NASA/TM-2013-218059

Systems Analysis of NASA Aviation Safety Program: Final Report

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November 2013

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November 2013

Acknowledgments

Thanks are extended to the members of the Joint Implementation and Data Analysis Team (JIMDAT), the Old Dominion University Department of Engineering Management and the managers and researchers of the NASA Aviation Safety Program.

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Executive Summary

A three-month study (February to April 2010) of the NASA Aviation Safety (AvSafe) program was conducted. This study comprised three components: (1) a statistical analysis of currently available civilian subsonic aircraft data from the National Transportation Safety Board (NTSB), the Federal Aviation Administration (FAA), and the Aviation Safety Information Analysis and Sharing (ASIAS) system to identify any significant or overlooked aviation safety issues; (2) a high-level qualitative identification of future safety risks, with an assessment of the potential impact of the NASA AvSafe research on the National Airspace System (NAS) based on these risks; and (3) a detailed, top-down analysis of the NASA AvSafe program using an established and peer-reviewed systems analysis methodology.

The statistical analysis of NTSB accident and FAA incident data from 1997 to 2006 identified the top "tall poles" based on four types of Federal Aviation Regulations (FAR) operations (Part 121, Part 135 scheduled, Part 135 non-scheduled and Part 91). The data were categorized using the Commercial Aviation Safety Team/International Civil Aviation Organization (CAST/ICAO) Common Taxonomy. The only tall poles that were common to all four of the FAR operations were "Fire-Post Impact", "Loss of Control – In Flight", "System Component Failure or Malfunction (Powerplant)" and "System Component Failure or Malfunction (Non-Powerplant)".

Multiple external sources (e.g., the National Transportation Safety Board's "Most Wanted List") were used to develop a compilation of future safety issues/risks. The ten "tall poles" in future safety risk are as follows:

- runway safety
- approach and landing accident reduction
- loss of control – in flight
- icing/ice detection
- super density operations (air traffic management under conditions of increased traffic volume)
- human fatigue
- increasing complexity and reliance on automation
- aircraft mixed fleet equipage
- inadequate protection
- sharing and dissemination of safety data
- enhanced survivability in the event of an accident.

The top-down analysis of the NASA AvSafe program was conducted by using a modification of the Gibson methodology. The results of the aviation statistical data analysis, the qualitative future safety risk identification, the literature search, and additional input from subject matter experts were used to

summarize a top-down set of goals and objectives for the AvSafe program and to develop a set of criteria for evaluating the research portfolio. These criteria were used to draw the following conclusions:

- The current NASA aviation safety research portfolio directly addresses all of the National Aeronautics R&D goals, with the exception of goal 3, "develop enhanced passenger and crew survivability in the event of an accident."

- The current portfolio, if successful, would indirectly impact over 50 percent of the historic and future safety "tall poles."

  - Most of the current projects contain a large amount of research that is at the fundamental level.
  - Most of the research directly impacts Part 121 operations. The only research that is directly applicable to Part 91 is in the area of "system component failure."

Of the 17 challenging safety issues that were identified, 11 are directly addressed by the current AvSafe program research portfolio.

1. Introduction

1.1 Background

The NASA Aeronautics Research Mission Directorate (ARMD) is focused on performing cutting edge, fundamental research in traditional aeronautics research disciplines. According to the ARMD Web site (Ref. 1), this research is based on three key principles:

> *"1. We will dedicate ourselves to the mastery and intellectual stewardship of the core competencies of aeronautics for the nation in all flight regimes.*
>
> *2. We will focus our research in areas that are appropriate to NASA's unique capabilities.*
>
> *3. We will directly address the fundamental research needs of the Next Generation Air Transportation System (NextGen) in partnership with the member agencies of the Joint Planning and Development Office (JPDO)."*

The charter of the Aviation Safety (AvSafe) program in 2010 within the ARMD was to conduct research to improve "the safety of current and future aircraft operating in the National Airspace System" (Ref. 2). The ARMD management uses information from a variety of sources, both internal and external, to guide their technical, programmatic, and budgetary decisions. In 2010, the ARMD had a need for a detailed systems analysis of the AvSafe program to obtain additional information for their portfolio decision process.

1.2 Study Objectives and Deliverables

The overarching objective of this study was to identify a set of challenging safety issues that can be addressed in NASA's aviation safety research portfolio. The results of this study could help NASA management better assess the potential impact of NASA's research portfolio on aviation safety and identify any gaps between areas that were being worked and those that needed to be addressed. The study specifically comprises three components: (1) a statistical analysis of currently available civilian subsonic aircraft data from the National Transportation Safety Board (NTSB), the Federal Aviation Administration (FAA), and the Aviation Safety Information Analysis and Sharing (ASIAS) to identify significant and overlooked aviation safety issues; (2) a high-level qualitative identification of future safety risks, with an assessment of the potential impact of the NASA AvSafe research on the National Airspace System (NAS) based on these risks; and (3) a detailed top-down analysis of the NASA AvSafe program using an established and peer-reviewed systems-analysis methodology.

2. Aviation Statistical Data Analysis

While many experts in the aviation community have often stated that the aviation events (accidents and incidents) in the past may not necessarily reoccur in the future, there is still the potential for some of these events to happen again in the future. This section contains an analysis of currently available civilian subsonic aircraft accident and incident data to identify to any significant or overlooked aviation safety issues. A detailed examination of medical transport aircraft data is also included in this section.

2.1 Introduction

The primary purpose of the analysis reported here is to identify the types of accidents with the greatest impact on the overall safety risk in U.S. civil aviation. The safety risk is here defined to include the number of total accidents, fatal accidents and incidents, and the number of total injuries and fatalities.

The NTSB is an independent federal agency that investigates every civil aviation accident in the United States, as well as significant accidents in other modes of transportation. The NTSB also conducts special investigations and safety studies and issues safety recommendations to prevent future accidents. The information that is collected during these investigations resides in the NTSB Aviation Accident and Incident Data System. A copy of this database in Microsoft Access format was obtained from the ASIAS department of the FAA's Office of Aviation Safety in April 2009.

The NTSB database includes events that involve a wide variety of aircraft (e.g., airplanes, helicopters, hot-air balloons, gliders, and ultralight aircraft) operating under various FARs (e.g., Part 91: General Aviation; Part 121: Commercial Air Carriers; Part 129: Foreign Air Carriers; Part 135: Commuters and On-Demand Air Taxis; and Part 137: Agricultural Operations). In March 1997, FAR Part 121 was changed to be applicable to all commuter operations with 10 or more passengers. Previously, FAR Part 135 regulations were applicable to commuter operations with less than 44 passengers, and FAR Part 121 was applicable to operations involving 44 or more passengers.

The NTSB considers each event to be either an accident or an incident, based on the following definitions (Ref. 3):

Accident: An occurrence that is associated with the operation of an aircraft, which takes place between the time that any person boards the aircraft with the intention of flight and the time that all such persons have disembarked, and in which any person suffers death or serious injury or in which the aircraft receives substantial damage.

Incident: An occurrence, other than an accident, that is associated with the operation of an aircraft and that affects or could affect the safety of operations.

Any injury or aircraft damage that occurs when there was no intent for flight (e.g., high-speed taxi tests, movement of the aircraft around the airfield, or maintenance run-ups) is, by definition, an incident.

The NTSB does not investigate all incidents; however, all incidents and accidents are reported to the FAA (which is an agency within the Department of Transportation) by pilots, airport personnel, and private citizens. The FAA maintains a database that contains the information that is received in these reports and obtained in any subsequent investigation. A copy of the FAA Accident/Incident Data System (AIDS) in Microsoft Access format was obtained from the ASIAS office in October of 2007.

2.2 Methodology

All recorded accidents and incidents that involved commercially built fixed-wing airplanes operating under FAR Part 121, Part 135, or Part 91 were included in this analysis, regardless of the state of the investigation (i.e., a preliminary stage versus finalized) and the location of the event (i.e., whether it occurred within or outside the U.S.). Home-built or experimental aircraft were excluded, as were helicopters, ultralight aircraft, gliders, and balloons. Also excluded were sky-diving incidents in which the main issue involved the parachute or the parachutist rather than the aircraft that was carrying the sky divers or the pilot of that aircraft.

Among the incidents in this analysis were some midair collisions and ground collisions between multiple aircraft. The AIDS database includes a record for each aircraft involved, unless the aircraft was parked and unoccupied. To reduce the analysis data set to one record per incident, each incident that involved multiple aircraft was reviewed, and the report for the passive aircraft (i.e., the aircraft that was hit during the collision) was eliminated. This procedure was not followed for the accident data.

Each accident that is included this report was assigned an occurrence category based on the taxonomy (Ref. 4) that was developed by the CAST/ICAO Common Taxonomy Team (CICTT). The author added several additional categories to this taxonomy for nontransport accidents; the details for all categories are provided in Appendix A. Categories were assigned by means of a computer program based on the occurrence codes and causal factor codes from the NTSB database. During the assignment process, many of the more complicated accidents were reviewed by the authors, and all of the fatal accidents for Part 121 and Scheduled Part 135 were reviewed by aviation safety program staff. Certain accidents were assigned multiple occurrence categories.

One CICTT specification was not followed. This change was with regard to loss of control when a system/component failure or malfunction rendered an aircraft uncontrollable. The CICTT taxonomy states that the loss of control should not be considered a separate category in these cases. However, for the purposes of this analysis, the loss-of-control category was retained for all circumstances, regardless of cause, in order to capture all loss-of-control events, including those that followed a system/component failure/malfunction or other circumstances (e.g., incapacitation, weather) that might have rendered the aircraft uncontrollable.

The incident data were not categorized according to the occurrence taxonomy. A single incident category was assigned to each incident to describe the primary occurrence. For example, if a system/component failure or malfunction occurred, the incident was classified according to the malfunctioning system, regardless of consequences (e.g., loss of control, gear-up landing, or runway excursion). Details regarding the incident classifications are available in another paper (Ref. 5). For the purposes of this analysis, the CICTT categories were mapped to the incident categories without additional review of the specific incident.

2.3 Results and Discussion

Figure 1 shows the accident rate (per 1 million flight hours) over time for each of the four types of flight operations. Data for total flight hours per year were obtained from tables published by the NTSB, which were based on data provided by the FAA. The lowest accident rates continue to be for Part 121 operations (large transport aircraft), while the highest rates are for Part 91 operations (general aviation). The greatest rate of decline during this ten-year time period was in Non-scheduled Part 135 operations (on-demand air taxi), while the greatest variation was in Scheduled Part 135 operations (commuter airlines). In general, these statements are also true for fatal accident rates (see Fig. 2) and incident rates (see Fig. 3).

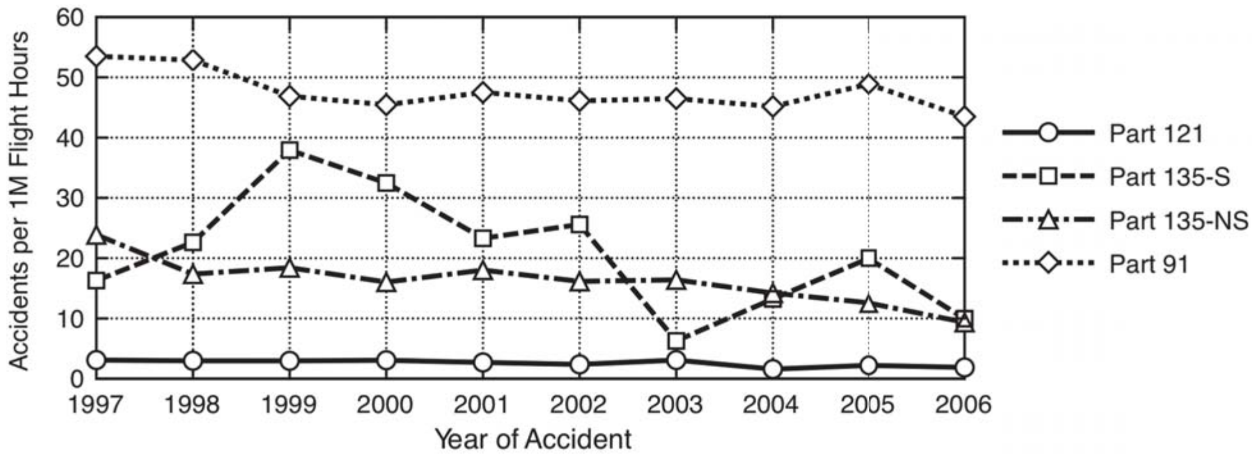

Figure 1. Accident rates for four categories of flight operations (1997–2006).

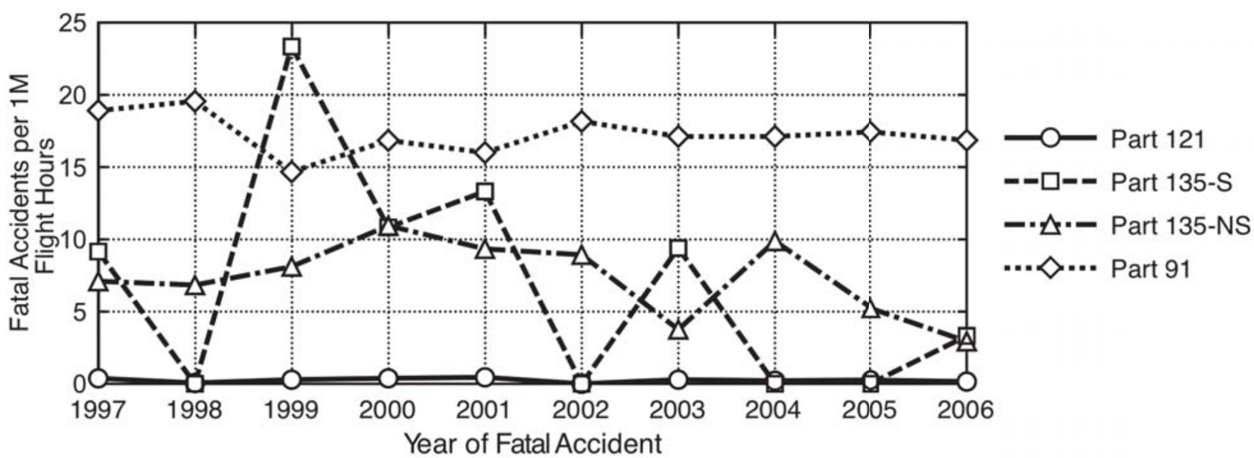

Figure 2. Fatal accident rates for four categories of flight operations (1997–2006).

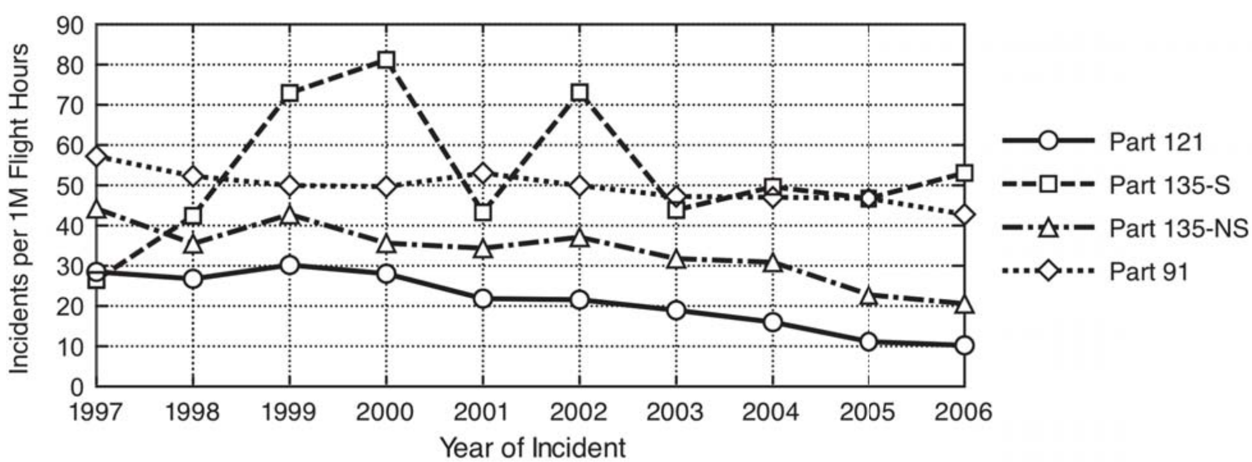

Figure 3. Incident rates for four categories of flight operations (1997–2006).

Although both the total accident and fatal accident rates show some evidence of decline for every flight operations category, the rates have remained disturbingly high for Part 91 and Part 135 operations relative to Part 121 operations. Additionally, the data indicate an increase in the rate of incidents for Scheduled Part 135. The frequencies of occurrence for each CICTT occurrence category for each type of flight operations are shown in a series of tables given in Appendix B.

The total numbers of accidents, incidents, and injuries for each category of flight operations also are provided in the tables. The percentages that are examined in this study are generated based on these totals. The reader is reminded that a particular accident may be assigned multiple occurrence categories (i.e., more multiple causes may have contributed to a given accident). The additional categories that are not part of the official CICTT taxonomy are denoted with an asterisk (*). Although the tables are organized by outcome (i.e., accident, incident, or injury), the discussion here is organized according to the flight operations under which the aircraft was operating at the time of the event. The most frequently occurring causes of the events within each category of flight operations were selected from each table. The actual number of categories that were selected varies, but in each case a clear demarcation in percentages exists to distinguish those that were selected from those that were not selected. Appendix C contains a number of charts that show the total number of accidents and fatal accidents for each type of occurrence (or cause) for each category of flight operations.

Part 121

The occurrence categories that were factors in more than 10 percent of Part 121 accidents were ground handling (26 percent) and turbulence encounter (25 percent). The following factors had the highest incidences of injuries: turbulence encounter (30 percent), post-impact fire (26 percent), and in-flight loss of control (21 percent). The largest numbers of fatal accidents occurred for ground handling (40 percent), post-impact fire (28 percent), in-flight loss of control (24 percent), and non-powerplant system/ component failure (20 percent). The largest numbers of fatalities occurred for in-flight loss of control (54 percent), post-impact fire (48 percent), the terrorist attacks of 9/11 (35 percent), and abrupt maneuvering (35 percent). For Part 121 incidents, the only categories that were factors in more than 5 percent of the total number of incidents were non-powerplant system/component failure (44 percent), powerplant system/component failure (16 percent), and ground handling (11 percent).

In summary, the following factors contributed the most to the overall safety risk for Part 121 operations: abrupt maneuver, post-impact fire, ground handling, in-flight loss of control, powerplant system/component failure, non-powerplant system/component failure, security-related event, and turbulence encounter.

Scheduled Part 135

The categories that were factors in more than 10 percent of the total number of accidents that occurred for Scheduled Part 135 operations were runway excursion (18 percent), in-flight loss of control (14 percent), abnormal runway contact (13 percent), controlled flight into or toward terrain (CFIT) (12 percent), bird strike (10 percent), icing (10 percent), and non-powerplant system/component failure (10 percent). The occurrence categories that included more than 20 percent of the total number of injuries were in-flight loss of control (49 percent), icing (35 percent), and post-impact fire (33 percent). The factors that had the highest numbers of fatal events and total number of fatalities were in-flight loss of control (53 percent of fatal events and 76 percent of fatalities), CFIT (27 percent of fatal events and 18 percent of fatalities), icing (20 percent of fatal events and 59 percent of fatalities), and post-impact fire (20 percent of fatal events and 50 percent of fatalities). Among Scheduled Part 135 incidents, the categories that were factors in more than 10 percent of the total number of incidents were non-powerplant system/component failure (37 percent), powerplant system/component failure (13 percent), and ground handling (12 percent).

In summary, the following factors contributed the most to the overall safety risk for Scheduled Part 135 operations: abnormal runway contact, bird strike, CFIT, post-impact fire, ground handling, icing, in-flight loss of control, runway excursion, powerplant system/component failure, and non-powerplant system/component failure.

Non-Scheduled Part 135

The three categories that were most frequently factors in Non-Scheduled Part 135 accidents were in-flight loss of control (17 percent), runway excursion (15 percent), and post-impact fire (13 percent). The factors for which more than 15 percent of the total number of injuries occurred were in-flight loss of control (33 percent), post-impact fire (30 percent), and CFIT (19 percent). Similarly, the three factors that had the highest percentages for both the total number of fatal events and the total number of fatalities were in-flight loss of control (46 percent of fatal events and 51 percent of fatalities), post-impact fire (41 percent of both fatal events and fatalities), and CFIT (26 percent of fatal events and 27 percent of fatalities). The categories that were factors for more than 10 percent of Non-Scheduled Part 135 incidents were non-powerplant system/component failure (40 percent) and powerplant system/component failure (14 percent).

In summary, the following factors contributed the most to the overall safety risk for Non-Scheduled Part 135 operations: CFIT, post-impact fire, in-flight loss of control, runway excursion, powerplant system/component failure, and non-powerplant system/component failure.

Part 91

The five categories that were most frequently factors in Part 91 accidents were runway excursion (20 percent), in-flight loss of control (20 percent), on-ground loss of control (15 percent), abnormal runway contact (13 percent), and fuel-related loss of engine power (13 percent). The categories for which more than 10 percent of the total number of injuries occurred were in-flight loss of control (40 percent), post-impact fire (24 percent), collision with an object/obstacle during takeoff or landing (15 percent), fuel-related loss of engine power (15 percent), and low-altitude operations (11 percent). The categories that had the highest number of fatal events and the highest number of fatalities were in-flight loss of control (55 percent of fatal events and 56 percent of fatalities), post-impact fire (36 percent and 38 percent), low-altitude operations (18 percent and 16 percent), and CFIT (13 percent of both fatal events and fatalities). The most frequently occurring factors for incidents in Part 91 operations were non-powerplant system/component failure (27 percent), abnormal runway contact (25 percent), powerplant system/component failure (10 percent), and runway excursion (9 percent).

In summary, the following factors contributed the most to the overall safety risk for Part 91 operations: abnormal runway contact, CFIT, collision with object/obstacle during takeoff or landing, post-impact fire, low-altitude operations, in-flight loss of control, on-ground loss of control, fuel-related loss of engine power, runway excursion, powerplant system/component failure, and non-powerplant system/component failure.

Table 1 summarizes the impact of each category that was found to be a top contributor to the safety risk within each flight operations category. The absence of summary statistics for a particular occurrence category within a particular flight operations category should not lead the reader to conclude that no events for that flight operations category occurred for the given occurrence category. Rather, the number of events assigned to that occurrence category may not have been large enough for it to be considered a major contributor to the safety risk. The following abbreviations are used in the tables:

TA: Total accidents
TAI: Total accident injuries
FA: Fatal accidents
TF: Total fatalities
TI: Total incidents

Table 1. Most Frequently Cited CICTT Occurrence Categories (1997–2006)

CICTT Occurrence Category	Part 121	Scheduled Part 135	Non-Scheduled Part 135	Part 91
Abrupt maneuver	35% of TF			
Abnormal runway contact		13% of TA		13% of TA 25% of TI
Bird strike		10% of TA		
Controlled flight Into terrain		12% of TA 27% of FA 18% of TF	19% of TAI 26% of FA 27% of TF	13% of FA 13% of TF
Collision with object during takeoff or landing				15% of TAI
Fire – post impact	26% of TAI 28% of FA 48% of TF	33% of TAI 20% of FA 50% of TF	13% of TA 30% of TAI 41% of FA 41% of TF	24% of TAI 36% of FA 38% of TF
Ground handling	26% of TA 40% of FA 11% of TI	12% of TI		
Icing		10% of TA 35% of TAI 20% of FA 59% of TF		
Low-altitude operations				11% of TAI 18% of FA 16% of TF
Loss of control – in flight	21% of TAI 24% of FA 54% of TF	14% of TA 49% of TAI 53% of FA 76% of TF	17% of TA 33% of TAI 46% of FA 51% of TF	20% of TA 40% of TAI 55% of FA 56% of TF
Loss of control – on ground				15% of TA
Power loss – fuel				13% of TA 15% of TAI
Runway excursion		18% of TA	15% of TA	20% of TA 9% of TI
System component failure – powerplant	16% of TI	13% of TI	14% of TI	10% of TI
System component failure – nonpowerplant	20% of FA 44% of TI	10% of TA 37% of TI	40% of TI	27% of TI
Security related	35% of TF			
Turbulence encounter	25% of TA 30% of TAI			

One accident (AA587 on 12NOV01) with abrupt maneuvering (which led to failure of the vertical stabilizer and a total loss of control) was responsible for 35 percent of the Part 121 fatalities in this time period. This was the same number of persons as were killed earlier that month in four aircraft on September 11th. Even this one accident highlights the need for stringent and comprehensive flight training.

Abnormal runway contact was a major contributor to the safety risk in Scheduled Part 135 and Part 91 operations (based primarily on the percentage of total accidents), but it was also a minor contributor for Part 121 and Non-Scheduled Part 135 operations (9 and 11 percent of total accidents, respectively).

Bird strikes appear to be a problem primarily for Scheduled Part 135 flights but also accounted for 3 percent of accidents and 3 percent of incidents for Part 121 operations.

Controlled flight into terrain (CFIT) was a major contributor to the safety risk for all flight operations categories except Part 121. Safety enhancements such as terrain awareness and warning systems (TAWS) and enhanced ground proximity warning systems (EGPWS) have been invaluable; more recent technologies such as synthetic vision are too new to have had an impact on these data.

Collision with an object or obstacle during takeoff or landing was primarily a Part 91 phenomenon; within Part 91, this factor accounted for 10 percent of all of the accidents, 9 percent of all of the fatal accidents, and 8 percent of the total number of fatalities.

Post-impact fire is one of four accident categories that presented as a major contributor in every flight operations category. Accidents with post-impact fires accounted for 20 to 41 percent of all fatal accidents and 38 to 50 percent of the total number of fatalities.

Ground handling accidents were most common in Part 121 but were not absent from other flight operations. Eight of the ten Part 121 fatal accidents with ground handling as a contributing factor resulted in a total of one fatality.

Icing was as factor mostly for Scheduled Part 135 flights. Interestingly, 83 percent of the Scheduled Part 135 accidents for which icing was a factor occurred in Alaska (65 of 78), compared with 8.5 percent (1123 of 13,246) across the other flight operations categories. Similarly, two-thirds of the Scheduled Part 135 fatal accidents occurred in Alaska (10 of 15), compared with 4.1 percent across the other flight operations categories (101 of 2475).

Low-altitude operation is another factor that affected mostly Part 91 flight. In general, the percentages of accidents and injuries that were attributed to low-altitude operations in Part 91 were nearly twice those for Non-Scheduled Part 135 and four times those for Part 121 and Scheduled Part 135 operations.

In-flight loss of control was an important part of the safety risk more as a result of the number of injuries, especially fatal injuries, than to the total number of accidents. The impact on fatalities was fairly consistent across all categories of flight operations (51 to 76 percent), with a spike in the number of injuries for Scheduled Part 135 operations. In-flight loss of control was so likely to result in injury or substantial aircraft damage that it was rarely categorized as a factor for incidents. For those incidents that did include in-flight loss of control as a contributing factor, the loss of control was nearly always preceded by a system or component failure/malfunction or severe weather, and control was regained prior to a collision.

On-ground loss of control (mostly ground loop and nose over or nose down) was another contributing factor that occurred most often in Part 91 operations. These Part 91 accidents were rarely fatal.

Fuel-related loss of engine power also contributed significantly to the safety risk for Part 91 operations; the percentages were only slightly lower for Non-Scheduled Part 135 operations as well. The loss of engine power *per se* was not the main problem in these accidents, but rather the inability to successfully complete an off-airport landing with little or no engine power.

Runway excursion accounted for 15 to 20 percent of accidents across all categories of flight operations except Part 121 (8 percent). However, runway excursion in Part 121 resulted in higher percentages of injuries (13 percent), fatal accidents (12 percent) and fatalities (8 percent) than were seen in other flight operations categories.

Both powerplant and nonpowerplant system/component failure/malfunction contributed to the safety risk mostly in terms of incidents. However, 20 percent of the fatal accidents for Part 121 operations (with 18 percent of all Part 121 fatalities), 10 percent of Scheduled Part 135 accidents, and 11 percent of Non-Scheduled Part 135 accidents were attributed to nonpowerplant system/component failure/malfunction. For Non-Scheduled Part 135 accidents, the percentages for powerplant system/component failure/malfunction were remarkably similar to those for fuel-related loss of engine power.

Although the security-related occurrence category manifests itself in Part 91 in terms of suicides and stolen aircraft, security was a major contributor to the safety risk only in Part 121 operations (35 percent of total fatalities).

Similarly, encounters with turbulence account for less than three percent of any accidents or injuries in flight operations categories other than Part 121. However, in Part 121, turbulence is responsible for 25 percent of accidents and 30 percent of injuries, making it the single largest cause of injuries in this operations category.

These 17 accident categories collectively were assigned to 89 percent of the accidents that occurred during the period 1997–2006 (Part 121: 86 percent; Scheduled Part 135: 85 percent; Non-Scheduled Part 135: 83 percent; Part 91: 90 percent), 94 percent of the fatal accidents (Part 121: 100 percent; Scheduled Part 135: 100 percent; Non-Scheduled Part 135: 92 percent; Part 91: 94 percent), and 84 percent of incidents (Part 121: 82 percent; Scheduled Part 135: 80 percent; Non-Scheduled Part 135: 82 percent; Part 91: 85 percent).

Because several occurrence categories were major contributors to the safety risk for only one flight operations category, Table 2 shows the percentage of accidents or incidents that have been assigned to the set of occurrence categories specific to that category of flight operations.

Table 2. Number of Events Assigned to at Least One of the Most Frequent CICTT Occurrence Categories Within Each Category of Flight Operations (1997–2006)

Type of outcome	Part 121	Scheduled Part 135	Non-Scheduled Part 135	Part 91
Total accidents	319 (69.5%)	57 (73.1%)	313 (58.0%)	10849 (88.6%)
Total injuries	1754 (89.7%)	128 (90.1%)	437 (74.7%)	8961 (91.0%)
Fatal accidents	23 (92.0%)	13 (86.7%)	102 (83.6%)	2150 (92.4%)
Fatal injuries	750 (99.7%)	77 (96.3%)	249 (85.3%)	4125 (91.0%)
Incidents	2881 (76.8%)	143 (76.1%)	677 (60.6%)	10320 (80.8%)

2.4 Conclusions from the Statistical Analysis Results

This analysis has identified four groups of occurrence categories (with between 6 and 11 categories per group) that contributed greatly to the safety risk within each of the flight operations categories. Collectively, the occurrence categories in these identified groups represent 89 percent of accidents and 84 percent of incidents. Individually, these groups represent 58 to 89 percent of accidents and 61 to 81 percent of incidents. In general, the occurrence categories that were most important to the safety risk across all categories of flight operations were post-impact fire and in-flight loss of control.

2.5 Statistical Analysis Medical Transport Accidents for the Period 1990–2008

A separate examination of accidents involving medical helicopters in the United States was conducted. The primary purpose of this statistical analysis was to describe the characteristics of accidents that involve U.S. civil aviation helicopter medical transports in order to determine whether this area of aviation safety requires additional attention.

Table 3 provides some basic statistics that pertain to helicopter accidents that are entered in the NTSB database. The first row gives the total number of helicopter accidents between 1990 and 2008. The second row gives these totals after amateur-built helicopters, military aircraft, and helicopters operated by persons and businesses based outside the United States have been excluded. The third row gives these totals for only those accidents that involved medical transport helicopters. Not all of these flights had patients on board at the time of the accident; some were en route to pick up the ill or injured persons, and others were traveling back to their home base after delivering the patient to a hospital.

Table 3. Description of Helicopter Accidents

	Number of accidents	**Accidents with any injury**	**Accidents with a fatal injury**	**Helicopter was destroyed**
All helicopter accidents	3910	2019 (51.6%)	793 (20.3%)	958 (24.5%)
Commercially built, U.S.-based civil helicopters	3424	1692 (49.4%)	590 (17.2%)	757 (22.1%)
Medical transport	156	98 (62.8%)	63 (40.4%)	62 (39.7%)

Eighty-eight percent of the helicopter accidents that are recorded in the NTSB database for the given time period involved commercially built, nonmilitary U.S.-based aircraft. These accidents tend to have less severe outcomes (in terms of injuries, fatalities, and aircraft destruction) than other helicopter accidents in the database. This observation is not surprising given that the NTSB is more likely to be involved in foreign or military accident investigation when the outcome is severe.

Less than 5 percent of the recorded helicopter accidents involved medical transport, but these accidents have significantly more severe outcomes than the general helicopter accidents. More than twice as many medical transport accidents resulted in a fatality than commercially built, U.S.-based civil helicopters as a whole. Medical transport helicopters were twice as likely to be destroyed. In addition, the number of medical transport accidents increased substantially during the given time period (see Fig. 4), whereas the total number of helicopter accidents and the number of accidents that involved commercially built, U.S.-based nonmilitary helicopters has remained relatively constant or even declined slightly.

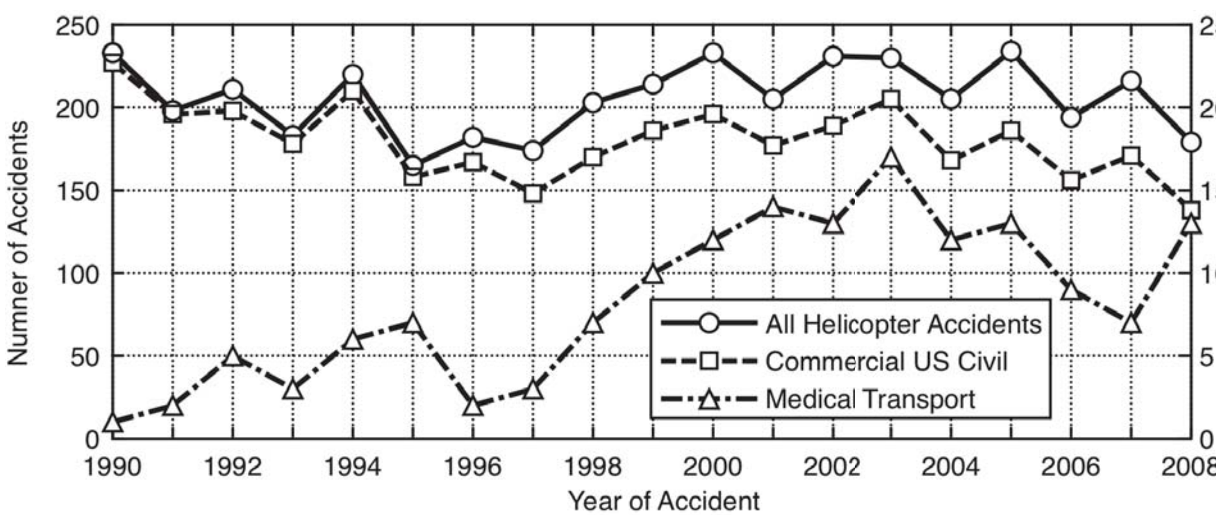

Figure 4. Number of helicopter accidents in three subsets (note that the plotted line for medical transport accidents uses the axis on the right).

These 156 medical transport accidents were assigned occurrence categories based on the taxonomy that was developed by the CICTT. The author added several categories to this taxonomy for non-transport accidents. Details on all of these categories can be found in Appendix A. Certain accidents were assigned multiple occurrence categories.

Table 4 shows the number of medical transport helicopter accidents that were assigned to each occurrence category. The most frequent causal factors among all accidents were in-flight loss of control (34 percent), collision with an object on takeoff or landing (21 percent), abnormal runway contact (20 percent), and system/component failure/malfunction – powerplant (16 percent). For fatal accidents, the most frequent causal factors were in-flight loss of control (56 percent), CFIT (30 percent), and post-impact fire (25 percent).

Table 4. CICTT Occurrence Categories for Medical Transport Helicopter Accidents

CICTT Occurrence Category	**Number of accidents**	**Number of fatal accidents**
Total accidents	156	63
Abrupt maneuver	1 (0.6%)	
Abnormal runway contact	31 (19.9%)	2 (3.2%)
Controlled flight into terrain	21 (13.5%)	19 (30.2%)
Collision with object – takeoff or landing	33 (21.2%)	4 (6.3%)
Collision with terrain – approach/landing*	5 (3.2%)	1 (1.6%)
Fire – nonimpact	3 (1.9%)	
Fire – post impact	20 (12.8%)	16 (25.4%)
Ground collision	1 (0.6%)	
Ground handling or preflight	7 (4.5%)	1 (1.6%)
Low-altitude operations	3 (1.9%)	3 (4.8%)
Loss of control – in flight	53 (34.0%)	35 (55.6%)
Loss of control – on ground	5 (3.2%)	
Midair collision	2 (1.3%)	2 (3.2%)
Power loss – fuel	5 (3.2%)	2 (3.2%)
Power loss – unknown reason*	4 (2.6%)	3 (4.8%)
System component failure – powerplant	25 (16.0%)	8 (12.7%)
System component failure – nonpowerplant	7 (4.5%)	2 (3.2%)
Unintended flight into IMC	9 (5.8%)	4 (6.3%)
Unknown or undetermined	4 (2.6%)	2 (3.2%)

* Denotes occurrence categories not in the official CAST/ICAO taxonomy.

3. Qualitative Future Safety Risk Identification

This section provides a high-level qualitative identification of future safety risks (i.e., future tall poles). These risks are the basis for assessing the potential impact(s) of NASA’s aviation safety research in these areas on the National Airspace System. This section contains qualitative descriptions of critical areas of future safety risk in the air transportation system. The information was compiled from a variety of sources, including:

1. Decadal Survey of Civil Aeronautics (National Research Council, 2006) (Ref. 6)
2. National Aeronautics Research and Development Plan, Biennial Update (National Science and Technology Council, 2010) (Ref. 7)
3. Most Wanted Aviation Safety Improvements (National Transportation Safety Board, 2010) (Ref. 8)
4. Safety Initiatives (Flight Safety Foundation, 2010) (Ref. 9)
5. Joint Planning and Development Office (JPDO) Safety Working Group Safety Issues database, 2008 (Ref. 10)
6. Future Aviation Safety Team (FAST) Areas of Change, 2010. (Ref. 11)
7. NextGen Implementation Plan (Federal Aviation Administration, 2009) (Ref. 12)
8. Commercial Aviation Safety Team (CAST) Safety Enhancements, Joint Implementation Measurement Data Analysis Team (JIMDAT) Meetings, and Aviation Safety Information Analysis and Sharing (ASIAS) Directed Studies (Refs. 13, 14)

The most critical future safety risk issues that were identified were those that were cited in several of these sources as an area of concern in terms of safety.

Runway Safety

Despite a significant reduction in catastrophic airport accidents during the past two decades, runway safety is still one of the most significant safety concerns in commercial aviation. Runway safety encompasses runway incursions, runway excursions, and runway confusion (i.e., takeoffs/landings on the wrong runway or taxiway).

The number of runway and taxiway incursions remains unacceptably high despite recent efforts to minimize their occurrence. While a number of initiatives have been undertaken to mitigate the risks that are associated with runway incursions, the trend remains flat in specific countries, most notably the United States. According to the International Air Transport Association (IATA), the majority of incursions are related to communications issues, which suggests that the use of standard International Civil Aviation Organization (ICAO) phraseology and improved proficiency in the use of aviation English are key factors to reducing the incidence of these events. Further, workload and distractions on the flight deck during the preflight phase have been identified as contributing factors. Improvements in airport surface markings and lighting, along with more accurate charting of airport infrastructure, have been implemented at many locations. Nevertheless, runway incursions are expected to remain a critical safety risk in the future. The NTSB considers runway incursions one of its top three aviation safety issues, noting that "these incidents continue to occur with alarming, and increased, frequency" (Ref. 8). The NTSB has recommended implementing a safety system for ground movement that will ensure the safe movement of airplanes on the ground and provide immediate warnings of probable collisions/incursions directly to flight crews in the cockpit. The NTSB has also proposed that operators be required to install cockpit moving map displays or automatic systems that alert pilots when a takeoff is attempted on a taxiway or runway other than the one intended.

The Flight Safety Foundation (FSF) conducted a project entitled Runway Safety Initiative (RSI) to address the challenge of runway safety. The RSI team consisted of about 20 organizations from around the world, including operators, manufacturers, air navigation service providers, pilot groups, and various other industry associations. After reviewing all areas of runway safety, the RSI team primarily focused on reducing the risk of runway excursions because 97 percent of runway accidents were found to be caused by excursions (Ref. 9). A runway excursion occurs when an aircraft on the runway surface leaves the end or the side of the runway surface. Runway excursions can occur on takeoff or landing and can be one of two types of events: a veer-off, in which the aircraft departs the side of the runway, and an overrun, in which the aircraft departs the end of the runway. The runway-excursion risk-reduction strategies that have been developed by the RSI team emphasize developing stabilized approaches and reducing the risk of flight crews landing long and fast with a tailwind on a contaminated runway.

Runway excursions are a continuing safety concern. The Joint Implementation Measurement Data Analysis Team (JIMDAT) of the Commercial Aviation Safety team studied worldwide fatal and hull-loss accident data over the period from 1987 to 2008 and found that runway excursions have exhibited an upward trend. The FSF also found that over the 14 years preceding this study, nearly 30 excursions have occurred per year for commercial aircraft (i.e., over 25 percent of all accidents). The study also noted that although the percentage of excursions that included fatalities was low, the sheer number of excursions still resulted in a high overall number of fatalities. Independent of the FSF effort, the International Air Transport Association's Safety Group had identified runway excursions as a significant safety challenge to be addressed. For this reason, runways excursions have been identified as a future aviation safety risk area.

An increased number of aircraft in the air transportation system not only increases the aircraft density in the air but also on the ground. To address this increase, research is needed to develop systems that improve pilot and controller awareness of airport surface conditions (e.g., aircraft locations, ground vehicle locations, runway occupancy, and pavement conditions), particularly in low-visibility situations. Improving the situational awareness of flight crews and ground controllers is critical to reducing incidents and accidents on the ground (Ref. 7).

Approach and Landing Accident Reduction

Approach and landing accidents include any landing or takeoff that involves abnormal runway or landing surface contact. This safety risk area also includes unstabilized approaches, that is, approaches where airspeed, rate of descent, aircraft attitude, aircraft configuration, or power settings do not meet stabilized approach criteria at the prescribed approach point. Events such as hard/heavy landings, long/fast landings, off-center landings, crabbed landings, gear-up landings (unless caused by a system/component malfunction), nosewheel-first touchdowns, tail strikes, and wingtip/nacelle strikes are also included in this category. These accidents often are manifestations of deficiencies that begin in the approach phase or even earlier.

Approach and landing accidents often involve high-energy approaches. The most significant threats during approach are fast approach airspeed, high ground speed (e.g., not appreciating wind effects), and a high and/or steep approach above the desired flight path. These conditions combine to create a high energy approach, and early control of energy can reduce these threats. A stabilized approach provides a basis for a good landing. It provides the crew with the optimum conditions to flare, land, and stop the aircraft. An approach must be stabilized by 1,000 ft in instrument meteorological conditions (IMC) and by 500 ft in visual meteorological conditions (VMC).

The Flight Safety Foundation Approach and Landing Accident Reduction task force cited several important contributing factors to approach and landing accidents (Ref. 9):

- Inadequate flight crew interaction with automatic flight systems.

- Incorrect or inadequate ATC communication and instruction to the flight crew.

- Failure in crew resource management (i.e., crew coordination, cross-check, and backup).

- Unstabilized approaches that involve incorrect management of aircraft energy condition (i.e., approaches conducted too low/slow or too high/fast).

- Failure to recognize the need for and execute a missed approach.

- Spatial disorientation and visual illusions (visual approaches at night typically present a greater risk).

Avoiding errors in situation awareness and situation assessment are key to preventing approach and landing accidents. The situation should be assessed on the basis of several parameters, including airspeed, altitude, runway length, runway surface conditions, wind, and visibility. Important situation cues for landing are:

- The actual approach path and airspeed of the aircraft in comparison with the ideal flight path and the target air speed.

- The runway conditions, friction, and the required level of braking.

- The landing distance available for the ambient conditions and the weight and configuration of the aircraft.

- Tailwind.

The general aviation community has also identified approach and landing accidents as a significant safety risk. The National Business Aviation Association (NBAA), which promotes the aviation interests of organizations that use general aviation aircraft for business purposes, has stated that for decades approach and landing accidents consistently have accounted for approximately 50 percent of U.S. business aviation accidents, with no evidence of recent improvement (Ref. 10).

Loss of Control – In Flight

Loss of control in flight involves accidents that occur during airborne phases of flight where aircraft control was lost. Loss of control can occur during either IMC or VMC. Occurrences that involve configuring the aircraft (e.g., setting of flaps, slats, on-board systems, and so on) are also considered loss of control. Loss of control during flight may occur as a result of a stall, an icing-related event, a severe atmospheric turbulence or wake vortex encounter, or a system/component malfunction or failure.

Aircraft stall leading to loss of control can have a number of contributing factors, including failure of the flight crew to follow the approach-to-stall procedures as a result of inadequate training; lack of flight crew preparation for the post-stall recovery task; failure of the stick-shaker system to provide an adequate time margin between activation and stall; overemphasis of test standards on minimum altitude loss, which can lead to negative training transfer; lack of regulatory requirements for post-stall recognition and recovery training; and inappropriate use or reliance on automation to recover from unusual attitude or in-flight situations (Ref. 10).

Loss of stability and maneuverability can result from an upset condition due to inadvertent encounters with hazardous weather conditions such as severe turbulence, convective weather, or icing. Recent incidents have highlighted new potential contributors to such upset conditions, including high ice water content atmospheric conditions capable of causing ice accretion on vital aircraft sensors and inside jet engines, at temperatures colder and altitudes higher than icing was previously known to occur (Ref. 7).

Accidents due to a loss of control may also occur as a result of a lack of attitude awareness (spatial disorientation) or a lack of energy-state awareness on the part of the flight crew. Loss of attitude awareness is typically characterized by an initial "mismatch" that develops between the actual airplane attitude and the attitude that is perceived by the pilot, followed by a failure to resolve the mismatch, leading to a loss of control. Loss of energy-state awareness is typically characterized by a failure to monitor or understand energy-state indications (e.g., airspeed, altitude, vertical speed, or commanded thrust) and a resultant failure to accurately forecast the ability to maintain safe flight. Both types of events typically involve the failure of the flight crew to maintain an awareness of critical flight deck indications.

Icing/Ice Detection

Adverse weather conditions, including storms and icing conditions, significantly reduce the capacity and reliability of the air transportation system. Adverse weather also degrades system safety. Accumulations of snow, ice, freezing rain, or frost on aircraft surfaces and sensors that occurs in flight or on the ground (i.e., deicing-related) can adversely affect aircraft control or performance. This issue is important to both civil and military aviation. It is also a critical issue for all types of aircraft and is particularly important for turboprop aircraft. Research is needed to improve the ability to predict and monitor environmental conditions and develop aerodynamic designs and techniques that are robust to adverse conditions. Techniques to predict and mitigate the impact of adverse environmental conditions on the aircraft operation, including validation of icing prediction capabilities, should be improved (Ref. 6).

The joint government/industry Commercial Aviation Safety team has recommended that manufacturers of new turboprop type designs adapt and implement systems that automatically detect the presence of icing conditions that exceed those for which the aircraft has been certified; monitor, if feasible, the accretion rate for advisory purposes; and provide annunciation to the flight crew. For current turboprop production aircraft and existing type designs, manufacturers should be requested to conduct a study to determine the feasibility of installing systems that automatically detect the presence of icing conditions and alert the flight crew. These recommendations apply to all turboprop aircraft that are operated in commercial passenger and cargo revenue service that have non-evaporative ice protection systems and non-powered flight controls (Ref. 13).

The consequences that result from operating an airplane in icing conditions without first having thoroughly demonstrated adequate handling and controllability characteristics for that airplane under adverse weather conditions are severe in most cases. This fact alone warrants a thorough certification test program, including the application of revised standards to airplanes that are currently certificated for flight in icing conditions. Specific NTSB recommendations for reducing the dangers to aircraft flying in icing conditions include using current research on freezing rain and large water droplets to revise the manner in which aircraft are designed and approved for flight in icing conditions, applying revised icing requirements to currently certificated aircraft, and requiring that airplanes with pneumatic deice boots activate the boots as soon as the airplane enters icing conditions (Ref. 8).

Super Density Operations

Expected growth in the demand for air transportation will require more efficient, denser en route and terminal area operations. This necessitates procedures that reduce minimum spacing requirements during all phases of flight and in all weather conditions, through an integrated approach that leverages a suite of emerging technologies such as performance-based navigation and automatic dependent surveillance broadcast (ADS-B). Performance-based navigation procedures, such as required navigation performance (RNP), area navigation (RNAV), optimized profile descents, and tailored arrivals for oceanic flights, are being developed to increase the capacity and efficiency of the National Airspace System, as well as to provide environmental benefits in terms of reductions in fuel emissions and aircraft noise. The National Science and Technology Council state that “reduced aircraft separation will require a move to trajectory-based operations, performance-based navigation, and a new allocation of responsibilities between air and ground and between humans and automation. In addition, planned advanced airspace design concepts that can be dynamically adjusted to meet demand requirements and to avoid hazardous weather conditions must be developed with safety in mind.”

Increasing capacity will depend not only upon reducing lateral and longitudinal separation standards for arrival and departure operations but on efficiently managing the movements of greater numbers of aircraft on airport surfaces as well. To accomplish this while maintaining or improving safety, procedures will be needed to efficiently accommodate a large number and wide range of aircraft types through spacing and sequencing based on aircraft type and equipment rather than a common worst-case standard. New concepts of operation should be evaluated in terms of their technological, business, and human factors issues as well as their impact on capacity, safety, and the environment. Furthermore, safe, high-capacity operations in a complex future airspace environment will require innovative ATM procedures, such as simultaneous non-interfering operations, in which general aviation and rotorcraft are threaded through airspace that is unused by commercial air traffic (Ref. 6).

Air traffic control is currently a labor-intensive process. FAA controllers, aided by radar, weather displays, and procedures, maintain traffic flow and assure separation by communicating instructions to aircraft in their sector of responsibility. In many busy terminal areas, system limitations constrain the capacity of the air transportation system, resulting in congestion-related delays. Initiatives to reduce aircraft separation by automating time-critical separation-assurance tasks and providing automated advisories to air traffic controllers and flight crews are being investigated. However, changing the role of the controller from tactical separation to traffic flow management and trusting automated systems to manage the tactical separation of aircraft is a source of potential risk in the NAS that will require resolution of major human factors, safety, and institutional issues (Ref. 6).

The expected growth in air transportation demand will likely require operators to perform a wider range of tasks and to collaborate more closely with one another and rely more heavily on modern technologies. For example, pilots may begin to play a more active role in traffic separation or spacing and will need to coordinate their activities and intentions with other pilots and controllers. With the introduction of technologies like ASAS (Airborne Separation Assistance Systems) and ADS-B (Automatic Dependent Surveillance), future flight crews may be faced with increased responsibility for separation assurance during all phases of flight (Ref. 11). The need to interact and exchange information and to distribute more information in a timely manner will become increasingly critical. In order to provide increased utilization of the airspace, separation standards may decrease between runways, between aircraft, between landing operations, and for vertical separation. The risk of runway incursions may also increase as a result. The reliability of the technologies and procedures that enable reduced separation must be assured. In addition, research into candidate concepts of operations and enabling technologies is needed for any change in separation responsibility from ground controllers to the cockpit.

Human Fatigue

Fatigue is a crosscutting issue that does not map to one particular accident category; rather, it can be an important contributing factor in all types of aircraft accidents. Generally speaking, fatigue is weariness from physical and/or mental exertion, which can often result in the degradation of human performance. It includes both human factors and human fatigue issues in design, operations, air traffic management, and maintenance, repair, and overhaul. Human fatigue can lead to a loss of situational awareness on the part of pilots or controllers, which in turn can lead to a lack of perception and comprehension of elements in the surrounding environment and a lack of projection of their status in the near future. Fatigue can result from many factors, including inappropriate prioritization of tasks, channeling of attention, or inappropriate allocation of tasks between humans and automation. Fatigue also can include loss of awareness of automation status, systems, terrain, traffic, and surrounding environment. Commercial airline pilots have identified sleep deprivation, high workload, and circadian rhythm interruption as the main factors that contribute to fatigue. The risk of increased fatigue of flight crews in future flight operations may occur as a result of the longer flight duty times that are associated with ultra long-range flights with minimum crew or the heavier workload that can be experienced in regional operations (Ref. 11).

Operating a vehicle without the operator’s having adequate rest, in any mode of transportation, presents an unnecessary risk to the traveling public. The NTSB has long been concerned about the effects of fatigue on persons performing critical functions in all transportation industries. In the aviation industry, this includes flight crews, aviation mechanics, and air traffic controllers. Their recommendations on the issues of human fatigue and hours-of-work policies have had a substantial effect on encouraging the modal agencies to conduct research and take action toward understanding the complex problem of operator fatigue in transportation and its effect on performance. However, the issue of fatigue has remained on the NTSB’s list of most wanted safety improvements since 1990. To reduce the number of accidents and incidents that are caused by human fatigue in the aviation industry, the NTSB has recommended that the FAA issue regulations that establish scientifically based duty-time limitations for air carrier maintenance personnel and flight crews. For air traffic controllers, the NTSB recommendations include revising controller work-scheduling policies and practices to provide adequate rest periods, modifying controller shift rotations to minimize fatigue, and developing fatigue awareness and countermeasures training programs for controllers (Ref. 8).

Recognizing that prior recommendations dealt primarily with flight- and duty-time regulations, the NTSB has recently recommended that the FAA oversee the implementation of a fatigue management system that would address the problems that are associated with fatigue in an operational environment and take a comprehensive, tailored approach to the problem of fatigue within the industry. A fatigue management system would encompass much more than just the establishment of guidelines or standards regarding duty, flight, and rest periods. As envisioned by the NTSB, a fatigue management system would incorporate various strategies to manage fatigue, such as scheduling practices, attendance policies, education, medical screening and treatment, rest environments, and commuting policies (Ref. 8).

Increasing Complexity and Reliance on Automation

Automation, as a concept, is the allocation to machines of functions that otherwise would be allocated to humans. The term also is used to refer to the machines that perform these functions. Flight-deck automation, therefore, consists of machines on the commercial transport aircraft flight deck that perform functions that otherwise would need to be performed by pilots. Current flight-deck automation includes autopilot systems, flight-path management systems, electronic flight instrument systems, and warning and alerting systems. With the advent of advanced technology and the so-called "glass cockpit," as well as the transfer of safety-critical functions away from human control, pilots, scientists, and aviation safety experts have expressed concerns about the safety of flight-deck automation (Ref. 11).

Commercial transport aircraft flight-deck automation has been well-received by pilots and the aviation industry as a whole. Accident rates for advanced technology aircraft are generally lower than those of comparable conventional aircraft. Nevertheless, pilots, scientists, and aviation safety experts have expressed some concerns about flight-deck automation, including fear that pilots may place too much confidence in automation, concern that pilots may lose manual flying skills, and concern that pilot-automation interfaces may be poorly designed (Ref. 11). Increasingly, aircraft systems are being designed to automatically reconfigure themselves in the event of system failures without notifying the crew of early trends that may indicate anomalous component performance.

Increasing pressure to replace humans with automated systems may characterize future design philosophies. An increasing need exists to adequately design systems from the start to take advantage of human flexibility and creativity and to augment human abilities and limitations with automated systems. This has been (and is still) the focus of many activities (e.g., human-machine interface, cockpit design, autopilot, and Flight Management System certification criteria); methodologies are being developed by manufacturers with the participation of human-factors specialists. However, the likelihood exists that crews will unconsciously relinquish command responsibilities momentarily to automated systems. The unknown effects of aircraft/pilot coupling potentially could result in a perfectly normal flight suddenly taking on characteristics that the pilot has seldom or never encountered previously.

The ever-increasing demand for air transportation, combined with the rapid pace of technological change, poses significant challenges for the effective integration of humans and automation. With the increasing reliance on and complexity of flight-deck automation, a better understanding of the causes of human error and of human contributions to safety is needed. In complex and highly automated aircraft, flight crews can lose situational awareness of the automation mode under which the aircraft is operating or may not understand the interaction between a mode of automation and a particular phase of flight or pilot input. Situations such as these can lead to the crew’s mismanagement of the energy state of the aircraft or to the deviation of the aircraft from the intended flight path for other reasons. Design guidelines should be developed that will help minimize the potential for design-induced error and facilitate positive human intervention in the event of system failure. The emphasis of air-carrier policies and procedures should be to help minimize the frequency with which flight crews induce automation errors and to help flight crews recognize and correct automation errors in a timely manner, regardless of the source of the error (Ref. 15).

Based on the National Research Council’s decadal survey of civil aeronautics (Ref. 6), research on human and machine integration technologies for vehicle applications should include the following:

- Development and testing of enabling technologies for pilot workload management and reduced crew operations (e.g., improved human and machine integration for a flight management system) that also maintain pilot awareness at the proper level.

- Development of display concepts for maintaining operator situational awareness in the monitoring of highly automated processes. Demonstration of the ability of operators to rapidly and accurately intervene in the event of a system failure.

- Development of technologies and display concepts that enable the effective fusion of information from multiple sources.

Aircraft Mixed Fleet Equipage

Not all aircraft may have the same level of equipage in future “free flight” environments. This could lead to multiple modes of conflict resolution (e.g., air-to-air, air-to-ground) and to problems in maintaining situational awareness when significant gaps in knowledge exist regarding other aircraft (e.g., flight path intent information may be lacking, or even knowledge that other aircraft exist). Technologies and procedures to manage the mix of low- and advanced-technology aircraft within the airspace must be developed, or low-technology aircraft must be excluded from airspace that is used by advanced aircraft (Ref. 11).

The operational capabilities of NextGen will provide air traffic controllers with improved tools to handle more complex traffic while improving service. Some of these capabilities will take advantage of existing avionics, such as RNAV and RNP, while others will require new avionics, such as ADS-B. The rate at which users equip for those capabilities that require new avionics will influence the magnitude and timeframe in which NextGen benefits are realized.

While lesser equipped aircraft will still be accommodated in the NAS, ensuring that a significant portion of the aircraft fleet is appropriately equipped to take advantage of capacity, efficiency, and environmental improvements is a critical issue for NextGen. However, recognizing that all aircraft will not be similarly equipped adds complexity to the task of air traffic service providers and presents a future safety challenge for NextGen. The FAA has established a set of governing principles for an integrated avionics equipage strategy that is aimed at accelerating the NextGen operational capabilities in the mid-term time frame (i.e., 2012–2018). These include (1) targeting equipage and associated capabilities to maximize operational benefits for the specific locations or airspace that require a higher performance level in order to elevate system performance and to satisfy demand and (2) providing a “best-equipped, best-served” priority in the NAS to early adopters of advanced avionics (Ref. 12).

Inadequate Protection, Analysis, and Dissemination of Safety Data

Through the collection, analysis, and dissemination of relevant data, decision makers throughout industry, air navigation service providers (ANSPs), and regulatory authorities will be able to proactively implement changes that have a positive effect on safety. Nonetheless, these organizations have historically collected a significant amount of data without having established common taxonomies or appropriate governance to facilitate the sharing of valuable safety data. Consequently, the industry as a whole is data rich and information poor. The IATA has been working with key airlines, ANSPs, and airport and regulatory authorities to create a global data-collection process to provide the ability to accurately measure and benchmark safety occurrences and, as a result, create effective mitigation strategies that are appropriate for airlines operating in specific regions.

Safety data provide the basis for discovering vulnerabilities in the air transportation system. The following issues must be addressed for future safety benefits to be attained by preventing potential vulnerabilities from becoming accidents (Ref. 10):

- Inadequate dissemination of flight-critical information within the organization.
- Failure to share significant data between airlines/operators.
- Failure to disseminate critical information between manufacturers.
- Lack of formalized, threat-free information reporting from operators to manufacturers.
- Insufficient analysis of incidents.
- Failure of regulators to disseminate critical flight safety information to flight crews.
- Timely flight safety information not shared between validating authority and certificating authority.
- Failure of the airline/operator and ATC processes to identify and stress the criticality of self-reporting of incidents and safety issues by operational personnel.
- Assurance to operational personnel that the data they provide will be protected and not used for punitive action.

The current air transportation system has reached a state in which low accident levels for commercial aviation, coupled with the traditional forensic investigation approach to aviation safety, are yielding fewer insights that significantly improve aviation safety (Ref. 7). Thus, traditional methods of historical or forensic review of accident data cannot be relied upon as the sole predictor of risk and future events. As the number of accidents and serious incidents decrease as a result of better design, better hazard elimination, and better risk mitigation, more attention will be needed on the identification of subtle system-level issues and anomalies in order to predict future safety issues before they lead to serious accidents or incidents. Advances in prognostic techniques enable insights into system safety through the examination of large numbers of normal operations as well as incident events.

In the National Aeronautics Research and Development Plan, the National Science and Technology Council offers two data-analysis recommendations that are aimed at reducing accidents and incidents. These involve the identification of system-wide safety risks through the examination of prognostic methodologies that are capable of organizing, managing, and mining data from all users in the entire airspace system. The first recommendation is to develop advanced methods to automatically analyze textual safety reports and extract system performance information for prognostic identification of safety risks for system operators and designers. Secondly, fundamentally new data-mining algorithms should be developed to support automated data-analysis tools to integrate information from a diverse array of data resources (i.e., numeric and textual) to enable rapid prognostic identification of system-wide safety risks. These research objectives will organize and manage data from all users in the entire airspace system and mine those data to actively identify safety risks to the affected users, rigorously integrating both objective statistical techniques and operator reports of safety concerns.

Proactive safety management and integrated safety cases allow the early identification of problems and the analysis of trends so that preventive measures are put in place before any accidents can occur. The

FAA's ASIAS program provides a suite of tools that extract relevant knowledge from multiple, disparate sources of safety information. The ASIAS program also helps the FAA and industry in monitoring the effectiveness of safety enhancements (Ref. 14). The ASIAS team has suggested that as aircraft become more complex, a need exists for standard logical frame layouts in aircraft data. Further, the need exists for global sharing of data and for standardization of data collection and common taxonomies for textual data. Finally, improving the quality and dissemination/sharing of regional jet, rotorcraft, and general aviation data and safety information is needed.

Enhanced Survivability in the Event of an Accident

Enhancing and protecting the safety of passengers, crews, and ground personnel in the event of an accident is a key research challenge to improving aviation safety. The research can be broken into two categories: (1) improving crash survivability of aircraft structures and (2) improving evacuation and accident response procedures. At present, nearly half of the aircraft fatalities in impact-survivable accidents are due to the effects of smoke and fire (Ref. 7). Research into understanding and reducing flammability of aircraft interiors is essential to making impact accidents survivable for crew and passengers, and firefighters as well. Post-impact fire and evacuation were two safety concerns that were expressed by several organizations that provided input to the JPDO Safety Working Group Safety Issues Database (Ref. 10). Accidents and incidents that were related to emergency evacuation were defined as those occurrences for which person(s) were injured during the evacuation, an unnecessary evacuation was performed, evacuation equipment failed to perform as required, or the evacuation was a factor in the outcome.

While significant progress has been made to mitigate the catastrophic effects of post-impact fires and structural damage to the aircraft, this remains an issue of concern for aviation safety. With the introduction of alternative fuel technologies and advanced composite and metallic materials, enhancing post-accident survivability will continue to be a safety risk area. Future aircraft will be made from advanced, novel materials in more complex configurations, with more technically advanced subsystems and avionics. When accidents do occur, the probability of survival for the passengers and crew on board must be as high as possible. Research into understanding the flammability of alternative fuels and smoke toxicity of advanced aircraft materials is needed. Restraint systems that are integrated into and as strong as the supporting aircraft structure offer the possibility of providing increased occupant survivability; further research into these systems is essential. Lastly, examination of current and future evacuation procedures and accident-response procedures will ensure that new aircraft are as safe as or safer than the aircraft of today (Ref. 7).

4. Top-Down Systems Analysis

An established, peer-reviewed systems-analysis methodology was used to conduct a detailed, top-down (goal-oriented) analysis of the NASA AvSafe program. This section contains a description of the study methodology, the top-level goals and objectives for the NASA AvSafe program, the assessment criteria, and a discussion of the impact of the current AvSafe portfolio based on these criteria.

4.1 Top-Down Systems Analysis Methodology

The overall goal of this study was to develop a set of challenging safety issues that NASA potentially could address in its aviation safety research portfolio. The systems analysis methodology that was developed by John Gibson (Ref. 16) was selected as the basis for this study because it is a top-down, goal-oriented approach to systems analysis that also contains elements of sociotechnical systems (Ref. 17) concepts. The methodology that was used for the analysis of the NASA AvSafe program is summarized in Fig. 5.

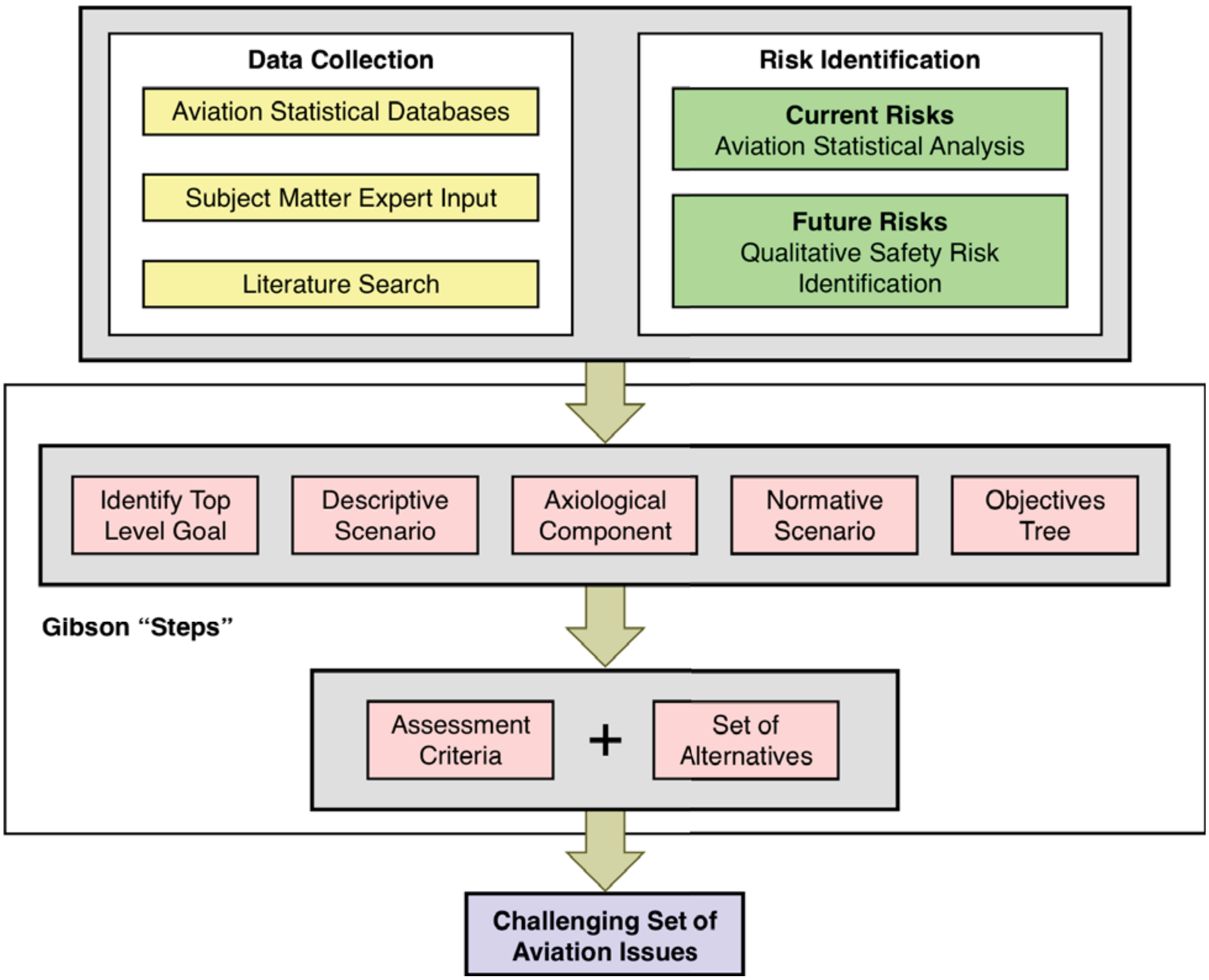

Figure 5. Methodology used for top-down analysis of NASA AvSafe program.

Data that were used in the study were collected from three sources: (1) aviation statistical databases, (2) subject-matter experts, and (3) literature review. The aviation statistical databases that were used in the study, as described in section 2, include those from the NTSB and the FAA. Input was obtained from various subject-matter experts, both internal (i.e., NASA researchers and management) and external to the agency. An exhaustive search of published literature, presentations, government and business plans, and other aviation-safety-related documents also was conducted. A complete listing of the documents that were reviewed in the study is given in the reference section. The results from the aviation statistical data analysis (given in section 2) were used to develop a set of current safety risks or "tall poles" for each of the three types of operations that were analyzed (i.e., FAR Parts 121, 135, and 91). Similarly, the qualitative safety risk identification (discussed in section 3) identified those issues that are likely to continue to pose a safety risk in the future.

The step entitled "Identify Top Level Goal", which is identical to the "Generalize the question" from Gibson's goal development process, was used to identify the top-level goal for the NASA AvSafe program (see Fig. 5). The information that was obtained from the data collection and the risk identification processes was used to gain a clear understanding of the current aviation safety problem ("Descriptive Scenario"), determine some of the ideal safety issues in the future NAS ("Normative Scenario"), and identify values that are important to NASA and the stakeholders in the NAS ("Axiological Component"). In addition, an "Objectives Tree" was developed to graphically display the relationship between the top-level goal and other high-level goals and objectives.

Based on all of this information, a high-level set of assessment criteria was generated, along with a list of research alternatives. Because of the time constraints on this study, the assessment criteria were used to evaluate only the current AvSafe research portfolio. This same set of criteria is recommended for use to assess any of the possible research alternatives that are not in the current portfolio.

Although not explicitly shown in figure 5, the "Iteration" and "Validation" steps for the goal-development process and the overall systems methodology were also conducted in this study.

4.2 NASA AvSafe Program Goal and Objectives

NASA AvSafe Research

To begin the process of determining the top-level goal of the NASA AvSafe program, a review of publicly stated goals and objectives yielded the following results:

- "To improve the safety of current and future aircraft operating in the NAS" (Ref. 2).

- "To identify and develop tools, methods, and technologies for improving overall aircraft safety of new and legacy vehicles operating in the Next Generation Air Transportation System" (Refs. 2, 18).

  "The AvSafe program will take a proactive approach to safety challenges with new and current vehicles and with operations in the nation's current and future air transportation system. In addition, the program will continue the effort to examine key challenges in verifying and validating flight critical systems" (Ref. 19).

- "The aeronautics research portfolio is closely aligned with this national plan (for aeronautics R&D) and includes research content as the key areas called outreach plan [sic] of mobility, energy and environment, safety and national security" (Ref. 19).

Secondly, the following U.S. government aviation safety research plans were examined for their relevance to NASA's AvSafe goals:

- National Aeronautics Research and Development Plan (Ref. 7)
- JPDO National Aviation Safety Strategic Plan (NASSP) (Ref. 20)
- FAA Aviation Safety Fiscal Year 2010 Business Plan (Ref. 21)
- FAA 2009 National Aviation Research Plan (Ref. 22)

Finally, the aviation safety research plans or stated needs for the following agencies and organizations were reviewed to obtain information about planned or ideal future goals and research activities:

- The Boeing Company
- European Aviation Safety Agency (EASA)
- EUROCONTROL
- International Helicopter Safety Team
- U.S. universities

Following discussions with the current AvSafe program management staff, the top-level goal for AvSafe is defined as:

> *To proactively identify and develop tools, methods, and technologies for improving overall aircraft safety of new and legacy vehicles operating in the Next Generation Air Transportation System.*

Both the NASA Strategic Plan and the NASA FY2011 Budget Request both imply that the goals of the AvSafe program should support, respectively, the Next Generation Air Transportation System and the National Plan for Aeronautics Research & Development. Therefore, the top-level AvSafe goal and the goals and objectives set forth in these two plans are connected in the high-level objectives tree (Fig. 6). Note that three of the NASSP objectives were not included in the objectives tree because they are not within the current charter of the NASA AvSafe program. The three objectives that were omitted are:

- Objective 1A: Provide consistent safety management approaches that are implemented throughout government and industry.
- Objective 3A: Encourage development and implementation of safer practices and safer systems worldwide.
- Objective 3B: Establish equivalent levels of safety across air transportation system boundaries.

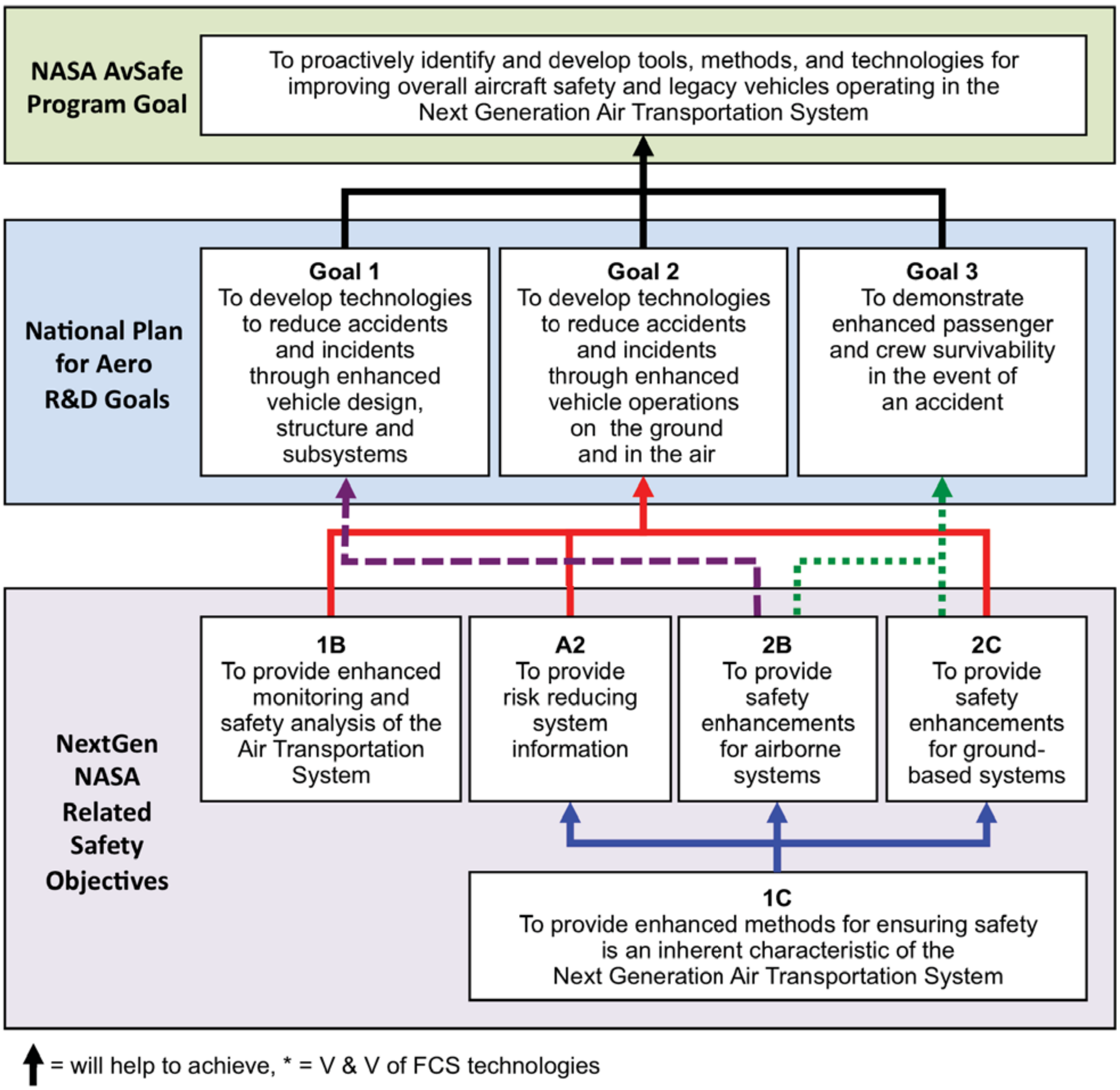

Figure 6. NASA AvSafe program objectives tree.

4.3 Portfolio Assessment Criteria

The set of assessment criteria is a means for evaluating the goals and objectives that were outlined for the AvSafe program and summarized in the previous section. The criteria are not performance indicators for the system. Performance indicators (Ref. 23, pp. 191–193) should be developed at the start of the proposed projects by principal investigators and other key research leads. The current AvSafe portfolio is evaluated by using a rating system that is a combination of the definitions that were used in the 2008 evaluation of NASA aeronautics research by the National Research Council (Ref. 24) and the interaction matrix concept (Ref. 16). Also, for the assessments that were conducted with these ratings, the technologies were assumed to be fully realized. The rating system is as follows:

D	Direct impact
I	Indirect impact
	Very little or no impact

- **Direct impact:** NASA technology will directly impact the potential either for reducing the likelihood of a future occurrence of this accident category or risk area or for achieving a technical goal. This technology will significantly advance the state of the art.

- **Indirect impact:** NASA technology will indirectly impact the potential either for reducing the likelihood of a future occurrence of this accident category or risk area or for achieving a technical goal. The research described, if successful, would make only moderate advances in the state of the art of relevant technologies, although the results would still be substantial.

- **Very little or no impact:** NASA technology will have very little or no impact on reducing the likelihood of a future occurrence of this accident category or risk area or in achieving this technical goal.

The criteria that will be used to evaluate the current NASA AvSafe program portfolio are as follows:

- Expected impact on historic Part 121 “tall poles”
- Expected impact on historic Part 135 “tall poles”
- Expected impact on historic Part 91 “tall poles”
- Expected impact on future safety risk “tall poles”
- Expected impact on JPDO NextGen “NASA-related” safety objectives
- Expected impact on *National Aeronautics R&D Plan* safety-related goals

The rationale for using this set of criteria is to evaluate the impact that the current NASA AvSafe portfolio will have on current safety risks (i.e., historic tall poles), future safety risks (i.e., future safety risk tall poles) and NASA’s high-level goals and objectives (i.e., both from National aeronautics R&D programs and the JPDO safety objectives).

Other criteria were considered but could not be used in this assessment as a result of the three-month time constraint for the study. For example, given the current limitations in the U.S. budget, one suggested criterion was the “uniqueness” of the research. Three suggested ratings for this criterion were: (1) totally unique to NASA (i.e., only one U.S. researcher), (2) collaboration with the FAA or other U.S. agency, and (3) duplication of other U.S. research without collaboration. Another suggested criterion that addresses the axiological component was the “correlation of the research activities to the NASA skill set.” Finally, given that the assessments that were conducted in this study did not account for impediments to successful completion of these research activities, the following additional criteria were also recommended for future assessments of the NASA AvSafe Research portfolio (Refs. 23, 25):

- Technology readiness level (TRL)
- Technical development risk (TDR)
- Implementation risk (IR)
- Cost
- Expected implementation cost
- Programmatic cost

Note that some categories of aviation accidents can continue long after mitigating technologies have been developed due to slow adaptation rates. For example, one researcher suggested that we not invest in research that addresses problems that have essentially been solved (e.g., CFIT) with modern equipage. Thus, if historic tall poles are used for portfolio evaluation, these criteria should only be used in combination with other criteria with a more future-oriented vision. Conversely, however, a totally forward-looking vision may overlook some long-established trends that continue to pose a safety risk.

4.4 Assessment of Current Portfolio

The AvSafe program research portfolio in January 2010 (Ref. 2) consisted of the following four projects:

- Integrated Vehicle Health Management (IVHM)
- Integrated Intelligent Flight Deck (IIFD)
- Integrated Resilient Aircraft Control (IRAC)
- Aircraft Aging and Durability (AAD)

Information that was used to assess these projects was obtained from several sources, including projects plans (Ref. 2), conference documents, internal presentations and white papers, informal discussions with NASA internal personnel, and prior knowledge of systems analysis team members. In the justification for each rating, a reference for a specific project milestone or subtopic (IIFD and IVHM), challenge problem (AAD), or technology number (IRAC) was provided. A list of technologies for the IRAC portfolio was previously developed for use in an FY2010 milestone by several of the authors of this document prior to the beginning of this study. This technology list also was used in this study in the evaluation of the IRAC portfolio and is included in Appendix D.

4.4.1 Expected Impact of Current Portfolio on Historic Part 121 Tall Poles

Table 5 contains a mapping of expected impact of the current AvSafe portfolio on the historic Part 121 tall poles.

Table 5. Impact of Current AvSafe Portfolio on Part 121 Tall Poles

Part 121 tall pole	**Aviation safety project**			
	IIFD	IRAC	IVHM	AAD
Abrupt maneuver	D	I		
Fire – post impact				
Loss of control – in flight	I	D / I	I	
System/component failure/malfunction – powerplant		D	D	D
System/component failure/malfunction – nonpowerplant	I		D	I / D
Turbulence encounter	I	I		

Abrupt Maneuver (AMAN)

This category is defined as the intentional abrupt maneuvering of the aircraft by the flight crew to avoid a collision with terrain, objects/obstacles, weather, or other aircraft (Ref. 4). Two research subtopics (SS.1 and SS.2) for the IIFD project address this CICTT occurrence category and, thus, will have a direct impact. Within the IRAC project portfolio, proposed research in maneuvering envelope identification algorithms (IRAC-2), aerodynamic modeling of off-nominal flight conditions (IRAC-4), and flight dynamic models of unsteady aerodynamics (IRAC-5) were classified as having an indirect impact.

Fire – Post Impact (F-POST)

This category is defined as "fire/smoke resulting from impact" (Ref. 4). None of the research areas in the current AvSafe portfolio address this occurrence category.

Loss of Control – In Flight (LOC-I)

This category is defined as loss of aircraft control or a deviation from the intended flight path in flight (Ref. 4). Note that in the CICTT definition of this category, if the loss of control is the direct result of a system/component failure or malfunction, then the event is classified solely as a system/component failure/malfunction rather than as a loss-of-control event. Given this restrictive definition of loss of control, the only research areas that were determined to have a direct impact on this occurrence category were within the IRAC portfolio; these include development of adaptive control algorithms (IRAC-1), development of maneuvering envelope identification algorithms (IRAC-2), development of emergency trajectory and flight-planning guidance algorithms (IRAC-3), aerodynamic modeling of off-nominal flight conditions (IRAC-4), flight dynamic modeling of unsteady aerodynamics (IRAC-5), and modeling of real-time full-envelope flight dynamics (IRAC-7). The remaining research within the IRAC portfolio (i.e., initiatives related to icing (IRAC 6 and 9) or to enabling technologies (IRAC 8 and 10)) was classified as having an indirect impact on this occurrence category. Hazard detection research within the IIFD project (e.g., forward-looking interferometric sensing) and the IVHM project (milestones 1.1.1.9 and 2.2.1.1) were also classified as having an indirect impact on the occurrence category. Note that loss of control due to icing is categorized under "Icing."

System Component Failure or Malfunction – Powerplant (SCF-PP)

This category is defined as the failure or malfunction of an aircraft system or component that is related to the powerplant (Ref. 4). This category includes failures or malfunctions that are maintenance related but excludes problems that are attributed to carburetor and induction icing or fuel problems (e.g., fuel starvation, fuel exhaustion, or fuel contamination); thus, IRAC icing research (IRAC-9) is not applicable to this category. All of the research in the AvSafe portfolio that does address this occurrence category would have a direct impact on these types of events. These specific AvSafe research areas include IRAC technology 10 (engine performance, usage, and prognostic modeling), the IVHMPropulsion Health Management element, and AAD challenge problems 5, 6, and 7.

System Component Failure or Malfunction – Non-Powerplant (SCF-NP)

This category is defined as the failure or malfunction of an aircraft system or component other than the powerplant (Ref. 4). The proposed research in IVHM element 2.1 (aircraft systems) and in AAD challenge problem 8 (wiring degradation and faults) directly impacts this occurrence category. The fault-tolerant system modeling research within the IIFD project (IM.3) and the AAD challenge problems (problems 1, 2, and 4) also impact this category, but the impact is expected to be indirect. Note that the airframe structural failure research within both the AAD and the IVHM projects (element 2.2: Airframe Health Management) and the verification and validation research of flight critical systems that is currently being conducted within both the IVHM project (element 2.4: Software Health Management) and the IRAC project were determined to have little no impact on this category because these types of malfunctions were not in the data set that was examined.

Turbulence Encounter (TURB)

Any in-flight encounters with turbulence, including clear air, mountain waves, and wake vortices are included in this category (Ref. 4). The research within the IIFD project that involves the detection of various external hazards, including turbulence (IIFD milestones SS.1–SS.3) and the IRAC project research that addresses recovery from encounters with turbulence (IRAC-2, -4, -5, and -7) will have an indirect impact on this occurrence category.

4.4.2 Expected Impact of Current Portfolio on Historic Part 135 Tall Poles

Table 6 contains a mapping of expected impact of the current AvSafe portfolio on the historic Part 135 tall poles.

Table 6. Impact of Current AvSafe Portfolio on Part 135 Tall Poles

Part 135 tall pole	Aviation safety project			
	IIFD	IRAC	IVHM	AAD
Abnormal runway contact	I	I		
Bird strike				
Controlled flight into terrain	I	I		
Fire – post impact				
Icing	I / D	D	D	
Loss of control – in flight	I	D / I	I	
Runway excursion	I			
SCF – powerplant		D	D	I
SCF – nonpowerplant	I		D	I / D

Abnormal Runway Contact (ARC)

This category is defined as any landing or takeoff that involves abnormal runway or landing-surface contact (Ref. 4). Specific types of events that are included in this category include tail strikes, hard/heavy landings, and gear-up landings. The research in the AvSafe portfolio that will have an indirect impact on this occurrence category includes emergency trajectory and flight-planning guidance algorithms (IRAC-3), aerodynamic modeling of off-nominal flight conditions (IRAC-4), and remote sensing and image-processing research (IIFD milestones SS.1–SS.2).

Bird Strike (BIRD)

This recently added category includes occurrences that involve collisions or near collisions with birds and other types of wildlife during any phase of flight. None of the research areas in the current AvSafe portfolio address this occurrence category.

Controlled Flight Into Terrain (CFIT)

Controlled flight into terrain is defined as an in-flight collision or near collision with terrain, water, or obstacle without the indication of loss of control (Ref. 4). IIFD project research in external hazard characterization (IIFD SS. 3.1) and multimodal interface technologies (IIFD MM.1–MM.3), in addition to IRAC project research regarding emergency trajectory and flight-planning guidance algorithms (IRAC-3), will have an indirect impact on this occurrence category.

Fire – Post Impact (F-POST)

As previously mentioned under Part 121, none of the research areas in the current AvSafe portfolio address this occurrence category.

Icing (ICE)

Icing is defined as the accumulation of snow, ice, freezing rain, or frost on aircraft surfaces that adversely affects aircraft control or performance (Ref. 4). This category includes events such as windshield icing that restricts visibility and ice accumulations on antennae and other external surfaces; however, carburetor and induction icing events are excluded from this category and are coded in the category for fuel-related issues. AvSafe research initiatives that directly impact this occurrence category are as follows: remote sensing and characterization of icing (IIFD SS.4), modeling of airframe and engine icing (IRAC-6 and IRAC-9), ice crystal sensing in high-density icing environments (IVHM milestone 1.1.1.2) and developing a real-time iced aerodynamic degradation detection system for flight envelope protection (IVHM milestone 1.1.1.13). Because the research within the IIFD project (SS.1–SS.3) is expected to detect some icing-related hazards (e.g., icy runways and in-flight icing conditions), this portion of the IIFD portfolio will indirectly impact this occurrence category.

Loss of Control – In Flight (LOC-I)

The research in the AvSafe portfolio that is applicable to this occurrence category under Part 135 is identical to the previously mentioned activities for this category under Part 121, except for the deletion of the IVHM research that is related to milestone 2.2.1.1 (i.e., the development of technologies for the detection of possible damage to or degradation of airframe structural components).

Runway Excursion (RE)

A runway excursion is defined as “a veer off of or an overrun of the runway surface.” This category is only applicable for events that occur during takeoff or landing. The IIFD project milestones for sensing, signal processing, and hazard characterization (IIFD SS.1–SS.3) will have an indirect impact on this category.

System Component Failure or Malfunction – Powerplant (SCF-PP)

The results for Part 135 are identical to the results that were previously described for this occurrence category under Part 121, except that the research that is being conducted for AAD challenge problems 5, 6, and 7 will have an indirect rather than a direct impact on this occurrence category.

System Component Failure or Malfunction – Nonpowerplant (SCF-NP)

Results for Part 135 are identical to the results that were previously described for this occurrence category under Part 121.

4.4.3 Expected Impact of Current Portfolio on Historic Part 91 Tall Poles

Table 7 contains a mapping of expected impact of the current AvSafe portfolio on the historic Part 91 tall poles.

Table 7. Impact of Current AvSafe Portfolio on Part 91 Tall Poles

Part 91 tall pole	**Aviation safety project**			
	IIFD	IRAC	IVHM	AAD
Abnormal runway contact	I	I		
Controlled flight into terrain	I	I		
Collision with object – takeoff or landing	I			
Fire – post impact				
Low-altitude operations	I			
Loss of control - in flight	I	I	I	
Loss of control – on ground	I			
Power loss - fuel				
Runway excursion	I			
SCF – powerplant			D	I
SCF – nonpowerplant	I		D	I

Abnormal Runway Contact (ARC)

The research activities in the AvSafe portfolio that are applicable to this occurrence category for Part 91 are identical to the activities that are applicable to Part 135 for the same category, with the exception of IRAC-4 (aerodynamic modeling of off-nominal flight conditions). As defined in the current IRAC portfolio, the research activities for IRAC-4 involve transport aircraft only.

Controlled Flight into Terrain (CFIT)

The results for Part 91 are identical to the results that are previously described for this occurrence category under Part 135.

Collision with Object(s) – Takeoff or Landing (CTOL)

The CICCTT defines this category as a collision with obstacle(s), during takeoff or landing, while airborne. The IIFD project includes research that examines hazards in the terminal area (IIFD SS.3.1) which will have an indirect impact on this occurrence category.

Fire – Post Impact (F-POST)

As previously mentioned under Part 121, none of the research areas in the current AvSafe portfolio address this occurrence category.

Low-Altitude Operations (LALT)

This category is defined as a collision or near collision with obstacles/objects/ terrain while intentionally operating near the surface, excluding takeoff and landing phases. The types of low-altitude operations that are included in the category are aerobatics, search-and-rescue operations, demonstration flights, and sightseeing. The multimodal interface research within the IIFD program (IIFD subtopics MM.1–MM.3) will have an indirect impact on this occurrence category.

Loss of Control – In Flight (LOC-I)

Several research areas in the AvSafe portfolio have a direct impact on in-flight loss of control. However, for Part 91 operations, all of the AvSafe research that is applicable to this occurrence category will have only an indirect impact. These specific research areas include the development of adaptive control algorithms (IRAC-1), the development of maneuvering-envelope identification algorithms (IRAC-2), the development of emergency trajectory and flight-planning guidance algorithms (IRAC-3), flight-dynamic modeling of unsteady aerodynamics (IRAC-5), hazard detection research within IIFD (e.g., the development of forward-looking interferometric sensing), and the development of lightning-strike sensors for avionics on composite-based aircraft (IVHM milestone 1.1.1.9).

Loss of Control – Ground (LOC-G) This occurrence category is defined as the loss of aircraft control while the aircraft is on the ground. The loss of control can result from contamination on the runway or taxiway, including rain, snow, or slush. The IIFD remote-sensing and image-processing research (IIFD subtopics SS.1–SS.2) will have an indirect impact on this occurrence category.

Power Loss – Fuel (FUEL)

Events in this category are defined as having one or more powerplants with reduced or no power output due to fuel exhaustion, fuel starvation/mismanagement, fuel contamination/wrong fuel, or carburetor and/or induction icing.” None of the research in the current AvSafe portfolio will have any impact on this category.

Runway Excursion (RE)

The results for Part 91 are identical to the results that were previously described for this occurrence category under Part 135.

System Component Failure or Malfunction – Powerplant (SCF-PP)

The research within the Propulsion Health Management element of the IVHM project will have a direct impact on this occurrence category for Part 91 operations. In addition, AAD research for challenge problem 6 (durability of engine superalloy disks) will have an indirect impact on this occurrence category.

System Component Failure – Nonpowerplant (SCF-NP) The results for Part 91 are identical to the results that were previously described for this occurrence category under Part 135.

4.4.4 Expected Impact of Current Portfolio on Future Safety Risk Tall Poles

Table 9 contains a mapping of expected impact of the current AvSafe portfolio on the future safety risk tall poles.

Table 8. Impact of Current AvSafe Portfolio on Future Safety Risk Tall Poles

Future safety risk tall pole	**Aviation safety project**			
	IIFD	IRAC	IVHM	AAD
Runway safety	D			
Approach and landing accident reduction	D	D		
Icing/ice detection	D I	D	D	
Loss of control – in flight	I	D I	D	I D
Super density operations	D			
Human fatigue	I			
Increasing complexity and reliance on automation	D	D	D	

Aircraft mixed fleet equipage				
Inadequate protection, analysis, and dissemination of safety data	D		D	
Enhanced survivability in the event of an accident				

Runway Safety

Runway safety, as previously defined in section 3, contains three components: runway excursions, runway incursions, and runway confusion. A large portion of the entire IIFD research portfolio (e.g., hazard detection and characterization, and so on) will have a direct impact on this area of future risk.

Approach and Landing Accident Reduction

According to the Flight Safety Foundation, the key to preventing these types of accidents is to avoid errors in situation awareness and situation assessment. Various research activities (e.g., robust automation-human systems, multimodal interfaces, and so on) within the IIFD portfolio will have a direct impact on preventing these types of errors. Additionally, three current IRAC technologies also will have a direct impact: maneuvering-envelope identification algorithms (IRAC-2), emergency trajectory and flight-planning guidance algorithms (IRAC-3), and flight dynamic models of unsteady aerodynamics (IRAC-5).

Icing/Ice Detection

Icing and ice detection is an area of future risk that was identified by several groups, including the National Research Council, the Commercial Aviation Safety Team, and the National Transportation Safety Board. The types of research that are needed to address this future safety risk are the same as those that address historic icing issues; thus, the results for this future risk are identical to those that were identified for the Part 135 Icing category.

Loss of Control – In Flight

As opposed to the CICTT definition of loss of control, the definition of loss of control in terms of future risk also encompasses the causes of these types of accidents, such as severe atmospheric turbulence and system/component malfunctions and failures. Therefore, the AvSafe research that will impact this area as a future risk is identical to the assessment results that were identified under Part 121 for Loss of Control – In Flight, with some minor modifications. The research in the IVHM portfolio will now have a direct impact on this risk category due to the large amount of system-component-failure research in the portfolio (e.g., health management, validation and verification of software, and so on). Similarly, because the AAD research portfolio also addresses system component failures, especially those that may occur as a result of the use of composite materials, all of the challenge problem areas (except challenge problem 1) will have a direct impact on this future risk area. The research in AAD challenge problem 1 (i.e., damage methodology for metallic airframe structures) will have only an indirect impact because it is not expected to significantly advance the state of the art in loss-of-control or system/component failure research.

Super-Density Operations

The future, as envisioned by the JPDO when the Next Generation Air Transportation System is implemented, is one in which more aircraft can safely travel closer together than in today's NAS. Technologies that address separation assurance and coordination of information between pilots and controllers will be critical in this future environment. Several subtopics (SS.1–SS.3) and milestones in the IIFD portfolio will directly impact this area of future risk.

Human Fatigue

Fatigue is an issue that impacts not only flight crews operating in the future NAS, but air traffic controllers and maintenance personnel as well. This risk area is closely aligned with both "super-density operations" and "increasing complexity and reliance on automation," but has been identified as a specific future safety concern by both the NTSB and the FAST. Many of the proposed solutions to this safety risk area are regulatory in nature and, therefore, under the charter of the FAA. However, research in the IIFD portfolio that examines the impact of fatigue on operator performance (IIFD milestone OC 3.4) will have an indirect impact on this area of future risk.

Increasing Complexity and Reliance on Automation

With the expected increased usage of more complex and automated technologies, concerns exist regarding future safety risks due to issues such as pilot and air traffic controller information overload and the potential failure of automated systems. IIFD research in the appropriate use of automation in the cockpit (milestone IIFD OP.2), along with IRAC/IVHM research in verification and validation of flight critical systems, will have a direct impact on these issues.

Aircraft Mixed-Fleet Equipage

The ability to safely move more aircraft in the NextGen Air Transportation System is contingent upon the use of more advanced equipment such as ADS-B, but not all aircraft will acquire these new technologies at the same time. Research that addresses this future safety risk is not in the current AvSafe portfolio.

Inadequate Protection, Analysis, and Dissemination of Safety Data

Global collection and sharing of data among stakeholders (i.e., operators, manufacturers, and regulators), data-mining algorithms to support automated data analysis, and prognostic identification of safety risks are some of the issues that fall within this area of future risk. The data-mining research in IVHM (i.e., research area 1.3: data mining and complex systems) and the IIFD predictive human performance modeling (milestone IIFD.IM.2) will have a direct impact on this future risk area.

Enhanced Survivability in the Event of an Accident

The goal of this future risk area is to reduce the likelihood of fatalities and serious injuries in the event of aviation accident. Specific research issues include reducing the possibility of post-impact fire/smoke, improving crash survivability of aircraft structures, and improving evacuation and accident response procedures. This area of future risk is not currently addressed in the current AvSafe research portfolio.

4.4.5 Expected Impact of Current Portfolio on NextGen NASA-Related Safety Objectives

The expected impact of the AvSafe portfolio was evaluated against the NASA related objectives and strategies within the NASSP (ref. 20). As previously stated, Objectives 1A, 3A and 3B were omitted from the evaluation because these objectives do not fall within the current charter of the NASA AvSafe Program. Table 9 contains a mapping of expected impact of the current AvSafe portfolio on the NASA related Next Gen safety objectives. Tables 10-13 contains a mapping of the current AvSafe portfolio to each of the NextGen NASA related safety objectives and strategies.

Table 9. Expected Impact of Current AvSafe Portfolio on NextGen NASA-Related Safety Objectives

NextGen NASA-related safety objective	**Aviation safety project**			
	IIFD	IRAC	IVHM	AAD
Provide enhanced monitoring and safety analysis of the Air Transportation System [1B].			D	
Provide enhanced methods for ensuring safety is an inherent characteristic of the Next Generation Air Transportation System [1C].		D	D	
Provide risk-reducing system interfaces [2A].	D			
Provide safety enhancements for airborne systems [2B].		D	D	D
Provide safety enhancements for ground-based systems [2C].				

Table 10. Mapping of Current AvSafe Portfolio to NextGen Objective 1B and Strategies

Objective 1B: Provide enhanced monitoring and safety analysis of the Air Transportation System		
Strategy	**AvSafe project**	**Technology area or milestone**
Increase data access for safety risk management	IVHM	Data mining (IVHM research area 1.3)

Table 11. Mapping of Current AvSafe Portfolio to NextGen Objective 1C and Strategies

Objective 1C: Provide enhanced methods for ensuring safety is an inherent characteristic of the Next Generation Air Transportation System		
Strategy	**AvSafe project**	**Technology area or milestone**
Advance capabilities for integrated safety assessment	IIFD	Predictive modeling of human interaction performance (IIFD subtopic IM.2)
Enhance the focus on safe operational procedures	IIFD	Multimodal interfaces (IIFD research area MM) Information and interaction modeling (IIFD research area IM)
Advance complex system validation and verification methods in support of operational use	IVHM	Verification and validation (IVHM research area 1.4)
	IRAC	Verification and validation methods (IRAC research area 1.3)

Table 12. Mapping of Current AvSafe Portfolio to NextGen Objective 2A and Strategies

Objective 2A: Provide risk-reducing systems interfaces		
Strategy	**AvSafe project**	**Technology area or milestone**
All four strategies within objective 2A	IIFD	Entire portfolio

Table 13. Mapping of Current AvSafe Portfolio to NextGen Objective 2B and Strategies

Objective 2B: Provide safety enhancements for airborne systems		
Strategy	**AvSafe project**	**Technology area or milestone**
Improve the reliability and airworthiness of aircraft	IRAC	Entire portfolio
	IVHM	Entire portfolio
	AAD	Entire portfolio
Improve vehicle systems health management	IVHM	Entire portfolio
Increase the reliability and accuracy of airborne systems data and information	IIFD	Information collection and management for reliability and integrity of service (IIFD subtopic EA.1)
	IRAC	Verification and validation methods (IRAC research area 1.3)
	IVHM	Verification and validation (IVHM research area 1.4)

4.4.6 Expected Impact of Current Portfolio on National Aeronautics R&D Plan Safety Goals

Figure 7 contains a listing of the safety goals within the National Aeronautics R&D Plan. The NASA AvSafe projects that are expected to have an impact on the safety goals in the National Aeronautics R&D Plan are contained in Figure 8.

Goal	Near Term (<5 years)	Mid Term (5-10 years)	Far Term (>10 years)
Goal 1 Develop technologies to reduce accidents and incidents through enhanced vehicle design, structure, and subsystems (see p. 32)	Develop vehicle health-management systems to determine the state of degradation for aircraft subsystems	Develop and demonstrate tools and techniques to predict, detect, and mitigate in-flight damage, degradation, and failures	Develop reconfigurable health-management systems for managing suspect regions in N+2 vehicles
	Develop and test adaptive-control techniques in flight to enable safe flight by stabilizing and establishing maneuverability of an aircraft from an upset condition	Develop, assess, and validate methods to avoid, detect, and recover from upset conditions	Develop formal methods to verify and validate the safety performance margins associated with innovative control strategies, decision-making under uncertainty, and flight path planning and prediction
	Develop improved mitigation techniques that prevent, contain, or manage degradation associated with aging, and show that tools and methods can predict the performance improvement of these techniques	Deliver validated tools and methods that will enable a designer or operator to extend the life of structures made of advanced materials	Develop advanced life-extension concepts (designer materials and structural concepts) by using physics-based computational tools
Goal 2 Develop technologies to reduce accidents and incidents through enhanced aerospace vehicle operations on the ground and in the air (see p. 33)	Validate and verify methods that enable improvements in pilot and controller workload, awareness, and error prevention and recovery, including during off-nominal scenarios, given the increased automation assumed in NextGen	Develop human-machine interfaces that enable effective human performance during highly dynamic conditions and allow for flexible intervention to ensure safety	Develop formal methods to verify and validate the safety of complex airspace operations
	Develop flight deck displays and automation to convey up-to-date weather conditions and near-term forecasts Investigate in-situ and remote observing systems, technologies, and architectures that will provide hazardous and other weather information	Develop an integrated flight deck system that alerts flight crews of all on-board and environmental hazards and defines and coordinates an appropriate, safe flight path Develop in-situ and remote observing technologies, systems, and architectures that will provide weather information to flight crews and air traffic controllers	Develop high-confidence, flight deck decision-support tools that use single authoritative information source for shared decision-making between air traffic management and flight crew about weather and other concerns in planning a safe flight path
	Develop advanced tools that translate numeric (continuous and discrete) system performance data into usable, meaningful information for prognostic identification of safety risks for system operators and designers Understand the concepts of degradation and failure as well as other potential safety issues associated with critical system functions integrated across highly distributed ground, air, and space systems (including UAS)	Develop advanced methods to automatically analyze textual safety reports and extract system performance information for prognostic identification of safety risks for system operators and designers Develop techniques to enable a priori safety assurance and real-time monitoring and assessment of critical system functions across distributed air and ground systems (including UAS)	Develop fundamentally new data-mining algorithms to support automated data analysis tools to integrate information from a diverse array of data resources (numeric and textual) to enable rapid prognostic identification of system-wide safety risks Validate and verify the safety of complex flight-critical systems (including UAS) in a cost- and time-effective manner
Goal 3 Demonstrate enhanced passenger and crew survivability in the event of an accident (see p. 35)	Develop occupant-restraint design tools that support occupant crash protection that is as strong as the fixed- and rotary-wing aircraft structure	Validate integrated vehicle structure and occupant restraint tools	Validate integrated vehicle structure and occupant restraint tools for advanced concept vehicles
	Develop analytical methodologies to model dynamic events in aircraft crashes to enable the development of lightweight and crash-absorbing airframe technologies for the fixed- and rotary-wing legacy fleet	Establish analytical methodologies to model dynamic events in aircraft crashes to enable the development of lightweight and crash-absorbing airframe technologies for advanced aircraft, including those made with advanced composite and metallic materials	Validate and verify analytical methods that model dynamic events in aircraft crashes for airframe structures
	Assess and reduce flammability and smoke toxicity of advanced materials to be used in aircraft platforms	Determine fuel vapor characteristics of alternative aviation fuel spills for post-crash survivability	Validate and verify methodologies to determine impact of alternative fuels on cabin material flammability and propulsion system fire safety and survivability

Figure 7. Aviation Safety R&D Goals and Objectives
(source: National Aeronautics R&D Plan, February 2010, p. 36).

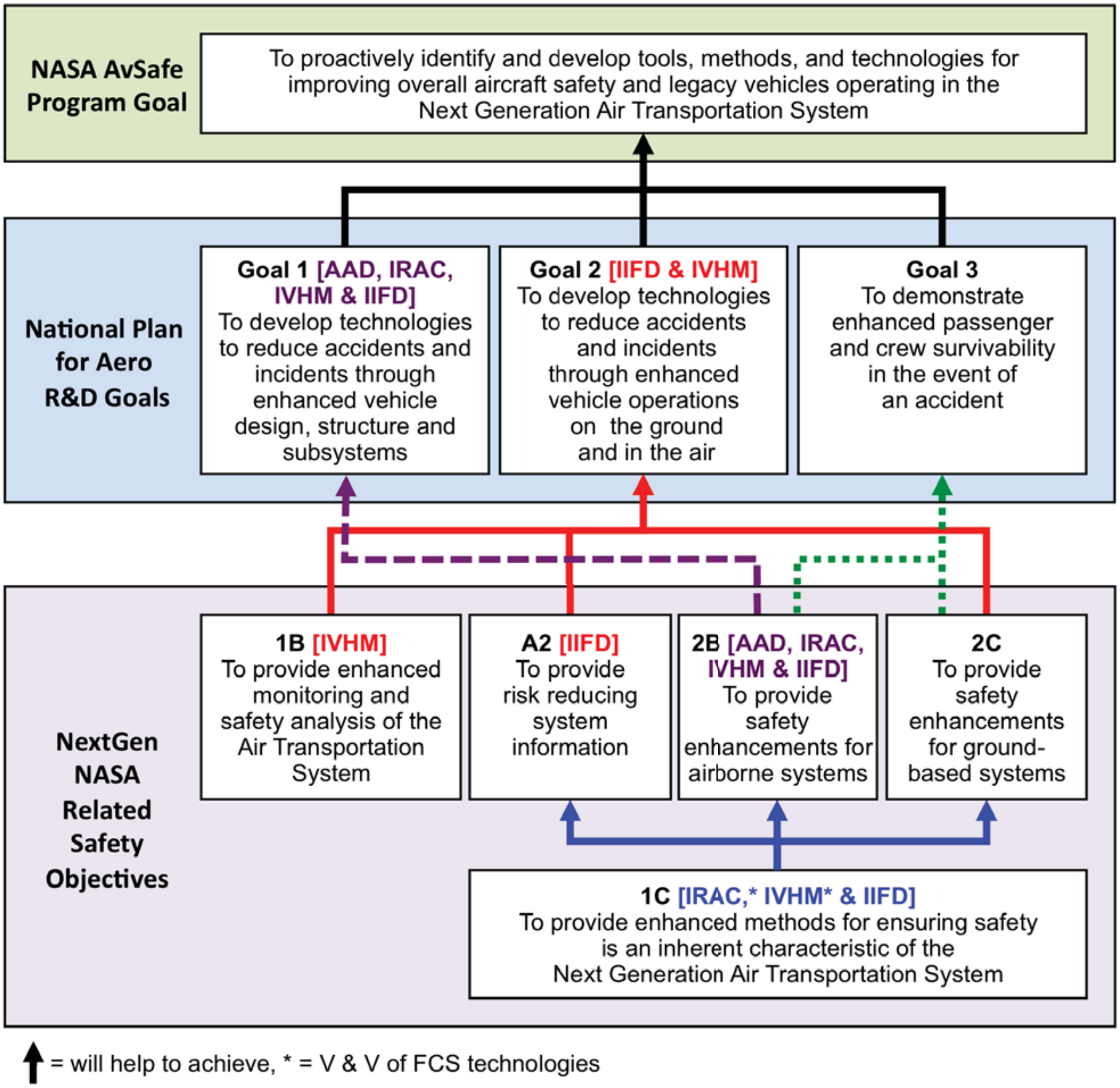

Figure 8. Expected impact of current research portfolio on NASA AvSafe objectives tree.

4.5 Set of Challenging Safety Issues

All of the goals, objectives, and tall poles that were identified through the use of the systems analysis methodology (see Fig. 5) were used to develop the set of challenging safety issues that are given below in table 14

Table 14 Challenging Safety Issues

GOAL 1: "Develop technologies to reduce accidents and incidents through enhanced vehicle design, structure, and subsystems."
Mitigate the consequences and hazards that are associated with in-flight loss of control.
Improve technologies for ice detection and operation in icing conditions.
Improve the reliability and airworthiness of aircraft.
Improve vehicle systems health management.
Increase the reliability and accuracy of airborne systems data and information.
Ensure aircraft conformance to more stringent operational requirements.
GOAL 2: "Develop technologies to reduce accidents and incidents through enhanced aerospace vehicle operations on the ground and in the air."
Improve technologies and procedures for addressing the increasing complexity of and reliance on automation.
Improve the protection, analysis, and dissemination of safety data.
Mitigate the consequences and hazards that are associated with runway safety.
Develop technologies and procedures to manage aircraft mixed fleet equipage in NextGen.*
Develop technologies and procedures to manage super-density operations.
Mitigate the consequences of human error and fatigue.*
Mitigate the consequences and hazards that are associated with approach and landing accidents.
Understand and mitigate the potential safety issues that are associated with unmanned aircraft systems (UAS).*
GOAL 3: "Develop enhanced passenger and crew survivability in the event of an accident."
Mitigate the consequences and hazards that are associated with post-impact fire/smoke/toxic fumes.*
Improve crash survivability of aircraft structures.*
Improve evacuation and accident response procedures.*

*Indicates a safety issue that is not currently being addressed in the AvSafe research portfolio.

4.6 Research Alternatives

Six of the safety issues that are given in table 14 are not currently being addressed in the AvSafe research portfolio. Note that human fatigue was included in this list because the IIFD research effort in the current portfolio that supports this safety issue is extremely limited and is not expected to have a direct impact on this in the future. For these six research areas, possible research alternatives that have the potential to address these safety issues were identified (see table 15. These research alternatives were derived primarily from input that was obtained from NASA AvSafe researchers and project management but are also based on suggestions from external sources (e.g., CAST JIMDAT). These research alternatives have not been evaluated against the assessment criteria, nor have their technical merits been thoroughly evaluated.

Table 15. Unaddressed Challenging Safety Issues and Corresponding Research Alternatives

Challenging safety issue	**Research alternative(s)**
Develop technologies and procedures to manage aircraft mixed-fleet equipage in NextGen.	Develop voice-free air traffic control systems.
Mitigate the consequences of human error and fatigue.	Research 'smart' systems that detect operator lapses in attention, such as vigilant crew members.
	Develop systems to monitor and detect pilot fatigue.
Understand and mitigate the potential safety issues that are associated with unmanned aircraft systems (UAS).	Manage and reduce risks from UAS accidents to other vehicles, persons, and property on the ground.
	Enable safe UAS operations by developing sense-and-avoid capabilities for autonomous vehicles.
Mitigate the consequences and hazards that are associated with post-impact fire/smoke/toxic fumes.	Develop materials and structures that are fire resistant and do not emit significant smoke.
	Improve fuel-containment methods and create reduced volatility fuels to prevent fires and explosions.
	Develop improved cabin materials for reduced flammability and develop automated fire detection/protection systems.
	Develop passenger-safe fire suppression systems.
Improve crash survivability of aircraft structures.	Develop materials and structures that fail in a predesigned manner to maximize energy absorption (similar to automobiles).
	Improve crash simulation capabilities for evolving composite structures and assess crashworthiness under various accident scenarios.
Improve evacuation and accident response procedures.	Conduct egress research for more efficient cabin evacuation.
	Investigate the effectiveness of extremely rapid fuel dump (automated at/near impact).
	Develop inflatable, floating shelters for survivability after water landings.

5. Discussion and Conclusions

Recall that the objectives tree for the National Aeronautics and Space Administration (NASA) Aviation Safety (AvSafe) program was organized to support both the safety goals of the National Aeronautics Research and Development (R&D) Plan and the safety-related objectives in the Joint Planning and Development Office (JPDO) National Aviation Safety Strategic Plan (NASSP). The current NASA AvSafe research portfolio, if successful, directly addresses all of the National Aeronautics R&D safety goals except goal 3 (i.e., develop enhanced passenger and crew survivability in the event of an accident). The fact that the NASA portfolio does not address this goal is not a major concern because, according to published reports (Refs. 21 and 22), the Federal Aviation Administration (FAA) is spending approximately $7.2 million in support of their Fire Research and Safety program. This FAA program is investigating technologies and procedures to (1) prevent accidents that are caused by in-flight fires and fuel-tank explosions and (2) improve the survivability of a post-crash fire. Note, however, that much of the FAA research portfolio is focused on reliability and on certification tools and methodologies, and that the FAA relies on collaboration with NASA in the following areas of research:

- Aircraft icing, turbulence, wake turbulence, and weather technologies
- Continued airworthiness
- Catastrophic engine failure
- Flight deck, maintenance, and human factors
- Data mining and satellite data

In regard to the JPDO NASSP safety objectives, the current NASA AvSafe research portfolio directly impacts all of the NASA-related safety objectives in the plan, except for objective 2C (i.e., provide safety enhancements for ground-based systems). However, many of the research goals that are contained in objective 2C actually fall under the charter of NASA's Airspace Systems program. According to the NASA Airspace Systems program Web site (Ref. 1), the primary roles of each of the research initiatives within the Aeronautics Research Mission Directorate (ARMD) are as follows:

- Airspace Systems program: operational aspects of the airspace system
- Fundamental Aeronautics program: vehicles
- AvSafe program: vehicle safety

Because the charters of the Airspace Systems and Fundamental Aeronautics programs do not specifically include vehicle safety, the expectation is that the AvSafe program is responsible for this area of research.

The evaluation of the NASA AvSafe research portfolio against both historic and future areas of significant safety risk indicates that the current AvSafe research portfolio will have no direct impact on three areas of future risk (i.e., human fatigue, aircraft mixed-fleet equipage, and enhanced survivability in the event of an accident), as well as no direct impact on the following historic areas of significant safety risk:

- Fire – post impact
- Turbulence
- Abnormal runway contact
- Bird strikes
- Controlled flight into terrain
- Collision with object – takeoff or landing
- Low-altitude operations
- Loss of control – on ground
- Power loss – fuel
- Runway excursion

Most of these research gaps in addressing the historic areas of safety risk are for Part 135 and Part 91 operations. In fact, the majority of the research in the current AvSafe research portfolio is solely applicable to Part 121 operations. The only research in the current portfolio that is expected to directly impact Part 91 is in the area of system/component failure/malfunction (i.e., the IVHM project). Overall, the current portfolio, if successful, would have an indirect impact on more than 50 percent of the historic and future areas of significant safety risk; however, most of the current AvSafe program initiatives include research that is primarily at the fundamental level.

Finally, of the 17 challenging safety issues that were identified, the current AvSafe program research portfolio directly addresses 11 of these issues. Of the six unaddressed issues, three can be categorized under National R&D goal 3 (i.e., develop enhanced passenger and crew survivability in the event of an accident). Another of these safety issues (i.e., mitigate the consequences of human error and fatigue) is categorized as unaddressed because the IIFD research effort in this area is extremely limited and is not expected to have a direct impact on this safety issue in the future. Additional resources would be needed to make a significant impact in this area. The remaining two unaddressed safety issues (i.e., (1) develop technologies and procedures to manage aircraft mixed-fleet equipage in NextGen and (2) understand and mitigate the potential safety issues associated with unmanned aircraft systems) generally fall more under the charters of the Airspace Systems program and the proposed Unmanned Aircraft Systems (UAS) research within the Integrated Systems Research program, respectively. The appropriate assignment of responsibility for this and other aviation safety research initiatives within the NASA ARMD should be based on some subset of the assessment criteria that were used in this study. A suggested rule of thumb is that any research effort that is subsequently funded within the Aviation Safety program should, at a minimum, indirectly address one of the identified current or future areas of significant safety risk.

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Appendix A. Aviation Occurrence Categories

The CAST/ICAO Common Taxonomy Team (CICTT) was jointly chartered by the International Civil Aviation Organization (ICAO) and the Commercial Aviation Safety Team (CAST) and was charged with developing common taxonomies and definitions for aviation accident and incident reporting systems. (For additional information, see http://www.intlaviationstandards.org/.) The occurrence categories that were used in this study are listed below, with a brief description of each category. The information is taken from a document that is dated October 2008.

CICTT Categories

Abnormal runway contact (ARC): Any takeoff or landing that involves abnormal contact with the runway or landing surface. Included are hard/heavy landings, long/fast landings, crabbed landings, nose-wheel-first touchdowns, tail strikes, wing/nacelle strikes, and gear-up landings.

Abrupt maneuver (AMAN): Occurrences that involve the intentional abrupt maneuvering of the aircraft (in flight or on the ground) by the flight crew to avoid a collision with terrain, objects, weather, or other aircraft.

Aerodrome (ADRM): Occurrences that involve aerodrome design, service, or functionality issues. The aerodrome includes runways, taxiways, ramp areas, parking areas, buildings and structures, lighting, signage, and crash/fire/rescue (CFR) services.

ATM/CNS (ATM): Occurrences that involve air traffic management (ATM) or communication, navigation, or surveillance (CNS) service issues.

Bird strike (BIRD): Occurrences that involve collisions or near collisions with bird(s) or other wildlife.

Cabin safety events (CABIN): Occurrences that involve significant events in the passenger cabin related to carry-on baggage, supplemental oxygen, missing or non-operational emergency equipment, the inadvertent deployment of emergency equipment, or the medical emergency (not caused by turbulence encounters) of persons other than the flight crew or medical evacuation patients.

Collision with obstacle(s) during takeoff and landing (CTOL): Occurrences that involve collision with an object or obstacle during airborne phases of takeoff or landing.

Controlled flight into or toward terrain (CFIT): Occurrences that involve an in-flight collision or near collision with terrain, water, or obstacle without indication of loss of control. Excludes intentional low-altitude operations, intentional flight into terrain, and runway undershoot/overshoot.

Evacuation (EVAC): Occurrences that involve one or more of the following: an unnecessary evacuation was conducted; person(s) were injured during the evacuation; evacuation equipment failed to perform as required; or the evacuation was a factor in the outcome.

Fire/smoke nonimpact (FI-NI): Occurrences that involve fire or smoke in the aircraft (in flight or on the ground) which was not the result of an impact.

Fire/smoke impact (FI-POST): Occurrences that involve fire or smoke resulting from impact.

Fuel related (FUEL): Occurrences that involve one or more powerplants experiencing reduced or no power output due to fuel exhaustion (i.e., no usable fuel on board), fuel starvation (i.e., usable fuel is not available to the engine), fuel contamination (i.e., by water, sand, dirt, bugs), wrong fuel, or carburetor and/or induction icing.

Ground handling (RAMP): Occurrences during (or as a result of) ground operations, including preflight configuration errors that lead to subsequent events (such as improperly latched doors, pitot tube contamination, or weight/balance issues).

Ground collision (GCOL): Occurrences that involve collision with an aircraft, person, animal, ground vehicle, building, and so on while taxiing to or from a runway in use.

Icing (ICE): Occurrences that involve the accumulation of snow, ice, freezing rain, or frost on aircraft surfaces to the extent that aircraft control or performance is adversely affected.

Loss of control – ground (LOC-G): Occurrences that involve the loss of aircraft control while the aircraft is on the ground, which may result from a contaminated runway, evasive action due to a runway incursion, or the failure or malfunction of a system or component.

Loss of control – in flight (LOC-I): Occurrences that involve the loss of aircraft control while in flight; may occur in instrument meteorological conditions (IMC) or visual meteorological conditions (VMC).

Low-altitude operations (LALT): Occurrences that involve collision or near collision with terrain/objects/obstacles while intentionally operating near the surface (excludes landing and takeoff phases). Includes aerobatics, sightseeing, aerial photography, aerial application, scud running, and flying in close proximity to mountains or box canyons where the aircraft aerodynamic capability is not sufficient to avoid impact.

Airprox/TCAS alert/loss of separation/near midair collision/midair collision (MAC): Occurrences that involve airprox, TCAS alerts, or loss of separation, or involve a near collision or collision between aircraft in flight.

Other (OTHER): Any occurrence not covered under another category.

Runway excursion (RE): A veer off the side or overrun off the end of the runway.

Runway incursion – animal (RI-A): Occurrences that involve collision with, risk of collision with, or evasive action taken by an aircraft to avoid an animal (other than birds) on the runway in use.

Runway incursion – vehicle, aircraft, or person (RI-VAP): Occurrences that involve the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for takeoffs or landings.

Security related (SEC): Occurrences that involve criminal- or security-related acts such as hijacking, aircraft theft, flight control interference, sabotage, or suicide.

System/component failure or malfunction – Non-powerplant (SCF-NP): Occurrences that involve failure or malfunction of an aircraft system or component other than the powerplant.

System/component failure or malfunction – Powerplant (SCF-PP): Occurrences that involve failure or malfunction of an aircraft system or component that is related to the powerplant.

Turbulence encounter (TURB): Occurrences that involve in-flight encounter with turbulence; includes clear-air or cloud turbulence, mountain wave, and wake vortex.

Undershoot/overshoot (USOS): Occurrences that involve a touchdown off the runway surface but in close proximity to the runway; excludes off-airport emergency landings.

Unknown or undetermined (UNK): Occurrences for which insufficient information exists to categorize the accident; includes missing aircraft.

Wind shear or thunderstorm (WSTRW): Occurrences that involve flight into wind shear or thunderstorm; includes hail and heavy rain.

Additional Categories

Many of the following categories were added in order to completely capture an event sequence. For example, an emergency landing is required for most cases in which a system/component fails or malfunctions and engine power is lost, and also may be performed after an encounter with adverse weather; furthermore, this type of landing is not likely to be without further incident. Control of the aircraft may be lost; hard or bounced landings may occur; terrain that is unsuitable for a proper landing may be encountered; the aircraft may collide with power lines, fences, or ground vehicles during an off-airport landing; or the aircraft may be unable to avoid rising terrain due to degraded performance. The single category of "Loss of engine power" is not sufficient to explain why the aircraft was destroyed.

Several categories (e.g., collisions with terrain or objects and loss of control) were further subdivided by general phase of flight (i.e., ground, takeoff, in flight, approach/landing) because either the root cause or the consequences of the occurrence differ by phase of flight.

Collision with object – ground (CWO-G): Occurrences that involve a collision with an object or obstacle on the ground away from an airport environment.

Collision with terrain – approach/landing (CWT-AL): Occurrences that involve a collision with terrain during the approach to land or during a go-around/missed approach. CFIT (i.e., controlled flight into terrain) is not an appropriate category in these cases for one of two reasons: a system/component failure/malfunction or nonmechanical loss of engine power necessitated the landing or the pilot did not maintain sufficient altitude above high vegetation. This code was also used in cases where the pilot ditched the aircraft in water.

Encounter with terrain – ground (EWT-G): Occurrences that involve an encounter with terrain on the ground away from an airport environment, causing damage to the aircraft.

In-flight break up (IFBU): Occurrences that involve separation of multiple surfaces of the aircraft, resulting either from loss of control or from forces associated with severe weather.

Pilot incapacitation or severe impairment (INCAP): Occurrences that involve the pilot becoming incapacitated (due to illness or fatigue) or severely impaired (due to illness, alcohol or illegal drugs). Does not include minor impairment caused by fatigue or the use of unapproved prescription medications.

Loss of engine power – fuel related (PL-FUEL): Occurrences that involve the loss of engine power due to fuel exhaustion (i.e., no usable fuel on board), fuel starvation (i.e., usable fuel is not available to the engine), fuel contamination (e.g., by water, sand, dirt, or bugs), wrong fuel, or carburetor and/or induction icing (see FUEL above).

Loss of engine power – other reasons (PL-OTHER): Occurrences that involve the loss of engine power due to other nonmechanical reasons. Reasons include foreign object damage (e.g., bird strikes), ice ingestion, improper simulated engine-out procedures, or other improper procedures.

Loss of engine power – unknown reasons (PL-UNK): Occurrences that involve the loss of engine power for which the exact cause is undetermined.

Appendix B. Accidents, Injuries, and Incidents by Aviation Occurrence Category

Table B-1. Number of Accidents by CICTT Occurrence Category (1997–2006)

CICTT occurrence category	Part 121	Scheduled Part 135	Non-scheduled Part 135	Part 91
Total accidents	459	78	540	12247
Abrupt maneuver	16 (3.5%)		1 (0.2%)	48 (0.4%)
Abnormal runway contact	43 (9.4%)	10 (12.8%)	57 (10.6%)	1577 (12.9%)
Aerodrome	8 (1.7%)	3 (3.8%)	20 (3.7%)	132 (1.1%)
Air traffic management	7 (1.5%)		7 (1.3%)	72 (0.6%)
Bird strikes	14 (3.1%)	8 (10.3%)	5 (0.9%)	27 (0.2%)
Cabin safety or pilot incapacitation	5 (1.1%)		5 (0.9%)	155 (1.3%)
Controlled flight into terrain	2 (0.4%)	9 (11.5%)	51 (9.4%)	384 (3.1%)
Collision with object – on ground*	12 (2.6%)	3 (3.8%)	31 (5.7%)	1225 (10.0%)
Collision with object – takeoff or landing		2 (2.6%)	28 (5.2%)	1209 (9.9%)
Collision with terrain – approach/landing*	2 (0.4%)	2 (2.6%)	32 (5.9%)	495 (4.0%)
Encounter with terrain – on ground *	1 (0.2%)	6 (7.7%)	32 (5.9%)	815 (6.7%)
Evacuation	28 (6.1%)	1 (1.3%)	1 (0.2%)	
Fire – nonimpact	15 (3.3%)	2 (2.6%)	9 (1.7%)	130 (1.1%)
Fire – post impact	14 (3.1%)	4 (5.1%)	69 (12.8%)	1137 (9.3%)
Ground collision	30 (6.5%)	1 (1.3%)	23 (4.3%)	223 (1.8%)
Ground handling or preflight	121 (26.4%)	4 (5.1%)	29 (5.4%)	279 (2.3%)
Icing	2 (0.4%)	8 (10.3%)	31 (5.7%)	148 (1.2%)
In-flight breakup*			5 (0.9%)	78 (0.6%)
Low-altitude operations	1 (0.2%)	2 (2.6%)	17 (3.1%)	686 (5.6%)
Loss of control – in flight	8 (1.7%)	11 (14.1%)	94 (17.4%)	2390 (19.5%)
Loss of control – on ground	1 (0.2%)	5 (6.4%)	53 (9.8%)	1813 (14.8%)
Midair collision	3 (0.7%)	1 (1.3%)	9 (1.7%)	152 (1.2%)
Power loss – fuel	1 (0.2%)		43 (8.0%)	1561 (12.7%)
Power loss – other reason*	5 (1.1%)		5 (0.9%)	105 (0.9%)
Power loss – unknown reason*	1 (0.2%)	1 (1.3%)	27 (5.0%)	708 (5.8%)
Runway excursion	36 (7.8%)	14 (17.9%)	79 (14.6%)	2434 (19.9%)
Runway incursion (Animal, vehicle, aircraft, or Person)	5 (1.1%)		7 (1.3%)	139 (1.1%)
SCF – powerplant	15 (3.3%)	3 (3.8%)	42 (7.8%)	776 (6.3%)
SCF – nonpowerplant	40 (8.7%)	8 (10.3%)	59 (10.9%)	877 (7.2%)
Security related	4 (0.9%)			38 (0.3%)
Turbulence encounter	116 (25.3%)	2 (2.6%)	5 (0.9%)	87 (0.7%)
Thunderstorm or windshear	6 (1.3%)		8 (1.5%)	112 (0.9%)
Undershoot or overshoot	2 (0.4%)	3 (3.8%)	17 (3.1%)	239 (2.0%)
Other		1 (1.3%)	4 (0.7%)	30 (0.2%)
Unknown or undetermined	2 (0.4%)		8 (1.5%)	103 (0.8%)

Table B-2. Number of Injuries in Accidents by CICTT Occurrence Category (1997–2006)

CICTT occurrence category	Part 121	Scheduled Part 135	Non-scheduled Part 135	Part 91
Total injuries	1956	142	585	9846
Abrupt maneuver	299 (15.3%)		1 (0.2%)	43 (0.4%)
Abnormal runway contact	44 (2.2%)	19 (6.3%)	16 (2.7%)	355 (3.6%)
Aerodrome	6 (0.3%)	0 (0.0%)	1 (0.2%)	24 (0.2%)
Air-traffic management	9 (0.5%)		4 (0.7%)	77 (0.8%)
Bird strikes	2 (0.1%)	0 (0.0%)	3 (0.5%)	6 (0.1%)
Cabin safety or pilot incapacitation	5 (0.3%)		11 (1.9%)	257 (2.6%)
Controlled flight into terrain	18 (0.9%)	33 (17.5%)	112 (19.1%)	750 (7.6%)
Collision with object – on ground*	144 (7.4%)	1 (0.7%)	23 (3.9%)	437 (4.4%)
Collision with object – takeoff or landing		1 (0.7%)	43 (7.4%)	1448 (14.7%)
Collision with terrain – Approach/Landing*	2 (0.1%)	8 (5.6%)	57 (9.7%)	591 (6.0%)
Encounter with terrain – on ground*	0 (0.0%)	6 (4.2%)	19 (3.2%)	421 (4.3%)
Evacuation	253 (12.9%)	8 (5.6%)	6 (1.0%)	
Fire – nonimpact	104 (5.3%)	0 (0.0%)	14 (2.4%)	81 (0.8%)
Fire – Post impact	498 (25.5%)	47 (33.1%)	175 (29.9%)	2348 (23.8%)
Ground collision	13 (0.7%)	0 (0.0%)	0 (0.0%)	58 (0.6%)
Ground handling or preflight	107 (5.5%)	11 (7.7%)	47 (8.0%)	423 (4.3%)
Icing	0 (0.0%)	50 (35.2%)	33 (5.6%)	206 (2.1%)
In-flight breakup*			9 (1.5%)	192 (2.0%)
Low-altitude operations	0 (0.0%)	4 (2.8%)	35 (6.0%)	1086 (11.0%)
Loss of control – in flight	405 (20.7%)	69 (48.6%)	195 (33.3%)	3941 (40.0%)
Loss of control – on ground	0 (0.0%)	1 (0.7%)	25 (4.3%)	408 (4.1%)
Midair collision	3 (0.2%)	5 (3.5%)	14 (2.4%)	344 (3.5%)
Power loss – fuel	2 (0.1%)		74 (12.6%)	1443 (14.7%)
Power loss – other reason*	0 (0.0%)		11 (1.9%)	108 (1.1%)
Power loss – unknown reason*	0 (0.0%)	1 (0.7%)	26 (4.4%)	669 (6.8%)
Runway excursion	244 (12.5%)	12 (8.5%)	39 (6.7%)	653 (6.6%)
Runway incursion (animal, vehicle, aircraft, or person)	1 (0.1%)		1 (0.2%)	45 (0.5%)
SCF – powerplant	17 (0.9%)	12 (8.5%)	72 (12.3%)	738 (7.5%)
SCF – nonpowerplant	319 (16.3%)	14 (9.8%)	26 (4.4%)	398 (4.0%)
Security related	265 (13.5%)			40 (0.4%)
Turbulence encounter	580 (29.7%)	4 (2.8%)	3 (0.5%)	96 (1.0%)
Thunderstorm or windshear	121 (6.2%)		17 (2.9%)	167 (1.7%)
Undershoot or overshoot	23 (1.2%)	0 (0.0%)	11 (1.9%)	120 (1.2%)
Other		0 (0.0%)	5 (0.9%)	24 (0.2%)
Unknown or undetermined	0 (0.0%)		29 (5.0%)	190 (1.9%)

Table B-3. Number of Fatal Accidents by CICTT Occurrence Category (1997–2006)

CICTT occurrence category	Part 121	Scheduled Part 135	Non-scheduled Part 135	Part 91
Total fatal accidents	25	15	122	2328
Abrupt maneuver	1 (4.0%)			15 (0.6%)
Abnormal runway contact		1 (6.7%)		23 (1.0%)
Aerodrome				1 (0.1%)
Air-traffic management			3 (2.5%)	40 (1.7%)
Bird strikes				1 (0.1%)
Cabin safety or pilot incapacitation			5 (4.1%)	121 (5.2%)
Controlled flight into terrain	1 (4.0%)	4 (26.7%)	32 (26.2%)	302 (13.0%)
Collision with object – on ground*	2 (8.0%)		2 (1.6%)	28 (1.2%)
Collision with object – takeoff or landing		1 (6.7%)	5 (4.1%)	209 (9.0%)
Collision with terrain – approach/landing*	1 (4.0%)	1 (6.7%)	7 (5.7%)	80 (3.4%)
Encounter with terrain – on ground*			1 (0.8%)	9 (0.4%)
Evacuation	1 (4.0%)	1 (6.7%)		
Fire – nonimpact			2 (1.6%)	16 (0.7%)
Fire – post impact	7 (28.0%)	3 (20.0%)	50 (41.0%)	831 (35.7%)
Ground collision				3 (0.1%)
Ground handling or preflight	10 (40.0%)	2 (13.3%)	4 (3.3%)	88 (3.8%)
Icing		3 (20.0%)	14 (11.5%)	62 (2.7%)
In-flight breakup*			5 (4.1%)	78 (3.4%)
Low-altitude operations		1 (6.7%)	9 (7.4%)	412 (17.7%)
Loss of control – in flight	6 (24.0%)	8 (53.3%)	56 (45.9%)	1276 (54.8%)
Loss of control – on ground				13 (0.6%)
Midair collision			4 (3.3%)	104 (4.5%)
Power loss – fuel	1 (4.0%)		8 (6.6%)	164 (7.0%)
Power loss – other reason*				10 (0.4%)
Power loss – unknown reason*		1 (6.7%)	6 (4.9%)	105 (4.5%)
Runway excursion	3 (12.0%)		1 (0.8%)	33 (1.4%)
Runway incursion (Animal, vehicle, aircraft, or person)				4 (0.2%)
SCF – powerplant		1 (6.7%)	8 (6.6%)	110 (4.7%)
SCF – nonpowerplant	5 (20.0%)	2 (13.3%)	6 (4.9%)	78 (3.4%)
Security related	4 (16.0%)			25 (1.1%)
Turbulence encounter	1 (4.0%)		2 (1.6%)	31 (1.3%)
Thunderstorm or windshear	1 (4.0%)		5 (4.1%)	55 (2.4%)
Undershoot or overshoot			1 (0.8%)	4 (0.2%)
Other			2 (1.6%)	12 (0.5%)
Unknown or undetermined			7 (5.7%)	88 (3.8%)

Table B-4. Number of Fatalities by CICTT Occurrence Category (1997–2006)

CICTT occurrence category	Part 121	Scheduled Part 135	Non-scheduled Part 135	Part 91
Total fatalities	752	80	292	4535
Abrupt maneuver	265 (35.2%)			23 (0.5%)
Abnormal runway contact		5 (6.3%)		34 (0.7%)
Aerodrome				1 (0.0%)
Air-traffic management			2 (0.7%)	73 (1.6%)
Bird strikes				2 (0.0%)
Cabin safety or pilot incapacitation			11 (3.8%)	199 (4.4%)
Controlled flight into terrain	13 (1.7%)	14 (17.5%)	79 (27.1%)	596 (13.1%)
Collision with object – on ground*	12 (1.6%)		2 (0.7%)	49 (1.1%)
Collision with object – takeoff or landing		1 (1.3%)	5 (1.7%)	358 (7.9%)
Collision with terrain – approach/landing*	1 (0.1%)	2 (2.5%)	10 (3.4%)	124 (2.7%)
Encounter with terrain – on ground*			1 (0.3%)	16 (0.4%)
Evacuation	1 (0.1%)	2 (2.5%)		
Fire – nonimpact			2 (0.7%)	30 (0.7%)
Fire – post impact	367 (48.4%)	40 (50.0%)	119 (40.8%)	1742 (38.4%)
Ground collision				3 (0.1%)
Ground handling or preflight	34 (4.5%)	11 (13.8%)	14 (4.8%)	200 (4.4%)
Icing		47 (58.8%)	17 (5.8%)	133 (2.9%)
In-flight breakup*			9 (3.1%)	191 (4.2%)
Low-altitude operations		2 (2.5%)	24 (8.2%)	730 (16.1%)
Loss of control – in flight	402 (53.5%)	61 (76.3%)	148 (50.7%)	2543 (56.1%)
Loss of control – on ground				17 (0.4%)
Midair collision			14 (4.8%)	300 (6.6%)
Power loss – fuel	1 (0.1%)		31 (10.6%)	270 (6.0%)
Power loss – other reason*				14 (0.3%)
Power loss – unknown reason*		1 (1.3%)	9 (3.1%)	193 (4.3%)
Runway excursion	61 (8.1%)		1 (0.3%)	58 (1.3%)
Runway incursion (Animal, vehicle, aircraft, or person)				6 (0.1%)
SCF – powerplant		2 (2.5%)	20 (6.8%)	237 (5.2%)
SCF – nonpowerplant	133 (17.9%)	6 (7.5%)	11 (3.8%)	145 (3.2%)
Security related	265 (35.2%)			29 (0.6%)
Turbulence	1 (0.1%)		3 (1.0%)	66 (1.5%)
Thunderstorm or windshear	11 (1.4%)		10 (3.4%)	123 (2.7%)
Undershoot or overshoot			1 (0.3%)	6 (0.1%)
Other			3 (1.0%)	15 (0.3%)
Unknown or undetermined			25 (8.6%)	166 (3.7%)

Table B-5. Number of Incidents by CICTT Occurrence Category (1997–2006)

CICTT occurrence category	Part 121	Scheduled Part 135	Non-scheduled Part 135	Part 91
Total incidents	3752	188	1117	12773
Abnormal runway contact	61 (1.6%)	12 (6.4%)	85 (7.6%)	3164 (24.8%)
Air-traffic management	2 (0.1%)			1 (0.0%)
Aerodrome	52 (1.4%)	1 (0.5%)	18 (1.6%)	185 (1.4%)
Bird strikes	128 (3.4%)	5 (2.7%)	20 (1.8%)	86 (0.7%)
Cabin safety or pilot incapacitation	60 (1.6%)	1 (0.5%)	3 (0.3%)	13 (0.1%)
Collision with object – on ground*	61 (1.6%)	9 (4.8%)	57 (5.1%)	434 (3.4%)
Collision with object – takeoff or landing	10 (0.3%)	3 (1.6%)	15 (1.3%)	175 (1.4%)
Evacuation	9 (0.2%)			
Fire – nonimpact	156 (4.2%)	10 (5.3%)	36 (3.2%)	155 1.2%)
Ground collision	10 (0.3%)		6 (0.5%)	45 (0.4%)
Ground handling or preflight	427 (11.4%)	23 (12.2%)	94 (8.4%)	525 (4.1%)
Icing	2 (0.1%)		9 (0.8%)	21 (0.2%)
Low-altitude operations		1 (0.5%)		25 (0.2%)
Loss of control – on ground	35 (0.9%)	2 (1.1%)	25 (2.2%)	560 (4.4%)
Midair collision	29 (0.8%)	2 (1.1%)	7 (0.6%)	110 (0.9%)
Power loss – fuel	22 (0.6%)	3 (1.6%)	15 (1.3%)	721 (5.6%)
Power loss – other or unknown reason*	2 (0.1%)	1 (0.5%)	9 (0.8%)	214 (1.7%)
Runway excursion	74 (2.0%)	13 (6.9%)	70 (6.3%)	1156 (9.1%)
Runway incursion (Animal, vehicle, aircraft, or person)	29 (0.8%)	1 (0.5%)	3 (0.3%)	37 (0.3%)
SCF – powerplant	592 (15.8%)	25 (13.3%)	159 (14.2%)	1220 (10.0%)
SCF – nonpowerplant	1650 (44.0%)	70 (37.2%)	448 (40.1%)	3474 (27.2%)
Security related	129 (3.4%)	1 (0.5%)	1 (0.1%)	12 (0.1%)
Turbulence encounter	83 (2.2%)	1 (0.5%)	6 (0.5%)	8 (0.1%)
Thunderstorm or windshear	25 (0.7%)	11 (5.9%)	2 (0.2%)	10 (0.1%)
Other weather	5 (0.1%)		3 (0.3%)	25 (0.2%)
Undershoot or overshoot	3 (0.1%)	1 (0.5%)	4 (0.4%)	69 (0.5%)
Other	65 (1.7%)	1 (0.5%)	13 (1.2%)	237 (1.9%)
Unknown or undetermined	31 (0.8%)	2 (1.1%)	9 (0.8%)	91 (0.7%)

Appendix C. Total Accidents and Fatal Accidents by Aviation Occurrence Category

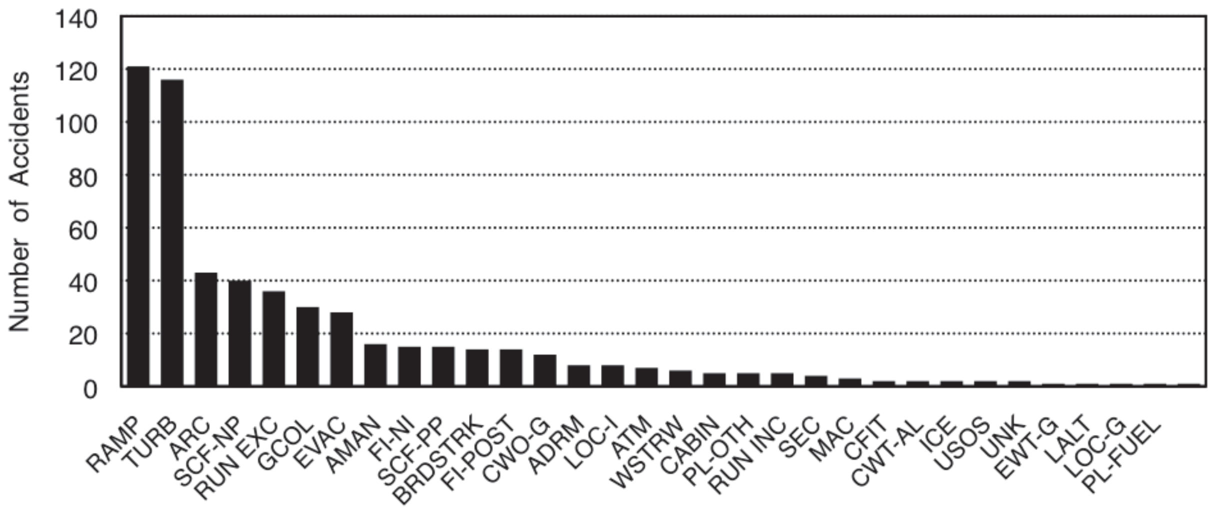

Figure C-1. Number of accidents by CICTT occurrence category for Part 121 operations (1997–2006).

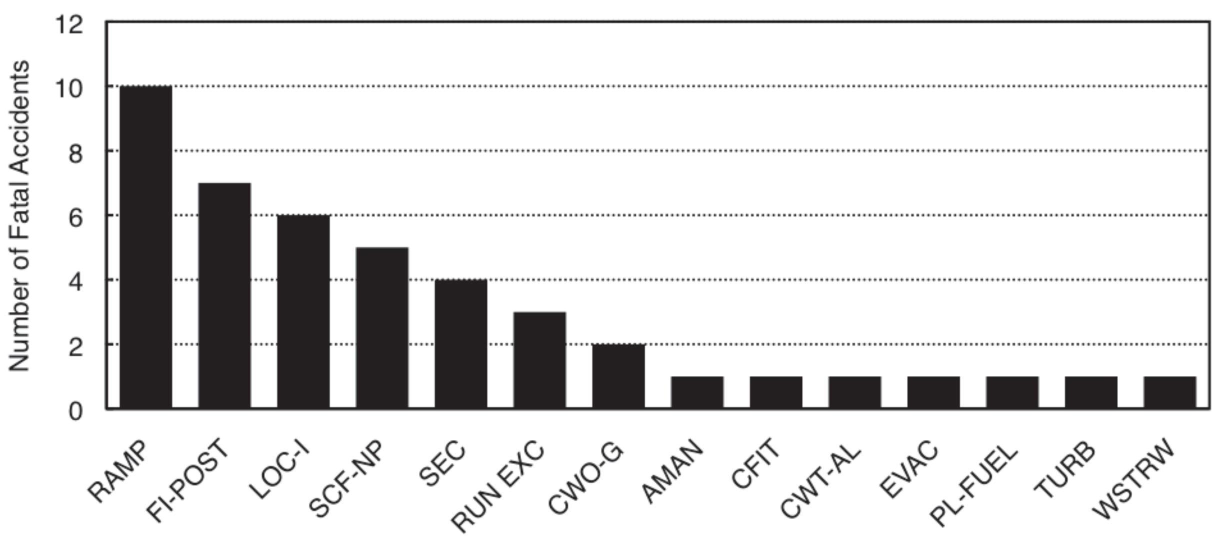

Figure C-2. Number of fatal accidents by CICTT occurrence category for Part 121 operations (1997–2006).

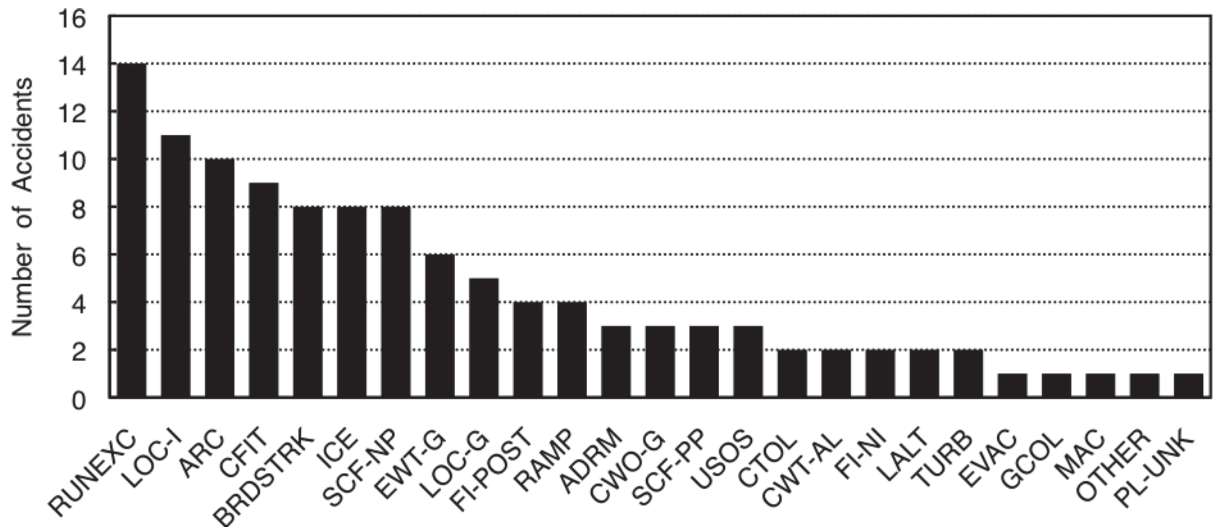

Figure C-3. Number of accidents by CICTT occurrence category for Scheduled Part 135 operations (1997–2006).

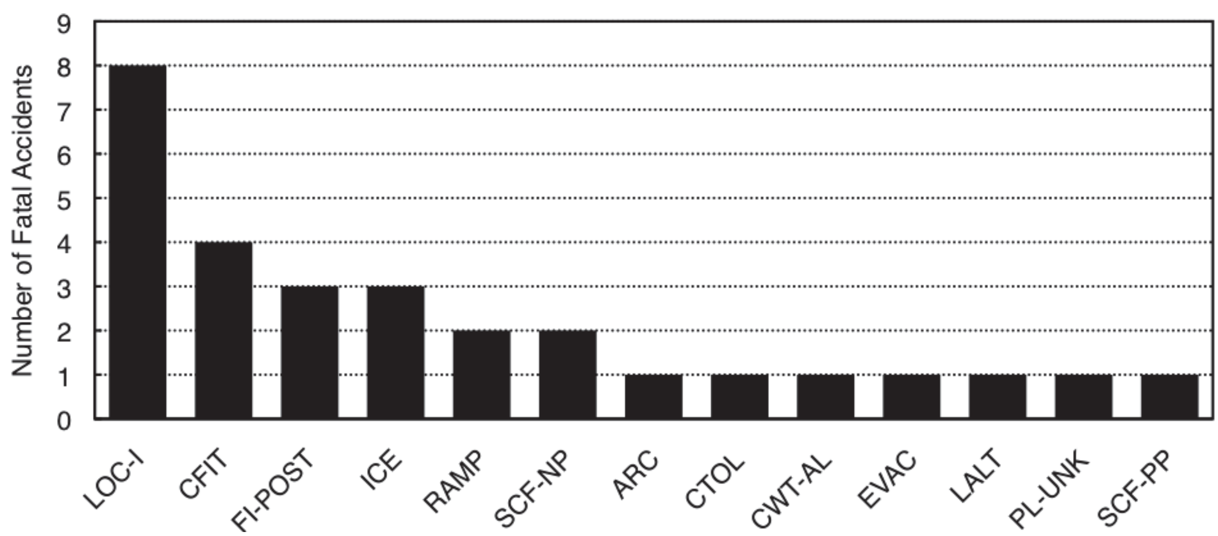

Figure C-4. Number of fatal accidents by CICTT occurrence category for Scheduled Part 135 operations (1997–2006).

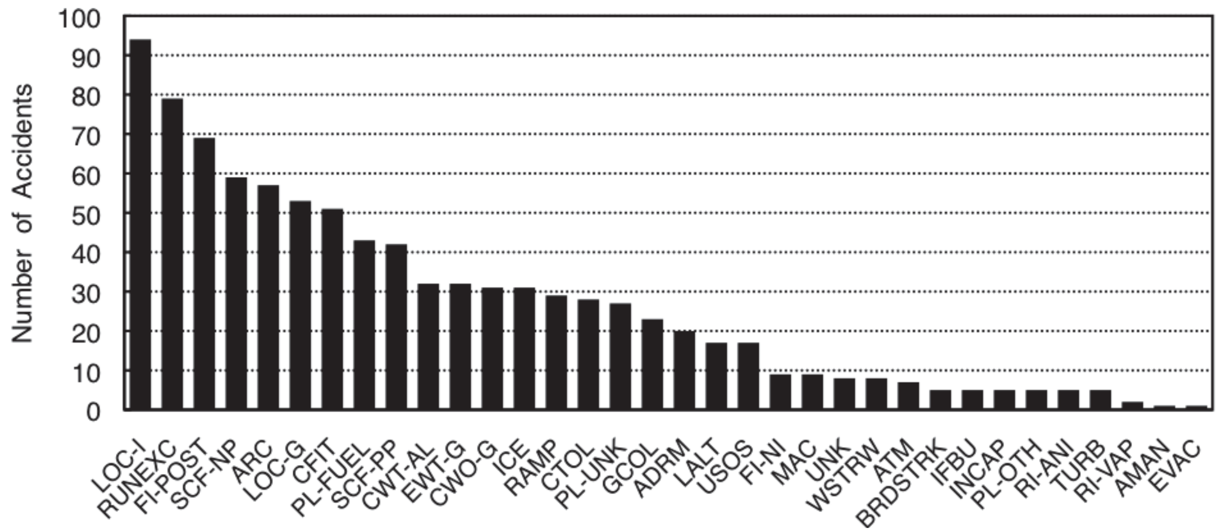

Figure C-5. Number of accidents by CICTT occurrence category for Non-Scheduled Part 135 operations (1997–2006).

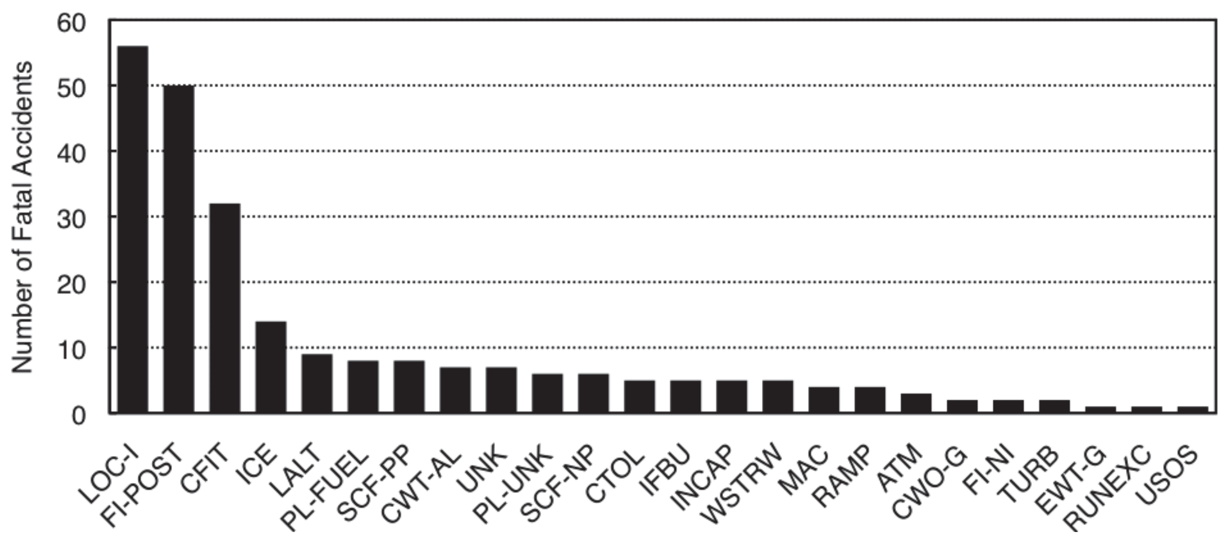

Figure C-6. Number of fatal accidents by CICTT occurrence category for Non-Scheduled Part 135 operations (1997–2006).

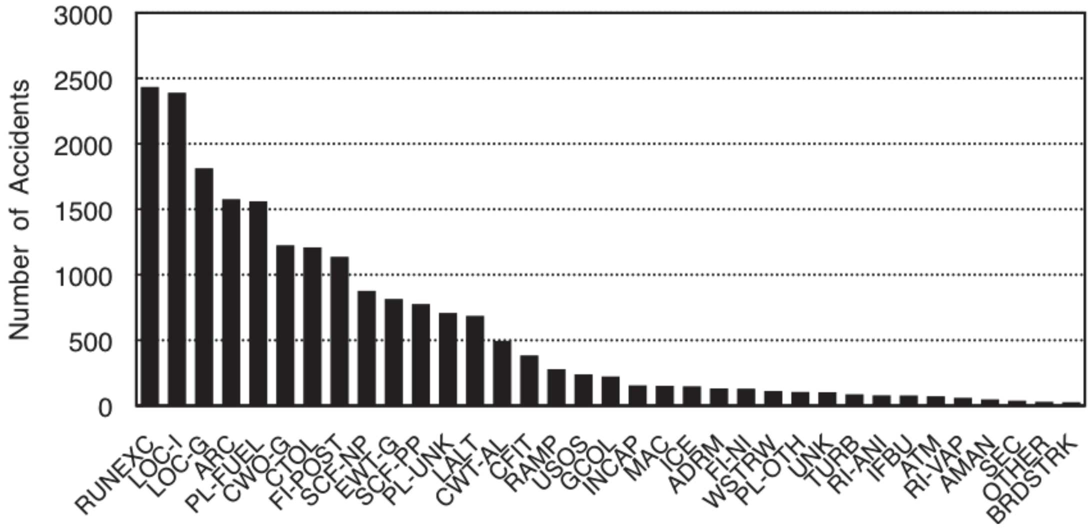

Figure C-7. Number of accidents by CICTT occurrence category for Part 91 operations (1997–2006).

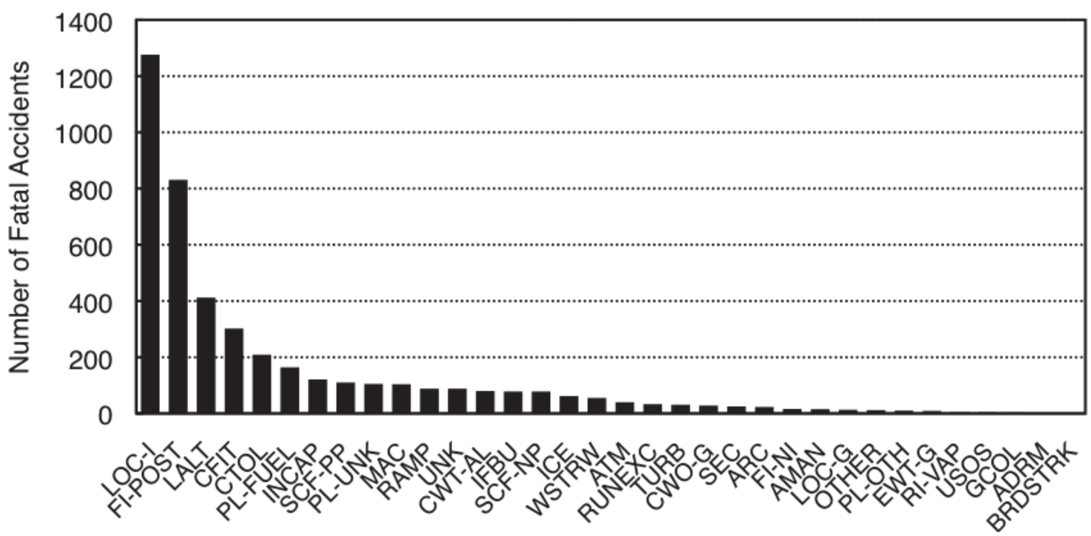

Figure C-8. Number of fatal accidents by CICTT occurrence category for Part 91 operations (1997–2006).

Appendix D. Integrated Resilient Aircraft Control (IRAC) Technology List

TECHNOLOGY NAME	DESCRIPTION
1 – Adaptive Control Algorithm Development	This control technology would be used in response to the unanticipated as well as anticipated flight anomalies. Adaptive control technologies will augment stability augmentation systems to make automatic modifications to the control system of an aircraft operating under adverse flight conditions to improve the closed-loop stability margins of the aircraft. Seven specific approaches are being examined: (1) hybrid direct-indirect, (2) L1, (3) direct, (4) linear quadratic (LQ) optimal, (5) robust composite, (6) adaptive loop recovery and (7) M-MRAC (Modified Model Reference Adaptive Control).
2 – Maneuvering Envelope ID Algorithms	All flight plans are based on "healthy aircraft" however, if there is damage, failure or degradation to the aircraft, the aerodynamics will not behave as designed. Given such an aircraft, this technology uses system ID and sensor output to predict new feasible trim states and to calculate a safe operation envelope. This information enables the pilot to make better decisions instead of relying solely on the flight controller. This technology feeds into #3 (Emergency Trajectory & Flight Planning Guidance).
3 – Emergency Trajectory & Flight Planning Guidance Algorithms	This technology would be used by an aircraft in an emergency situation that needs to land immediately. Emergency planning uses mathematical optimization techniques to assist the pilot in finding the best airport to land and trajectory planning does the analysis to determine the path to get the aircraft to this identified airport. Sources of inputs for the algorithm include the pilot and the output of technology #2 (Maneuvering Envelope ID Algorithms). This technology could be used on both commercial and GA aircraft.
4 – Aerodynamic Modeling of Off-Nominal Flight	The primary objective of this technology is to model the flight dynamic characteristics of a transport aircraft in damaged or failure conditions. The results of this research will enable a better understanding of how an aircraft will fly under extreme off-nominal conditions. For example, one specific research experiment in this area examines the impact of losing a significant portion of the wing on aerodynamic stability and control.
5 – Flight Dynamic Models of Unsteady Aerodynamics	This technology will enable a better understanding of the stability and control characteristics of aircraft under upset or adverse conditions. The primary objective of this technology is to develop dynamic and physics based models of unsteady aerodynamics. Research in this area consists of collecting wind tunnel data, conducting corresponding flight tests and comparing these results to see if there are correlations or discrepancies.
6 – Airframe Icing Modeling	The outputs of the research in this technology are airframe related icing models that examine: (1) how does ice accumulate and (2) what are the effects of icing on aircraft stability and control. Specific research steps in the development of this technology include an examination of the physics of ice accretion on a swept wing and updates to a 3D ice accretion code (LEWICE3D).

TECHNOLOGY NAME	DESCRIPTION
7 – Real Time Full-Envelope Flight Dynamic Modeling	The end result of this technology is the development of a 6 DOF full-envelope simulation model rapidly from flight data. One step in the creation of this model is the development of a real-time dynamic model from flight data. The overall goal of this research is the ability to estimate aircraft stability and control derivates in real time. The results of this technology will enable realistic flight mission rehearsal and pilot training.
8 – C-MAPSS Enhancements	C-MAPSS (Commercial Modular Aero-Propulsion System Simulation) is a tool for the simulation of a realistic large commercial turbofan engine. The code is a combination of Matlab (The MathWorks, Inc.) and Simulink (The MathWorks, Inc.). It is a generic engine simulation that is intended for general release to the public for research purposes. Proposed research includes an effort to collect engine dynamic data at altitude to understand the true engine capability as well as stall margin behavior during the transients. In addition, data will be analyzed by an engine company to model the engine dynamic performance. The results of these research efforts will be used to calibrate the C-MAPSS2 model
9 – Engine Icing Modeling	Ice can accrete inside an aircraft engine during flight into a cloud of ice crystals/water droplets, resulting in engine surge, stall, roll back, or flameout. The output of this technology is engine icing formation models that enable a better understanding of engine icing conditions, which could be used to design controllers that alleviate ice formation.
10 – Engine Performance, Usage & Prognostic Modeling	This technology could be helpful to pilots in determining the potential for failure of an engine while in flight. The modeling in this research examines: (1) engine performance at various operating conditions which are not normally included in engine baseline simulations (high angle of attack engine performance model and engine dynamic performance models) and (2) engine life monitoring and prognosis (stochastic component life models, engine "life meter" for monitoring life usage, prognostic model to predict risk).
11- Probabilistic Based Tool Suite for Quantitative Assessment of Adaptive Control Systems	Despite more than 5 decades of research, the robustness of adaptive control is not well understood. This technology is key to the implementation of technology #1 (Adaptive Control Algorithm Development). The results of this research will be used in the assessment and certification of adaptive control technologies.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01- 11 - 2013

2. REPORT TYPE
Technical Memorandum

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Systems Analysis of NASA Aviation Safety Program: Final Report

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Jones, Sharon M.; Reveley, Mary S.; Withrow, Colleen A.; Evans, Joni K.; Barr, Lawrence C.; Leone, Karen

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
284848.02.01.07.04

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER
L-20323

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA/TM-2013-218059

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 03
Availability: NASA CASI (443) 757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT
A three-month study (February to April 2010) of the NASA Aviation Safety (AvSafe) program was conducted. This study comprised three components: (1) a statistical analysis of currently available civilian subsonic aircraft data from the National Transportation Safety Board (NTSB), the Federal Aviation Administration (FAA), and the Aviation Safety Information Analysis and Sharing (ASIAS) system to identify any significant or overlooked aviation safety issues; (2) a high-level qualitative identification of future safety risks, with an assessment of the potential impact of the NASA AvSafe research on the National Airspace System (NAS) based on these risks; and (3) a detailed, top-down analysis of the NASA AvSafe program using an established and peer-reviewed systems analysis methodology. The statistical analysis identified the top aviation “tall poles” based on NTSB accident and FAA incident data from 1997 to 2006. A separate examination of medical helicopter accidents in the United States was also conducted. Multiple external sources were used to develop a compilation of ten “tall poles” in future safety issues/risks. The top-down analysis of the AvSafe was conducted by using a modification of the Gibson methodology. Of the 17 challenging safety issues that were identified, 11 were directly addressed by the AvSafe program research portfolio.

15. SUBJECT TERMS
Aircraft accidents; Aircraft safety; Civil aviation; Flight safety; Helicopters; Risk; Safety; Safety management; Statistical analysis; Systems analysis

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	72	(443) 757-5802