# Crossing-Restriction Altitude Deviations on SIDs and STARs

*by*
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## Background and Motivation

Throughout 21 years of operation by the Aviation Safety Reporting System (ASRS), approximately 35 percent of all incidents reported to the ASRS have been altitude deviations. Previous ASRS reviews of altitude errors have identified multiple contributing factors for these events. A 1982 ASRS study, *Probability Distributions of Altitude Deviations*, found that altitude deviations reported to ASRS were exponentially distributed with a mean of 1080 feet, and that deviations from ATC-assigned altitudes were equally likely to occur above or below the assigned altitude.[1]

More recently, ASRS analysts have noted that approximately 15 to 20 percent of the altitude deviations reported to ASRS involve crossing-restriction errors on Standard Instrument Departure's (SIDs) and Standard Terminal Arrival Routes (STARs). SIDs and STARs are published instrument routings whose primary purpose is to simplify ATC's clearance delivery procedures. They are commonly established at airports with high traffic volume, and two or more major airports in close geographic proximity.

The altitude **crossing restrictions** associated with SIDs and STARs may be published on navigation charts or assigned by ATC. They exist for two primary purposes, 1) to provide vertical separation from traffic on different routings that cross the same fix, and 2) to vertically contain traffic within a given ATC controller's sector in cases where other sectors within the same facility, or sectors in another facility, are layered above and below. ATC-assigned crossing restrictions (as opposed to published crossing altitudes) may be temporary requirements imposed to meet changing operational conditions, including facilitating traffic hand-offs to another sector. Pilot compliance with SID and STAR altitude assignments is important, for if a controller permits traffic penetration of another sector either laterally or vertically without prior coordination and approval from the controller in that sector, an operational deviation results.

No previous ASRS review of SID and STAR-related altitude deviations has been conducted. Thus we undertook this research to determine the causes and contributors to altitude deviations that occur during SID and STAR procedures, and to compare the results of this analysis with selected findings of the 1982 ASRS study.

## Objectives and Scope

### Objectives

This research had the following objectives:

1. To categorize the types (i.e., undershoot or overshoot) and frequency of crossing restriction altitude deviations;
2. To determine the types of human performance errors that contribute to crossing restriction altitude deviations;
3. To determine how, and by whom, these deviations are detected and corrected;
4. To compare the number of deviations for traditional versus glass cockpit technology aircraft.

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[1] Ralph E. Thomas and Loren J. Rosenthal, *Probability Distributions of Altitude Deviations* (NASA Contractor Report 166339), Ames Research Center: Moffett Field, California, p. 32.

NASA ASRS (Pub. 58)

## Scope

Reports selected for the sutyd were required to meet the following incident criteria:

1. Involve a Part 121 or 135 aircraft in scheduled or non-scheduled air carrier operations;
2. Involve an aircraft conducting Standard Instrument Departure (SID) or Standard Terminal Arrival Route (STAR) procedures under Instrument Rules;
3. Involve an aircraft failing to level at or cross a specified crossing restriction altitude as instructed by ATC or as required by a published procedure.

# Approach

## Data Set

The ASRS data base was searched for records meeting the selection criteria. Two hundred full-form records that complied with the scoping requirements, from December 1988 through February, 1996, were extracted and reviewed. Of these, 172 met the criteria for inclusion in this study.

## Research Method

A coding form of five pages was developed to extract pertinent information from the data set. The coding instrument examined the following categories of questions:

1. When and where was the deviation detected?
2. Was the error detected by ATC or the flight crew?
3. What was the magnitude of the deviation?
4. What was the degree of subjective risk of the deviation?
5. Were charting issues involved?
6. Were ATC procedural issues involved?
7. Did flight crew workload contribute or cause the altitude deviation?

Development of the coding instrument required several iterations. Trial coding was conducted to validate and refine the coding form. Some questions allowed multiple responses.

# Findings and Discussion

## General Information

Of the 172 air carrier reports in the study, 159 involved turbojet aircraft and 13 involved turboprop aircraft. We found no evidence that the day of the week, time of day, aircraft type or configuration or weather factors played a role in these altitude deviations. Similarly, it did not intuitively appear that crossing-restriction altitude deviations were more likely to occur at any given ATC facility.

## Event Description

### Event Detection

Altitude crossing-restriction errors were detected by ATC and the flight crew in approximately equal proportions: 53 percent were detected by flight crews, and 41 percent by ATC controllers.

### ATC-Assigned Crossing Restriction *versus* a Charted Requirement

Where the required crossing-restriction altitude was assigned by ATC, the flight failed to meet a crossing restriction on a SID or a STAR in 66 percent of events, while in 34 percent of events the crossing restriction was a charted requirement. The preponderance of incidents in which ATC assigned the crossing-restriction altitude may be attributable to diminished time for climb or descent planning and to breakdowns of communications.

**Deviation on STARs *versus* SIDs**

Seventy-seven percent of altitude deviation events in the data set occurred on STARs (in descent), while 23 percent occurred on SIDs (climb). One possible explanation for this variation may be workload: in the descent (STAR) phase of flight, flight crews have a large number of tasks and issues to contend with, including obtaining ATIS, adjusting or planning for changing weather conditions, conducting company communications, confirming gate assignments, alerting and communicating with cabin crew, planning for terminal procedures and runway configurations, traffic watch, configuring the aircraft, and more. In contrast, the climb (SID) phase of flight typically has a lower workload, as pilots do not yet need to be concerned with arrival prepations.

It is also possible that on STARs there is greater ambiguity about ATC expectations, that is, *when* or *where* ATC expects the flight to initiate descent.

**Type of Deviation**

Seventy-five percent of events were altitude undershoots (failure to reach the assigned altitude–usually on descent). This indicates that flight crews were late in planning or execution of the procedure.

**Point of Detection**

In over half of all events in the data set (51 percent), the error was detected before reaching the required or specified altitude. In 28 percent of events, the error was discovered at the required or specified crossing-restriction altitude. In 17 percent of events the error was discovered after passing the required altitude.

In those events where the error was discovered at or before the required crossing altitude, climb or descent rates may have been sufficiently high to preclude recovery before the deviation occurred.

**Magnitude of Deviation**

***Point of Detection:*** The magnitude of the altitude deviation at the point of detection averaged 2,400 feet, with a median of 1,500 feet

***Point of Maximum Excursion:*** The altitude deviation magnitudes at the point of maximum excursion were examined using methods employed by the 1982 ASRS study, and were found to be exponentially distributed, with a mean deviation of approximately 2,500 feet. The mean for crossing restriction deviations at point of maximum excursion was substantially larger (approximately 1,400 feet greater) than the mean for undifferentiated altitude deviations (1,080 feet) reported in the 1982 ASRS study on altitude deviations. The median for the point of maximum excursion was 1,500 feet.

**Controller Actions**

ATC did not intervene, or was not required to intervene in order to avoid airborne conflict in 43 percent of incidents in the data set. (This supports the research team's subjective assessments of incident severity.) In 60 percent of incidents (100 of 168), the flight continued the climb or descent, with ATC concurrence.

**Advanced Cockpit vs. Traditional Cockpit Aircraft**

There were slightly more (61 percent) advanced cockpit (EFIS and/or nav control) than traditional cockpit aircraft in the data set. This compares to 51 percent advanced cockpit *versus* 49 percent traditional cockpit air carrier aircraft in the ASRS database for the same time period.

It was expected that advanced cockpit aircraft would be more likely to be involved in crossing-restriction altitude deviations due to the greater complexity in programming descents and descent crossing fixes. While we did see this pattern, the difference in numbers between advanced and traditional cockpit aircraft was not large.

## Contributing Factors

### Types of Human Performance Errors

Reporters of incidents in this data set referenced the following human errors:

| **Table 1 — Human Errors**<br>*Based on 233 Citations from 171 of 172 Reports* | | |
|---|---|---|
| **Human Errors** | **Citations** | **Percent** |
| Exercised poor judgment | 43 | 25.1 |
| Neglected to cross-check data | 42 | 24.6 |
| Delayed implementing procedure | 41 | 24.0 |
| Misunderstood clearance | 35 | 20.5 |
| Other (unspecified) | 32 | 18.7 |
| Forgot clearance | 15 | *8.8* |
| Did not read, or mis-read chart | 14 | 8.2 |
| Not stated or ambiguous | 9 | 5.3 |
| Did not hear clearance | 1 | 0.6 |
| Looked at wrong chart | 1 | 0.6 |
| ***TOTALS*** | ***233*** | ***136.4%*** |
| ***Note: Multiple citations are possible in this category, thus the total number of citations exceeds the number of reports.*** | | |

An example of poor judgment is flight crew failure or reluctance to use speed brakes to meet descent profile requirements. Flight crews failing to cross-check data typically resulted in use of the wrong waypoint.

### Cockpit Workload

Reporters cited cockpit workload on SIDs and STARs as a factor in 44 percent of reports. The most commonly noted workload issues are shown in Table 2.

| **Table 2 — Cockpit Workload Issues**<br>*Based on 75 Citations from 172 of 172 Reports* | | |
|---|---|---|
| **Workload Issues** | **Citations** | **Percent** |
| FMS Programming (automation issues) | 18 | 24.0% |
| High quantity radio communication with ATC | 17 | 22.7% |
| Lack of planning on the part of the flight crew that led to time-compression, (such as cabin attendant in cockpit) | 17 | 22.7% |
| Other, (misread altimeter, company com, etc.) | 15 | 20.0% |
| Flight attendant call or cockpit-cabin interphone communication | 12 | 16.0% |
| A change in clearance | 10 | 13.3% |
| Weather factors | 8 | 10.7% |
| ***TOTALS*** | ***97*** | ***129.4%*** |
| ***Note: Multiple citations are possible in this category, thus the total number of citations exceeds the number of reports.*** | | |

### SID and STAR Charts

In 88 percent of reports, there were no complaints about chart graphic depiction or procedures. There were, however some complaints regarding chart text narratives, specifically that the font size was small, and that text blocks were sometimes not placed sufficiently close to the appropriate area of the graphic depiction. In one event, the flight crew of a turbojet transport followed instructions specific to turboprop aircraft, thus deviating from an altitude requirement.

## Incident Results

### Event Resolution

The following table provides event resolution information:

**Table 3 — Incident Resolution**
*Based on 172 Citations from 172 Reports*

| **Event Resolution Categories** | | **Citations** | **Percent** |
|---|---|---|---|
| Controller Actions | | 68 | 39.5% |
| Controller Intervened | *52* | | |
| Controller Issued New Clearance | *16* | | |
| Flight Crew Action | | 84 | 48.8% |
| No Action Taken / Anomaly Accepted | *26* | | |
| No Action Taken / Detected After the Fact | *23* | | |
| Flight Returned to Original Clearance / Course | *14* | | |
| No Action Taken / Insufficient Time | *13* | | |
| Flight Crew Overcame Equipment Problem | *4* | | |
| Flight Crew became Reoriented | *3* | | |
| Avoidance Maneuvers / Evasive Action | *1* | | |
| Unspecified | | 20 | 11.6% |
| Not Resolved / Unable / Other | *17* | | |
| Other | *3* | | |
| ***TOTALS*** | *172* | ***172*** | ***99.9%*** |

**Incident Severity**
In more than 95 percent of incidents in the data set, the analysts subjective assessment was that there was minimal impact on safety of flight or efficiency (Figure 1). While there was no direct evidence of loss of separation in the majority of these events, there may have been implications for ATC, such as sector penetration, of which the pilot reporters in this study were unaware. In less **than** 4 percent of incidents did there appear to be a non-negligible impact on flight safety.

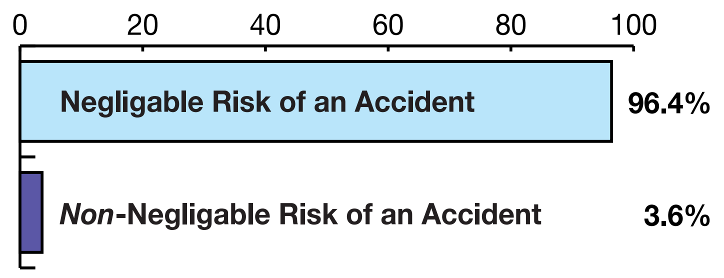


**Figure 1 — Analyst's Subjective Opinion on Risk**
*(Based on 172 of 172 Reports)*

## Summary and Conclusions

- Crossing-restriction altitude deviations occur more often on STARs than SIDs.
- Aircraft configuration or type did not appear to play a role in these incidents.
- Most deviations were altitude *undershoots*. An altitude undershoot on a STAR may indicate a flight crew's failure to adequately plan for the STAR, or their distraction from properly monitoring the descent.
- The mean of the altitude deviation at the point of maximum excursion was large: 2,500 feet.
- In instances of altitude overshoots, the flight crew or ATC often detected the error *before* the altitude deviation occurred. Climb or descent rates may have been sufficiently high to preclude recovery before a deviation occurred.
- Crossing-restriction altitude deviations occurred more often when the crossing altitude was assigned by ATC.
- It is good practice to advise ATC of any altitude change, especially the altitude being vacated and the destination altitude, and to confirm with ATC when descent is to begin.
- Flight crews anticipating or experiencing difficulty adhering to crossing-restriction requirements should advise ATC as soon as practical.
- Cockpit workload was commonly cited as a contributing factor in altitude deviations on STARs. Flight crews may therefore wish to complete checklists early (mid-cruise or before descent), and review STAR charts before descent initiation.
- Traffic separation was known to be compromised in only a small portion of these events.