Human Factors Assessment of RNAV Approach and Departure Procedures

Version 1.0

Analysis Conducted August 2012

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Prepared for:
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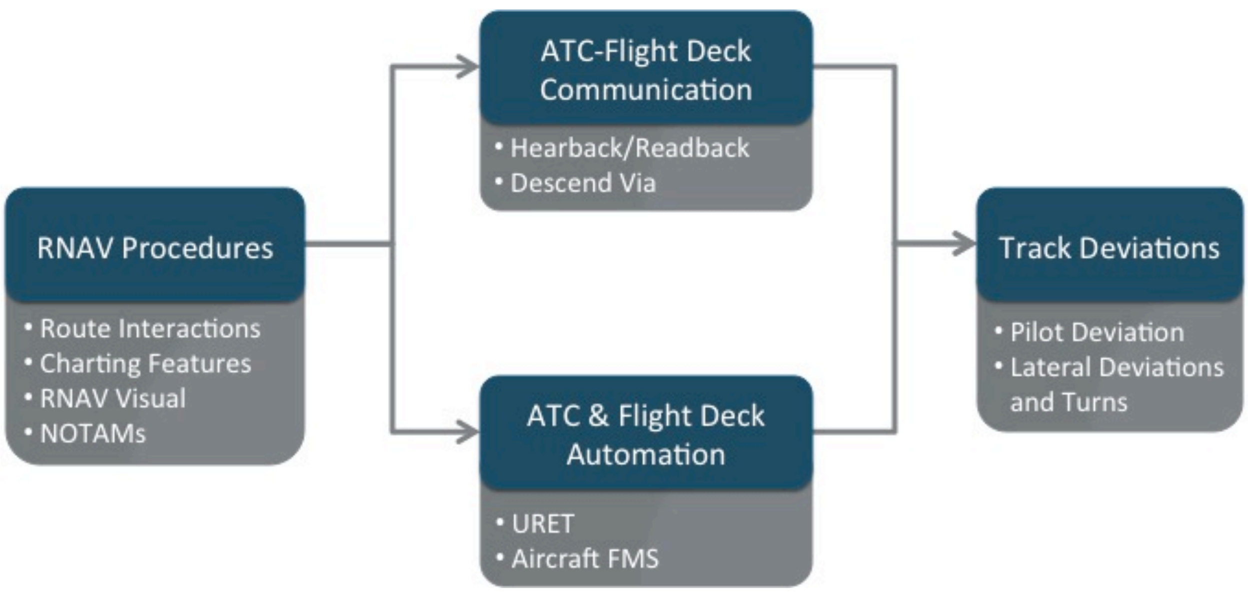
For Distribution Outside the FAA

EXECUTIVE SUMMARY

The NextGen goals of increased capacity and efficiency are being supported by performance-based navigation through Area Navigation (RNAV) approach and departure procedures. RNAV procedures enable aircraft to have better access and flexibility for point-to-point operations (FAA, 2012b). Conducting a human factors safety assessment of these procedures allows for the current day human factors causal factors within the air traffic control (ATC) domain to be identified in a methodical and comprehensive manner.

While controllers are responsible for the issuance of RNAV procedures, the flight deck is responsible for executing the procedures. In order to obtain a well-rounded overview of current day RNAV procedures and operations, both air traffic control and flight deck aspects were incorporated into this human factors assessment. To examine the air traffic perspective, a human factors analysis of 100 Air Traffic Safety Action Program (ATSAP) RNAV safety reports were analyzed utilizing the Air Traffic Analysis and Classification System (AirTracs) taxonomy. To obtain more information from the flight deck perspective, reports from NASA's Aviation Safety Reporting System (ASRS) database were examined to identify flight deck impacts. The leading contributing factors to RNAV safety events identified in this assessment are displayed in the figure below.



Mitigation strategies and opportunities for addressing these key human factors causal factors were then developed utilizing the results of the AirTracs assessment. These are provided in the Findings section of the report.

LIST OF ACRONYMS

Acronym	Definition
AIM	Aeronautical Information Manual
AirTracs	Air Traffic Analysis and Classification System
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
ATSAP	Air Traffic Safety Action Program
C&C	Communication and Coordination
DoD	Department of Defense
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FD	Flight Deck
FMS	Flight Management System
HERA	Human Error in ATM
HFACS	Human Factors Analysis and Classification System
IAP	Instrument Approach Procedures
LOA	Letter of Agreement
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
NOTAM	Notice to Airmen
RNAV	Area Navigation
RVFP	RNAV Visual Flight Procedures
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival Route
TMU	Traffic Management Unit
URET	User Request Evaluation Tool

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Introduction

The FAA is currently executing a considerable transformation of the National Airspace System (NAS). NextGen aims to improve the convenience and dependability of air travel while increasing safety and reducing environmental impact. NextGen plans to meet these goals by introducing a variety of new aviation systems and capabilities (FAA, 2012a). The NextGen goals of increased capacity and efficiency are being supported by performance-based navigation through RNAV approach and departure procedures. RNAV procedures enable aircraft to have better access and flexibility for point-to-point operations (FAA, 2012b). RNAV procedures can be utilized for standard terminal arrival routes (STAR), instrument approach procedures (IAP), and standard instrument departures (SID).

Purpose

The purpose of this assessment is to identify causal factors present in current day RNAV operations in order to provide recommendations and mitigation strategies for reducing the impact of these causal factors during procedure design. To meet this objective, a human factors analysis of safety reports involving RNAV procedures was conducted. The results identified areas of opportunity in the RNAV development and implementation process where targeted mitigation strategies could be implemented to minimize human factors causal factors.

Methodology

In order to identify leading contributing factors in current day RNAV operations, a comprehensive methodology for examining human factors issues in safety reports was needed. To examine the air traffic perspective, the AirTracs was applied. AirTracs systemically and thoroughly examines the impact of human performance in air traffic safety events. Additionally, an annotated, flight deck version of AirTracs was developed to gain insight into the flight deck contributing factors.

Air Traffic Control Perspective

Air Traffic Analysis and Classification System

Two air traffic controller human factors taxonomies, Human Factors Analysis and Classification System (HFACS) and HERA-JANUS, were merged to develop AirTracs. This combination allowed for the strengths of each taxonomy to be incorporated, while the individual weaknesses could be addressed (Berry, Sawyer, & Austrian, 2012). The framework of the AirTracs causal factor model was based on the Department of Defense

(DoD) HFACS model (DoD, 2005), and the detailed causal factor categories incorporated factors from HERA-JANUS (Isaac et al., 2003). The AirTracs framework promotes the identification of human factors causal trends by allowing factors from the immediate operator context to agency-wide influences to be traced for individual events and for a comprehensive analysis to be executed. The AirTracs causal factor model can be found in Figure 1, and the details of the causal factors can be found in Table 1.

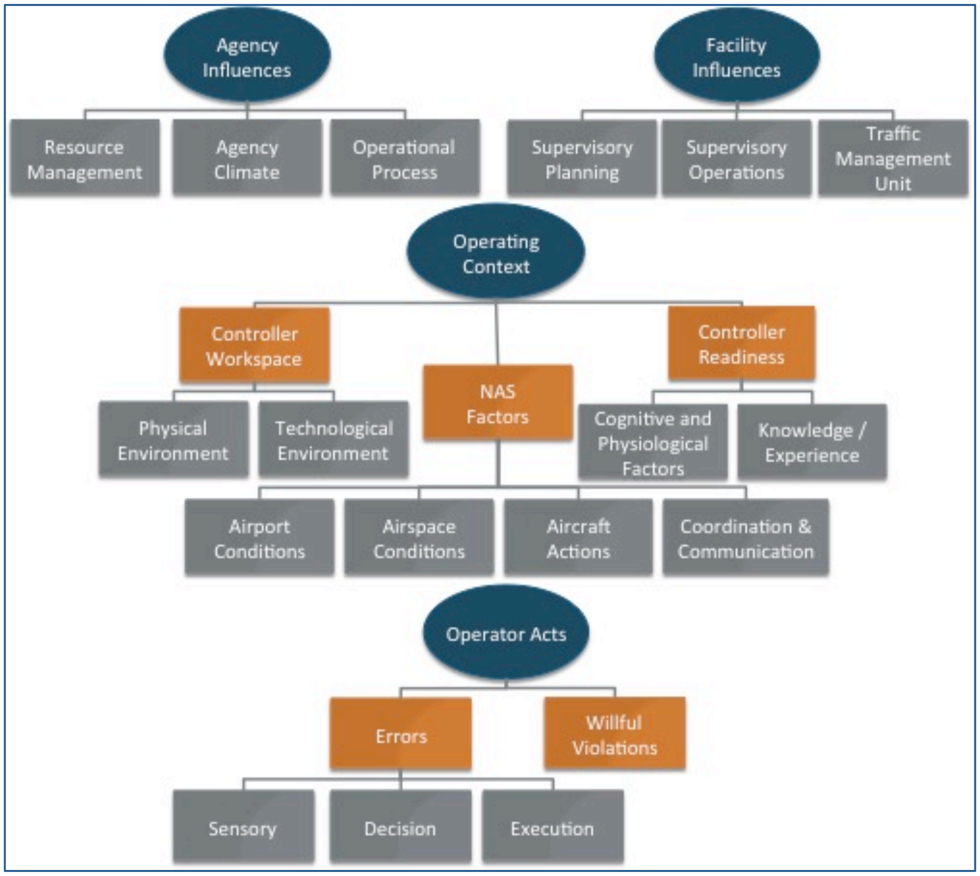

Figure 1: The Air Traffic Analysis and Classification System – AirTracs

The AirTracs model follows a tiered approach. The first tier, Operator Acts, addresses those causal factors most closely linked to the actual safety event and describes the actions or inactions of the operator. Operator Acts causal factors are classified as sensory acts, decision acts, execution acts or willful violations. The second tier, Operating Context, describes the immediate environment associated with the operator and the safety event. Operating Context causal factors are classified as controller workspace (physical and technological environment), controller readiness (cognitive and physiological factors and knowledge/experience), and NAS factors (airport conditions, airspace conditions, aircraft actions, and coordination and communication). The third tier, Facility Influences, describes the factors related to the actions or inactions of individuals at an ATC facility that have the ability to impact the whole facility or multiple individuals at a facility. Facility Influences causal factors are classified as supervisory planning, supervisory operations, and traffic management unit (TMU). The fourth tier, Agency Influence, examines those factors related to the actions or inactions of the agency and is classified as resource management, agency climate, and operational process.

Table 1: AirTracs Causal Factor Descriptions

Operator Actions
Sensory Acts: Occur when a controller's sensory input is degraded and a plan of action is determined based upon faulty information.
Categories: Auditory Error, Temporal Error, Visual Error
Decision Acts: Occur when a controller's behaviors or actions proceed as intended, yet the chosen plan proves inadequate to achieve the desired end-state and results in an unsafe situation.
Categories: Alert Error, Knowledge-Based Error, Prioritization Error, Rule-Based Error, Tool/Equipment Error
Execution Error: Occur when a controller's execution of a routine, highly practiced task relating to procedure, training, or proficiency result in an unsafe a situation.
Categories: Attention Error, Communication Error, Inadvertent Operation, Memory Error, Procedural/ Technique Error
Willful Violation: The actions of the operators that represent a willful and knowing disregard for the rules and regulations. Willful Violations are deliberate.
Categories: Willful Violation
Operator Context
Physical Environment: The operational and ambient environment of the controller's immediate workspace.
Categories: Ergonomic Issues, Lighting, Noise Interference, Vision Restrictions, Workspace Clutter
Technological Environment: The workspace automation factors encompass a variety of design and automation issues, including the design of equipment and controls, display/interface characteristics, checklist layouts, task factors, and automation.
Categories: Procedure, Communication Equipment, Display/Interface, Software/Automation, Warnings/ Alarms
Airport Conditions: The environmental and design conditions of the airport involved in the event.
Categories: Ground Vehicle Traffic, Aircraft Traffic, Combined Positions, Airport Weather, Signage/ Lighting, Construction, Layout/Design
Airspace Conditions: The physical or design conditions of the airspace involved.
Categories: Sector Overload/Traffic, Sector Weather, Turbulence, Sector Design, Combined Sectors, Combined Positions
Aircraft Actions: The actions or inactions of the aircraft involved in the event that lead to an unsafe situation.
Categories: Deviation, Unexpected Aircraft Performance, Equipment/System Malfunction, Flight Planning, Responding to Abnormal Situation, Go Around
Coordination and Communication: The teamwork factors of coordination and communication involved with the preparation and execution of a plan that result in an unsafe situation.
Categories: Controller-Controller Communication, Controller-Flight Deck Communication, Coordination
Cognitive and Physiological Factors: Cognitive or mental conditions and the physiological or physical factors that result in an unsafe situation.
Categories: Attention, High Workload, Complacency/Boredom, Automation Reliance, Expectation Bias, Fatigue, Medical Illness/Medication

Knowledge/Experience: The experience or knowledge level a controller has for a task, procedure, or policy that results in an unsafe situation.	
Categories: On-the-Job Training/Developmental, Low Experience CPC, Unfamiliar Task/Procedure	
Facility Influence	
Supervisory Planning: The planning and preparation of operations conducted by facility management that result in an unsafe situation.	
Categories: Procedures/Policy, Staffing, Equipment, Training/Briefing, Planning Violation	
Supervisory Operations: The day-to-day operations and tasks conducted by facility management that result in an unsafe situation.	
Categories: Sector Combination, Position Combination, Sector/Airport Configuration, Controller Assignment, Operational Tempo, Supervisory Coordination, Operational Violation, Facility Safety Culture	
Traffic Management Unit: The operations of the traffic management unit and their impact on the controller that result in an unsafe situation.	
Categories: Weather Response, Special Use Airspace, Traffic Management Initiatives	
Agency Influence	
Resource Management: The organizational-level decision-making regarding the allocation and maintenance of organizational assets that result in an unsafe situation.	
Categories: Equipment/Facility Resources, Human Resources, Monetary/Budget	
Agency Climate: The organizational variables including environment, structure, policies, and culture that result in an unsafe situation.	
Categories: Culture, Organizational Structure, Policy	
Operational Process: The organizational process including operations, procedures, operational risk management, and oversight that result in an unsafe situation.	
Categories: Operations, Procedures, Oversight	

For safety events classified with the AirTracs framework, the presence or absence of each AirTracs causal factor at all four tiers was examined. The AirTracs causal factors are not mutually exclusive, and safety event classifications may include causal factors from all four tiers. For example, an individual safety event can include an execution error, a sensory error, a cognitive and physiological factor, supervisory operations, and an operational process.

Application of AirTracs

The data utilized for this assessment was gathered from the FAA's ATSAP program. ATSAP is a voluntary, non-punitive reporting system for air traffic controllers. For this assessment, ATSAP reports describing RNAV incidents from the April 2011 to July 2012 time period were queried resulting in 408 narratives. Due to time and resource constraints, this assessment sampled 100 reports. Six primary airports of interest were identified by members of the Office of Safety and Technical Training and include ATL (Atlanta), CLT (Charlotte), DCA (DC National), DFW (Dallas-Ft. Worth), IAH (Houston), and PHL (Philadelphia). All reports from these key airports were included in the 100 sample cases resulting in 42 key airport reports. The remaining 58 reports were randomly sampled from the remaining non-primary reports.

The resulting 100 ATSAP reports were classified with AirTracs utilizing the consensus method, which required a consensus or agreement on the causal factors contributing to the report by a panel. The panel members included human factors representatives, air traffic controllers, and flight deck experts. Each report was evaluated across all levels of the AirTracs framework, and the presence or absence of each AirTracs causal factor was recorded. It is important to note that the AirTracs categories are not mutually exclusive. For example, an individual report can include both an execution act and a decision act.

Additional Factors

In addition to AirTracs causal factors, many additional factors were assessed for each report. The severity of each report was classified on the following scale: No Event, Near Airspace Violation, Airspace Violation, Near Loss of Separation Minima, or Loss of Separation Minima. The type of RNAV procedure applicable to the report was categorized as SID, STAR, or IAP.

Flight Deck Perspective

ATSAP reports were submitted by controllers and have the potential to be biased towards ATC. In order to obtain more information from the flight deck perspective, NASA's ASRS database was queried for reports filed by the flight deck regarding RNAV procedures and incidents. The queried reports were from the same time period as the ATSAP reports. The 68 ASRS reports were classified on an annotated, flight deck version of AirTracs, which can be seen in Table 2.

Table 2: Annotated, Flight Deck RNAV AirTracs

Flight Deck Automation
FMS Malfunctioning: Inadequate or malfunctioning FMS
FMS Incomplete/Out-of-date: FMS navigational database is incomplete or out-of-date
Other Flight Deck Equipment Failure: Other automation or equipment fails or malfunctions

Pilot Error
Failure to Monitor: Flight deck inadequately monitors flight deck automation and/or flight
FMS Input: Flight deck inadequately inputs information into the FMS
General Pilot Error: General flight deck error
Procedure Interpretation: Flight deck misinterprets the RNAV procedure
Route Planning: Flight deck inadequately plans flight or route

Communications
ATC-ATC Conflicting Instructions: Downstream ATC and upstream ATC issue conflicting instructions
ATC-RNAV Conflicting Instructions: ATC issues instructions conflicting with RNAV procedures
Captain-First Officer Communications: Inadequate communications between the captain and first officer
Descend Via: Flight deck misinterprets Descend Via instruction or ATC inadequately utilized Descend Via instruction
Hearback/Readback Error: Flight deck or controller inadequately hear and/or readback instructions

RNAV Procedure
Airline Procedures: Inadequate airline-specific procedures
Charting - (ATC): Confusion regarding (ATC) notion on charting
Procedure Design – Crossing Restrictions: Crossing restrictions are confusing or inadequate
Procedure Design – Inefficient Design: Flight deck perceives procedure as inefficient
Procedure Design – Speed Restrictions: Speed restrictions are confusing or inadequate
Procedure Design – Waypoints: Waypoints are confusing or inadequate
Inadequate NOTAMs: Inadequate NOTAMs for RNAV procedures
RNAV Visual: Misunderstanding of RNAV Visual procedures
STARS-IAP Transition: Inadequate transition between STAR and IAP procedures
Vectoring: RNAV procedures result in vectoring

FINDINGS

Findings will be presented and discussed in the sections below. The key findings from the air traffic and flight deck AirTracs analysis will be presented. Additionally, the overall high-level AirTracs results and the high-level flight deck ASRS assessment will be outlined. Detailed results will be presented in Appendix A.

KEY AIRTRACS CAUSAL FACTOR FINDINGS

The key causal factors from the AirTracs assessment of the ATSAP reports resulted in the causal chain shown in Figure 2. Each element of the causal chain will be discussed in the following sections.

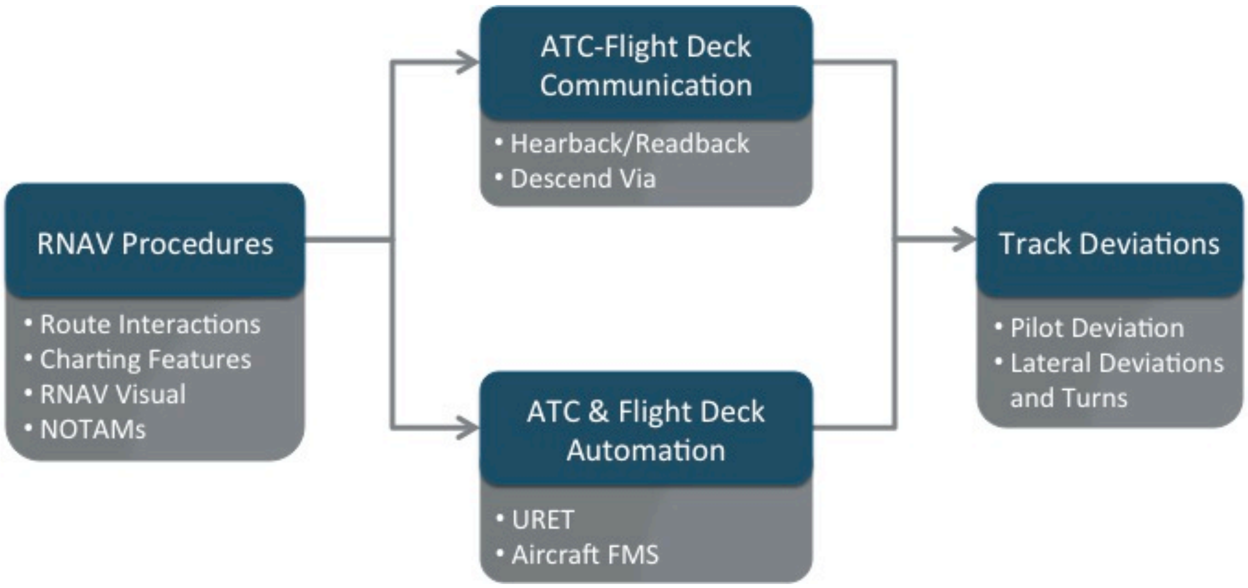

Figure 2: AirTracs RNAV Key Causal Chain

Track Deviations

Track deviations occur when the aircraft deviates from the published RNAV procedures without instruction from a controller. Pilot deviations, a causal factor within Aircraft Actions, were classified in 54 of the 100 ATSAP reports. Table 3 details the deviations by severity. The leading deviation type was a lateral deviation with a majority of those lateral deviation events resulting in near or actual loss of separation minima.

Table 3: Deviations by Severity

Deviation	No Event	Near Airspace Violation	Airspace Violation	Near Loss of Separation	Loss of Separation	Total
Lateral	5	6	2	11	4	**28**
Vertical	2	5	9	3	0	**19**
Lateral and Vertical	2	0	4	2	0	**7**

In a similar manner, unexpected aircraft performance was a causal factor within aircraft actions. The unexpected aircraft performance causal factor described situations when the performance or flight path of the aircraft does not meet the controller's expectations or plan. While the performance of the aircraft was unexpected to the controller, the performance was not a pilot deviation. This contributing factor was classified in 17 of the 100 ATSAP reports. Table 4 details the 17 unexpected aircraft performance reports. Most unexpected performance issues were associated with an unexpected turn. In these instances, the controller was able to remedy the situation before any additional adverse events occurred.

Table 4: Unexpected Aircraft Performance

Unexpected Aircraft Performance Issue	Count
Inadequate Turn	8
Altitude	5
Route	2
Speed	2

Controller-Flight Deck Communication

Controller-Flight Deck Communication was the top factor within the communication and coordination causal factor category. The controller-flight deck communication category was identified when the communication between the controller and the flight deck was inadequate and contributed to the safety event. This factor was classified in 30 of the 100 ASTAP reports and 14 of the 68 (21%) of the ASRS reports. Table 5 describes the communication issues in both the ATSAP and ASRS reports. For both the ATSAP and ASRS reports, hearback/readback errors were the most prominent communication issues.

Table 5: Controller-Flight Deck Communication

(Note: Findings reported represent the percentage of ATC (ATSAP) or flight deck (ASRS) communication and coordination (C&C) reports)

Communication Issue	% of ATC C&C	% of FD C&C
Hearback/Readback	43%	43%
Descend Via Phraseology	17%	21%
Waypoint	17%	--
ATC-ATC Conflicting Instruction	7%	7%

Communication Issue	% of ATC C&C	% of FD C&C
ATC-RNAV Conflicting Instruction	3%	21%
Frequency Issues	3%	--
Other	10%	7%

Descend Via Phraseology

In both the ATSAP and ASRS reports, the "descend via" phraseology was cited as confusing from both the controller and pilot perspective. As described in the 7110.65 (FAA, 2013), when controllers issue a "descend via" clearance, the pilot is authorized to "vertically and laterally navigate" in accordance with the procedure and published restrictions. However, pilots and controllers expressed concern regarding the phraseology when the published procedure was modified either through NOTAMs or clearances. In both the ASRS and ATSAP reports, the use of the "descend via" phraseology for a procedure with a NOTAM associated with the procedure was called into question. The 7110.65 described a specific situation when the "descend via" phraseology should not be utilized. In the case that the RNAV arrival procedure included an "expect" altitude restriction, the phraseology should not be used in conjunction with the RNAV procedure. For example, the JAIKE3 arrival procedure into Teterboro airport (TEB) included an "expect" altitude restriction of FL240 at the PEEDS waypoint. However, in ASRS case 968108, which is detailed in Appendix B, the "descend via" phraseology was applied to the procedure with additional crossing restriction instructions. The controller reporting this safety case identified the issues with the JAIKE3 procedure and the "descend via" phraseology. The "descend via" phraseology should be examined in more detail, and the instances when the phraseology should not be utilized should be identified. Furthermore, situations where the phraseology should not be applied need to be thoroughly detailed to controllers and pilots.

ATC and Flight Deck Automation

Automation in both the flight deck and air traffic environments were cited as contributing factors in both ATSAP and ASRS reports. Automation issues related to air traffic control systems were described by controllers in 23 of the 100 ATSAP reports. Similarly, issues with automation in the flight deck were reported by the flight crew in 31 of the 68 ASRS reports (46%) and by controllers in 15 of the 100 ATSAP reports. Table 6 provides a detailed view of the types of automation issues citied in these reports.

Table 6: ATC and Flight Deck Automation

ATC Automation	Count
URET	7
Flight Plan System	3
Scope	3
Auto Handoff	2
Host	2
Radar	2
Conflict Alert	1
Other	3

FD Automation (ATSAP)	Count
FMS	10
Equipage Level	2
General Automation	2
Compass	1
FD Automation (ASRS)	**Count**
FMS Malfunction	15
FMS Incomplete	13
Other	3

URET

For the controller, the User Request Evaluation Tool (URET) was the most frequently reported automation issue. URET provides the controller with the recommended approach procedure assignment (RNAV and non-RNAV) for an individual aircraft. In these reports, controllers detailed events when URET would recommend an RNAV procedure for an aircraft that was not capable of executing an RNAV procedure. In order for an aircraft to conduct an RNAV procedure, the aircraft must be equipped for the procedure and the aircrew must have completed the required training. If URET did not contain accurate information on aircraft equipage and aircrew capabilities, URET may have recommended an inappropriate RNAV approach procedure assignment to the controller.

Aircraft FMS

Issues with the Flight Management System (FMS) were the most frequently cited flight deck automation issue in both the ATSAP and ASRS reports. The ATSAP reports were typically limited in their description of the specific FMS issue as the controller completing the report was limited to the information received from the flight crew. The ASRS reports completed by the flight crew, however, provided considerably more detail on the types of FMS issues present in RNAV operations. In many of the ASRS reports, the FMS navigational database was out-of-date, causing the programmed RNAV procedure to be inconsistent with the assigned RNAV procedure. Other reports cited an incomplete FMS navigational database causing the programmed RNAV procedure to be a partial procedure that truncated the route in the middle of the procedure. Sample reports detailing the automation issues can be viewed in Appendix B.

RNAV Procedures

In an effort to gain a full perspective of the impacts of RNAV procedure design, AirTracs causal factors from the Operation Process and Supervisory Planning categories were combined to detail both NAS-level and facility-level issues. RNAV procedure issues were identified in 55 of the 100 ATSAP reports as a contributing factor. The issues, detailed in Table 7, were organized into five categories (airspace issues, application of procedure, charting issues, update cycle/NOTAMs, procedure design) and into sub-categories where necessary. Sample reports detailing the categories and sub-categories can be viewed in Appendix B.

Table 7: RNAV Procedure Issues in ATSAP Reports

Procedure Issue	Count
Airspace Issues	**2**
Non-Radar Airspace	1
Sector Design	1
Application of Procedure	**15**
Inefficient LOA	4
Phraseology Procedures	3
RNAV Procedure Briefing	3
Airline Specific Procedures	2
RNAV Handoff	1
RNAV Visual Separation	1
STAR-IAP Transition	1
Charting Issues	**7**

Procedure Issue	Count
Update Cycle/NOTAMs	**6**
Procedure Design	**25**
Route Interaction	9
Disagreement with LOA	3
Inefficient Design	3
Separation Standards	2
Surrounding Airspace	2
Waypoints	2
Altitude	1
Operating Conditions	1
Unclear to ATC	1
Wake Separation	1

Route Interactions

The most frequently reported procedure issue was procedure design, with route interaction being the most frequently reported sub-category. In these reports, controllers detailed the issues associated with the use of more than one procedure (both RNAV and non-RNAV) at a time. For example, one report cited the use of an RNAV SID and non-RNAV SID being utilized for parallel runway departures. This route combination created potential conflicts when both aircraft were being turned. It is suggested that the various route interactions be examined in more detail during the RNAV design process.

Charting Features

Charting issues were cited as an issue in both ATSAP and ASRS reports. In particular, the charting feature "(ATC)" caused confusion for both controllers and pilots. As an example, the "(ATC)" feature can be viewed in Las Vegas (LAS) BOACH FOUR RNAV SID in Figure 3. In many reports, confusion on the meaning of the symbol created mismatched expectations between the flight crew and controller on the expected altitude at a waypoint. Both parties requested that the feature be re-examined and possibly removed.

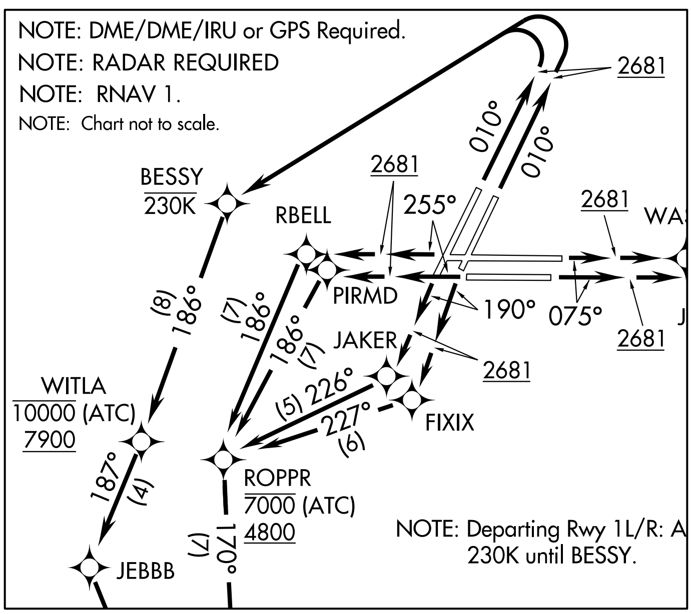

Figure 3: Excerpt from LAS SID BOACH FOUR RNAV Procedure (Not for Navigational Use)

RNAV Visual Flight Procedures

One of the procedural issues identified by both controllers and pilots involved the application RNAV visual instructions. In several ASRS reports, pilots expressed confusion regarding RNAV visual procedures being issued at LAS. When examining the latest Federal

Aviation Regulations (FAR)/Aeronautical Information Manual (AIM) and 7110.65, no official mention or explanation of RNAV visual procedures was found.

The FAA issued Order 8260.55 “Special Area Navigation Visual Flight Procedures” to detail RNAV visual procedures. This order permits aircraft operators to develop approved RNAV Visual Flight Procedures (RVFP). RVFPs are airline-specific and not considered available to the public. RVFPs are approved in a manner similar to special instrument approach procedures. (Order 8260.55, Section 4). The Lead Operator initiates and designs the RVFP with the assistance of the FAA. Once the RVFP is approved, the Lead Operator is permitted to utilize the new approach procedure. Other operators may develop a unique RVFP or may also utilize the Lead Operator’s RVFP by requesting approval.

When examining the various roles and responsibilities of RVFP, ATC may utilize an RVFP when a participating flight crew requests the RVFP approach, when the aircraft is properly equipped, and when the controller and pilot have received training on the approach. Below is sample phraseology for requesting and issuing RVFP as outlined in Appendix E of Order 8260.55:

Pilot: (On initial contact with approach controller) Request RNAV visual runway two nine.

Controller: Expect RNAV visual runway two nine, report airport in sight.

Pilot: Airport in sight.

Controller: Proceed direct GIMEE. Cross GIMEEE at two thousand five hundred. Cleared for RNAV visual runway two nine.

The flight crew is responsible for requesting the RVFP and must fly the published RVFP route (unless instructed otherwise by ATC). Additionally, operators must train pilots on RVFP and incorporate the procedures into the FMS navigational database. Pilots were not authorized to manually build the procedures into the FMS.

The assessment of ASRS reports indicated inconsistencies with RNAV visual instructions into LAS. ASRS Reports 968436 and 975177 indicated the following issues:

- Controllers issued RVFP without a request from the flight crew
- Controllers issued RVFP to unapproved flight crews
- Flight crews were not aware of and were not trained on LAS RVFP
- LAS RVFPs were not in FMS navigational databases

RVFPs offer many benefits to the NAS. However, it is suggested that controllers and pilots be provided with additional information and training for RVFPs. Additionally, those airports with RVFPs should be monitored to ensure the correct roles and responsibilities are being followed.

Update Cycle/NOTAMs

Controllers also identified issues related to the update cycle of RNAV procedures. Several reports cited instances where NOTAMs were used as interim corrections to mitigate procedure design flaws due to the length of time required to publish an updated procedure. Controllers reported that the NOTAMs were temporary and non-ideal fixes for out-of-date or inadequately designed procedures. NOTAMs have been utilized to alter which aircraft types can fly a procedure and to dictate who can assign/request the procedure. Additionally, NOTAMs have been utilized to change altitudes, crossing restrictions, and communication frequencies that were inadequate in the published procedure.

RECOMMENDATIONS

Figure 4 summarizes the causal chain for the human factors RNAV assessment discussed in the above sections. Mitigation strategies and recommendations for the key causal chain are also described in the following sections.

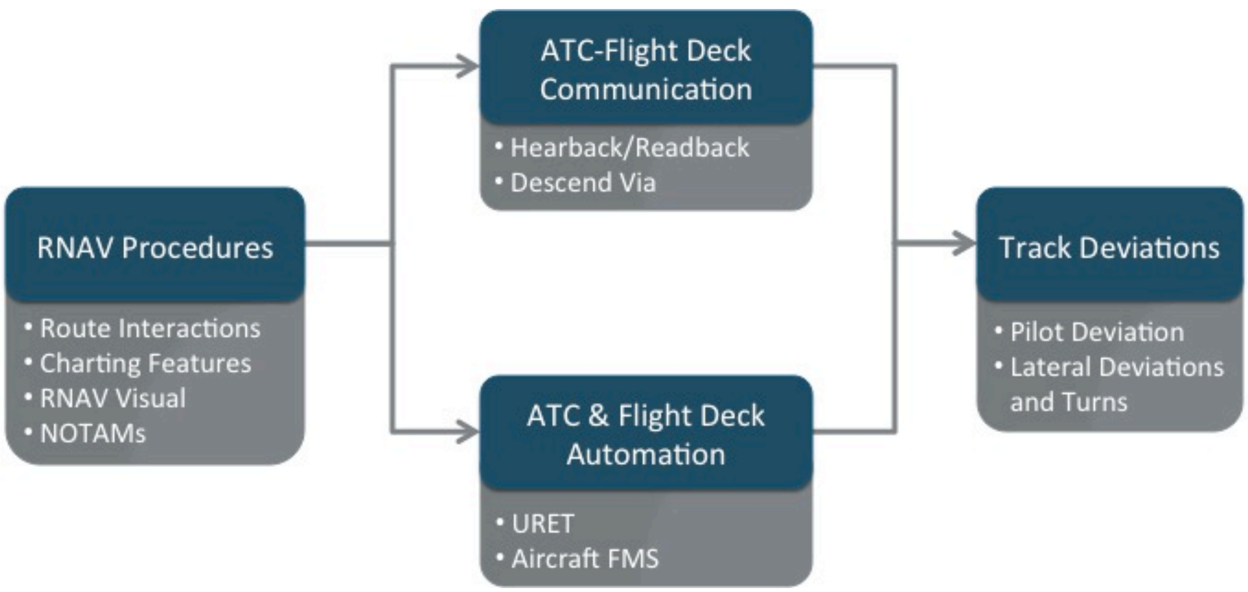

Figure 4: AirTracs RNAV Key Causal Chain

NOTAMs – Aircraft FMS – Descend Via

Upon further examination of the detailed contributing factors Figure 4, a common theme emerged regarding NOTAMs and update frequencies of RNAV procedures.

- RNAV Procedures: NOTAMs were being utilized to address procedure inadequacies during the update period of the procedure.
- Flight Deck Automation: Pilots were reporting FMS navigational databases that lacked current and complete RNAV procedures. Pilots also identified issues related to inconsistencies between NOTAMs and the FMS navigational databases.

- ATC – Flight Deck Communication: Both controllers and pilots detailed confusion when using the "descend via" phraseology with RNAV procedures with NOTAMs.

While revisions to RNAV procedures are conducted less frequently, NOTAMs are published and modified on a daily basis. Many NOTAMs are necessary to ensure safe NAS operations in response to temporary events such as airport construction or special use airspace. Many of the NOTAMs identified for the airports in the study, however, were not issued in response to temporary events, but rather were used to alter the characteristics of the RNAV procedure. For example, these RNAV procedure NOTAMs included changes to crossing and speed restrictions, altitude restrictions, departure vectors, communication frequency, aircraft authorization, and equipage information. A detailed review of these NOTAMs showed that many were in place for most, if not all, of the time period of this study. These long-standing NOTAMs are not being issued in response to temporary events and may indicate inadequate procedure features and design. While these RNAV procedure NOTAMs range from minor to major modifications, these changes are not necessarily being incorporated into the aircraft FMS navigational database or the mental models of the controller or pilot. This mismatch between pilot – controller expectations led to many of the reported flight deviations. It is recommended that these RNAV procedure NOTAMs be examined in more detail to determine the frequency of NOTAMs for non-temporary events and to identify the procedure features these RNAV procedure NOTAMs are impacting. This information should be fed forward to procedure design and incorporated into lessons learned. Additionally, due to the longevity of many of the RNAV procedure NOTAMs, the update cycle for RNAV procedures should be examined to determine if the process can be safety streamlined.

Route Interaction

Route Interaction was demonstrated to be an operational issue for many airports and airspaces. Airports operate in an environment where more than one arrival procedure or departure procedure are used concurrently. For example, ATL operates simultaneous, parallel departures. Frequently, aircraft departing at the same time on parallel runways utilize different departure procedures, and if route interaction among the various procedures has not been examined, separation may be compromised under certain combinations and conditions. In this assessment, certain procedures when utilized simultaneously, while adequately independent of one another, create route interactions and lead to safety events. When it is known that multiple procedures will be concurrently utilized (e.g., parallel departures/arrivals utilizing different procedures), it is recommended that new RNAV procedures be examined for route interactions during operational conditions.

Charting Features

Charting Issues was cited as a contributing factor in both ATSAP and ASRS cases. In particular, the charting feature "(ATC)" caused confusion for both controllers and pilots. In many cases, the pilots were misinterpreting the "(ATC)" feature and requesting the feature to be re-examined and possibly removed. It is recommended that the "(ATC)" feature be removed due to the existing confusion of the feature. If the feature is not removed, it is recommended that the intent of the "(ATC)" feature be clearly defined in instrument charting legends. Furthermore, it is recommended that new and existing RNAV procedure charts and charting features be examined for other potentially confusing features through a human factors usability assessment.

RNAV Visual Flight Procedures

An additional procedural issue identified by both controllers and pilots involved the application RNAV visual flight procedures. In safety reports included in this assessment, the RVFP roles and responsibilities of the controller and flight deck were not being fully understood. It is recommended that controllers and pilots be provided with additional information and training for RVFPs roles, responsibilities, and operational usage. Additionally, those airports and airspaces with RVFPs should be monitored to ensure the correct roles and responsibilities are being followed.

URET

For the controller, URET was the most frequently reported automation issue. The reports cited instances when URET was recommending inadequate RNAV procedures for aircraft. It is recommended that the URET automation platform be examined to identify the reasoning for incorrect procedural recommendation. Furthermore, the incorporation of extensive quality checks in the development of RNAV procedures should ensure the accuracy of the automation coding.

Descend Via Phraseology

In both the ATSAP and ASRS reports, the "descend via" phraseology was cited as confusing from both the controller and pilot perspective. As noted previously, pilots question the use of the phraseology for RNAV STAR procedures with NOTAMs. Controllers question the use of the phraseology for RNAV STAR clearances with certain features, such as block crossing restrictions. The "descend via" phraseology should be examined in more detail, and the instances when the phraseology should not be utilized should be identified. Furthermore, the situations where the phraseology should not be applied need to be thoroughly detailed to controllers and pilots.

Track Deviations

Track deviations were identified in 71% of the ATSAP reports. During procedure design, designers should concentrate on the potential for deviations. Therefore, it is recommended that the worst credible outcomes of track deviations at various points along the RNAV procedure be thoroughly examined.

OVERALL AIRTRACS RESULTS

The findings from the overall AirTracs analysis of 100 ATSAP reports can be viewed in Table 8. The percentages in Table 8 do not sum to 100% since reports are typically associated with more than one causal factor. Along with the percentage of reports containing a particular causal factor, the leading category for each causal factor was identified. For example, 12% of reports contained an execution error with the leading execution error being a procedural/technique error.

Table 8: AirTracs Findings

Operator Actions	Percentage of Reports	Leading Category
Decision Acts: Occur when a controller's behaviors or actions proceed as intended yet the chosen plan proves inadequate to achieve the desired end-state and results in an unsafe situation. Categories: Alert Error, Knowledge-Based Error, Prioritization Error, Rule-Based Error, Tool/Equipment Error	19%	Rule-Based Error
Execution Error: Occurs when a controller's execution of a routine, highly practiced task relating to procedure, training, or proficiency result in an unsafe a situation. Categories: Attention Error, Communication Error, Inadvertent Operation, Memory Error, Procedural/Technique Error	12%	Procedural/ Technique Error
General Operator Act: The actions or inactions committed by the operator result in human error or an unsafe situation. In these instances, not enough information regarding the act is known to be able to classify the act.	5%	N/A
Sensory Acts: Occur when a controller's sensory input is degraded and a plan of action is determined based upon faulty information. Categories: Auditory Error, Temporal Error, Visual Error	2%	Auditory Error
Willful Violation: The actions of the operators that represent a willful and knowing disregard for the rules and regulations. Willful Violations are deliberate. Categories: Willful Violation	0%	N/A

Operator Context	Percentage of Reports	Leading Category
Aircraft Actions: The actions or inactions of the aircraft involved in the event that lead to an unsafe situation. Categories: Deviation, Unexpected Aircraft Performance, Equipment/System Malfunction, Flight Planning, Responding to Abnormal Situation, Go Around	61%	Deviation
Coordination and Communication: The teamwork factors of coordination and communication involved with the preparation and execution of a plan that result in an unsafe situation. Categories: Controller-Controller Communication, Controller-Flight Deck Communication, Coordination	42%	Controller-Flight Deck
Airspace Conditions: The physical or design conditions of the airspace involved. Categories: Sector Overload/Traffic, Sector Weather, Turbulence, Sector Design, Combined Sectors, Combined Positions	23%	Sector Overload/ Traffic
Technological Environment: The workspace automation factors and includes a variety of design and automation issues, including the design of equipment and controls, display/interface characteristics, checklist layouts, task factors and automation. Categories: Procedure, Communication Equipment, Display/Interface, Software/ Automation, Warnings/ Alarms	22%	Software/ Automation
Cognitive and Physiological Factors: Cognitive or mental conditions and the physiological or physical factors that result in an unsafe situation. Categories: Attention, High Workload, Complacency/Boredom, Automation Reliance, Expectation Bias, Fatigue, Medical Illness/Medication	8%	High Workload
Knowledge/Experience: The experience or knowledge level a controller has for a task, procedure, or policy that results in an unsafe situation. Categories: On-the-Job Training/Developmental, Low Experience CPC, Unfamiliar Task/Procedure	5%	On-the-Job Training
Airport Conditions: The environmental and design conditions of the airport involved in the event. Categories: Ground Vehicle Traffic, Aircraft Traffic, Combined Positions, Airport Weather, Signage/Lighting, Construction, Layout/Design	4%	Layout/ Design
Physical Environment: The operational and ambient environment of the controller's immediate workspace. Categories: Ergonomic Issues, Lighting, Noise Interference, Vision Restricted, Workspace Clutter	1%	Vision Restricted
Facility Influence	**Percentage of Reports**	**Leading Category**
Supervisory Planning: The planning and preparation of operations conducted by facility management that result in an unsafe situation. Categories: Procedures/Policy, Staffing, Equipment, Training/Briefing, Planning Violation	15%	Procedure/ Policy
Supervisory Operations: The day-to-day operations and tasks conducted by facility management that result in an unsafe situation. Categories: Sector Combination, Position Combination, Sector/Airport Configuration, Controller Assignment, Operational Tempo, Supervisory Coordination, Operational Violation, Facility Safety Culture	6%	Supervisory Coordination

Traffic Management Unit: The operations of the traffic management unit and their impact on the controller that result in an unsafe situation. Categories: Weather Response, Special Use Airspace, Traffic Management Initiatives	0%	None
Agency Influence	**Percentage of Reports**	**Leading Category**
Operational Process: The organizational process including operations, procedures, operational risk management, and oversight that result in an unsafe situation. Categories: Operations, Procedures, Oversight	39%	Procedures
Agency Climate: The organizational variables including environment, structure, policies, and culture that result in an unsafe situation. Categories: Culture, Organizational Structure, Policy	15%	Culture
Resource Management: The organizational-level decision-making regarding the allocation and maintenance of organizational assets that result in an unsafe situation. Categories: Equipment/Facility Resources, Human Resources, Monetary/Budget	0%	None

The overall leading causal factors of Aircraft Actions, Technological Environment, Communication, and Operational Process were discussed in more detail in the previous sections. Of important note is the low percentage of reports associated with an Operator Acts causal factor. Typically, 40%-60% of reports contain an Operator Act causal factor. This finding indicates the RNAV procedure cases are not associated with an ATC error or violation.

ASRS Flight Deck Results

The findings from the annotated flight deck AirTracs analysis of 68 ASRS reports can be viewed in Table 9. The percentages in Table 9 do not sum to 100% since reports are typically associated with more than one causal factor.

Table 9: ASRS Findings

Flight Deck Automation	Percentage of Reports
FMS Malfunctioning: Inadequate or malfunctioning FMS	22%
FMS Incomplete/Out-of-date: FMS navigational database in incomplete or out-of-date	19%
Other Flight Deck Equipment Failure: Other automation or equipment fails or malfunctions	4%
Communications	**Percentage of Reports**
Hearback/Readback Error: Flight deck or controller inadequately hear and/or readback instructions	9%
ATC-RNAV Conflicting Instructions: ATC issues instructions conflicting with RNAV procedures	4%

Descend Via: Flight deck misinterprets Descend Via instruction or ATC inadequately utilized Descend Via instruction	4%
ATC-ATC Conflicting Instructions: Downstream ATC and upstream ATC issue conflicting instruction	1%
Captain-First Officer Communications: Inadequate communications between the captain and first officer	1%
Pilot Error	**Percentage of Reports**
FMS Input: Flight deck inadequately inputs information into the FMS	10%
Procedure Interpretation: Flight deck misinterprets the RNAV procedure	9%
General Pilot Error: General flight deck error	4%
Failure to Monitor: Flight deck inadequately monitors flight deck automation and/or flight	3%
Route Planning: Flight deck inadequately plans flight or route	1%
RNAV Procedure	**Percentage of Reports**
Charting - (ATC): Confusion regarding (ATC) notion on charting	4%
Procedure Design – Waypoints: Waypoints are confusing or inadequate	4%
RNAV Visual: Misunderstanding of RNAV Visual procedures	3%
STARS-IAP Transition: Inadequate transition between STAR and IAP procedures	3%
Airline Procedures: Inadequate airline-specific procedures	1%
Procedure Design – Crossing Restrictions: Crossing restrictions are confusing or inadequate	1%
Procedure Design – Inefficient Design: Flight deck perceives procedure as inefficient	1%
Procedure Design – Speed Restrictions: Speed restrictions are confusing or inadequate	1%
Inadequate NOTAMs: Inadequate NOTAMs for RNAV procedures	1%
Vectoring: RNAV procedures result in vectoring	1%

CONCLUSIONS

This report presents an overview of the contributing factors present in a series of air traffic and flight deck safety event reports related to RNAV arrival and departure procedures. The findings identified a series of key causal factors related to procedure design, the role of automation, ATC-flight deck communication, and track deviations. These causal factors present a sample of the most frequently cited issues associated with current day RNAV operations in the NAS. Additionally, mitigation strategies and recommendations were detailed for the factors identified in the key causal chain. These issues will become increasingly important to manage given the proposed increased frequency and operational dependency on RNAV operations proposed under NextGen. Mitigating these causal factors in the early stages of concept development should be a high priority in order to ensure NextGen can meet the proposed targets for safety, efficiency, and capacity.

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APPENDIX A: OVERALL ATSAP CAUSAL FACTOR RESULTS

AirTracs Operator Acts

Operator Acts	Percentage of Reports
Sensory	**2%**
Auditory Error	2%
Decision	**19%**
Rule-Based Error	12%
Knowledge-Based Error	5%
Prioritization Error	2%
Execution	**12%**
Procedural/Technique Error	8%
Attention Error	4%
Communication Error	1%
Inadvertent Operation	1%
Memory Error	1%
General Operator Act	**5%**

AirTracs Operator Context

Operator Context	Percentage of Reports
Physical Environment	**1%**
Vision Restricted	1%
Technological Environment	**22%**
Software/Automation	16%
Display/Interface Characteristics	5%
Procedure	1%
Communication Equipment	1%
Warnings/Alarms	1%
Cognitive and Physiological Factors	**8%**
High Workload	3%
Attention	2%
Expectation Bias	2%
Fatigue	1%
Knowledge/Experience	**5%**
On-the-Job Training/ Developmental	3%
Unfamiliar Task/Procedure	2%

Operator Context	Percentage of Reports
Airport Conditions	**4%**
Layout/Design	2%
Airport Weather	1%
Other Airport Condition	1%
Airspace Condition	**23%**
Sector Overload/ Traffic	15%
Sector Design	6%
Sector Weather	3%
Aircraft Actions	**61%**
Deviation	42%
Unexpected Performance	15%
Equipment/System Malfunction	13%
Coordination and Communication	**42%**
Controller-Flight Deck	30%
Controller-Controller	7%
Coordination	7%

AirTracs Facility and Agency Influences

Facility Influences	Percentage of Reports
Sensory Planning	**15%**
Procedure/Policy	12%
Training/Briefing	3%
Supervisory Operations	**6%**
Supervisory Coordination	4%
Operational Tempo	1%
Supervisory Safety Culture	1%

Agency Influences	Percentage of Reports
Agency Climate	**15%**
Culture	12%
Policy/Procedure	3%
Operational Process	**39%**
Procedures	31%
Oversight	7%
Operations	2%

RNAV Procedure Type

Category	SID	STAR	IAP
Sensory Error	1	2	0
Decision Error	14	7	0
Execution Error	5	7	0
Unsafe Act	3	3	0
Physical Environment	1	0	0
Technological Environment	9	14	1
Airport Conditions	4	0	0
Airspace Conditions	13	11	1
Aircraft Action	35	27	1
Communication & Coordination	20	21	2
Cognitive & Physiological	4	4	0
Knowledge / Experience	2	3	0
Supervisory Planning	11	4	1
Supervisory Operations	4	2	0
Organizational Climate	1	2	0
Operational Process	21	19	2

Severity Analysis

Category	No Event	Near Airspace Violation	Airspace Violation	Near Loss of Separation	Loss of Separation	Total
Sensory Error	1	-	-	1	-	**2**
Decision Error	5	-	-	9	5	**19**
Execution Error	2	3	2	5	-	**12**
Unsafe Act	-	2	2	1	1	**6**
Physical Environment	1	-	-	-	-	**1**
Technological Environment	12	1	4	4	1	**22**
Airport Conditions	1	-	-	1	2	**4**
Airspace Condition	7	3	3	9	1	**23**
Aircraft Action	13	10	14	18	6	**61**
Communication & Coordination	13	7	13	6	3	**42**
Cognitive & Physiological	3	1	-	3	1	**8**
Knowledge / Experience	-	2	-	2	1	**5**
Supervisory Planning	10	-	1	4	-	**15**
Supervisory Operations	4	-	-	1	1	**6**
Organizational Climate	1	1	1	-	-	**3**
Operational Process	16	4	9	9	1	**39**
Total Reports	**36**	**13**	**18**	**26**	**7**	

Appendix B: Sample Reports

Descend Via Phraseology

ASRS Case 950778: Flight Deck

ABQ Center then cleared us RNAV direct to GEELA, then a *Descend Via clearance* for the remainder of the arrival.

During the descent approaching GEELA, ABQ Controller asked if we were going to make the GEELA restriction at 17,000'. After checking our charts, we did not see any restriction for any altitude at GEELA. I then asked ABQ what altitude he wanted to which he replied, *"It's in the NOTAMS."*

There was no restriction listed for GEELA at 17,000'; however, there was a temporary NOTAM to cross GEELA at 16,000', not 17,000' that the Controller had asked us to comply with, and which we did comply with. I guess with the rushed Crew change and late departure I *missed the NOTAM* for GEELA.

ASRS Case 968108: ATC

The JAIKE3 arrival has been problematic since its inception; *several modifications* have been made to reduce the occurrences of pilots descending early.

The procedure has aircraft cross JAIKE at 13,000, cross ILENE at 13,000, cross WACKI at 11,000 and 250 knots and cross REGLE at 7,000. We end up with a very high percentage of aircraft that are instructed to "*descend via the JAIKE3 arrival*" that begin their descent prior to ILENE.

The one aircraft I had on the JAIKE3 descended early. The pilot stated, "the box started me down early." There is a problem here somewhere. Normally I figure there is about 30% of the aircraft on the JAIKE3 that descend early. Many controllers here at PHL have resorted to issuing *"Cross ILENE at 13,000 then descend via the JAIKE3."* This is not the *proper phraseology*.

Procedure Design

Charting Issues – ASRS Report 973920

We were assigned to do the BOACH FOUR RNAV Departure out of LAS. We departed off of runway 1L. We were told by departure to climb via the BOACH FOUR RNAV Departure. We started complying with the departure crossing BESSY at 230 KTS. Next restriction was at WITLA. It reads *at or below 10,000 (ATC) and at or above 7,900*. I read that to mean that ATC assigns the 10,000 and if not assigned by them, we were to climb at or above 7,900 FT, which is what we were doing. We decided to ask for clarification, unfortunately too late.

When we called, they proceeded to tell us we did not comply with climb altitude. We asked them if they wanted us to descend back down and they told us no. We continued to fly the departure with no further complications. *Remove the (ATC) off of the restriction*.

RNAV Visual Flight Procedures – ASRS Report 968436

While on the GRANDPA ONE arrival into LAS, somewhere between FRAWG and TRROP waypoints, Las Vegas Approach Control asked us if we could do the *RNAV VISUAL approach to Runway 19L*.

Although *neither one of us have heard that terminology before*, we both assumed it meant you could do a visual approach to Runway 19, backed up by the RNAV?

I replied that we could do so. LAS Approach then cleared us for the RNAV Visual to Runway 19L. I found and loaded the RNAV Runway 19L approach in the FMS.

A few minutes later, LAS Approach asked if we were doing the RNAV Visual to 19L. I replied that we were doing the visual to Runway 19L and heading to the FAF for the RNAV approach. He came back stating that we were cleared for the RNAV Visual NOT the RNAV Approach but to contact Tower now. LAS Tower cleared us to land 19L and nothing more was mentioned. Since this event I have learned the following: *There are no published RNAV VISUAL APPROACH procedures in any of our normal aero chart packages for* LAS.

Waypoint Names

ASRS Case 984125

Flying BEERT4 RNAV arrival into MEM was assigned 10,000 at 'RGILL.' *[We] mistakenly planned descent to be at 10,000 FT early at Walnut Ridge (ARG), which looks like it could be 'ARGIL [RGILL].'* Descent was steep and apparently ATC has seen this happen before because the Controller told us we were *probably mistaking ARG for RGILL*. We shallow-ed our descent and proceeded uneventfully. I was not careful enough making sure I was looking at the correct points on our arrival. The arrival also has three points on it that can be easily confused: ARG (Walnut Ridge), RGILL, and Gillmore (GQE). I'll be more careful in checking waypoints given. *More distinct names could greatly alleviate confusion for those not used to the area.*