-Benefit Analysis, and a Sustainability Analysis. These results demonstrate that PSAL can not only improve boarding safety, but also benefit airports from economic, operational, environmental, and social perspectives. Furthermore, the proposed boarding equipment has positive impacts on sustainability and resilience in airport operations and could be practically implemented in all sized airports in the future.

Appendix A: Contact Information

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Appendix B: Description of the University

About Purdue University (Purdue University Polytechnic Institute, para. 1)

"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's 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 rival."

About Purdue University's School of Aviation and Transpiration Technology (Purdue University Polytechnic Institute, para. 3)

"Purdue University's School of Aviation and Transportation Technology (SATT), 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."

Vision Statement (Purdue University SATT, para. 2)

"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."

Appendix C: Description of Non-University Partners

There are no non-university partners.

Appendix E: Evaluation of Educational Experience Provided by the Project

Students

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 Airport Cooperative Research Program (ACRP) University Design Competition provided a meaningful learning experience for all our group members. It provides us a great opportunity to find a problem in real world and apply our aviation knowledge and skills to give a better solution.

This three-month long project requires a lot of teamwork, creativity, industry interaction, time management, etc. Early in the design process, our team proposed and discussed several designs considering functions that we want to improve from multiple aspects. Different opinions from team members made us rethink our design, made changes, and lead to the final version in this report. Our faculty advisor and industry experts also helped us identify some potential hazards and we received great feedbacks to think about. After finalized our design, we split the work and cooperated well. Especially starting from the end of March, Purdue University transferred all courses online due to the breakout of COVID-19. Team members canceled face-to-face meetings and communicated online instead. Looking back, our team has overcome all the difficulties, and now our team are capable to develop and present a solution to an identified problem.

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

The biggest challenge our team encountered during the design challenge was dealing with changing circumstances from the global pandemic COVID-19. Things were quite different this year with many of us are stuck at home. In these unprecedented times, it was a real challenge for the team to transfer form in person meetings to other forms of communication including video calls, group chats, and communication though online documents.

Another challenge our team faced was using our very different backgrounds to come together to a common problem-solving approach and design solution. We all have different backgrounds in aviation from engineering and maintenance, management, and safety. The way each member envisioned our project was very different at the beginning and required a lot of brainstorming meetings and roundtable meeting with outside perspectives to help the team focus our ideas to one design and eliminate personal biases.

A final challenge our team faced was completing all the research, work, and design during one semester. To overcome this our team had multiple meeting a week and had to really rely on each other for support in completing each step of our process.

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

To create our hypothesis for the ACRP competition our team focused on common problems at airports that effect both suitability and safety. Each member had different experiences with multiple facets of the aviation industry. We began with having brainstorming meetings and roundtables to identify a common design our group wished to purse. The team utilized our personal experiences, interaction with industry experts and research of relevant literature review to further define our hypothesis and problem statement. Once a solid idea was formulated, the team went one step further to define criteria form our literature review of regulations and from relevant association and organizations, suggestions from our industry expert contacts, and our teams own identified criteria to define a final solution to the identified problem.

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

Participation and interaction with industry experts was imperative to the successful deign of our project. Each industry expert we interacted with brought a different unique point of view from their respective perspectives of the aviation industry. From all the information we received from them, we were able to create a meaningful assessment of the current industry solutions to boarding aircraft via portable stairs. The insight we gathered from helped us address our teams concerns in an appropriate way. Our contacts influenced our design criteria, problem-solving approach, and decision-making process. Overall, we believe the input of our contact form industry was invaluable and indispensable.

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?**

This project helped to enhance our research skills, design skills, writing skills, time management, and teamwork that is all significant to our future academic studies or professional careers. Followed by the ACRP guideline, we made a full-scale analysis on our product design including a safety risk assessment, a cost-benefit assessment, and a sustainability assessment. This project guided us how to propose a possible solution when diagnose new problem in the future, which could apply to both research and working challenges.

Faculty – Dr. Johnson

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

This group came from different parts of aviation – maintenance, operations, management, and safety. Yet, together, this group succeeded under trying circumstances in the world, perhaps their hometowns, 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 to 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 to support proposed design changes to equipment and processes. 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 overcame the challenge of communicating with each other. Each student had a different undergraduate educational background and social background. For instance, two of the students can easily envision product design changes even without drawings or photos – they learned that they need to sketch out the changes so that everyone is on the same page. The other two students may have much more experience in loosely defined, open ended questions – they learned that one must slow down and be a little more patient because the rest of the world may not see it the same way you do. They all learned that the first design they think of may not be the best design. They experienced the forming, storming, norming, and performing seen in team-focused literature and in real life teams. 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.

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