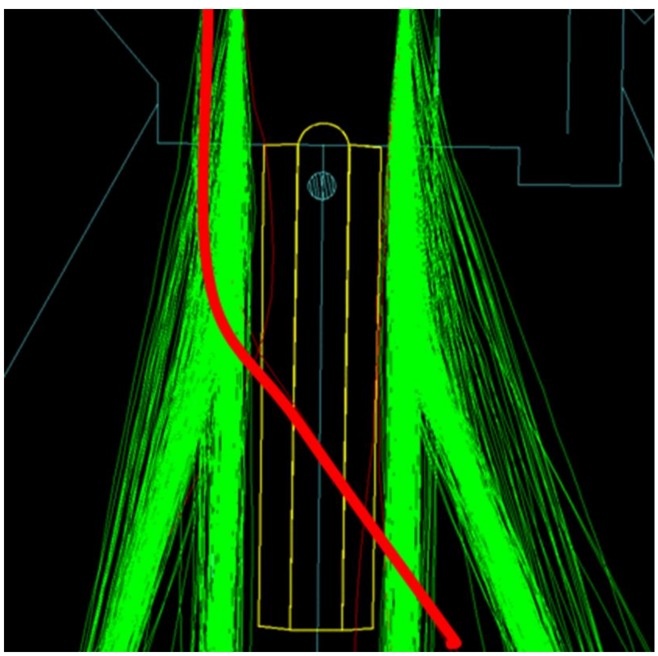
RNAV Departures and STAR Operations Joint Safety Analysis and Implementation Team



Final Report
Analysis and Recommendations

February 12, 2015

RNAV Departures and STAR Operations Joint Safety Analysis and Implementation Team Final Report

Analysis and Recommendations

Provided to the Commercial Aviation Safety Team

from

The Runway Excursion Joint Safety Analysis Team

February 12, 2015

OVERVIEW

Structured arrival and departure procedures are critical elements of the Federal Aviation Administration's (FAA) efforts to modernize the air traffic system to be more efficient while maintaining or improving the current level of safety. The design of these procedures has evolved over time, with significant changes occurring between 2000−2010, including the implementation of area navigation (RNAV) departure routes that are programmed on the airport surface before takeoff and activated near takeoff. Changes were also made to standard terminal arrival (STAR) routes to minimize fuel usage by optimizing vertical profiles.

As more RNAV departures and optimized STARs were put into service, new safety issues were observed and previous safety issues were highlighted. The FAA and airline community recognized these new or increased risks and requested studies by the Aviation Safety Information Analysis and Sharing (ASIAS) program to investigate these issues before they result in a fatal accidents. This is part of the evolution of safety analysis from a reactive, forensic activity toward a more proactive analysis.

The first ASIAS study was initiated in 2010 and focused on RNAV departure procedures. The second ASIAS study on STAR operations began in 2012. The results of the RNAV departure study were forwarded to the Commercial Aviation Safety Team (CAST) in 2012 and a Joint Safety Analysis and Implementation Team (JSAIT) was formed to examine the findings and evaluate mitigations. While the JSAIT analysis was in progress, the ASIAS study on STAR operations was completed and the scope of the JSAIT was expanded to include mitigations for those safety issues. The JSAIT work culminated in recommendations that CAST to adopt three new safety enhancements (SE) that apply to RNAV departures and STAR operations.

SAFETY CONCERNS AND CONTRIBUTING FACTORS

RNAV DEPARTURES

RNAV departure procedures that start from the runway have many advantages for both pilots and air traffic controllers. When correctly programmed by the flight crew and translated through the flight management system (FMS) and other aircraft systems uniformly across equipment types and weather conditions, RNAV departures generally improve conformance to the designed procedure. RNAV departure procedures do, however, introduce new initiating events that were not issues with conventional procedures. Specifically, RNAV departures require the flight crew to program the FMS correctly before departure and to modify the FMS to align with air traffic control (ATC) clearance changes before and during flight. Errors in programming can lead to unexpected and possibly large deviations from the nominal flight path. Moreover, variations in the way different FMS units and aircraft auto-flight and avionics systems process input data can result in unintentional deviations from the expected flight path.

Numerous occurrences of unexpected deviations from nominal departure flight paths have been observed at airports with RNAV departures that start from the runway. Of particular concern are those events at airports with independent departures on parallel runways where deviations early in the flight path can increase the risk of midair collisions between the departing aircraft. While there have been no midair collisions associated with RNAV departures to date, issues have been reported at every airport in the ASIAS study and the rate of reporting has not declined over time.

ASIAS analysis of pilot reports from the Aviation Safety Action Program (ASAP) found that lateral, speed, and altitude deviations occur on all RNAV departure procedures at all seven airports in the study. Lateral deviations are the most common, and they occur most frequently before the first fix on the departure procedure. This location correlates to the highest risk of midair collision because there is typically less separation from other departing aircraft immediately after takeoff. Some lateral deviations are very abrupt and have resulted in loss of separation from other departing aircraft. Other deviations—lateral, speed, and altitude—occur farther along the departure route, including the en route transition.

Most RNAV departure deviations result from pilots incorrectly programming the FMS and subsequently failing to identify the error through flight crew monitoring or cross-checking. Many of these errors occur before departure when the flight plan is entered into the FMS for the first time. Typically, errors are more likely when there are distractions or changes to the planned flight route before takeoff, such as a pre-departure clearance (PDC) from ATC that is not expected by the crew.

ATC changes to the published departure procedure in flight also can trigger pilot errors in reprogramming the FMS to align with the revised course or restrictions. Other significant contributors to inflight errors are complex (multiple airspeed or altitude restrictions) or confusing procedures and chart clutter.

Separately from pilot errors, there is some indication that different types of aircraft and FMS equipment execute the published route along slightly different paths. The differences seem to be more pronounced with higher departure winds and certain RNAV departure leg types on the initial segment.

STAR OPERATIONS

STARs are instrument flight procedures that facilitate the transition of aircraft from the en route environment to the terminal area. A major goal of recent STAR procedures is to optimize the vertical profiles by adding altitude and speed restrictions that allow arriving aircraft to maintain a fuel efficient descent profile, while still procedurally separating aircraft. These altitude and speed restrictions in optimized profile descent (OPD) procedures are designed as an integral part of the procedure, coded in FMS databases, and published on STAR charts.

There has been an increasing trend in ATC and pilot reports of altitude deviations while operating on OPD STARs. Missed crossing restrictions (MCR), which are violations of an assigned or published altitude (and occasionally speed) at a specific waypoint or point-in-space on the procedure, create a situation in which aircraft that were expected to be separated can be in close proximity. When an aircraft violates an altitude crossing restriction, the altitude barrier separating traffic is lost and the risk of a midair collision may increase. While there have been no midair collisions associated with MCRs on OPD STARs to date, reporting of the safety issue has dramatically increased with OPD procedures and there have been instances where separation was lost.

ASIAS analysis of ASAP reports found that the reported rate of MCRs during OPDs is increasing over time. The study investigated the reported rate of MCRs for the various types of STARs, including all four combinations of conventional vs. RNAV and OPD vs. non-OPD. The reported rate of MCRs on OPDs is two to three times the rates of those procedures that have not been optimized; reported MCR rates between conventional and RNAV STARs are virtually identical. In addition, not only is the rate of ASAP reporting of MCRs on OPD STARs greater than on non-OPD STARs, but the rate is increasing at a significantly faster rate.

Pilot lapses or omissions were the most commonly cited contributors to MCRs on STARs, including failure to monitor, crosscheck, or capture an error; distractions and preoccupation; and failure to adequately plan or prepare. In addition, automation programming issues, including FMS and incorrect auto-flight system programming, were also strong contributors. Automation programming issues leading to MCRs often resulted from ATC clearance amendments. These clearance amendments could include ATC changes to the published crossing restrictions or speeds, ATC removal of an aircraft from the STAR lateral or vertical path and subsequent clearance to rejoin the procedure, or ATC changes the runway that the crew is expecting.

The design of a STAR has a strong influence on the rate of MCRs. The number of “cross at” and ”cross between” altitude restrictions in a procedure has the highest correlation to the MCR rate, followed by the number of segments less than 5 NM, the number of runway transitions (inverse relationship), and the total segment count. Charting and the presence of Notices to Airmen (NOTAM) also play a role in the rate of MCRs. Charts that are cluttered, non-standardized, and contain too much information can contribute to MCRs. Crowding on navigational displays, a by-product of cluttered procedures, is an additional contributor to MCRs, as is the use of NOTAMs for an extended period of time instead of revising the charted and FMS stored restrictions.

JSAIT ANALYSIS PROCESS

The standard CAST process involves the identification of standard problem statements (SPS) after reviewing the details of multiple accidents involving fatalities or hull losses, development of potential intervention strategies to solve those problems, and ranking of the intervention strategies using a structured scoring process to evaluate their effectiveness and feasibility. Because there have been no such accidents involving RNAV departures or STAR operations, the standard CAST process was modified to leverage the ASIAS analysis to identify the safety issues, as shown in figure 1, below.

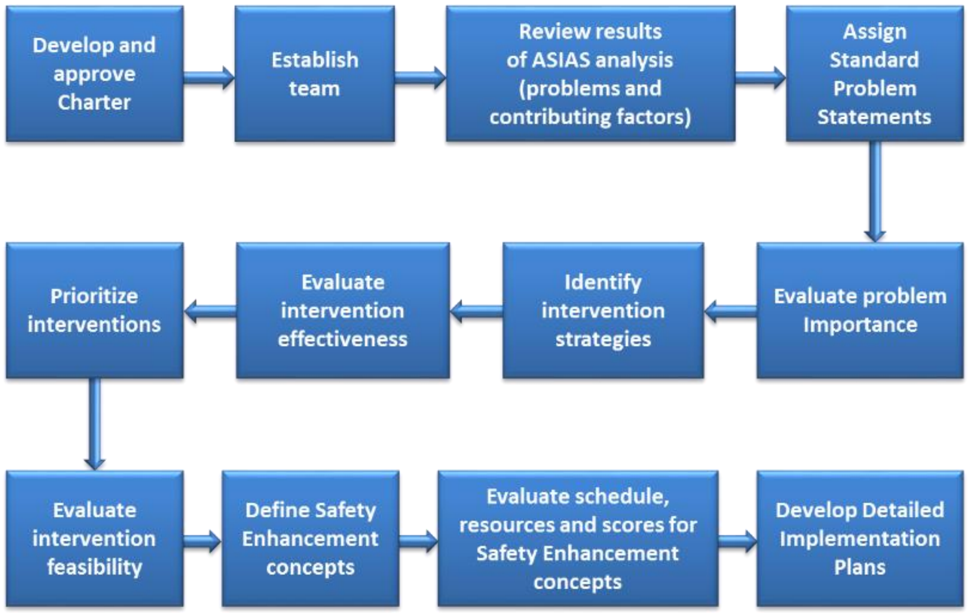


Figure 1. JSAIT Process

The largest change to the standard CAST process is the use of ASIAS analysis of precursors to develop SPSs rather than extracting them from accident analysis. Most of the subsequent steps in the process were similar to the standard process, although a different approach had to be developed to estimate risk.

STANDARD PROBLEM STATEMENTS (SPS)

There are many commonalities in the factors that contribute to pilot error for RNAV departures and STAR operations. In both cases, managing FMS entries and monitoring to ensure they reflect the correct flight paths are critical. Any changes from ATC that require reprogramming must first be recognized and then programmed correctly. This is particularly challenging when procedures or charts are complex and confusing, or there is a misunderstanding of the clearance intent between pilots and controllers.

Figure 2, below, summarizes the contributing factors for both types of operations and illustrates the points of commonality. The most significant difference in results between the two studies is that PDC changes and confusion are strong drivers for RNAV departure errors, but are not a factor for STAR operations.

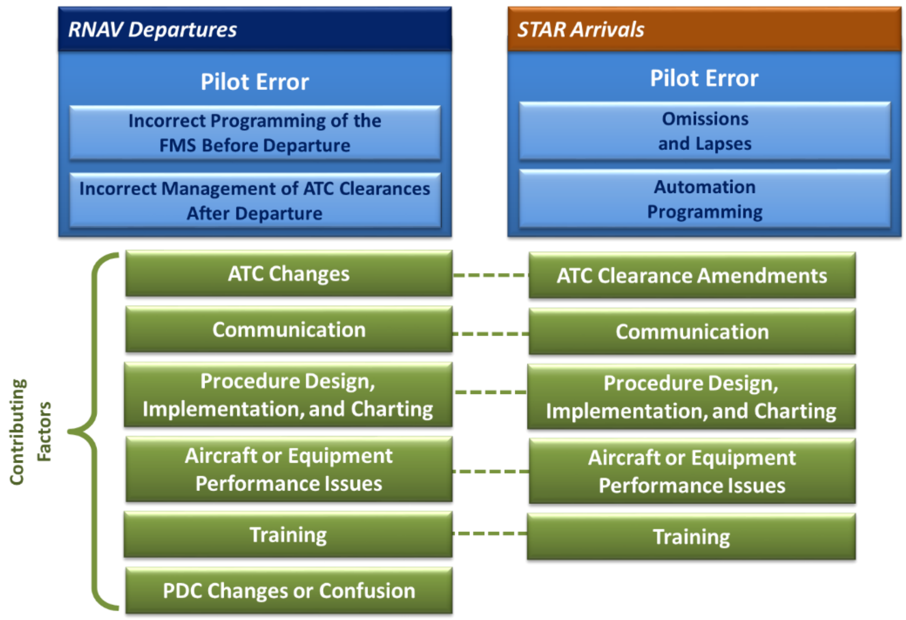


Figure 2. Summary of Contributing Factors from ASIAS Analyses

SPSs were extracted separately from the ASIAS analysis of RNAV departures and STAR arrivals. Fourteen SPSs were identified by the JSAIT for RNAV departures and another 10 SPSs were developed for STAR operations.

Following the standard CAST process, scores were developed for the SPSs for Importance, a measure of the strength of the problem or contributing factor as a causal link in the accident. These and other scores were developed after discussion among the JSAIT team, leveraging expert judgment in a consensus mode.

INTERVENTION STRATEGIES (IS)

The JSAIT developed ISs to address the SPSs for RNAV departures and STAR operations. The team scored the ISs individually for their ability to mitigate each of the SPSs. These scores were combined with the problem Importance to create Power, and supplemented with two additional scores: Confidence that the IS would work as planned and Applicability, an assessment of the extent to which the problem will be present in future operations. As a final step, an Overall Effectiveness score was calculated from the other component scores. Overall Effectiveness was used to screen out less effective interventions or interventions for less important problems. Table 1, below, lists the 16 ISs that result from the screening.

Table 1. Intervention Strategies after Scoring and Screening

1400 - To avoid FMS programming errors on RNAV departures, airline dispatchers and the FAA should take steps to minimize changes in the clearance to the filed flight route.
1401 - To avoid flight crew confusion about the PDC and associated FMS programming errors on RNAV departures, the FAA should standardize the PDC format and depiction of flight plan changes.
1402 - To reduce flight crew errors from reprogramming the FMS on RNAV departures, the FAA should improve processes for managing changes to runways, standard instrument departures routes, and en route transitions.
1403 - To avoid flight crew and ATC confusion, the FAA and airline operators should investigate opportunities to eliminate or minimize the impacts of departure clearances that alternate between initial RNAV and non-RNAV departures.
1404 - To reduce flight crew confusion and errors, the FAA should minimize changes to altitude or speed constraints that are followed by a clearance to rejoin an RNAV departure procedure or a STAR.
1405 - To minimize flight crew FMS programming errors on RNAV departures or STARs, the FAA and Airline Operators should establish commonly-accepted safe operating practices specific to FMS operation during RNAV departure and STAR procedures; integrate the practices into airline training programs, SOPs and checklists; and monitor their effectiveness.
1406 - To minimize effects of route conflicts and complex design on flight crew and controller errors, the FAA should develop and apply best practices for RNAV departure and STAR procedure design and implementation.
1407 - To reduce flight crew confusion and errors on RNAV departure and STAR procedures, the FAA should improve and standardize charting.
1408 - To minimize differences in aircraft/FMS performance on RNAV departures and STARs, FAA and airline operators should ensure that the procedures can be flown as intended by procedure designers and controllers.
1409 - To understand evolving RNAV departure and STAR issues, the FAA, airline operators, and CAST should monitor and evaluate RNAV departure and STAR safety metrics.
1410 - The FAA and Airline Operators should reconcile differences in the expectations of pilots, controllers and procedure designers for how closely flight paths must be followed, and ensure those expectations reflect flight guidance system capabilities.
1411 - To minimize differences in conformance to nominal path on RNAV departures and STARs, the FAA and manufacturers should investigate and mitigate equipment issues that result in deficiencies in track conformance.
1412 – To minimize flight crew FMS programming errors in loading the initial pre-departure route clearance, the FAA and manufacturers should enhance and implement data communication to autoload route clearance with crew acknowledgement of changes.
1413 - To minimize flight crew FMS programming errors on RNAV departures or STARs, the FAA should establish commonly-accepted safe operating practices specific to air traffic control of these procedures; integrate these practices into ATC training programs, SOPs and checklists; and monitor their effectiveness.

1414 - To minimize flight crew FMS programming errors on RNAV departures or STARs, the FAA should establish common phraseology across all ATC facilities.
1415 - To minimize flight crew FMS programming errors that arise from changes to route, altitude, or speed in flight, the FAA and manufacturers should enhance and implement data communication to autoload in-flight changes with crew acknowledgement.

SAFETY ENHANCEMENTS (SE)

Each of the 16 ISs were rated for Feasibility along six dimensions (technical, financial, operational, schedule, regulatory, and social) using the guidelines in the JSIT Handbook. These feasibility scores were combined with the Overall Effectiveness scores to get a combined score for each IS. After a final review by subject matter experts, the following ISs were incorporated into three SEs, as summarized in table 2, below.

Table 2. SEs and ISs

Safety Enhancement (SE)	Detailed Elements
SE 1 Equipment and Procedures to Improve Route Entry for RNAV Departures	• Improvements to airline dispatch filing • Standardization of PDC format • Auto-load routes and changes in PDC
SE 2 Safe Operating and Design Practices for STARs and RNAV Departures	• Alignment of training activities • Best practices for flight crews • Best practices for ATC • Best practices for procedure designers
SE 3 Procedures and Standards to Improve Path Compliance for STARs and RNAV Departures	• Aircraft performance criteria improvements • Standards to improve path conformance in new equipment

DEVELOPING SEs

Upon completion of the feasibility assessment, the JSAIT initiated the development of new SEs for the CAST Plan. The development of SEs includes the following steps:

1. Develop SE concepts for CAST level F approval.
2. Develop DIPs for each approved SE concept.
3. Perform a risk reduction estimation for each SE.

SE CONCEPTS

SE concepts were developed from the ISs with high scores for OE and Feasibility. Starting with SE concepts provided CAST the opportunity to approve the general direction of the proposed solutions before the development of detailed SEs. Further, this step provided an opportunity for the JSAIT to preview the SEs concepts with implementing organizations to elicit any concerns and develop consensus.

The JSAIT developed seven SE concepts by screening out less useful or infeasible ISs and grouping similar ones. The seven SE concepts, shown in table 3, were presented to CAST in April 2013.

Table 3. Initial SE Concepts

1	Improve system to make initial FMS entry errors less likely
2	Enhance safe operating practices for flight crews
3	Enhance safe operating practices for air traffic service providers
4	Establish best practices for procedure design and charting
5	Ensure that aircraft can fly procedures as published
6	Monitor issues
7	Standardize functional performance

CAST recommended that the concepts be refined and grouped to form three SEs for continued analysis. The final three SEs are shown in figure 3.

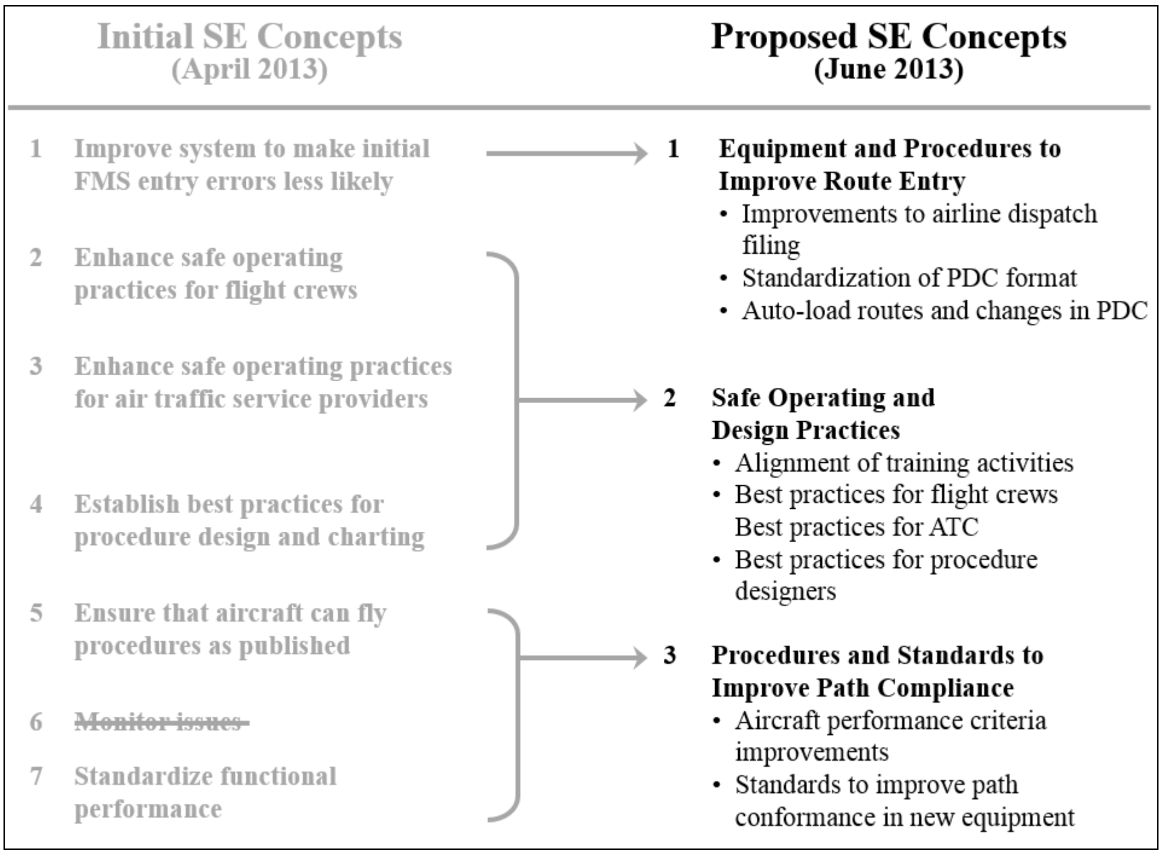


Figure 3. SE Concepts Refinement

Initially, the SPSs, ISs, and SEs were all targeted to focus on safety issues associated with RNAV departures. ASIAS conducted a detailed analysis of STAR operations and MCRs in parallel with the JSAIT analysis. When the ASIAS conclusions became available in September 2013, it was apparent that the SEs developed for RNAV departures were very closely aligned with ISs that would be effective in resolving STAR operations safety issues. CAST authorized an expansion of the JSAIT to include STAR operations.
The JSAIT revisited all the previous scoring that had been specific to RNAV departures and assessed its applicability to STAR operations. The conclusion of the JSAIT was that two of the three SEs were directly applicable to STAR operations with only a slight

expansion to cover STARs as well as RNAV departures. The modified language is reflected in the descriptions of the SEs in table 4.

Table 4. SEs Revised to Include STAR Operations

Safety Enhancement (SE)	Detailed Elements
SE 1 Equipment and Procedures to Improve Route Entry for RNAV Departures	• Improvements to airline dispatch filing • Standardization of PDC format • Auto-load routes and changes in PDC
SE 2 Safe Operating and Design Practices for STARs and RNAV Departures	• Alignment of training activities • Best practices for flight crews • Best practices for ATC • Best practices for procedure designers
SE 3 Procedures and Standards to Improve Path Compliance for STARs and RNAV Departures	• Aircraft performance criteria improvements • Standards to improve path conformance in new equipment

These SEs can be mapped to the SPSs, including both RNAV departures and STAR operations, as shown in table 5.

Table 5. Correspondence Between SEs and SPSs

STANDARD PROBLEM STATEMENTS: DEPARTURES	SE 1 Equipment and Procedures to Improve Route Entry for RNAV Departures	SE 2 Safe Operating and Design Practices for STARs and RNAV Departures	SE 3 Procedures and Standards to Improve Path Compliance for STARs and RNAV Departures
1400 ATC assigns PDCs that are different from those filed by airline dispatch	✓	✓	
1401 ATC generates PDCs in a format that is confusing to flight crews	✓	✓	
1402 ATC changes runway or assigns runway other than expected by the flight crew		✓	
1403 ATC assigns SID or en route change after FMS is programmed and before takeoff	✓	✓	
1404 ATC clears an aircraft to rejoin a procedure after being vectored off a published procedure or after in-flight change of published altitude or speed restrictions		✓	

STANDARD PROBLEM STATEMENTS: DEPARTURES	SE 1 Equipment and Procedures to Improve Route Entry for RNAV Departures	SE 2 Safe Operating and Design Practices for STARs and RNAV Departures	SE 3 Procedures and Standards to Improve Path Compliance for STARs and RNAV Departures
1405 ATC alternates initial clearance between vectors for heading and RNAV navigation		✓	
1406 ATC uses non-standard phraseology (departures)		✓	
1407 ATC inconsistently uses RNAV to first fix phraseology		✓	
1408 ATC does not correctly communicate heading/procedure from one ATC position or facility to the next		✓	
1409 Procedure designers create complex designs with multiple restrictions		✓	✓
1410 Procedure designers develop departure routes that conflict with independent flows/routes or special use airspace		✓	
1411 When departure and arrival routes overlap, procedure designers set up the transition to the STAR at an intermediate point		✓	
1412 Charting authorities reference speed or altitude restrictions in notes		✓	
1413 Differences in aircraft FMS processing, navigation system precision, or control systems result in minor course deviations		✓	✓
1414 Procedure designers and implementers overlook details that contribute to flight crews missing crossing restrictions		✓	
1415 Flight crews lack depth of knowledge about automation		✓	
1416 ATC issues amendments or clearance changes on STARs		✓	
1417 ATC uses inconsistent phraseology (arrivals)		✓	
1418 Procedure designers and implementers overlook details that contribute to flight crews missing crossing restrictions		✓	
1419 Procedure designers do not follow design guidance		✓	

STANDARD PROBLEM STATEMENTS: DEPARTURES	SE 1 Equipment and Procedures to Improve Route Entry for RNAV Departures	SE 2 Safe Operating and Design Practices for STARs and RNAV Departures	SE 3 Procedures and Standards to Improve Path Compliance for STARs and RNAV Departures
1420 ATC training on the implementation of new STAR is not adequate		✓	
1421 Some airplane types cannot fly procedures with many restrictions; additionally, airplane types not equipped with auto-throttles and coupled VNAV may contribute to increased pilot workload and errors		✓	✓
1422 Airspace with high rates of traffic-in-proximity events or where traffic flows routinely interact can increase the likelihood of midair collisions		✓	
1423 Charting requirements and depiction of those requirements contribute to clutter and other formatting issues		✓	

The Intervention Strategies can also be mapped to the SEs, as shown in Table 6.

Table 6. Correspondence Between SEs and ISs

Intervention Strategies	SE 1 Equipment and Procedures to Improve Route Entry for RNAV Departures	SE 2 Safe Operating and Design Practices for STARs and RNAV Departures	SE 3 Procedures and Standards to Improve Path Compliance for STARs and RNAV Departures
1400 - To avoid FMS programming errors on RNAV departures, airline dispatchers and the FAA should take steps to minimize changes in the clearance to the filed flight route.	✓		
1401 - To avoid flight crew confusion about the PDC and associated FMS programming errors on RNAV departures, the FAA should standardize the PDC format and depiction of flight plan changes.	✓		
1402 - To reduce flight crew errors from reprogramming the FMS on RNAV departures, the FAA should improve processes for managing changes to runways, standard instrument departures routes, and en route transitions.		✓	

Intervention Strategies	SE 1 Equipment and Procedures to Improve Route Entry for RNAV Departures	SE 2 Safe Operating and Design Practices for STARs and RNAV Departures	SE 3 Procedures and Standards to Improve Path Compliance for STARs and RNAV Departures
1403 - To avoid flight crew and ATC confusion, the FAA and airline operators should investigate opportunities to eliminate or minimize the impacts of departure clearances that alternate between initial RNAV and non-RNAV departures.		✓	
1404 - To reduce flight crew confusion and errors, the FAA should minimize changes to altitude or speed constraints that are followed by a clearance to rejoin an RNAV departure procedure or a STAR.		✓	
1405 - To minimize flight crew FMS programming errors on RNAV departures or STARs, the FAA and Airline Operators should establish commonly accepted safe operating practices specific to FMS operation during RNAV departure and STAR procedures; integrate the practices into airline training programs, SOPs and checklists; and monitor their effectiveness.		✓	
1406 - To minimize effects of route conflicts and complex design on flight crew and controller errors, the FAA should develop and apply best practices for RNAV departure and STAR procedure design and implementation.		✓	
1407 - To reduce flight crew confusion and errors on RNAV departure and STAR procedures, the FAA should improve and standardize charting		✓	
1408 - To minimize differences in aircraft/FMS performance on RNAV departures and STARs, FAA and airline operators should ensure that the procedures can be flown as intended by procedure designers and controllers.			✓
1410 - The FAA and Airline Operators should reconcile differences in the expectations of pilots, controllers and procedure designers for how closely flight paths must be followed, and ensure those expectations reflect flight guidance system capabilities.		✓	
1411 - To minimize differences in conformance to nominal path on RNAV departures and STARs, the FAA and manufacturers should investigate and mitigate equipment issues that result in deficiencies in track conformance.			✓

Intervention Strategies	**SE 1** Equipment and Procedures to Improve Route Entry for RNAV Departures	**SE 2** Safe Operating and Design Practices for STARs and RNAV Departures	**SE 3** Procedures and Standards to Improve Path Compliance for STARs and RNAV Departures
1412 - To minimize flight crew FMS programming errors in loading the initial pre-departure route clearance, the FAA and manufacturers should enhance and implement data communication to autoload route clearance with crew acknowledgement of changes.	✓		
1413 - To minimize flight crew FMS programming errors on RNAV departures or STARs, the FAA should establish commonly-accepted safe operating practices specific to air traffic control of these procedures; integrate these practices into ATC training programs, SOPs and checklists; and monitor their effectiveness.		✓	
1414 - To minimize flight crew FMS programming errors on RNAV departures or STARs, the FAA should establish common phraseology across all ATC facilities.		✓	
1415 - To minimize flight crew FMS programming errors that arise from changes to route, altitude, or speed in flight, the FAA and manufacturers should enhance and implement data communication to autoload in-flight changes with crew acknowledgement.	✓		

In July 2013, CAST granted level F approval of the SE concepts for RNAV departures, signifying that the JSAIT should proceed with developing DIPs and final cost-benefit analysis for the approved concepts. CAST granted approval to incorporate STAR operations into the final analysis in September 2013.

DIPS

The JSAIT developed DIPs for the three SEs, covering both RNAV departures and STAR operations. The outputs for the SE concepts aligned with the detailed elements shown in table 4, which were built from lower level ISs that were grouped into the broader SEs. Outputs were further broken down into specific actions required for completion. The JSAIT identified organizations responsible for the execution of each action and nominated an organization (designated the "Lead Organization") to lead overall coordination of each output.

The JSAIT, in collaboration with the implementing organizations developed additional information, including financial resources required to complete the SE, timelines with milestones, and performance goal indicators. They included all of this information in the DIPs for the three SEs.

The final DIPs for all SEs are provided in appendix 3 to this report. They may also be found on the European Aviation Safety Agency (EASA) SkyBrary Web site at http://www.skybrary.aero/index.php/Category:CAST_SE.

IMPLEMENTATION COSTS AND RISK REDUCTION BENEFITS

The JSAIT estimated the implementation cost for each of the SEs. It developed detailed implementation plans (DIP) and estimated resources, including identification of the lead organization and all supporting organizations. Labor resources for attending meetings, developing and implementing guidance and training, and conducting analysis were estimated and translated into costs using one full time equivalent for 1 year of labor valued at $250K. Travel costs and administrative support were also estimated and included as part of the costs. These estimates were made in collaboration with the lead organizations for the SEs. The overall cost to implement all three SEs was estimated to be $7.17 million.

The benefit of implementing the three new SEs is the cost saved by avoiding accidents. Using conservative CAST assumptions, it is estimated that the loss of a single passenger aircraft in a fully fatal accident costs on average approximately $1 billion. Because the accidents of interest for RNAV departures and STAR operations involve midair collisions, more than one aircraft could be lost in a single event.

There have been no fatal accidents or hull losses to use as a basis for estimating the probability of a future midair collision resulting from deviations on RNAV departures or STAR operations, so a new approach based on the concept of "credible risk" was developed for estimating that probability. The JSAIT applied a simulation model to the FAA's radar track data for aircraft on RNAV departures and STAR operations arrivals to estimate the number of close encounters. It treated the simulation model output as precursor data and used it in a Bayesian transition model to estimate the expected value of the probability of collision. This result was used to estimate the expected number of midair collisions over the next 20 years. The number of midair collisions was translated into the number of aircraft lost by applying a multiplier to account for the fact that two aircraft could be lost in a midair collision. Finally, the JSAIT conducted analysis to estimate the fraction of midair collision risk that is likely to be eliminated by the SEs. The combined risk reduction probability of the three SEs acting together was determined to be approximately 61 percent for RNAV departures and 36 percent for STAR operations.

BENEFIT-TO-COST RATIO

The expected value of costs associated with accidents involving RNAV departures over 20 years was calculated to be $1.8 billion; the corresponding value for STAR operations is $2.2 billion. Because the risk reduction associated with the SEs collectively is 61 percent for RNAV departures and 36 percent for STAR arrivals, the expected value of risk reduction for the SEs is $1.89 billion over 20 years,[1] as indicated in figure 4, below. The total estimated cost of the three SEs is $7.17 million; thus the benefit-to-cost ratio of the combined SEs is more than 200 to 1. While there is considerable uncertainty in the calculation of risk reduction probability, the benefit-to-cost ratio for the three RNAV/STAR Arrival SEs is so strongly positive it is likely to be beneficial even if the risk is significantly lower than estimated.

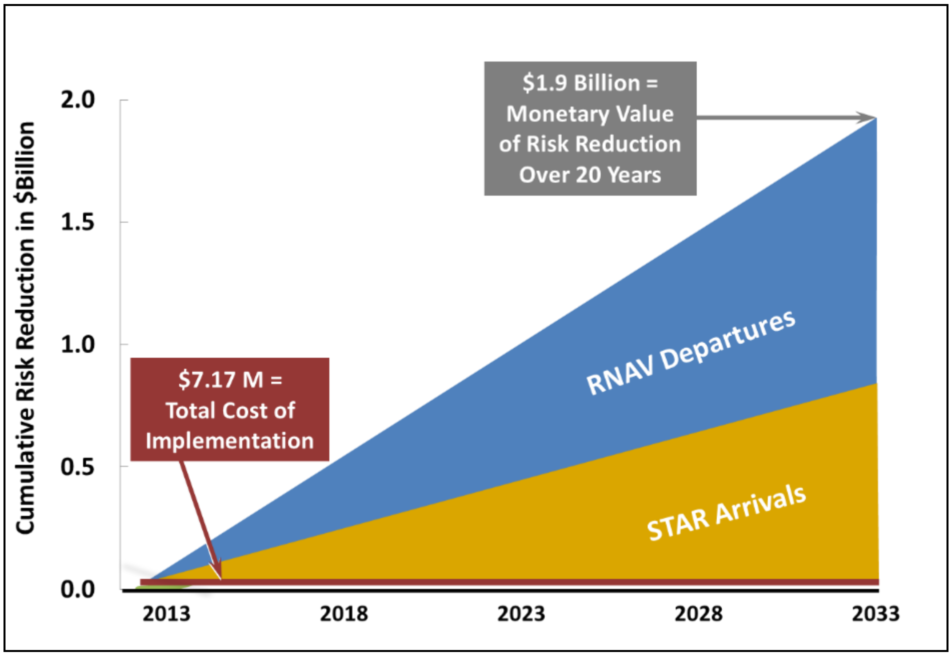


Figure 4. Monetary Value of Avoided Risk for All SEs Over 20 Years

[1] Calculated as follows: $1.8 billion * 0.61 + $2.2 billion * 0.36

RECOMMENDATION

The JSAIT recommends the adoption of the three SEs described in section 6.0. These SEs are cost effective and beneficial in reducing the risks identified for RNAV departures and STAR operations.

APPENDIX A. DETAILED IMPLEMENTATION PLANS

SE 212: Equipment and Procedures To Improve Route Entry for RNAV Departures

Status: Underway

Background

To reduce the frequency of crew errors during initial FMS programming of departure routes, regulators and air carriers take steps to address issues concerning PDCs and pre-departure route changes.

- Improve the likelihood that air carrier dispatch files a route that is not changed in the cleared route of flight. (Output 1)
- Standardize PDC format, with PDC changes from the flight plan clearly alerted in a consistent manner. (Output 2)
- Implement tower ability to provide data communications clearance delivery and encourage operator deployment of the capability to autoload pre-departure route clearances, with crew acknowledgement, into the FMS. (Output 3)

SE 213: Safe Operating and Design Practices for STARs and RNAV Departures

Status: Underway

Background

To mitigate errors on STARs and RNAV departures, the regulator, the FAA's Air Traffic Organization (ATO), and industry develop and implement safe operating and design practices for these procedures.

The FAA and industry will collaborate in establishing elements of commonly-accepted safe operating and design practices for flight crews, air traffic service providers, and procedure designers.

- The FAA, in collaboration with industry, develops guidance to align training for flight crews, training for controllers, and procedure and chart design and implementation. (Output 1)
- FAA Flight Standards, in collaboration with industry, develops commonly-accepted safe operating practices for crews in order to enhance safety on STARs and RNAV departures. Air Carrier training organizations will develop, review, and amend training syllabi to emphasize each air carrier's policies relating to STARs and RNAV departures. (Output 2)

- The FAA ATO, with air carrier input, develops commonly-accepted safe operating practices for air traffic control of STARs and RNAV departures. The FAA ATO will develop, review, and amend air traffic control training syllabi to incorporate these practices and emphasize policies and procedures relating to STARs and RNAV departures. (Output 3)
- The FAA ATO, in collaboration with air carriers and industry aeronautical chart providers, develops and implement guidance for improved procedure design and charting to mitigate operational errors on STARs and RNAV departures. (Output 4)

SE 214: Procedures and Standards To Improve Path Compliance for STARs and RNAV Departures

Status: Underway

Background

The purpose of this SE is to reduce deviations from the aircraft's intended path. In order to reduce deviations, the FAA, air carriers, and manufacturers will implement procedural and standards improvements to consistently execute departure or arrival procedures as published. Aircraft capability to consistently execute the arrival or departure procedure as published will be validated.

1. Develop aircraft, operator, and procedure design criteria for aircraft performance on arrival and departure procedures under the expected range of operational conditions.
2. Support development of aircraft and avionics standards to improve path conformance and reduce pilot automation errors on STARs and RNAV departures for new aircraft and equipment.