FAA
Human Performance Team (AJI-155)
FAA-HPT-2018/7

Human Performance Assessment of Altitude Compliance Events

Pilot-Focused Executive Summary and Full Report

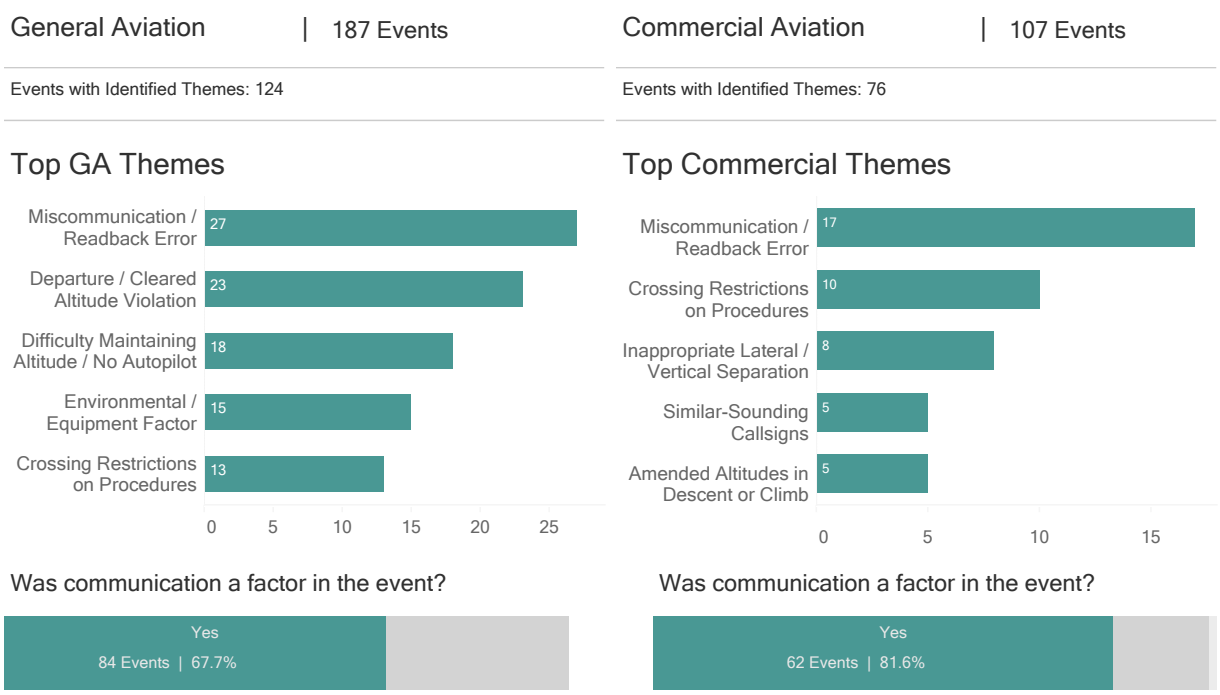
Top 5 Activity Fiscal Year 2019

December 18, 2018

Pilot-Focused Executive Summary

A Top 5 Steering Committee identified Altitude Compliance, defined as "aircraft operating at unexpected or unintended altitude," as a Top 5 item in Fiscal Year 2018. The Altitude Compliance Corrective Action Plan Team identified phraseology and procedural best practices as potential mitigations. To help define specific recommendations, a one-day focus group was held at Federal Aviation Administration Headquarters in Washington, DC. Participants included air traffic control and pilot subject matter experts from the Air Line Pilots Association, International (ALPA); National Business Aviation Association (NBAA); Safety and Technical Training (AJI); Air Traffic Services (AJT); and Mission Support Services (AJV). The Aircraft Owners and Pilots Association (AOPA) additionally reviewed the findings and provided comments outside of the focus group.

To guide the focus group discussion, the Human Performance Team completed an initial data analysis identifying 13 common altitude compliance themes based on an in-depth analysis of operational events. In in-depth analysis of 294 events involving an altitude compliance event by either a General Aviation or Commercial aircraft was conducted to assess the prevalence of non-compliance themes. The most frequently occurring themes are presented in the figure below, with full analysis results provided in the body of the report.



The focus group agreed that the data analysis and additional group had captured the majority of possible causal factors. The focus group discussed mitigations that were ongoing and identified additional new mitigations. Each mitigation was mapped to the relevant themes to show the cross-cutting potential of proposed mitigations.

Provided below is a summary of mitigation related to flight crew and aircraft performance.

Pilot-Focused Mitigation Strategies

Pilot Readback Training

Incorporate and emphasize listening skills in pilot training and simulation activities specifically related to reducing readback errors. This training should specifically emphasize active listening when similar sounding callsigns are operating in the area or when a previously issued clearance is being amended.

Prospective Memory

Participants described memory techniques that pilots use to ensure they would not forget to execute a clearance after a long delay (e.g., a pilot discretion descent). Participants discussed techniques of descending early to avoid forgetting, setting a timer to remind the crew to descend, inputting a reminder message into the FMS scratchpad, or stopping conversations until the descent begins.

STAR Education

Develop materials that encourage commercial pilots to pay close attention to bi-directional STARs where altitude windows are set up to accommodate different direction arrivals (e.g., North arrivals vs. South).

Automation Use Best Practices

Encourage pilots to take 30-60 seconds to program new constraints into their FMS before informing the controller that they can accept a new restriction, given the time it takes for thrust / attitude changes to take place and for the computer to calculate a new descent path. Similarly, pilots must input runway expectation into their flight management systems (FMSs) early, so that the computer can calculate the most appropriate descent path for the direction of the STAR they are flying.

Communicate Difficulty Executing Clearance

Provide awareness training for pilots that emphasizes the importance of alerting controllers when they may be unable to conform to a clearance or procedure restriction. When controllers give speed / lateral changes during a STAR where the aircraft will be unable meet the constraint, it can be difficult for the pilot to discern if the aircraft will meet the constraint, especially when the clearance is given far out from the constraint. If the pilot says they are unable to make it, then controllers may authorize missing the restriction in speed or altitude or they may provide vectors.

Not Cleared for Approach

Pilots who report the airport in sight and expect to receive a visual approach clearance sometimes believe they are cleared to descend to the airport before they are issued a visual approach clearance.

Climb/Descend Via Phraseology Education

Disseminate training to pilots that explains the use of proper phraseology when executing a climb via or descend via clearance. Possible Letter to airmen.

Technology Enhancements to Reduce Altitude Compliance Events

Technology to send pre-departure clearance information to General Aviation pilots via email / application is currently undergoing testing. Having the data available for reference may reduce confusion in flight. Additionally, improving the quality of Controller–Pilot Data Link Communications (CPDLC) Pre-Departure Clearance information may reduce non-compliance events. Specifying the initial and top altitudes for each departure runway to pilots as part of the transmitted data message may reduce confusion.

Mitigation-Theme Mapping

Pilot Mitigation Mapping

		Mitigation Categories							
Causal Factor Themes	**% Events**	Pilot Readback Training	Prospective Memory	STAR Education	Automation Use Best Practices	Communicate Difficulty Executing Clearance	Not Cleared for Approach Training	Phraseology Education	Technology Enhancements
Miscommunication / Readback Error	24.0%	♦							♦
Departure / Cleared Altitude Violation	13.0%				♦	♦			♦
No Autopilot / Difficulty Maintaining Altitude	12.0%					♦			
Crossing Restrictions on Procedures	12.0%			♦	♦	♦			
Environmental / Equipment Factor	11.0%					♦			
Inappropriate Lateral / Vertical Separation	9.5%								
Not Cleared for Approach	8.5%	♦					♦		
Amended Altitudes in Descent or Climb	6.5%	♦							
Altitude Pre-Select / Autopilot Issues	6.0%		♦		♦				
Similar-Sounding Callsigns	6.0%	♦							
Departure Climbs Stopped Below 2000'	5.5%		♦					♦	♦
Climb / Descend Via and Maintain	3.0%							♦	
Incorrect Altimeter Setting	2.0%				♦				

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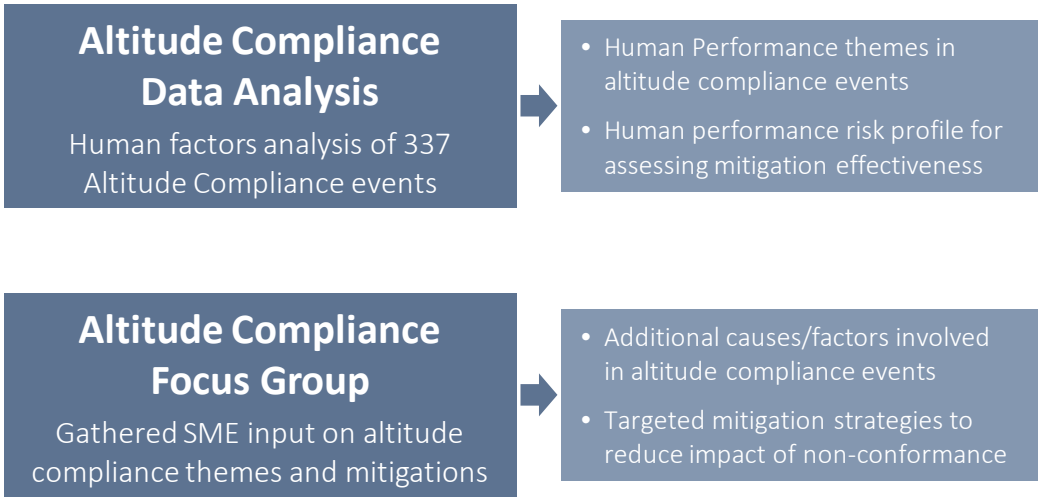
Introduction

The Federal Aviation Administration (FAA) Air Traffic Organization (ATO) Top 5 Steering Committee compiles an annual list of Top 5 issues contributing to safety risk in the National Airspace System (NAS). A Top 5 Steering Committee identified ***Altitude Compliance***, defined as "aircraft operating at unexpected or unintended altitude," as a Top 5 item in Fiscal Year (FY) 2018. The Altitude Compliance Corrective Action Plan (CAP) Team identified phraseology and procedural best practices as potential mitigations. To support the understanding of human performance factors involved in these events, the Human Performance Team (HPT, AJI-155) conducted an in-depth analysis of altitude compliance in the NAS.

FY18 Human Performance Altitude Compliance Assessment

To help define specific altitude compliance recommendations, the Human Performance Team conducted an in-depth data analysis of altitude compliance events and hosted a one-day focus group at FAA Headquarters in Washington, DC. Focus group participants included Subject Matter Experts (SMEs) from both air traffic and pilot communities, with representatives from Safety and Technical Training (AJI), Air Traffic Services (AJT), and Mission Support Services (AJV).

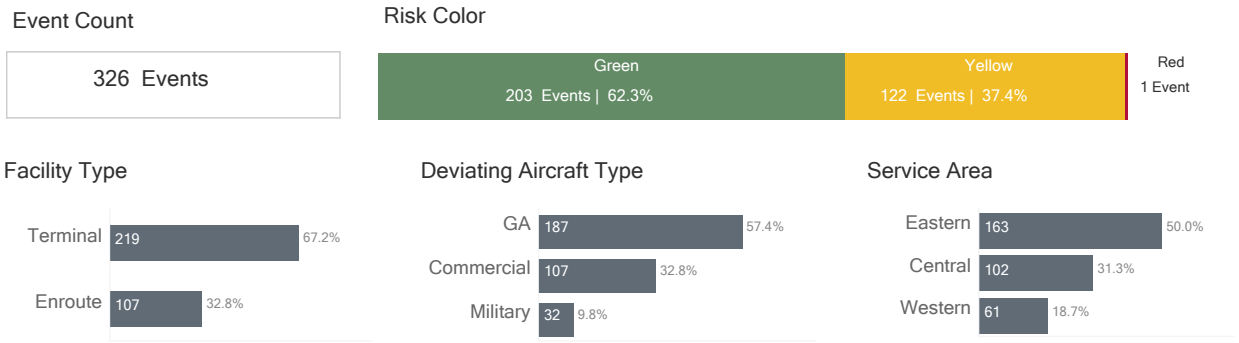


This report captures the discussion around the questions and the review of the examples of the themes. The discussion was mapped to the themes when possible. Topics that did not map to a theme are included separately in the SME discussion section or at the end of the report. For each theme, there is a brief description of the issue, including a list of the causal factors that were commonly observed in the events or were covered in the discussion and were relevant to the theme. Potential mitigations mapped to each theme are also provided.

Altitude Compliance Data Analysis

In order to better understand the role of human performance in altitude compliance events, AJI-155 conducted an in-depth analysis of 337 altitude compliance Risk Analysis Events (RAEs) that occurred between January 2017 and April 2018. The Human Performance Team reviewed the audio and radar replays available for 326 of these events to identify the factors impacting human performance. For each event, salient information including the facility type (Terminal, En Route), deviating aircraft type (General Aviation [GA], commercial, or military) and the service area (Eastern, Central, Western).

Below is a summary of analyzed risk analysis events.



The initial event review assessed the radar replay and verbal communication involved in each event to determine whether there was sufficient detail to better understand the role of human performance in the event. During this process, 200 events were deemed to have sufficient detail for in-depth analysis. The following figure shows the full distribution of events reviewed and human performance factors derived from the Altitude Compliance Safety Risk Management Document (SRMD) used in the review.

200 Events

Full Human Factors Analysis

Review audio and replay to identify the role of factors that impact human performance in altitude compliance events.

Phraseology	ADS-B/C Mitigation	GA / Com / Mil Operation
Pilot Deviation	Equipment Issue	Acknowledge no Readback
Amended Altitude	Environmental Issue	Below MVA
Hearback/Readback Issue	Communication	TCAS RA
Instrument Procedure	Plain Language	

126 Events

Replay analysis did not reveal additional information

11 Events

No replay available

Human Performance Analysis

For each reviewed event, the Human Performance Team identified the presence of human performance themes related to altitude compliance events. The themes served as a framework for additional analysis and discussion of altitude compliance events. A brief description of these 13 themes is provided below.

Miscommunication / Readback Error

A loss of separation occurred when the flight crew read back an altitude assignment incorrectly, took the wrong clearance, failed to respond to a clearance, or misinterpreted an instruction.

Departure / Cleared Altitude Violation

A loss of separation occurred when an aircraft was issued an initial climb altitude by clearance delivery or issued a pre-departure clearance and, after departure, it did not level at its assigned altitude.

Crossing Restrictions on Procedures

A loss of separation occurred when an aircraft did not cross a fix / vertical constraint point at the instructed altitude or at an altitude designated by charted procedure.

No Autopilot / Difficulty Maintaining Altitude

A loss of separation occurred involving an aircraft that either reported autopilot difficulty or appeared to have difficulty maintaining altitude for minutes leading up to the event (typically represented by fluctuations in altitude of 200+ feet below and above their assigned altitude).

Environmental / Equipment Factor

A loss of separation occurred when an aircraft deviated from its altitude due to weather conditions or as a result of the failure of aircraft equipment such as an engine or flight control system (as reported on frequency).

Inappropriate Lateral / Vertical Separation

A loss of separation occurred when a controller's vectors or instructions resulted in two aircraft operating with less than the required separation. Even though the controller sent the aircraft to that altitude, the controller must have had a different altitude in mind to maintain separation.

Not Cleared for Approach

A loss of separation occurred after an aircraft descended on an approach without authorization. Typically, this occurred when the aircraft descended after either being told to report the airport in sight for a visual approach, or when the aircraft was told to join a localizer / final approach course, but before an approach clearance was issued.

Amended Altitudes in Descent or Climb

A loss of separation occurred when a climb / descent altitude was issued initially and then amended to restrict the climb / descent, but the deviating aircraft climbed / descended to the initially-assigned altitude.

Altitude Pre-Select / Autopilot Issues

A loss of separation occurred when the flight crew reported an issue with their autopilot capturing a selected altitude or when the altitude selector was incorrectly set, resulting in a deviation from the expected climb / descent altitude.

Similar-Sounding Callsigns

A loss of separation occurred when two aircraft with similar-sounding callsigns were operating on the same frequency.

Departure Climbs Stopped Below 2,000'

A loss of separation occurred when an aircraft was issued an initial altitude of 2,000 feet Above Ground Level (AGL) or less as its initial climb altitude, and the aircraft was not leveled in time after takeoff.

Climb / Descend Via and Maintain

A loss of separation occurred after an aircraft was issued a climb via or descend via clearance and it did not comply with that instruction.

Incorrect Altimeter Setting

A loss of separation occurred when an aircraft was operating with the altimeter calibration set incorrectly.

Additional Areas of Interest

In addition to the themes identified during the initial analysis, several specific areas of interest were assessed for each event.

Communication

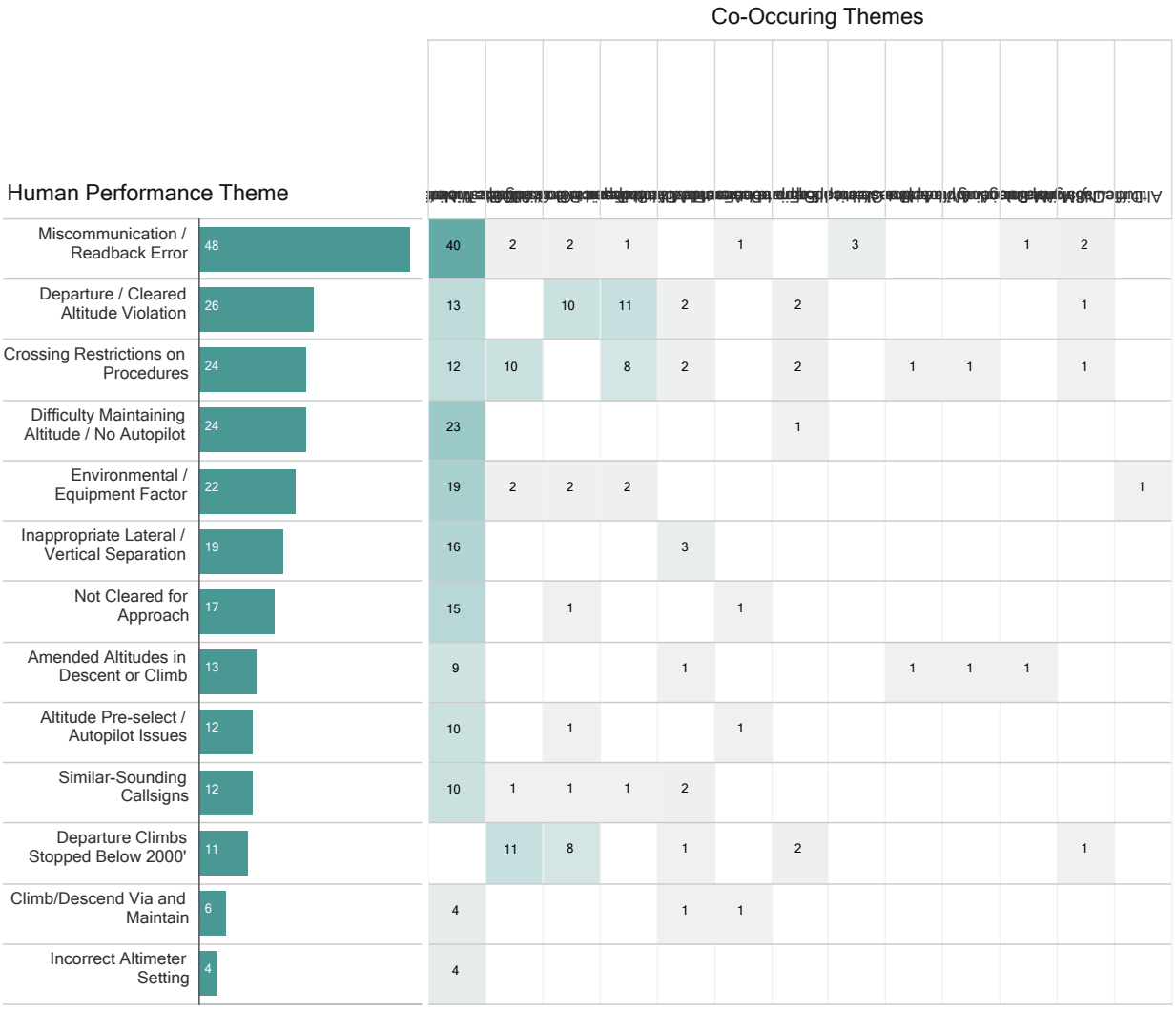
For each event, the presence of any communication-related issue was identified. This included factors such as hearback / readback issues, miscommunication events, interrupted radio broadcasts, or other similar events.

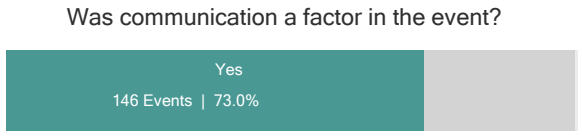
Automatic Dependent Surveillance – Broadcast / – Contract (ADS-B/C) Intent Data Effectiveness

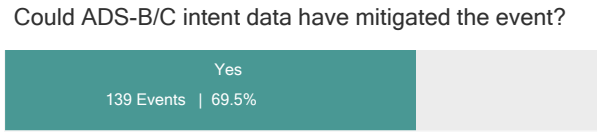
For each event, the review team assessed whether providing the controller with intent data on the pilot's programmed altitude would enhance the controller's ability to identify the potential deviation more quickly and effectively.

Human Performance Impact Assessment

Provided below is an overview of event themes identified in the 200 RAEs with sufficient information. As multiple themes could be present in a single event, co-occurring themes are also presented in the table below.

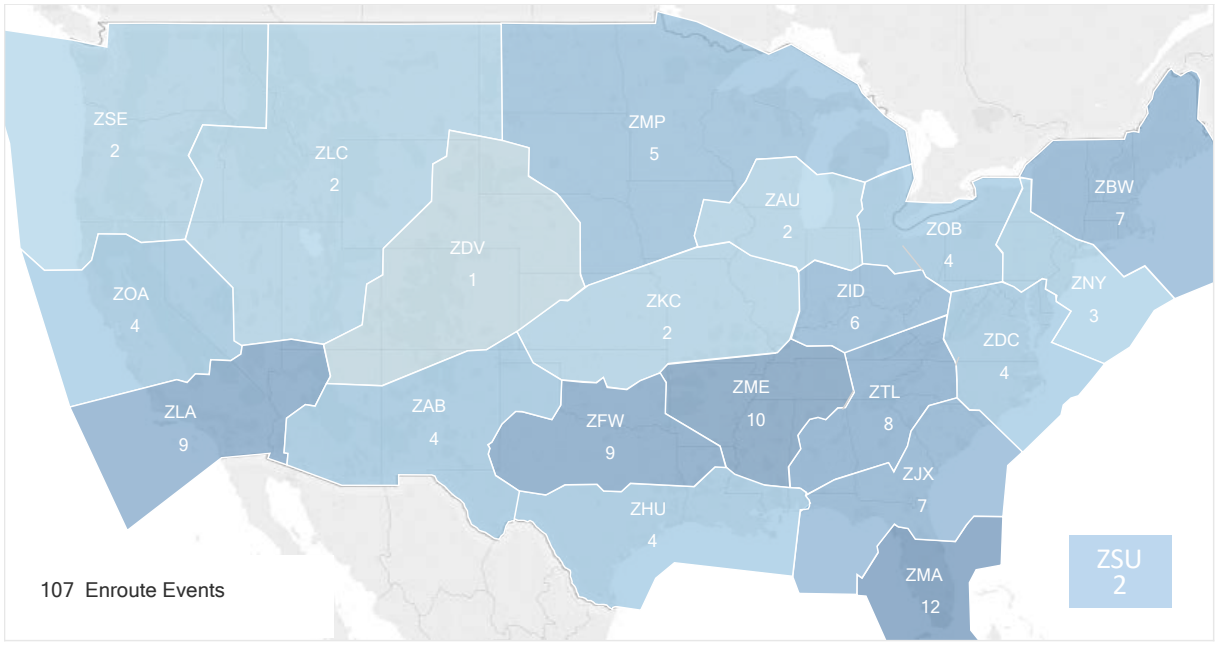




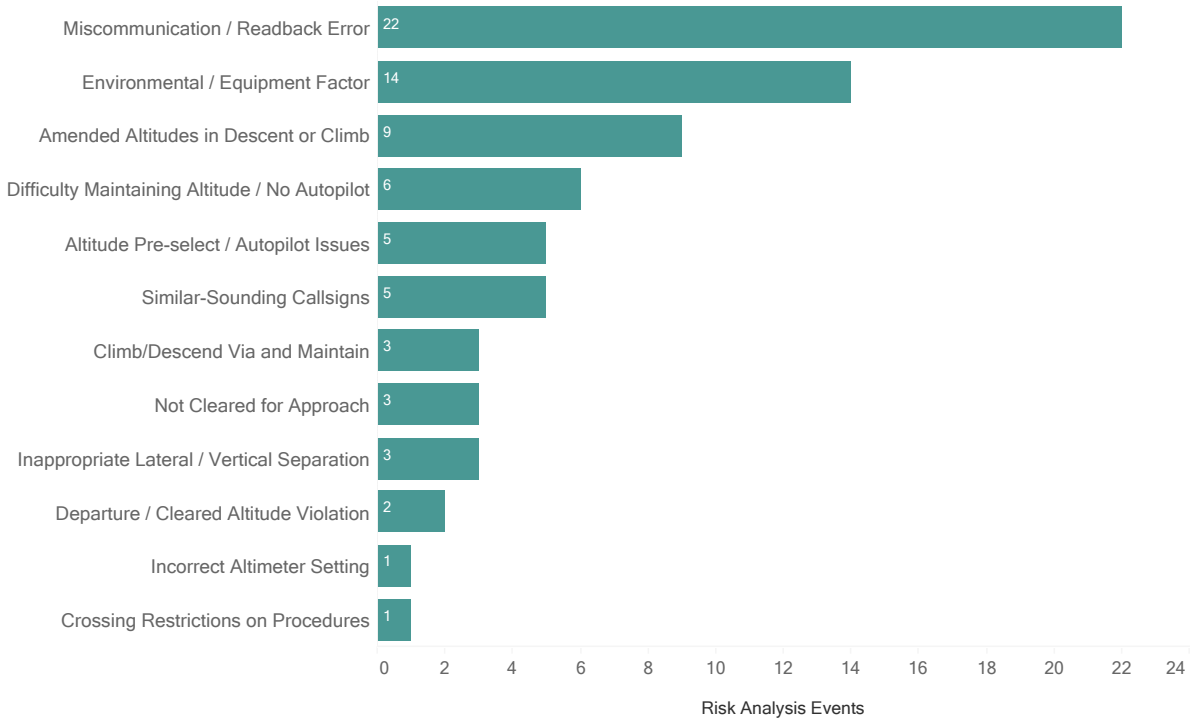


**Based on 200 RAEs*

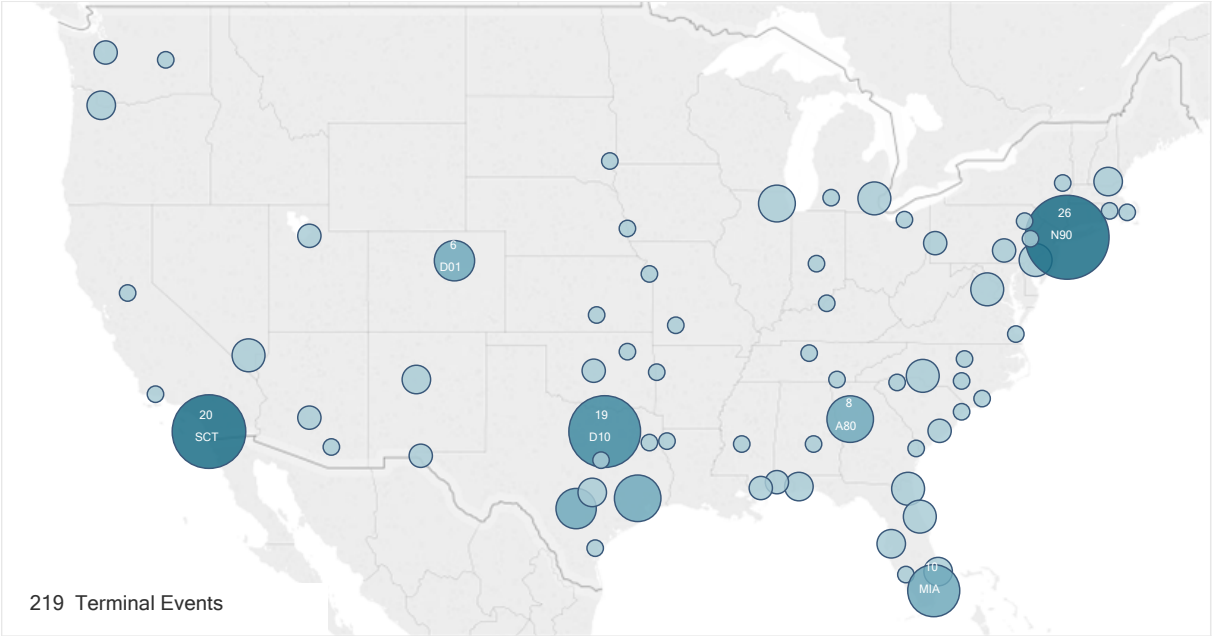
En Route Altitude Compliance Events



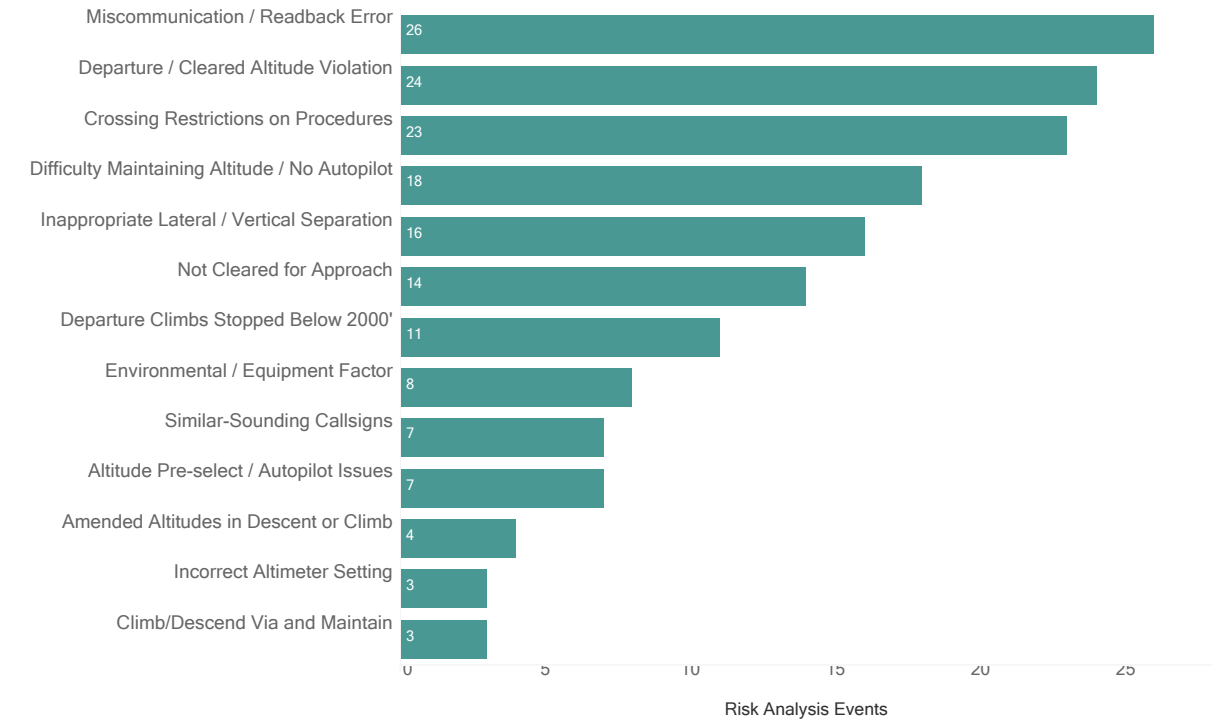
Events with Identified Themes: 68



Terminal Altitude Compliance Events



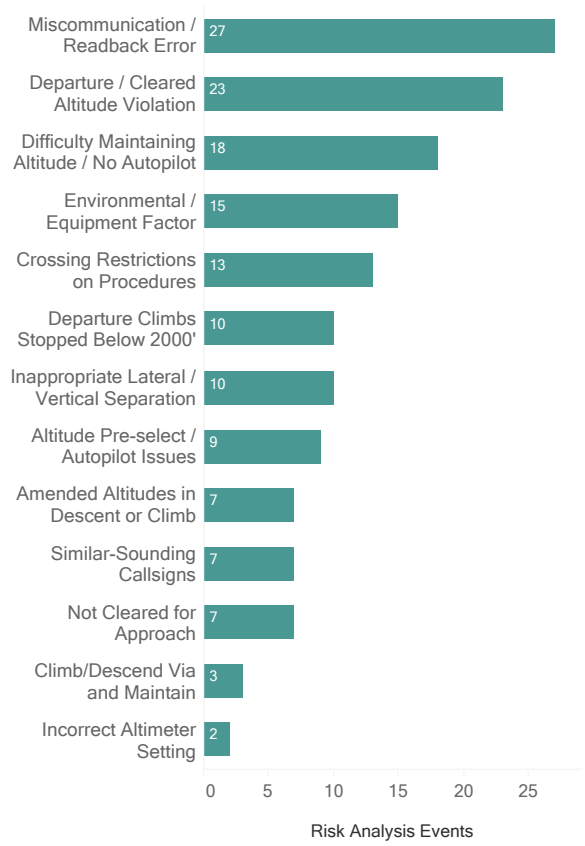
Events with Identified Themes: 132



General Aviation | 187 Events

Events by Facility Type

Events with Identified Themes: 124

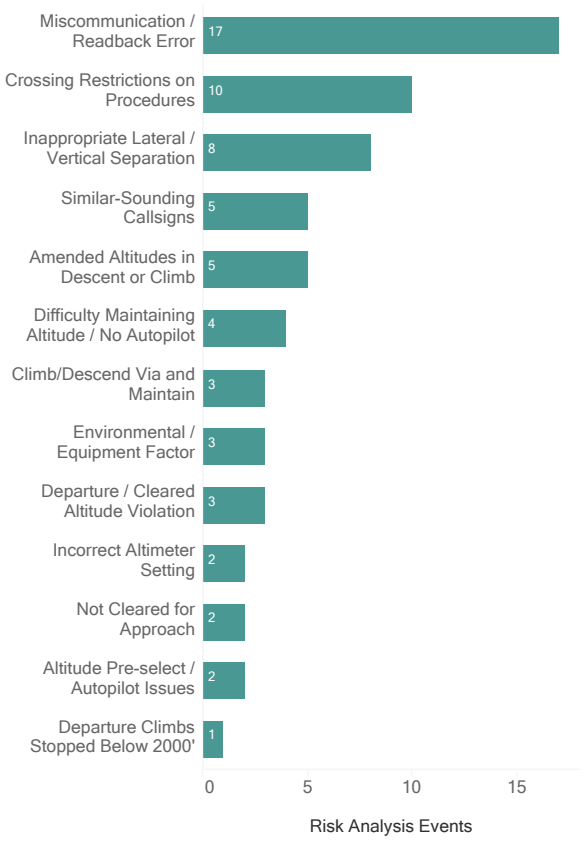


Was communication a factor in the event?

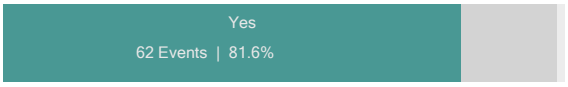
Commercial Aviation | 107 Events

Events by Facility Type

Events with Identified Themes: 76



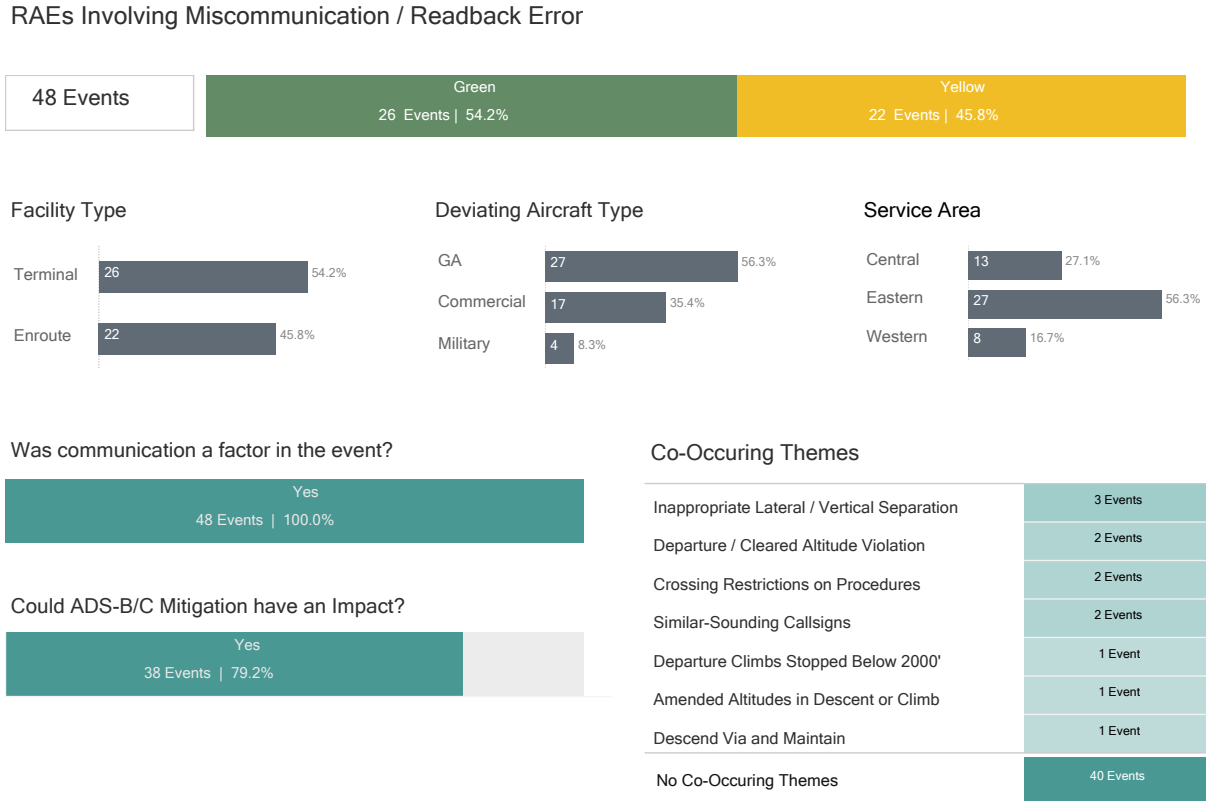
Was communication a factor in the event?



Miscommunication / Readback Error

Theme Description

A loss of separation occurred when the flight crew read back an altitude assignment incorrectly, took the wrong clearance, failed to respond to a clearance, or misinterpreted an instruction.



Explanatory Factors

- Person sending communication (speaking) verbalizes information they did not intend to.
- Person listening to communication (hearing) does not confirm that they heard the correct information or believes that what they heard was correct.
- One part of the communication loop interprets words from the other in an unintended manner (e.g., the listener misinterprets what the speaker is intending).
- Distractions and/or task-load result in an inadequate confirmation that communication took place.

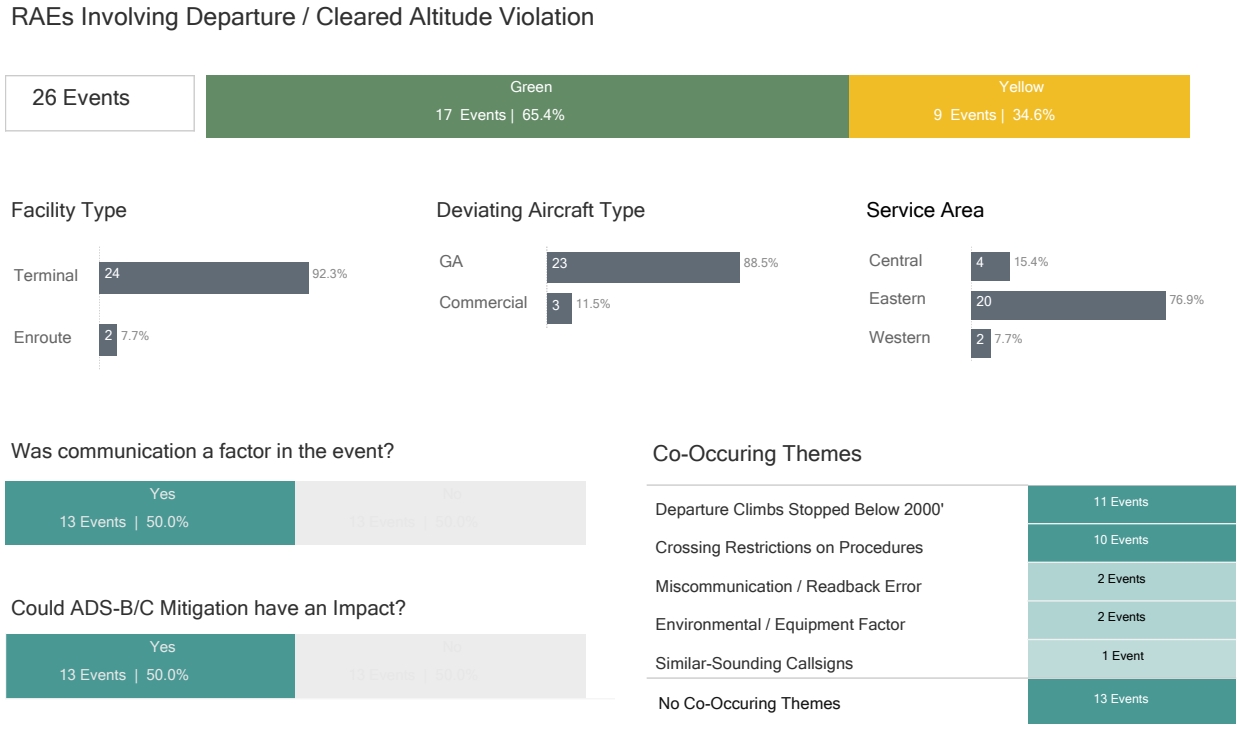
Proposed Mitigations

- **ATC & Pilot**: Emphasize listening skills in training for controllers and flight crew using simulations.
- **ATC & Pilot:** Include common scenarios in initial training and refresher courses to ensure pilots / controllers are sharpening their listening ability over time.
- **ATC:** Develop training scenarios to include demonstration of readback errors to influence the trainee to listen carefully for correct information.
- **ATC:** Include the technique of repeating intended altitude after issuing a traffic call in FAA Order JO 7110.65, *Air Traffic Control*.

Departure / Cleared Altitude Violation

Theme Description

A loss of separation occurred where an aircraft was issued an initial climb altitude by clearance delivery or issued a pre-departure clearance and, after departure, it did not level at its assigned altitude.



Explanatory Factors

- Clearance issued a long time before it is acted on (i.e., clearance delivery clears the pilot to the initial altitude; then, many minutes later, the aircraft departs with no further altitude instruction)
- Confusion regarding the initial altitude that was assigned, either by voice or Pre-Departure Clearance, when information must be recalled later
- Confusion regarding altitudes specified by departure procedure, when issued as part of a clearance

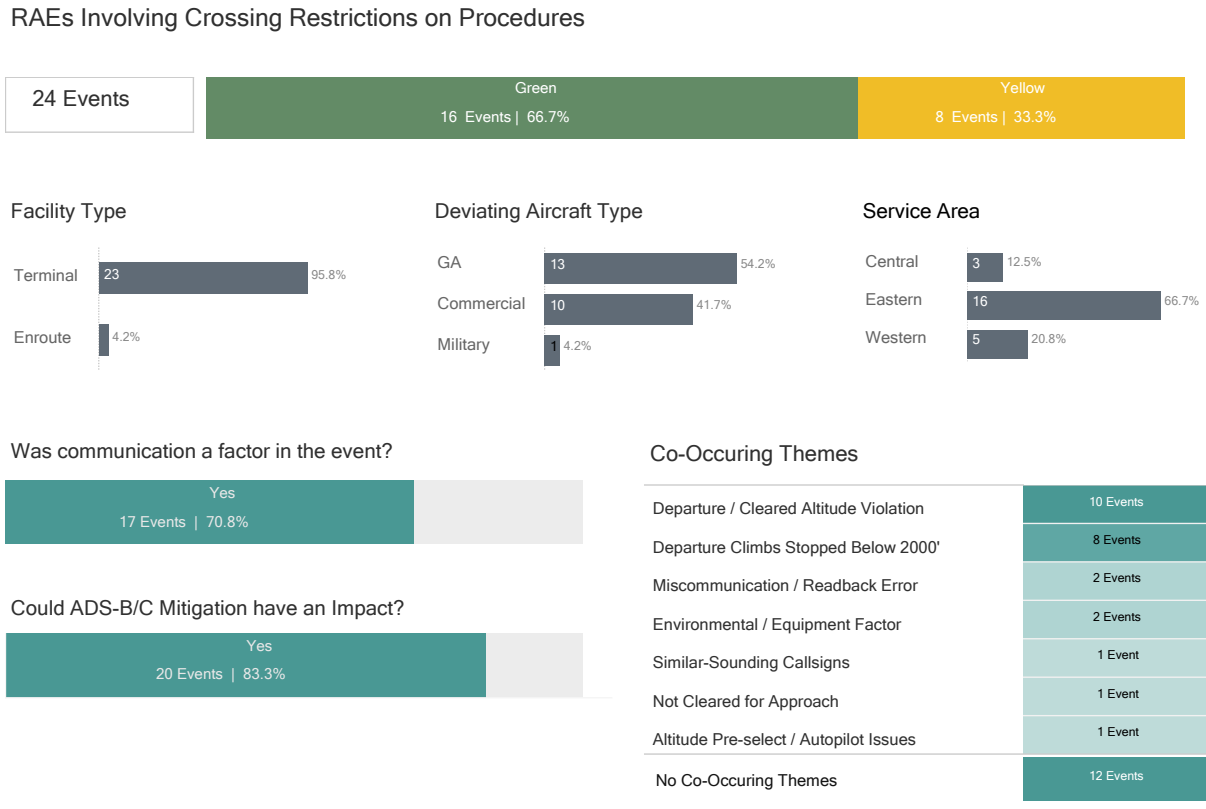
Proposed Mitigations

- **ATC & Pilot:** Technology to send pre-departure clearance information to General Aviation pilots via email or using an application is currently undergoing testing. Providing the data in a way that it is available for future reference may reduce confusion later.
- **ATC:** Encourage the tower to reissue altitude on departure.
- **ATC:** Encourage the Departure controller to re-issue altitude on initial check-in, even if it has not changed.
- **ATC:** Improve the amount of relevant information in Controller–Pilot Data Link Communications (CPDLC) Pre-Departure Clearances; specify initial and top altitudes for each departure runway to pilots as part of the transmitted data.

Crossing Restrictions on Procedures

Theme Description

A loss of separation occurred when an aircraft did not cross a fix / vertical constraint point at the instructed altitude or at an altitude designated by charted procedure.



Explanatory Factors

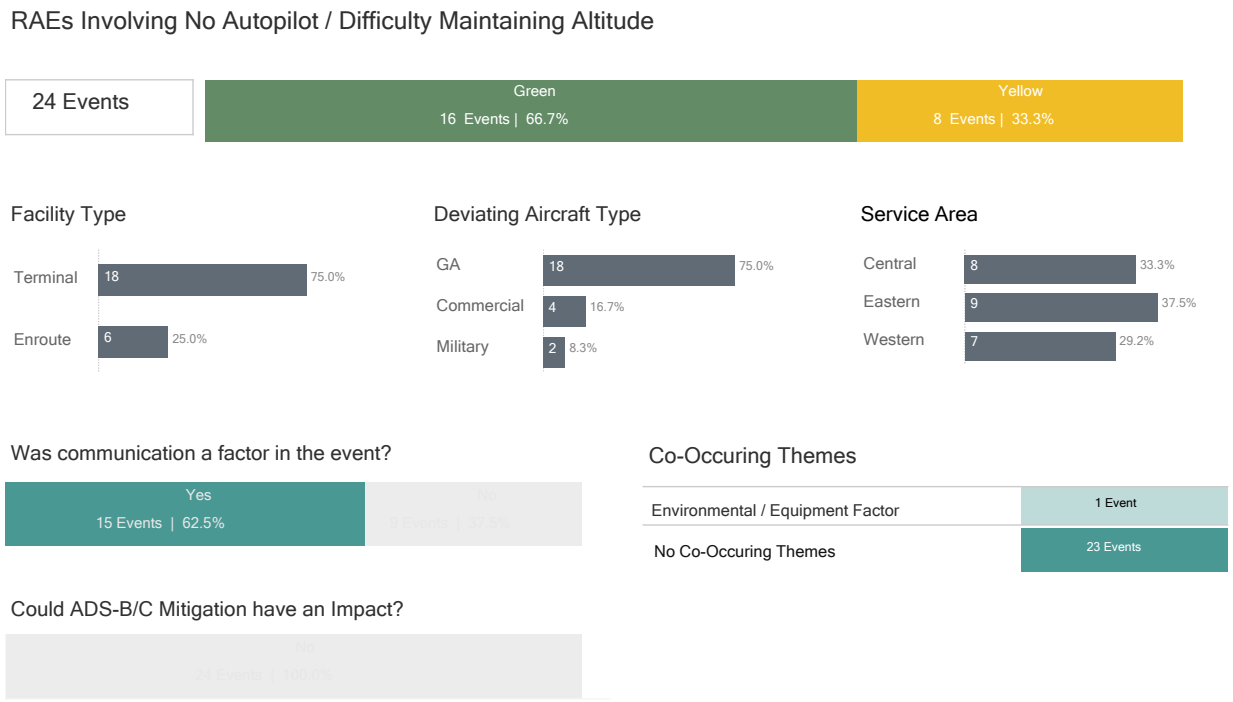
- Controller's manipulation of the aircraft's data block to indicate a descent / climb to an altitude not yet issued.
- Aircraft performance issue related to the constraints on a procedure, typically a Standard Terminal Arrival Route (STAR), which results in aircraft not meeting restrictions.
    - Variation in descent characteristics between aircraft causes some to fly a STAR efficiently, some to add thrust in descent, and others to not possibly meet the crossing restrictions.
    - Variation in characteristics between aircraft of the same model can mean a controller cannot anticipate differences (e.g., split scimitar winglets on some 737s can cause them to descend slower than other 737s without these types of winglets).
- Controller focus on efficiency and reliance on STAR routing without employing vectors.
- Some pilots will make every effort to meet the controller's request instead of reporting that they will be unable to make restrictions due to aircraft performance. There may be a fear among pilots that saying they are unable to meet restrictions will result in them being taken off the STAR and losing their place in line for the airport.

Proposed Mitigations

- **Pilot:** Encourage pilots to discern and communicate when they anticipate being unable to meet an assigned altitude. When controllers give speed / lateral changes during a STAR where the aircraft will be unable meet the constraint, it can be difficult for the pilot to discern if the aircraft will meet the constraint, especially when the clearance is given far out from the constraint. If the pilot says they are unable to make it, then controllers may authorize missing the restriction in speed or altitude or they may provide vectors.
- **Pilot:** Educate pilots to pay close attention to bi-directional STARs where altitude windows are set up to accommodate different direction arrivals (e.g., North arrivals vs. South). Similarly, pilots must input runway expectation into their flight management systems (FMSs) early, so that the computer can calculate the most appropriate descent path for the direction of the STAR they are flying.
- **Pilot:** Train pilots to identify early on and communicate to controllers that they will not be able to meet a STAR constraint.
- **Pilot:** Train pilots to quickly identify if there is an aircraft performance limitation that will prevent them from meeting an assigned constraint.
- **Pilot:** Encourage pilots to take 30-60 seconds to program new constraints into their FMS before informing the controller that they can accept a new restriction, given the time it takes for thrust / attitude changes to take place and for the computer to calculate a new descent path.
- **ATC:** Provide training to controllers to help anticipate the effect of a shortcut on aircraft route, where pilot workload could be increased and the risk of an unstable approach / go-around is increased. Knowing when the shortcut is beneficial to the pilot would be helpful for the controller.
- **ATC:** Train controllers to encourage pilots to report performance limitations and not to chastise pilots or threaten to re-sequence them if a performance limitation is reported.

No Autopilot / Difficulty Maintaining Altitude

A loss of separation occurred involving an aircraft that either reported autopilot difficulty or appeared to have difficulty maintaining altitude for minutes leading up to the event (typically represented by fluctuations in altitude of 200+ feet below and above their assigned altitude).



Explanatory Factors

- Aircraft equipment and equipment failures may require a pilot to manually fly the aircraft.
- Environmental factors such as turbulence, low visibility, aeromedical factors (for the pilot), Instrument Meteorological Conditions, and night time may increase the difficulty of maintaining an assigned altitude.
- A lack of traffic advisory to aircraft may lead to pilots paying less attention to maintaining altitude.
- A traffic advisory may lead to a pilot fixating on searching for traffic, allowing the aircraft to climb or descend as needed.
- Pilot inexperience and / or task load may lead to difficulty maintaining altitude.

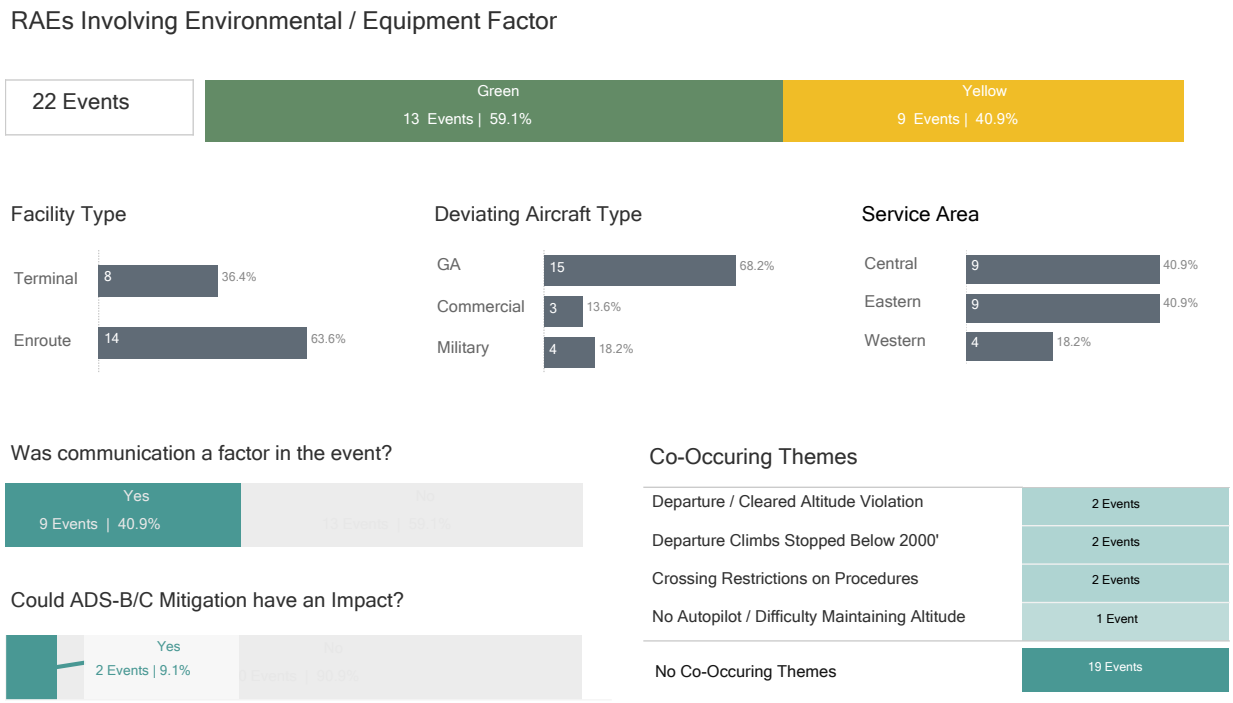
Proposed Mitigations

- **Pilot:** Provide awareness training for pilots that emphasizes the importance of alerting controllers when experiencing difficulty with equipment or environment that may prevent the pilot from conforming to a clearance.
- **ATC:** Include altitude deviation examples as part of traffic advisory training for controllers, to illustrate the need for traffic advisories.
- **ATC:** Conduct controller awareness training that demonstrates how to manage an aircraft that is struggling to maintain altitude. This training should include examples that demonstrate the many factors beyond a pilot not paying attention that could contribute to altitude deviations.

Environmental / Equipment Factor

Theme Description

A loss of separation occurred when an aircraft deviated from its altitude due to weather conditions or as a result of the failure of aircraft equipment such as an engine or flight control system (as reported on frequency).



Explanatory Factors

- Unexpected updrafts, downdrafts, and turbulence can cause altitude deviations with little warning.
- Higher than expected winds aloft can cause aircraft on arrival procedures to have difficulty meeting crossing restrictions, due to increased ground speed.
- Equipment malfunction can cause pilot workload, distraction, or inability for the aircraft to maintain altitude (e.g., failure of autopilot, radio, cockpit lights, engine).
- Weather and equipment issues can be compounded in severity if the pilot does not communicate the need for altitude deviation.
- Aircraft encountering wake turbulence can cause altitude deviation.

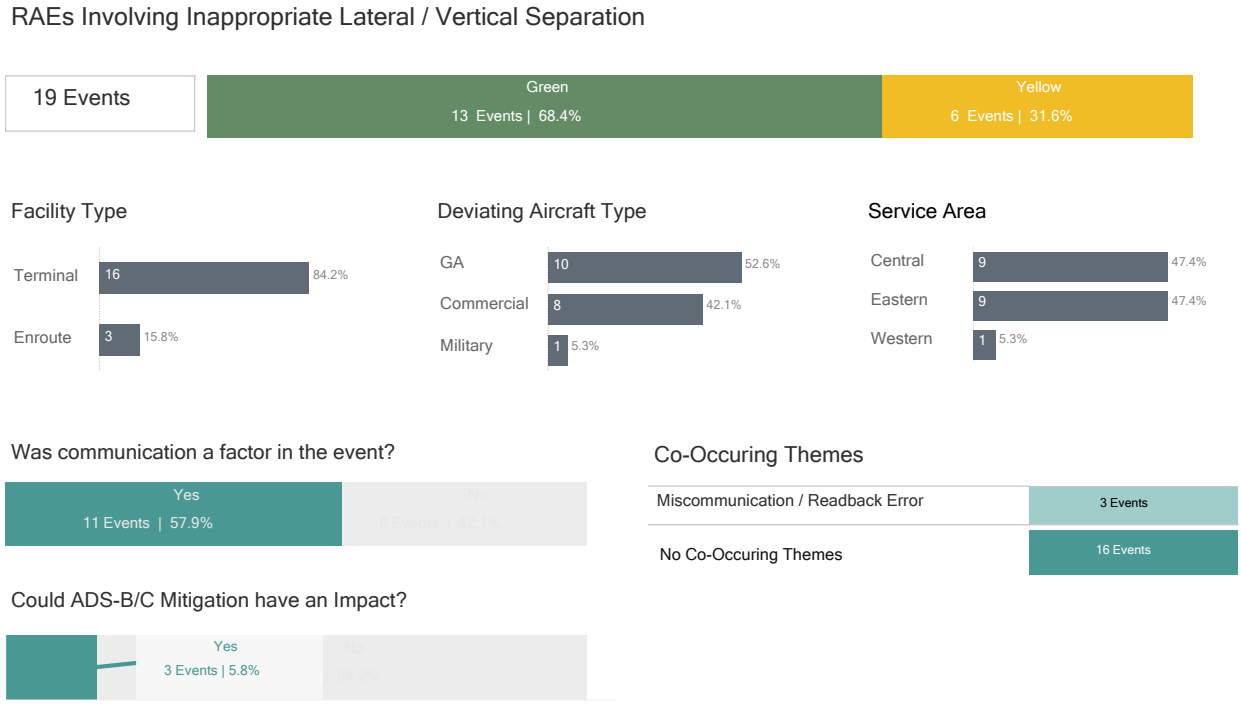
Proposed Mitigations

- **Pilot:** Conduct pilot education to increase awareness of the need for self-reporting of deviations from altitude.
- **ATC:** Conduct a controller awareness campaign regarding the signs of pilot difficulty with aircraft control.
- **ATC:** Ensure that procedures are designed adequately to account for expected wind conditions.

Inappropriate Separation

Theme Description

A loss of separation occurred when a controller vectored / cleared two aircraft to operate with less than the required separation.



Explanatory Factors

- Controller distractions and / or increased task load within the facility (e.g., position relief briefing, changing configurations, traffic volume)
- Lapses in knowledge of facility Standard Operating Procedures or FAA Order JO 7110.65

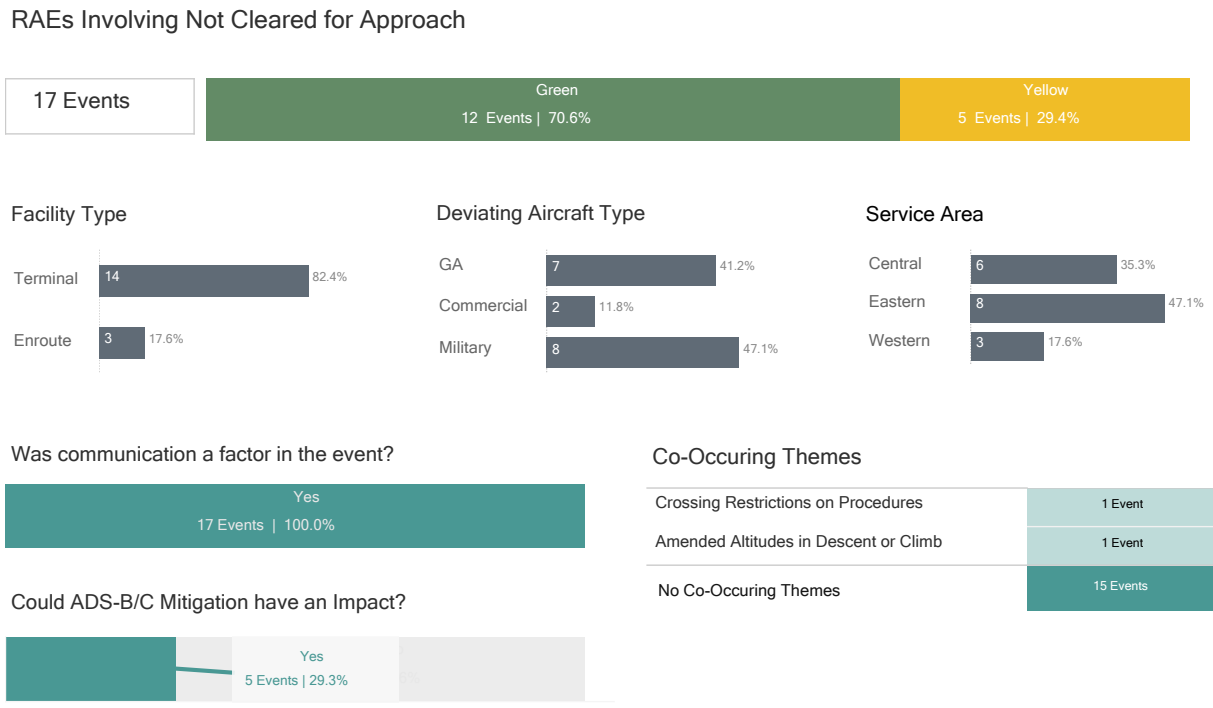
Proposed Mitigations

- **ATC:** Provide facility awareness training regarding most common issues experienced locally.
- **ATC:** Supervisory monitoring of workforce task load.
- **ATC:** Provide awareness training regarding the risk of missed readbacks / memory issues during and following a relief briefing.

Not Cleared for Approach

Theme Description

A loss of separation occurred after an aircraft descended on an approach without authorization. Typically, this occurred either when the aircraft was told to report the airport in sight for a visual approach or when told to join a localizer / final approach course but an approach clearance was not issued.



Explanatory Factors

- This often occurs when the pilot is expecting an altitude assignment, with respect to published procedure, and mistakes a traffic call for the altitude assignment.
- Pilots expecting an approach clearance may interpret a traffic call to be an approach clearance, satisfying their expectation.
- Pilots who report the airport in sight and expect to receive a visual approach clearance sometimes believe they are cleared to descend to the airport before they are issued a visual approach clearance.

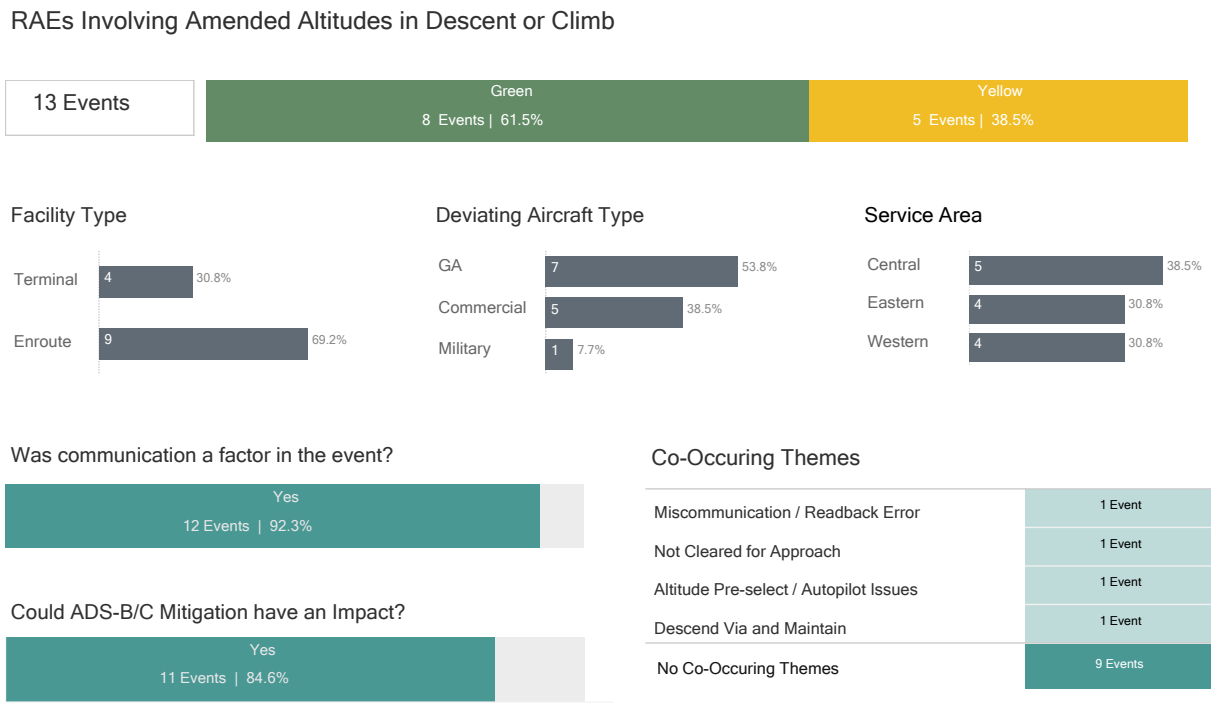
Proposed Mitigations

- **Pilot:** Provide awareness training to pilots to remind them to be wait for visual approach clearance before beginning to descend for the airport.
- **ATC:** For complicated clearances involving multiple instructions: enable, require, or encourage controllers to restate their altitude assignment at the end of the instruction to ensure that the pilot does not descend on the published approach procedure before receiving approach clearance.
- **ATC:** Make approach clearance issues an awareness item at facilities so that controllers might anticipate pilot confusion and ensure that aircraft will remain at the assigned altitude until the controller wants them to descend.

Amended Altitudes in Descent or Climb

Theme Description

A loss of separation occurred when a climb / descent altitude was issued initially and then amended to restrict the climb / descent, but the deviating aircraft climbed / descended to the initially-assigned altitude.



Explanatory Factors

- The fact that an aircraft was initially cleared to an altitude before that altitude was amended leads to the flight crew believing that they were cleared to the original altitude, even if the amended altitude was read back correctly.
    - E.g., An aircraft cruising at Flight Level (FL) 410 is given a descent to FL240 at pilot's discretion. The altitude is then amended to FL350 for crossing traffic, which the pilot reads back. It is likely that the pilot will descend to FL350, then continue the descent to FL240; as soon as the pilot was issued FL240, they began planning for the descent and FL240 became a prominent part of their mental model. The pilot is likely under the false impression that they are still cleared to descend to FL240 at their discretion. The pilot fails to recognize FL350 as a change to the original plan and sees it as an intermediate step.
- Certain data block entries contribute to this type of deviation; if a temporary altitude is not entered, or if that temporary altitude is removed in favor of the initial altitude to affect a handoff to the next sector, it is possible that the controller will not recognize that the aircraft has descended/climbed beyond the amended altitude.
- Miscommunications including hearback / readback errors commonly occur with this type of altitude deviation.

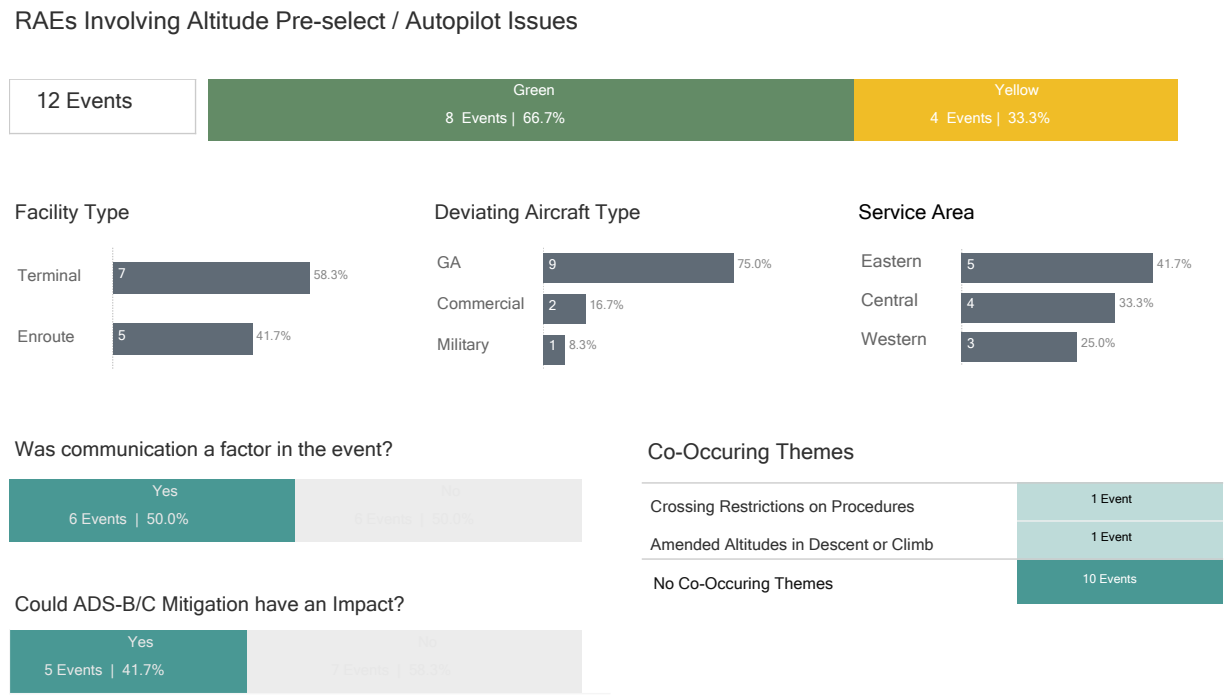
Proposed Mitigations

- **ATC & Pilot:** Reduce risk by improving the amended altitude phraseology so that it emphasizes to pilots when their originally cleared altitude is no longer valid.
- **ATC:** Controllers should use selected FL/ cleared FL technology to verify whether pilots are descending or climbing to the correct altitude.
- **ATC:** Facilities should develop local procedures to ensure that the management of data blocks for handoffs does not prevent a controller from assessing altitude conformance.

Altitude Pre-Select / Autopilot Issues

Theme Description

A loss of separation occurred when the flight crew reported an issue with their autopilot capturing a selected altitude, or when the altitude selector was incorrectly set, resulting in a deviation from the expected climb / descent altitude.



Explanatory Factors

- Distractions in the flight deck environment can lead to pilots missing the automation performing unexpectedly (e.g., not capturing a selected altitude, transitioning to an unexpected mode, disengaging).
- Late changes to altitude assignments or quick level-offs after departure can lead to Visual Navigational Aid (VNAV) automation incorrectly capturing the altitude selection.
- Miscommunication, prospective memory failures, confusion about a procedure, and other human factors can result in the flight crew selecting the incorrect altitude in the pre-select window.

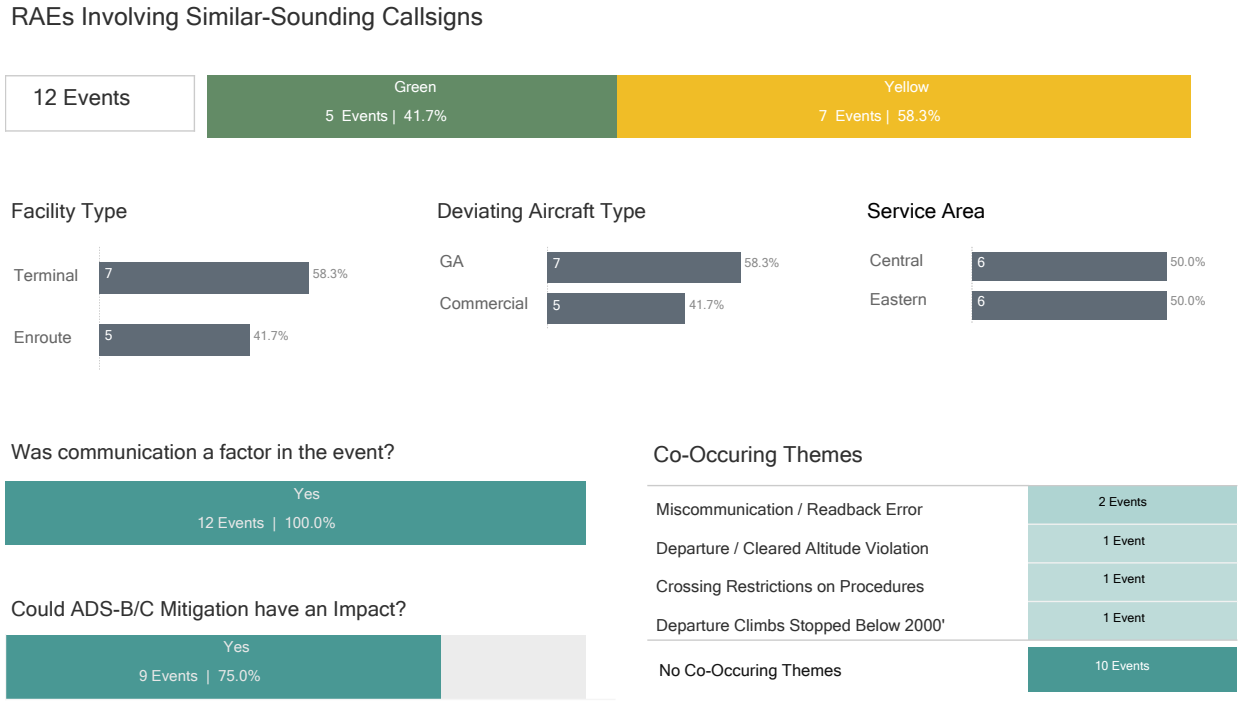
Proposed Mitigations

- **ATC & Pilot:** The agency should evaluate individual operational differences in aircraft types and issue targeted guidance to reduce the risk of automation failure that causes a pilot deviation.
- **ATC & Pilot:** Enable En Route environment CPDLC to allow controllers to pass altitude clearances via data link to aircraft, mitigating the risk of miscommunication.
- **ATC:** Cleared FL / Selected FL data communication would allow verification of the pilot's intent to climb / descend to the cleared altitude.

Similar-Sounding Callsigns

Theme Description

A loss of separation occurred when two aircraft with similar-sounding callsigns were operating on the same frequency.



Explanatory Factors

- Two or more aircraft operating in a sector have similar-sounding callsigns, and one pilot accepts a clearance for the other aircraft.
- Controller phraseology exists to assist pilots in differentiating similar callsigns, but it may not always be employed.

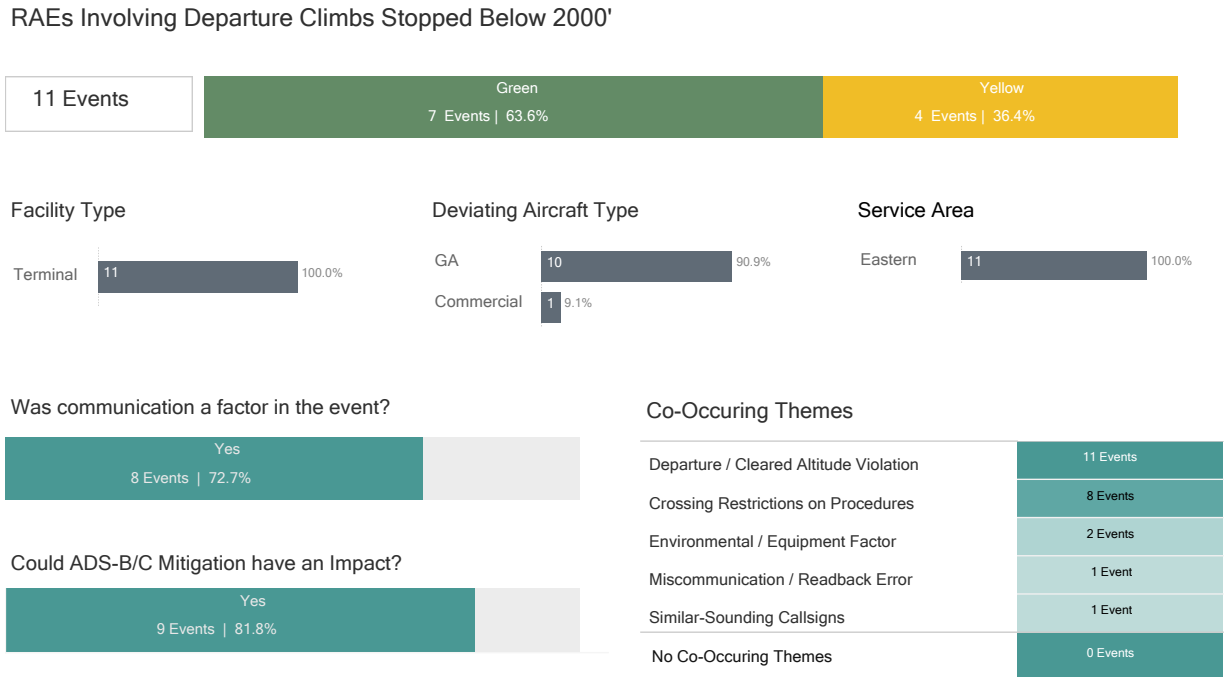
Proposed Mitigations

- **ATC:** Update FAA Order JO 7110.65 to provide additional examples and/or more clear guidance on how to distinguish between similar-sounding aircraft identification. The examples provided only cover notification to the pilots.
- **ATC:** Use phraseology in the similar-sounding callsigns section of FAA Order JO 7110.65 to emphasize all clearances issued to aircraft when the similar-sounding callsign exists in the sector (e.g., use “United 31 United” phrasing for all communications with UAL31 while DAL31 is in the same sector).
- **ATC:** Review mitigations proposed for similar-sounding callsigns in the 2013 Similar Sounding Callsigns Top 5 CAP.

Departure Climbs Stopped Below 2000’

Theme Description

A loss of separation occurred when an aircraft was issued an initial altitude of 2,000 feet AGL or less as its initial climb altitude, and the aircraft was not leveled in time after takeoff.



Explanatory Factors

- There are performance factors that may result in not meeting departure constraints.
    - Some aircraft manufacturers do not recommend the use of VNAV on takeoff, which may result in the aircraft automation commanding the pilot to fly through its departure constraint.
- Improper use of “climb via” phraseology. If a pilot is climbing via a departure procedure that has an intermediate crossing restriction of 1,500’, then 2,000’, and the pilot checks on with departure saying “N12345 climbing to 2,000 feet,” this is misleading and improper. The controller does not know if the pilot plans to level at 1,500’ before climbing to 2,000’. When the pilot checks on, he or she should indicate that they are climbing via the assigned procedure.
- High workload period for both controllers and pilots. It may be especially difficult for a controller to catch improper phraseology (such as “climbing to 2,000 feet” instead of “climbing via the departure procedure”) during high workload periods.
- Prospective Memory (forgetting to accomplish a task after a period of time has passed). Pilots reported issues with remembering to stop their climb when engaged in other tasks. This was highlighted as a primary cause in the SME discussion as well.

Proposed Mitigations

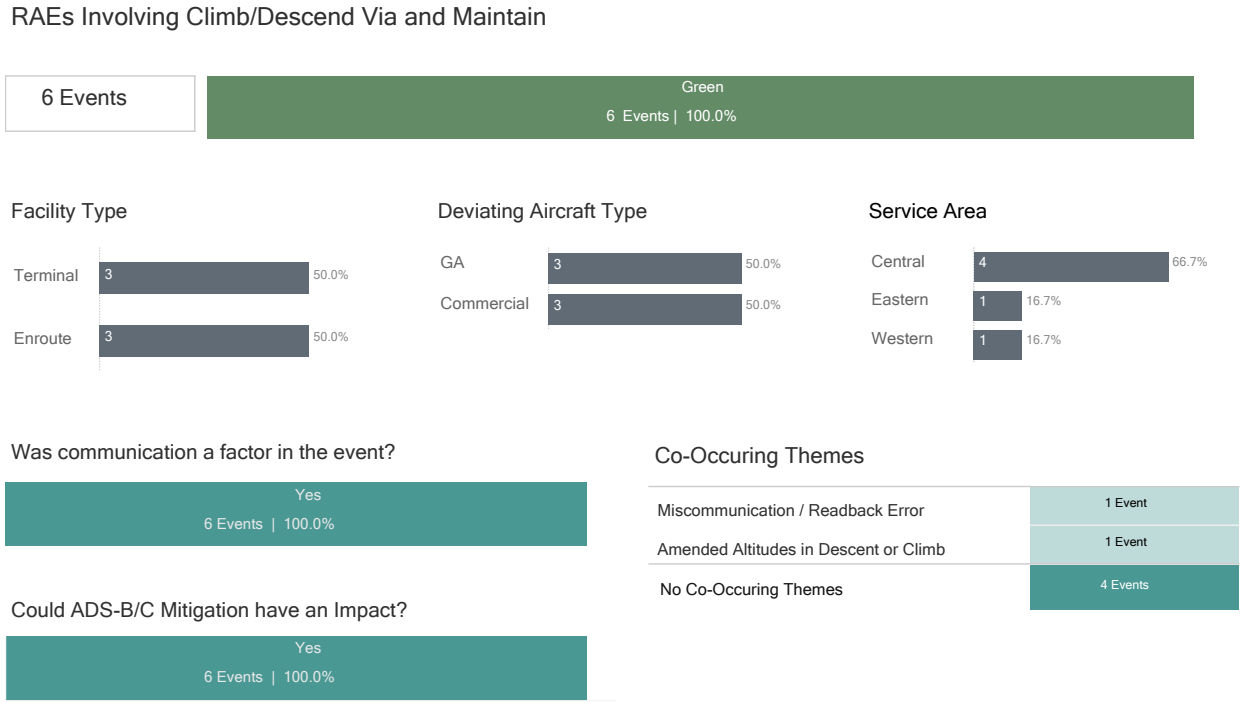
- **Pilot:** Disseminate training to pilots that encourages the use of proper phraseology when flying climb via or descend via procedures.

- **ATC:** Improve the design of instrument procedure charts to explicitly call out potential difficulties or areas of confusion (e.g., Teterboro publication warning of common Standard Instrument Departure (SID) deviations).
- **ATC:** Modify FAA Order JO 7110.65 to allow a controller, when the take-off clearance is issued, to restate the altitude or climb via clearance to the pilot. This could improve pilot comprehension and conformance to phraseology, helping pilots meet altitude crossing restrictions.

Climb / Descend Via and Maintain

Theme Description

A loss of separation occurred after an aircraft was issued a climb via or descend via clearance and it did not comply with that instruction.



Explanatory Factors

- A controller's use of improper phraseology; specifically, "Climb / Descend via **except** maintain # feet" or, less frequently, "Climb / Descend via **and** maintain # feet"
- A pilot's use of improper phraseology; specifically, "XYZ123 climbing to 2,000" instead of "Climbing via the XYZ procedure"
- The experience level of the controller could contribute to misapplied or confusing climb via or descend via clearances.
- Dissemination of information regarding the climb via / descend via procedures to pilots, especially those who were experienced with old procedures.
    - In 2014, when the descend via / climb via phraseology was introduced, the ATO issued controller and pilot training. The package produced for pilots came from the National Business Aviation Association (NBAA), and the package for controllers was issued 60 days prior. The Air Line Pilots Association, International (ALPA) received links to videos and a bulletin, but the procedures may not have been trained as well as they could have been to all operators. The timing of the rollout and the differences in information provided to different stakeholders may have contributed to confusion. In addition, the transition was challenging linguistically, especially the subtle difference between "and" and "except" when issuing a "descend via except maintain" clearance.

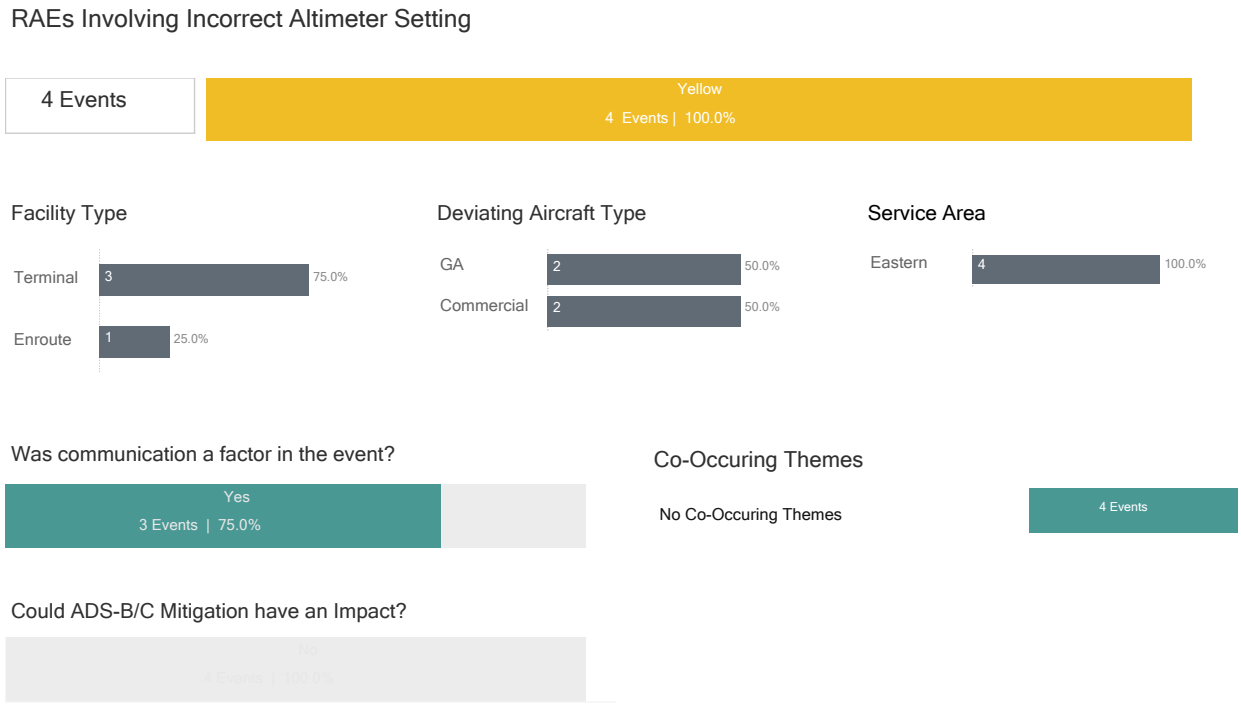
Proposed Mitigations

- **Pilot:** Issue a letter to airmen that is drafted as a method to address the phraseology concern with saying “Climbing via the SID,” which leaves ambiguity about the altitude an aircraft is climbing to.
- **ATC:** Develop improved phraseology training (the best case being person-to-person classroom training) to address confusion of “descend via and maintain” with “descend via except maintain.”
- **ATC:** The air traffic controller queries the pilot to ensure that they are climbing / descending via the assigned procedure.
- **ATC:** Ensure FAA-approved phraseology is aligned with International Civil Aviation Organization (ICAO) phraseology for climb / descend via to reduce confusion.
- **ATC:** Issue altitude clearances separately from other clearances to reduce clearance complexity. Once the pilot has read back the altitude assignment, continue the second instruction separately.

Incorrect Altimeter Setting

Theme Description

A loss of separation occurred when an aircraft was operating with the altimeter calibration set incorrectly.



Explanatory Factors

- If the radar controller does not properly radar-identify an aircraft that has departed, it is possible for the incorrect altimeter setting to cause an incorrect level-off on initial climb-out.
- If an altimeter setting is read by a controller but not properly read back by the pilot, it is possible that the incorrect value is put into the pilot's altimeter.
- If an aircraft's mode C transponder is not functioning properly, it may display the incorrect altitude to the controller.

Proposed Mitigations

- **ATC:** Emphasize to facilities the importance of conducting mode C checks on initial check-in.
- **ATC:** Employ data communications technology to conduct mode C checks in the En Route environment automatically and / or use this technology to conduct transfer of control and altitude intent data simultaneously.

Insufficient Data

Theme Description

A loss of separation occurred between two aircraft, and the cause of the deviation could not be explained using the data that was available at the time. Of 200 analyzed events, 24% did not provide sufficient explanation in radar / voice replay to indicate why the altitude deviation occurred. A review of Confidential Information Share Program reports indicated that most of the causes were consistent with the themes identified here.

Explanatory Factors

- The nature of this theme makes identifying specific explanatory factors difficult.
- It is likely that causal factors identified in other themes apply to events in this category.

Next Steps

- Without a deeper understanding of the reason for each of these deviations, identifying mitigations would be challenging.
- Studying sources of data that could fill in the gaps (e.g., Flight Operational Quality Assurance data, Aviation Safety Information Analysis and Sharing study) would be beneficial.

Focus Group Discussion and Review of Data

The focus group included two rounds of SME discussion questions designed to elicit discussion of potential causes and mitigations for altitude compliance issues. The first series of questions was designed to facilitate an open discussion on altitude compliance issues independent of the completed data analysis. After completion of the data analysis review, a second round of questions was discussed to identify any relevant issues beyond those discussed in the data analysis. The insights provided by the SMEs during both rounds of questions were used to provide additional details for the description of analysis theme areas. The list of focus group participants is provided in Appendix A, and the discussion questions are listed in Appendix B.

The SME discussions covered examples of altitude deviations that the SMEs have either experienced or witnessed. This discussion described how the deviations were handled, addressed with trainings, or could be prevented in the future. A pilot SME noted three common causes of altitude deviations: similar-sounding call signs, controllers failing to recognize when a pilot does not provide a readback, and last minute changes to STARs.

In addition to the causal factors addressed in the following section, the SMEs identified several overarching areas of interest associated with altitude compliance.

Overarching Areas of Interest

Prospective Memory: Participants described memory techniques that pilots use to ensure they would not forget to execute a clearance after a long delay (e.g., a pilot discretion descent). One discussion centered around the technique of descending early to avoid forgetting, setting a timer to remind the crew to descend, inputting a reminder message into an FMS scratchpad, or, to avoid distraction, stopping conversation until the descent had begun. However, controllers noted that early descents could cause a compression issue if the aircraft slows earlier than other aircraft.

> *Conclusion*: Remembering to execute a future action after a period of time can be challenging for both controllers and pilots. Are there lessons to be learned from the flight deck that could benefit controllers in addressing prospective memory challenges?

Altitude Compliance Standard Discussion: Pilots indicated that there may be some confusion over the tolerance for variation allowed for vertical crossing restrictions. Some aircraft will tolerate ≈100 feet above or below an altitude constraint. Similarly, participants considered the question of when to report an altitude deviation. If the pilot crosses a fix 100 feet higher or lower (FAA Airline Transport Pilot Standard), have they deviated from instructions? How large of a deviation (how many feet) necessitates the pilot reporting the deviation to Air Traffic Control?

> *Conclusion*: This understanding helps pilots to know when to intervene and/or inform Air Traffic Control that they will not make an altitude restriction.

Aircraft variation: A discussion regarding autopilot performance revealed that some aircraft will (in VNAV descent mode) allow the aircraft to fly 100 feet above or below an altitude constraint, with all constraints looking achievable. In this case, the pilot decides to intervene, which creates an increase in workload for the pilot. The pilot's impression is that descent planning software allows for greater variation from altitudes than they would like.

Conclusion: This relates to the tolerance associated with the altitude compliance standard. If pilots are unsure about the level of tolerance, they could intervene unnecessarily, increasing pilot workload and potentially increasing risk. Conversely, they could fail to intervene, allowing an altitude deviation to occur.

Procedure design and development: Several discussions focused on the impact of procedure design on the risk of altitude non-compliance. Participants suggested that when procedures are designed for typical weather conditions, it can be challenging for aircraft to meet crossing restrictions when winds or temperatures are abnormally unfavorable.

Participants also described how the performance and navigation sections of airplane flight manuals are sometimes written from such an expert perspective that novice pilots have difficulty relating to the information. These participants reported that their strategy for learning advanced navigation techniques was to rely on the experience of the captain initially, gain experience of their own, and then re-read the manual sections once they had flown the aircraft.

Conclusion: Procedure design plays a role in mitigating the risk of altitude deviation by ensuring that reasonable tolerance is built in to allow for environmental variability. Government publications and the industry should both be mindful of the complexity of new types of procedures and adequately describe them to users to ensure a common understanding.

Shared understanding: Pilots and controllers should understand each other's domain. Pilots should have opportunities to tour facilities and participate in learning sessions with controllers in their local area to better understand what is expected of them and how to help Air Traffic Control. Similarly, controllers should have the opportunity to fly on familiarization flights. One participant recommended that these flights be required twice per year, to ensure controllers understand pilot workload. A training curriculum focused on teaching aircraft characteristics, flight deck familiarization, simulator training, and familiarization training is likely to increase controller awareness of pilot challenges.

Conclusion: This was a recurrent topic of discussion and touched many of the themes. Pilots and controllers can best avoid altitude deviations by better understanding the operating conditions and constraints of the other person.

Common Causal Factors

During the focus group, several causal factors that could apply to all themes in some way were discussed.

- If the controller was undergoing on-the-job training, it is possible that the training environment could lead to distraction, or the recovery from a deviation could be impacted by a trainer stepping in or providing guidance.
- If a controller issues traffic to an aircraft and includes the altitude (especially if the aircraft is already descending / climbing) the pilot may mistake the traffic altitude for a new altitude assignment and descend / climb to that incorrect altitude instead.
- If a pilot requests a new altitude and the controller issues an altitude other than what was requested (e.g., the pilot requests FL350 and the controller issues FL330), the pilot may mistakenly climb to the requested altitude.
- If a compound altitude clearance includes other elements such as traffic, a heading to fly, or an approach to expect, the complexity of the clearance and the presence of other numbers may lead to pilot confusion regarding the issued altitude.

- Pilots may respond to altitude instructions with “wilco” or “roger.” This response is ambiguous and does not confirm accurate pilot receipt of the instruction. The Aeronautical Information Manual recommends that pilots read back the full clearance.

Common Mitigations:

- For complex clearances and traffic calls, controllers sometimes reiterate the altitude assignment for the aircraft (e.g., “Traffic 12-o’clock and 5 miles, westbound, a 737 at 12,000; maintain 11,000”).
- Clearance complexity awareness is made into a facility interest item, including pre-duty briefing information, to help reduce confusion for pilots.
- The use of selected FL / cleared FL technology (allowing controllers to confirm what a pilot has selected on the flight deck for altitude) may reduce risk for many of the identified themes, but this is dependent on aircraft equipage and operation.
- The use of data communications to send altitude instructions to pilots may reduce the likelihood of miscommunication and other verbal errors, but it may introduce other unknowns into the system.

Nav Canada produced a series of videos that describe workload in the cockpit and how it can contribute to vertical track deviation; dissemination of these resources could provide a benefit.

Mitigations Summary

Provided below is a summary of mitigation strategies, developed based on data reviewed and input from the focus group. These mitigation strategies represent potential opportunities to direct efforts at the identified causal factors involved in these events. This list is intended to be an informed starting point, and it is not necessarily comprehensive.

Emphasize restating altitude assignments at critical times in flight

There are a number of instances in which having the controller (workload allowing) restate the altitude assignment has the potential to improve altitude compliance. For complex clearances and traffic calls, controllers sometimes reiterate the altitude assignment for the aircraft (e.g., “Traffic 12-o’clock and 5 miles, westbound, a 737 at 12,000; maintain 11,000”). For complicated clearances involving multiple instructions, restating altitude assignment at the end of the instruction may help ensure that the pilot does not descend on the published approach procedure before receiving an approach clearance. Tower controllers reissuing altitude on departure and initial check-in may additionally provide benefit.

Develop training / awareness materials describing the execution and monitoring of complex arrival and departure procedures

Increased awareness or training could improve the execution and monitoring of complex arrival and departure procedures. Train controllers on the impact of clearance complexity. Making clearance complexity awareness a facility interest item and including pre-duty briefing information may help reduce confusion for pilots. Improve the design of instrument procedure charts to explicitly call out potential difficulties or areas of confusion (e.g., Teterboro publication warning of common SID deviations).

Deploy automation enhancements to equip controllers to prevent and identify altitude compliance issues

During the discussions, four main types of automation or engineering solutions were identified. Those include presentation of the selected FL to controllers, providing a form of data communication between

GA pilots and controllers, enhancing the information and use of CPDLC, and providing automatic mode-C checks. The data on the number and types of events where these automation solutions could improve altitude compliance will be provided to the organizations responsible for implementing the automation.

Update phraseology standards and examples in FAA Order JO 7110.65 to address common causes of altitude compliance

Further evaluation is warranted on whether to update JO 7110.65 to provide additional examples and/or guidance on how to distinguish between similar sounding aircraft identification. The examples provided only cover notification to the pilots. Consider increasing alignment of FAA-approved phraseology with ICAO phraseology for climb / descend via, to reduce confusion. Assess risk reduction resulting from changing the amended altitude phraseology to emphasize to pilots when their originally-cleared altitude is no longer valid.

Procedure Design and Training

There were a number of discussions on procedure design and training. As a product of the focus group, the focus group can provide lessons learned and data that point to aspects of procedure design that contribute to altitude deviations. Those include the variety of aircraft types, weather conditions, and pilot skill and experience. The focus group identified issues with the training provided on proper climb / descend via phraseology. Specifically, there were issues with controllers and pilots differentiating between “except maintain” and “and maintain.”

Emphasize unexpected or potentially confusing altitude assignments

Emphasize when unexpected or potentially confusing altitude assignments that are known to contribute to altitude non-compliance are present. Identified factors that may contribute to confusion include clearances with similar-sounding callsigns, altitude changes, or atypical altitude assignments. The confusion may result from confirmation bias whereby the controller or pilot hears what they expected to hear, missing elements of the actual message. Design training for both controllers and pilots on identifying and combatting confirmation bias. For example, a facility could create an awareness item concerning potential pilot confusion around the proper altitude when climbing via an SID.

Develop training / awareness materials that describe aircraft performance constraints / ability to meet procedure requirements

The focus group identified mitigations training opportunities to increase pilot and controller awareness of the ability of different types of aircraft to meet different types of procedures. While pilots and controllers will not be expected to learn all the different types of aircraft or the nuances of different FMSs, having exposure to the range of operating characteristics and having awareness of new aircraft performance characteristics may be helpful. Training may cover topics such as new aircraft, updates to aircraft systems, or the performance envelope for different types of automation. This information could be delivered in a variety of training or awareness campaign venues, including academy training, recurrent training, webinars, and safety publications. There are some existing videos that could be useful in conveying this information. Nav Canada produced a series of videos that describe workload in the cockpit and how it can contribute to vertical track deviation; dissemination of these resources could provide a benefit. Information on the performance envelope of procedures and a range of weather and aircraft types could be enhanced during initial training. SMEs recommended having controllers review examples of altitude compliance events during this training.

Mitigation–Theme Mapping

Each identified mitigation category was mapped to altitude compliance themes based on SME input. The mapping is intended to show overlapping impacts of themes across multiple themes. The following table lists the themes and the mitigation categories that map to those themes.

ATC Mitigation Mapping

		Mitigation Categories						
Causal Factor Themes	**% Events**	Restating Altitude Assignments	Execution of Complex Procedure Training	ATC Automation Enhancements	Phraseology Standards & Examples	Procedure Design Guidance	Confusing Altitude Assignment Training	Aircraft Performance Constraints Training
Miscommunication / Readback Error	24.0%		♦	♦	♦	♦	♦	♦
Departure / Cleared Altitude Violation	13.0%	♦	♦	♦			♦	
No Autopilot / Difficulty Maintaining Altitude	12.0%					♦		♦
Crossing Restrictions on Procedures	12.0%	♦	♦	♦		♦		♦
Environmental / Equipment Factor	11.0%			♦		♦		♦
Inappropriate Lateral / Vertical Separation	9.5%		♦					
Not Cleared for Approach	8.5%	♦	♦	♦	♦		♦	
Amended Altitudes in Descent or Climb	6.5%	♦	♦	♦	♦		♦	♦
Altitude Pre-Select / Autopilot Issues	6.0%							♦
Similar-Sounding Callsigns	6.0%			♦	♦		♦	
Departure Climbs Stopped Below 2000'	5.5%	♦	♦	♦		♦		♦
Climb / Descend Via and Maintain	3.0%		♦	♦	♦		♦	♦
Incorrect Altimeter Setting	2.0%			♦				

**Percentages do not add to 100% as each event may involve more than one theme*

Pilot Mitigation Mapping

		Mitigation Categories							
Causal Factor Themes	**% Events**	Pilot Readback Training	Prospective Memory	STAR Education	Automation Use Best Practices	Communicate Difficulty Executing Clearance	Not Cleared for Approach Training	Phraseology Education	Technology Enhancements
Miscommunication / Readback Error	24.0%	♦							♦
Departure / Cleared Altitude Violation	13.0%				♦	♦			♦
No Autopilot / Difficulty Maintaining Altitude	12.0%					♦			
Crossing Restrictions on Procedures	12.0%			♦	♦	♦			
Environmental / Equipment Factor	11.0%					♦			
Inappropriate Lateral / Vertical Separation	9.5%								
Not Cleared for Approach	8.5%	♦					♦		
Amended Altitudes in Descent or Climb	6.5%	♦							
Altitude Pre-Select / Autopilot Issues	6.0%		♦		♦				
Similar-Sounding Callsigns	6.0%	♦							
Departure Climbs Stopped Below 2000'	5.5%		♦					♦	♦
Climb / Descend Via and Maintain	3.0%							♦	
Incorrect Altimeter Setting	2.0%				♦				

Conclusions

The focus group used SME discussions and a review of events that exemplified causal factor themes to obtain a comprehensive understanding of the causal factors driving altitude deviations. The group concluded that the themes and discussions described below cover the majority of causal factors. The group reviewed existing mitigations, identified additional mitigations, and mapped mitigations to causal factors that could be impacted by each mitigation. During the course of the assessment, several considerations for future work were also identified.

Communication Training

Of the analyzed events, 73% of events involved some type of communication issue. The current analysis did not provide the opportunity to fully investigate communication issues beyond the identified themes. Future work could fully classify the communication issues present and develop potential mitigations targeting the specific communication issues. This could include communications training, including the risk of missed readbacks, memory issues during / following a relief briefing, or the development of training scenarios that demonstrate the influence of readback errors on performance.

Distribution of Mitigation Materials

Participants discussed the available methods that could be employed to disseminate information to stakeholders. These should be considered as distribution mechanisms for developed materials. The recommended distribution methods include:

- FAA Air Traffic Bulletins and National Air Traffic Controllers Association (NATCA) Bulletins
- Air Traffic Safety Action Program Bulletins tied to the specific types of events under review
- Communicating for Safety Annual Convention of NATCA in Las Vegas
- Review of / insertion into FAA Academy curriculum
- Facility incentives for controllers who catch readback errors or prevent losses of separation in some other measurable way
- Expanding guidance in the Aeronautical Information Manual
- Collaboration with the FAA Safety Team to publish guidance in a medium similar to EUROCONTROL's Aircraft Collison Avoidance System Bulletin or the National Aeronautics and Space Administration's Aviation Safety Reporting System Callback

Future Analysis Propositions

In addition to the findings of the altitude compliance study, several additional questions and comments were identified by participants. These represent opportunities for additional and related analysis:

- Is there a particular aircraft type that might be more prone to altitude compliance issues?
- Analyze aircraft type, size, engine, navigational capabilities, etc. to help develop mitigations that are targeted for specific types of operators.
- Assess crossing restrictions on procedures, including a comparison of of climb vs descent events.
- New phraseology and experience: could a new person grasp "descend via" and "maintain" more easily than an experienced controller?
- How do weather conditions affect possibly disoriented aircraft?
- During inappropriate separation, what was the root cause?
    - Variance of FMS / fleet mix
    - Airspace design
    - Misapplication of separation standards by controllers

Appendix A: Focus Group Attendees

Provided below is a list of participants from the altitude compliance focus group.

Name	Affiliation	Email
Mike Blake	NATCA	mblake@natca.net
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Chandra Smith	AT	Chandra.Smith@faa.gov
Scott Dehart	A4A	Scott.Dehart@wnco.com

Appendix B: Focus Group Questions

Focus Group Discussion Questions – Pre-Data Review

- Is there an instance you can talk about from your own experiences where there was altitude non-compliance?
  - How did you did you handle it? What did you pay attention to? What were the decision points?
  - Why did you handle it the way you did?
  - What other courses of action were considered or available?
  - What would you do differently?
- What is difficult about maintaining / ensuring altitude compliance?
- How is a controller-in-training or student pilot trained to ensure altitude compliance?
- What types of errors do controller / pilot trainees typically make?

Focus Group Discussion Questions – Post-Data Review

- What did you observe in the incidents we discussed?
  - If this were your trainee, what would you tell them?
  - Did these remind you of any previous incidents you were involved in?
- Are there any other examples of a potential cause of altitude non-compliance that we have not talked about yet?
- Do we have a comprehensive understanding of altitude non-compliance?