Graphical NOTAM Interface

For Improving Efficiency of Reporting NOTAM Information

April 2021

Design Challenge: Runway Safety/Runway Incursions/Runway Excursions

Challenge E: Optimizing application of NextGen technology to improve runway safety in particular and airport safety in general.

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02 Executive Summary

Runway excursions are a type of aviation incident where an aircraft makes an unsafe exit from the runway. According to the Ascend World Aircraft Accident Summary (WAAS), 141 runway excursion accidents involving the Western-built commercial aircraft fleet occurred globally from 1998 to 2007, resulting in 550 fatalities; 74% of landing phase excursions were caused by either weather-related factors or decision-making factors (Ascend, 2007). One mitigation strategy is training pilots how to interpret Runway Condition Codes (RWYCCs) to understand runway conditions. Recent developments such as NextGen and Electronic Flight Bags (EFBs) have improved the quality of weather condition reporting. However, Notices to Airmen (NOTAMs), the primary source of runway condition information and any other irregularities in airspace, are still presented to pilots in an inefficient format contributing to runway excursions and safety concerns NOTAMs consist of confusing abbreviations and do not effectively convey the relative importance of information.

The team developed an Electronic Flight Bag (EFB) user interface that provides a graphical representation of NOTAM and weather information to improve how pilots receive condition changes at airports. The graphical NOTAM interface utilizes Automatic Dependent Surveillance-Broadcast (ADS-B) to receive real time NOTAM updates. The interface was inspired by existing aviation weather displays and airport charts. The team collaborated with airport operators, pilots, and a human factors professional to develop an interface that allows for the presentation of information while minimizing the risk of misinterpretation. Additionally, costs are expected to be minimized by utilizing technologies that are already increasingly more common as the FAA's NextGen program progresses. The graphical NOTAM interface is accessible to a wide range of pilots to improve runway safety.

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03.1 Table of Acronyms

ACRP	Airport Cooperative Research Program
ADS-B	Automatic Dependent Surveillance-Broadcast
AIREP	Aircraft Report
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATPA	Automated Terminal Proximity Alert
BACF	Braking Action Computation Function
BWE	Built World Enterprise
EFB	Electronic Flight Bag
EMAS	Engineering Materials Arresting System
FAA	Federal Aviation Administration
FIS-B	Flight Information Service-Broadcast
FSF	Flight Safety Foundation
GA	general aviation
GPS	Global Positioning System
HFES	Human Factors and Ergonomics Society
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
KCMX	Houghton County Memorial Airport
KSAW	Sawyer International Airport
METAR	Meteorological Aerodrome Report
MTU	Michigan Technological University
MSpecs	Management Specifications
NextGen	Next Generation Air Transportation System
NOTAM	Notices to Airmen
OpSpecs	Operations Specifications
PIREP	Pilot Report
RCAM	Runway Condition Assessment Matrix
RWYCC	Runway Condition Code
SWIM	System Wide Information Management
TAF	Terminal Aerodrome Forecast
TALPA	Takeoff and Landing Performance Assessment
TIS-B	Traffic Information Service-Broadcast
US	United States
WAAS	World Aircraft Accident Summary
WITC	Weather Technology in the Cockpit

04 Problem Statement and Background

04.1 Background of Aviation Safety

In the aviation industry, safety is of the utmost importance; airport management, ground crew and pilots are principally responsible for the safety and security of freight and passengers. In the United States (US), the Federal Aviation Administration (FAA) is principally responsible for providing safety training courses and briefings for pilots, ground crew, and airport management. The FAA created the Pilot's Handbook of Aeronautical Knowledge to provide pilots basic knowledge of proper safety procedures. Safety, however, is not limited to the sky. According to a study by Boeing, 53% of fatal commercial aviation accidents worldwide between 2010 and 2019 occurred during the final approach and landing phases; 12% of fatal commercial aviation accidents occurred during the takeoff and initial climb phases (Boeing, 2020). One such incident that commonly occurs during the landing phase is a runway excursion.

04.2 Background of Runway Excursions and Current Mitigation Strategies

A runway excursion is defined as a "veer-off or overrun from the runway surface" (FAA, 2020). According to the Flight Safety Foundation (FSF), between 1995 and 2008, excursions were the cause of 97% of all runway accidents and 29% of all aviation accidents (FSF, 2009). Although runway excursions are typically non-fatal, their prevalence results in many fatalities worldwide. Between 1995 and 2008, 417 excursions involving commercial planes resulted in the deaths of 712 people (FSF, 2009). The most common factors resulting in runway excursions are poor flight crew decisions and weather conditions.

Around the world, several measures have been taken to reduce excursions. One such measure to reduce the severity of excursions is Engineering Materials Arresting Systems (EMAS), which is a clay-like material placed at the end of runways. Much like a runaway truck ramp, EMAS works by slowing down planes that have overrun the runway. Prior to 2009, this measure was implemented at 68 airports and has stopped planes in the US on 15 different occasions (FAA, 2009). However, the FAA found many pilots will veer off the runway instead of succumbing to the EMAS because pilots want to avoid both the cost and negative publicity associated with an EMAS excursion (FAA, 2016). EMAS dramatically reduces the severity of excursions; however, EMAS does not prevent runway excursions. There are few strategies to prevent runway excursions; most current strategies aim to mitigate their impacts. Finding efficient and effective methods to reduce runway excursions is a major goal of public and private aviation research. Other mechanisms to prevent excursions would be the safest, most cost effective option for improving safety during takeoff and landing.

04.3 Background of Conditions Reporting

On December 8, 2005, a plane at Chicago Midway Airport overran a snowy runway and crashed through a fence and into several cars, resulting in several injuries and one fatality. This accident prompted the FAA to create the Takeoff and Landing Performance Assessment (TALPA) to research methods to improve runway conditions reporting (Combs, 2009). Prior to October 2016 (FAA, 2016), pilots were standardly given Mu values, which are directly measured runway friction coefficients. This information was not intuitive to use and required different interpretation with different aircraft. Furthermore, this data was generalized for an entire runway--which is not ideal as conditions can change along the length of a runway. There are no worldwide standardized procedures for collecting Mu values, leading to a decrease in reliability. In 2016, with the help of the FAA as well as aviation stakeholders, TALPA produced a new method for reporting runway conditions: the Runway Condition Assessment Matrix (RCAM), which is seen in Figure 1.

Assessment Criteria		Downgrade Assessment Criteria		
Runway Condition Description	**Code**	**Mu (μ)** [1]	**Vehicle Deceleration or Directional Control Observation**	**Pilot Reported Braking Action**
• Dry	6		---	---
• Frost • Wet (Includes Damp and 1/8 inch depth or less of water) ***1/8 inch (3mm) depth or less of:*** • Slush • Dry Snow • Wet Snow	5	40 or Higher	Braking deceleration is normal for the wheel braking effort applied AND directional control is normal.	Good
5º F (-15ºC) and Colder outside air temperature: • Compacted Snow	4		Braking deceleration OR directional control is between Good and Medium.	Good to Medium
• Slippery When Wet (wet runway) • Dry Snow or Wet Snow (Any depth) over Compacted Snow ***Greater than 1/8 inch (3mm) depth of:*** • Dry Snow • Wet Snow ***Warmer than 5º F (-15ºC) outside air temperature:*** • Compacted Snow	3	39 to 30	Braking deceleration is noticeably reduced for the wheel braking effort applied OR directional control is noticeably reduced.	Medium
Greater than 1/8 (3mm) inch depth of: • Water • Slush	2	29 to 21	Braking deceleration OR directional control is between Medium and Poor.	Medium to Poor
• Ice [2]	1		Braking deceleration is significantly reduced for the wheel braking effort applied OR directional control is significantly reduced.	Poor
• Wet Ice [2] • Slush over Ice • Water over Compacted Snow [2] • Dry Snow or Wet Snow over Ice [2]	0	20 or Lower	Braking deceleration is minimal to non-existent for the wheel braking effort applied OR directional control is uncertain.	Nil

Figure 1: FAA RCAM (FAA, 2016)

Instead of reporting Mu friction values, the RCAM is used to generate runway condition codes (RWYCCs) between zero (0) and six (6). A RWYCC of six (6) represents a dry runway, whereas a RWYCC of zero (0) is equivalent to braking action nil. RWYCCs are reported by each third of the runway--touchdown, midpoint, and rollout--and are only generated if contaminant coverage exceeds 25% of the runway surface. If any third of the runway has a generated RWYCC of zero (0) the entire runway is closed; otherwise, RWYCCs do not inherently restrict airport operations (TALPA Data Analysis Briefing, 2017). Since the implementation of the

RCAM, Mu values are no longer reported to pilots, but are still used to downgrade RWYCCs if friction measurements are worse than what the RCAM suggests. If pilots experience braking action poorer than what the issued RWYCC suggests, pilots may issue braking action reports via pilot reports (PIREPs) to air traffic control (ATC) to downgrade RWYCCs. Runway condition reports may be accessed either by ATC or by Notices to Airmen (NOTAMs).

04.4 Notices to Airmen and Automatic Terminal Information Service

NOTAMs are text-based notices to alert pilots and personnel of any irregularities in controlled airspace. The changes in conditions and procedures reported by NOTAMs are crucial to ensuring safety during flight. Irregularities reported by NOTAMs include runway closures, runway contaminants, unserviceable navigation aids, and airspace restrictions. NOTAMs are normally issued through paper dispatches but are available in digital formats as well. In addition to paper dispatches, NOTAMs may also be reported via Automatic Terminal Information Service (ATIS).

ATIS is a continuous broadcast of aeronautical information pertaining to a particular airport and its immediate surroundings. ATIS broadcasts typically contain information regarding current weather conditions, runways in use, available approaches, and other information including runway conditions and NOTAMs. ATIS broadcasts are typically updated every hour, but may be updated more frequently if sudden condition changes warrant an update. The infrastructure required to install ATIS systems at airports is expensive, and ATIS is often only available at towered airports (AeroSavvy, 2018). ATIS Runway condition reports and NOTAMs reported through ATIS typically are not as detailed as full length NOTAM dispatches.

While NOTAMs contain critical information needed to prepare for flight, NOTAMs are safety risks themselves due to the inefficient presentation of NOTAMs to pilots. NOTAM dispatches are lengthy, consist of confusing abbreviations and do not effectively convey the importance of information. In July 2017, Air Canada Flight 759 into San Francisco International Airport narrowly avoided a collision with four other aircraft when attempting to land on Taxiway C. A report by the National Transportation Safety Bureau (NTSB) on the incident stated that the flight crew misidentified Taxiway C as Runway 28R due to the pilots flying at night and not being aware of a NOTAM that Runway 28L was closed at the time (Lau, 2018). Further review by the NTSB revealed that the pilots reviewed their NOTAM dispatches prior to takeoff and the runway closure was included in the dispatch. However, the NOTAM's placement and format in the dispatch did not stand out to the pilots; therefore, the flight crew was unable to recall the NOTAM when needed (NTSB, 2018).

The NTSB identified one of six safety issues pertaining to Air Canada Flight 759 as "Need for more effective presentation of flight operations information to optimize pilot review and retention of relevant information" (NTSB, 2018). According to the NTSB report, the inefficient presentation of NOTAMs has also affected other flight crews. The NTSB has recommended that the FAA establishes a team of human factors experts to develop a standardized solution to optimize the presentation of flight information to pilots. Despite the NTSB's recommendations to the FAA, changes in the presentation of NOTAMs have not yet been standardized.

05 Summary of Literature Review

05.1 Communication of Runway Conditions to Pilots

The primary advantage of RWYCCs is that the assigned numbers are based on objective data that reflects the actual runway conditions. This change in the FAA's reporting system solves issues with Mu values being too variabile and not correlating with aircraft performance. However, the communication of runway conditions remains problematic. During a 2017 TALPA update meeting, stakeholders gave feedback regarding the implementation of TALPA recommendations. The audience commented that when RWYCCs are reported through ATIS, RWYCCs are often reported without reporting the specific contaminants; the resulting communication delays between pilots, dispatchers, and airports make it difficult to make timely decisions (TALPA Data Analysis Briefing, 2017).

During the same meeting, the facilitators suggested that NOTAMs are the most efficient way to receive full reports on runway conditions. However, the inefficiencies of NOTAMs cause hesitance in using them to make runway condition reports. In 2020, 75% of runway excursions in the United States involving contaminated runways did not have a field condition NOTAM published (Advanced Aircrew Academy, 2021). Though the RCAM improved the runway conditions reporting methodology, the RCAM's effectiveness is limited by how the information is communicated to pilots.

05.2 Alternate Methods of Evaluating Runway Conditions

In addition to runway condition codes, other companies have attempted to improve runway conditions by removing the subjectivity of friction reports previously in use. One example is the Braking Action Computation Function (BACF), a technique developed by Airbus that generates braking action reports from landing data aircraft automatically collects. BACF began development in 2015, began testing in 2017, and is only only available for a limited selection of Airbus aircraft. The BACF adds Global Positioning System (GPS) data collected during landing to the braking reports, allowing the braking action to be specified to particular sections of the runway. BACF reports are distributed through RunwaySense, a product owned by Airbus's subsidiary company NavBlue. RunwaySense displays recent braking action reports under the section of the runway where they are applicable, as seen in Figure 3. In order to supplement the usefulness of RunwaySense, Airbus has made their BACF software free of charge on the condition that airlines share their braking reports with the RunwaySense platform (Airbus, 2020).

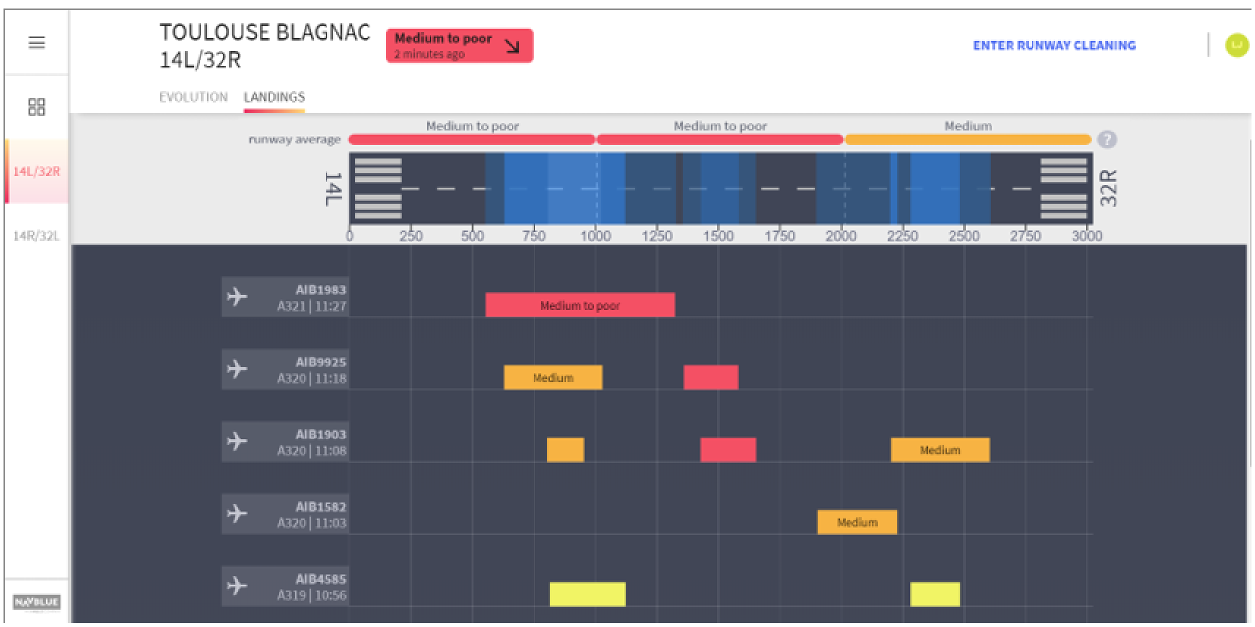

Figure 2: RunwaySense Example (Airbus, 2020)

However, Airbus's distribution of BACF is not sufficient to make significant gains in runway safety. The BACF is only available on certain Airbus aircraft; this limitation means that airlines with mixed fleets or fleets without these aircraft would see limited direct benefit. Additionally, even though the BACF software is free of charge, RunwaySense is not. Airports themselves can pay for a subscription to RunwaySense, which would allow them to access braking reports made by BACF on their runways. However, the cost of RunwaySense is a significant deterrent, particularly for smaller, general aviation (GA) airports. Overall, the BACF's limitations in compatible aircraft and RunwaySense's costs have deterred airlines and GA airports from investing in Airbus's developments.

05.3 NextGen and Automatic Dependent Surveillance-Broadcast

The Next Generation Air Transportation System (NextGen) is the FAA-led modernization of America's air transportation system with the goal of making flying safer, more efficient, and predictable (FAA, n.d.). This system is not just one idea or technology, but a series of improvements. NextGen is not scheduled to be released all at once; instead, NextGen technology will be rolled-out over a period of multiple years; work for NextGen began in 2007 and is expected to be completed by 2025 (FAA, 2016). Through NextGen, the FAA is looking to improve three areas: surveillance, navigation, and communication. Certain aspects of NextGen have been released already, such as Automated Terminal Proximity Alert (ATPA) and System Wide Information Management (SWIM) systems. These new systems have been implemented at several airports across the US with the intention of studying their benefits and detriments before they are included in every major US airport. Of these new implementations, many improve communication among pilots and airport personnel.

One key piece of technology in the FAA's NextGen program is Automatic Dependent Surveillance-Broadcast (ADS-B), which utilizes satellites, aircraft receivers, and ground station receivers to broadcast aircraft positions, weather conditions, and other information to air traffic control and other aircraft. There are two components to ADS-B: ADS-B Out and ADS-B In. ADS-B Out allows aircraft to broadcast their position to ground stations and ADS-B In-equipped aircraft. Meanwhile ADS-B In allows aircraft to receive aircraft positions from ground stations and ADS-B Out-equipped aircraft, as well as receive weather and other airport information from ground stations.

The FAA has mandated that by January 1, 2020 all aircraft operating within congested, or classes B and C, higher altitude, or class A, and general controlled, or class E, US airspace are equipped with ADS-B Out. The class E airspace mandate applies to operations at or above 10,000 feet above mean sea level, but excludes operations at or below 2,500 feet above ground level. ADS-B Out mandates of varying levels are also in effect worldwide (Fishlock, 2020). Currently ADS-B In is not mandated for any aircraft in any airspace. ADS-B In consists of two services: Traffic Information Service-Broadcast (TIS-B), and Flight Information Service-Broadcast (FIS-B). TIS-B allows pilots to receive traffic information on either a 978 MHz or 1090 MHz signal. FIS-B allows pilots to receive weather and other information on a 978 MHz signal only (FAA, 2020). While general aviation pilots and commercial airlines are expected to cover the costs to install ADS-B receivers, the TIS-B and FIS-B services are free of charge if the receivers are compatible with the correct frequencies (FAA, 2020).

05.4 Electronic Flight Bag Applications

A recent critical innovation in aviation has been the development of electronic flight bags (EFBs), which are either portable or installed electronic devices that are intended to reduce or replace paper-based information in a pilot's carry-on flight bag. In addition to digital information storage, EFBs have also expanded their capabilities to other functions such as more timely updates to weather and NOTAM information and automated flight performance calculations.

Advancements in the FAA's NextGen program have allowed pilots to utilize EFBs to receive information updates during flight. This is achieved through ADS-B In receivers. While the costs of the appropriate receivers are left to pilots or airlines, ADS-B In services and information is free of charge. This advancement has the potential to make significant gains in aviation safety due to allowing pilots to receive real time information updates during flight. Alternatives to ADS-B also exist, such as SiriusXM, which can provide higher resolution weather information with fewer time delays and altitude restrictions, but requires an additional receiver, a paid monthly subscription, and does not provide NOTAM information (NexAir Avionics, 2015).

The most prominent example of an EFB application is ForeFlight. The application was originally developed for the Apple iPhone in 2007 by general aviation pilots Tyson Weihls and Jason Miller as an aviation weather planning service. As mobile device technology has improved, ForeFlight has been consistently updated to expand its capabilities. ForeFlight was originally targeted toward general aviation, but has since seen use in business aviation, the military, and commercial airlines. In March 2019, ForeFlight was acquired by Boeing for an undisclosed amount of money (Haines, 2019).

EFB applications such as ForeFlight have made great strides in enhancing the flight planning process, but there is still room for improvement. While the information provided by ADS-B In is free of charge, many applications that utilize them such as ForeFlight are not. ForeFlight requires a yearly subscription that can range from $99 per year to $299 per year, depending on the plan selected. Optional features include additional instrument flight rule charts for various regions of the world, charged annually on a per-region basis, and runway analysis, charged annually on a per-aircraft basis. The runway analysis feature is beneficial due to the ability to automatically perform performance calculations with input on runway information, current weather and field conditions, and nearby obstacles. However, the service costs $600 per year per aircraft, and is currently only compatible with 6 different models of Cessna aircraft (ForeFlight, n.d.). These limitations to the software are similar to those of RunwaySense, as the services cannot apply to all aircraft types and are not free of charge, meaning general aviation pilots are at a risk of being priced out of the innovations delivered by ForeFlight.

05.5 Salience of Aviation Weather Displays

When weather conditions prevent pilots from navigating based on their own vision alone, pilots must fly by instrument flight rules (IFR). During these conditions, pilots may opt to use digital weather displays to keep track of in-flight weather changes. Digital weather displays convey weather changes using various text, line, color, or symbol changes. Digital weather displays add another element to keep track of in a pilot's visual scan pattern; as a result, pilots risk missing important updates to weather conditions due to the increase in workload.

One method to improve pilot detection and retention of information is improving salience of symbols and text in weather displays. Salience refers to the ability of an item to stand out from the item's surroundings. The Weather Technology in the Cockpit (WITC) program conducted a study to analyze the effects of symbol and line salience on change-discrimination performace. Change discrimination refers to the ability to detect a change in stimuli. The study consisted of trials in which participants were shown two aviation weather displays in quick succession. Participants then had to report whether a change occurred between the two displays or not. The independent variables were symbol color, time stamp text color, line color, line thickness, and line orientation. The dependent variables were participant response type--hit, miss, false alarm, and correct rejection--and response time.

The symbol and text colors utilized are displayed in Figure 3. The line colors utilized were black, red, and blue. Enhanced salience significantly improved change-discrimination performance in weather symbols. Blue lines had the highest discrimination performance; black lines had the lowest discrimination performance. Medium and high thickness lines had significantly higher discrimination performance than low thickness lines. Line orientation did not significantly impact discrimination performance (Ahlstrom and Racine, 2019). The results remained consistent across all ages and levels of weather display experience. Accounting for a variety of ages and weather display experience levels establishes a framework for which colors are most effective in aviation weather displays.

Symbol	Control	Enhanced
D1 - IFR METAR symbol	Yellow RGB (231, 255, 7)	Blue RGB (6, 24, 244)
D1 – Lightning symbols	White RGB (255, 255, 255)	Dark Purple RGB (150, 1, 243)
	Yellow RGB (255, 252, 1)	Light Purple RGB (254, 1, 250)
	Orange RGB (252, 151, 0)	Red RGB (254, 0, 0)
D1 - Time stamp text	Black RGB (0, 0, 0)	Blue RGB (6, 26, 247)
D3 - IFR METAR symbol	Red RGB (255, 0, 21)	Blue RGB (6, 26, 247)
D3 – Lightning symbols	Yellow RGB (255, 251, 6)	Light purple RGB (254, 1, 250)
D3 - Time stamp text	Black RGB (0, 0, 0)	Blue RGB (6, 26, 247)

In Experiment 1, we manipulated a change of the following weather symbols:

1. METAR—The onset/offset of 14 METAR symbols in the display;
2. METAR—A change in the color of two groups of 7 METAR symbols;
3. Lightning—The onset/offset of lightning symbols in the display; and
4. Time stamp—The onset/offset of the time stamp text.

Figure 3: Control Colors and Enhanced Salience Colors in WITC Symbol Salience Experiment (Ahlstrom and Racine, 2019)

Older pilots demonstrated lower discrimination performance and longer response time than younger pilots. However, improved discrimination performance of enhanced salience symbols remained significant across all ages and levels of weather display experience. Improving salience of digital weather displays is an effective way to mitigate lower discrimination performance from older age or pilot inexperience. NOTAM dispatches currently do not apply any salience enhancement techniques covered in the WITC program’s experiment. Traditional NOTAM dispatches are monochromatic and do not feature any variance in capitalization, font size, font type, or boldness; NOTAMs are also currently not displayed using symbolic approaches. However, the ability to digitally access NOTAMs during flight on EFBs via ADS-B provides a means to improve the salience of NOTAM dispatches. The salience enhancement results from the WITC program's experiment can be used to guide improving discrimination performance in the development of future digital information displays.

06 Team's Problem Solving Approach

The team utilized the design thinking process to help define the problem to be solved and develop a final solution. Design thinking is "a non-linear, iterative process that teams use to understand users, challenge assumptions, redefine problems and create innovative solutions to prototype and test," (Interactive Design Foundation, n.d.). Design thinking consists of five stages: empathizing with the user, defining the problem to be solved, ideating potential solutions, prototyping a solution, and testing the solution.

06.1 Investigating the Problem

The team selected Runway Safety as the general category from the Airport Cooperative Research Program (ACRP). Category H: Runway excursions, was the initial challenge the team selected. Runway excursions are a large problem in runway safety, accounting for about one-fourth of all air transportation accidents (IATA, 2009). The team explored several technologies relating to runway excursions; one such solution explored in depth was EMAS. The team noted how EMAS only reduces the severity of excursions and does not prevent excursions. Seeing a need, the team decided to focus on runway excursion prevention.

Through research, the team discovered that weather-related factors were a significant cause of excursions, prompting the team to research current methods used to report runway conditions. The team discovered runway condition reporting standards recently changed from the use of Mu values to the use of the RCAM; despite the change in methodology, runway conditions are still reported via NOTAMs. The team also discovered alternative methods of runway condition assessment such as the Alaska Airlines Takeoff RCAM (Collet, 2019), PIREPs, and the Airbus BACF. The team also noticed that the presentation of reporting runway conditions had not changed significantly alongside the development of the FAA's NextGen program.

06.2 Brainstorming

The team conducted two brainstorming sessions via Google Jamboard wherein the team members wrote on virtual sticky notes and grouped them into categories. During the first brainstorming session, the team identified potential problems to solve. The team's identified problems were sorted into four major categories: communication errors, conditions reporting, pilot considerations and takeoff RCAM standardization. The team chose to pursue conditions reporting and conducted a second brainstorming session on ways to improve conditions reporting. The team identified that multiple sources of runway conditions reporting were all independent. The team decided that implementing multiple sources of runway conditions into NextGen would be their initial solution proposal. This decision prompted the team to change their selected ACRP challenge to category E: "Optimizing application of NextGen technology to improve runway safety in particular and airport safety in general" (ACRP, 2020).

06.3 Development of Final Solution

Upon further review of the team's literature review, the team concluded that the RCAM had largely addressed the runway condition assessment methodology. However, NOTAMs, the primary source of runway condition reports, still remain inefficiently reported to pilots. Despite advancements in NextGen, NOTAMs dispatches remain lengthy, utilize confusing abbreviations, and do not effectively convey the relative importance of information. This realization prompted the team to expand their focus from improving runway condition reporting to improving reporting of all NOTAMs. The team's redefinition of the problem was confirmed by further correspondence with pilots.

The team researched opportunities within the FAA NextGen program that would enable the team's proposed solution. The team discovered that ADS-B allows pilots to receive NOTAM information during flight, improving communication with pilots and airport personnel and allowing pilots to make safe landing decisions. While ADS-B In does not have any current mandates in the United States, the team's research revealed that ADS-B In is becoming more common in aviation to receive weather updates in real time during flight via EFBs. The team utilized this opportunity to shape an EFB application interface.

The team met with two commercial airline pilots to test the team's solution. The pilots the team met with believed that EFBs are the most significant recent innovation to aviation; the pilots were highly satisfied with EFBs' ability to replace traditional paper charts and provide real time updates to weather information. The pilots wished to see similar advancements in presentation of NOTAMs to reduce pilot workload when reading NOTAM dispatches. The team met with a human factors professional, who provided suggestions to improve the salience and organization of NOTAMs to optimize reduction in pilot workload.

07 Description of Technical Aspects

07.1 Overview of Features

The graphical NOTAM interface will provide access to various sources of weather information such as Meteorological Aerodrome Reports (METARs), which are updates to current weather conditions at airports; Terminal Aerodrome Forecasts (TAFs), which are forecasts of weather conditions at airports; and PIREPs, which are reports of weather conditions encountered by pilots during flight. The primary feature of the application is the modification of how NOTAM information is presented to pilots. Two ways of visualizing NOTAM information would be provided: maps and airport diagrams.

The map section will feature symbols over each airport summarizing NOTAM information that pertains to the safest runway available. Pilots may need to make several flights in a single day and struggle to read several full length NOTAM dispatches. Changing conditions may also prevent pilots from landing at their intended destination and require an alternative destination. The map section will allow pilots to briefly review NOTAM information at several airports to make safe and timely decisions. Pilots will be allowed to tap on the symbols to obtain more detailed NOTAM information, if needed. An example of the map section is illustrated in Figure 4.

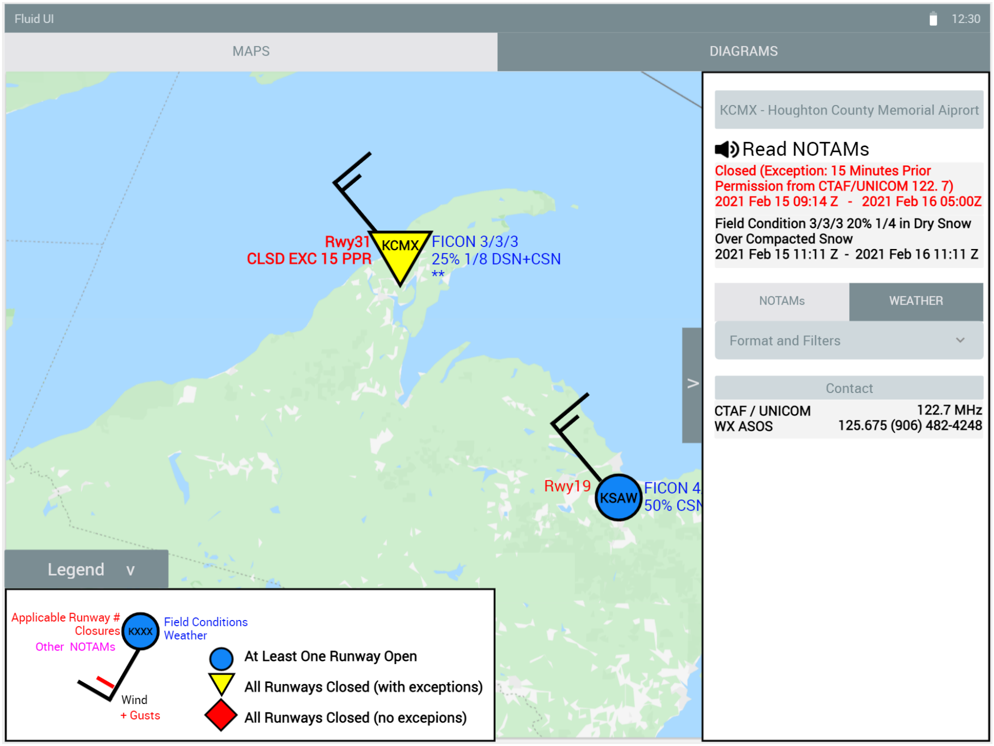

Figure 4: NOTAM Map Component of Prototype

The airport diagram section will overlay symbols similar to those in the map section onto airport diagrams. Unlike the map section, which will condense multiple NOTAMs into a single summary for an entire airport, the diagram section will split the information into multiple symbols conveying a single piece of information each. Airports, especially large hubs, may have several NOTAMs active at a time. Not every active NOTAM will pertain to a pilot's particular flight path, landing procedure, and taxi route. Therefore, pilots will be able to input their intended flight path and taxi route into the app to filter NOTAMs relevant to their flight plan. NOTAMs can be filtered further based on their class--i.e., runway, taxiway, apron, procedure, navaid, service, or obstruction NOTAMs. An example of the airport diagram section is illustrated in Figure 5.

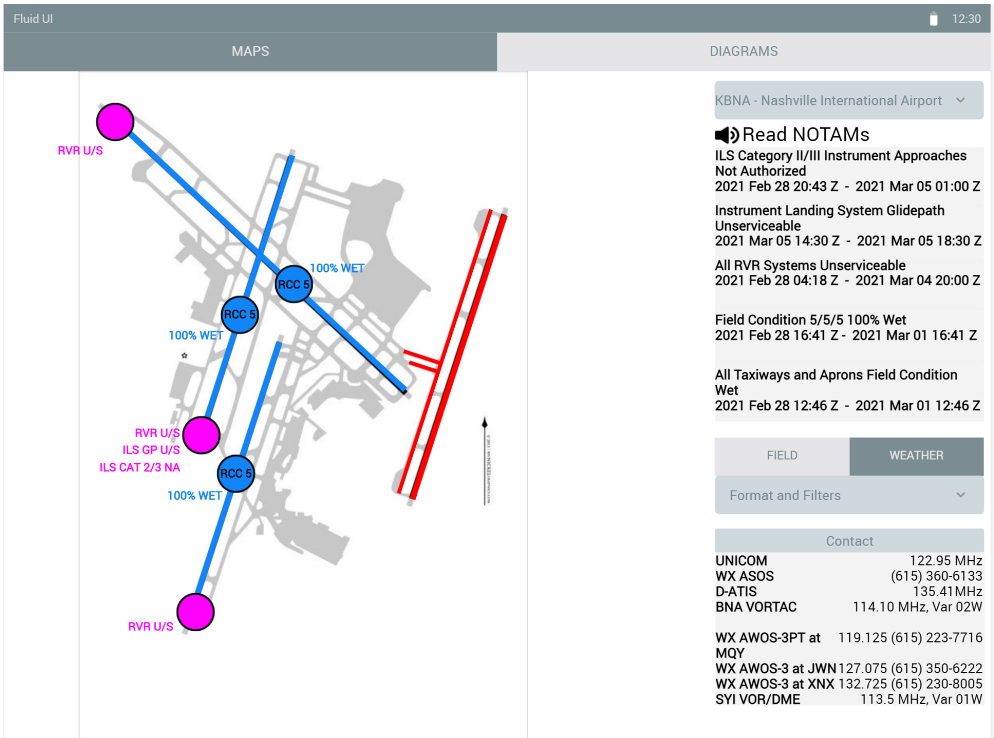

Figure 5: NOTAM Airport Diagram Component of Prototype

Three other key features of the application are NOTAM formatting, NOTAM readout, and airport contact information. Pilots can choose to present NOTAM information in either FAA format, International Civil Aviation Organization (ICAO) format, or plain text, and quantitative information can be given in either customary or metric units. Pilots can press a button to read out NOTAMs to allow them to auditorily process NOTAM information without having to spend excessive time looking at the screen. Pilots are also provided with airport contact information for their destination airport below the NOTAM text section.

07.2 Symbol Design

The map section symbol design in the graphical NOTAM interface was inspired by weather chart symbols used for METARs. The center of the symbol will include the airport designator and change shape based on runway availability. A blue circle will indicate that at least one runway is available without closures. A yellow triangle will indicate that all runways are partially closed, with at least one having exceptions to closures. A red diamond will indicate that all runways are closed with no exceptions. A wind barb also extends from the center of the symbol reflecting wind speed and direction from METAR data. The left side of the symbol will use red text to indicate the safest runway, as well as any closures if applicable. Below that, magenta text will be used to indicate NOTAMs regarding system outages or short term procedure changes that would affect landing decisions. The right side of the symbol will use blue text to indicate field condition reports as well as current weather conditions from METAR data. An example of a NOTAM symbol for Houghton County Memorial Airport (KCMX) is illustrated in Figure 6.

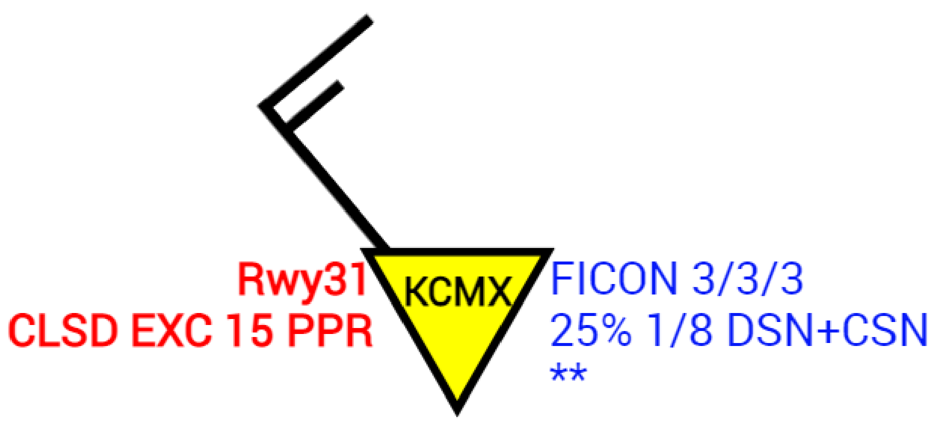

Figure 6: NOTAM Map symbol for KCMX.

The airport diagram section will overlay symbols similar to those in the map section onto airport diagrams. Unlike the map section, which would condense multiple NOTAMs into a single summary for an entire airport, the diagram section would split this information into multiple symbols each conveying a single piece of information. Each symbol would be positioned over the related section of the airport diagram. The symbols displayed on the diagram can be filtered based on the pilot's taxi route and the type of NOTAMs the pilot chooses to have visible. If NOTAM symbols are filtered out, runways, taxiways, and aprons would still be highlighted in either red to indicate a closure, blue to indicate contaminants present, or magenta to indicate another type of NOTAM applies.

07.3 Implementation of Team's Solution

The graphical NOTAM interface is an EFB application interface with ADS-B and FIS-B compatibility. These services allow aircraft to transmit and receive NOTAM and weather data during flight. The equipment carries a cost to pilots or airlines to retrofit their aircraft with proper receivers, but once installed, the NOTAM and weather data is available free of charge. Due to application's use of weather information and NOTAMs, the application is classified as a Type B EFB Application according to AC 120-76D, Appendix B1 (FAA, 2017). Type B applications have a failure condition of a minor hazard. Type B applications may substitute paper products of information required for dispatch, but may not substitute installed equipment required for airworthiness. Type B applications also require operations specifications (OpSpecs) or management specifications (MSpecs) authorization by the FAA. OpSpecs and MSpecs are legal documents outlining the authorizations of operators or program managers; OpSpecs are utilized by commercial airlines while MSpecs are utilized by general aviation.

Within the United States, the application is subject to the approval processes outlined in FAA Order 8900.1, Volume 3, Chapter 1, Section 1 (FAA, 2020) and FAA Order 8900.1, Volume 4, Chapter 15, Section 1 (FAA, 2019). A diagram of the approval process is illustrated in Figure 7. It is expected that prior to tests during flight, extensive testing will be conducted in simulations to gauge how well users can process the presented NOTAM information. According to FAA AC 120-76C, once approved for use during flight, it is expected that pilots will need to follow a six month operational demonstration to test the application's airworthiness. During the operational demonstration, traditional paper information remains accessible during flight (FAA, 2014).

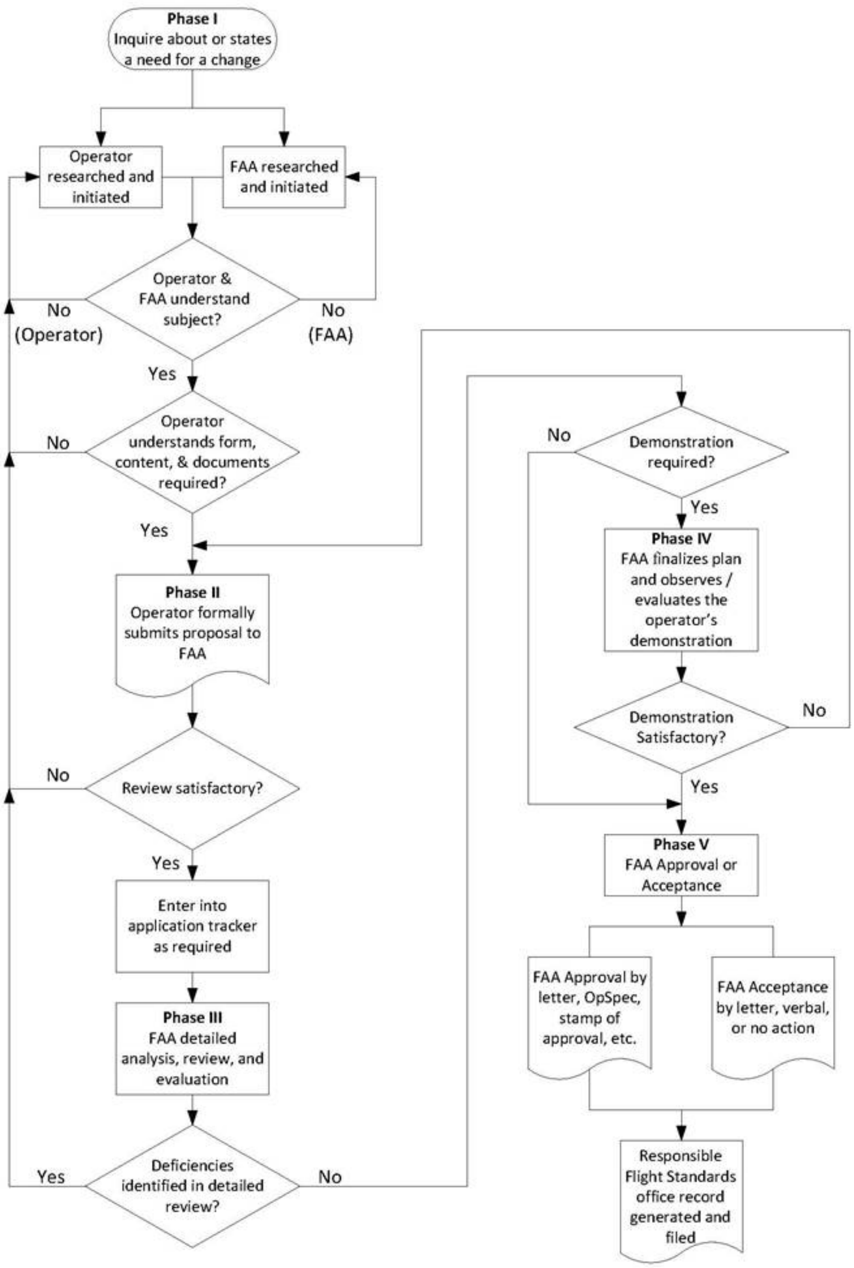

Figure 7: Application approval process under FAA Order 8900.1, Volume 3, Chapter 1, Section 1 (FAA, 2020)

The graphical NOTAM interface is expected to serve as an appropriate substitute as the graphical NOTAM interface does not rely on data sources external from the FAA. The filtering capabilities of the graphical NOTAM interface will not remove pilot access to any NOTAMs. Because the graphical NOTAM interface relies on information that is free of charge, the interface can be implemented into other existing EFB apps with ADS-B In capabilities.

08 Safety Risk Assessment

08.1 Defining the Risk of the Project

In aviation, safety is the highest priority. For commercial pilots, the safety of their passengers is of utmost importance. Runway excursions are the most common type of runway accident, caused by poor communication of current runway conditions and poor judgement by pilots. An EFB application allows pilots to quickly view and interpret the most current runway conditions and make their best judgment on landing procedures.

Many airlines are implementing paperless cockpits, where all of the data necessary for their flights are consolidated throughout several applications on tablets. The proposed solution creates a straightforward way for pilots to access data. When designing applications for pilot use, one major consideration is determining the information that is pertinent and to display the information in a manner that does not overwhelm pilots. Several safety risks exist with using tablets for EFBs. While a tablet reduces clutter in the cockpit compared to the pounds of papers traditionally carried, tablet malfunctions result in a situation in which pilots would be left without information necessary for safe flights and landings.

The use of icons is useful for presenting information in a succinct manner, as long as they are easily understandable. The EFB application design considers this by using symbols that can be easily interpreted. Most pilots use tablets for their flight information without a visual display of current runway conditions. Instead of sifting through pages of NOTAMs and contacting ATC, pilots can use the designed interface to briefly view the current runway conditions, along with other important landing information.

08.2 Mitigation Strategies

Executive Jet Management, a private air transport company, has tested the use of tablets in the cockpit and had a 100% success rate with not a single tablet malfunctioning during flight (Paur, 2011). A mitigation strategy for tablet malfunction that airlines have considered is carrying an extra tablet as a backup in the instance of a tablet malfunction, as well as keeping the traditional paper flight bags on hand. Another safety risk to consider when implementing the use of tablet applications for pilot use is potential distraction. Pilots could get distracted using tablets if they are unfamiliar with how to efficiently operate them, as well as if they have personal applications on them. To prevent such distraction, airlines should provide training to pilots on how to properly navigate their EFBs. Also, most airlines prohibit personal use on their tablets, such as texting and social media.

08.3 Safety Risk Matrix

Figure 8:Safety Risk Matrix used to evaluate potential situations to determine the safety risk

Graphical NOTAM Interface		Severity				
		Insignificant (A)	Minor (B)	Moderate (C)	Major (D)	Catastrophic (E)
Likelihood	Almost Certain (1)	1A	1B	1C	1D	1E
	Probable (2)	2A	2B	2C	2D	2E
	Possible (3)	3A	3B	3C	3D	3E
	Unlikely (4)	4A	4B	4C	4D	4E
	Rare (5)	5A	5B	5C	5D	5E

Figure 9: Potential safety risks assigned safety ratings by likelihood and severity of incident

Risks	Severity and Occurrence Rating
Graphical NOTAM Interface	
App/Tablet Malfunction	3B
Confusion with Icons	3C
Pilot Distraction	4C
Incorrect Information	3D

As seen in Figure 9, confusion with icons would be the greatest safety concern. Interpreting the icons incorrectly could result in improper landing procedures. However, this should not be a common occurrence as pilots would be trained to use the interface and demonstrate competence before its use in the cockpit. Although an infrequent occurrence, tablet malfunction and pilot distraction are possible with the use of the graphical NOTAM interface. The results of these safety risks would not likely result in major accidents. Pilots can keep paper flight bags to fall back to incase of tablet malfunction. Also, commercial pilots distracted during flight is a moderate safety concern because commercial airplanes operate almost completely automatically when in flight. The interface would also have a voice read out option, which would limit pilot screen time on the tablet. Lastly, incorrect information could be a possible occurrence as well as a major safety concern. The information presented in the interface should match current NOTAMs and would not differ from the information pilots receive traditionally. If pilots are concerned there is an error in the runway conditions presented, additional multiple contact information is available in the interface to verify current runway conditions.

09 Cost Benefit Analysis

09.1 Cost of App Development

The largest costs associated with the graphical NOTAM interface will come from the programming of the interface. Even though multiple avenues of distribution, including building another app entirely from scratch were discussed, the team decided that it would be best if the graphical NOTAM interface was implemented in an existing flight planning application. These mobile apps are accessed by the pilot through the Electronic Flight Bag, which is typically in the form of an Apple iPad. Some existing apps that are used for flight-planning include Garmin Pilot, Jeppesen Mobile FD and Boeing's ForeFlight. The graphical NOTAM interface should be implemented as additional functionality to those present in these existing apps. To simplify the cost breakdown, the team will treat the implementation the same as creating a small-scale app.

According to a survey run by Clutch in 2017, the price of creating an app can vary significantly, ranging from $30,000 to about $700,000, with the median lying around $171,000 (Panko, 2017). However, this number considers the approximate cost of all types of apps developed. As the team is treating this implementation as a simple app, the approximate costs will likely fall on the lower end of that spectrum. Utility NYC estimates the total cost of a simple app starts at $10,000, and the development of an enterprise-level app priced at $50,000 (UtilityNYC, 2020). The application will be simple in functionality but serve at an enterprise-level scale. Seeing as this implementation is a combination of the two categories, an approximate total cost between $10,000 and $50,000 seems to be the most likely for the team's proposed app.

In addition to app development fees, another cost that could be incurred is that required to train airline pilots on use of the app. The time a pilot would take to learn the software would vary, it would be unlikely for anyone to take over five hours total due to the size of the feature set. According to studies from 2015, the average salary of a pilot ranges from $20 to $50 an hour (Phoenix East Aviation, 2020). Using the higher value, an approximate cost of $250 is required to train pilots on the app.

09.2 Benefit Analysis

The goal of the graphical NOTAM interface is to provide pilots with the most accurate and up-to-date runway information in a way that is easily comprehensible. This is exceedingly important to runway safety as a full understanding of the landing situation is needed to prevent potential accidents. A false or incomplete understanding of airport conditions could lead to runway excursions due to contaminants on the runway, such as ice or slush, or other hazards, as specified by NOTAMs.

These potential accidents can incur costs including damage to aircraft and possible injuries sustained by individuals involved. According to the FAA, the average cost of an accident depends on whether the damage results in a replacement of the aircraft or a restoration. For a replacement, the average market value of a passenger aircraft in 2018 was $17.6 million and the average market value of an all-cargo aircraft was $15.9 million (FAA, 2018). The average loss value of a U.S. passenger aircraft involved in an accident was $3.6 million; this figure for an all-cargo aircraft was $4.9 million. Considering these statistics, the cost of implementing the proposed interface, estimated to be between $10,000 and $50,000. will be nearly insignificant when compared to the potential costs that could be incurred from even a single aircraft accident.

09.3 Comparison With Alternatives

Current technology and flight planning apps currently do not feature a system for displaying NOTAMs and runway contaminant information in a single, cohesive interface.

According to several pilots questioned as part of this research, NOTAMs are typically received in the form of a packet of papers which can be very time-consuming to flip through. While the paper solution is low-cost, the immediacy and clarity is lacking as compared to an app-based solution. ForeFlight, a flight planning app owned by Boeing, has a NOTAM viewing system integrated within the app. However, this app requires a yearly subscription ranging from $99 to $299 dollars (ForeFlight, 2021). In addition, there is no graphical display for potential runway contaminants. As mentioned earlier, Airbus's RunwaySense interface contains a visual layout for runway condition codes. Along with being an isolated interface, the use of this service requires a subscription similar to ForeFlight. The interface designed by the team aims to combine runway contaminant information and NOTAMs in a cohesive, easy-to-understand fashion, which has yet to be performed on any commercially available flight applications.

10 Interactions with Airport Operators

10.1 Duane DuRay

Duane DuRay is the Director of Operations for Sawyer International Airport (KSAW), located near Marquette, Michigan. DuRay has worked in the aviation industry for 30 years working with management and operations. The team called DuRay to expand their understanding of conditions reporting and investigate the limitations of RCAM. During the interview, DuRay was accompanied by Megan Murray, an assistant manager with experience at several different airports. DuRay and Murray described that there is little standardization in friction testing machines and the process of soliciting pilot braking action reports. DuRay also explained how vehicle weight class should be taken in consideration by the pilot when making a report. DuRay mentioned how pilots' interpretations of RWYCCs can vary based on their experience. They also noted how pilots often complain about the lack of a Mu number, as they had been removed from the conditions reporting in 2016 with the introduction of RCAM (Combs, 2018). After the interview, the team noted how there was an apparent lack of standardization regarding runway conditions reporting and utilized this information to further define the problem area.

10.2 Dave Spaulding

Dave Spaulding is a pilot for American Airlines whose current title is an Airbus A320 First Officer. The team contacted Spaulding during the initial information gathering stage of their process, while focusing on the RCAM system. Spaulding highlighted that since the RCAM unilaterally applies to all aircraft, it is easier for airline pilots--who fly many different planes from different manufacturers--to adapt the information to suit their current aircraft. Spaulding also mentioned how the RCAM attempts to resolve the ambiguity of pilot braking action reports by replacing them. Spaulding concluded communications by asking the team to consider if pilots receive too much information or too little. He stresses that information overload can harm pilots' ability to make quick decisions in high-stress high-risk environments. This consideration became one the team's principles that guided their design moving forward.

10.3 Stuart Sarasin

Stuart Sarasin is a pilot for Delta Airlines with 45 years of experience. His current title is Captain for the B747-400 and A-350. He was referred to the team by Duane DuRay, as Sarasin frequently flies through KSAW. The team called Sarasin to expand their understanding of how pilots make landing decisions. During the call, he stated that the process of determining the safest runway to land on is an objective process based on the length of the runways, the wind direction, and contaminants. The team utilized these comments to decide what information to display on the NOTAM maps for the team's interface. Sarasin believes the team's solution will improve aviation safety by improving the accessibility of NOTAM dispatches. He stated that commercial airline dispatches have made significant progress in prioritizing the most important NOTAMs for flight preparation; however, general aviation pilots may not have access to the personnel to efficiently organize traditional NOTAM dispatches. He also commented that if flight plans make unexpected changes, rereading the NOTAMs to look for the most important information is a daunting task. He also stated that reading NOTAM dispatches is challenging for pilots who need to make several flights in a single day.

10.4 John Doe

John Doe is a Boeing pilot for Southwest Airlines with 23 years of experience. He also has experience as a flight instructor prior to flying with commercial airlines. The team called Doe to expand their understanding of the shortcomings of NOTAMs and runway condition reporting. After explaining some shortcomings and limitations of NOTAMS, he stated he would like to see NOTAMs integrated into EFBs in a similar manner to weather information. Doe suggested that he would personally prefer using text to receive NOTAM updates; however, he was also open to utilizing symbols to convey NOTAM information in a similar manner to weather information. The team utilized Doe's suggestions to guide the initial organization of the team's interface.

10.5 Kathryn Maki

Kathryn Maki is a graduate student affiliated with Michigan Technological University's Human Factors & Ergonomics Society (HFES) Student Chapter. HFES is a national society whose mission is "to advance the science and practice of designing for people in systems through knowledge exchange, collaboration, and advocacy," (HFES, n.d.). When reviewing the team's prototype, Maki suggested prioritizing the salience of any runway or airport closures in place, as runway closures determine whether pilots can or cannot land. She suggested maximizing the salience of runway closure information by changing both the symbol color and symbol shape based on runway closure status. She also advised minimizing the total number of colors utilized to convey NOTAM information to further increase salience; according to her, using too many different colors reduces the salience of different pieces of information. In addition, she gave guidance on placement of the NOTAM text to minimize eye movement between maps, diagrams, and full NOTAM reports. The team utilized Maki's recommendations to refine the map symbol design and reorganize the formatting of the NOTAM text reports of the team's prototype.

11 Projected Impacts

11.1 Meeting Goals

The objective of the graphical NOTAM interface is to improve runway safety at airports by reducing runway excursions through improved presentation of NOTAM information. According to the FAA's Strategic Plan FY 2019-2022, one of the FAA's strategies to address their goal of aviation safety is to "identify the risk factors that contribute to fatalities and serious injuries and implement evidence-based risk elimination and mitigation strategies," (FAA, 2019). Throughout the team's research, the inefficient presentation of NOTAM information was defined as a significant factor contributing to runway excursions. The graphical NOTAM interface was designed to allow relevant NOTAMs to catch the pilot's attention; therefore it is expected that the risk of pilots missing important NOTAMs will be reduced.

11.2 Adaptation Potential

The FAA's NextGen program seeks to improve runway safety through improved communications, navigation, and surveillance in the National Airspace System. A key component to meeting these goals is improving how information is presented to pilots. The graphical NOTAM interface will be most beneficial to pilots who make several flights in a single day and need to quickly access information on changing conditions for several different airports. However, the graphical NOTAM interface is still applicable to a wide range of general aviation and commercial pilots. As addressed in Section 5, the graphical NOTAM interface is expected to become accessible beyond the United States due to an increase in worldwide ADS-B mandates and the information being free of charge. As addressed in Section 9, the cost of development and training for the graphical NOTAM interface is significantly less than that of runway excursion, which the application seeks to prevent. Overall, the graphical NOTAM interface is a versatile tool that would complement the FAA's NextGen rollout and support safe decision making for a wide range of pilots.

Appendix A

Faculty Advisor:

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Students: The team consists of three undergraduate students. All three of the undergraduate students are working on Bachelor of Science degrees in Civil Engineering..

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Appendix B

Michigan Technological University (MTU) is a four year public school located in Houghton, Michigan. The largest unit at MTU is the College of Engineering, which includes 16 degree options. The University has developed the Enterprise Program, which provides undergraduate students the opportunity to get real world experience before going into a professional environment. It is a hands-on program that applies skills learned in the classroom. There are 24 different enterprise teams, each with a different focus. The team pursuing the Airport Cooperative Research Program is part of the Built World Enterprise (BWE), which started in the spring of 2019. Previously, the enterprise program lacked a civil and environmental engineering focused group.

Appendix C

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Appendix E

Student Questions

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?

The ACRP University Design Competition provided a great learning opportunity for our team. Our technical writing all improved throughout the project, as well as our researching skills. We were able to talk to industry professionals, which gave us great experience setting up meetings and asking questions to people with expertise.

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

Our team faced two challenges in particular during this project. The first challenge was getting responses back from industry contacts. We would receive roughly 1 response per five emails sent, which was discouraging at first. After enough times contacting, as well as help from others in our enterprise, we were able to meet with several contacts that proved to be very valuable to our project. The second challenge our team faced was making the graphical NOTAM interface as concise, but useful as possible. Through talking with several pilots and an expert in human factors, we were able to confidently optimize our design to include all the necessary information we wished to convey, without overwhelming the screen with too much data.

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

The design thinking process guided much of the team's activities, especially in the earlier phases of the project. The team was investigating areas that seemed to be in need of improvement in the aviation industry, and used the RCAM system as a starting point. Through research and talking to industry professionals, the defining of the problem got narrowed down, and the team was eventually able to develop a final hypothesis.

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

Industry participation was one of the key reasons that our design was able to be legitimized. Since the interface is going to be used primarily by pilots, getting contacts in the industry that could help the team get feedback on the initial prototypes. Learning what a pilot needed and preferred to be included in the interface was immensely useful in the design process. In addition, contacts that were talked to early on in the project helped the team narrow down and define the hypothesis.

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 developed many valuable skills through participation in the ACRP. The team developed their skills in conducting and presenting technical research and reviewing literature. Sharing research with other team members and interactions with aviation industry members strengthened the team's technical and professional communication skills. The team anticipates that all of these skills will be applicable to entering the engineering workforce.

Faculty Questions

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

The ACRP competition provides an opportunity for students to learn the challenges and opportunities facing airport operation, maintenance and design. Civil engineering students, in particular, gain an experience that transcends many traditional civil engineering curriculum.

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

Yes, the diversity of challenges faced by airports allows for students to select problems to solve appropriate for their course level and context.

3. What challenges did the students face and overcome?

For this team in particular, their first challenge was to determine a scope and identify a problem they could solve. This is an important skill to learn. The next problem was to learn the context and appropriate solutions, which required them to speak with pilots and airport personnel. Creating a technical network is a valuable experience for students.

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

Yes! We plan on participating again next year. I like that the context is appropriate for students at almost any level and that the competition is outside of our civil engineering curriculum.

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

I suggest moving to electronic submissions in the future.

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