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16. ABSTRACT

As new flight deck automation is introduced, there is interest in considering whether unintended uses of such new flight deck automation could affect the safety of operations in the NextGen NAS. The study team collected 24 examples of present day unintended uses from 22 current and retired commercial airline pilots, and identified the systems associated with each example (e.g. FMS, radio altimeter, etc.). These examples were examined to identify attributes that might allow pilots to use these systems in ways other than intended by their designers, and other than as approved by the FAA Aircraft Certification Service, and the FAA Flight Standards Service. Focus group comments revealed many unintended uses in operations where pilots use existing flight deck automation. Comments were grouped into categories, including: Over-Reliance on Automation and Complacency; Strategic Behavior – Gaming the System; Emboldened Behavior; ADS-B CDTI Uses; Unintended Use of the FMS; and Potential Processes To Discover Unintended Uses. The human factors analysis also identified the potential for how these unintended uses could have adverse safety consequences.

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Unintended Uses of Automation Human Factors Study

Executive Summary

The FAA's Next Generation Air Transportation System (NextGen) will introduce new technologies including new flight deck automation to support new operational capabilities in the National Airspace System (NAS). As the automation is introduced, there is interest in considering whether unintended uses of such new flight deck automation could result affect the safety of operations in the NextGen NAS. The FAA engaged NASA and its contractor, Monterey Technologies, to study the potential considerations and consequences of such unintended uses in the NextGen context, starting from an assessment of unintended uses in today's flight deck. The study team collected 24 examples of present day unintended uses from 22 current and retired commercial airline pilots, and identified the systems associated with each example (e.g. FMS, radio altimeter, etc.). These examples were examined to identify attributes that might allow pilots to use these systems in ways other than intended by their designers, and other than as approved by the FAA Aircraft Certification Service, and the FAA Flight Standards Service. The analysis also identified the potential for how these unintended uses could have adverse safety consequences.

A team of three human factors research scientists identified 23 attributes that two company pilot SMEs used to rate each of the systems. The pilots rated the systems on the degree to which each system possessed each attribute. The pilots also ranked each system on their likelihood of allowing unintended uses. Statistical analyses of these pilot SME data identified attributes that were highly correlated with each other, and the attributes that best predicted the estimated likelihood of the systems allowing unintended uses. Two attributes were found to reliably predict unintended use:

- A19: To what degree can the system be used to monitor own aircraft position and trajectory?
- A06: To what degree can the pilot usefully combine the information from this system with information from other systems or existing knowledge (e.g., combining newly available flight ID data with prior knowledge about a particular carrier's tendencies)?

A linear regression of the pilot SME data showed that ten attributes accounted for nearly 94% of the variability in predicting whether or not a system had a known unintended use. Our evaluation technique may hold promise for inclusion in a future handbook-style job aid that might assist FAA Aviation Safety personnel when evaluating NextGen flight deck automation.

Introduction

The FAA's Next Generation Air Transportation System (NextGen) will introduce new technologies including new flight deck automation to support new operational capabilities in the

National Airspace System (NAS). As the automation is introduced, there is interest in considering whether unintended uses of such new flight deck automation could result affect the safety of operations in the NextGen NAS. The FAA engaged NASA and its contractor, Monterey Technologies, to study the potential considerations and consequences of such unintended uses in the NextGen context, starting from an assessment of unintended uses in today's flight deck.

The nature and range of problems associated with human-automation interaction (HAI) are well known, and, in aviation, are well documented (Parasuraman and Riley, 1997; Funk, Lyall and Riley 1995 and 2003). Many HAI issues emerged with the introduction of Flight Management Systems (FMS) in the 1980s. There is some concern that the introduction of the NextGen technologies will spawn another wave of flight deck HAI issues (Funk, Mauro, and Barshi, 2009). One such HAI issue is that of unintended use of flight deck automation that might adversely affect flight safety in NextGen operations.

The main goal of this project is to develop a methodology that FAA Aviation Safety personnel might use to evaluate NextGen flight deck automation, to identify and predict potential unintended uses (U2s) that could adversely affect safety.

Background

Affordances Allow Unintended Uses

Our methodology is a novel approach and conceptually links several bodies of research. The general goal of this work is to produce a method that can predict possible unintended uses of automation before the automation comes into operational use. Thus, it is a method to be used by FAA Aviation Safety personnel, namely Aircraft Certification and Flight Standards professionals. The unintended use may emerge as a premeditated action or as an opportunistic discovery, which may or may not adversely affect flight safety. The identifying characteristics are not in the automation hardware or software but in the perceptions of the user. J. J. Gibson referred to perceptions of the environment meaningful to the perceiver as "affordances" (Gibson, 1979).

Affordances are latent in the perceiver - object relationship. Knowledge of only one or the other is insufficient to identify affordances that result in unintended uses of automation. The important characteristics of the perceiver are the goals and motivations present in the work context. The important characteristics of the automation are those that offer the potential for achieving the goals and satisfying the motivations.

Rather than predicting specific unintended uses, our approach identified "suspect" automation likely to allow unintended use; it is similar to the concept of predictive profiling in threat assessment. The method is based on a threat assessment model used in the intelligence community to profile individuals of interest (e.g. terrorists) from a larger group of individuals. It relies on "indications and warnings" (I & W, aka indications analysis) to point to likely suspects (Cid, 2012) and their activities. These approaches use objective data gathering techniques that sum to an overall likelihood estimate that the person might have ill intentions. Their connections to other known terrorists are examined, as is their past history and their motivations. However, when applied to NextGen, the focus would be on *equipment and systems of interest* (e.g., Automatic Dependent Surveillance-Broadcast, or ADS-B), and would examine the potential that certain combinations of attributes of a particular system may allow unintended uses. This approach considers the equipment's functional capabilities and other characteristics, and the likelihood they could allow unintended uses. The benefit of threat profiling is to increase the level of attention and consideration of what might happen and how to prevent (mitigate) the actual occurrence.

Prior Work

In review, the first deliverable, the Interim Report, reviewed the status of the work accomplished in the initial months of the project, which included a literature review of prior research and search for examples of unintended uses. There exists a wealth of research in the area of humans and aviation automation, but little to none of it specifically addresses instances where automation is used in ways the designers or certifiers did not intend, nor does it address methods for predicting such phenomena in the future.

MTI's Task 1 Interim Report (Sharkey, Loomis, and Lakinsmith, 2011) reviewed the literature on unintended uses of automation, and a survey given to current and retired commercial airline pilots to indentify unintended uses of current automation. We introduced the idea that perhaps unintended uses of automation were instances of innovation, or invention to fill some unaddressed need in the cockpit. Work described in Report #1 (Hennessy, Lakinsmith, Loomis, and Sharkey, 2011) focused on identifying which flight tasks pilots are motivated to seek alternative or "better" ways of performing, using present day unintended uses to develop a predictive model for NextGen, and studying NextGen automation so that we may get a sense of how it may tempt pilots to use it in unanticipated ways. Report #1 is included in Appendix A of this report.

Work presented in Loomis and Lakinsmith (2012) describes the application of the Human Error and Safety Risk Analysis process (HESRA) (FAA, 2008, 2009; Hewitt, 2006; Piccione, 2008). HESRA was applied to a set of 24 unintended uses in order to assess their severity and potential mitigations to avoid negative outcomes. The process identified the use of Surface Only Cockpit Display of Traffic Information (CDTI) while airborne as the only high risk usage in the set of 24. The HESRA process also identified 10 medium risk usages where the severity of a mishap was major or hazardous, but the probability of occurrence was low.

This report summarizes our work to develop and apply a methodology for predicting which systems are likely to cause unintended uses.

Definitions and Assumptions

Our definition of automation is as follows:

> **Automation** is the independent accomplishment of a function by a device or system that was formerly carried out by a human (National Research Council, 1998; Parasuraman & Riley, 1997).

We assume the following definition of an "unintended use" for the purpose of this work:

An **unintended use** is a deliberate (i.e., non-accidental) use of NextGen automation other than that intended by the designers, sanctioned by management, or approved by the FAA.

- Emphasis is on potentially deleterious uses of NextGen automation.
- Includes behaviors provoked by the automation, e.g. attentional capture due to the compelling nature of a display.
- Does not include pilot errors.

The term "unintended" refers to the intent of the designer or the certifier, not the pilot; it is not to be confused with the term "unintentional".

The main premise of our approach is our original theoretical proposal that unintended uses arise when pilots are motivated to find alternative ways of accomplishing their goals in the cockpit, and that the affordances of the automation influence the development of alternative (unintended, unexpected) ways of performing their tasks.

A couple of assumptions support our methodology development. First, we firmly believe that something can be learned about unintended uses in general by studying unintended uses of *currently* fielded automation. We do not believe that NextGen automation is largely different from some types of present day automation that pilots use in unanticipated ways, and it is not unreasonable to expect that unintended uses of new automation would arise in similar ways as they do today. Therefore, once we understand the circumstances surrounding unintended uses of *current* automation, a methodology can be developed to project this knowledge into the future to predict unintended uses of NextGen automation.

Our second assumption concerns whether we are predicting individual, specific unintended uses, or rather helping the FAA to focus attention on equipment that may invite unintended uses. Our assumption is the latter; we seek to call attention to equipment that has the potential to encourage unintended uses. Unintended uses are driven as much by complex combinations of events surrounding individual contexts of use as they are the affordances of the automation, and these may not be known in advance. We envision that our work product will be used to screen new automated systems undergoing certification (or ideally, will be used during system development), and that it will be useful in identifying automation that *has the potential* to be used in ways that the designer, management, or the FAA had not intended.

Method

Overview

There are five steps in our U2 prediction methodology development process.

1. Gather U2 examples
2. Extract attributes
3. Develop rating scale and gather ratings for each attribute on each system
4. Gather rank data on systems
5. Analyze methodology effectiveness

First, we gathered examples of unintended uses of current automation, and the aviation systems associated with each example were noted. One example of NextGen unintended use (using the CDTI while airborne) was added, as were several examples that at first seemed like U2s but were determined to be authorized uses. Next, our human factors team brainstormed a number of attributes that these examples might have in common. Once the attributes were listed and defined, a rating scale was developed and the SME pilots provided ratings on each attribute for each system. Each of them also provided rank data for the likelihood that each of the systems would be used in unintended ways, to be used as a criterion value in regression analyses. Finally, we explored a number of different quantitative analyses to determine whether our method was able to discriminate between benign (intended) uses and unintended uses, and which attributes seemed to be the best predictors. The details of each step are provided in the sections below.

Step 1: Gather examples of unintended uses using currently fielded cockpit automation

In the initial months of this project we conducted an informal survey of 24 airline pilots to gather examples of unintended uses of present day automation. The examples are intended to achieve a shared understanding of what is meant by "unintended use", and to provide the basis for understanding how and why currently fielded automation is used in unintended ways. The assumption is that by studying a group of these examples in detail it will be easier to find similarities and ultimately parameters useful in prediction for NextGen automation.

Participants

Two experienced airline pilots, both with over 25 years of commercial piloting experience, were asked to participate as SMEs in the identification of examples where commercial pilots use avionics and automated systems in ways unintended by the designer or manufacturer. Note that the SMEs are affiliated with MTI.

SMEs reviewed the questions and points of interest described below with the researchers prior to starting to fill in the spreadsheet. In addition to documenting examples from their own experience, examples from colleagues comprised of 22 commercial pilots, all with various lengths of experience as captains. Colleagues were chosen on the basis of availability and willingness to participate as well as their experience with a variety of aircraft types including: Airbus 319 and 320, Boeing 737-300, 747-400, 757, 767, 767-ER and 777, and McDonnell Douglas DC-9, MD-11, and MD-80. Not all pilots contacted were able to provide any examples of unintended use. Examples were collected from the SMEs and colleagues over a period of three months during 2011.

Results

SMEs and airline pilot colleagues identified 24 examples of what they believed to be use of flight deck automation in ways unintended by the manufacturer, airline, or FAA. Ideally it would have been better to have a much larger set of examples to work with, but unintended use appears to be rare, as well as challenging to recognize. In this very early survey in our work the respondents were given the following definition of an unintended use: "use that may be outside of the developer's intent and/or a latent capability that resides within the automated system itself."

The examples are listed below along with our research team's comments. Examples 18-24 are those which were offered by our survey respondents as unintended uses, but that upon review were determined to be valid uses (i.e. they did not meet our subsequent definition of an unintended use). Our quantitative assessment step will address how well the attributes were able to discriminate between the valid U2s and the intended uses. While not meeting our initial goal of acquiring a large dataset to analyze, the valid uses were useful in terms of testing the validity of our predictive methodology.

1. In older Flight Management Systems (FMS's) pilots may add an additional waypoint 5 miles prior to a hard altitude crossing fix to begin an earlier reduction of airspeed for turbulent air penetration and provide a more comfortable ride for passengers when excessive tailwind during descent and descending into high altimeter settings will affect FMS descent calculations and not allow the FMS profile to meet the target altitude.

   Comment: Barometric pressure is set at 29.92 in (1013.2 MB) for all altitudes above 18K feet. When descending below 18K feet, barometric pressure might then be set at a value above 29.92 in, meaning the aircraft will be above the point the original descent calculations intended it to be, thus requiring a steeper descent to get to the required altitude at the crossing point. By starting descent earlier, the descent can be smoothed out. We believe that this is an example of an <u>unintended use</u> where pilots have worked around a 'glitch' where the design of the automation did not account for the 18K foot crossover. Apparently newer FMS's do account for the 18K foot crossover.

2. Use the Traffic Alert and Collision Avoidance System (TCAS) selection of 5 or 10 NM

display range to more accurately determine actual separation from preceding aircraft and provide an increased buffer behind heavy or turbulent aircraft to avoid upset in wake.

Comment: TCAS is intended to alert the flight crew of potential collision situations. The use of the range arcs to monitor separation is not approved nor intended.

3. Prior to takeoff in low visibility, aircrew may adjust TCAS display to 5 NM range to accurately determine whether another aircraft is attempting to land.

   Comment: Given a low visibility situation, pilots want some way to augment surveillance of other aircraft in addition to relying on ATC to improve safety. TCAS provides additional information about relative position and direction of aircraft in the vicinity, so pilots use it even though it's not intended to provide traffic information for takeoff. We believe that this is an unintended use of the TCAS, but regard it as less potentially harmful than other unintended uses since it reflects the use of automation to augment information obtained from ATC and out-the-window sources.

4. Adjusting the weather radar antenna to "paint" other aircraft in radar field of view to determine aircraft separation. Weather is superimposed on the Navigation Display and there are range marks to measure the distance. Used when TCAS was not available.

   Comment: Aircrew recognized that capability to identify and roughly measure distance to storm clouds could be applied to aircraft, which was valuable information not yet available from other flight deck instruments. Aircraft separation information could augment situational awareness from visual surveillance and potentially improve safety with little or no cost. Pilots recognized that the capabilities developed for weather could be applied to aircraft separation, and we regard this as a use that was not intended by developer or the FAA.

5. As a reminder to the pilot regarding the amount of fuel required at a certain point of a flight, the Pilot Flying (PF) selects a fix on FIX page of the FMS and enters a bearing value that reflects the required fuel quantity at that point in flight plan.

   Comment: Aircrew is using the avionics as an alarm clock/memory 'jogger' to remind them to check the fuel at a certain point in the flight, which was not intended by the developer nor the FAA.

6. When an older FMS-equipped aircraft does not have capability to intercept an airway between two points, pilots may insert anchor points in the FMS to establish airway (jet route) starting point. This is done when one of two waypoints usually defining the desired navigation airway is behind the aircraft's current position and heading. Thus, the pilot has to position a waypoint in the FMS on the airway that's in front of the aircraft's current position to start that airway.

   Comment: Pilots found a relatively easy workaround for a system design that apparently did not consider the need to intercept an airway between its established waypoints.

(Perhaps the pilots interpret it that way because of the irritation involved in having to add a waypoint, which may be how the manufacturer intended to intercept airways mid way.) This is another case where pilots had to work around gaps in the automation, and we consider this a valid example of an unintended use.

7. Modify calculated gross weight of aircraft for takeoff and landing entered in the FMS to meet weight requirements for takeoff or landing. Calculations are based on information provided to the pilot that the pilot then enters. The pilot is not expected to make/modify the estimate.

   Comment: Pilots know that fully loaded weight estimates are quite inaccurate and are usually overestimated. Thus in certain circumstances where they feel safety is not compromised, they are willing to make adjustments to weight estimates to save time and fuel costs. On takeoff, a lower weight will give you a higher V1 (abort) speed which can have a negative impact on stopping distance should the aircraft have to abort. We regard this as an unintended in the sense that this is an unsanctioned use of the FMS to enter a false value.

8. To meet altitude clearance requirements in some Airbus aircraft, pilots may enter a lower altitude in the Flight Management Guideance Computer (FMGC) to maintain higher rates of descent in the transition to a level off altitude at the cleared altitude which would not have be met if actual altitude was entered.

   Comment: Again, we consider this a valid example of an unintended use because pilots have learned a workaround to overcome a deficiency in the automation design using the FMGC in a way that the designer and FAA did not envision. Without this workaround, altitude clearances would not otherwise be met.

9. When directed to change the start of decent point from that entered into the FMGC, pilots use FMGC to help the aircrew calculate a more precise descent point and to utilize the autopilots VNAV function to fly a parallel descent to a point & altitude that is not in specified in the navigation database/flight plan.

   Comment: We believe this is a valid unintended use. One of the problems frequently cited for automation is that it may not be able to quickly respond to system changes or unusual circumstances. In this case the automation cannot respond to an unanticipated change in ATC direction, forcing humans to calculate a new descent profile. Pilots have learned to use the part of calculations the automation can provide and then use heuristics to finish the calculations of the required descent. This use is unintended because it is being used to overcome a design flaw that does not accommodate changes in ATC commands.

10. PF cycles between the Track Flight Path Angle (TRK FPA) and the Heading Vertical/Speed (HDG V/S) switch on the Flight Control Unit (FCU) to compare actual AC heading with assigned ATC heading after entering assigned heading as a track in the TRK FPA mode.

Comment: This is a valid unintended use. See detailed discussion in next section (or click on Link). Used as a work-around to respond to ATC commands and yet stay in track mode for the FPA support.

11. Aircrew adjust the radar altimeter warning altitude bug slightly out of the stowed or off position which causes the radar altimeter warning light to illuminate to remind them as they go through that altitude to open the fuel cross feed valve and reconfigure the wing fuel boost pumps to correct for a fuel imbalance.

    Comment: This is another example of the flight crew using the automation as an alarm clock or memory aid, which was not intended by the developer nor the FAA

12. Aircrew selects Anti-ice ON in descent page of FMS when Thermal Anti-Ice (TAI) will not actually be used in descent to ensure the FMS does not miscalculate the descent profile and miss the crossing restriction.

    Comment: Aircrew experience has been that the FMS miscalculates the descent profile, causing them to violate altitude restrictions. They have found an unintended way to 'tweak' the system for a higher rate of descent, thereby overcoming a system limitation and increasing the likelihood of meeting crossing restrictions.

13. Aircrews create designs such as Christmas Trees and Tic Tac Toe board with pixels in the Route 2 (inactive route) page of the Primary Flight Display for amusement.

    Comment: We believe this to be a valid unintended use. The pilot who gave this example mentioned that he experienced pilots playing with the FMS when it was first introduced and not later after they were more familiar with it. This type of "play" was an exercise to learn more about the capabilities of the system and explore the potential usefulness of various features.

14. For fun, aircrew enters a pilot's name into a field intended for the flight number when entering route plan information into the Global Positioning System (GPS) Flight Management System (GFMS) such that the pilot's name show up on that page of the GFMS.

    Comment: This is a valid (though trivial) example of unintended usage.

15. Use of Vertical Speed (V/S) control of the FMC instead of VNAV for climbs to higher flight levels to reduce the rapid increase of engine thrust and higher pitch angles when climbing to higher cruise altitudes for passenger comfort.

    Comment: While the expectation is to continue to use Vertical Navigation (VNAV) for vertical climbs, the pilots have placed a higher value on passenger comfort and believe they can climb more comfortably using the V/S function. We regard this as an intended use, and may only be an issue if the stated policy is to use VNAV.

16. Generating lines of bearing to or from a Navaid or fix to identify airways not on the flight plan and provide a visual reference to the crew, identifying alternate airways or restricted areas.

    Comment: This is another example of an unintended use for the purpose of augmenting situation awareness.

17. Modifying altitude restriction from 10,000 ft to 10,001 to remove the speed reduction feature of the FMS.

    Comment: By modifying the altitude at 10,000 ft to 10,001 the aircraft will not calculate a speed reduction point and a higher descent speed can be maintained after level off at 10K. This is an Example (albeit a trivial example) of unintended use to enter slightly off altitude restriction to circumvent the speed reduction automation.

18. Changing Cost Index in FMS to emphasize speed more than fuel or vice versa in the FMS to different than calculated value for personal gain/preference.

    Comment: The Cost Index weighting of time/speed versus fuel and other airline costs is intended to minimize airline costs rather than aircrew preferences. If aircrews feel the cost benefit to them is worth the cost and risk, then they can be expected to use it to their advantage. We do not believe that this is a true example of an unintended use as we have defined it. The FMS's Cost Index function was designed to allow the user to enter parameters of their own choice.

19. Using a range circle to identify a crossing restriction which is not based on the active waypoint to provide a visual reference to identify a crossing restriction without changing the active waypoint or altering the flight plan route. Thus, the pilots are manually drawing on the PFD to make it look more like the charts, thereby making it easier to visualize the ATC restrictions.

    Comment: Extremely similar use as those listed in examples 20 and 21. Use of the FMS capability on the FIX page to draw circles of specific radii labeled with the altitude. This is probably not an unintended use.

20. Use of the FIX Page Zulu time as an aide to mandatory position reporting during international crossings on Track Systems where there is a requirement for the aircrew to stay within 3 minutes of the time reported to the controlling agency.

    Comment: The Fix page on the FMS provides the capability to set a point and a radius of a specific distance around that point as well as the ability to mark a waypoint along the flight path according to ETA or altitude. In this case it seems like that the intended use of the Fix page on the FMS was general enough that this is probably not an unintended use.

21. Use of Fix Page for timely reminders.

    Comment: Another example of a use of the FIX page for a memory aid or alarm clock.

Same comment as that for 19. This is probably not an unintended use.

22. Generating range circles around a fix or airport to visually identify climb altitude crossing restrictions to give the aircrew a visual depiction of the crossing restriction on the PFD without having to reference the paper charts

    Comment: Use of the capability on the FIX page to draw circles of specific radii labeled with the altitude. Same comment as that for 19. This is probably not an unintended use.

23. Aircrews use the "Hold" page of the FMC to get information about the aircraft's best holding speed at current cruise altitude when asked by ATC for minimum speed at altitude.

    Comment: Selecting the 'Hold' page has the slight risk of subsequently actually selecting hold and sending the aircraft into the hold mode. Aircrews believe the risk to be minimal and the page easily provides the minimum speed at the current altitude in answer to ATC queries. Thus, not only does the page have information about the aircraft, it can provide information sensitive to the current context of the aircraft situation. This is not an unintended use as the display is providing the information it is intended to provide.

24. Using the alternate route (route 2) capability of some FMS's, pilot pre-programs an alternate route into FMS as an emergency high-terrain escape route to be used in the event of cabin depressurization and descent to a lower altitude is necessary.

    Comment: We believe that this may actually be the intended use, especially if companies are spending time and money to validate these escape routes. It's an example of pre-loading information to reduce the number of tasks and associated time and stress required in an emergency situation.

Systems Represented

Table 1 shows the systems represented by our list of 24 U2 examples, and photos of the pages referenced within these systems are provided in Appendix B. It was clear to us that some decomposition within large, complex systems such as the FMS was required, so those were broken down into the specific FMS pages implicated in the U2 example.

Table 1. Systems represented in our list of 24 unintended use examples.

System No.	System
S01	TCAS
S02	Weather Radar
S03	LEGS page within FMS
S04	FMS - Perf Init Page
S05	CDTI
S06	FMS - Descent Page
S07	FMS - Fix Page
S08	FMGC
S09	FMGC, Flight Plan Page A (equivalent to Boeing "Legs" page)
S10	Radar/Radio Altimeter
S11	Route 2 page on Primary Flight Display
S12	GPS FMS, 1st page of ROUTE page.
S13	GPS FMS
S14	"Hold" page of the FMC
S15	FCU

Step 2: Extract attributes from the examples of unintended use.

Overview

The first part of this process was aimed at identifying a set of automation attributes or indicators that may reflect a system's probability of being used in an unintended way. The next step was to assess selected automated systems implicated in some of the unintended usage examples on these attributes to see if any meaningful patterns emerge.

This should be viewed as a very preliminary attempt at developing a methodology, which requires additional attribute development, testing and discussion to understand how the FAA might adopt such an approach.

Attribute identification

The second step in our process was to brainstorm a list automation attributes that might indicate a system's likelihood of being used in an unintended way. The attributes were developed based on an examination of the examples of current day unintended uses gathered to date, and through

Human Factors team brainstorming[1]. Because our ultimate goal is a checklist style tool these attributes were developed in question form, and worded such that the amount of each attribute or quality in a system being evaluated for certification could easily be rated using a simple scale. It is not the case that any one particular attribute would suggest likely unintended uses, but it may be the case that a combination of these attributes might indicate such. Table 2 contains a list of attributes, along with our rationale.

Table 2. Attributes and supporting rationales.

Attribute Number	Attribute	Rationale
A01	How much user interaction is possible?	Without a user interface, the probability that the system would be used in unintended ways is low.
A02	How much new information content is offered by the system?	New information may prompt exploratory behavior. New information offers potential for new actions or effects on decisions. New information may provide new opportunities to use the information in potentially unexpected ways, whereas if the information already exists, the unexpected uses probably would have already been tried. A new capability, display or mode may evoke exploratory behavior in the cockpit (e.g. "what else can this thing do?")
A03	How much of the information format (presentation) is new?	Novel information format may invite exploratory behavior.

[1] Initially we began with "Yes / No" attribute questions, and subsequently decided to collect magnitude ratings that might allow for greater resolution in our predictions.

Attribute Number	Attribute	Rationale
A04	To what degree is this new component[2] integrated with other components?	Unexpected use of a component that is tightly integrated with other components may increase the potential for negative outcomes. . Users may also explore the relationships among the systems to determine whether there might be beneficial controls or added information
A05	How much influence does the pilot have over the information flow between this system and the aircraft?	Automation that is integrated with other subsystems onboard the aircraft have a greater potential to affect system safety (e.g. CDTI versus a magnetic compass), and the capability to combine functions or information in new ways.
A06	To what degree can the pilot usefully combine the information from this system with information from other systems or existing knowledge (e.g., combining newly available flight ID data with prior knowledge about a particular carrier's tendencies)?	Information enables action. Unexpected uses may potentially arise from new combinations of information or functions.
A07	To what degree does the system provide information that evokes an immediate action? (attention-getting and provokes you to do something)	If the system tells the user to do something like: "Pull up" or "turn right", maybe the user could respond with other actions.
A08	To what degree does the display portray the information as having more detail and accuracy than reality?	People seek more accurate or unambiguous information. The portrayal of greater detail or accuracy may engender unwarranted decisions or actions. Pilots may attempt to use the device for a purpose that requires more accuracy than the device has, e.g., using an auto GPS for aircraft navigation.

[2] A "new component" could be an entirely new system, a new page in an existing FMS, or new capability in an existing system.

Attribute Number	Attribute	Rationale
A09	To what degree can the user put something on the display that has nothing to do with the purpose/function of the system? (e.g. scratchpad or other free text entry functionality).	Freeform input potentially opens the use of the device to more uses. Also, may interact adversely with intended functions.
A10	How much inherent complexity is there which might invite exploration (numerous pages/modes) – are the users familiar with all the pages or modes?	Complexity suggests not all interactions are known. Familiarity suggests the pilot spends a lot of time with the system and has more opportunity to discover new forms of use. When flight crews are required to use at least a portion of complex devices like the FMS, they continually are confronted with other modes/and options with which they are not familiar and may become curious and begin to explore which may lead to uses of modes not fully understood, or discoveries of other capabilities interesting to the pilot, but not intended by the designer.
A11	How much information does the system provide about other aircraft operating in the NAS?	Knowledge of other systems in the flight environment may prompt more frequent or aggressive actions to achieve a more advantageous flight situation. ADS-B, for example affords this possibility.
A12	To what degree does the system allow information not related to the flight to be accessed by the pilots?	Accessing non-flight related information such as checking stock values or searching for movies would distract pilots from their duties.
A13	To what degree does the display portray rapid or continuous movement of imagery or symbols?	Moving imagery is attractive and may 'tunnel' attention beyond what is warranted for that display and away from more important information, like out the windshield viewing.

Attribute Number	Attribute	Rationale
A14	To what degree can the system be used to locate heavy weather, such as thunderstorms?	Focus group pilots expressed high motivation to find a better way to perform this task.
A15	To what degree can the system be used to locate uncomfortable weather, such as turbulence?	Focus group pilots expressed high motivation to find a better way to perform this task.
A16	To what degree can the system be used to identify intersecting routes (e.g., when given “direct to” clearance)?	Focus group pilots expressed high motivation to find a better way to perform this task.
A17	To what degree can the system be used to streamline voice communications with ground and Air traffic controllers?	Focus group pilots expressed high motivation to find a better way to perform this task.
A18	To what degree can the system aid in observing and avoiding other ground traffic during taxi?	Focus group pilots expressed high motivation to find a better way to perform this task.
A19	To what degree can the system be used to monitor own aircraft position and trajectory?	Focus group pilots expressed high motivation to find a better way to perform this task.
A20	To what degree can the system be used to comply with crossing restrictions?	Focus group pilots expressed high motivation to find a better way to perform this task.
A21	To what degree does the system offer a simpler or easier method of performing a task than a prior method (Does it offer a way of reducing workload)?	Systems that appear to offer the user “shortcuts” may not have been designed to support that function, and may result in unintended negative consequences.

Attributes 14-20 represent the motivational factor in our predictive equation. These were the six tasks that active and retired line pilots in our focus group rated being the most motivated to find a better way of performing (Hennessy, Lakinsmith, Loomis, and Sharkey, 2011). Thus, in a predictive equation, to the degree that a system could be used for tasks such as these (along with other attributes), there would be a greater likelihood of unintended use. It simply represents whether or not the system in question was one that had been associated with higher levels of frustration, error, or insufficient capability in the past.

Some of the attributes reflect simple logic, e.g. the less user interface a system has, the less chance that it will be used in unintended ways. Similarly, the more isolated a system is (versus integrated, possibly with flight control related items), the less chance that it will cause unintended actions in other systems.

Some of the attributes are supported by psychological research. Attribute 10 addresses the notion that novelty or complexity invites exploration, which could possibly lead to unintended uses (James, 1890). Research has shown that novel stimuli invite exploratory behavior in humans and rats (Saklofske, 1975). Attribute 13 is supported by literature on attention capture, or cognitive tunneling (Weintraub, Haines, and Randle, 1984; Fischer, Haines & Price, 1980).

In addition to the attributes shown in Table 2, two other key attributes pertaining to historical data about the system were developed, but were not assessed (i.e. the pilot SMEs did not provide ratings for them). The first references data presumably held by the applicant or manufacturer, and the second refers to information held by the certifying agency. These are shown in Table 3.

Table 3. Attributes related to prior system history.

Attribute Number	Attribute	Rationale
A22	To what degree is there evidence suggesting that the applicant or manufacturer believes that the system will be used for purposes other than those for which certification is being sought?	Perhaps the certifier has experience with a similar device or perhaps the certifier recognizes that the device seems to satisfy a known problem area or gap. Further, if the designer/developer specifically states that the device is *not* to be used for something – might the flight crew try to use it for that, e.g., TCAS for separation?
A23	To what degree has the system been implicated previously as a problem area in legacy systems?[3] A certifier should check TBD records to see if there is documented evidence of prior problems.	When the device is similar to other devices that have a history of unintended use, the new device can be expected to have the same unintended uses. Known problems with legacy systems should be corrected or similar problems can continue.

[3] *While the focus of this effort is on pilot motivation and automation affordances, historical and collateral data should be taken into account when investigating whether or not a NextGen system is likely to invite unintended uses.*

These two attributes tap into knowledge that the manufacturer and the FAA may have about the system under evaluation, and thus were not included in the attribute rating assessment performed by the pilot SMEs on this project.

Step 3: Develop rating scale and test the methodology (gather ratings for each attribute on each system)

A simple rating scale was developed for use in assessing the amount of each attribute inherent in each system. The notion is that when a new NextGen system or capability is being considered for certification, an Aviation Safety person would use the attribute rating scales in a handbook form to essentially compute a score reflecting the likelihood that the system might engender unintended use, and if it was sufficiently high, additional scrutiny would be required before the system could be fielded. A test of this approach was required to determine if it had merit.

Figure 1. Sample rating scale format. shows an example of how the attributes would be rated. The hypothesis is that when ratings across all attributes for a given system are summed, larger scores would indicate those systems with a higher propensity to be used in unintended ways.

Evaluation Question:

How much user interaction is possible?

0	1	2	3	4
None				A Lot

Figure 1. Sample rating scale format.

Ratings were gathered from MTI's pilot SMEs using a consensus-building approach over the course of a number of telephone meetings of our geographically dispersed team. A Human Factors Engineer (HFE) facilitator described the attributes to the pilots until they were understood, and then (without reference to the original example) asked the pilots to provide a rating from 0 to 4 indicating the amount of that attribute possessed by the system under evaluation. This was a very time consuming process, with much discussion about the attributes' meaning and intent, and about the system functionality. The result of the meetings was the creation of a database with 266 ratings (21 attributes x 14 systems).

Step 4. Gather rank data on systems

The same pilots who provided attribute ratings independently rank ordered each of the systems in terms of how likely the systems could be used in unintended ways. These were used as criterion values in our subsequent quantitative analyses. Table 4 shows the rank orders along with the average across these two pilots.

Table 4. Rank Orders of the Likelihood of Each System Being Used in Unintended Ways.

SYSTEM NO.	SYSTEM	Pilot 1	Pilot 2	Average
S01	TCAS	1	13	7
S02	Wx Radar	15	14	14.5
S03	FMS Legs Page	6.5	8.5	7.5
S04	FMS Performance Initialization Page	2	5.5	3.75
S05	CDTI	4	12	8
S06	FMS Descent Page	8	5.5	6.75
S07	FMS Fix Page	10	4	7
S08	Flight Management Guidance Computer	3	1	2
S09	Flight Management Guidance Computer: Flight Plan Page A	6.5	8.5	7.5
S10	Radar/Radio Altimeter	13	15	14
S11	Primary Flight Display Route 2 Page	5	3	4
S12	GFMS	9	2	5.5
S13	GFMS - GPS Flight Management System Route 1 Page	11	10	10.5
S14	FMC Hold page	12	7	9.5
S15	Flight Control Unit	14	11	12.5

Step 5. Analyze methodology effectiveness.

We performed a number of quantitative analyses on our data set hoping to determine whether 1) the attributes were able to discriminate between systems that were associated with our examples of U2s and those which were associated with valid uses, and 2) whether some attributes were more helpful than others. The results of our analyses are presented in the following section.

Results

Systems and Attributes

Ratings of the amount of each of the 21 attributes (those in Table 2) for each of the 15 systems listed in Table 4 were obtained from two experienced airline pilots.[4] These attribute ratings were obtained on a 5-point scale. A rating of "0" (zero) indicated that "None" of the attribute was present in that system and a rating of "4" (four) indicated that there was "A lot" of that attribute present in the system. No verbal anchors were associated with intermediate values on this scale.

Correlations between Attributes

In order to identify attributes that are highly associated, and thus redundant as predictors, the correlations between the attribute ratings were computed. Table 6 shows these correlations. Each of these 210 correlations is based on 15 pairs of attribute ratings, one pair of each of the 15 systems. A correlation greater than or equal to 0.534 is statistically significant at the 5% probability level. A correlation greater than or equal to 0.641 is statistically significant at the 1% level. Highlighted cells indicate that the correlation is significant at the 1% level.[5] The absolute values of the correlations ranged between +0.927 (between attributes A12 and A18) and -0.734 (between A01 and A08).

Table 5 lists the most significant correlations and offers some possible explanations.

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[4] The 15 systems are those for which Loomis & Lakinsmith (2012) obtained Risk Priority and Hazard Index values.

[5] These significance values are not corrected for multiple post hoc comparisons. If one uses a Dunn-Bonferroni type correction a probability of 0.00023 would be needed for a true 5% probability of a false alarm. This corresponds to a correlation with an absolute value of 0.813.

Table 5. Correlations significant at the .01 level and possible explanations.

Attribute	Attribute	Correlation (r)	POSSIBLE RATIONALE FOR CORRELATION
12. To what degree does the system allow information not related to the flight to be accessed by the pilots?	18. To what degree can the system aid in observing and avoiding other ground traffic during taxi?	+0.927	Information about ground traffic is unrelated to the flight.
11. How much information does the system provide about other aircraft operating in the NAS?	12. To what degree does the system allow information not related to the flight to be accessed by the pilots?	+0.888	Both attributes are related the amount of information available regarding other entities in the NAS.
3. How much of the information format (presentation) is new?	21. To what degree does the system offer a simpler or easier method of performing a task than a prior method (Does it offer a way of reducing workload)?	+0.829	Unclear.
11. How much information does the system provide about other aircraft operating in the NAS?	18. To what degree can the system aid in observing and avoiding other ground traffic during taxi?	+0.804	Both attributes deal are related to the amount of information provided about other aircraft; the first being inclusive and the second being aircraft on the ground.
17. To what degree can the system be used to streamline voice communications with ground and Air traffic controllers?	21. To what degree does the system offer a simpler or easier method of performing a task than a prior method (Does it offer a way of reducing	+0.782	Both deal with streamlining the process; the first being limited to voice communications with

	workload)?		ATC and the second being more general.
11. How much information does the system provide about other aircraft operating in the NAS?	13. To what degree does the display portray rapid or continuous movement of imagery or symbols?	+0.764	Information about the position of other aircraft can be displayed as moving imagery or moving symbology.
1. How much user interaction is possible?	8. To what degree does the display portray the information as having more detail and accuracy than reality?	-0.734	Unclear.
2. How much new information content is offered by the system?	13. To what degree does the display portray rapid or continuous movement of imagery or symbols?	+0.732	Unclear.
1. How much user interaction is possible?	5. How much influence does the pilot have over the information flow between this system and the aircraft?	+0.691	Both attributes address how much interaction flight deck personnel have with the system.
4. To what degree is this new component integrated with other components?	5. How much influence does the pilot have over the information flow between this system and the aircraft?	+0.690	Both attributes address information flow through the system.
10. How much inherent complexity is there which might invite exploration (numerous pages/modes) – are the users familiar with all the pages or modes?	16. To what degree can the system be used to identify intersecting routes (e.g., when given “direct to” clearance)?	+0.690	Unclear.
4. To what degree is this new component integrated with other	17. To what degree can the system be used to streamline voice	+0.688	Unclear.

components?	communications with ground and Air traffic controllers?		
5. How much influence does the pilot have over the information flow between this system and the aircraft?	17. To what degree can the system be used to streamline voice communications with ground and Air traffic controllers?	+0.670	Unclear.
2. How much new information content is offered by the system?	7. To what degree does the system provide information that evokes an immediate action? (attention-getting and provokes you to do something)	+0.659	Unclear.
1. How much user interaction is possible?	17. To what degree can the system be used to streamline voice communications with ground and Air traffic controllers?	+0.646	Unclear.

Note that all of these correlations are positive except the correlation between Attributes 1 and 8.

The pairs of attributes were inspected to determine the underling associations. In a number of instances plausible reasons for the high correlations were identified, but in many cases no rationale could be identified. Based on these correlations and the limited understanding of the relationship between the correlated attributes we were unable to reduce the set of attributes used to predict the Hazard Index, the Risk Priority Numbers, the rank order of likelihood of a system being used in a unintended way, or whether or not a system was known to have been used in an unintended way. Consequently, the regression analyses discussed below all began using the full set of 21 attributes as predictors.

Table 6. Correlation between Attribute Ratings. Correlations that are statistically significant at the 1% level are highlighted in dark gray. Correlations greater than or equal to 0.534 are statistically significant at the 5% probability level and are highlighted in light gray.

		ATTRIBUTE NUMBER																				
		A01	**A02**	**A03**	**A04**	**A05**	**A06**	**A07**	**A08**	**A09**	**A10**	**A11**	**A12**	**A13**	**A14**	**A15**	**A16**	**A17**	**A18**	**A19**	**A20**	**A21**
Attribute Number	**A01**	---	-0.276	0.128	0.411	0.691	0.218	-0.176	-0.734	0.331	0.623	-0.297	-0.068	-0.211	0.158	0.190	0.380	0.646	0.139	0.080	0.412	0.403
	A02		---	-0.127	-0.329	-0.207	0.473	0.659	0.536	-0.332	-0.544	0.511	0.294	0.732	0.229	0.025	-0.419	-0.403	0.322	-0.237	-0.127	-0.313
	A03			---	0.162	0.138	-0.075	-0.460	0.113	0.122	0.159	-0.431	-0.535	-0.135	0.135	0.049	0.279	0.383	-0.443	0.166	-0.034	0.829
	A04				---	0.690	-0.358	-0.320	-0.480	0.316	0.506	0.080	0.058	0.063	-0.364	-0.137	0.421	0.688	0.207	0.633	0.449	0.480
	A05					---	-0.023	-0.095	-0.373	-0.071	0.460	-0.165	-0.165	0.074	-0.028	-0.111	0.158	0.670	-0.023	0.259	0.558	0.334
	A06						---	0.270	0.063	-0.005	-0.301	0.195	0.141	0.281	0.377	0.273	0.005	-0.097	0.131	-0.325	-0.225	-0.148
	A07							---	0.432	-0.517	-0.178	0.302	0.191	0.410	0.080	0.025	-0.249	-0.454	0.268	-0.077	0.329	-0.594
	A08								---	-0.531	-0.530	0.195	-0.161	0.434	0.163	-0.059	-0.389	-0.554	-0.245	-0.218	-0.322	-0.318
	A09									---	0.400	0.237	0.409	-0.114	-0.108	0.395	0.552	0.502	0.474	0.224	-0.042	0.481
	A10										---	-0.224	-0.046	-0.187	0.070	0.324	0.690	0.498	0.186	0.600	0.475	0.399
	A11											---	0.888	0.764	0.000	0.235	-0.077	0.015	0.804	0.227	-0.070	-0.195
	A12												---	0.553	0.072	0.367	0.037	0.119	0.927	0.165	0.064	-0.141
	A13													---	0.371	0.269	-0.100	-0.102	0.591	0.132	-0.057	-0.129
	A14														---	0.344	0.132	-0.153	0.140	-0.281	-0.219	0.020
	A15															---	0.526	0.103	0.449	0.026	0.024	0.170
	A16																---	0.402	0.211	0.459	0.290	0.467
	A17																	---	0.180	0.415	0.466	0.782
	A18																		---	0.250	0.212	-0.047
	A19																			---	0.353	0.378
	A20																				---	0.225
	A21																					---

Regression

Three stepwise regression analyses were conducted with the goal of identifying attributes that are useful predictors of the safety of systems or of the likelihood of a system being used in unintended ways.[6]

Hazard Index

Hazard Index (HI) ratings were obtained for Unintended Uses by Loomis & Lakinsmith (2012). These values had a possible range from "1" to "25", with smaller numbers indicated a greater hazard. The system(s) associated with the unintended uses were identified, and these values were used as the measure to be predicted in a regression analysis. Where no unintended use was identified for a system, a maximum value of 25 was used in the analysis.

A stepwise regression was performed using the ten (of 21) attributes that had the highest absolute value correlation with the HI scores. In descending order of the absolute value of the correlation, these are: A10, A11, A15, A01, A14, A12, A16, A02, A02, and A20. Using liberal criteria for including or removing attributes from the regression equation (0.20 and 0.40, respectively), the resulting equation is:

Hazard Index = 13.4777 + 6.6127* A10 -2.7649 * A19 – 1.8536 * A20

A10: How much inherent complexity is there which might invite exploration (numerous pages/modes) – are the users familiar with all the pages or modes?

A19: To what degree can the system be used to monitor own aircraft position and trajectory?

A20: To what degree can the system be used to comply with crossing restrictions?

This equation accounts for 72.8% or the variability in the HI scores.

Risk Priority Numbers

Risk Priority Numbers (RPN) were also obtained by Loomis & Lakinsmith (2012). These values had a potential range from "1" to "125", with smaller numbers indicating a greater level of risk. As in the case of HI values, the system(s) associated with the unintended uses were identified, and these values were used as the measure to be predicted in a regression analysis. Where no unintended use was identified for a system, a maximum value of 125 (the maximum value) was used in the analysis.

A stepwise regression was conducted using the ten (of 21) attributes that had the highest correlation with the RPN scores. In descending order of the absolute value of the correlation, these are: A10, A01, A02, A07, A11, A16, A08, A15, A05 and A12. Again, liberal criteria for including or removing attributes from the regression equation were used (0.20 and 0.40, respectively). The resulting equation is:

Risk Priority Number = 37.1982 + 19.2477 * A10 – 7.8010 * A07

A10: How much inherent complexity is there which might invite exploration (numerous pages/modes) – are the users familiar with all the pages or modes?

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[6] The stepwise regressions were conducted using an add-in to Microsoft Excel downloaded on 17 Oct 2012 from http://faculty.fuqua.duke.edu/~kamakura/bio/WagnerKamakuraDownloads.htm

A07: To what degree does the system provide information that evokes an immediate action? (attention-getting and provokes you to do something)

This equation accounts for 56.8% of the variability in the RPN scores.

Likelihood of Unintended Use

The same pilots who provided attribute ratings rank ordered each of the systems in terms of how likely the systems could be used in unintended ways. Table 4 shows the rank orders along with the average across these two pilots.

Table 7. Rank Orders of the Likelihood of Each System Being Used in Unintended Ways.

SYSTEM NO.	SYSTEM	Pilot 1	Pilot 2	Average
S01	TCAS	1	13	7
S02	Wx Radar	15	14	14.5
S03	FMS Legs Page	6.5	8.5	7.5
S04	FMS Performance Initialization Page	2	5.5	3.75
S05	CDTI	4	12	8
S06	FMS Descent Page	8	5.5	6.75
S07	FMS Fix Page	10	4	7
S08	Flight Management Guidance Computer	3	1	2
S09	Flight Management Guidance Computer: Flight Plan Page A	6.5	8.5	7.5
S10	Radar/Radio Altimeter	13	15	14
S11	Primary Flight Display Route 2 Page	5	3	4
S12	GFMS	9	2	5.5
S13	GFMS - GPS Flight Management System Route 1 Page	11	10	10.5
S14	FMC Hold page	12	7	9.5
S15	Flight Control Unit	14	11	12.5

Figure 2 shows the rank orders from Participants 1 and 2. The Kendall's Tau[7] for these rank orders is 0.391 ($z = 1.237$, $p > 0.20$). This indicates that there is not a strong relationship between the rank orders of the likelihood that the systems would be used in unintended ways from the two pilots.

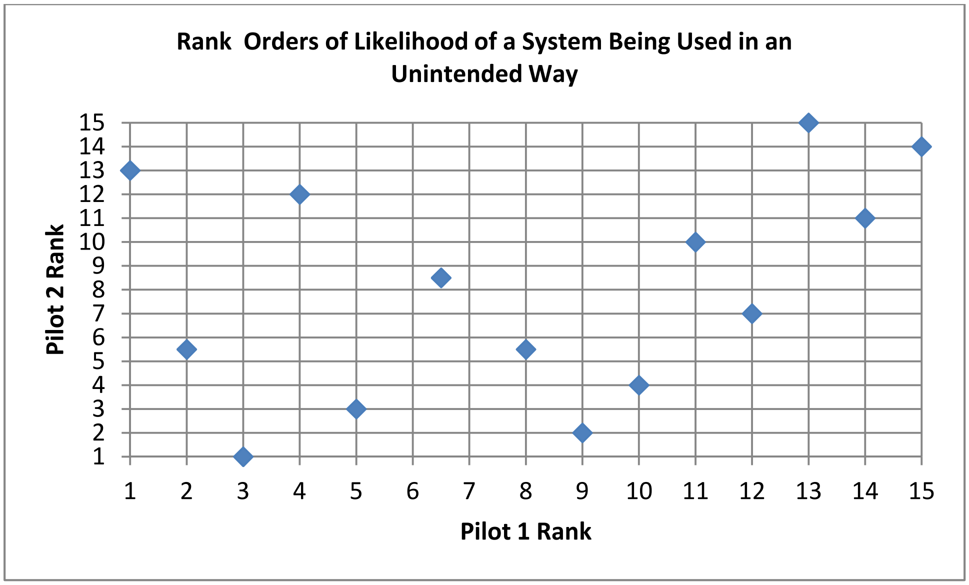

Figure 2. Rank orders of the likelihood of systems being used in unintended ways.

A stepwise regression was conducted using the average of the ratings of the likelihood of a system being used in an unintended way as the value to be predicted (i.e., the dependent measure) and the attribute ratings. The predictors were the ten attributes having the strongest correlation with the dependent measure. (That is, the ten attributes having the highest absolute values of the correlations between the attribute ratings and the rank order of the pilots' likelihood of a system being used in an unintended way.) Using a value for the probability for entering a predictor of 0.40 and a value of 0.80 for the probability for dropping a predictor the following equation was derived:

$$DV = 12.7863 - 2.2116 * A02 + 0.7910 * A19 - 1.1084 * A21$$

Where:

A02: How much new information content is offered by the system?

A19: To what degree can the system be used to monitor own aircraft position and trajectory?

A21: To what degree does the system offer a simpler or easier method of performing a task than a prior method. (Does it offer a way of reducing workload)?

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[7] Kendall's Tau is similar to the more familiar Pearson Product-Moment Correlation as both quantify the degree of relationships between two sets of data. Kendall's Tau is appropriate when both sets of data are rank orders. The Tau statistic was computed using the procedure in Bruning, J.L. & Kintz, B.L. (1968). Computational Handbook of Statistics. Glenview, IL: Scott, Foresman and Company.

This equation accounted for 50.1% of the variability in the average ratings.

We would note that this result must be taken as being very preliminary. As the ratings of the pilots as to the likelihood of the systems being used in unintended ways did not show much agreement (Tau = 0.391 as stated above) it is unlikely that the average is a reliable estimator of the ratings from the pilot community as a whole.

In addition, the criteria used to determine when to enter or remove an attribute from the regression equation were unusually liberal. Using more conservative criteria of $P_{entry} = 0.3$ and $P_{removal} = 0.6$ (although still quite liberal in an absolute sense) resulted in the following regression equation:

DV = 11.2577 – 2.1472 * A02

This equation accounted for 41.3% of the variability in the average ratings of the likelihood of a system being used in an unintended manner. As one can see, adding additional parameters to the equation by relaxing the criteria did not markedly increase the predictive power of the equation.

Individual Pilot Regression Analyses

Pilot 1

The ten attributes most highly related to Pilot 1's rank order of the likelihood of a system being used in an unintended way are, in descending order of the absolute value of Spearman's Rho[8], are A11, A17, A19, A09, A04, A21, A03, A12, A18, and A02. All of the Rho values were negative.

A stepwise regression using P_{entry} of 0.30 and $P_{removal}$ of 0.60 was conducted. The resulting regression equation is:

DV = 18.4195 – 1.7173 * A03 – 2.4924 * A02

A03: How much of the information format (presentation) is new?

A02: How much new information content is offered by the system?

This equation accounts for 51.0% of the variability in Pilot 1's ordering of the likelihood of the systems being used in unintended ways.

Pilot 2

The same stepwise regression process was conducted with the rank ordering of the systems from pilot 2. The attributes with the strongest relationship with this order are, in descending order of the absolute value of Spearman's Rho, are A21, A17, A02, A09, A10, A07, A13, A16, A03, and A08 . The value of Rho was positive for attributes A02, A07, A13, and A08. All other Rhos were negative. The resulting regression equation is:

DV = 13.5505 - 4.6894 * A21 - 1.2179* A02 + 1.7206 * A10 + 2.8682 * A03 – 2.5912 * A08

---

[8] Spearman's Rho is used to determine the relationship between a set of rank ordered data and a corresponding set of continuous data. The technique used here is from Bruning & Kintz (1968) op cit.

A21: To what degree does the system offer a simpler or easier method of performing a task than a prior method (Does it offer a way of reducing workload)?

A02: How much new information content is offered by the system?

A10: How much inherent complexity is there which might invite exploration (numerous pages/modes) – are the users familiar with all the pages or modes?

A03: How much of the information format (presentation) is new?

A08: To what degree does the display portray the information as having more detail and accuracy than reality?

This equation accounts for 78.5% of the variability in Pilot 2's rank ordering of the likelihood of the systems being used in unintended ways.

Comparison of Pilot 1 and Pilot 2 Regressions

The fact that most of the attributes that correlated highly with the pilots' order of the systems likelihood were negative values is an expected finding because of the wording selected for the attribute rating scales[9]. The negative correlation is interpreted as indicating that the more of an attribute that is present, the more likely that a system will be used in unintended ways. It is interesting to note that when an attribute has a positive relationship with the order of likely unintended use (attributes A02, A07, A13, and A08 for Pilot 2 have positive values for Rho) then "a lot" of the attribute indicates that the system is <u>less</u> likely to be used in unintended ways, which is contrary to our original expectations.

Only three attributes, A09, A17, and A21, were present in both sets of ten attributes that were most strongly correlated with the pilots ordering of systems. These three attributes were negatively associated with the ordering of systems in terms of likelihood of unintended use for both pilots. The small number of common attributes is consistent with the finding that the pilots' rank orderings of the systems in terms of the likelihood of unintended use are not strongly related. We interpret this as indicating that the pilots believing that the attributes that contribute to the potential to use a system in unintended ways differed. It may be that the experience of the pilots (e.g., the type of equipment in the aircraft that they operated, the unintended uses that they have observed) contributes to this difference. However, with the small sample size it is not possible to do more than speculate at the underlying cause of this difference.

Predicting Whether or Not a System is Associated with an Unintended Use

Analyses

Three of the 15 systems were not associated with known unintended uses, These were the FMS Perf Init Page (S04), FMS-Fix Page (S07), and the Hold page of the FMC (S14) Unintended uses of all other systems have been identified.

[9] The negative correlations are a consequence of the wording used in the attribute rating scales. Specifically, the wording was selected with the intent that higher numbers would suggest more opportunity for the system to be used in unintended ways. In contrast, smaller numerical values in the rank orders indicated an increased likelihood of a system being used in unintended ways. Thus we expect that high attribute scores will be associated with low rank orders.

A series of regression analyses were conducted to identify the combinations of attribute rating scores that predict whether or not a system will be used in an unintended manner[10]. The systems that had no known unintended use were coded as "1" and those with an unintended use were coded as "0" for these analyses. The data used in these analyses is shown in Table 8.

The ten attributes with the highest absolute value of the point-biserial correlation with the existence of an unintended use were included in the regression analysis. The number of attributes was determined arbitrarily.[11] These attributes are, in descending order of the absolute value off the point-biserial correlation, A07, A06, A09, A13, A21, A02, A14, A17, A03, and.A19. (The point-biserial correlations ranged from +0.361 to -0.614. Point-biserial correlations with 13 degrees of freedom and an absolute value of 0.514 or greater are statistically significant at the 5% level. Only the A07 and A06 reached this threshold.) All possible multiple regressions were performed[12].

[10] Megastate was used for these analyses. This Microsoft Excel add-in was downloaded from http://glencoe.mcgraw-hill.com/sites/0010126585/student_view0/megastat.html on 30 Oct 2012.

[11] Because of the small sample size and limitations in the statistical routines available it was not possible to include all 21 attributes in a regression analysis. It was decided to use the "top 10" attributes based on the absolute value of their correlation with the dependent variable as those would have greater predictive value than attributes with lower correlations.

[12] These regressions included between 1 and 10 of the attributes, a total of 1022 regression equations were examined. These regressions were not conducted in a step-wise manner due to singularity problems making it impossible to properly enter and remove attributes from the process.

Table 8. Attribute rating data used to predict systems associated with an unintended use.

			Attribute Number									
System Number	**System**	**Authorized Use (1 = Authorized, 0 = Unintended)**	**A19**	**A07**	**A13**	**A06**	**A02**	**A14**	**A09**	**A15**	**A05**	**A18**
S01	TCAS	0	4	4	4	3	4	0	0	0	2	0
S02	Weather Radar	0	0	4	2	4	3.5	4	0	3	1	0
S03	LEGS page within FMS	0	4	2	1	3	2	0	1	0	3	0
S04	FMS - Perf Init Page	1	0	0	0	3	2	0	3	0	2	0
S05	CDTI use while Airborne	0	4	3.5	4	3	3	1	4	3	1.5	3.5
S06	FMS - Descent Page	0	4	3	0	1	1	0	0	0	2	0
S07	FMS - Fix Page	1	3	1	0	1	0	0	3	2	2	0
S08	Flight Management Guidance Computer	0	4	4	0	3	2	0	4	2	2	1
S09	Flight Management Guidance Computer (Flight Plan Page A, equivalent to Boeing "Legs" page)	0	4	3	0	3	2	0	1	1	2	0
S10	Radar/Radio Altimeter	0	2	4	0	2	2	0	0	0	0	0
S11	Route 2 page on Primary Flight Display	0	4	0	0	3	0	2.5	3	0	2	0
S12	GPS Flight Management System, 1st page of ROUTE page.	0	4	0	0	3	0	0	3	4	2	0
S13	GFMS (GPS Flight Management System)	0	4	2.5	3	2	2	2.5	1	2	4	1
S14	“Hold” page of the FMC	1	4	0	0	1	1	0	2.5	0	2	0
S15	Flight Control Unit	0	0	4	0	3	1	0	1.471	0	4	0

Best Equation

The regression equation that best predicts whether or not an unintended use has been identified with a system regardless of the number of attributes included is:

DV = 0.8854 -0.1512 * A07 -0.3593 *A06 + 0.1420 * A09 -0.0340 * A13 – 0.2976 * A21 + 0.2354 * A02 – 0.0285 * A14 + 0.1531 * A17 + 0.2810 *A03 – 0.1350 * A19

This equation accounts for 94.0% of the variability and is statistically significant ($p \leq 0.05$).

Best Single Attribute Equation

The best single predictor of whether or not a system had a known unintended use was A07, with a correlation of -0.614. The regression equation accounting for 37.7% of the variability is

DV = 0.5515 – 0.1506 * A07

This equation is statistically significant ($p \leq 0.05$).

Best Two Attribute Equation

The best regression equation using two of the ten highest correlating attributes is:

DV = 0.8982 – 0.1275 * A07 – 0.1582 * A06

This accounts for 49.0% of the variability and is statistically significant ($p \leq 0.05$).

Best Three Attribute Equation

The best regression equation using three of these ten attributes is:

DV = 1.4258 – 0.1353 * A07 – 0.2230 * A06 – 0.1151 * A19

This equation accounts for 67.6% of the variability and is statistically significant ($p \leq 0.01$).

Analysis Summary

These analyses suggest that ratings of attributes can be used to predict whether or not an existing system will or will not be used in an unintended way. This prediction can be done reliably using only ratings of two attributes, A19 and A06:

A19: To what degree can the system be used to monitor own aircraft position and trajectory?

A06: To what degree can the pilot usefully combine the information from this system with information from other systems or existing knowledge (e.g., combining newly available flight ID data with prior knowledge about a particular carrier's tendencies)?

The accuracy of the prediction can be improved, as defined by the proportion of variance in the dichotomous variable accounted for, by including additional attributes. The best predictions of whether or not a system had a known unintended use included all ten attributes, and accounted for nearly 94% of the variability.

Discussion

This initial assessment of our experimental U2 prediction methodology shows that the methodology has promise, despite the fact that two of the most (we believe) powerful predictor attributes were not used (the two addressing historical data known to the applicant or manufacturer, and to the FAA). If prior knowledge from either the applicant or the FAA are used in considering whether a system might provoke unintended use the power of this methodology would likely increase greatly.

One of a number of unresolved issues with this approach is the fact that as a profiling methodology that tries to separate signal from noise (similar to signal detection), it is likely to implicate "innocent" systems from time to time. It does not predict specific instances or types of usage, only equipment or systems that have the propensity to *invite* unintended use, and, with all signal detection approaches, there are likely to be false alarms (systems that may not invite unintended use are noted), and misses (the methodology fails to call attention to a system that ends up inviting unintended use). If this approach is adopted by the FAA some care should be taken in determining the criterion value (i.e. the total rating value) above which the system seeking certification is noted for further scrutiny. Also, the capacity of a certifier or the certifying agency to spend time reviewing systems using this methodology (or any new methodology) will affect the utility and practicality of this approach.

Another problematic issue to be resolved in future work is the fact that the systems shown in Table 1 are at varying levels of resolution. While in most cases we defined a FMS "system" as a specific page in the FMS, in some cases we did not. For example, System 8 (FMGC) appears to be the same as System 9 (Flight Plan Page "A"). Likewise, System 13 (the GFMS) is actually the FMS Fix Page on a GPS equipped aircraft, and should be combined with System 7[13]. An alternative analysis was performed to address this issue and the results are presented in Appendix C.

Expert vs Novice

It makes a difference whether the person trying to predict U2s is a certification or flight standards expert within the FAA, or someone outside this area. FAA professionals involved in certifying and fielding new equipment have specialized knowledge about the process, about historical data associated with specific equipment or types of devices. They have intimate knowledge about the various ways that equipment has been used (in an intended manner) and misused (in an unintended manner) by simulation and flight test pilots involved in system development, initial testing, and during early operational test and evaluation. They have a feel for pilot motivation, frustration, and tendencies, as well as a deep understanding of the commercial airline corporate environment, and should be readily able to anticipate how a new piece of equipment may be received. They are able to see patterns in a set of events that others outside might not (e.g. how a group of pilots uses equipment), and have a rich historical perspective from which new problems can be viewed (Chase and Simon, 1973). We are not suggesting that prediction of unintended uses in NextGen will be purely a matter of common sense, we merely suggest that this rich knowledge base be leveraged in conjunction with the methodology we have developed in this work.

If it is not yet part of the process, we suggest that the FAA certification process include a searchable database of historical data associated with equipment, types of equipment, and all development and test activities. Pilot reports from flight test should be linked into this system, so that instances are noted when pilots comment that a system undergoing certification does not meet their needs in certain ways. One of the biggest reasons why pilots invent new, unintended uses for their avionics is because the equipment they are given does not allow them to do their job in the way that they, their company, or the FAA requires. If a user centered design process is used to develop these systems it is more likely that the resulting system meets the users' needs, and consequently, that users will not be inventing new ways of getting their work done.

Future Work

This work has been helpful in identifying potential future research areas regarding unintended use of aviation automation, but further research is needed before this approach could be considered ready to implement. The general approach of studying unintended usages of *present day* avionics and automation to learn more about the phenomenon of unintended use in NextGen is solid. The implementation of this idea could be improved in the following ways.

1. Solicit examples of unintended use from FAA Aviation Safety personnel.

The examples we used to develop our predictive approach were gathered from line pilots, who may be less familiar with the concept of unintended use than those working in the safety and certification industry. As it turned out, a number of the examples initially gathered from the pilot survey were determined not to be unintended uses after all. It may be the case that Aviation Safety personnel are more familiar with trends in unintended uses, and may have a different or broader perspective on this phenomenon.

2. Get system unintended usage likelihood rankings from FAA Aviation Safety personnel who have experience and insight into the ways that the systems are being used.

The work presented here used a small sample of two line pilot SMEs to rank order the systems in terms of their likelihood of being used in unintended ways, and there was a fair amount of disagreement in their data. This might have been due to the fact that one pilot SME flew mostly FMS-equipped aircraft, and the other (while retired for a number of years) flew mainly DC-9s or older military aircraft, and thus their perspectives on automation may have been different. It would also be helpful to get the same ranking data from others in the Aviation Safety industry to see how they compare. A user's perspective can often be quite different from an Aviation Safety person's perspective, and a larger sample size for these rankings would also be helpful in determining the validity of this approach.

3. Include an equal number of systems from two different groups: those which have invited unintended uses and those which have not.

Our data set was heavily biased (as originally intended) toward systems that have been associated with unintended uses. This is warranted when the goal is to extract relevant attributes related to unintended use, but for methodology assessment purposes it would be better to have larger, equal sets of systems that represent the signal (problematic systems) and noise (systems that do not invite unintended use).

4. Leverage system development and early operational data.

We believe that unintended uses are probably not complete surprises to the manufacturers and the FAA. There are likely many analyses, simulation and flight test reports where indications of unintended use are noted prior to application for certification. Flight data recorders can be used during early flight testing to capture instances of unintended use. Designated Engineering Representatives with a background in Human Factors or other engineering disciplines are often involved from the beginning of the certification process, and are aware of the applicant's early development work. Manufacturers may have a reason to believe that a system will be used for a purpose other than that which they intend (or equally, may not definitively know what the intended use might be for a new system), and those suspicions should be noted and factored in to any effort designed to anticipate problematic systems. Unintended uses known to the FAA prior to widespread usage can be addressed in design and training prior to operational fielding.

5. Apply methodology to mature NextGen automation.

When more is known about the user interfaces associated with new systems under development in NextGen it will be possible to apply this profiling methodology to predict which automation might prompt unintended uses. Ratings data can be collected from company pilots helping engineers to build the systems, and from FAA certification pilots. Once specific systems likely to be used in unintended ways are identified, resources can be allocated to study the likely specific unintended uses with those systems (most likely not a surprise, and known to the people described above) and the HESRA safety assessment methodology demonstrated in Loomis and Lakinsmith (2012) can be applied.

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Acronyms

Acronym	Definition
ADS-B	Automatic Dependent Surveillance-Broadcast
ATC	Air Traffic Control
FAA	Federal Aviation Administration
FCU	Flight Control Unit
FMGC	Flight Management Guidance Computer
FMS	Flight Management System
FPV	Flight Path Vector
GFMS	GPS Flight Management System
GPS	Global Positioning System
HAI	Human-Automation Interaction
HCI	Human Computer Interaction
HDG V/S	Heading Vertical/Speed
HESRA	Human Error and Safety Risk Analysis
HFE	Human Factors Engineer
HI	Hazard Index
MDU	Multi-function Display Unit
MTI	Monterey Technologies, Inc.
NAS	National Air Space
PF	Pilot Flying
PFD	Primary Flight Display
RPN	Risk Priority Numbers
SA	Situation Awareness
SME	Subject Matter Expert
TAI	Thermal Anti-Ice
TCAS	Traffic Alerts and Collision Avoidance System
TRK FPA	Track Flight Path Angle
U2	Unintended Use

VNAV	Vertical Navigation

Appendix A. Report #1.

Unintended Uses of Automation Human Factors Study

NASA Contract No. NNA07BB01C

Task Order Number: 01C-048

FAA Task/Annex Title: *Annex 14: Evaluation and Approval of Automated Systems – Mitigating Unintended Uses of Automation*

Deliverable No. 2 – Report #1

Part I: Data Collection and Attribute Extraction

4 December 2012

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Introduction

The main goal of this project is to develop a methodology that aircraft certification personnel can use to predict unintended uses (U2s) of NextGen automation. A related goal is to assess the safety implications of identified U2s, and to suggest potential mitigations for the predicted U2s. Ultimately we will implement the methodology in a checklist form that can be used by Aviation Safety personnel to evaluate presented equipment or procedures.

This report covers work in the first year of this two year project to develop a methodology to identify and evaluate new operating dynamics and unintended uses (U2s) of automation associated with NextGen technologies and procedures.

The first deliverable, the Interim Report, reviewed the status of the work accomplished in the initial months of the project, which included a literature review of prior work and search for examples of unintended uses. There has been much research in the area of humans and aviation automation, but little to none of it specifically addresses instances where automation is used in ways the designers or certifiers did not intend, nor does it address methods for predicting such phenomena in the future.

Since the Interim Report our efforts have been focused on identifying which flight tasks pilots are motivated to seek alternative or "better" ways of performing, understanding the nature of present day unintended uses in order that we may predict how the next generation of aviation automation may be used, and studying NextGen automation so that we may get a sense of how it may tempt pilots to use it in unanticipated ways.

Definitions and Assumptions

Our definition of automation is as follows:

> **Automation** is the independent accomplishment of a function by a device or system that was formerly carried out by a human (National Research Council, 1998; Parasuraman & Riley, 1997).

We assume the following definition of an "unintended use" for the purpose of this work:

An **unintended use** is a deliberate (i.e., non-accidental) use of NextGen automation other than that intended by the designers, sanctioned by management, or approved by the FAA.

- Emphasis is on potentially deleterious uses of NextGen automation.
- Includes behaviors provoked by the automation, e.g. attentional capture due to the compelling nature of a display.
- Does not include pilot errors.

The term "unintended" refers to the intent of the designer or the certifier, not the pilot; it is not to be confused with the term "unintentional".

The main premise of our approach is our original theoretical proposal that unintended uses arise when pilots are motivated to find alternative ways of accomplishing their goals in the cockpit, and that the affordances of the automation influence the development of alternative (unintended, unexpected) ways of performing their tasks.

A couple of assumptions support our methodology development. First, we firmly believe that something can be learned about unintended uses in general by studying unintended uses of *currently* fielded automation. We do not believe that NextGen automation is largely different from some types of present day automation that pilots use in unanticipated ways, and it is not unreasonable to expect that unintended uses of new automation would arise in similar ways as they do today. Therefore, once we understand the circumstances surrounding unintended uses of *current* automation, a methodology can be developed to project this knowledge into the future to predict unintended uses of NextGen automation.

Our second assumption concerns whether we are predicting individual, specific unintended uses, or rather helping the FAA to focus attention on equipment that may invite unintended uses. Our assumption is the latter; we seek to call attention to equipment that has the potential to encourage unintended uses. Unintended uses are driven as much by complex combinations of events surrounding individual contexts of use as they are the affordances of the automation, and these may not be known in advance. We envision that our work product will be used to screen new automated systems undergoing certification (or ideally, will be used during system development), and that it will be useful in identifying automation that *has the potential* to be used in ways that the designer, management, or the FAA had not intended.

Organization of this Report

This report comprises a collection of related efforts which as a group support the overall project goal to develop a predictive methodology to ultimately be used by Aviation Safety personnel.

Part Ia describes an informal survey we performed in the initial months of this project with commercial airline pilots to discover unintended uses of today's fielded cockpit automation. Part 1b describes a follow-on to this survey where Human Factors researchers extracted attributes from these examples for potential use in a tool for Aviation Safety personnel.

Part II describes a survey we administered to a different group of 24 airline pilots to identify the tasks where pilots are most likely (i.e. motivated) to discover and employ equipment in unintended ways. The hypothesis is that pilots invest their time and effort in finding "better ways" of accomplishing their tasks in areas where they perceive the most benefit, and that these efforts lead to the discovery of unintended uses (U2) of equipment.

Part III describes an initial three-pronged effort to try to identify U2s from NextGen avionic concepts as described in the Application Integrated Work Plan (AIWP), Version 2 (Capezzuto, 2010). This effort incorporated a literature review, brainstorming sessions with pilots, and affordance analyses to try to identify potential U2s from FAA concepts for NextGen Automatic Dependent Surveillance-Broadcast (ADS-B)- based, aircraft-to-aircraft applications.

Part Ia: Informal Survey of Examples of Current Unintended Uses

In the initial months of this project we conducted an informal survey of 24 airline pilots to gather examples of unintended uses of present day automation. The examples are intended to achieve a shared understanding of what is meant by "unintended use", and to provide the basis for understanding how and why currently fielded automation is used in unintended ways. The assumption is that by studying a group of these examples in detail it will be easier to find similarities and ultimately parameters useful in prediction for NextGen automation.

Method

Participants

Two experienced airline pilots, both with over 25 years of commercial piloting experience, were asked to participate as Subject Matter Experts (SMEs) in the identification of examples where commercial pilots use avionics and automated systems in ways unintended by the designer or manufacturer. Note that the SMEs are affiliated with Monterey Technologies, Inc.

SMEs reviewed the questions and points of interest described below with the researchers prior to starting to fill in the spreadsheet. In addition to documenting examples from their own experience, examples from colleagues comprised of 22 commercial pilots, all with various lengths of experience as captains. Colleagues were chosen on the basis of availability and willingness to participate as well as their experience with a variety of aircraft types including: Airbus 319, 320, Boeing 737-300, 747-400, 757, 767, 767-ER , 777, and McDonald Douglas DC-9, MD-11, and MD-80. Not all pilots contacted were able to provide any examples of unintended use. Examples were collected from the SMEs and colleagues over a period of 3 months.

Template/Questionnaire

Based upon questions and points of interest about unintended usage from the literature search as well as questions the researches had themselves, a set of questions about the examples was developed. A Microsoft Excel® spreadsheet was created with column headings for each of the questions and points of interest about each example. Additional descriptions were added after discussions between the researchers and SMEs to further clarify the intent of the questions. **Error! Reference source not found.** Table Ia-1d shows the field titles and descriptions used in the spreadsheet to document examples of unintended use.

Column Titles	Field Description
Description	A brief description of the unintended use of automation. What task was the actor trying to perform? What were the relevant circumstances (e.g. day, night)?
Actor	Was it the Captain or First Officer who used the equipment in an unintended way?
Actor's Goal	What goal was the actor trying to achieve, or what task was the actor attempting to perform when the unintended use occurred? Was he/she attempting to enter or change a flight plan segment? Was he/she attempting to check the weather for a specific area?

Column Titles	Field Description
How the equipment designer/mfr intended the equipment to be used	Describe the "standard", authorized, accepted way that the task is typically performed.
How the Actor used it instead	Describe the specific way in which the actor used the equipment in a way other than that which was envisioned by the designer.
Motivation or Need (what capability was not provided)	Specifically, why did the actor use the automation in this way? Why could he/she not have done what they needed to do using the avionics in the way they were supposed to be used?
Risk(s)	What risk did the actor put him/herself in by using the equipment in this way? Examples are, punishment or fines by his employer, loss of separation, etc. List all risks.
Cost	Monetary cost of the unintended use (e.g. extra fuel cost)
Reward(s)	What possible rewards could come from the unintended use of automation? Examples are, "on-time" flight status, collision avoidance, etc.
Avionics Equipment	What specific avionics were used in this example (e.g. the FMS)?
Aircraft Type	
Flight Phase	
Environmental	Were there any contributing weather parameters for this example?
Where did you hear about this practice?	This field is to document the source of the example, e.g. if it's commonly known among line pilots, etc.

Table Ia-1. Descriptions of Fields in Template/Spreadsheet of Examples

Results and Discussion

Commercial Aviation Examples of Unintended Uses of Automation

SMEs and colleagues identified 25 examples of what they believed to be use of flight deck automation in ways unintended by the manufacturer, airline, or FAA. The examples are listed below along with our research team's comments. The details of each example as written by the SMEs are shown in individual tables in Appendix A. Control click on *{Link}* next to the example number will take you to the specific table for that example.

25. *{Link}* In older Flight Management Systems (FMS's) pilots may add an additional waypoint 5 miles prior to a hard altitude crossing fix to begin an earlier reduction of airspeed for turbulent air penetration and provide a more comfortable ride for passengers when excessive tailwind during descent and descending into high altimeter settings will affect FMS descent calculations and not

allow the FMS profile to meet the target altitude.

Comment: Barometric pressure is set at 29.92 for all altitudes above 18K feet. When descending below 18K feet, barometric pressure might then be set at a value above 29.92, meaning the aircraft will be above the point the original descent calculations intended it to be, thus requiring a steeper descent to get to the required altitude at the crossing point. By starting descent earlier, the descent can be smoothed out. We believe that this is an example of an unintended use where pilots have worked around a 'glitch' where the design of the automation did not account for the 18K foot crossover. Apparently newer FMS's do account for the 18K foot crossover.

26. *{Link}* Use the TCAS selection of 5 or 10 NM display range to more accurately determine actual separation from preceding aircraft and provide an increased buffer behind heavy or turbulent aircraft to avoid upset in wake.

    Comment: TCAS is intended to alert the flight crew of potential collision situations. The use of the range arcs to monitor separation is not approved nor intended.

27. *{Link}* Prior to takeoff in low visibility, aircrew may adjust TCAS display to 5 NM range to accurately determine whether another aircraft is attempting to land.

    Comment: Given a low visibility situation, pilots want some way to augment surveillance of other aircraft in addition to relying on ATC to improve safety. TCAS provides additional information about relative position and direction of aircraft in the vicinity, so pilots use it even though it's not intended to provide traffic information for takeoff. We believe that this is an unintended use of the TCAS, but regard it as less potentially harmful than other unintended uses since it reflects the use of automation to augment information obtained from ATC and out-the-window sources.

28. *{Link}* Changing Cost Index in FMS to emphasize speed more than fuel or vice versa in the FMS to different than calculated value for personal gain/preference.

    Comment: The Cost Index weighting of time/speed versus fuel and other airline costs is intended to minimize airline costs rather than aircrew preferences. If aircrews feel the cost benefit to them is worth the cost and risk, then they can be expected to use it to their advantage. We do not believe that this is a true example of an unintended use as we have defined it. The FMS's Cost Index function was designed to allow the user to enter parameters of their own choice.

29. *{Link}* Adjusting the weather radar antenna to "paint" other aircraft in radar field of view to determine aircraft separation. Weather is superimposed on the Navigation Display and there are range marks to measure the distance. Used when TCAS was not available.

    Comment: Aircrew recognized that capability to identify and roughly measure distance to storm clouds could be applied to aircraft, which was valuable information not yet available from other flight deck instruments. Aircraft separation information could augment situational awareness from visual surveillance and potentially improve safety with little or no cost. Pilots recognized that the capabilities developed for weather could be applied to aircraft separation, and we regard this as a use that was not intended by developer or the FAA.

30. {Link} As a reminder to the pilot regarding the amount of fuel required at a certain point of a flight, the PF selects a fix on FIX page of the FMS and enters a bearing value that reflects the required fuel quantity at that point in flight plan.

    Comment: Aircrew is using the avionics as an alarm clock/memory 'jogger' to remind them to check the fuel at a certain point in the flight, which was not intended by the developer nor the FAA.

31. {Link} When an older FMS-equipped aircraft does not have capability to intercept an airway between two points, pilots may insert anchor points in the FMS to establish airway (jet route) starting point. This is done when one of two waypoints usually defining the desired navigation airway is behind the aircraft's current position and heading. Thus, the pilot has to position a waypoint in the FMS on the airway that's in front of the aircraft's current position to start that airway.

    Comment: Pilots found a relatively easy workaround for a system design that apparently did not consider the need to intercept an airway between its established waypoints. (Perhaps the pilots interpret it that way because of the irritation involved in having to add a waypoint, which may be how the manufacturer intended to intercept airways mid way.) This is another case where pilots had to work around gaps in the automation, and we consider this a valid example of an unintended use.

32. {Link} Modify calculated gross weight of aircraft for takeoff and landing entered in the FMS to meet weight requirements for takeoff or landing. Calculations are based on information provided to the pilot that the pilot then enters. The pilot is not expected to make/modify the estimate.

    Comment: Pilots know that fully loaded weight estimates are quite inaccurate and are usually overestimated. Thus in certain circumstances where they feel safety is not compromised, they are willing to make adjustments to weight estimates to save time and fuel costs. On takeoff, a lower weight will give you a higher V1 (abort) speed which can have a negative impact on stopping distance should the aircraft have to abort. We regard this as an unintended in the sense that this is an unsanctioned use of the FMS to enter a false value.

33. {Link} To meet altitude clearance requirements in some Airbus aircraft, pilots may enter a lower altitude in the FMGC to maintain higher rates of descent in the transition to a level off altitude at the cleared altitude which would not have be met if actual altitude was entered.

    Comment: Again, we consider this a valid example of an unintended use because pilots have learned a workaround to overcome a deficiency in the automation design using the FMGC in a way that the designer and FAA did not envision. Without this workaround, altitude clearances would not otherwise be met.

34. {Link} Using the alternate route (route 2) capability of some FMS's, pilot pre-programs an alternate route into FMS as an emergency high-terrain escape route to be used in the event of cabin depressurization and descent to a lower altitude is necessary.

Comment: We believe that this may actually be the intended use, especially if companies are spending time and money to validate these escape routes. It's an example of pre-loading information to reduce the number of tasks and associated time and stress required in an emergency situation.

35. {Link} When directed to change the start of decent point from that entered into the FMGC, pilots use FMGC to help the aircrew calculate a more precise descent point and to utilize the autopilots VNAV function to fly a parallel descent to a point & altitude that is not in specified in the navigation database/flight plan.

    Comment: We believe this is a valid unintended use. One of the problems frequently cited for automation is that it may not be able to quickly respond to system changes or unusual circumstances. In this case the automation cannot respond to an unanticipated change in ATC direction, forcing humans to calculate a new descent profile. Pilots have learned to use the part of calculations the automation can provide and then use heuristics to finish the calculations of the required descent. This use is unintended because it is being used to overcome a design flaw that does not accommodate changes in ATC commands.

36. {Link} PF cycles between the Track Flight Path Angle (TRK FPA) and the Heading Vertical/Speed (HDG V/S) switch on the Flight Control Unit (FCU) to compare actual AC heading with assigned ATC heading after entering assigned heading as a track in the TRK FPA mode.

    Comment: This is a valid unintended use. See detailed discussion in next section (or click on Link). Used as a work-around to respond to ATC commands and yet stay in track mode for the FPA support.

37. {Link} Aircrew adjust the radar altimeter warning altitude bug slightly out of the stowed or off position which causes the radar altimeter warning light to illuminate to remind them as they go through that altitude to open the fuel cross feed valve and reconfigure the wing fuel boost pumps to correct for a fuel imbalance.

    Comment: This is another example of the flight crew using the automation as an alarm clock or memory aid, which was not intended by the developer nor the FAA

38. {Link} Aircrew selects Anti-ice ON in descent page of FMS when Thermal Anti-Ice (TAI) will not actually be used in descent to ensure the FMS does not miscalculate the descent profile and miss the crossing restriction.

    Comment: Aircrew experience has been that the FMS miscalculates the descent profile, causing them to violate altitude restrictions. They have found an unintended way to 'tweak' the system for a higher rate of descent, thereby overcoming a system limitation and increasing the likelihood of meeting crossing restrictions.

39. {Link} Aircrews create designs such as Christmas Trees and Tic Tac Toe board with pixels in the Route 2 (inactive route) page of the Primary Flight Display for amusement.

    Comment: We believe this to be a valid unintended use. The pilot who gave this example mentioned that he experienced pilots playing with the FMS when it was first introduced and not later after they were more familiar with it. This type of "play" was an exercise to learn more about the capabilities of the system and explore the potential usefulness of various features.

40. {Link} Aircrews use the "Hold" page of the FMC to get information about the aircraft's best holding speed at current cruise altitude when asked by ATC for minimum speed at altitude.

    Comment: Selecting the 'Hold' page has the slight risk of subsequently actually selecting hold and sending the aircraft into the hold mode. Aircrews believe the risk to be minimal and the page easily provides the minimum speed at the current altitude in answer to ATC queries. Thus, not only does the page have information about the aircraft, it can provide information sensitive to the current context of the aircraft situation. This is not an unintended use as the display is providing the information it is intended to provide.

41. {Link} For fun, aircrew enters a pilot's name into a field intended for the flight number when entering route plan information into the GFMS such that the pilot's name show up on that page of the GFMS.

    Comment: This is a valid (though trivial) example of unintended usage.

42. {Link} Use of Vertical Speed (V/S) control of the FMC instead of VNAV for climbs to higher flight levels to reduce the rapid increase of engine thrust and higher pitch angles when climbing to higher cruise altitudes for passenger comfort.

    Comment: While the expectation is to continue to use VNAV for vertical climbs, the pilots have placed a higher value on passenger comfort and believe they can climb more comfortably using the V/S function. We regard this as an intended use, and may only be an issue if the stated policy is to use VNAV.

43. {Link} Use of the FIX Page Zulu time as an aide to mandatory position reporting during international crossings on Track Systems where there is a requirement for the aircrew to stay within 3 minutes of the time reported to the controlling agency.

    Comment: The Fix page on the FMS provides the capability to set a point and a radius of a specific distance around that point as well as the ability to mark a waypoint along the flight path according to ETA or altitude. In this case it seems like that the intended use of the Fix page on the FMS was general enough that this is probably not an unintended use.

44. {Link} Use of Fix Page for timely reminders.

    Comment: Another example of a use of the FIX page for a memory aid or alarm clock. Same comment as that for 19. This is probably not an unintended use.

45. {Link} Generating range circles around a fix or airport to visually identify climb altitude crossing restrictions to give the aircrew a visual depiction of the crossing restriction on the PRF without having to reference the paper charts

    Comment: Use of the capability on the FIX page to draw circles of specific radii labeled with the altitude. Same comment as that for 19. This is probably not an unintended use.

46. {Link} Generating lines of bearing to or from a Navaid or fix to identify airways not on the flight plan and provide a visual reference to the crew, identifying alternate airways or restricted areas.

    Comment: This is another example of an unintended use for the purpose of augmenting situation awareness.

47. {Link} Using a range circle to identify a crossing restriction which is not based on the active waypoint to provide a visual reference to identify a crossing restriction without changing the active waypoint or altering the flight plan route. Thus, the pilots are manually drawing on the PFD to make it look more like the charts, thereby making it easier to visualize the ATC restrictions.

    Comment: Extremely similar use as those listed in examples 20 and 21. Use of the FMS capability on the FIX page to draw circles of specific radii labeled with the altitude. This is probably not an unintended use.

48. {Link} Modifying altitude restriction from 10,000 ft to 10,001 to remove the speed reduction feature of the FMS.

    Comment: By modifying the altitude at 10,000 ft to 10,001 the aircraft will not calculate a speed reduction point and a higher descent speed can be maintained after level off at 10K. This is an Example (albeit a trivial example) of unintended use to enter slightly off altitude restriction to circumvent the speed reduction automation.

Avionics Cited in Examples

The avionic equipment most often cited in these examples by far is the Flight Management System (FMS) or GPS Flight Management System (GFMS) which was mentioned 15 times. The Multi-function Display Units (MDU) used for FMS/GFMS provide both flexible controls and displays that can be used for a wide variety of purposes. Displays and controls for several of the other avionics cited may be in the MDU as well. The controls and displays of the MDU as well as well as the other avionics will be further analyzed to try to identify the affordances that make them susceptible to unintended uses. Hopefully this analysis can then be applied to NextGen midterm avionics.

The breakdown of examples by avionic system is as follows:

Flight Management System / GPS Flight Management System (15)

- Examples: 1,4, 6, 7, 8, 9, 10, 11, 14, 16, 17, 18, 19, 20, 21, 22, 23

Terrain Collision Avoidance System (2)

- Examples: 2, 3

Weather Radar (1)

- Example: 5

Radar Altimeter (1)

- Example 13

Flight Path Vector / Vertical Speed Display/Control (1)

- Example 12, 18

Primary Flight Display (1)

Example 15

Part Ib: Attribute Extraction from Present-Day Examples

Overview

Three MTI researchers held a series of meetings to develop a prototype profiling methodology that would identify "suspect" automation likely to provoke unintended use. This method is based on practices in other countries and by some law enforcement agencies to isolate individuals of interest (e.g. terrorists) from a larger group of individuals. This approach scores individuals on a number of sub-critera that sum to an overall likelihood estimate that the person might have ill intentions. Their connections to other known terrorists are examined, as is their past history and their motivations. However, when applied to NextGen, the focus would be on *equipment and systems of interest* (e.g. ADSB-IN) rather than the pilots, and would examine the likelihood that the attributes of a particular system may invite behaviors that lead to unintended uses. This approach considers the equipment's functional capabilities and the likelihood that some of those things might invite unintended uses.

The first part of this process was aimed at identifying a set of automation attributes that may reflect a system's probability of being used in an unintended way. The next step was to assess selected automated systems implicated in some of the unintended usage examples on these attributes to see if any meaningful patterns emerge.

This should be viewed as a very preliminary attempt at developing a methodology, which requires additional attribute development, testing and discussion to understand how the FAA might adopt such an approach.

Procedure

Attribute identification

The first step in our process was to list automation attributes that might indicate a system's likelihood of being used in an unintended way. The attributes were developed based on an examination of the examples of current day unintended uses gathered to date. Because our ultimate goal is a checklist style tool these attributes were developed in question form. It is not the case that any one particular attribute would suggest likely unintended uses, but it may be the case that a combination of these attributes might indicate such. Table 1 contains a list of attributes, along with our rationale.

Attribute	Rationale
1. Is user interaction possible? I.e., is there a display or are there user controls?	Without a user interface, the probability that the system would be used in unintended ways is low.
2. Is the information being provided additional information to what is available prior to the addition of the avionics/automation?	New information offers potential for new actions or effects on decisions. New information may provide new opportunities to use the information in potentially unexpected ways, whereas if the information already exists, the unexpected uses probably would

	have already been tried.
3. Is the form or content of the information new?	A new capability, display or mode may evoke exploratory behavior in the cockpit (e.g. "what else can this thing do?")
4. Is this a component of an integrated system? (e.g. weight on wheels sensor) If YES, can you transfer information/data from one system to another?	Automation that is integrated with other subsystems onboard the aircraft have a greater potential to affect system safety, and the capability to combine functions/information in new ways.
5. Can the pilot usefully combine the information from this system with information from other systems or existing knowledge (e.g., combining newly available flight ID data with prior knowledge about a particular carrier's tendencies)?	Information enables action. Unexpected uses may potentially arise from new combinations of information or functions.
6. Does the system provide information that evokes an action?	If the system tells the user to do something like: "Pull up" or "veer right", maybe the user could respond with other actions.
7. Does the display portray the information as having more detail and accuracy than ground truth or reality?	People seek more accurate or unambiguous information. The portrayal of greater detail or accuracy may engender unwarranted decisions or actions. Pilots may attempt to use the device for a purpose that requires more accuracy than the device has, e.g., using an auto GPS for aircraft navigation.
8. Can the user put something on the display that has nothing to do with the purpose/function of the display? (e.g. scratchpad or other free text entry functionality).	Freeform input potentially opens the use of the device to more uses. Also, may interact adversely with intended functions
9. Is there inherent complexity that invites exploration (numerous pages/modes) – are the users familiar with all the pages or modes?	Complexity suggests not all interactions are known. Familiarity suggests the pilot spends a lot of time with the system and has more opportunity to discover new forms of use. When flight crews are required to use at least a portion of complex devices like the FMS, they continually are confronted with other modes/and options with which they are not familiar and may become curious and begin to explore which may lead to uses of modes not

	fully understood, or discoveries of other capabilities interesting to the pilot, but not intended by the designer.
10. Has the system been implicated previously as a problem area in legacy systems?[14]	When the device is similar to other devices that have a history of unintended use, the new device can be expected to have the same unintended uses. Known problems with legacy systems should be corrected or similar problems can continue.
11. Does the system provide information about other systems outside of own aircraft? (e.g., flight ID of proximal A/C, pilots' names, their destination)	Opening up the domain to which the information applies may also open up the possibilities for new and unintended uses.
12. Can the information be used for reasons other than normal pilot duties? (e.g., internet to check stock values, movies for entertainment)	If the database provides access to a wide variety of types, or extensive instances of limited data, it provides the opportunity for an expanded number of uses, e.g., all Aircraft in the NAS, a comprehensive weather database).
13. Can you query the system for information from limited or larger data base, e.g., all AC in NAS (e.g. a weather database).	Pictures and graphics attract attention and can frequently be interpreted in different ways.
14. If pictographic imagery is displayed, does the display portray rapid or continuous movement: Is the display dynamic? Is there a potential for attentional capture?	Moving imagery is attractive and may 'tunnel' attention beyond what is warranted for that display and away from more important information, like out the windshield viewing.
15. If pictographic imagery is displayed, does the display portray rapid or continuous movement (is the display dynamic)? (is there a potential for attentional capture?)	Perhaps the certifier has experience with a similar device or perhaps the certifier recognizes that the device seems to satisfy a known problem area or gap. Further, if the designer/developer specifically states that the device is not to be used for something – might the flight crew try to use it for that, e.g., TCAS

[14] *While the focus of this effort is on pilot motivation and automation affordances, historical and collateral data should be taken into account when investigating whether or not a NextGen system is likely to invite unintended uses.*

	for separation?
16. Is there evidence to suggest that the applicant (manufacturer) believes that the system will be used for purposes other than those for which certification is being sought?[15]	Information that is useful outside of normal pilot duties may evoke those outside uses. An example that is less straight forward than those given with the attribute might be – weather information. (e.g., internet to check stock values, movies for entertainment)

Automation assessment

This set of questions was applied to three of the present-day examples gathered in our informal survey (described in Part Ia), representing a harmful and a benign unintended use, and an authorized use:

Example of a potentially harmful unintended use: Use the TCAS selection of 5 or 10 NM display range to more accurately determine actual separation from preceding aircraft and provide an increased buffer behind heavy or turbulent aircraft to avoid upset in wake. This is not an authorized use of the TCAS display.

Example of an unintended use that may not be harmful: Prior to takeoff in low visibility, aircrew may adjust TCAS display to 5 NM range to accurately determine whether another aircraft is attempting to land. As long as the crew are using the TCAS display to provide additional situation awareness information to that coming from their out the window view and from other sources, it may not be harmful.

Example of an authorized use: Changing the Cost Index in FMS to emphasize speed more than fuel or vice versa in the FMS to different than calculated value for personal gain/preference.

The research team answered the questions using a "Yes" or a "No" for both examples, considering the *system* referenced in each of these examples as if it had been submitted for certification by the FAA (this is how the ultimate user of our work product might use such a tool). During this process the team did not consider the unintended use per se, but rather focused on the *equipment* or *automation* that had been used in an unintended way.

The objective of this procedure was to try to discover patterns of similarities and differences across these attributes, and narrow the attribute list to a set that effectively discriminates unintended uses (particularly harmful ones) from authorized uses.

[15] *While the focus of this effort is on pilot motivation and automation affordances, historical and collateral data should be taken into account when investigating whether or not a NextGen system is likely to invite unintended uses.*

Ultimately we would like to change the attribute assessment from a binary one (e.g. does the automation have the characteristic or not?) to an analog or continuous value (e.g. how much of the attribute does the automation have?).

	Potentially harmful unintended use	Potentially harmful unintended use	Potentially benign unintended use	Authorized use
Current-day Unintended Use	Use the TCAS selection of 5 or 10 NM display range to more accurately determine actual separation from preceding aircraft and provide an increased buffer behind heavy or turbulent aircraft to avoid upset in wake.	Pilots may use the FMS to add an additional waypoint 5 miles prior to a hard altitude crossing fix to begin an earlier reduction of airspeed for turbulent air penetration and provide a more comfortable ride for passengers when excessive tailwind during descent and descending into high altimeter settings will affect FMS descent calculations and not allow the FMS profile to meet the target altitude.	Prior to takeoff in low visibility, aircrew may adjust TCAS display to 5 NM range to accurately determine whether another aircraft is attempting to land.	Changing the Cost Index in FMS to emphasize speed more than fuel or vice versa in the FMS to different than calculated value for personal gain/preference.
		SYSTEM		
Attribute	**TCAS**	**NAV page within FMS**	**TCAS**	**Cost Index function within FMS**
1. Is user interaction possible? I.e., is there a display or are there	Y	Y	Y	Y

user controls?				
2. Is the information being provided additional information to what is available prior to the addition of the avionics/automation?	Y	Y	Y	N
3. Is the form or content of the information new?	Y	Y	Y	N
4. Can the system of interest transfer information/data to another cockpit system?	Y	Y (rated HIGH)	Y	Y
5. Can the pilot usefully combine the information from this system with information from other systems or existing knowledge (e.g., combining newly available flight ID data with prior knowledge about a particular carrier's tendencies)?	N	Y	Y	N
6. Does the system provide information that evokes an action from the crew?	Y	Y	Y	N
7. Does the display portray the information as having more detail and accuracy than ground truth or reality?	Y	N	Y	N
8. Can the user put something on the display that has nothing to do	N	Y	N	Y

with the purpose/function of the display? (e.g. scratchpad or other free text entry functionality).				
9. Is there inherent complexity that invites exploration (numerous pages/modes) – are the users familiar with all the pages or modes?	N	Y	N	Y
10. Has the system been implicated previously as a problem area in legacy systems?[16]	Y	Y	Y	N
11. Does the system provide information about other systems outside of own aircraft? (e.g., flight ID of proximal A/C, pilots' names, their destination)	Y	N	Y	N
12. Can the information be used for reasons other than normal pilot duties? (e.g., internet to check stock values, movies for entertainment)	N	N	N	N
13. Can you query the system for information from limited or larger data base, e.g., all AC in NAS (e.g. a weather database).	N	N	N	N

[16] *While the focus of this effort is on pilot motivation and automation affordances, historical and collateral data should betaken into account when investigating whether or not a NextGen system is likely to invite unintended uses.*

14. If pictographic imagery is displayed, does the display portray rapid or continuous movement: Is the display dynamic? Is there a potential for attentional capture?	Y	Y (rated low on the scale)	Y	N
15. Is there evidence to suggest that the applicant (manufacturer) believes that the system will be used for purposes other than those for which certification is being sought?[17]	Y	N	Y	N
16. Can unauthorized software be added to the system?	N	N	N	N

Table Ia-1. Automation assessment results for three fielded systems.

[17] *While the focus of this effort is on pilot motivation and automation affordances, historical and collateral data should be taken into account when investigating whether or not a NextGen system is likely to invite unintended uses.*

Items 2,3,6,7,8,9,10,11,14 and 15 appear to discriminate between a system that has the potential for unintended use (TCAS) and one that does not (the FMS Cost Index function). Again, our profiling methodology is not attempting to predict specific instances of unintended use, but instead to identify systems that have the potential to invite unintended uses.

Discussion

This is a preliminary attempt to develop a profiling methodology to indentify automation that is likely to invite unintended use. If the automation assessment information were translated into a checklist format such as that used by Chamberlain et. al (2003), a certifier could use it to single out automation that might warrant a higher level of scrutiny in the certification process.

Clearly, much more work needs to be done to identify candidate attributes and test the sensitivity of them to the nuances in the automation that might indicate a potential for unintended use. It would be helpful to perform the automation assessment on all examples obtained in our informal pilot survey, to get a better sense of the assessment's sensitivity to the characteristics thought to identify problematic automation.

It may also be helpful to take a specific bit of NextGen automation from Part III and apply the Automation Assessment to it and see if it predicts any of the U2s identified in the pilot brainstorming sessions.

We have not yet fully considered the affordances of NextGen automation identified in Part III to the Attribute Identification and Automation Assessment piece. Those affordances might lead to additional attributes.

It is not yet clear to us how we might tie in motivation ratings results. Clearly the methodology suggests that it is the intersection between the profiled automation and levels of high motivation that predict the what and when of unintended use, but at the moment it is not clear to us how to do that. In addition, we would like to develop a scoring approach that enables the user to determine when the evidence for a particular piece of automation is strong enough to suggest likely intended use.

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Acronyms

Acronym	Definition
FAA	Federal Aviation Administration
FCU	Flight Control Unit
FMGC	Flight Management Guidance Computer
FMS	Flight Management System
FPV	Flight Path Vector
GFMS	GPS Flight Management System
GPS	Global Positioning System
MDU	Multi-function Display Unit
NAS	National Air Space
PFD	Primary Flight Display
SA	Situation Awareness
SME	Subject Matter Expert
TCAS	Traffic Alerts and Collision Avoidance System
VNAV	Vertical Navigation

Appendix I-1. Details from Pilot Example Spreadsheet

Example 1. **Back to Top**

Field	**Responses**
Description	Adding an additional waypoint 5 miles prior to a hard altitude crossing fix .
Actor (Captain or First Officer)	Either
Actor's Goal	Providing a 5-mile buffer to meet the altitude restriction.
Intended usage	Accept the flight plan/FMS waypoint and crossing restriction and do not alter.
Actor's usage	Captain or First Officer altered the descent profile.
Motivation or Need	To ensure the FMS does not miscalculate the descent profile and miss the crossing restriction.
Risk(s)	Improper entry of data into FMS resulting in altitude deviation
Cost	Possible additional fuel cost due to being at lower altitude for longer duration.
Reward(s)	Ensure altitude compliance. Additional buffer can be used to reduce airspeed for turbulent air penetration and provide a more comfortable ride for passengers.
Avionics Equipment	FMS, GFMS
Aircraft Type	All FMS, GFMS aircraft.
Flight Phase	Descent
Environmental	Excessive tailwind during descent and descending into high altimeter settings will affect FMS descent calculations and not allow the FMS profile to meet the target altitude.
Where heard	Common practice for FMS aircraft.

Example 2. **Back to Top**

Field	**Responses**
Description	Using TCAS display for aircraft separation

Field	Responses
Actor	Either
Actor's Goal	Provide internal separation for wake turbulence from preceding aircraft.
Intended usage	Accept separation provided by ATC.
Actor's usage	Adjust TCAS display to 5 or 10 NM range to accurately determine actual separation of preceding a/c.
Motivation or Need	TCAS not procedurally used to provide separation other than conflict resolution for collision avoidance. In IFR, ATC is required to provide separation.
Risk(s)	Not a violation to use TCAS for separation and situational awareness. Only risk is reduced visual lookout in high density areas when concentrating on display.
Cost	None
Reward(s)	Increased buffer for separation behind heavy or turbulent a/c to avoid upset in wake
Avionics Equipment	TCAS
Aircraft Type	All TCAS equipped a/c.
Flight Phase	Any, but usually Approach phase
Environmental	None, but more frequently used in IMC.
Where heard	Common practice for TCAS aircraft.

Example 3. **Back to Top**

Field	Responses
Description	Using TCAS display to determine whether or not an aircraft is attempting to land
Actor	Either
Actor's Goal	Provide internal separation for clearing final approach corridor prior to taking runway.

Field	**Responses**
Intended usage	Accept separation provided by ATC/Tower.
Actor’s usage	Adjust TCAS display to 5 NM range to accurately determine if another a/c is attempting to land.
Motivation or Need	TCAS not procedurally used to provide separation other than conflict resolution for collision avoidance. In IFR, ATC is required to provide separation.
Risk(s)	None
Cost	None
Reward(s)	Collision avoidance.
Avionics Equipment	TCAS
Aircraft Type	All TCAS equipped a/c.
Flight Phase	Prior to T/O.
Environmental	None, but more frequently used in IMC.
Where heard	Common practice for TCAS aircraft.

Example 4. **Back to Top**

Field	**Responses**
Description	Changing Cost Index in FMS to different than calculated value.
Actor	Either
Actor’s Goal	Either increase or decrease airspeeds calculated by FMS to increase or decrease time of flight.
Intended usage	Enter Cost Index as calculated by company flight planning computers.
Actor’s usage	Pilot modifies Cost Index value for personal preference.
Motivation or Need	Easiest way to program FMS to increase or decrease flight time.
Risk(s)	Excessive speed might reduce min. fuel at arrival and cause diversion. Greatly reducing speed will reduce stall margin. Slow flight used to increase pilot's pay and could result in disciplinary action by employer.
Cost	Exceeds programmed fuel costs for both fast and slow flights.

Field	Responses
Reward(s)	Getting to gate on time or getting home on time for fast flight. Increased pay for flight if slow flight.
Avionics Equipment	FMS or PMS
Aircraft Type	All FMS, GFMS aircraft
Flight Phase	Any
Environmental	None
Where heard	Common

Example 5. **Back to Top**

Field	Responses
Description	Using weather radar for a/c separation.
Actor	Either
Actor’s Goal	Provide separation, ranging and situational awareness.
Intended usage	Used for weather only.
Actor’s usage	Radar antenna may be adjusted to "paint" other a/c in radar field of view.
Motivation or Need	Can be used in non-radar/oceanic environment for SA.
Risk(s)	None
Cost	Increased time on radar for no operational gain.
Reward(s)	Situational awareness.
Avionics Equipment	WX Radar
Aircraft Type	All WX Radar equipped a/c.
Flight Phase	Any, but usually in cruise.
Environmental	Can only be used in clear WX with no or minimal returns to be able to identify a/c.
Where heard	Common during long oceanic flights.

Example 6. **Back to Top**

Field	Responses
Description	Use FIX page to enter visual, "target fuel " entries on HSI.
Actor	Either
Actor's Goal	Have a visual reference of fuel requirements displayed on HSI.
Intended usage	Used to identify a fix for information or navigation.
Actor's usage	PF selects a fix on FIX page and enters a bearing value that reflects the required fuel quantity at that point in flight plan.
Motivation or Need	FMS not capable of making fuel entries in HSI along route of flight.
Risk(s)	None
Cost	None
Reward(s)	Fuel awareness
Avionics Equipment	FMS
Aircraft Type	All FMS, GFMS aircraft.
Flight Phase	Cruise
Environmental	None
Where heard	Common during oceanic flights

Example 7. **Back to Top**

Field	**Responses**
Description	Intercept airway.
Actor	Either
Actor's Goal	Intercept airway between to fixes.
Intended usage	Some (older) FMS equipped a/c do not have capability to intercept airway between two points.
Actor's usage	Insert anchor point to establish airway starting point.
Motivation or Need	Capability does not reside in older FMS.
Risk(s)	Inaccurate data entry.
Cost	None
Reward(s)	Gives intercept capability to FMS.
Avionics Equipment	FMS
Aircraft Type	All FMS, GFMS aircraft.
Flight Phase	Any
Environmental	None
Where heard	Technique taught in ground school.

Example 8. **Back to Top**

Field	**Responses**
Description	Modify calculated gross weight of a/c.
Actor	Either
Actor's Goal	Modify a/c gross weight to within limitations.
Intended usage	Enter accurate data.
Actor's usage	Modify Zero Fuel Weight (ZFW) in fuel quantity guage to adjust a/c gross weight.
Motivation or Need	Adjust gross weight to not exceed weight limitations.
Risk(s)	High risk. Violation of company procedures and FAR.
Cost	Cost of overweight inspection if situation is identified.
Reward(s)	Saves time and fuel.
Avionics Equipment	Fuel quantity totalizer and FMS
Aircraft Type	DC-9/MD-80
Flight Phase	Before T/O or LNDG
Environmental	None
Where heard	Not common or accepted but used.

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Field	Responses
Description	Input of lower altitude in the FMGC so as to maintain higher rates of descent in the transition to a level off altitude
Actor	Either
Actor's Goal	Level off prior to or over mandatory crossing altitude on an arrival prodecure
Intended usage	On descent, both the FMGC and FCU are programmed for the same level off altitudes
Actor's usage	PF tricks the FMGC into thinking it needs to be at a lower altitude at a particular mandatory crossing altitude. For example, the mandatory crossing altitude on an arrival is 12,000 feet. 12,000 feet is input into the FCU (the auto pilot will not let the aircraft descend below the altitude input and displayed in the FCS). Then, the PF inputs 11,700 feet into the FMGC which in effect increases the rate of descent to 12,000 feet.
Motivation or Need	Pilot is trying to conform to clearance. A-320 auto-pilot "smooth to a fault" and does not fully anticipate level off altitudes during the final stages of descent. Descent rates are significantly reduced during the last 300-400 feet above level off even if the aircraft will be high over a mandatory crossing altitude on an arrival procedure.
Risk(s)	May not comply with standard procedures for vertical navigation
Cost	Unknown
Reward(s)	Decrease the chance of aircraft being above the mandatory crossing altitude on an arrival procedure
Avionics Equipment	Flight Management Guidance Computer (FMGC) & Flight Computer Unit
Aircraft Type	A-320
Flight Phase	Cruise, prior to descent
Environmental	
Where heard	Cited by colleagues

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Field	Responses

Field	**Responses**
Description	High terrain escape routes preprogrammed into FMS. (Escape routes are used in the event of cabin depressurization and descent to a lower altitude is necessary)
Actor	Company directed and implemented. Utilized by Either Pilot Flying and Pilot Monitoring
Actor's Goal	To provide visual representation of predetermined terrain escape routes while operating over mountainous terrain
Intended usage	Point to point enroute navigation and approach
Actor's usage	Escape route alternate airport programmed as RTE 2 destination by pilots. Critical terrain escape routes are found preprogrammed where STAR's are normally programmed on DEP/ARR page of FMC in Route 2
Motivation or Need	To ensure a pre planned escape from high terrain is programmed in FMC.
Risk(s)	Involves closer monitoring of position to ensure proper escape route is programmed .
Cost	Time and money spent by the company to develop, program and validate escape route data in FMC
Reward(s)	Helps maintain situational awareness of planned escape route. Has preprogrammed escape route visible and ready to activate on FMC if needed
Avionics Equipment	FMC
Aircraft Type	757/767
Flight Phase	Climb, cruise or descent
Environmental	
Where heard	Company directed and implemented. Standard procedure when operatiing over mountainous terrain.

Example 11.

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Field	Responses
Description	Use FMGC to help the aircrew calculate a more precise descent point and to utilize the autopilots VNAV function to fly a parallel descent to a point & altitude that is not in specified in the navigation database/flight plan
Actor	Either
Actor's Goal	To employ the VNAV function of the autopilot to descend to a point & altitude not specified in the navigation database/flightplan
Intended usage	In a managed descent mode to a specified fix and altitude programmed into the FMGC
Actor's usage	Condition - ATC has assigned the aircraft to descend and level-off at a point not specified in the navigation database/flight plan. For example, the programmed crossing altitude is FL 250 at the "XYZ" fix. Now, ATC directs the flight to cross 30 miles this side of "XYZ" at FL 250. Aircrew verifies FL 250 set for fix "XYZ", which visually displays the calculated descent point. Aircrew now mentally computes a 3 to 1 descent (300' lost for every 1 NM traversed), taking into account known head or tail winds to come up with a modified descent point. Then a alternate "thrust idle, open descent mode' is used to fly a parallel descent to the ATC directed point & altitude.
Motivation or Need	Allows aircrew to visualize and calculate a more precise descent point and use the VNAV function of the autopilot for descent
Risk(s)	If you stay in a managed descent mode the aircraft will level 30 miles late at fix "XYZ" & FL 250. This is very bad.
Cost	Possible loss of vertical and or horizontal separation and flight violation.
Reward(s)	Visual aid to view and aid in the calculation of a more prescise descent point. Allows for a idle thrust parallel descent which saves fuel.
Avionics Equipment	GFMS
Aircraft Type	A-319/320
Flight Phase	Top of descent or descent
Environmental	Would add to aircrew situational awareness and taking into account tailwinds which would put the aircraft high and/or fast over an assigned point & altitude.
Where heard	Colleague

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Field	**Responses**

PF cycles between the Track Flight Path Angle (TRK FPA) and the Heading Vertical/Speed (HDG V/S) switch on the Flight Control Unit (FCU) to compare actual AC heading with assigned ATC heading after entering assigned heading as a track in the TRK FPA mode.

There are two modes associated with the Airbus Flight Control Unit (FCU) shown below: Track with Flight Path Angle (TRK FPA) and Heading with Vertical Speed (HDG V/S).

A320 Flight Control Unit (FCU)
http://www.meriweather.com/320/glare/fcu.html
Screen clipping taken: 6/7/2011, 12:49 PM

Description

The switch in the middle of the panel toggles the FCU mode between HDG V/S) and TRK FPA:

- When in the TRK FPA mode (not displayed in the FCU picture above), track can be entered by twisting the knob with the blue triangle and is displayed where the dashes are shown above the knob. In this mode the Flight Path Angle in degrees is set by the knob on the far right and the value visible where the dashes are shown above the knob. When in TRK FPA mode, a Flight Path Director or 'bird' is displayed on the PFD and the AC autopilot adjusts descent rate to maintain the FPA entered to arrive over the Final Approach Fix (FAF) at the published altitude.
- When in the HDG V/S mode, heading can be entered by twisting the knob with the blue triangle and is displayed where the dashes are shown above the knob. In this mode vertical speed in feet per minute is set by the knob on the far right and visible where the dashes are shown above the knob. When in HDG V/S mode the Flight Path Director is not available on the PFD and the PF must manually adjust AC vertical speed to compensate for a headwind or tailwind to arrive

Field	Responses
	over the FAF at the published altitude. Airline directives (of some airlines) as well as reduced workload from the Flight Path Director and the autopilot's maintenance of the FPA provide strong motivation to the pilot to use the TRK FPA mode. ATC, however, assigns vectors in terms of heading. Standard practice is to enter the ATC headings into the Track setting in the HDG-FPA mode. Normally, this practice does not cause much of a problem. When flying a non-precision approach in strong crosswinds the PF must be mindful of the difference between heading and track (and thus the difference between ATC assigned heading and actual heading). PF may cycle from TRK FPA to HDG V/S to view the difference between the AC's actual HDG and the HDG assigned by ATC. Then, with the motivation of using FPA and the Flight Path Director 'bird', the PF may cycle back to the TRK FPA mode and re-engage the FPA.
Actor	PF
Actor's Goal	Maintain ATC's assigned HDG while adhering to Airline directives and using the Flight Path Director and FPA to reduce workload.
Intended usage	Stay in one mode or the other, usually the HDG V/S. However in a non-precision, glide slope inoperative situation, TRK FPA is very helpful.
Actor's usage	**Cycle from TRK FPA mode to HDG V/S mode to view AC actual heading and note difference from ATC assigned heading.**
Motivation or Need	**Motivation to cycle into HDG V/S - PF needs to see AC's actual heading which requires switching to the HDG V/S mode.**
Risk(s)	Commencing approach in an unintended Flight Director Mode. Confusion of heading and track.
Cost	Unknown
Reward(s)	Allows the PF to effectively use the Flight Path Vector (FPV) display to get a "fly to" flight director using track when ATC assigned headings or vectors.
Avionics Equipment	Flight Control Unit, Heading with Vertical Speed (HDG V/S) and Track with Flight Path Angle (TRK FPA) modes PFD – Flight Path Director
Aircraft Type	A-319/320
Flight Phase	Non-precision approach where glide slope is not available.

Field	Responses
Environmental	Wind direction, relative to assigned heading and the velocity of the wind a significant factor.
Where heard	Commonly used technique?

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Field	**Responses**
Description	Use of the radar altimeter "low altitude" warning light as a visual reminder
Actor	Either Captain or First Officer
Actor's Goal	Provide a supplemental reminder that the fuel cross-feed valve is open and wing fuel boost pumps are in a non-standard configuration
Intended usage	Radar altimeter warning lights are used in conjunction with the respective Captain's and First Officer's radar altimeter indicator. Aircrew preselects an altitude value between 0-5000 feet AGL in the radar altimeter so as to provide a visual alert, i.e. a yellow light, when the aircraft descends through the preselected altitude. This preselected altitude is most often an approach minimum descent altitude
Actor's usage	Aircrew, normally the PF, moves radar altimeter warning altitude bug slightly out of the stowed or off position which causes the radar altimeter warning light to illuminate. Once this happens, the PF opens the fuel cross feed valve and reconfigures the wing fuel boost pumps to correct for a wing fuel imbalance. The radar altimeter warning light provides a supplemental, visual indication that the fuel system is in a non standard configuration.
Motivation or Need	Prospective memory aid to remind pilot that the fuel system is in a non standard configuration that could lead to an unsafe condition such as a significant fuel wing imbalance and/or fuel starvation.
Risk(s)	If used as a reminder for other non standard configurations, the aircrew could become desensitized to the importance of the illumination of the radar warning light.
Cost	None
Reward(s)	Reduces the risk of leaving the fuel cross-feed valve and wing fuel boost pumps in a non standard configuration. Prolonged operations in with the fuel cross-feed open and the wing fuel boost pumps in a non standard configuration could lead to unsafe fuel imbalances in the wing tanks, and under certain conditions may cause fuel starvation to an engine.
Avionics Equipment	Captain and First Officer's radar altimeter and associated altimeter warning light (yellow)
Aircraft Type	DC-9 50/40/30

Field	Responses
Flight Phase	Cruise. Opening the fuel cross-feed and turning off selected wing fuel boost pumps to correct a fuel imbalance is discouraged in higher workload flight conditions such as climb, descent and approach.
Environmental	Not known
Where heard	Varied – One airline directs the use of the TRK FPA mode of the FCU during certain non-precision approaches, e.g., ILS with glide slope inoperative. Another airline trains very little in the functions of the TRK FPA mode of the flight director and does not encourage its use.

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Field	Responses
Description	Selecting Anti-ice ON in descent page of FMS a/c when Thermal Anti-Ice (TAI) will not be used in descent.
Actor	Pilot Flying
Actor's Goal	Trick the FMS into calculating the descent profile with TAI ON in order to alter the descent profile to meet crossing restriction.
Intended usage	Accept FMS descent profile.
Actor's usage	Captain or First Officer altered the descent profile by entering bogus data.
Motivation or Need	To ensure the FMS does not miscalculate the descent profile and miss the crossing restriction.
Risk(s)	No Risk
Cost	Higher power setting during descent. Possible additional fuel cost due to being at lower altitude for longer duration.
Reward(s)	Ensure altitude compliance. Additional buffer can be used to reduce airspeed for turbulent air penetration and provide a more comfortable ride for passengers.
Avionics Equipment	FMS
Aircraft Type	All FMS equipped aircraft

Field	Responses
Flight Phase	Descent
Environmental	Excessive tailwind during descent and descending into high altimeter settings will affect FMS descent calculations and not allow the FMS profile to meet the target altitude.
Where heard	Common practice for FMS aircraft.

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Field	Responses
Description	Creating designs such as Christmas Trees and Tic Tac Toe lines with pixels in the Route 2 (inactive route) page of the Primary Flight Display for amusement
Actor	Either
Actor's Goal	Amusement
Intended usage	Primary Flight Display
Actor's usage	Making designs by entering bogus data into the FMS
Motivation or Need	Amusement
Risk(s)	Route 2 display momentarily unavailable should it be needed. Slight possibility of altering actual flight path by accident. Pilot's attention diverted from flight duties.
Cost	Time and Pilot attention
Reward(s)	Amusement
Avionics Equipment	FMS / PFD
Aircraft Type	All FMS equipped aircraft
Flight Phase	En-Route
Environmental	N/A
Where heard	Shown by fellow pilot

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Field	Responses
Description	Use of the "Hold" page of the FMC to get information about the aircraft's best holding speed at current cruise altitude when asked by ATC for minimum speed at altitude.
Actor	Either
Actor's Goal	Quickly obtain information about the aircraft's best holding speed at a particular cruise altitude. This ensures the speed is safe.
Intended usage	Set a holding speed.
Actor's usage	Quickly obtain information about minimum speed at cruise altitude.
Motivation or Need	Easiest way to access the information
Risk(s)	Just be sure you do NOT hit the execute button, or the airplane WILL try to enter holding at present position.
Cost	No cost compared to time and effort required to obtain the information elsewhere.
Reward(s)	Easy access to information
Avionics Equipment	FMC/FMS Holding page
Aircraft Type	Any FMS aircraft
Flight Phase	Usually cruise
Environmental	N/A
Where heard	Used by Pilot reporting - This is certainly not what the hold function of the FMC was designed for, but I have used it for that more often than for actual holds.

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Field	Responses
Description	Entering pilot's names into a GFMS field intended for the flight number when entering route plan information into the GFMS.
Actor	Either
Actor's Goal	Amusement and gaining understanding of FMS

Field	**Responses**
Intended usage	Show flight number on the GFMS route page. Apparently, contents of field do not show up or are used elsewhere.
Actor's usage	Show's name associated with route in GFMS on that page, for fun.
Motivation or Need	Amusement
Risk(s)	None identified
Cost	Time and Pilot attention
Reward(s)	Amusement
Avionics Equipment	GFMS/FMS
Aircraft Type	All FMS equipped aircraft
Flight Phase	Pre-flight
Environmental	N/A
Where heard	Done by respondent

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Field	**Responses**
Description	Use of V/S function of the FMC for climbs to higher flight levels
Actor	PF
Actor's Goal	To reduce the rapid increase of engine thrust and higher pitch angles when climbing to higher cruise altitudes
Intended usage	During cruise flight the autopilot would typically remain in the VNAV mode. If there is a change in cruise flight level, 2000 feet or greater, and the autopilot remains in VNAV, the power will go to full climb thrust and the nose will pitch up. During long international flight and domestic red-eye flights this can be a nuisance for sleeping passengers

Field	**Responses**
Actor's usage	Some pilots have developed a technique to use the V/S mode of the autopilot to change flight levels so as to not disturb passengers who may be sleeping on long international flights or on red-eye flights. This is accomplished by changing the Cruise flight Level in the FMC and selecting the V/S mode as opposed to leaving the autopilot in the VNAV mode. Once V/S is selected, the FPM window opens and the rate of climb (Feet Per Minute -FPM) can be slowly increased. Once the power reaches full Climb power, VNAV is re-engaged for the final portion of the climb.
Motivation or Need	Passenger comfort
Risk(s)	VNAV takes into account aircraft performance, so using V/S the entire climb may create some risk depending on aircraft weight and change in the cruise flight level.
Cost	Negligible
Reward(s)	Passenger comfort
Avionics Equipment	FMC
Aircraft Type	Boeing 757-200, 757-300 767-300, 767-300ER
Flight Phase	Cruise
Environmental	
Where heard	Technique learned during line operations

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Field	Responses
Description	This example the same as #14 except it is a different aircraft type(s) VNAV descent programmed with the engine anti-ice on even though it [engine anti-ice] is not required
Actor	Either
Actor's Goal	Create an earlier Top of Descent so as to arrive at a mandatory crossing altitude sooner
Intended usage	VNAV descent programmed based on whether or not icing conditions are present or expected
Actor's usage	Captain or First Officer programmed the VNAV descent with the Engine Anti-ice so as to make the FMS believe it will descend at a higher power setting
Motivation or Need	This technique creates a more conservative descent profile which gets you down sooner. Often used at airports that are known to keep inbound arrival traffic at higher altitudes
Risk(s)	None
Cost	Possible increase in fuel consumption due to an earlier calculated descent and level off
Reward(s)	Provides a buffer when descending to make a mandatory crossing altitude during an arrival procedure. This buffer is particularly good when making descents into conditions where tailwinds are present. Mitigates risk by keeping descents from flight level more stable, i.e. reduced flight deck/cabin angles and slower airspeeds if turbulence encountered during the descent
Avionics Equipment	FMS
Aircraft Type	Boeing 757-200, 757-300 767-300, 767-300ER
Flight Phase	Descent
Environmental	
Where heard	Technique utilized during line operations

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Field	**Responses**
Description	Use of the FIX Page Zulu time as an aide to mandatory position reporting Condition - During international crossings on Track Systems there is a requirement for the aircrew to stay within 3 minutes of the time reported to the controlling agency. If the time changes by more than 3 minutes it must be reported immediately.
Actor	Either
Actor's Goal	Provide a useful and timely visual cue to the aircrew so they know when the arrival time over their next fix will vary by 3 minutes or more
Intended usage	Fixes and flight planned ETA programmed into the FMC
Actor's usage	Utilizing the FIX Page in the FMC, the Zulu time that was reported for the next fix is entered. Select the map to a 320nm range. The map will display a circle representing the Zulu time. This Zulu time circle will remain inside the next fix circle if the ETA over the next fix remains within 3 minutes. If the Zulu time circle drifts outside of the fix circle this alerts the aircrew that they need to make an immediate call to ATC and update the ETA over the next fix.
Motivation or Need	This procedure provides a very easy way to anticipate changes in the ETA over a downrange fix. This procedure enhances situational awareness and keeps the aircrew engaged in monitoring the FMS, especially during long overwater crossings.
Risk(s)	None
Cost	None
Reward(s)	This procedure aids the aircrew in providing timely and accurate changes in ETA over the next fix
Avionics Equipment	FMS and HSI
Aircraft Type	Boeing 757-200, 757-300 767-300, 767-300ER
Flight Phase	Cruise flight during international crossings on track systems
Environmental	N/A
Where heard	Procedure

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Field	Responses
Description	Use of Fix Page for timely reminders. Condition - International procedures require crews [at this airline] to complete checks 10 minutes prior to an overwater Class II fix and 10 minutes after the fix
Actor	Either
Actor's Goal	Provide a useful and timely visual cue to the aircrew so they know when to complete "checks" before and after an overwater Class II fix
Intended usage	
Actor's usage	Class II overwater fix is input to the FMS fix page. The fix page allows the aircrew to place a distance ring around a fix, in this case the Class II overwater fix. At normal cruise speeds and 80nm distance ring around the Class II fix equates to a 10 minute reminder prior to and after the fix.
Motivation or Need	This procedure provides a useful visual reminder for the aircrew to complete mandatory "checks" 10 minutes prior to and 10 minutes after an overwater Class II fix
Risk(s)	None
Cost	None
Reward(s)	This procedure aids the aircrew in providing a timely and accurate reminder of required "checks"
Avionics Equipment	FMS & HSI
Aircraft Type	Boeing 757-200, 757-300 767-300, 767-300ER
Flight Phase	Cruise flight prior to any overwater Class II fix
Environmental	N/A
Where heard	Procedure

Example 22. [Back to Top]

Field	**Responses**
Description	Generating range circles around a fix or airport to visually identify climb altitude crossing restrictions.
Actor	Either
Actor's Goal	Provide a visual reference to the crew.
Intended usage	The standard procedure is to reference the paper charts to ensure compliance.
Actor's usage	The pilot is able to generate range circles on the FIX page of the FMS around airports, fixes or Navaids.
Motivation or Need	The range circles, if entered correctly, resemble range circles on a SID, giving the aircrew a visual depiction of the crossing restriction on the PRF without having to reference the paper charts. This information is not available to the aircrew electronically on a PFD.
Risk(s)	A potential risk would arise from an incorrect entry by the aircrew, resulting in non-compliance with the restriction and a potential violation.
Cost	None
Reward(s)	Reduce pilot workload in a critical phase of flight.
Avionics Equipment	FMS
Aircraft Type	737-800, and other aircraft with updated FMS.
Flight Phase	Departure
Environmental	None
Where heard	Common practice, taught as technique.

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Field	**Responses**
Description	Generating lines of bearing to or from a Navaid or fix to identify airways not on the flight plan.
Actor	Either
Actor's Goal	Provide a visual reference to the crew, identifying alternate airways or restricted areas.
Intended usage	The standard procedure is to reference the paper charts for SA or identify restricted areas.
Actor's usage	The crew is able to draw additional airways on the PFD using the bearing feature of the FIX page.
Motivation or Need	Current FMS does not have the ability to overlay additional airways or jet routes other than what is entered into the route page of the FMS.
Risk(s)	None
Cost	None
Reward(s)	Situational awareness. Visual depiction of an alternate route for wx avoidance.
Avionics Equipment	FMS
Aircraft Type	All FMS equipped aircraft
Flight Phase	Cruise
Environmental	None
Where heard	Common practice, taught as technique.

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Field	Responses
Description	Using a range circle to identify a crossing restriction which is not based on the active waypoint.
Actor	Either
Actor's Goal	Provide a visual reference to identify a crossing restriction without changing the active waypoint or altering the flight plan route.
Intended usage	Establish a new waypoint along the route of flight by adding distances from leg segments to determine location of new fix/crossing restriction.
Actor's usage	Pilot is able to visually identify a position along his route of flight that is not based on the active waypoint.
Motivation or Need	Current FMS does not have the ability to generate a fix that is not based on the active waypoint.
Risk(s)	None
Cost	None
Reward(s)	This is a much easier entry in the FMS, potentially avoiding errors.
Avionics Equipment	FMS
Aircraft Type	737-800, and other aircraft with updated FMS.
Flight Phase	Descent
Environmental	None
Where heard	Common practice, taught as technique

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Field	Responses
Description	Modifying altitude restriction from 10,000 ft to 10,001 removes the speed reduction feature of the FMS.
Actor	Either
Actor's Goal	Maintain descent speed at 10K vice slowing to 250KIAS
Intended usage	Use calculated speed reduction point to reduce to 250KIAS
Actor's usage	By modifying the altitude at 10,000 ft to 10,001 the aircraft will not calculate a speed reduction point and a higher descent speed can be maintained after level off at 10K
Motivation or Need	Reduce flight time or maintain an assigned speed set by ATC
Risk(s)	Failure to slow descending below 10K
Cost	Excess fuel consumption
Reward(s)	Arrive early or make up time
Avionics Equipment	GFMS
Aircraft Type	MD-80
Flight Phase	Descent
Environmental	None
Where heard	Flight Crew Interview

Unintended Uses of Automation Human Factors Study

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Deliverable No. 2 – Report #1

Part II: Predicting Pilot Motivation

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Introduction

This section describes a series of three focus groups conducted to achieve two goals:

1) Attempt to solicit pilot input on the potential affordances of a subset of near-term NextGen automation (avionics) using brainstorming techniques (described in Part III)

2) Obtain pilot ratings on which flight tasks they were most motivated to find alternative ways of achieving their goals

The pilot rating data collected during the focus groups identified the tasks where pilots are most likely to discover and employ equipment in unintended ways. Our hypothesis is that pilots invest their time and effort in finding "better ways" of accomplishing their tasks in areas where they perceive the most benefit, and that these efforts lead to the discovery of unintended uses of equipment. To put this in practical terms, we believe that pilots are more likely to spend time searching for U2s of equipment to help them perform the tasks where they perceive the largest return on the investment of their time, rather than on tasks where they are not motivated to find an alternative to the current practice. It is axiomatic that when searching for a "better way" of performing a task, that the "better way" is not the use of the equipment that is intended by the designers. If the "better way" was an intended use (as disclosed on an application for a supplemental type certificate [STC] or other certification), then it would have been subject to certification.

Method

Participants

Twenty-four active and retired commercial airline pilots were recruited to participate in one-day focus groups at NASA Ames Research Center. Two human factors scientists and one pilot SME were also present, as was a court reporter to document the pilot comments during the brainstorm sessions described in Part III. Four of the 24 pilot participants were retired for less than 5 years from the Captain's seat. A recruiter local to NASA Ames was used to locate pilots affiliated with US commercial carriers (including cargo), with experience on Boeing and Airbus equipment.

The average age of the pilots was 52.5, and all but one were male. Seven were Captains, 13 were First Officers, and two were simulator instructors in addition to being First Officers. Average hours for Captains in their primary equipment was 2688 (s.d. = 1830), while average hours for First Officers was 2741 (s.d. = 1819). Average hours for Captains in their secondary type was 2550 (s.d. = 1955), while for First Officers it was 2254 (s.d. = 1838). Nine of the 24 pilots had some prior military flying experience, and all 24 had experience flying internationally.

Four of the 24 pilots had current or prior experience with their company's safety initiatives, e.g. performing as a line check airman, in Flight Operations Quality Assurance, in a Critical Incident

Response Program, or accident investigation teams, or Advanced Qualification Programs. Airlines represented in this group included American, Avensa, Allegiant Air, Cathay Pacific, Continental, Delta, DHL, Northwest, Southwest, United and UPS.

Pilot experience with NextGen automation and specific cockpit technologies is shown in Table II-1.

	No Familiarity	**Aware of some of the avionics or procedures changes**	**Very Familiar**
NextGen Program	2	20	2
	Have not used at all	**Have used it a little**	**Have used it frequently**
Terrain Awareness Warning System (TAWS)	0	0	24
ADS-B	8	6	10
TCAS	0	0	24
Moving map displays (in aircraft)	2	0	22
CDTI	5	4	15

Table II-1. Pilot experience with NextGen automation and specific cockpit technologies.

Procedure

Pilots arrived at NASA Ames Research Center in groups of 8 on three separate days. The day was spent completing demographic and motivational surveys, followed by presentations on ADS-B related NextGen avionics, and brainstorming about potential unintended uses.

The motivation analysis consists of three steps.

- Weighting of motivating factors
- Rating the levels of motivation for each task
- Using the weights and ratings to identify the tasks where U2s are most likely

The data collection form used in this process is contained in Appendix II-A.

Identification of Motivations

Interviews with experienced pilots were used to identify the things that motivate pilots to identify or employ a U2. In alphabetical order, the motivating factors identified in these interviews are:

- Avoid deviating from clearance (and incurring sanctions from the FAA)
- Avoid violating company policy
- Passenger comfort and satisfaction
- Reduce fuel consumption
- Reduce pilot workload
- Reduce time on the ground or enroute
- Safety in flight or on the ground

These factors are not mutually exclusive; more than one may be applicable in a given situation.

Weighting of Motivating Factors

It is expected that the motivating factors are *not* equally important to each pilot. For example, one pilot may be more motivated to discover or use a U2 that improves passenger comfort than by reduced fuel consumption. Other pilots may have value reduced fuel consumption more than passenger comfort. In order to determine the relative importance of the motivating factors to each pilot a rating form was developed. This form, which is in Appendix 1 (page A-4), contains all 21 pairs of motivating factors.

Pilots indicate which of the two motivating factors in each pair is more important to them. The total number of time each motivating factor is preferred is then counted. This number is then divided by 21 to determine the weight for that factor. For example, if the factor "Reduce fuel consumption" was selected over the other motivators four times, then the weight would be computed as 0.190 (= 4/21). If this factor had been selected only twice, then the weight would be 0.095 (= 2/21). Using this computational method the sum of weights of all seven of the factors combined equals 1.00. This approach is similar in concept and computation to that used in the NASA-TLX workload rating approach (Hart & Staveland, 1988).

One of the questions we hope to answer based on the data we obtain in the focus groups is whether or not the process of obtaining weights for these motivating factors and applying them to the ratings of individual tasks adds value to the prediction.

Ratings of Flight Tasks

Flight tasks performed during current day arrival and departure scenarios were identified from task listings (Gore et al, 2010). The arrival and departure task rating forms are shown in Appendix 1 beginning on pages A-6 and A-9, respectively.

Pilot provided ratings reflecting how much each of the seven motivating factors causes them to desire a "better way" of accomplishing each task, where a "better way" of doing a task could mean using equipment in new ways, following a different procedure, or some combination of both.

Pilots rated how motivated they were to discover a "better way" of accomplishing each task on the 5-point scale shown in Table .

Rating	Description
1	Not at all motivated to find a better way of accomplishing this task.
2	Slightly motivated to find a better way of accomplishing this task.
3	Moderately motivated to find a better way to accomplish this task.
4	Highly motivated to find a better way to accomplish this task.
5	Extremely motivated to find a better method of accomplishing this task.

Table II-2. Task Rating Scale.

For instance, consider the task of "Complying with crossing restrictions". In this case a pilot would likely be highly motivated by the motivating factors of "Safety" and "Compliance with Clearance", so the pilot would enter a high numerical value (i.e., a "4" or "5") in the appropriate cells. They would not be as highly motivated by concerns of "Passenger Comfort" or "Reducing Fuel Consumption" to find a better way of doing this task, so the pilot would enter lower ratings in those cells (i.e., a "1" or "2").

Computationally, the seven ratings of how much the pilot desired a "better way" of performing each task were a task were then weighted to provide an overall rating of how much a new way of doing that task was desired by that pilot. The algorithm used to compute this overall rating is:

$$
\begin{aligned}
X_i = \; & ((W_{\text{Avoid Deviating from clearance}} * R_{\text{Avoid Deviating from clearance}}) + \\
& (W_{\text{Avoid violating company policy}} * R_{\text{Avoid violating company policy}}) + \\
& (W_{\text{Reduce fuel consumption}} * R_{\text{Reduce fuel consumption}}) + \\
& (W_{\text{Reduce time on the ground or enroute}} * R_{\text{Reduce time on the ground or enroute}}) + \\
& (W_{\text{Safety in flight or on the ground}} * R_{\text{Safety in flight or on the ground}}))
\end{aligned}
$$

Where:

X_i is the overall rating of how much that pilot desires a better way to perform the i^{th} task,

W is the weight of that factor for that pilot, and

R is the rating made by the pilot for that factor.

The overall ratings are then used to rank order how much the pilots are interested in a "better way" of accomplishing each task. The assumption is that where pilots are more motivated to find a "better way" they will invest more time and effort into discovering a U2. So certification efforts should be focused on the ability of new equipment to be used in unintended, uncertified ways by pilots, rather than on the potential to use equipment in unintended ways for tasks where the pilots are not as likely to search for U2s.

Estimation of Missing Data

This section describes the method used to address missing ratings in the data set.

Weightings.

One participant failed to indicate whether they rated "Reduce Pilot Workload" as more or less motiviation to find a "better way" to accomplish their tasks than "Passenger Comfort and Satisfaction." This was estimated by making each option in this pair equally motivating.

Ratings

Each participant was asked to make a total of 105 ratings in the Departure section and 175 ratings in the Arrival section. The rating forms are in Appendix 1. Table shows the number of missing ratings by participant. Overall, approximately 0.6% of the ratings in the Departure section were omitted by the participants. In the Arrival section, approximately 2.4% of the ratings were omitted. Inspection of Table II-3 shows that that one participant accounted for the vast majority of the missing ratings. Manual inspection of the ratings shows that this participant appears to have inadvertently failed to complete an entire page of ratings.

Participant	Missing Cells in Departure	Missing Cells in Arrival
1	1	4
2	1	0
3	7	0
4	0	0
5	0	1
6	1	84
7	0	2
8	0	1
9	0	0
10	0	0
11	1	1
12	3	0
13	1	1
14	0	0
15	0	0
16	0	1
17	0	0
18	0	0
19	0	0
20	0	0
21	0	0
22	0	0
23	0	0
24	0	5

Table II-3. Missing data .

Because of the large number of ratings omitted by this participant, their ratings were excluded from further analysis. This reduced the number of participants to 23.

After excluding data from this one participant due to the large amount of missing data, a total of 30 ratings were missing; 14 out of 2415 (0.6%) in the departure scenario and 16 out of 4025 (0.4%) in the arrival scenario. Inspection of the raw data showed that in no case was the same rating omitted by more than one participant. That is, no two participants missed providing ratings for the same combination of task and motivating factor. No pattern is evident in the pattern of missed ratings; they appear to be essentially random omissions. With this in mind, it was decided to estimate these ratings. Missing ratings were estimated as the average rating assigned to that task and motivation by the other 22 participants. This is a conservative approach to estimating the rating as it does not change the average rating across all participants.

Results

This section describes two approaches to identifying the tasks for which pilots are most motivated to discover "better ways" to do the job. The first uses pilot ratings of how motivated they are generally on seven motivating factors to find a "better way" to accomplish each of a series of tasks. These factors are:

- Safety
- Compliance with clearance
- Compliance with company policy
- Reduce pilot workload
- Passenger comfort and satisfaction
- Reduce time on ground or enroute
- Reduce fuel consumption

The ratings on each motivating factor are then averaged to come up with an overall measure of how much pilots want a "better way" of doing that task. Tasks with higher average ratings are those where pilots are more likely to discover and use a U2.

The second approach is similar to the first except that weightings are computed for each of the seven motivating factors. These weights are computed using a process in which the pilots select which of each pair of factors is more of a motivation to find alternative ways of performing flight tasks in general. These weights are applied to their corresponding rating in each specific task. The weighted ratings are then averaged to come up with an overall measure of the pilot's motivation to discover a U2 for that task.[18]

These processes produce lists of the tasks ordered by how motivated pilots are to find a 'better way" to perform each task. A certifier would examine a piece of equipment to determine if it has the potential to be used in unanticipated ways for some arbitrary percentage of the tasks, the top

[18] The process used here is mechanically similar to that used in the NASA-TLX workload rating scale (Hart & Staveland, 1988.)

10% or 33% for instance. This approach focuses the certification effort on the same tasks pilots are predicted to invest their efforts to find U2s that are "better ways" of doing the job than with current equipment and procedures.

Weighting of Motivators

Overall

The average weight of each of the seven motivators, the standard deviation of the weights (n = 23), and the rank are shown in Table .

Motivator	Average Weight	Std Dev	Rank
Safety	0.275	0.0320	1
Compliance with clearance	0.240	0.0175	2
Compliance with company policy	0.133	0.0657	3
Reduce pilot workload	0.107	0.0746	4
Passenger comfort and satisfaction	0.105	0.0684	5
Reduce time on ground or enroute	0.077	0.0551	6
Reduce fuel consumption	0.064	0.0510	7

Table II-4. Weight of Motivators.

Table II-5 shows the t statistics for differences between each pair of the motivators[19]. All of these t-tests have 22 degrees of freedom. This table shows that:

- "Safety" was rated as a greater motivator than any of the other factors.
- "Avoid deviating from clearance" was rated as a greater motivator than any of the other factors except "Safety".
- "Avoid violating company policy" was rated as being a greater motivator than "Reduce time on ground or enroute" and "Reduce fuel consumption", but not different than "Reduce pilot workload" or "Passenger comfort and satisfaction".
- "Reduce pilot workload" was not rated differently than "Passenger comfort and satisfaction", Reduce time on ground or enroute" or "Reduce fuel consumption"
- "Passenger comfort and satisfaction" is rated as a greater motivator than "Reduce fuel consumption" but not differently than "Reduce time on ground or enroute".
- "Reduce time on ground or enroute" and "Reduce fuel consumption" were not reliably different than one another.

---

[19] Statistical computations are based on the formulas contained in Bruning, J.L. & Kintz, B.L. (1968).

	Safety	Compliance with clearance	Compliance with company policy	Reduce pilot workload	Passenger comfort and satisfaction	Reduce time on ground or enroute	Reduce fuel consumption
Safety	--	4.101**	8.066**	8.942**	12.258**	13.949**	20.512**
Avoid Deviating from clearance		--	7.629**	8.978**	8.506**	14.189**	14.500**
Avoid violating company policy			--	1.153	1.269	2.826**	3.616**
Reduce pilot workload				--	0.081	1.486	1.938
Passenger comfort and satisfaction					--	1.352	2.192**
Reduce time on ground or enroute						--	0.720
Reduce fuel consumption							--

$*p \leq 0.05$ $**p \leq 0.01$ (Note: The probability values have not been adjusted for multiple comparisons.)

Table II-5. T-test of Motivator Weightings.

By Aircraft Type

In order to examine the question of whether or not pilots who fly different aircraft place different weights on the motivations, the weightings of motivators were grouped based on the primary aircraft flown by the participant. The groups are:

* Pilots of Airbus aircraft (n = 2)
* Pilots of Boeing aircraft (n = 19)
* Pilots of Commuter aircraft (n = 2)

These groups were identified though discussions with pilots and other SMEs as distinctions that might be associated with different motivations and flight demands. These differences might be due to a combination of factors that are not mutually exclusive, such as the different equipment typical of Airbus and Boeing aircraft, and different types of flights between Commuter aircraft and the Airbus/Boeing aircraft.

Because of the small number of pilots who primarily fly Airbus and Commuter aircraft in this sample, and the fact that a number of pilots fly aircraft of different types as secondary aircraft, these results and conclusions drawn from those results must be considered very preliminary.

Table contains the weights of motivators by aircraft type, and Table contains the correlations between these ratings.

	Aircraft Type		
Motivator	**Airbus (n=2)**	**Boeing (n =19)**	**Commuter (n =2)**
Safety	0.285714	0.273183	0.285714
Compliance with clearance	0.238095	0.240602	0.238095
Compliance with company policy	0.095238	0.135338	0.142857
Reduce pilot workload	0.190476	0.105263	0.035714
Passenger comfort and satisfaction	0.047619	0.110276	0.107143
Reduce time on ground or enroute	0.047619	0.080201	0.071429
Reduce fuel consumption	0.095238	0.055138	0.119048

Note 1: The aircraft types are listed alphabetically.

Note 2: The order of motivators reflects the rank order across all pilots as described in the "Weighting of Motivator" section, above

Table II-6. Weights of Motivators by Aircraft Type.

	Airbus	Boeing	Commuter
Airbus	----	0.845*	0.699*
Boeing		----	0.899**
Commuter			----

** $p \leq 0.05$ **$p \leq 0.01$*

Table II-7. Correlations Between Weightings of Motivators by Aircraft Type.

Table shows that the weightings of the motivations of the pilots across all three aircraft types are positively correlated, and that the correlations are statistically significant. This suggests that they type of aircraft flown and the difference between commuter aircraft and larger aircraft do not lead to different motivations to find U2s.

The rank orders of the weighting data were also examined. Table contains the rank orders of the motivations by aircraft type. Table contains the rank order correlations (Spearman's rho) of the values contained in Table .

	Aircraft Type		
Motivator	**Airbus (n =2)**	**Boeing (n =19)**	**Commuter (n =2)**
Safety	1	1	1
Compliance with clearance	2	2	2
Compliance with company policy	4.5	3	3
Reduce pilot workload	3	5	7
Passenger comfort and satisfaction	6.5	4	5
Reduce time on ground or enroute	6.5	6	6
Reduce fuel consumption	4.5	7	4

Table II-8. Rank orders of Motivators by Aircraft Type.

	Airbus	Boeing	Commuter
Airbus	----	0.612	0.629
Boeing		----	0.750**
Commuter			----

** $0.5 \leq p \leq 0.10$*

Table II-9. Rank Order Correlations (Spearman's rho) Between Rank Orders of Motivators by Aircraft Type.

Table indicates that "Safety" and "Compliance with Clearance" are the most important two motivators for pilots in these three groups.

Table shows that the rank orders of the motivators are positively correlated across all aircraft types. However, only the correlation between ratings of Boeing and Commuter pilots approached statistical significance (rho(5) = 0.750, p = 0.052).

We believe that the marginal significance between the Airbus and other pilots is attributable to the small number of pilots in the Airbus and Commuter categories resulting in less reliable values. Small individual differences in the rating process result in changes in weightings, causing changes in the relative ranks of motivators that are weighted similarly. However, the fact that these rank orders are only marginally significant suggests that further work should be conducted to determine if the

Weighting vs Raw Ordering of Tasks

Ratings of how motivated pilots are to find a better way of accomplishing flight tasks in departure and arrival flight segments were used to rank order those flight segments in two ways. First, the ratings were averaged across all of the participants, and these average ratings were rank ordered. In this scheme the weightings of the motivations obtained from each participant were not used. In essence, each of the motivations was weighted identically.

The second approach was to weight the ratings of how much the participant wanted a "better way" of doing each task with the weights appropriate to each motivation. In this approach the rating in each motivation category (e.g., "safety", "compliance with clearance") was multiplied by the weighting of that motivation generated for that participant. The tasks were then rank ordered using these weighted ratings. Appendices II-2 and II-3 contain tables summarizing the raw and weighted task ratings, respectively, along with the rank orders.

The use of two different computational approaches to identifying the flight tasks where pilots are most motivated to find and use unintended uses of equipment begs the question of "which approach is a better predictor." Unfortunately, at this point in the process of developing a U2 prediction approach we lack the data to answer this question. However, we can examine the results with an eye to determining if the two approaches produce similar results and, if not, where they differ.

Comparison of Weighting Techniques

Rank orders of the ratings of each flight task in the departure and arrival listings were computed using the raw and weighted scores. In both departure and arrival flight segments the rank orders of the raw and weighted scores were positively correlated. In the case of the departure flight tasks the Spearman's rho was 0.90 ($t(13) = 7.445$, $p \leq 0.001$), and in the case of the arrival flight tasks the Rho was 0.965 ($t(23) = 17.546$, $p \leq 0.001$). While the correlations are high, the rank orders are not identical, suggesting that there is an effect of the weighting.

Examination of the rank orders did not revealed a pattern of differences between the raw and weighted approaches. As noted above, at this phase of the effort we do not have sufficient information to determine which approach is a better predictor of pilots searching for a U2.

Departure Tasks

Table contains an ordered listing of the Departure tasks. The order is based on the Raw ratings.

	RANK ORDER	
Task	**Raw**	**Weighted**
Identifying heavy weather (e.g., thunderstorms).	1	1
Intersecting routes in ways not planned (e.g., when given "direct to" clearance).	2	3
Identifying "uncomfortable" weather (e.g., turbulence).	3	6
Voice communications with ground and Air traffic controllers.	4	2
Navigating from gate to runway.	5	5
Monitoring aircraft state during takeoff and climb (e.g., monitoring speeds, accelerations, rates of climb, pitch and roll).	6	8
Meet crossing restrictions.	7	4
Conform with clearance.	8	7
Selecting legs of the route.	9	13
Configuring aircraft (gear, flaps & slats) at appropriate speeds & conditions (e.g., positive rate of climb).	10	11
Entering waypoints into Nav systems.	11	10
Observing and avoiding other ground traffic during taxi.	12	9
Identifying wake turbulence.	13	12
Completion of checklists.	14	14
Changing frequencies on voice radios.	15	15

Table II-10. Rank Ordering of Departure Tasks.

Tasks in the top third of the ratings regardless of which rating approach is used are:

- Identifying heavy weather (e.g., thunderstorms).

- Intersecting routes in ways not planned (e.g., when given “direct to” clearance).
- Voice communications with ground and Air traffic controllers.
- Navigating from gate to runway.

The flight task that is in the top third using the raw weightings only is:

- Identifying “uncomfortable” weather (e.g., turbulence).

The flight task that would be in the top third based on weighted ratings is:

- Meet crossing restrictions.

But the following task which is in the top third using the raw values would not be included when the weighted values are used:

- Identifying “uncomfortable” weather (e.g., turbulence).

However, this task is just outside the top third, so the difference is not as great as it might seem on first blush.

Arrival Tasks

Table contains tan ordered list of the Arrival tasks. Again, the ordering is based on the raw ranks.

Task	RANK ORDER Raw	Weighted
Identifying heavy weather (e.g., thunderstorms).	1	1
Monitoring/ aircraft position and trajectory.	2	3
Identifying "uncomfortable" weather (e.g., turbulence).	3	2
Navigate from runway to gate.	4	6
Comply with crossing restriction.	5	4
Observe and avoid ground traffic while taxiing.	6	5
Configuring Flight Management and Navigation Computers for approach.	7	10
Confirm selected approach constraints are met (e.g., runway visual range).	8	7
Identifying wake turbulence.	9	9
Maintain awareness of traffic	10	8
Configure displays appropriately for approach and landing.	11	16
Configuring aircraft (e.g., flaps, Auto brakes set if desired).	12	11
Review planned approach	13	13
Verbal communications with ATC.	14	15
Obtain Initial Clearance (Approach ATIS through ACARS)	15	17
Manually entering and verifying approach‑specific data (e.g., decision height) into the Electronic Flight Information System (EFIS) or other systems	16	14
Visually verify no intrusions on runway once runway in sight.	17	12
Monitoring/operating aircraft systems (e.g., engines).	18	19
Performing checklists.	19	18
Mental computations (e.g., "Calculate target landing speed: Vref + 5, plus gusting wind factor")	20	22
Manually flying the aircraft from short final to touchdown.	21	21
Tune radios to correct frequencies at appropriate times.	22	20
Tune radios	23	23

Set Barometric Altimeter	24	24
Communications with passengers.	25	25

Table II-11. Rank ordering of Arrival Tasks.

The top third of the approach tasks identified by both the raw and weighted methods are:

- Identifying heavy weather (e.g., thunderstorms).
- Monitoring/ aircraft position and trajectory.
- Identifying "uncomfortable" weather (e.g., turbulence).
- Navigate from runway to gate.
- Comply with crossing restriction.
- Observe and avoid ground traffic while taxiing.
- Configuring Flight Management and Navigation Computers for approach.
- Confirm selected approach constraints are met (e.g., runway visual range).

Comparison Between Pilots Flying Different Aircraft

One interesting question is whether or not flying different aircraft types rate their desire for a "better way" to accomplish flight tasks the same or differently. More specifically, there is interest in determining if there is a difference in which tasks pilots are likely to search for U2s attributable to the different design philosophies and equipment in Boeing and Airbus aircraft, and between pilots who fly these larger aircraft and those who fly commuter aircraft.

Departure Scenario

It is of practical importance to determine if the type of aircraft flown (i.e., Airbus or Boeing) or if the type of airline service (scheduled service or commuter) affects how motivated pilots are to discover a U2. If there are reliable differences, certification efforts will need to be tailored to take these different factors into account. The following section is intended to demonstrate one approach to determining if there are reliable differences. However, as the average ratings for the tasks are based on only two pilots in the Airbus and Commuter categories, these data must be considered to be very preliminary, and caution taken not to over generalize the results.

Table II-12 shows the average raw and weighted ratings for each departure task made by Airbus, Boeing and Commuter aircraft pilots. The correlations between raw and weighted ratings made by these groups across the 15 departure tasks are shown in Tables II-13 and II-14, respectively.

	Raw Ratings			Weighted Ratings		
TASK	Airbus	Boeing	Commuter	Airbus	Boeing	Commuter
Voice communications with ground and Air traffic controllers.	3.7857	3.6015	4.2143	4.4762	4.1270	4.5238
Changing frequencies on voice radios.	2.9613	2.8797	2.2857	3.7321	3.4550	3.5238

	Raw Ratings			Weighted Ratings		
TASK	Airbus	Boeing	Commuter	Airbus	Boeing	Commuter
Observing and avoiding other ground traffic during taxi.	3.1429	3.3863	3.6429	4.0476	3.8727	4.0000
Navigating from gate to runway.	3.4286	3.6767	3.6667	3.9762	4.0926	4.1429
Completion of checklists.	3.2143	3.3076	3.8571	3.9286	3.7593	4.2381
Configuring aircraft (gear, flaps & slats) at appropriate speeds & conditions (e.g., positive rate of climb).	3.1429	3.3684	4.2857	3.7143	3.7778	4.1429
Monitoring aircraft state during takeoff and climb (e.g., monitoring speeds, accelerations, rates of climb, pitch and roll).	3.2857	3.5188	4.1429	3.8333	3.9444	3.6905
Conform with clearance.	3.5000	3.3083	4.6429	4.1667	3.9048	3.7619
Meet crossing restrictions.	3.5000	3.4211	4.5000	4.3571	3.9894	4.5952
Selecting legs of the route.	3.5000	3.3534	4.2143	4.0952	3.6878	4.2619
Entering waypoints into Nav systems.	3.0714	3.3910	3.7857	3.5714	3.8360	6.5000
Intersecting routes in ways not planned (e.g., when given “direct to” clearance).	3.2143	3.6917	4.1429	3.6429	4.1429	4.5714
Identifying heavy weather (e.g., thunderstorms).	3.2857	3.8070	4.2857	3.7619	4.1825	3.6310
Identifying “uncomfortable” weather (e.g., turbulence).	3.5714	3.6617	3.9286	3.8810	4.0476	3.0714
Identifying wake turbulence.	2.9286	3.3383	3.9494	3.3571	3.8651	3.6429

Table 9. Comparison of Departure Task Ratings by Group.

		Raw Ratings		
		Airbus	Boeing	Commuter
Raw Ratings	Airbus	----	0.477□	0.523*
	Boeing		----	0.565*

□ *0.10 ≤ p ≤ 0.05   * p ≤ 0.05   ** p ≤ 0.01   (n = 15 in all cases)*

Table II-13. Correlations Between Raw Ratings of Departure Tasks.

		Weighted Ratings		
		Airbus	Boeing	Commuter
Weighted Ratings	Airbus	----	0.205	-0.018
	Boeing		----	0.005

□ *0.10 ≤ p ≤ 0.05   *p ≤ 0.05   ** p ≤ 0.01 (n = 15 in all cases)*

Table II-14. Correlations Between Weighted Ratings of Departure Tasks.

Looking only at the raw ratings (Table) we see that the correlations are modest, ranging from 0.477 to 0.565. These are statistically significant or marginally significant (the probability associated with the correlation between the raw Airbus and Boeing ratings is between 0.10 and 0.05). This suggests that in general, the pilots are rating their motivation to discover a better way to perform the tasks in similar ways.

When we look at the correlations between the weighted ratings (Table), we see a different picture. Here the correlations are not different from zero. There are several ways this could be interpreted. One is that the weighted ratings reflect a true difference between pilot groups in terms of their motivations to discover "better ways" of performing the tasks. Alternatively, this may indicate that the weighting process may be hiding the actual similarities in the pilots motivations by de-emphasizing ratings of factors with low weights differentially between the pilot groups.

There is insufficient information available at this time to examine this issue. We would again urge caution in interpreting these results as the average ratings in the Airbus and Commuter pilot groups were based on only two pilots, so these data may not generalize to a larger population of pilots.

Arrival Scenario

Table II-15 shows the average raw and weighted averages from each of the three groups of pilots for each arrival task. Tables II-16 and II-17 show the correlations between the raw and weighted ratings of the groups of pilots, respectively.

	Raw Ratings			Weighted Ratings		
TASK	Airbus	Boeing	Commuter	Airbus	Boeing	Commuter
Obtain Initial Clearance (Approach ATIS through ACARS)	3.5000	3.2180	4.4286	4.0714	3.5767	4.5714
Maintain awareness of traffic	2.9286	3.5113	3.8571	3.8571	4.1032	4.1429
Tune radios	3.1429	2.7970	2.7857	3.7143	3.3175	3.5238
Set Barometric Altimeter	2.5714	2.5899	3.5000	2.9762	3.0791	4.0000
Review planned approach	3.2857	3.3744	3.8571	3.7619	3.8738	4.1429
Manually entering and verifying approach-specific data (e.g., decision height) into the Electronic Flight Information System (EFIS) or other systems	3.4286	3.2707	3.8571	3.9286	3.7751	4.2381
Confirm selected approach constraints are met (e.g., runway visual range).	3.6429	3.4812	3.9286	4.2857	4.0106	4.1429
Configure displays appropriately for approach and landing.	2.7143	3.5514	3.5714	3.1905	3.8393	3.6905
Performing checklists.	3.7857	3.1344	3.7143	4.2381	3.7087	3.7619
Comply with crossing restriction.	3.5000	3.5940	4.5000	3.9762	4.0450	4.5952
Configuring Flight Management and Navigation Computers for approach.	3.4286	3.5414	3.9286	3.8810	3.9735	4.2619
Configuring aircraft (e.g., flaps, Auto brakes set if desired).	3.2857	3.3233	5.0714	3.7857	3.7725	6.5000
Verbal communications with ATC.	3.2143	3.2707	4.2857	3.6905	3.7725	4.5714
Tune radios to correct frequencies at appropriate times.	2.7857	3.0226	3.2857	3.4048	3.5847	3.6310
Communications with passengers.	2.4286	2.6999	2.5714	2.7143	3.1726	3.0714
Monitoring/operating aircraft systems (e.g., engines).	3.2857	3.2860	3.2857	3.5000	3.7144	3.6429
Monitoring/ aircraft position and trajectory.	3.7143	3.7594	3.8571	3.9048	4.1587	4.2619

	Raw Ratings			Weighted Ratings		
TASK	Airbus	Boeing	Commuter	Airbus	Boeing	Commuter
Visually verify no intrusions on runway once runway in sight.	2.7857	3.3935	3.0714	3.6667	4.0018	3.5952
Mental computations (e.g., “Calculate target landing speed: Vref + 5, plus gusting wind factor”)	3.2143	3.1278	2.7857	3.6667	3.5238	3.2024
Manually flying the aircraft from short final to touchdown.	3.2143	3.0984	2.7857	3.8571	3.5406	3.4762
Observe and avoid ground traffic while taxiing.	2.9286	3.6541	3.8571	3.9524	4.1032	4.0476
Navigate from runway to gate.	3.6429	3.6808	3.5714	4.1429	4.0926	4.0000
Identifying heavy weather (e.g., thunderstorms).	3.2143	3.8947	4.0714	4.0952	4.3254	4.2857
Identifying “uncomfortable” weather (e.g., turbulence).	3.5714	3.7064	4.4286	4.1905	4.1400	4.6190
Identifying wake turbulence.	3.1429	3.4887	4.0714	3.9048	4.0026	4.3333

Table II-15 Comparison of Arrival Task Ratings by Group.

		Raw Ratings		
		Airbus	Boeing	Commuter
Raw Ratings	Airbus	----	0.480*	0.461*
	Boeing		----	0.542*

*$p \leq 0.05$ ** $p \leq 0.01$ ($n = 25$ in all cases)*

Table II-16 Correlations Between Raw Ratings of Arrival Tasks.

		Weighted Ratings		
		Airbus	Boeing	Commuter
Weighted Ratings	Airbus	----	0.680**	0.374
	Boeing		----	0.354

*$p \leq 0.05$ ** $p \leq 0.01$ ($n = 25$ in all cases)*

Table II-17. Correlations Between Weighted Ratings of Arrival Tasks.

Table II-16 shows that the raw ratings of all three groups of pilots are significantly correlated. This suggests that the type of aircraft and type of operations don't result in a different pattern of motivations to discover U2s. II-17 presents a different picture. This pattern of results suggests that pilots of Airbus and Boeing aircraft rate their motivation to find a better way of doing tasks similarly. However, the pattern of motivations is different for pilots of Commuter aircraft.

Conclusions

This section describes an approach to identifying the flight tasks where pilots are most motivated to find a "better way" of performing that task. It also describes a first attempt at applying that approach. These are the tasks for which the pilot community will invest their time to discover capabilities in equipment that satisfy those motivations.

The top five tasks in the Departure phase (raw and weighted ranks of these tasks are noted parenthetical) are:

- Identifying heavy weather (e.g., thunderstorms). (Raw = 1, Weighted = 1)
- Intersecting routes in ways not planned (e.g., when given "direct to" clearance). (Raw =1, Weighted = 3)
- Identifying "uncomfortable" weather (e.g., turbulence). (Raw =1, Weighted = 6)
- Voice communications with ground and Air traffic controllers. (Raw =1, Weighted = 2)
- Navigating from gate to runway. (Raw =1, Weighted = 5)

The top five tasks in the Arrival phase are

- Identifying heavy weather (e.g., thunderstorms). (Raw =1, Weighted = 1)
- Monitoring/ aircraft position and trajectory. (Raw =1, Weighted = 3)
- Identifying "uncomfortable" weather (e.g., turbulence). (Raw =1, Weighted = 2)
- Navigate from runway to gate. (Raw =1, Weighted = 6)
- Comply with crossing restriction. (Raw =1, Weighted = 4)

Given current equipment and procedures, certification personnel should focus the effort they devote to identifying U2s on these tasks as these are the tasks for which pilots will most actively search new equipment to discover capabilities, intended or not, that help them do a "better job".

Clearly, as NextGen or other equipment is incorporated into the cockpit that satisfies the pilot's motivations for better ways to do these tasks, then other tasks will move up in the queue. To the extent that new equipment satisfies a need then we would anticipate that pilots would no longer be highly motivated to find another way to do that task. If the new equipment only partially satisfies the pilot's motivations, then we would anticipate that the affected tasks would fall to lower places on the list. Conversely, if new equipment or procedures are introduced that make ti more difficult for pilots, then we would anticipate that the affected tasks will move up the list of motivations for "better ways" of doing the job.

Although discussed here, the issue of whether or not the type of aircraft flown (e.g, Airbus, Boeing) and the type of service provided (e.g., major carrier or Commuter) affects pilot's motivations to discover U2s have not been resolved. We did not obtain data from suitably large number of Airbus or Commuter pilots to address the issue definitively. However, this paper does present a statistical approach to dealing with data addressing these questions.

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Acronyms

Acronym	**Definition**
FAA	Federal Aviation Administration
NASA-TLX	NASA Task Load Index
SME	Subject Matter Expert
STC	Supplemental Type Certificate

Appendix II-1 - Rating Package

Participant Code: ____________

Task and Motivation Survey

Introduction

One of the goals of this program is to develop a method for identifying uses of flight deck equipment that are unexpected or unanticipated by the designers of that equipment. As part of this work, we are attempting to identify the areas where pilots are most interested in finding a "better way" of accomplishing a task. We believe that pilots are likely to search for alternative ways of using the equipment at their disposal discover or develop an unintended use of equipment in these areas. Identifying the areas where pilots are most interested in a "better way" of accomplishing a task is a precursor to identifying how specifically the equipment might be used in unanticipated ways to create that "better way."

The methodology we are developing consists of three steps which are described briefly below. The information you provide here is used in the first two of these steps. The first step is to determine how factors that motivate pilots to look for alternative ways to accomplish tasks should be weighted. To develop the weightings we are asking you to select the factor from each pair that most motivates you find a "better way" of doing your job. For example, if "passenger satisfaction and comfort" is more motivating than "reducing fuel consumption" then you would circle "passenger satisfaction and comfort".

The second step is to rate how interested you are in a "better way" of accomplishing a set of tasks based on each of the factors identified above. These ratings will be made on a five (5) point scale. On this scale you will assign a value of "1" to indicate that you are not motivated at all because of that factor to find an alternative way to perform that task. A value of "5" will indicate that you are very motivated by that factor to find an alternative way to perform that task.

For example, consider the task of reaching an assigned altitude at a specific crossing point. As an example, assume that you know the FMS slows the rate of climb or descent for the last few hundred feet for passenger comfort. Also assume that because of the slower rate of climb or descent aircraft occasionally fail to be at the assigned altitude at the crossing point. That is, in order to avoid abrupt changes in the rate of climb or descent, the system occasionally "busts" the altitude restriction. If you were most motivated to find a better way of complying with the altitude restriction by the "Safety in flight or on the ground" and "Avoid deviating from clearance and incurring FAA sanctions" factors then you would assign high numerical values (e.g., a "4" or "5") to these factors. If you are not motivated to find a better way of reaching the assigned altitude that "Reduces fuel consumption" than you would assign a low value (e.g., a "1" or "2") to that factor. You would similarly decide how much you are motivated to find a better way to accomplish this task by each of the other factors and assign them appropriate values.

The third step is to use the weightings of the motivations and the ratings of interest in having a "better way" of doing a task available to predict the areas where most effort will be spent by the pilot community to discover a "better way" of accomplishing tasks. We will be using the ratings you provide on the following pages to perform this task.

Weighting of Motivating Factors

Previous work has identified a number of factors as being important external motivations for commercial airline pilots. In alphabetical order, these factors are:

- Comply with clearance (to avoid incurring sanctions from the FAA)
- Comply with company policy (to avoid incurring company sanctions)
- Passenger comfort and satisfaction
- Reduce fuel consumption
- Reduce pilot workload
- Reduce time on the ground or enroute
- Safety in flight or on the ground

These factors are not mutually exclusive; more than one may be applicable in a given situation.

Using the form below, please indicate which factor in each pair is more of a motivation for finding new ways to use equipment or to develop improved procedures when considering the entire set of tasks you perform on the flight deck. For example, if you would generally be more motivated to find a better way of performing your role as a pilot by Passenger comfort and satisfaction than by Reducing pilot workload, you would simple circle Passenger comfort and satisfaction when these items are on the same line.

Weighting of Motivating Factors

Circle only one of the two factor titles on each line - the factor title that represents the more important contributor to your desire to new ways to use equipment or to develop improved procedures to accomplish your tasks.

Participant Code: ____________

Reduce pilot workload	Comply with company policy
Reduce time on ground or enroute	Safety in flight or on the ground
Comply with clearance	Comply with company policy
Reduce time on ground or enroute	Passenger comfort and satisfaction
Comply with clearance	Reduce time on ground or enroute
Comply with company policy	Safety in flight or on the ground
Reduce pilot workload	Passenger comfort and satisfaction
Safety in flight or on the ground	Reduce pilot workload
Reduce pilot workload	Comply with clearance
Passenger comfort and satisfaction	Reduce fuel consumption
Reduce fuel consumption	Safety in flight or on the ground
Passenger comfort and satisfaction	Comply with clearance
Comply with clearance	Reduce fuel consumption
Safety in flight or on the ground	Comply with clearance
Passenger comfort and satisfaction	Comply with company policy
Safety in flight or on the ground	Passenger comfort and satisfaction
Comply with company policy	Reduce fuel consumption
Reduce time on ground or enroute	Reduce pilot workload
Reduce fuel consumption	Reduce time on ground or enroute
Reduce fuel consumption	Reduce pilot workload
Comply with company policy	Reduce time on ground or enroute

Ratings for Each Task or Pilot Function

Major tasks performed by pilots during approach and departure phases of flight were identified from FAA and NASA task analyses. Your job is to rate how much each of the seven motivating factors would causes you to desire a “better way” of accomplishing each task. For the present purpose, a “better way” of doing a task could mean using equipment in new ways, following a different procedure, or some combination of both.

You may find that none of the motivating factors leads you to want a “better way” of accomplishing some of these tasks. In such a case you would enter a value of “1” for each of the motivating factors. In other cases, you may find that one or more of the motivating factors leads you to want a “better way” of performing a task while other motivating factors don’t lead you to want a “better way” of accomplishing that task. For example, the motivating factor of “Passenger Comfort and Satisfaction” is the reason you’d like to find a “better way” of determining an altitude or route that has a smoother ride. In this case, you would assign a higher value in the “Passenger Comfort and Satisfaction” cell than in the other cells.

You may find that you would like to identify a “better way” of doing a particular task for multiple reasons, as the motivating factors are not mutually exclusive. For example, you might decide that you want a “better way” of identifying altitudes with less turbulence for both “Passenger Comfort and Satisfaction” and to “Reduce Fuel Consumption”.

Rating Scale

The 5-point rating scale you will use to indicate how much each of the motivating factors would cause you to seek out a better way of doing each task is shown below.

1 = Not at all motivated to find a better way of accomplishing this task.

2 = Slightly motivated to find a better way of accomplishing this task.

3 = Moderately motivated to find a better way to accomplish this task.

4 = Highly motivated to find a better way to accomplish this task.

5 = Extremely motivated to find a better method of accomplishing this task.

Participant Code: ____________

Ratings of Desire to Find “Better Ways” to Accomplish Tasks – Present Day Departure Scenario

TASK	Reduce Pilot’s Workload	Save Time on the Ground or in Flight	Comply With Clearance (Avoid Incurring FAA Sanctions)	Reduce Fuel Consumption	Comply With Company Policy (Avoid Incurring Company Sanctions)	Passenger Satisfaction and Comfort	Safety in Flight or on the Ground
Voice communications with ground and Air traffic controllers.							
Changing frequencies on voice radios.							
Observing and avoiding other ground traffic during taxi.							
Navigating from gate to runway.							
Completion of checklists.							
Configuring aircraft (gear, flaps & slats) at appropriate speeds & conditions (e.g., positive rate of climb).							

Participant Code: ____________

TASK	Reduce Pilot's Workload	Save Time on the Ground or in Flight	Comply With Clearance (Avoid Incurring FAA Sanctions)	Reduce Fuel Consumption	Comply With Company Policy (Avoid Incurring Company Sanctions)	Passenger Satisfaction and Comfort	Safety in Flight or on the Ground
Monitoring aircraft state during takeoff and climb (e.g., monitoring speeds, accelerations, rates of climb, pitch and roll).							
Conform with clearance.							
Meet crossing restrictions.							
Selecting legs of the route.							
Entering waypoints into Nav systems.							
Intersecting routes in ways not planned (e.g., when given "direct to" clearance).							
Identifying heavy weather (e.g., thunderstorms).							

Participant Code: ____________

TASK	Reduce Pilot's Workload	Save Time on the Ground or in Flight	Comply With Clearance (Avoid Incurring FAA Sanctions)	Reduce Fuel Consumption	Comply With Company Policy (Avoid Incurring Company Sanctions)	Passenger Satisfaction and Comfort	Safety in Flight or on the Ground
Identifying "uncomfortable" weather (e.g., turbulence).							
Identifying wake turbulence.							

Participant Code: ____________

Ratings of Desire to Find "Better Ways" to Accomplish Tasks – Present Day Arrival Scenario

TASK	Reduce Pilot's Workload	Save Time on the Ground or in Flight	Comply With Clearance (Avoid Incurring FAA Sanctions)	Reduce Fuel Consumptio n	Comply With Company Policy (Avoid Incurring Company Sanctions)	Passenger Satisfaction and Comfort	Safety in Flight or on the Ground
Obtain Initial Clearance (Approach ATIS through ACARS)							
Maintain awareness of traffic							
Tune radios							
Set Barometric Altimeter							
Review planned approach							
Manually entering and verifying approach-specific data (e.g., decision height) into the Electronic Flight Information System (EFIS) or other systems							

Participant Code: ____________

TASK	Reduce Pilot's Workload	Save Time on the Ground or in Flight	Comply With Clearance (Avoid Incurring FAA Sanctions)	Reduce Fuel Consumption	Comply With Company Policy (Avoid Incurring Company Sanctions)	Passenger Satisfaction and Comfort	Safety in Flight or on the Ground
Confirm selected approach constraints are met (e.g., runway visual range).							
Configure displays appropriately for approach and landing.							
Performing checklists.							
Comply with crossing restriction.							
Configuring Flight Management and Navigation Computers for approach.							
Configuring aircraft (e.g., flaps, Auto brakes set if desired).							
Verbal communications with ATC.							

Participant Code: ____________

TASK	Reduce Pilot's Workload	Save Time on the Ground or in Flight	Comply With Clearance (Avoid Incurring FAA Sanctions)	Reduce Fuel Consumptio n	Comply With Company Policy (Avoid Incurring Company Sanctions)	Passenger Satisfaction and Comfort	Safety in Flight or on the Ground
Tune radios to correct frequencies at appropriate times.							
Communications with passengers.							
Monitoring/operating aircraft systems (e.g., engines).							
Monitoring/ aircraft position and trajectory.							
Visually verify no intrusions on runway once runway in sight							
Mental computations (e.g., "Calculate target landing speed: Vref + 5, plus gusting wind factor")							

Participant Code: ____________

TASK	Reduce Pilot's Workload	Save Time on the Ground or in Flight	Comply With Clearance (Avoid Incurring FAA Sanctions)	Reduce Fuel Consumptio n	Comply With Company Policy (Avoid Incurring Company Sanctions)	Passenger Satisfaction and Comfort	Safety in Flight or on the Ground
Manually flying the aircraft from short final to touchdown.							
Observe and avoid ground traffic while taxiing.							
Navigate from runway to gate.							
Identifying heavy weather (e.g., thunderstorms).							
Identifying "uncomfortable" weather (e.g., turbulence).							
Identifying wake turbulence.							

Appendix II-2 – Departure Task Ratings

	Raw Scores				Weighted Scores		
TASK	Average	Std Dev	Rank		Average	Std Dev	Rank
Voice communications with ground and Air traffic controllers.	3.6708	0.5656	4		4.1760	0.4489	2
Changing frequencies on voice radios.	2.8351	0.8716	15		3.4022	0.9513	15
Observing and avoiding other ground traffic during taxi.	3.3874	0.7793	12		3.9138	0.7204	9
Navigating from gate to runway.	3.6542	0.6892	5		4.0832	0.6354	5
Completion of checklists.	3.3473	0.7035	14		3.7963	0.6911	14
Configuring aircraft (gear, flaps & slats) at appropriate speeds & conditions (e.g., positive rate of climb).	3.4286	0.8796	10		3.8385	0.8768	11
Monitoring aircraft state during takeoff and climb (e.g., monitoring speeds, accelerations, rates of climb, pitch and roll).	3.5528	0.7922	6		3.9803	0.7442	8
Conform with clearance.	3.4410	0.5857	8		4.0186	0.4645	7
Meet crossing restrictions.	3.5217	0.5407	7		4.0932	0.5069	4
Selecting legs of the route.	3.4410	0.7296	9		3.8157	0.8254	13
Entering waypoints into Nav systems.	3.3975	0.7181	11		3.8706	0.7838	10
Intersecting routes in ways not planned (e.g., when given "direct to" clearance).	3.6894	0.7086	2		4.1159	0.6351	3

Identifying heavy weather (e.g., thunderstorms).	3.8033	0.5537	1		4.1884	0.4566	1
Identifying “uncomfortable” weather (e.g., turbulence).	3.6770	0.5119	3		4.0828	0.4838	6
Identifying wake turbulence.	3.3558	0.5907	13		3.8257	0.6180	12

Appendix II-3 – Arrival Task Ratings

TASK	Raw Scores				Weighted Score	
	Average	Std Dev	Rank		Average	Std Dev
Obtain Initial Clearance (Approach ATIS through ACARS)	3.3478	1.0372	15		3.7516	1.1471
Maintain awareness of traffic	3.4907	0.6458	10		4.0393	0.5807
Tune radios	2.8261	0.8035	23		3.3230	0.9040
Set Barometric Altimeter	2.6674	0.9499	24		3.1137	1.1376
Review planned approach	3.4086	0.7856	13		3.8660	0.8571
Manually entering and verifying approach-specific data (e.g., decision height) into the Electronic Flight Information System (EFIS) or other systems	3.3354	0.7254	16		3.8509	0.7149
Confirm selected approach constraints are met (e.g., runway visual range).	3.5342	0.6606	8		4.0600	0.5929
Configure displays appropriately for approach and landing.	3.4803	1.2934	11		3.7624	0.7388
Performing checklists.	3.2415	0.9042	19		3.6954	0.9469
Comply with crossing restriction.	3.6646	0.6101	5		4.1263	0.5817
Configuring Flight Management and Navigation Computers for approach.	3.5652	0.6790	7		4.0041	0.6833
Configuring aircraft (e.g., flaps, Auto brakes set if desired).	3.4720	1.0078	12		3.9772	1.2891
Verbal communications with ATC.	3.3540	0.7257	14		3.8323	0.7558
Tune radios to correct frequencies at appropriate times.	3.0248	0.7394	22		3.5621	0.7927
Communications with passengers.	2.6651	0.9886	25		3.0295	1.2150
Monitoring/operating aircraft systems (e.g., engines).	3.2860	1.0238	18		3.6626	1.0509
Monitoring/ aircraft position and trajectory.	3.7640	0.7603	2		4.1284	0.7288
Visually verify no intrusions on runway once runway in sight.	3.3126	0.7745	17		3.9331	0.7715

	Raw Scores				Weighted Scores	
TASK	Average	Std Dev	Rank		Average	Std Dev
Mental computations (e.g., "Calculate target landing speed: Vref + 5, plus gusting wind factor")	3.1056	0.8830	20		3.5166	0.9376
Manually flying the aircraft from short final to touchdown.	3.0813	0.8354	21		3.5493	0.9351
Observe and avoid ground traffic while taxiing.	3.6087	0.8520	6		4.0994	0.7408
Navigate from runway to gate.	3.6680	0.8196	4		4.0911	0.8487
Identifying heavy weather (e.g., thunderstorms).	3.8509	0.7663	1		4.3230	0.6253
Identifying "uncomfortable" weather (e.g., turbulence).	3.7575	0.6481	3		4.1613	0.5619
Identifying wake turbulence.	3.5093	0.6458	9		4.0041	0.6303

Unintended Uses of Automation Human Factors Study

NASA Contract No. NNA07BB01C

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Deliverable No. 2 – Report #1

Part III:

NextGen Traffic Situation Awareness:

Avionic Enablers, Applications, and Affordances

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Table of Contents

Introduction

This section documents an initial attempt to identify U2s from NextGen avionic concepts as described in the Application Integrated Work Plan (AIWP), Version 2 (Capezzuto, 2010) . The purpose of this exercise is two-fold: (1) actually identify potential U2s of some NextGen avionics, and (2) try out some basic processes for identifying U2s.

This exercise used three approaches to try to identify potential U2s from FAA concepts for NextGen Automatic Dependent Surveillance-Broadcast (ADS-B)- based, aircraft-to-aircraft applications using three different approaches:

Literature reviews of Human Factors research
Brainstorming sessions with experienced pilots
Rudimentary analysis of potential physical and perceived affordances

This exercise examined avionic enablers and applications at the conceptual level as described in the AIWP rather than analysis of specific implementations, although various examples of implemented systems were reviewed to get a better understanding of the concept. Discussion of NextGen flight deck applications and avionics 'enablers' was based upon the definitions and description in the AIWP and the NextGen Implementation Plan, March 2011, Appendix A, NextGen Investments for Operators and Airports (FAA, 2011).

Design Affordances

In attempting to find a process by which avionics certifiers could identify potential unintended uses, one approach might be to analyze their physical and functional attributes to identify characteristics that might afford or 'invite' unintended uses. Perhaps even more important, as D.A. Norman points out, might be to identify what pilots perceive as affordances (Norman, year unkown).

The term 'affordance' was first coined by J.J. Gibson in 1977 to refer to the (actual) actionable properties of objects, both those that have been discovered and those that are yet to be discovered (Gibson, 1977, 1979). Norman (1988) further promulgated the notion of affordance relative to design and usability in his book "The Psychology of Everyday Things". Norman (year unkown) in his website essay on affordances and design, points out that *"…in design, we care much more about what the user perceives than what is actually true. What the designer cares about is whether the user perceives that some action is possible (or in the case of perceived non-affordances, not possible"*. Thus, affordances are latent in the perceiver-object relationship. Knowledge of only one or the other is insufficient to identify affordances that result in unintended uses of automation. The important characteristics of the perceiver are the goals and motivations present in the work context. The important characteristics of the automation are those that are perceived to offer the potential for achieving the user's goals and satisfying the user's motivations.

Ayres, Wood, Schmidt, Young, and Murray (2000) discuss affordance perception relative to safety intervention where they state: "*The notion that people consider accident risk during driving and other activities has long dominated safety research. The practical importance of risk perception and risk* *compensation, however, has been overrated. As an alternative formulation, behavior may be affected by action-oriented perception of affordances - we act in ways that we think will be adequate for success."* They continue on to advocate research on affordance perception as a way to better understand the causes of accidents.

As a starting point in advising avionic equipment certifiers regarding potential unintended use, one might discuss the characteristics of the device that might allow or even invite alternative or unintended uses such as: number and flexibility of user inputs, the amount and flexibility of data displayed, and the number of functions controlled by the device. The multi-function display (MFD) coupled with the Flight Management System (FMS) represents a good example given the number of unintended uses associated with them identified in the survey of unintended uses documented herein. The complexity of programming and incomplete understanding of the FMS is well documented and frequently leads to errors in data entry or interpretation (Durso, Feigh, Fischer, Morrow, & Mosier, 2010; Rudisill, 1995; Sarter & Woods, 1992). The MFD allows a wide range of user inputs from button presses to flexible text entry, controls numerous functions, and displays a significant amount of information which seem to invite pilots to investigate potential uses, intended or not. Given that the FMS can exert control over the aircraft, unintended uses of the MFD can have significant impact on flight safety.

Obviously, simply recommending that avionic certifiers pay more attention to devices with complex user interfaces that include multiple controls and information displays is not particularly helpful. The capabilities and major functions performed by the device and information provided by its displays need to be examined along with their interaction with pilot motivations and processes. At some point this effort of identifying unintended uses seems to become extremely similar to the Systems Engineering Requirements Definition effort along with a Safety Engineering Failure Modes and Effects Analysis (Funk, 2009a).

As an initial explorative assessment of the concepts for ADS-B applications and enablers, the analysis of affordances in this effort is quite rudimentary, only identifying the obvious attributes that may provide an affordance. Pilot brainstorming sessions were used to try to identify perceived affordances.

ADS-B Applications and Avionic Enablers

The AIWP defines 17 'applications' of aircraft-to-aircraft ADS-B capabilities and eight technological advancements termed 'avionic enablers' required to make the applications feasible. Applications are somewhat hierarchical sets of avionics and processes that provide operational improvements and capabilities that build toward the FAA's NextGen vision for the NAS. The descriptions of applications provide a context for discussions about the capabilities of the avionics and how they are expected to be used. As applications are described in relatively general term, discussion of associated unintended uses must also be at a conceptual level rather than a detailed device manipulation level, e.g., what might a pilot do with the Flight ID provided on a Cockpit Display of Traffic Information (CDTI) that may be unintended by the developers?

To limit the scope of this exercise, the seven applications were chosen that had a maturity ranking of 4 or above according to the AIWP. The maturity ranking of 4 is defined as: Concept well developed, identified research in progress and 7 being: Fielded, standards exist. These seven applications were primarily focused on Traffic Situation Awareness (TSA).

The AIWP uses avionic enabler categories to describe the minimum avionic capability necessary to implement an application. Enabler categories are groupings of a minimum set of aircraft equipment, configurations, and capabilities required to conduct applications using ADS-B data. Seven enabler categories are described in general terms that allow significant variation in how various developers actually implement the avionics. This exercise examined potential unintended uses of the six, avionic enablers employed in the seven applications chosen for this exercise.

Each of the six avionic enablers is described below followed by descriptions and discussions of seven applications that employ them.

Avionic Enablers

There are six avionic enabler categories associated with the seven applications chosen for this exercise. Those avionic enabler categories include:

1. ADS-B Out Transmission
2. CDTI (Ground only – no surface indications or alerts)
3. CDTI (Ground) with Surface Indications and Alerts
4. CDTI (Air-Ground)
5. CDTI (Air-Ground) with Surface Indications and Alerts
6. Along-Track Guidance

Each of these enabler categories are described below. Additional enabler capabilities and potential unintended uses are discussed within the context of their associated TSA applications.

Relevant Definitions

The AIWP provides the following relevant definitions:

ADS-B Out: The capability of an aircraft or surface vehicle to periodically broadcast its position, velocity, and other information. ADS-B Out is *automatic* in the sense that no flight crew or controller action is required for the information to be transmitted. It is *dependent surveillance* in the sense that the surveillance information depends on the navigation and broadcast capability of the source.

ADS-B In: The capability to receive and process the data received from aircraft with ADS-B Out capability and/or ADS-B uplinks from ground systems, plus the ability to display any of this information to flight crews

CDTI: The pilot interface portion of a surveillance system. This interface includes the traffic display and all the controls that interact with such a display. The CDTI is defined as a graphical plan-view (top down) traffic display. The CDTI receives position information of traffic and Ownship from the airborne surveillance and separation assurance processing (ASSAP) function. The ASSAP receives such information from the surveillance sensors and Ownship position sensors.

Enabler 1: ADS-B Out Transmission

The automatic transmission of ADS-B data is the fundamental basis for all AIWP applications. ADS-B Out transmits Global Positioning System (GPS) (or equivalent navigational system)-based latitude, longitude, altitude, and velocity data as well as other aircraft data such as Flight Identification. The ADS-B position and velocity data is significantly more accurate than radar and the accuracy does not diminish with distance from the radar/aircraft. ADS-B data is transmitted every second when airborne or when moving on the airport surface, and every five seconds when stationary on the airport surface. ADS-B avionics must meet the requirements of 14 CFR 91.227 which specifies the message content, accuracy, reliability, self test, and other performance standards. ADS-B systems provides significantly more accurate and timely position data than radar systems where accuracy deteriorates with distance from the radar and data is update about once every twelve seconds. With this increased accuracy and timeliness of position data, ADS-B will enable the NextGen NAS to confidently maintain closer separation and safely increase NAS aircraft throughput.

Discussion of ADS-B Out Affordances

The user interface (UI) associated with the ADS-B out transponders is minimal and is extremely similar to existing mode a/c transponders. An example general aviation transponder from Filser can be viewed at: http://www.powershow.com/view/2341e9NjJlN/ADSB_Avionics_for_General_Aviation_flash_ppt_presentation, which shows a UI with the basic capabilities to select modes (A/C or S), enter Flight ID's, send an 'Ident' message to Air Traffic Control (ATC), and other minor controls. As the transponder is automatic and the user interface includes minimal control options and displayed information, the devices itself does not seem interesting in regard to unintended uses. The data that it transmits is more interesting, but the user accesses that data through the ADS-B In receiver and is displayed in the CDTI rather than the transponder/transceiver itself.

Enabler 2: CDTI (Ground Only)

CDTI (Ground Only) the graphic display of relative horizontal and vertical positions of aircraft and surface vehicles, including ownship position and moving map while ownship is on the ground with groundspeed less than 40 knots. This display may also include indications of runway occupancy or other normal traffic status information. This display is required to be in the primary field of view. If an Electronic Flight Bag (EFB) is used to implement this enabler, it may be Class II (removable by the user.) CDTI (Ground Only) requires a database of runways and taxiways of intended use.

Electronic Flight Bag Systems and Multi Function Display Systems

The controls and physical displays for CDTI are provided by EFB or Multi-Function Display (MFD) flight deck systems. CDTI represents one module among several in either of those systems. In their survey of the EFB Industry, Gabree, Yeh, and Jo (2010) describe numerous EFB systems from 23 hardware and software developers which ranged from handheld Class 1 to integrated Class 3 implementations with a wide range of display sizes. The survey also lists over 18 categories of software packages that can be included in the EFB systems. Most of these software packages are not directly associated with NextGen ADS-B applications. For the applications chosen from the AIWP document for this exercise, the following software packages hosted in either an EFB or MFD system are of interest: GPS/Navigational Display, Moving Map, Surface Moving Map, and Traffic Surveillance. The affordances of these map and surveillance packages are discussed briefly within their associated applications.

Enabler 3: CDTI (Ground) with Surface Indications/Alerts

CDTI - Ground Only (Enabler 2) with the addition of alerts for non-normal traffic status displayed in the primary field of view and/or using aural alerts. If EFB is used to display or generate alerts, it must be Class III. Enabler requires the addition of advanced ADS-B detection and alerting algorithms for conflicts with arriving and departing aircraft with varying runway geometries.

Enabler 4: CDTI (Air-Ground)

This enabler is the graphic display of relative horizontal and vertical positions of aircraft which may include a moving map that is recommended, but not required to be in the primary field of view. This enabler can support any or all of the following applications: Traffic Situation Awareness-Basic, Airport Traffic Situation Awareness, and Traffic Situation Awareness-Visual Approaches. If EFBs are used to implement this enabler, they must be Class III (installed equipment). Key requirements include: a database of runways and taxiways at airports of intended use for applications supporting surface operations (e.g., Airport Traffic Situation Awareness); augmentation with a processing algorithm and indications to validate and indicate applicability of target aircraft for some applications (e.g., In-Trail-Procedures).

Enabler 5: CDTI (Airborne) with Conflict Detection

This enabler builds upon the CDTI (Air-Ground) enabler and is used on aircraft that are not equipped with TCAS II. The traffic display is recommended to be in the primary field of view. Additional algorithms are needed to process ADS-B reports from airborne aircraft and to provide potential traffic conflict alerts calculated independently from TCAS advisories. Indications and alerts provided for this enabler must be in the primary field of view. Key requirements include: processing and display of ADS-B information from target aircraft and detection and indication of potential conflict.

Enabler 6: Along-Track Guidance

Primary field-of-view display(s) of along-track (speed and/or distance) guidance, control, and indications and alerts derived from associated processing of ADS-B messages and ownship information that is provided to achieve and maintain a given interval between aircraft, relative to a common point, that is large enough to have collision risk mitigated by external mitigations (e.g., ATC monitoring, flight crew procedures, environmental conditions, other equipment, etc.).

ADS-B Applications

Each of the seven TSA applications are described using wording consistent with the general descriptions in the AIWP rather than description of specific implementations. Application 1: Traffic Situation Awareness – Basic is the cornerstone upon which the other applications are based. Application 1 is described in more detail and subsequent applications are described in terms of what they add to Application 1.

The five TSA applications are:

- Traffic Situation Awareness-Basic
- Traffic Situation Awareness for Visual Approach
- Airport Traffic Situation Awareness
- Airport Traffic Situation Awareness with Indications and Alerts
- Oceanic In-Trail Procedures
- Flight-Deck Based Interval Management-Spacing
- Traffic Situation Awareness with Alerts

Traffic Situation Awareness–Basic

Objective:

To provide enhanced traffic situational awareness to flight crews increasing the safety and efficiency of flight operations.

Description:

This application is the most basic Aircraft Surveillance (AS) application and is used as the foundation for all the other ADS-B related applications described in the AIWP. The application uses a cockpit display to provide the flight crew with a graphical depiction of traffic using relative range and bearing, supplemented by altitude, flight ID and other information. It is used to assist the out-the-window visual acquisition of airborne and surface traffic for enhancing flight crew situational awareness and air traffic safety in the NAS.

Traffic Situation Awareness–Basic is a background application that runs at all times without flight crew input. It does not require flight crew or automated traffic selection. However, specific traffic selection is permitted to enable the flight crew to determine additional information beyond that which is displayed by default, e.g., relative speed.

Flight crews using this application will refer to the display during the instrument scan to supplement their visual scan. The display enables detection of traffic by the flight crew and aids in making positive identification of traffic advised by ATC. The information provided on the display also reduces the need for repeated air traffic advisories and is expected to increase operational efficiencies.

Avionic Enablers Used In this Application

- ADS-B Out Transmission
- Enabler 4: CDTI (Air-Ground)

Literature Review

Although a review of Human Factors literature identified numerous articles discussing potential Human Factors issues associated with CDTI and NextGen avionics, that review revealed no clearly unintended uses per the definitions in this study. There are however, some recurring issues that seem close to unintended usage that should be discussed. Funk, Mauro, and Birdseye (2008), in their review of NextGen/CDTI Human Factors literature and applying a failure modes and effects analysis approach, listed 10 general theoretical issues:

1. Procedures using different sources of traffic information (visual, ADS-B, TCAS-II, ATC) may lead to unsafe situations.
2. Pilots using CDTIs may be more likely to unsafely deviate from ATC clearances.
3. Excessive use of CDTIs may reduce visual traffic scan skills.
4. ADS-B equipment may increase workload and distractions.
5. Pilots may become overconfident in and over-reliant on ADS-B.
6. Pilots may not adequately understanding ADS-B capabilities and limitations.
7. Lack of standardization of ADS-B cockpit equipment may lead to errors.
8. CDTI placement may make displays difficult to read.
9. CDTI display clutter may exacerbate conflicts.
10. ADS-B pilot training may be inadequate.

Of these 10 issues, four of them might be argued as being unintended uses:

Using CDTI to deviate from ATC clearances,
Excessive use of the CDTI to the detriment of visual traffic scan
Over-reliance on ADS-B
Lack of adequate understanding of ADS-B capabilities and limitations.

The potential for flight crews to use the CDTI to deviate from ATC clearances is certainly unintended by the developer and the FAA, but it is also expressly prohibited, and thus should perhaps be classified as a misuse of the CDTI. Thankfully, the strong motivation of the flight crew to maintain their licenses makes this action very unlikely, just as it does now without CDTI. The question becomes whether or not it is worthwhile to identify to avionic certifiers that the information provided by ADS-B/CDTI might embolden flight crew to deviate from ATC clearance. While probably not useful to the certifier, it may be wise to consider the possibility when developing procedures and to monitor incidents for any trends.

Excessive use of the CDTI to the detriment of visual traffic scan and over-reliance on ADS-B/CDTI are common themes in Human Factors literature (Casner, 2010; Joseph, Domino, Battiste, Bone, & Olmos, 2003). The pilots in the brainstorming session of this exercise frequently related their observance of pilots who focused on the TCAS and navigational displays and in their opinion did not perform adequate visual searches out the windshield. This behavior represents excessive reliance on the CDTI and thus is classified as misuse rather than unintended use. Further, it is probably not useful information for the certification of avionics. However, it should be mentioned so that training and procedures can be developed to mitigate the tendency to focus on the CDTI.

Lack of adequate understanding of ADS-B capabilities and limitations seems like it could lead to unintended use. However, details in Funk (2009b) clarify what was meant by the term as: Flight crew misunderstands resulting Human-System Interface/CDTI configuration, misinterprets traffic picture, or violates separation/spacing requirements. This is more of a usability issue rather than unintended use and should be covered when proving the CDTI's suitability for intended use. There have been anecdotal discussions regarding the use of auto or hiking Global Positioning Systems (GPS) in general aviation cockpits where signal status, position accuracy, and map adequacy may be questionable, resulting an unintended and dangerous misuse of that device for aviating. In the case of FAA avionics certification, it would seem ensuring the avionics are ADS-B complainant and that installed flight charts and maps are up-to-date and appropriate for use would be part of the process, thereby precluding that kind of misuse. The current review has not identified any unintended uses stemming from inadequate understanding of ADS-B and CDTI capabilities and limitations.

Casner (2010) suggests that flight crews might exhibit 'strategic behavior', and challenge or second-guess ATC. The idea here being that now the flight crew has essentially the same, presumably reliable and accurate information regarding surrounding traffic as ATC, the flight crew will feel emboldened to push their own agenda and impact controller workload. Relative to this 'strategic behavior' Hunter and Huina (2011) investigated the effect of different gaming strategies on NAS-wide congestion, concluding that while gaming does add to NAS congestion, the impact would be minimal and does not warrant strong steps to prohibit it. Concerns regarding strategic behavior were also expressed frequently by the pilots in the brainstorming session performed for this study. Strategic behavior mentioned included: speeding up to get ahead of an aircraft from an airline known to go slow before having to get in the oceanic flight line, and strategically slowing down or speeding up to enable a fellow airline aircraft to fit into a slot in line for approach. The pilots in the brainstorming sessions also stated that they believed flight crew would 'badger' ATC for clearance changes, also pointed out by Casner (2010). It can be argued that while 'badgering' or excessive clearance change requests may be unintended, however by providing pilots with additional information, increased pilot participation in flight path decisions seems to be intended. Again, pointing out that availability of more traffic information enables flight crews to 'work the system' does not seem helpful for avionics certification, but should be considered in procedures.

Affordances and Pilots' Perceptions

The basic CDTI (Air-Ground) is a graphical display of relative horizontal and vertical positions of aircraft including own ship which may include a moving map. Several examples of existing CDTI systems included a TCAS II–like navigational display with the option for a moving map display. In its basic form, CDTI does not have the indications and alerts of TCAS II. The physical display and controls are provided by and EFB or MFD system.

Basic CDTI displays and controls are similar to those of existing navigational displays with added information from the ADS-B link such as:

- Accurate latitude, longitude, altitude, and velocity of displayed aircraft of ADS-B equipped aircraft
- Aircraft identification / Flight ID
- Emitter category: (e.g., Light, Small Aircraft, Large Aircraft, High Vortex Large)

One new piece of information displayed in the CDTI that seems to catch pilots' attention is the Flight ID. Pilots in the brainstorming sessions quickly grasped the utility of the Flight ID to help identify the aircraft in controller instructions to follow or for in-trail procedures, clearly an intended use. Then they started thinking of other ways to use it such as:

- Identifying aircraft from airlines known to be slow so that they can rush to get ahead of it in the airway
- Identifying fellow airline aircraft and altering flight parameters to accommodate their approach or departure
- Identifying the gate of pilot's own commuter aircraft to facilitate his or her own commute home

The safety impacts from these uses can vary from contributing to heads-down time to influencing pilots to take ill-advised chances that they might not take without the CDTI. Some pilots suggested that pilots already exhibit these behaviors using voice communications and data link. The intended use of the Flight ID on the CDTI is to enable the pilot to identify the displayed aircraft. The purposes for which that information is used as identified above, are probably not intended. Once again this seems like a procedure and training issue rather than an avionics certification issue.

Traffic Situation Awareness for Visual Approach

Objective

To augment the flight crew's ability to maintain visual separation and traffic situational awareness by enabling target coupling during visual approach operations increasing the safety and efficiency of air traffic and flight operations.

Description

This application adds to the Traffic Situation Awareness–Basic application by providing a coupled target function during an ATC-assigned visual approach where the flight crew has responsibility for visual separation from the target aircraft. The application adds to the Traffic Situation Awareness–Basic application by providing a coupled target function to assist in maintaining visual contact with specific traffic pointed out by ATC for a visual approach procedure. As an extension of the Visual Approach Procedure, Visual Meteorological Conditions (VMC) is required to initiate and maintain visual contact to continue the application. Pilots operating under VFR may also use this application for enhanced situation awareness for operations such as the Visual Flight Rules (VFR) traffic pattern for early recognition of aircraft overtake situations. Figure 3 shows an example CDTI display from Mogford & Lohr (2000).

Figure 1. NASA Concept for CDTI with In-Trail Separation

The flight crew uses the display to assist in the visual acquisition of a specific target to follow and manual selection of the traffic for coupling. The cockpit display provides ground speed or closure rate information relative to the coupled target continuously throughout the approach.

Flight crews using this application will refer to the display during the instrument scan to supplement their out-the-window visual scan. The display enables detection of traffic by the flight crew and aids in making positive identification of traffic advised by ATC. The information provided on the display also reduces the need for repeated air traffic advisories and is expected to increase operational efficiencies. Traffic Situation Awareness-Basic is a coupled application that requires specific flight crew selection and coupling of the target traffic. This coupling function is the foundation for other applications that require specific aircraft coupling input.

Avionic Enablers Used In this Application

- ADS-B Out Transmission
- Enabler 4: CDTI (Air-Ground)

Literature Review

Human Factors articles reviewed identified issues relative to the usability and effectiveness of various versions of CDTI displays for separation (Dao et al., 2009; Holforty & Powell, 2002; Knecht, 2008; Mogford & Lohr, 2000; Nadler, Yost, & Kendra, 2007) but did not identify any unintended uses.

Affordances and Pilots' Perceptions

The primary addition to the basic CDTI is the ability to specify a target aircraft to follow and have the display provide cues that support the flight crew in the maintenance of the assigned separation. No unintended use of that feature was identified.

Although very interested in the intended capability provided by this application, the pilots in the brainstorming sessions did not identify any unintended uses unique to this CDTI variation.

Airport Traffic Situation Awareness Without and With Indications and Alerts

Objectives

Airport TSA Without Indications: To provide enhanced traffic situational awareness to flight crews in the vicinity of an airport, increasing the safety and efficiency of flight operations.

Airport TSA with Indications and Alerts: To provide flight deck indications and alerts of potential or actual traffic conflicts on or near the airport surface reducing runway incursion risk and enhancing surface safety.

Description

Airport TSA adds an airport map to the Traffic Situation Awareness–Basic application capable of displaying traffic and ownship from the surface to 1500 feet above the airport encompassing the airport traffic pattern, generally within 5 miles of the airport.

The application is expected to be used by the flight crew to aid in detection of traffic related safety hazards on taxiways and runways including aircraft on final approach. This assists the flight crew with early detection of traffic conflicts and runway incursions. The displayed information may assist the flight crew in the decision-making process in order to take the most effective action. The application may also be used in conjunction with controller use of aircraft flight ID to assist the flight crew in determining the position of other taxiing aircraft or ground vehicles simplifying taxi and sequencing instructions. The improved situational awareness will be most apparent in low visibility, at night, and/or where a portion of a runway is not visible from the takeoff or runway crossing position, even in good visibility.

Airport TSA with Indications and Alerts adds to the Airport TSA application by graphically highlighting traffic or runways on the airport map to inform flight crew of detected conditions which may require their attention. For detected non-normal—alert level—situations, which require immediate flight crew awareness, additional attention getting cues are provided.

The Indications enhancement includes automated specific traffic highlighting or relevant runway status highlighting for normal situations which do not require immediate (Alert level) flight crew awareness but are contextually relevant to ownship operation. Each relevant runway's final approach and occupancy status is displayed to the flight crew in graphical format. This assists the flight crew in maintaining situational awareness of other traffic using the runway and suitability for ownship operations. This provides accurate and timely flight crew interpretation of potentially hazardous traffic situations to prevent runway incursions.

Alert (cautions and warnings) enhancements provide immediate traffic and runway situational awareness cues directly to the flight crew should a runway incursion be predicted or occur when one or both aircraft involved are above taxi speed (i.e., on approach, landing, takeoff). These alerts increase the likelihood of hazard detection by the flight crew enabling more timely flight crew actions to remedy the unsafe situation and mitigate the severity of the hazard.

Numerous examples of airport moving maps with and without indications and alerts can be found in the Yeh and Eon(2009) survey of the surface moving map industry.

Avionic Enablers Used In this Application

- ADS-B Out Transmission
- Enabler 4: CDTI (Air-Ground)
- Enabler 5: CDTI (Air-Ground) with Indications/Alerts

Literature Review

A literature review of articles relating to surface moving maps yielded articles determining the effectiveness of the displays relative to reducing runway incursions (Chase, Eon, & Yeh, 2010; Jones & Young, 1995; Livack, McDaniel, & Battiste, 2001; McCann, Foyle, Andre, & Battiste, 1996; Yeh & Goh, 2011). Other articles explored design issues associated with moving maps (Gabree & Yeh, 2010; Yeh & Gabree, 2011). Casner(2005) found use of the moving map lowered pilots' navigational awareness, an issue also brought up in the brainstorming session and termed by one pilot as the "children of the magenta line" effect. No unintended uses were identified in the literature, however.

Affordances and Pilots' Perceptions

Pilots in the brainstorming sessions were especially interested in the capability to "see" aircraft behind them when pulling back from the gate. They felt that if they had that CDTI view of aircraft and vehicles behind their own aircraft they would be tempted, if not encouraged, to pull back even when one or both wing-walkers were not yet available to monitor the movement. The safety impact would be from people, luggage, or non-ADS-B equipped vehicles like baggage carts that wouldn't show up on the CDTI.

Some other uses to which the pilots thought they might apply the surface moving map were:

- Using the map to identify number of aircraft in line for departure and lobbying for a runway and departure route with a shorter line
- Identifying a long line for de-icing to determine whether or not to wait at the gate or add fuel
- Upon landing, look for the nearest taxiway to quickly exit the runway so that a fellow airline aircraft can land sooner.

One pilot in the sessions had extensive experience with ADS-B CDTI with surface moving maps as an evaluator for a commercial carrier. He was a big advocate for ADS-B CDTI and especially appreciated the capability to see aircraft on approach behind him when he was about to take off. When asked if he had found any alternative or creative uses for the CDTI he responded that he didn't find a need to deviate from company policy on its usage. He said he did, however, use the CDTI while his aircraft was parked to identify and monitor the progress of incoming aircraft with whom he was waiting to exchange freight.

Oceanic In-Trail Procedures

Objective

To enable more frequent approval of flight level requests between properly equipped aircraft using a reduced separation standard in Oceanic Airspace, improving flight efficiency and safety.

Description

Oceanic In-Trail Procedures (ITP) enables flight level change maneuvers that are otherwise not possible within Oceanic procedural separation standards. ITP allows ATC to approve these flight level change requests between properly equipped aircraft using reduced procedural separation minima during the maneuver. Flight crews request flight level changes for various reasons to improve flight efficiency and safety including; optimum fuel burn, accessing favoring wind conditions, avoidance of turbulence.

The ITP procedure requires the flight crew use information derived by the aircraft avionics and ADS-B data received from the target aircraft to determine if the criteria required for the ITP flight level request are met (maximum of two target aircraft). This information is then reported to ATC by the flight crew as part of the flight level change request. After ATC receives the flight level change request from the flight crew, ATC evaluates all relevant traffic for conflicts, including Non-ADS-B equipped aircraft prior to approving. ATC also checks to make sure the closing Mach differential between the aircraft is no more than 0.06. If no traffic conflict exists and the Mach check is satisfied, ATC may approve the request. Upon receiving the ITP flight level change request clearance the flight crew will reassess the ITP initiation criteria and if the criteria are still met, the flight crew will execute the procedure. Upon reaching the destination altitude the flight crew will report completion of the maneuver to ATC. If the flight crew is unable to initiate or complete the maneuver, they will advise ATC.

Safety of the ITP maneuver is based on an analysis of safe separation under the expected operating conditions. The flight crew should monitor the ITP conditions (distance, closure rate) and paths of the Reference Aircraft during the maneuver to accommodate unanticipated changes, such as maneuvering by the Reference Aircraft. The flight crew should ensure the safety of the operation by detecting any changes in the environment that affect the ITP maneuver and taking appropriate actions.

Functionally, ITP is a vertical crossing maneuver where ATC retains responsibility for aircraft separation, and will be a stepping stone towards a future application where the flight crew is delegated the responsibility for separation during the maneuver.

Avionic Enablers Used In this Application

- ADS-B Out Transmission
- CDTI (Air-Ground) with processing of ITP target aircraft ADS-B and TCAS data.

Literature Review

Two Human Factors articles were reviewed relative to ITP or Oceanic ITP, neither of which suggested potential unintended uses. Casner(2010) discusses the flight crew actions involved in ITP which in addition to monitoring the CDTI/TCAS II to ensure procedure criteria are met, involves setting the MFD/FMS to the appropriate altitude. Bussinik, Merdock, Chamgberlain, Chartrand, & Jones (2008) analyzed error involved in the process as well as subjective workload measures were obtained.

Affordances and Pilots' Perceptions

This application is procedural in nature and utilizes the avionics already discussed. Other than the potential for flight crews to 'push the envelope' regarding the criteria to change flight levels, it does not appear to afford unintended uses.

The pilots in the brainstorming sessions were very interested in the capabilities provided by this application. They soon started discussion of its use to get by slower aircraft and to get to desired flight levels for speed and fuel efficiency, all of which are clearly intended. They did not however, identify unintended uses.

Flight-Deck Based Interval Management–Spacing

Objective

To create operational benefits through precise management of intervals between aircraft whose trajectories are common or merging, thus maximizing airspace throughput while reducing ATC workload and enabling more efficient aircraft fuel burn reducing environmental impacts.

Description

Flight-Deck-Based Flight Interval Management-Spacing (FIM-S) is a suite of functional capabilities that can be combined to produce operational applications to achieve or maintain an interval or spacing from a target aircraft. ATC will be provided with a new set of (voice or data link) instructions directing, for example, that the flight crew establish and maintain a given time from a reference aircraft. These new instructions will reduce the use of ATC vectoring and speed control, which is expected to reduce the overall number of transmissions. These reductions are expected to reduce ATC workload per aircraft.

The flight crew will perform these new tasks using new avionics functions, e.g., airborne surveillance, display of traffic information, and spacing functions with advisories. A few examples of FIM-S in various phases of flight include: Cruise - delivering metering or miles-in-trail prior to top-of-descent; Arrival – interval management during optimum profile descents to merge (if applicable); Approach – achieve and maintain appropriate interval to stabilized approach point; and Departure – maintain interval no-closer-than to previous departure. These examples provide more efficient flight trajectories, better scheduling performance, reduced fuel burn and decreased environmental impacts.

Avionic Enablers Used In this Application

ADS-B Out Transmission
CDTI (Air-Ground)
Along-Track Guidance

Literature Review

Prinzo (2002) and Prinzo and Hendrix (2003) examined several aspects of the use of CDTI applications for Departure and Approach Spacing Application respectively. Casner (2010) discussed the generic flight crew tasks and communications associated with an FIM-S that includes integration into an existing autoflight system which is not specified for the AIWP which only requires along-track guidance which provides a visual aid to maintain separation. These articles did not suggest an unintended use.

Affordances and Pilots' Perceptions

The capability to maintain specified time or distance separation interested the pilots in the brainstorming sessions, during which two potential unintended uses (at least in their opinion) of the FIM-S were suggested:

1) "A while back, a Qantas flight going to Sydney lost radar after takeoff. What they did was, they visually locked onto another aircraft that had radar, and they followed them all the way down, around the weather. With this, you wouldn't even need to have a visual. That would be a way to use it."

2) The second suggestion was based upon the pilot's experience in a NASA study of a CDTI display with an application was integrated with the autoflight system where the pilot could pick a target aircraft and the system would maintain a specified distance. "I could easily see a guy being lazy and just not -- with a clearance or anything, just take an aircraft in front of him, say 20 miles ahead of him, because he knows he's not -- over eight hours, he's not going to catch the guy, just because of the speed differential

between the two aircrafts. He just tags him and says: I'll just stay 20 miles behind him. So, when he gets to the other side of the world, he's still 20 miles behind him. You know, being lazy."

In both cases the CDTI and FIM-S devices were used as intended to visually follow or "lock on" to maintain separation from a target, but the purpose for which that capability was applied was not intended.

Discussion of the Exercise's Effectiveness in Identifying Unintended Uses

The purpose of this exercise was to try three approaches to identifying unintended uses of NextGen concepts. It was hoped that the exercise would to contribute to the overall objective of specifying a process or processes that will help certifiers of NextGen avionics identify potentially deleterious uses, unintended by the developers or the FAA.

For this exercise, it was decided try to use the conceptual descriptions in the AIWP to somewhat standardize the definitions for the avionics rather than try to pick a specific implementation which could have unique problems or suffer from interrelationships with other avionics. The difficulty of identifying specific, unintended uses based upon the conceptual descriptions in the AIWP was soon recognized. However, it should be noted that finding examples of unintended uses of existing, frequently used flight deck avionics has been difficult as well.

Literature Review

The literature searches for this exercise focused on Human Factors related articles which are valuable for identifying design issues, performance assessments, and other factors such as pilot workload and crew coordination. The Human Factors literature was not, however, fruitful relative to unintended or inappropriate uses of NextGen avionics. There are some other sources that may identify inappropriate or unintended uses may be Preliminary Hazard Analyses (PHA) such as that performed for the Capstone project (Capstone System Safety Working Group, 2000) and for ADS-B (Allocco & Thornburg, 2001). PHAs use a form of fault-tree analysis and are usually performed in advance or near the beginning of implementation and might provide insight to potentially hazardous system uses. Reviews of those particular PHAs, unfortunately, did not yield unintended uses. The terms 'unintended ' and 'inappropriate' were associated with operator error and mistakes in display interpretation.

Another potential source that should be explored further are safety bulletins such as that for inappropriate use of ACAS II /TCAS II put out by Eurocontrol to warn of the inappropriate use of TCAS for aircraft separation (Law, 2005). Relative to a process for certification, however, such bulletins become available after the fact, and thus less valuable.

A pilot in the brainstorming session suggested review of company Aviation Safety Action Program (ASAP) reports, although he pointed out the difficulty in getting airlines to release them.

Affordances

The analysis of affordances of avionic enablers and TSA application concepts in this exercise did not yield unintended uses. Nevertheless, it still seems like it could be useful when applied in more depth and with more system definition. Perhaps too, application of a more mature model of pilots' motivational interests might help to focus on affordances that address those motives.

To better explore the idea of identifying affordances for unintended and deleterious systems uses, the next exercise should research the detailed CDTI (Airborne) operational requirements documents (e.g., TSOs, RTCA DO's) in depth and develop a fault-tree-like analysis relating features and affordances to motive and consequences.

Brainstorming Sessions

Procedure

Informal brainstorming sessions with commercial pilots[20] were conducted within the focus groups in which the motivation ratings were gathered with two objectives: (1) elicit their ideas about potential unintended uses of the avionics associated with the NextGen ADS-B Traffic Situation Awareness (TSA) applications, and (2) use brainstorming as a possible approach to identifying affordances and unintended uses.

The approach focused on the characteristics of the FAA's concepts, rather than specific vendor implementations. The FAA document, *Application Integrated Work Plan* (AIWP), Version 2 (Capezzuto, 2010) was chosen as an authoritative source for the FAA's concepts for Automatic Dependent Surveillance-Broadcast (ADS-B)-related applications and avionics. From the 17 applications described in the AIWP, the seven applications with maturity rankings of 4 or above and their associated avionics were chosen to be included in this exercise. A maturity ranking 4 meaning that the concept is well developed and identified research is in progress.

These seven applications focused on TSA and included:

- Traffic Situation Awareness–Basic
- Traffic Situation Awareness for Visual Approach
- Airport Traffic Situation Awareness
- Airport Traffic Situation Awareness With Indications and Alerts
- Traffic Situation Awareness with Alerts

After the general introduction and motivation rating exercise described in Part II of this report, pilots were introduced to the brainstorming session. They were told that the session was intended to be informal and that they should feel free to speak up with questions and comments as they arise. The hope was that these comments would trigger thoughts and comments from other pilots, as they should in a brainstorming session. In the first of the three sessions, the pilots were told about the goal to identify unintended uses of avionics and presented with the definition. They were then told not to concern themselves about whether or not a use was unintended in hopes they could respond more freely. In spite of that instruction, pilots still struggled over the term 'unintended uses'. For subsequent presentations,

[20] See Part II for a description of the participant pilot's experience and demographics.

reference to the term 'unintended' was removed and where necessary the terms 'additional' or 'alternative' uses were substituted. This change seemed to help somewhat.

Within the informal environment where pilots could comment or ask questions at any time, the following information was presented in a manner similar to that in this section augmented with pictures and examples of CDTIs from research and industry:

- Overview of the FAA's NextGen Program
- Overview the FAA's vision for ADS-B, Flight Information System- Broadcast (FIS-B), and Traffic Information System-Broadcast (TIS-B).
- Overview of the avionics that 'enable' applications
    - ADS-B Out
    - CDTI (Ground)
    - CDTI (Ground with Surface Indications)
    - CDTI (Air-Ground)
    - CDTI (Airborne with Conflict Detection)
    - Along Track Guidance
- Overview of NextGen ADS-B applications (building blocks toward the FAA NextGen vision)
    - Traffic Situation Awareness–Basic
    - Traffic Situation Awareness for Visual Approach
    - Airport Traffic Situation Awareness
    - Airport Traffic Situation Awareness With Indications and Alerts
    - Oceanic In-Trail Procedures
    - Flight-Deck Based Interval Management-Spacing (FIM-S)
    - Traffic Situation Awareness with Alerts

While pilots were free to comment at any time, specific breaks were taken after each of the topics of: Airport TSA with Indications and Alerts, and TSA with Alerts to encourage discussion. Selected comments from the Brainstorming sessions are provided in Appendix A of this report.

The Brainstorming sessions, while very interesting, were not very productive in eliciting unintended uses from these conceptual descriptions of avionics and applications. There were several factors that made this effort very difficult for the pilots:

- The pilots in the first session were confused by the term 'unintended use', and often thought we were referring to unintended consequences, or to unintentional behavior. To alleviate the pilots from the burden of thinking about what is or what is not 'unintended', we abandoned the request for 'unintended' uses after the first session and shifted to using the terms 'additional uses' or 'alternative uses' for the second and third sessions.
- Many of the operational concept details were either unavailable or unknown to our research team, making it challenging to convey functionality at a deep level. The pilots commented that if they had detailed training on the systems, they would be in a better position to think of alternate uses.

- The pilots needed more instruction on the avionic enablers and applications than would be possible in a 7- to 8-hour session. One pilot suggested several days or even weeks in a simulator might be required.

There were some interesting trends relative to what drew the pilots' attention and some of the perceived affordances such as use of the Fight ID in the CDTI. They quickly perceived it as a solution to frequent problems verifying the aircraft to which ATC was referring during communications. They then started thinking about other uses such identifying slow aircraft to beat or fellow airliners to aid. This strategic/competitive attitude was evident in all three pilot sessions.

The best example of a way a U2 was found came from a pilot's comment in the brainstorming session which described a case on an Airbus where after an aborted takeoff the flight crew attempts to come back around to try to take off again and the FMS won't allow them to change the departure runway or V speeds once it's been in the take-off phase:

> PILOT2- 7: …and this process -- for us in the Airbus, this started, you know, six years ago. And they implemented it at our airline two years ago. In all of that development, the other users who used it, nobody ever thought if you take off and abort the takeoff and come back around and try to take off again, you can't change the departure runway, you can't change the V speeds once it's in the takeoff phase. Okay? And this is just a limitation associated with our box. Well, nobody knew that this was going to happen until they experienced it on the line and line operation. And the initial solution was… well, we don't know what's going on. Shut the FMG speed down. Well, can't do that. Shut the airplane down, power the engines off, make the airplane go dark, let it sit for three minutes and power it back up and now it will work the way it's supposed to. What a terrible solution for a line operation. Scares passengers, everybody.
>
> So, you know, we get in the simulator, and we spend six hours trying to figure out, between the three of us, how can you do this without causing it to do that. Well, we go in there and fiddle around and find a work-around that allows you to leave the engines on, using a secondary flight plan. Anyway, my point is this: I don't know what's going to be wrong with it or how to shortcut it until I use it. And -- this example here, it was five years. They used it for five years, and no one ever figured out a way to do this.
>
> PILOT 2-4: Until it was a problem.
>
> Until there was a problem. It became an operational issue. And it's like, How could we anticipate it if we never use it? I mean, I don't know how else to say that. You know what I'm saying? I mean, it's a very complex thing. I don't know feasibility of it.
>
> *****: So you're talking about a situation where your primary motivation to find a work-around is something that didn't work as you expected it to in the beginning or as you want it to?
>
> PILOT 2-7: Yeah.

It is evident that scope of what we were trying to communicate to the pilots was too broad for the time allotted. We were trying to communicate the nature of the NextGen program to provide context for the ADS-B applications, the capabilities of the avionic enablers required to implement the applications, and the concepts for the applications within an eight-hour session. There was not enough time to communicate the details needed to make the pilots understand intended uses and become comfortable enough to think about other uses. Brainstorming sessions with groups of pilots focusing on more specific pieces of avionics may yield more uses. However, eliciting alternative uses from pilots might be more effective using simulations of specific avionic capabilities in a simulated flight environment.

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Acronyms

Acronym	Definition
ADS-B	Automatic Dependent Surveillance - Broadcast
AIWP	Application Integrated Work Plan (FAA document)
AS	Aircraft Surveillance
ASSAP	Airborne surveillance and separation assurance processing
ATC	Air Traffic Control
CDTI	Cockpit Display of Traffic Information
EFB	Electronic Flight Bag
FIM-S	Flight Interval Management-Spacing
FMS	Flight Management System
GPS	Global Positioning System
MFD	Multi-Function Display
NAS	National Airspace System
NextGen	Next Generation Air Transportation System
PHA	Preliminary Hazard Analysis
RTCA	Radio Technical Commission for Aeronautics
TCAS	Traffic Alert and Collision Avoidance System
TSA	Traffic Situation Awareness
TSO	Technical Standard
U2	Unintended Use
U2A2	Unintended Use of Aviation Automation
UI	User Interface
VFR	Visual Flight Rules

VMC	Visual Meteorological Conditions

Appendix III-1: Selected Focus Group Comments

The following are various comments recorded by the court reporter during the three brainstorming sessions with experienced commercial pilots regarding ADS-B CDTI Applications and Avionics. These comments have been selected from over 18 hours of comments based upon relevance to the U2A2 effort and in some cases examples of current CDTI usage. Very few can be classified as actual unintended uses, but the comments may still be useful indications of potential problems. The comments have been informally grouped around a common theme, frequently comments could have been placed in multiple themes. These themes are not intended to have theoretical meaning and are only meant to provide some overall organization. The themes are:

- Over-Reliance on Automation and Complacency
- Strategic Behavior – Gaming the System
- Emboldened Behavior
- Actual ADS-B CDTI Experience
- Example of Unintended Use of the FMS
- Potential Processes To Discover Unintended Uses

Pilots are designated by their session number first (1-3), followed by their pilot number (1-8). Speakers designated by "*****" are members of the research team. Follow on comments are nested below the initial comment in the discussion.

Over-Reliance on Automation and Complacency

Comments regarding over-reliance on automation to the exclusion of looking out the windshield and scanning of other instruments came up frequently. Over-reliance on the automation at the expense of other informational sources is an unintended use, as it is unintended by the developer and the FAA that the automation is the only source of traffic information.

PILOT #1-5: It just -- came to mind, since this whole picture thing is about unintended consequences[21]. It's systems like you were describing or some of the things that you're talking about -- I think the biggest unintended consequence that comes of a lot of this automation is complacency. There's too much reliance and not enough, you know, verification of this information. Because, you know, now TCAS is, for example, telling you when you're about to hit somebody, which is great. But it causes the people to not look as much for that aircraft because they rely on this TCAS. So for a lot of these things that you're talking about, it induces a level of complacency that can be dangerous. And that's the biggest unintended consequence I can see that's coming with all this stuff.

PILOT #2-6: Along those lines, as another "gotcha" -- another unintended possible negative is that we become complacent, thinking, Well, this thing is displaying everything out there. Every vehicle, every airplane. And that may not be the case. Just like TCAS. You see some airplanes but not all airplanes. You're not going to see all the vehicles. Somebody's switch may be turned off or whatever.

> *****: That brings up a good point. It's like, you know, you've seen the way ground vehicles get treated around the airlines. I mean, how many – how many luggage carts -- you know, when

[21] This is an example of how the pilots in the first session were a bit confused about the term "unintended uses".

you come to work and -- you know, how do they do -- how do they know that the transponder on their vehicle is not working, for instance? Or even if they say, Hey, the transponder doesn't work. It's like -- well, who do you tell? And then how do the -- how do you – you know.

PILOT #2-2: Or would they turn it off because they're going over to the cafeteria and it's not break time?

Pilot #3-3: So I guess my comment is technology is great but when it starts becoming too useful where someone could -- that's where you are going to see the overreliance and the abuse.

PILOT #3-9: I would say, first of all, using the Capstone example -- is that kind of what you were looking for? Basically people abusing the technology. Normally I can't see to fly over the mountain pass because it's too cloudy. Hey, I have this thing and it shows me exactly where the rocks are and I'll just fly right in between here.

[Overuse of Technology (Capstone example – misleading in that Pilots were already flying into weather, whether or not it was bad. Capstone reduced collisions about 30%.)]

PILOT #3-6: Over dependence on the automation is the bottom line to the detriment of basic flying skills. An example would be the abundance of GPS portable units and general aviation aircraft. People are over-relying on that. If it goes out, then, shit, we have to grab a map and figure out where they were because they didn't really know where they were rather than looking at the pink line. We all are seeing this because we are children of the magenta line and we just follow the pink line wherever it goes, but to have the basic flying skills and to have that awareness if something fails all this automation that are tools that help us, if those fail or if there's a problem or all this stuff right here is depending on the satellite.

PILOT #3-4: I think there's two different things. One is you have so much information and then you become over-relying on it while you can put in a system in your check flight every year or every third flight you have to fly a visual to make sure you keep up on your hand flying, but I think what he was talking about is like when American went into the rocks and we have training clearance technology we could have used earlier but now everybody is going to have it.

Strategic Behavior – Gaming the System

This is another type of comment that came up frequently. While one could argue that using the information to lobby ATC for better position is unintended, one could also argue that that's precisely an intended use of the additional information and capabilities from ADS-B. It is however, behavior that should be expected.

PILOT #1-7: One bad thought, more pilots personally like to be in control of things. I can see them actually mucking things up a little bit. Because they're trying to <u>game</u> the system, whereby -- -- that's looking at it from an airline standpoint. ATC is looking at it from a systems standpoint. And you have an individual pilot saying, I'm going to do this. So I can see it really screwing things up. Especially in high-traffic/low vis situations, where I could easily see a situation becoming very, very garbled very, very

quickly.

PILOT #1-6: Or like with TCAS, this whole thing where the controller tells you to do one thing and TCAS says do another thing. You can start gaming the controller as the controller has got the plan in his or her head. And you start saying, Well, if I slow down now a little bit, it's going to make it a little hole for me. And -- you know, think of San Francisco, when you have two runways crossing two runways, how that could really mess things up if everybody starts, you know, just pulling on the rope. Who is in control?

Who is doing this? And sometimes maybe a little too much information can become a little distracting too.

PILOT #1-5: We already do some of that now, with the information that we have. Right? Trying to <u>game</u> the system or get an advantage for our position by looking out the window and seeing, hey -- like I was taxiing out of Chicago, pushing back from the runway, which is right here (indicating). And Chicago made me taxi all the way around the whole airport to get to it. And there was nobody was there, you know. So I had to jump in and say, How come you had me do that? Well, controllers have got their own plan. But we already knew that. But the point I think is being made here is that more information is going to lead to more of that type of behavior that we're already engaged in.

PILOT #1-1: Okay. One leads to the other. The perfect example: getting back to the system here. Now, we have all been in situations where pilots at some point fly -- or the pilot force fly by the book. Fly by the book, right? There might be some contract negotiation going on. It's almost always -- some airline is in there. And what happened? Captain says, I'm going to taxi slower here. And guess what? Now he can look and see all these airplanes lined up in Chicago behind you. And guess what? Now he's taxiing a little slower because he's working the system. Why? Before he didn't know exactly where all these airplanes were, how they were sitting there behind him, lined up. And, you know, the -- well, I can see there's ten of them. Yeah, let me tell you. He's going to do a nice, relatively slow taxi. So he's using it in an unintended way, but the consequence is going to be phenomenal. So there are some -- just like he said, some disadvantages to giving all that information out.

PILOT #1-4: He was talking about times of unpleasantness during contract talks. And a long time ago, one of our first contracts with UPS, they were some flights from the East to West Coast to Louisville. There's like a four- or five-minute critical window -- a four- or five-minute critical window where you're supposed to be there. And they would – management would go in and pull up the information on the seven five that could tell them their speed, and they would check their speed -- because people might be slowing down for turbulence or whatever. And they would check their speed to make sure that -- why they were slowing down. If you did slow down too much, they'd want an answer when you landed why you were slowing down. So I don't even know what the purpose of that information is originally, but that's what they were using it for.

> PILOT #1-5: Management does that now.
>
> PILOT #1-4: Yeah, but they were more emphasized at that point about the contract and stuff like that.

PILOT #1-2: I'd like to see if I was taking off, East Coast, West Coast; carrier in front of me takes off, going the same destination. I could see what his flight plan is. You know, time. Doing seven eight; I'm going to do eight O. And I can start calculating. I can pass this guy somewhere down the road and get ahead of him instead of having to slow down and burn more fuel. Maybe go up or down.

> PILOT #1-3: We do that right now. And believe me, that guy sees we're cheating and trying to overtake him -- there's a great equalizer – Locking on to target Aircraft and Following

PILOT #2-4: Well, that is one other thing that we all integrate into our own operational planning is corporate culture. You know if you're following Southwest, they're going to be going fast. You know if you're going to be behind Korean, you're going to be doing 250 for 150 miles out. You know, here's just --there's procedural cultures in different companies. And you base your operations on what's going on around your airplane, starting -- you know, coming into "Jockeying for position" with Korean Anchorage, 150 miles out -- you know, we jockey all the way across the ocean, looking at "Where is Korean?" Because everybody wants to get in front of them, because they slow up the entire world. Whereas you know that –

PILOT #2-4: Yeah. Well, because what they -- they program their FMS with this cost index zero, which is -- you know, trades time for fuel savings. So from 150 miles out, starting into Anchorage, they're -- they're going as slow as they can. And they plug up the whole world. When everybody else is doing 85, 86 or 87, they're at .80. You know, they're 40 or 50 knots slower than everybody else. And they're ten miles in-trail or twenty miles in-trail. Coming across the Pacific, there is 50 airplanes crossing the Pacific at once. If they're in the head of the line, everybody is slowed up. So, you know, all the way across the ocean, everybody is jockeying altitudes and –

> *****: Trying to get out.

> PILOT #2-4: On CBLC -- you know, you – because obviously you listen -- you listen when everybody checks on, coming across -- you know, six hours out, leaving Japan, everybody listens. Where -- where is everybody in the stack?

PILOT #3-3: [relative to the capability to 'see' behind your ownship] You want to know how close they are. So if there's nobody behind me or they are pretty far back, and let's say I've got a higher approach speed and a higher landing speed, I might not put on the brakes as hard and say I can go to the next taxiway. I'll spare the brakes today, but if I know my company is right behind me three miles facing, one of the bad decisions I might make is, well, gee, I have a high approach speed but I really want him to be able to land. So I have to get off the runway quick. So I'm going to slam on the brakes and get off on that reverse high speed quickly and maybe that's not a good decision. Maybe it's wet or whatever, but because I have that knowledge I'm -- in this phase of flight where I should be looking only at the runway and only concerned about my particular situation, because I'm like, yeah, let's make dollars, let's have profit sharing, let's get my company on the ground right after me, I'm now looking behind me and 300 feet above the runway on approach, and I'm looking behind me saying am I going to slam on the brakes to make this early taxiway or can I let it roll out and I'm not going to worry about my buddy going around?

> PILOT #3-8: That's interesting because if you are going to use some of your brain power to be doing that, you may not be looking down the runway and seeing what is in front of you.

PILOT #3-3: Right. That's where maybe too much information -- yeah. To a certain extent I should worry about who is behind me but that should be cut off at a certain point. But the temptation is -- especially in an environment you are worried about cutting costs and you don't want to go around or you don't want to send your buddy around. You might make a decision on braking action and which taxiway to get off that's not the best decision for you, and you are making it for someone else who is behind you.

PILOT #3-8: **** made a great point about if you had the information of where – which departure someone is on, then you can work the system to say, hey, we can take this intersection departure and get ahead of him. That's another example of possibly too much information.

PILOT #3-3: Yes. Another way would be you are on approach. You know you're on a long final. You know there's aircraft behind you, and you know that one of your company's aircraft or somebody you want to allow in on a downwind on a visual, and you go I'll slow down my approach speed so they have plenty of time. Aircraft will let them in. So you start being the traffic controller and you start trying to help someone get in front of you before so they can get in before that long line of aircraft.

PILOT #3-7: At the end of the day, we can end up at the same bar having a good time having a beer, but when we are flying, we are all trying to beat each other.

*****: One more question for Pilot #3-3 based on what you said where you are thinking with your company hat on about costs and preventing the guy behind you from your airline having to go around. How often do any of you find yourself in that mode where you have more or less put, you know, your own responsibilities for your vehicle number two behind thinking with the cost hat? How often?

PILOT #3-3: I think almost everybody to a certain extent is on the radio. If you are going around the radar pattern and you're checking for visuals and you are looking for people on final, you are also listening to the radios and kind of figuring out how am I going to fit into this, and to a certain extent, yeah, I mean, I think everybody here will attest to the fact there's possibly been sometime they have said, well, okay, I'm not going to put my aircraft in danger. I'll be at a thousand feet and stabilized but maybe final approach I'll fly a little bit faster because there's a line of aircraft coming, and a lot of times air traffic control is giving those instructions. A lot of times you will see it on the screen or you'll hear it on the radio and you will kind of do a little bit of your own speed adjustment to help the situation.

PILOT #3-3: I have seen it where lots of times you treat -- other airlines trying to help us out and we try to help them out, and we'll say so-and-so is not going to have separation with us if we do this or whatever. So let's slow down or speed up to help that other person. I mean, you do that. You do that for other airlines also.

PILOT #3-3: I could see where two UPS aircraft coming back and maybe merging to the same point. So they set up a separation between them and one of them goes, I'm going to try to make that commuter flight home and I'm going to push it up and abort ATC's plans, and assuming they didn't get a speed yet to fly but, you know, sort of racing to get to a merge point or good altitude, and the guy behind him slows down and they get into the airport first. We are assuming that is not going to happen, that kind of shenanigans.

Emboldened Behavior

These are examples where the information provided by the ADS-B CDTI embolden the flight crew to push harder to act where without the information they might not. This behavior is not unintended use of the avionics, per se, but it should be considered in procedures and training.

PILOT #1-8: Something that -- now, I've got to look back a year, a year and a half, because it's been that long since I last flew the triple 7. But something I learned at United, flying to the island so much, with very busy tracks and offsetting a mile or two. I'd see people who would do that right under the airplane. But I learned the hard way. It takes 20 miles for wake turbulence to come down a thousand feet. So, based on what the relative wind is and the traffic ahead of you, when that traffic is 20 miles ahead, that weight will be down at your altitude. So it's not ten miles, it's not thirty, but right at twenty. Because it comes down about 400 -- three or four hundred feet per second. Takes almost three minutes to come down a thousand feet, and that's where you'll hit it. So, again, using the system -- it wasn't designed for that, the TCAS system. But it's a great wake turbulence tool for en route operations. I'm sure everybody has got their own dozens of little techniques like that too.

Pilot: You know, one of the – another unintended use was that now if you have a situation where behind you -- in other words, you can see other airplanes and ground vehicles -- now, you know, when you -- you can say, Hey, are we ready for push back yet? And they say, No, we're waiting for another ramp guy, a wing walker. Let's go ahead. Do it. I'll take responsibility for it. I can see back there, you know.

[…] Backing up where you can't see is still a problem. And I think somebody else just mentioned -- well, the other one that we talked about all the time when I -- when I was a check airman -- or I was doing OE. Particularly on -- well, a lot of times it was just the FOs. But you would go -- you would go out to the runway, and they would say, Position -- which I think that's changed recently. But -- sorry for the terminology. But start out on the runway. And, you know, you're always -- you know, the book says, you know, you're supposed to visually clear the final. You see a lot of people now who just -- they look down at the TCAS display and see if there's somebody on short final and then just taxi out on the runway without even looking out the window.

> PILOT #1-8: On the other hand, if he's short of flying time for the month -- because the clock starts when you release the brakes.

PILOT #1-8: Or, on the other side of that, you start anticipating things, and I'll bet you you'll have more runway crossings without clearances. Because now you stop being -- that's a good time to be passive, when you're on the ground, getting pushed around an airport. If you start getting a little more proactive, you may stop -- you may stop thinking. Or you're thinking, but then you take a controller out of that equation and, being fatigued, you may do something that -- well, I thought he was going to cross me. I thought he did. And then you're building a greater problem.

PILOT #1-2: Or just assuming that this is a clearance I'm going to get. I know I get this all the time. And all of a sudden he's giving you a totally different clearance, and now you're assuming that clearance is coming.

PILOT #2-2: Well, on departure, you could potentially adjust your climb by looking at the traffic, anticipating that they're going to re-clear you. You're cleared to 3,000 feet on takeoff, for traffic. You look and say, Ah, he'll be out of the way. I'll get clearance to four or five, so you delay your level-off in anticipation, on that clearance. That could be something.

PILOT #3-3: You might suddenly start badgering the tower can we take an intersection takeoff? We can get out in front of those guys because we have a different departure. I know Southwest would be all over that. Let me get ahead and --

> PILOT #3-4: And they would say sure, because they always do.
>
> PILOT #3-3: You end up having everybody kind of working their own special deal. Even on approach they see a bunch of aircraft lined up and they say, hey, I can get in front of that guy on a visual. Will you let me do it? Then tower and ground and all these situations are badgered with more radio calls of pilots trying to work their own deal based on the scenario they see on the map.

PILOT #3-3: Do they envision -- one of the things I keep thinking also is the push back from the gate because there's a lot of airports I know like Orange County when you are constantly saying I would like to push back and they go we have traffic and it's always because it's got one taxiway and it's behind all the gates, and I have a visual picture of all aircraft lined up behind me. In one sense it should be better because they should be able to say you push back after United 231 goes by you and there should be a picture of that, and it should say United 231, but I wonder if there's also maybe a potential for acommunication problem where they go -- I guess it would have to be a screw up where they go, you go behind United or you go behind the next aircraft and they are looking at something else and you see something on your screen and you see an opening and you tell your guy, let's go, because you see it and you push back when they don't want you to.

Actual ADS-B CDTI Experience

PILOT #3-1: Just with my experience, you know, all those things, the Allegiant stuff – you don't need to put that -- but it's the cultural thing. UPS is kind of an anomaly. We have this one experience with one fleet type and we have all the aircraft are equipped. So from the line perspective I see guys using it as a tool to supplement their decisions. So, you know, we increase our situational awareness when we go

position and hold, being able to look behind you, you can see if traffic is going to land on top of you. So that's the added benefit.

PILOT #3-7: One thing you can bring back is, he made an excellent point, sitting on the runway and using that to look behind you. Many times I sat on the runway wondering, the guy is clear for landing. Is he going to land on me or not? And it's been proven over and over again like LA and other places guys have landed on other guys, visual conditions.

PILOT #3-1: For us that's procedural now that we make the displays so we can see behind us when we go in position hold.

*****: Did you experience any odd uses --what did people do with your display?

PILOT #3-1: Essentially used it for the most part as advertised and then they use it just to -- I think just more creative uses for increase in situational awareness. I don't think we first thought of the airplane landing on top of you, that type of scenario. We actually had an incident somewhere in Asia where an airplane almost landed on one of our aircraft, and we were, hey, it's there. Why don't we use it?

I would say initially the implementation when we first get it you are a little overloaded because it's something new and there are many buttons. It's getting a little sensory overload, but once you get used to it, it's like second nature like anything. Whenever you transition to a new aircraft, it's different, but then you get used to it.

*****: Did you find it similar to using TCAS?

PILOT #3-1: The TCAS for us is integrated within it.

*****: Right. But let's say TCAS without it then TCAS with it.

PILOT #3-1: I would say it's used for different purposes. It's more -- TCAS is kind of a last stitch safeguard before somebody hits you. Whereas, this is more of a tool for planning and stuff like that.

*****: So did you play with it?

PILOT #3-1: Oh, yeah.

*****: What kind of things did you do with it to play with it?

PILOT #3-1: Like there's different features that are useful, and some guys use it and some guys don't. You can create -- you mentioned range ring. So you can create like a 5-mile ring around your aircraft. So depending whoever you are following for weight turbulence separation, make sure that guy doesn't get in your ring. Different guys do different things. It's not a formal procedure for us to use it for wake turbulence separation but some guys do use it.

*****: So you did use it for that?

PILOT #3-1: Yeah.

*****: Any other things that were not formal that you used it for?

PILOT #3-1: No. As far as the -- the only other thing I can think of using it for is a lot of times we wait. Our airplanes will connect. So they will come from two different spots and we swap freight and go someplace else. So a lot of times you are waiting for somebody. So we'll use that. If you are eager to have them come –

*****: To find out --

PILOT #3-1: Yeah. You have a better, more accurate -- instead of relying on operations telling you the white lie that they are going to be here in 30 minutes. You can actually watch them. That's about it. It's pretty cool.

Example of Existing Unintended Use of the FMS

PILOT #1-3: Obviously, to enter most of the information into the FMS, you use a scratch pad. The scratch pad comes in handy for a lot of other things. You know, little clearances they give us. All of your taxi instructions like that. So, commonly, the industry does use it for that because it's fast and easy.

> PILOT #1-2: Let alone crossing restrictions, route altitude changes, new frequency changes, all types.

Potential Processes To Discover Unintended Uses

Simulator Time

*****: So the simulator, how much time do you think you would need to play with some of this stuff in a simulator before you started -- or were ready to or open to discovering these new uses? I mean, part of that time –

> PILOT #2-7: You're not going to like the answer. Because you can't put me in the box and give me ten hours of work in that box and I'd be comfortable with it. It's going to take a couple of weeks.

> PILOT #2-6: You're going to do that on the line. You're not going to do it in the simulator.

> PILOT #2-7: I just don't think you could -- Cost-wise, if you could do two weeks of activity in the simulator, you would probably drive me crazy, but you could get it -- it would take two weeks, like I said.

{Regarding training before NASA test of CDTI User Interface}

PILOT #2-4: When we actually -- when we actually do them for a couple of weeks, the sum total of our training was, we showed up to brief, and then we got a little memo that said, Hey, you're part of the ASB testing. And then we had a little CD to watch, like 15-minute video on here is how you select your target and this is what the system looks like. And we launched a little 15-minute CD and a memo that said, Go forth and multiply.

How Pilots Learn About Unintended Uses

PILOT #2-8: There's a lot of information – you can make it do this or you can do this with it. There's a lot of that information out there. But it's usually just derived from somebody showing you. Finding additional alternative uses in the Testing Phase.

PILOT #2-7: As a simulator instructor and an operator, we have a lot of chances to go in and see things that you would never see in the airplane: Emergency electrical configuration. And you're in the simulator, fiddling with these different things in a testing phase or things like, for instance, trying to set up course information, and you stumble upon things in that fashion as well. Or someone will say something to you like, Hey, you know what? I was on that airplane out of Newark that lost the electrical system, and this is what I saw happen. I don't understand what happened or why did that happen. So you want to -- then you try to replicate that, and you realize, Hey, there is a feature in here that we didn't realize was even available to us. And you go to the manufacturer, and they go, Well, we knew about that but we didn't certify that feature. So it's an uncertifiable feature. It may or may not work in all of the airplanes, in the configurations that you have. So we don't want to say anything about certifying it or writing it in a flight manual or anything like that. So it's an uncertified feature type of thing. That's another way we can discover stuff.

PILOT #2-5: If it's in there, they're going to find it.

PILOT #2-4: Eventually.

PILOT #2-5: Sixteen-hour flight, they're going to find it. Even a three-hour flight, I'm going to find it. Doesn't mean that I'm going to do anything about it. But we will learn about it, and then I'm going to tell Vern and he's going to show them and there you go.

PILOT #2-7: I think an example of what you're trying to -- I think you're trying to accomplish and the complexities associated with it: FMS 2 is designed by Honeywell. And this process -- for us in the Airbus, this started, you know, six years ago. And they implemented it at our airline two years ago.

In all of that development, the other users who used it, nobody ever thought if you take off and abort the takeoff and come back around and try to take off again, you can't change the departure runway, you can't change the V speeds once it's in the takeoff phase. Okay? And this is just a limitation associated with our box. Well, nobody knew that this was going to happen until they experienced it on the line and line operation. And the initial solution was, Well, we don't know what's going on. Shut the FMG speed down. Well, can't do that. Shut the airplane down, power the engines off, make the airplane go dark, let it sit for three minutes and power it back up and now it will work the way it's supposed to. What a terrible solution for a line operation. Scares passengers, everybody.

So, you know, we get in the simulator, and we spend six hours trying to figure out, between the three of us, how can you do this without causing it to do that. Well, we go in there and fiddle around and find a work-around that allows you to leave the engines on, using a secondary flight plan. Anyway, my point is this: I don't know what's going to be wrong with it or how to shortcut it until I use it. And -- this example here, it was five years. They used it for five years, and no one ever figured out a way to do this.

PILOT #2-4: Until it was a problem.

PILOT #2- 7: Until there was a problem. It became an operational issue. And it's like, How could we anticipate it if we never use it? I mean, I don't know how else to say that. You know what I'm saying? I mean, it's a very complex thing. I don't know feasibility of it.

PILOT #2-8: You don't know what you don't know.

PILOT #2-7: Exactly.

*****: So you're talking about a situation where your primary motivation to find a work-around is something that didn't work as you expected it to in the beginning or as you want it to?

PILOT #2-7: Yeah.

*****: Are there other things like that that occur a lot or that occur at all?

PILOT #2-2: At first, with a new system, there is. And then as it matures, it calms down. So the first time I flew an FMC up there, every other sentence was, Why is it doing that?

*****: I was telling everybody -- you know, these guys that one of the best sources of information that I've ever seen on this kind of stuff is the NASAP reports. I mean, it is -- it's unbelievable what comesthrough that program. But the information is like -- almost impossible to get at. [NASAP – Nortwestern Aviation Safety Action Program]

Appendix B. System photos.

Figure 4. TCAS display.

Figure 5. Weather Radar display.

Figure 6. FMS Legs page.

Figure 7. FMS Performance Init Page

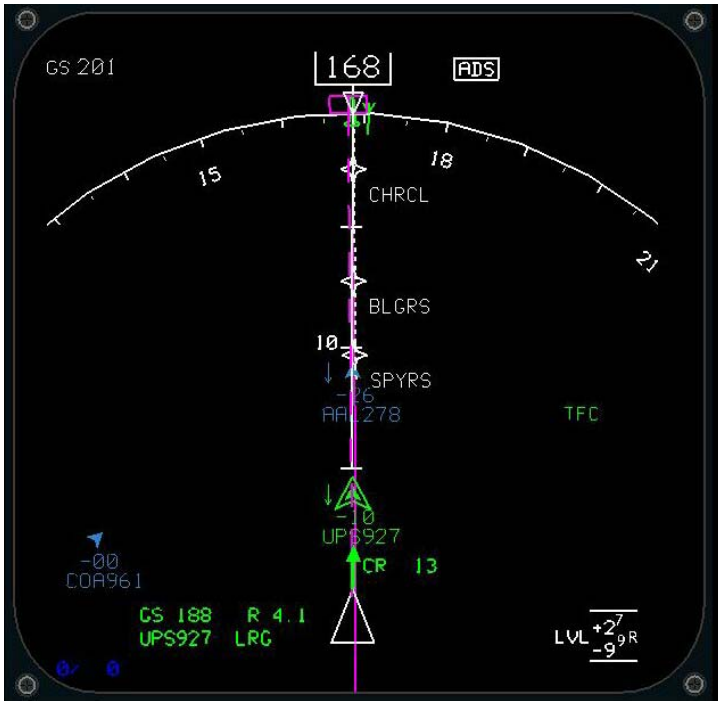

Figure 8. CDTI display.

Figure 9. FMS Descent Page.

Figure 10. Fix Pages 1 and 2.

Figure 11. A-319/320 Flight Plan Page A.

Figure 12. DC-9 Radio Altimeter.

Figure 12. Route 2 (Inactive Route) page as displayed on PFD.

Figure 13. GPS Flight Management System, 1st page of ROUTE page.

Figure 14. GPS FMS.

Figure 15. FMC Hold Page.

Figure 16. A320 Flight Control Unit.

Appendix C. Removal of Duplicate Systems

This section describes work performed to predict the ratings of the likelihood that a system would be used in an unintended way, and the Hazard Index (HI) and Risk Priority Numbers (RPN) that were computed for these systems. The systems are listed in Table 10 This work corrects prior work by combining data from two systems which, while previously considered distinct, are actually quite similar, and by deleting a system for which no unintended use was identified. The two similar systems are the FMS Fix Page (formerly system number 7) and GPS Flight Management System (formerly system number 13).

One system was removed from all these analyses as no unintended use of that system had been identified. This is the Flight Management Guidance Computer system (formerly system number 8). Unintended uses of all of the other systems had been identified.

Two approaches were explored to deal with the systems that were so similar that for practical purposes they could be considered to be the same. The first approach was to average the dependent measures (ie., the rank orders of the likelihood of the systems being used in unintended ways, the RPN and HI scores) and to average the attribute scores for the systems being combined. The second approach explored was to exclude the data from the GPS Flight Management System from the analyses;

For the purposes of the analyses reported here, the ratings of the likelihood of the systems being used in unintended ways were averaged, as were the Hazard Index (HI) and Risk Priority Numbers (RPN). For the HI and RPN computations there were only 12 systems, HI and RPN values were not obtained for the Flight Control Unit (FCU) system.

Table 10. Systems included in analyses.

System No.	SYSTEM
S01	TCAS
S02	Weather Radar
S03	LEGS page within FMS
S04	FMS - Performance Initialization Page
S05	CDTI use while Airborn
S06	FMS - Descent Page
S07	FMS - Fix Page / GFMS (GPS Flight Management System)
S08	Flight Management Guidance Computer (Flight Plan Page A, equivalent to Boeing "Legs" page)

S09	Radar/Radio Altimeter
S10	Route 2 page on Primary Flight Display
S11	GPS Flight Management System, 1st page of ROUTE page.
S12	“Hold” page of the FMC
S13	Flight Control Unit

The twenty one attributes used as predictors are shown in Table 11. For brevity, these will be referred to by their attribute numbers i.e., A01 to A21, throughout this section.

Table 11. Attributes included in the analyses.

Attribute No.	Attribute
A01	How much user interaction is possible?
A02	How much new information content is offered by the system?
A03	How much of the information format (presentation) is new?
A04	To what degree is this new component integrated with other components?
A05	"How much influence does the pilot have over the information flow between this system and the aircraft?"
A06	To what degree can the pilot usefully combine the information from this system with information from other systems or existing knowledge (e.g., combining newly available flight ID data with prior knowledge about a particular carrier’s tendencies)?
A07	To what degree does the system provide information that evokes an immediate action? (attention-getting and provokes you to do something)
A08	To what degree does the display portray the information as having more detail and accuracy than reality?
A09	To what degree can the user put something on the display that has nothing to do with the purpose/function of the system? (e.g. scratchpad or other free text entry functionality).
A10	How much inherent complexity is there which might invite exploration (numerous pages/modes) – are the users familiar with all the pages or modes?
A11	How much information does the system provide about other aircraft operating in the NAS?
A12	To what degree does the system allow information not related to the flight to be accessed by the pilots?

A13	To what degree does the display portray rapid or continuous movement of imagery or symbols?
A14	To what degree can the system be used to locate heavy weather, such as thunderstorms?
A15	To what degree can the system be used to locate uncomfortable weather, such as turbulence?
A16	To what degree can the system be used to identify intersecting routes (e.g., when given “direct to” clearance)?
A17	To what degree can the system be used to streamline voice communications with ground and Air traffic controllers?
A18	To what degree can the system aid in observing and avoiding other ground traffic during taxi?
A19	To what degree can the system be used to monitor own aircraft position and trajectory?
A20	To what degree can the system be used to comply with crossing restrictions?
A21	To what degree does the system offer a simpler or easier method of performing a task than a prior method (Does it offer a way of reducing workload)?

Pearson Product-Moment Correlations between Attribute Ratings. (df = 11 in all cases absolute value (r) ≥ 0.553 are significant at the 5% level and absolute value(r) ≥ 0.684 are significant at the 1% level)

ATTRIBUTE NUMBER

SYSTEM NUMBER	A01	A02	A03	A04	A05	A06	A07	A08	A09	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21
A01	---	-0.526	0.078	0.319	0.707	0.150	-0.430	-0.735	0.530	0.406	-0.304	-0.041	-0.405	0.068	0.134	0.308	0.470	-0.022	-0.203	0.368	0.305
A02		---	-0.124	-0.447	-0.339	0.409	0.652	0.673	-0.401	-0.690	0.541	0.309	0.755	0.167	0.046	-0.468	-0.328	0.284	-0.210	-0.117	-0.279
A03			---	0.128	0.121	-0.056	-0.525	0.146	-0.086	0.210	-0.415	-0.527	-0.141	0.154	0.000	0.216	0.583	-0.505	0.291	-0.125	0.839
A04				---	0.628	-0.408	-0.423	-0.458	0.475	0.429	0.127	0.092	-0.074	-0.599	-0.225	0.381	0.648	0.139	0.531	0.421	0.430
A05					---	-0.027	-0.157	-0.342	0.193	0.283	-0.160	-0.167	-0.113	-0.246	-0.176	0.105	0.428	-0.125	0.003	0.602	0.231
A06						---	0.200	0.137	0.057	-0.422	0.194	0.140	0.307	0.425	0.342	0.078	-0.142	0.089	-0.390	-0.207	-0.143
A07							---	0.559	-0.650	-0.457	0.344	0.218	0.466	0.077	-0.008	-0.371	-0.629	0.206	-0.231	0.320	-0.677
A08								---	-0.691	-0.481	0.185	-0.182	0.553	0.249	-0.030	-0.387	-0.456	-0.185	-0.095	-0.307	-0.260
A09									---	0.401	0.314	0.512	-0.006	-0.005	0.324	0.469	0.570	0.524	0.155	-0.132	0.348
A10										---	-0.150	0.033	-0.222	0.088	0.294	0.666	0.494	0.099	0.617	0.257	0.442
A11											---	0.887	0.842	-0.002	0.283	-0.011	0.091	0.872	0.268	-0.013	-0.139
A12												---	0.606	0.078	0.408	0.098	0.171	0.990	0.193	0.116	-0.100
A13													---	0.241	0.319	-0.097	-0.014	0.622	0.166	-0.046	-0.096
A14														---	0.394	0.171	-0.089	0.098	-0.263	-0.255	0.048
A15															---	0.478	0.151	0.438	0.049	-0.086	0.139
A16																---	0.451	0.157	0.459	0.130	0.418
A17																	---	0.196	0.521	0.268	0.915
A18																		---	0.209	0.166	-0.073
A19																			---	0.172	0.493
A20																				---	0.087
A21																					---

Correlations significant at the p ≤ 0.01 level are highlighted

Regression Analyses

The goals of the of the regression analyses are (a) to determine if the likelihood of a system being used in an unintended way can be predicted based on the attribute rating and (b) if so, to identify the combination of attributes that results in the best prediction.

Number of Attributes used to make a prediction

The data set we are working with is small; there are not a lot of systems to be predicted. There are two rules of thumb used to determine how many predictors should be used; Doane's and Evan's[22] (Doane & Seward, 2011). Doanes' Rule is to have one predictor for every 10 variables. Evan's Rule is more liberal and suggests one predictor for every five variables. In this case, we have a maximum of 22 variables (attributes). Using the most conservative approach we would limit the regression equation to two predictors. However, as this is effort is exploratory, we will use the more liberal Evan's rule and allow up to four predictors in the regression equation.

Procedure

The process of identifying the best two, three, and four attribute regression equations is as follows.

Stepwise regressions[23] were conducted using attributes 1 to 10 and then using attributes 11 to 21. The five attributes from each of these regressions were identified. This reduced the number of attributes from 21 to 10 for the purpose of conducting further regression analysisThese ten attributes were then used in a stepwise regression to identify the two, three, and four factor equations that had the highest proportion of variance accounted for. That is, the equations with the highest value of r^2.

Once the attributes were identified, linear regressions were conducted using the regression data analysis feature built into Microsoft Excel. The regression coefficients reported here were obtained from the equations computed using Excel.

This process was repeated for each measure to be predicted; Likelihood of a system being used in unintended ways, RPN, and HI.

Likelihood Of A System Being Used in An Unintended Manner

As the statistical program used was limited to 12 variables it was necessary to select a subset to be included in the analyses. Preliminary regressions in which attributes 1 to 10 and then 11 to 21 were computed. These analyses indicated that the predictive

[22] Doane, D.P. & Seward, L.E. (2011). Applied Statistics in Business and Economics. McGraw-Hill Companies.

[23] Orris, J.B. (2007). MegaStat, (Version 10.1, dated 10/1/2008). McGraw-Hill. www.mhhe.com.

value of attributes, Based on these analyses, attributes A01, A02, A03, A04, A10, A11, A12, A17, and A18 were excluded from further consideration.

A05, A06, A07, A08, A09, A13, A14, A15, A16, A19, A20, and A21 were used in the regression computation as predictors. The values to be predicted were the pilot's ratings of the likelihood that a system would be used in an unintended way. A stepwise regression was conducted to identify the two and four attributes that accounted for the most variability in the ratings. (The number of attributes selected is based on Doane's and Evan's rules.)

Two Attribute Prediction

The equation using two attributes that accounts for the most variability in the ratings of likelihood of a system being used in an unintended is:

DV = 15.29149 + 0.759963 * A15 - 2.53798 * A21

This equation accounts for 66.5% of the variability.

Three Attribute Prediction

The best three attribute equation is:

DV = 3.149475 -0.28853 * A09 + 0.846529 * A15 + 0.733864 * A21

The three attribute equation accounts for 73.4% of the variability in the U2 likelihood rankings.

Four Attribute Prediction

The best four attribute equation is:

DV = 5.56402 + 1.28551 * A09 + 0.9806 * A13 – 0.7113 * A15 – 0.7422 * A21

The four attribute equation accounts for 80.5% of the variability/

Risk Probability Number (RPN) Prediction

It is also of interest to determine whether or not these attributes could be used to predict the RPN number. RPN numbers were available for 12 systems. The linear regression equations that best predict the RPN values of these systems using two, three, and four attributes are shown below. The number of attributes was selected based on Evan's and Doane's rules.

Most of the variability in RPN scores is accounted for by two attributes, A10 and A20. Consequently, a two attribute equation accounts for nearly as much variability as is accounted for with equations containing a greater number of terms. That is, there is little improvement in the accuracy of the prediction over and above that contained in A10 and A20.

Two Attribute Prediction

RPN = 19.91263 + 29.75877 * A10 – 12.4272 * A20

The two attribute equation accounts for 78.6% of the variability.

Three Attribute Prediction

RPN = 27.15089 + 27.85299 * A10 – 8.71606 * A11 – 11.9261 * A20

The three attribute equation accounts for 86.2% of the variability.

Four Attribute Prediction

RPN = 30.64166 -1.20016 * A07 + 26.88054 * A10 -8.21576 * A11 – 11.5056 * A20

The four attribute equation accounts for 87.4% of the variability

Hazard Index (HI) Prediction

The attribute ratings were also used to predict the HI scores. The procedure used was the same as that for predicting the RPN values. Regression equations using two, three, and four attributes are shown below. Note that the amount of variability accounted for using a three attribute equation is much better than with a two attribute equation, and nearly as good as with a four attribute equation.

Two Attribute Prediction

HI = 26.9206 -7.8142 * A04 + 5.02445 * A10

The two attribute equation accounts for 57.6% of the variability.

Three Attribute Prediction

HI = 23.78743 – 6.10186 * A04 + 5.517748 * A10 – 1.68171 * A20

The three attribute equation accounts for 73.2% of the variability.

Four Attribute Prediction

HI = 23.32182 -5.28053 * A04 + 4.987165 * A10 – 1.65262 * A11 – 1.67134 * A20

The four attribute equation accounts for 80.3% of the variability

Removal of Systems 8 and 13

The second approach to dealing with the two similar systems, the FMS Fix Page and GPS Flight Management System was to simply exclude the latter from the analyses. This section presents the results of regressions in which the GPS Flight Management System was not included. As with the prior analyses, the FMS Fix Page was not included as no unintended uses had been identified.

Ratings of Likelihood of a System Being Used in an Unintended Way

The attributes used in this regression were identified through a series of stepwise regressions. This process resulted in the following attributes being included: A03, A04, A05, A09, A10, A11, A15, A16, A17, and A21.

Two Attribute Prediction

DV = 14.9457 + 0.88297 * A15 – 2.9487* A17

The two attribute equation accounts for 73.8% of the variability.

Three Attribute Prediction

DV = 22.3134 – 3.2208 * A04 +1.13086 * A10 – 2.0642 * A21

The three attribute equation accounts for 81.1% of the variability.

Four Attribute Prediction

DV = 13.2608 + 1.55505 * A10 +1.13367 * A15 - 0.8826 * A16 – 3.0346 *A17

The four attribute equation accounts for 89.0% of the variability.

RPN Values

The attributes used in this regression were identified through a series of stepwise regressions. The attributes identified for inclusion are A02, A05, A07, A09, A10, A11, A13, A15, A19 and A20

Two Attribute Prediction

RPN = 23.3467 + 27.7475 * A10 – 13.161 * A20

This equation accounts for 79.7% of the variability in the RPN values of the systems.

Three Attribute Prediction

RPN = 30.2352 + 25.9635 *A10 – 8.3839 * A11 - 12.74 * A20

This equation accounts for 87.5% of the variability in the RPN values of the systems.

Four Attribute Prediction

RPN = 23.6409 + 23.6409 * A10 -10.191 * A11 + 4.57385 * A15 – 12.297 * A20

This equation accounts for 90.3% of the variability in the RPN values of the systems.

Hazard Index (HI)

The attributes used in this regression were identified through a series of stepwise regressions. The attributes identified for inclusion are A02, A04, A07, A09, A10, A11, A15, A16, A19, and A20.

Two Attribute Prediction

HI = 46.8407 – 9.5881 * A04 – 3.0141 *A07

This equation accounts for 61.2% of the variability in the HI values of the systems.

Three Attribute Prediction

HI = 57.2689 – 16.183 * A04 – 3.9419 * A07 + 3.11411 *A19

This equation accounts for 81.9% of the variability in the HI values of the systems.

Four Attribute Prediction

HI = 25.0046 – 5.6536 * A04 + 4.53353 * A10 – 1.5197 * A11 – 1.867 * A20

This equation accounts for 84.2% of the variability in the HI values of the systems.

Discussion

The results obtained with the two methods of handling the similar systems (i.e., averaging them together, deleting one) while similar, suggest that deleting one is preferred. This conclusion is based on the proportion of variance accounted for. In all nine cases, the r^2 value was greater when system 13 was deleted from the analysis than when systems 7 and 13 were averaged. This difference is statistically significant ($t (8) = 4.90$, $p < 0.01$). We believe that this better performance when system 13 was removed is attributable to the fact that averaging systems 7 and 13 moved the combined dependent measure and all of the attributes closer to the means, reducing the predictive power.

Both approaches to dealing with the similar systems resulted in smaller r2 values than when both systems were included in the regressions.

Summary

This work was necessitated by the similarity between two systems, the FMS Fix Page and the GPS Flight Management System. Two methods of dealing with the similarity of these systems were explored. The first was to combine the data on these systems by averaging it. The second was to use the data from the FMS Fix page in the analyses and exclude that obtained on the GPS Flight Management System.

It must be noted that there is some question as to whether or not either of these approaches is justified. A small sample of pilots and Human Factors practitioners provided ratings use to generate the HI and RPN values, and not one mentioned that these were the same system (Loomis & Lakinsmith, 2012). Further, the attribute ratings for these systems were quite a bit different. This suggests that these two systems, while related, are viewed and used as distinctly different by the pilot community. To the extent that the systems are considered distinct it is appropriate to include them both in these regression analyses as was done previously.

Attribute A10 was the most frequently included in the regression equations. This suggests that the complexity of the system is a good predictor of the likelihood of a system being used in an unintended way and of the system presenting a risk. Intuitively, this makes sense. If a system is simple there is less opportunity to use it ways not envisioned by the designers and certifiers, and there it is more likely to have been tested exhaustively as there are fewer control combinations to explore. Attribute A04 was the next most common attribute appearing in the regression equations. The more likely and complex the interactions between a system and other flight deck systems the greater the likelihood that it will be used in unintended ways. The unintended uses may be intentional, or may be due to unforeseen interactions between the systems.

The next attributes most often included in the best regression equations are A07, A11, and A20. These attributes deal with information presented to pilots that has a time critical nature, including compliance with crossing restrictions (A20). It is not clear from these data how the presentation of data would allow unintended use of the system. One could conjecture that the increased information could be used by pilots to "game" the system in ways that are advantageous. However, this use seems to be somewhat intended as it results in increased efficiency for that aircraft. While it is true that in some instances increasing the efficiency of one aircraft may come at the expense of other aircraft or at the expense of the efficiency of the system as a whole, this is not true in all cases. We believe that the system has the flexibility to allow increases in the efficiency of a single aircraft without any adverse effects on other National Airspace System users.