NASA/TM—2011-216967

Causal Factors and Adverse Events of Aviation Accidents and Incidents Related to Integrated Vehicle Health Management

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March 2011

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Level of Review: This material has been technically reviewed by technical management.

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Executive Summary

The causal factors of accidents from the National Transportation Safety Board (NTSB) database and incidents from the Federal Aviation Administration (FAA) database associated with failures and malfunctions of the various systems and components of commercial aircraft were examined for the years 1988 to 2003 for three types of flight operations: Federal Aviation Regulation Part 121, Scheduled Part 135, and Non-Scheduled Part 135. The aircraft systems were divided into the most frequently cited groups of failure or malfunction: engine or fuel system, flight control or structure, and landing gear or hydraulics. The remaining systems and components were grouped into the "other" category. Most accidents in the NTSB database have more than one causal factor cited by accident and incident investigators. The total number of accidents found in the NTSB database with a system/component failure/malfunction (SCFM) was 370, while the total number of incidents found in the FAA database was 7732.

Maintenance error was a cause in 38 percent of the 179 commercial accidents with an engine or fuel SCFM. Some part of the engine or fuel system was said to have failed in 35 percent of the accidents, and component fatigue was noted in 23 percent of the accidents.

Flight control or structural SCFM was involved in 54 of the accidents. Of these, 46 percent were related to maintenance errors. Manufacturing or design elements were a causal factor in 40 percent of the Part 121 flight control or structural malfunction accidents. A component was said to have failed in 29 percent of the accidents, a component separated in 23 percent of the accidents, and a component jammed in 20 percent of the accidents.

Of the 115 accidents with landing gear or hydraulic system malfunctions in commercial aircraft, 28 percent were related to maintenance errors. A landing gear or hydraulic system component was said to have failed in 48 percent of the accidents.

The Aviation Safety Reporting System (ASRS) incident database was examined for two types of flight operation: Part 121 and Part 135, from January 1993 to March 2008. Equipment problems were the cause of 93 percent of the aircraft primary problem events found in ASRS. The most frequent component failures were turbine engine, pressurization system, hydraulic main system, flight management system/computer, and engine. The data was further categorized in aircraft systems. The monitoring and management system accounted for 14.1 percent of all failures, the propulsion system accounted for 13.7 percent, the control surfaces accounted for 9.1 percent, the environmental control system accounted for 8.8 percent, and the landing gear system accounted for 7.8 percent of the total equipment failures.

An adverse events table was updated to provide focus to the direction of the Integrated Vehicle Health Management Project. The table contains five types of adverse faults: incipient, slow progression, intermittent, cascading, and fast progression. Seventeen different example damage conditions were gleaned from ASRS and the NTSB databases as well as from failure modes and effects analyses abstracts. The severity and frequency of the damage conditions are also provided.

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Summary

Causal factors in aviation accidents and incidents related to system/component failure/malfunction (SCFM) were examined for Federal Aviation Regulation Parts 121 and 135 operations to establish future requirements for the NASA Aviation Safety Program's Integrated Vehicle Health Management (IVHM) Project. Data analyzed includes National Transportation Safety Board (NSTB) accident data (1988 to 2003), Federal Aviation Administration (FAA) incident data (1988 to 2003), and Aviation Safety Reporting System (ASRS) incident data (1993 to 2008). Failure modes and effects analyses were examined to identify possible modes of SCFM. A table of potential adverse conditions was developed to help evaluate IVHM research technologies. Tables present details of specific SCFM for the incidents and accidents. Of the 370 NTSB accidents affected by SCFM, 48 percent involved the engine or fuel system and 31 percent involved landing gear or hydraulic failure and malfunctions. A total of 35 percent of all SCFM accidents were caused by improper maintenance. Of the 7732 FAA database incidents affected by SCFM, 33 percent involved landing gear or hydraulics, and 33 percent involved the engine and fuel system. The most frequent SCFMs found in ASRS were turbine engine, pressurization system, hydraulic main system, flight management system and flight management computer, and engine. Because the IVHM Project does not address maintenance issues, and landing gear and hydraulic systems accidents are usually not fatal, the focus of research should be those SCFMs that occur in the engine and fuel and flight control and structures systems, as well as power systems.

Introduction

Purpose of Study

NASA's Integrated Vehicle Health Management (IVHM) Project is one of four projects within the Agency's Aviation Safety Program (AvSafe) in the Aeronautics Research Mission Directorate. The IVHM Project, which was updated August 14, 2008, conducts research to develop validated tools and technologies for automated detection, diagnosis, and prognosis that enable mitigation of adverse events during flight. Adverse events include those that arise from system, subsystem, or component faults or failures due to damage, degradation, or environmental hazards that occur during flight (Ref. 1).

The purpose of this study is to review statistical data and literature from academia, industry, and other Government agencies to interpret and extract information about causal factors in current aircraft safety incidents and accidents and failure modes and effects analyses (FMEAs) that are related to the key research areas in IVHM. From this information, a list of potential adverse conditions was established against which IVHM technologies can be evaluated. This study is considered a waypoint to establish future requirements for the project with the following expected outcomes (Ref. 1):

(1) Report and document causal factors gleaned from the analyses of the incidents and accidents related to IVHM utilizing the most current statistical and prognostic data available from the Aviation Safety Information Analysis and Sharing (ASIAS) Project.

(2) Report and document causal factors gleaned from FMEAs available from relevant literature.

(3) Develop a list of potential adverse conditions against which IVHM technologies can be evaluated.

Overview of Study Contents

The expected outcomes for this study are addressed in sequential order. Outcome 1 is addressed in the NASA Analyses of NTSB and FAA Accident and Incident Data section and the NASA Analysis of ASRS Incident Data section; these analyses have been conducted by NASA researchers for this Key Decision Point. Outcome 2 is the focus of Failure Modes and Effects Analysis section, while outcome 3 is addressed by the Adverse Events Table. Finally, discussion and the conclusions that have been drawn are provided.

The first expected outcome of this study is the results of an examination of the most recent statistical and prognostic incident and accident data that is available to determine the causal factors of system or component failures and/or malfunctions in U.S. commercial aviation accidents and incidents. The next two sections contain the results of two separate statistical analyses that have been conducted by NASA to address this expected outcome. The first statistical analysis examined publicly available National Transportation Safety Board (NTSB) and Federal Aviation Administration (FAA) accident and incident data. A second statistical analysis was conducted with the Aviation Safety Reporting System (ASRS) reports as the data source. All of these data sources can be accessed using ASIAS (Ref. 2)

NASA Analyses of National Transportation Safety Board and Federal Aviation Administration Accident and Incident Data

A statistical analysis was conducted to determine the causal factors of accidents and incidents associated with failures or malfunctions of the various systems or components of commercial aircraft from 1988 to 2003. A causal factor is described as why the accident or incident happened. In determining the causes, the NTSB considers all facts, conditions, and circumstances associated with the accident. Often several causes explain why an accident occurred. For this reason, a single accident report can include multiple causes (Ref. 3). The safety risk is based on both accidents and incidents, which are defined as follows (Ref. 4):

Accident	An occurrence associated with the operation of an aircraft, which takes place between the time any person boards the aircraft with the intention of flight and 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, associated with the operation of an aircraft, which affects or could affect the safety of operations.

In this analysis, "commercial" is defined as Part 121, Scheduled Part 135, and Non-Scheduled Part 135 flights. Part 121 operations applies to major airlines and cargo carriers that fly large transport-category aircraft, and Part 135 applies to commercial aircraft air carriers commonly referred to as commuter airlines. Prior to March 1997, Part 121 operations included aircraft with 30 or more seats. In March 1997, the definition of Part 121 operations changed and now includes those aircraft with 10 or more seats. Scheduled operation refers to "any common carriage passenger-carrying operation for compensation or hire conducted by an air carrier or commercial operator for which the certificate holder or its representative offers in advance of the departure location, departure time, and arrival location." A non-scheduled operation refers to "any operation for compensation or hire in which the departure time, departure location, and arrival location are specifically negotiated with the customer" (Ref. 5).

The source for accident data is the NTSB Aviation Accident and Incident Data System, while the source for incident data is the FAA's Accident/Incident Data System. Although both databases contain both accident and incident data, the FAA has primary investigative responsibility for incidents and the NTSB is the authority for accident investigation.

For each accident and incident, the system affected by the system/component failure/malfunction (SCFM) was determined (see Tables 1 and 2). In some events, multiple systems were affected, and in these cases the first system affected was selected. For example, if an electrical malfunction preceded an engine fire, that event was categorized under electrical.

The NTSB database includes causal factors for each accident that occurs within the United States. The aircraft systems identified in Table 1 were divided into four system groups: engine or fuel system; flight control or structure; landing gear or hydraulic; and instrumentation/communication/navigation, electrical, other, unknown. The first three groups account for the most frequent SCFM-related events.

TABLE 1.—FREQUENCY OF SYSTEM/COMPONENT FAILURE/MALFUNCTION ACCIDENTS GROUPED BY SYSTEM AFFECTED AND BY OPERATION CATEGORY

System	Operation category			
	Part 121	Scheduled Part 135	Non-Scheduled Part 135	Parts 121 and 135 combined
Engine	36 (33%)	12 (36%)	111 (49%)	159 (43%)
Landing gear	23 (21%)	10 (30%)	64 (28%)	97 (26%)
Flight control	10 (9%)	3 (9%)	9 (4%)	22 (6%)
Electrical	8 (7%)	1 (3%)	12 (5%)	21 (6%)
Fuel	4 (4%)	3 (9%)	13 (6%)	20 (5%)
Hydraulic	9 (8%)	2 (6%)	7 (3%)	18 (5%)
Structure	5 (5%)	1 (3%)	7 (3%)	13 (4%)
Other	8 (7%)	1 (3%)	4 (2%)	13 (4%)
Instrumentation/ communication/ navigation	5 (5%)	0 (0%)	0 (0%)	5 (1%)
Unknown	1 (1%)	0 (0%)	1 (0%)	2 (1%)
Total accidents	109	33	228	370

TABLE 2.—FREQUENCY OF SYSTEM/COMPONENT FAILURE/MALFUNCTION INCIDENTS GROUPED BY SYSTEM AFFECTED AND BY OPERATION CATEGORY

System	Operation category			
	Part 121	Scheduled Part 135	Non-Scheduled Part 135	Parts 121 and 135 combined
Engine	1384 (28%)	486 (31%)	349 (29%)	2219 (29%)
Landing gear	990 (20%)	509 (33%)	558 (46%)	2057 (27%)
Other	615 (12%)	135 (9%)	47 (4%)	797 (10%)
Flight control	431 (9%)	43 (3%)	28 (2%)	502 (6%)
Hydraulic	414 (8%)	57 (4%)	45 (4%)	516 (7%)
Fuel	215 (4%)	80 (5%)	54 (4%)	349 (5%)
Structure	214 (4%)	80 (5%)	49 (4%)	343 (4%)
Comfort systems	246 (5%)	54 (4%)	20 (2%)	320 (41%)
Electrical	191 (4%)	64 (4%)	47 (4%)	302 (4%)
Pressurization	174 (4%)	15 (1%)	8 (1%)	197 (3%)
Instrumentation/communication/navigation	83 (2%)	34 (2%)	13 (1%)	130 (2%)
Total incidents	4957	1557	1218	7732

TABLE 3.—FREQUENCY OF SYSTEM/COMPONENT FAILURE/MALFUNCTION ACCIDENT CHARACTERISTIC BY SYSTEM GROUP AND BY OPERATION CATEGORY

System group	Accident characteristics	Operation category			
		Part 121	Scheduled Part 135	Non-Scheduled Part 135	Parts 121 and 135 combined
Engine or fuel system	Total accidents	40	15	124	179
	Fatal accidents	4 (10%)	3 (20%)	37 (30%)	44 (25%)
	Total fatalities	151	33	92	276
Flight control or structure	Total accidents	15	4	16	35
	Fatal accidents	7 (47%)	1 (25%)	4 (25%)	12 (34%)
	Total fatalities	279	14	4	297
Landing gear or hydraulic	Total accidents	32	12	71	115
	Fatal accidents	0 (0%)	1 (8%)	0 (0%)	1 (1%)
	Total fatalities	0	5	0	5
Instrument/ communication/ navigation, electrical, other, unknown	Total accidents	22	2	17	41
	Fatal accidents	5 (23%)	0	6 (35%)	11 (27%)
	Total fatalities	347	0	13	360

Further analysis of the SCFM accidents compared the severity of the four system categories. Table 3 compares the four system groups' fatal accidents and fatality rates. Although the landing gear or hydraulic system category has 115 total accidents, only one was a fatal accident with five fatalities. In contrast, within the engine or fuel system category, 25 percent of the total accidents were fatal with 276 fatalities. The flight control or structural systems category has 40 accidents, yet 12 were fatal accidents, or 30 percent with 297 fatalities. Even though flight control/structural SCFM accidents were less frequent than landing gear/hydraulic SCFMs, the outcomes were far worse.

The next four tables list the causal factors that are linked to the SCFMs for the four system groups identified in Table 3. Some of the causal factors specify the problem with the component (corroded, fractured, separated, etc.), and others address errors by individuals (maintenance personnel) or groups of people (the manufacturer, the company, or operator) or regulatory deficiencies (the FAA). As stated earlier, most events have more than one causal factor.

Each table includes the number of accidents within the particular group of systems; the percentages given are based on the number of accidents, not on the number of causal factors. Most accidents contain more than one causal factor. For those events for which "unknown" is listed in the table as a causal factor, no other causal factors appear in the table for that event. In other words, for those 21 accidents, the cause of the failure or malfunction in completely unknown.

In Table 4, 39 percent of engine or fuel SCFMs in commercial aircraft were related to maintenance errors; 42 percent were in Part 121 operations, 20 percent in Scheduled Part 135 and 40 percent in Non-Scheduled Part 135. Some part of the engine or fuel system failed in 35 percent of the accidents, and fatigue was noted in 23 percent of the accidents. A component separated from its normal position in 14 percent of the accidents. Manufacturing or design issues were cited much more frequently in Part 121 or Scheduled Part 135 than in Non-Scheduled Part 135 accidents.

Flight control or structural SCFM causal factors are shown in Table 5. Maintenance errors were a causal factor in 46 percent of the accidents; Part 121 accounted for 53 percent of these, 50 percent in Scheduled Part 135, and 38 percent in Non-Scheduled Part 135. Manufacturing or design elements were named as a cause in 40 percent of the Part 121 flight control or structural SCFM accidents. A component failed in 29 percent of the accidents, a component separated in 23 percent of the accidents, and a component jammed in 20 percent of the accidents.

Landing gear or hydraulic SCFMs are shown in Table 6. Maintenance errors were a causal factor in 28 percent of the accidents; Part 121 accounted for 25 percent of these, 33 percent in Scheduled Part 135, and 28 percent in Non-Scheduled Part 135. A component failed in 48 percent of the accidents, component fatigue occurred in 18 percent of the accidents, and there was a loss of hydraulic fluid in 15 percent of the accidents. In 33 percent of Scheduled Part 135 accidents a component was inoperative. Manufacturing or design issues were cited more frequently in Part 121 or Scheduled Part 135 than in Non-Scheduled Part 135 accidents.

The remaining SCFMs are shown in Table 7. Maintenance errors were a causal factor in 32 percent of the accidents; Part 121 accounted for 41 percent of these, 50 percent in Scheduled Part 135, and 17 percent in Non-Scheduled Part 135. There was an electrical failure in 17 percent of the accidents, wire chafed/arcing in 15 percent of the accidents, and an electrical short in 12 percent of the accidents.

TABLE 4.—FREQUENCY OF CAUSAL FACTORS OF ENGINE OR FUEL SYSTEM/COMPONENT FAILURE/ MALFUNCTION (SCFM) ACCIDENTS BY OPERATION CATEGORY

Causal factors of engine or fuel SCFM	Operation category			
	Part 121	Scheduled Part 135	Non-Scheduled Part 135	Parts 121 and 135 combined
Total engine or fuel SCFM accidents	40	15	124	179
Maintenance related	17 (42%)	3 (20%)	49 (40%)	69 (39%)
Component failure	18 (45%)	5 (33%)	39 (31%)	62 (35%)
Component fatigue	8 (20%)	3 (20%)	30 (24%)	41 (23%)
Component separated	6 (15%)	3 (20%)	16 (13%)	25 (14%)
Manufacturing/design	9 (22%)	3 (20%)	8 (6%)	20 (11%)
Component fractured	3 (8%)	1 (7%)	16 (13%)	20 (11%)
Component disconnected	3 (6%)	1 (7%)	15 (12%)	19 (11%)
Oil deprivation	1 (2%)	1 (7%)	13 (10%)	15 (8%)
Component worn	2 (5%)	1 (7%)	8 (6%)	11 (6%)
Unknown	3 (8%)	0 (0%)	7 (6%)	10 (6%)
Ignition erratic	1 (2%)	1 (7%)	0 (0%)	8 (4%)
Incorrect, improper, or inadequate component	0 (0%)	1 (7%)	7 (6%)	8 (4%)
Component loose	0 (0%)	1 (7%)	6 (5%)	7 (4%)
Company/operator error	2 (5%)	0 (0%)	5 (4%)	7 (4%)
Component corroded	1 (2%)	1 (7%)	5 (4%)	7 (4%)
Component deteriorated	1 (2%)	0 (0%)	6 (5%)	7 (4%)
Fuel leak	2 (5%)	1 (7%)	3 (2%)	6 (3%)
Overspeed/overtemperature	1 (2%)	1 (7%)	3 (2%)	5 (3%)
Overtorque/undertorque	0 (0%)	0 (0%)	5 (4%)	5 (3%)
Federal Aviation Administration	1 (2%)	2 (13%)	1 (1%)	4 (2%)
Component malfunction	1 (2%)	0 (0%)	3 (2%)	4 (2%)
Component ruptured/severed	2 (5%)	0 (0%)	2 (2%)	4 (2%)
Loss of oil pressure	1 (2%)	0 (0%)	3 (2%)	4 (2%)
Component inoperative	1 (2%)	0 (0%)	2 (2%)	3 (2%)
Component bent	1 (2%)	0 (0%)	1 (1%)	2 (1%)
Component movement restricted	1 (2%)	0 (0%)	1 (1%)	2 (1%)
Bolt not secured	1 (2%)	0 (0%)	1 (1%)	2 (1%)
Burned piston	0 (0%)	1 (7%)	1 (1%)	2 (1%)
Mechanical binding of component	1 (2%)	0 (0%)	1 (1%)	2 (1%)
Wiring chafed/arcing	1 (2%)	0 (0%)	1 (1%)	2 (1%)
Fouled spark plug	0 (0%)	0 (0%)	1 (1%)	1 (1%)
Magneto jammed	0 (0%)	0 (0%)	1 (1%)	1 (1%)
Seal not installed	0 (0%)	0 (0%)	1 (1%)	1 (1%)

Flight control or structural SCFM causal factors are shown in Table 5. Maintenance errors were a causal factor in 46 percent of the accidents; Part 121 accounted for 53 percent of these, 50 percent in Scheduled Part 135, and 38 percent in Non-Scheduled Part 135. Manufacturing or design elements were named as a cause in 40 percent of the Part 121 flight control or structural SCFM accidents. A component failed in 29 percent of the accidents, a component separated in 23 percent of the accidents, and a component jammed in 20 percent of the accidents.

Landing gear or hydraulic SCFMs are shown in Table 6. Maintenance errors were a causal factor in 28 percent of the accidents; Part 121 accounted for 25 percent of these, 33 percent in Scheduled Part 135 and 28 percent in Non-Scheduled Part 135. A component failed in 48 percent of the accidents, component fatigue occurred in 18 percent of the accidents, and there was a loss of hydraulic fluid in 15 percent of the accidents. In 33 percent of Scheduled Part 135 accidents a component was inoperative. Manufacturing or design issues were cited more frequently in Part 121 or Scheduled Part 135 than in Non-Scheduled Part 135 accidents.

The remaining SCFMs are shown in Table 7. Maintenance errors were a causal factor in 32 percent of the accidents; Part 121 accounted for 41 percent of these, 50 percent in Scheduled Part 135, and 17 percent in Non-Scheduled Part 135. There was an electrical failure in 17 percent of the accidents, wire chafed/arcing in 15 percent of the accidents, and electrical short in 12 percent of the accidents.

TABLE 5.—FREQUENCY OF CAUSAL FACTORS OF FLIGHT CONTROL OR STRUCTURAL SYSTEM/ COMPONENT FAILURE/MALFUNCTION (SCFM) ACCIDENTS BY OPERATION CATEGORY

Causal factors of flight control or structural SCFM	Operation category			
	Part 121	Scheduled Part 135	Non-Scheduled Part 135	Parts 121 and 135 combined
Total flight control or structural SCFM accidents	15	4	16	35
Maintenance related	8 (53%)	2 (50%)	6 (38%)	16 (46%)
Component failure	3 (20%)	2 (50%)	5 (31%)	10 (29%)
Component separated	4 (27%)	1 (25.0%)	3 (19%)	8 (23%)
Manufacturing/design	6 (40%)	0 (0%)	1 (6%)	7 (20%)
Component jammed	2 (13%)	1 (25%)	4 (25%)	7 (20%)
Component inoperative	2 (13%)	0 (0%)	3 (19%)	5 (14%)
Federal Aviation Administration	3 (20%)	1 (25%)	0 (0%)	4 (11%)
Company/operator error	2 (13%)	1 (25%)	0 (0%)	3 (9%)
Component corroded	2 (13%)	0 (0%)	1 (6%)	3 (9%)
Component fatigue	1 (7%)	0 (0%)	2 (12%)	3 (9%)
Unknown	3 (20%)	0 (0%)	0 (0%)	3 (9%)
Screws/bolts not secured	1 (7%)	1 (25%)	0 (0%)	2 (6%)
Component fractured	1 (7%)	0 (0%)	1 (6%)	2 (6%)
Elevator control movement restricted	1 (7%)	0 (0%)	1 (6%)	2 (6%)
Elevator trim/tab control disconnected	1 (7%)	0 (0%)	1 (6%)	2 (6%)
False indication	1 (7%)	0 (0%)	0 (0%)	1 (3%)
Inadequate lubrication	1 (7%)	0 (0%)	0 (0%)	1 (3%)
Jackscrew assembly worn	1 (7%)	0 (0%)	0 (0%)	1 (3%)

TABLE 6.—FREQUENCY OF CAUSAL FACTORS OF LANDING GEAR OR HYDRAULIC SYSTEM/COMPONENT FAILURE/MALFUNCTION (SCFM) ACCIDENTS BY OPERATION CATEGORY

Causal factors of landing gear or hydraulic SCFM	Operation category			
	Part 121	Scheduled Part 135	Non-Scheduled Part 135	Parts 121 and 135 combined
Total landing gear or hydraulic SCFM accidents	32	12	71	115
Component failure	18 (56%)	3 (25%)	34 (48%)	55 (48%)
Maintenance related	8 (25%)	4 (33%)	20 (28%)	32 (28%)
Component fatigue	7 (22%)	2 (17%)	12 (17%)	21 (18%)
Hydraulic fluid loss	8 (25%)	3 (25%)	6 (8%)	17 (15%)
Component fractured	4 (12%)	1 (8%)	8 (11%)	13 (11%)
Manufacturing/design	6 (19%)	2 (17%)	4 (6%)	12 (10%)
Component inoperative	3 (9%)	4 (33%)	3 (4%)	10 (9%)
Component overload	1 (3%)	1 (8%)	4 (6%)	6 (5%)
Component collapsed	0 (0%)	1 (8%)	4 (6%)	5 (4%)
Component frozen	0 (0%)	1 (8%)	4 (6%)	5 (4%)
Component separated	1 (3%)	1 (8%)	3 (4%)	5 (4%)
Federal Aviation Administration	1 (3%)	0 (0%)	3 (4%)	4 (3%)
False indication	1 (3%)	0 (0%)	3 (4%)	4 (3%)
Unknown	1 (3%)	0 (0%)	3 (4%)	4 (3%)
Component corroded	0 (0%)	0 (0%)	3 (4%)	3 (3%)
Component jammed	0 (0%)	1 (8%)	2 (3%)	3 (3%)
Component malfunction	0 (0%)	0 (0%)	3 (4%)	3 (3%)
Gear switch movement restricted	1 (3%)	0 (0%)	1 (1%)	2 (2%)
Component disconnected	0 (0%)	0 (0%)	2 (3%)	2 (2%)
Component vibration	1 (3%)	0 (0%)	1 (1%)	2 (2%)
Mechanical binding of component	0 (0%)	1 (8%)	1 (1%)	2 (2%)
Company/operator surveillance	1 (3%)	0 (0%)	0 (0%)	1 (1%)
Bolt sheared	0 (0%)	0 (0%)	1 (1%)	1 (1%)
Brakes overheated	1 (3%)	0 (0%)	0 (0%)	1 (1%)
Gear strut washer worn	0	0 (0%)	1 (1%)	1 (1%)
Nose gear strut underinflated	1 (3%)	0 (0%)	0 (0%)	1 (1%)
Tires underinflated	0 (0%)	0 (0%)	1 (1%)	1 (1%)
Wiring chafed/arcing	0 (0%)	0 (0%)	1 (1%)	1 (1%)

TABLE 7.—FREQUENCY OF CAUSAL FACTORS OF OTHER[a] SYSTEM/COMPONENT FAILURE/ MALFUNCTION (SCFM) ACCIDENTS BY OPERATION CATEGORY

Cause of other SCFM	Operation category			
	Part 121	Scheduled Part 135	Non-Scheduled Part 135	Parts 121 and 135 combined
Total other SCFM accidents	22	2	17	41
Maintenance related	9 (41%)	1 (50%)	3 (17%)	13 (32%)
Electrical failure	1 (4%)	0 (0%)	6 (35%)	7 (17%)
Wiring chafed/arcing	3 (14%)	1 (50%)	2 (12%)	6 (15%)
Manufacturing/design	4 (18%)	1 (50%)	0 (0%)	5 (12%)
Component failure	3 (14%)	0 (0%)	2 (12%)	5 (12%)
Electrical short	4 (18%)	0 (0%)	1 (6%)	5 (12%)
Company/operator error	2 (9%)	1 (50%)	1 (6%)	4 (10%)
Unknown	2 (9%)	0 (0%)	2 (12%)	4 (10%)
Federal Aviation Administration	1 (4%)	1 (50%)	0 (0%)	2 (5%)
Battery discharged	0 (0%)	0 (0%)	2 (12%)	2 (5%)
Hazardous material	2 (9%)	0 (0%)	0 (0%)	2 (5%)
Alternator belt disconnected	0 (0%)	0 (0%)	1 (6%)	1 (2%)
Alternator wiring disconnected	0 (0%)	0 (0%)	1 (6%)	1 (2%)
Alternator inoperative	0 (0%)	0 (0%)	1 (6%)	1 (2%)
Anti-ice system inoperative	0 (0%)	0 (0%)	1 (6%)	1 (2%)
Auxiliary power unit (APU) combustor cap drain line clogged	1 (4%)	0 (0%)	0 (0%)	1 (2%)
APU malfunction	1 (4%)	0 (0%)	0 (0%)	1 (2%)
Attitude indicator malfunctioned	1 (4%)	0 (0%)	0 (0%)	1 (2%)
Autopilot servo frozen	1 (4%)	0 (0%)	0 (0%)	1 (2%)
Galley elevator drive shaft fatigue/failure	1 (4%)	0 (0%)	0 (0%)	1 (2%)
Heater over temperature	0 (0%)	0 (0%)	1 (6%)	1 (2%)
Hydraulic fluid loss	1 (4%)	0 (0%)	0 (0%)	1 (2%)
Oxygen leak	1 (4%)	0 (0%)	0 (0%)	1 (2%)
Wiring not secured	0 (0%)	1 (50%)	0 (0%)	1 (2%)

[a]Other includes electrical, instrumentation/communication/navigation, anti-ice/deice system, APU, cargo fire, galley, heating, oxygen, pressurization, warning systems, vacuum pump, and unknown.

NASA Analysis of Aviation Safety Reporting System Incident Data

This section examines the composition of SCFM incidents as reported in the Aviation Safety Reporting System (ASRS). ASRS is a voluntary, nonpunitive, self-reporting system administered by NASA Ames Research Center that includes incident reports submitted by members of the flightcrew and other people working in the aviation industry (Ref. 2). The ASRS reports do not represent an unbiased sample of aviation incidents, and the results presented here should not be considered statistically representative, but rather informational in nature.

Data used in this analysis are from the years January 1993 through March 2008. While the ASRS online database includes incidents starting in 1988, information on which Federal Aviation Regulation (FAR) flight operation the incident occurred during is available only beginning in 1993. Because other flight operations, such as Part 91 (general aviation), may have substantially different data compared with Parts 121 and 135, it was decided to use only those years for which FAR part was known (1993 to 2008). During this time period, there were 60 380 incident reports for Part 121 operation and 6151 incident reports for Part 135 operation. Each ASRS incident report lists the primary problem (or causal factor), and, if applicable, the component involved. While this categorization is performed by the experts at ASRS, the component data was further categorized into groups based on aircraft subsystems.

To obtain information relevant to SCFM, the ASRS Web tool was used to query the database. The initial selection criterion was incidents in which the primary problem was "aircraft." The Web tool allows the user to export the results to an Excel file, and relevant information such as the FAR Part and Primary Problem were kept. Because the Web tool's data export function only includes those fields that can be queried using the tool, component information was later obtained through permission of the ASRS team at NASA Ames Research Center. These data were provided in a spreadsheet with only the component and incident report number (ACN), and were matched to the exported data using the ACN. After combining the data in one file, the aircraft system categorization was added, and SAS software was used to perform the analysis.

Primary Problems of Incidents

ASRS identifies the most significant factor of the incident and includes it under the category Primary problem. Table 8 shows the frequency of different primary problems or causal factors of incidents from January 1993 to March 2008 for both Part 121 and Part 135 operations. It must be noted that not every incident report has an identified primary problem. Therefore, the number of incidents shown in Table 8 are less than the total of 66 531 incidents contained in the database for the given time period.

TABLE 8.—FREQUENCIES OF PRIMARY PROBLEM BY FLIGHT OPERATION CATEGORY

Primary problem	Operation category		
	Part 121	Part 135	Parts 121 and 135 combined
Flight crew human performance	20378 (37%)	3181 (56%)	23559 (39%)
Aircraft	12179 (22%)	1211 (21%)	13390 (22%)
Air traffic control (ATC) human performance	7811	571	8382
Maintenance human performance	4500	102	4602
Company	2947	80	3027
Weather	1865	221	2086
Passenger human performance	1349	2	1351
Airport	1132	136	1268
Chart or publication	888	40	928
Environmental factor	513	35	548
Federal Aviation Administration	375	38	413
Navigational facility	350	28	378
Airspace structure	247	25	272
Cabin crew human performance	230	0	230
ATC facility	108	9	117
Total	54872 (100%)	5679 (100%)	605551 (100%)

The aircraft primary problem category is the second most frequent primary problem (causal factor) in both Parts 121 and 135 incidents containing 22 percent of all primary problems. It occurs more frequently than all other primary problems combined excluding the flight crew human performance category. Of interest to the IVHM Project is the aircraft category because it contains incident causal factors related to SCFM. ASRS reports include more specific descriptions of the type of problem in the aircraft category. Table 9 shows a further breakdown of the aircraft primary problem category into different types of subcategories. The most frequent subcategory cited is the equipment problem subcategory.

The numbers reflected in Table 9 are the number of ASRS incident reports citing each of these problem subcategories. For example, there were 12 395 reports that listed the primary problem as being aircraft and the type of aircraft problem being equipment problem for the combined Parts 121 and 135. During some incidents, multiple components failed in succession. Later in this study, the tables will reflect higher numbers because of multiple component failures in a single report. Separately and combined, equipment problems account for approximately 93 percent of incidents whose primary factor was aircraft for both FAR Parts 121 and 135. A closer look at the equipment problem subcategory is presented next.

TABLE 9.—SUBCATEGORY FREQUENCIES OF THE PRIMARY PROBLEM: AIRCRAFT BY FLIGHT OPERATION CATEGORY

Subcategory	Operation category		
	Part 121	Part 135	Parts 121 and 135 combined
Equipment problem	11268 (93%)	1127 (93%)	12395 (93%)
Nonadherence	164	31	195
Airspace violation	5	0	5
Altitude deviation	203	11	214
Cabin event	44	1	45
Conflict	77	10	87
Excursion	2	1	3
Ground encounter	4	0	4
Incursion	2	1	3
Inflight encounter	62	9	71
Maintenance problem	15	0	15
Other anomaly	325	20	345
Other spatial deviation	8	0	8
Total	12179 (100%)	1211 (100%)	13390 (100%)

Aircraft SCFM Analysis

Most ASRS incident reports include a list of which components failed during the occurrence. Unfortunately, because ASRS is voluntarily reported, not all reports included the same amount of detail. A small number of those reports listing the primary problem as aircraft were excluded because they did not state which components were affected. For the remainder of this section, all results are based only on reports that list the primary problem as aircraft and include specific component failures. The data presented shows FAR Parts 121 and 135 combined.

The top 20 most frequent individual component failures can be seen in Table 10. The components are labeled as they were listed in ASRS and any acronyms can be found in the appendix of this document. One difficulty with this study was the lack of clarity in the reports concerning engine failures. Although many pilots and ASRS officials were very specific in noting exactly which component of the engine failed, others just listed "engine" or "turbine engine" as having failed without providing any more detail.

The top 10 failures in Table 10 account for 22 percent of all of the equipment failures in the ASRS incident reports. In the incident reports, 463 different component failures were cited.

TABLE 10.—MOST FREQUENT COMPONENT FAILURES OR MALFUNCTIONS

Component	Frequency of failure or malfunction
Turbine engine	752
Pressurization system	351
Hydraulic main system	274
Flight management system/flight management computer	267
Engine	259
Autopilot	241
Air conditioning and pressurization	192
Flap/slat control system	175
Gear extend/retract mechanism	174
Trailing edge flap control	170
Main gear tire	165
Pressurization control system	162
Indicating and warning-landing gear	142
Air conditioning distribution system	130
Nose gear	128
Cockpit window	128
Hydraulic system	127
Trailing edge flap	124
Ground proximity warning system (GPWS)	120
Aircraft logbook	105

Aircraft System Category Failures

To provide an alternative look at the incident data, the component failures were later grouped by aircraft system. Then the systems were ranked in order of frequency within the new subcategories. Shown in Table 11, the top five systems cause 54 percent of all aircraft equipment failures during incidents. Those systems are monitoring and management, propulsion, control surfaces, environmental control, and landing gear. Some ASRS incident reports included multiple failures, and that is why 12 772 component failures came from 10 121 reports.

TABLE 11.—FREQUENCIES OF COMPONENT FAILURES/MALFUNCTIONS GROUPED BY SYSTEM

Aircraft system	System description	SCFM frequency
Monitoring and management	Any component or system that monitors the aircraft status and functions and relays them to the pilots; centralized control of complex systems including health monitoring	1801
Propulsion	Propulsion system components	1754
Control surfaces	Moving surface used for attitude, lift, and drag control	1166
Environmental control	Provides air supply, thermal control cabin pressurization, avionics cooling, smoke detection, and fire suppression	1127
Landing gear	Components that provide support on the ground and allow taxiing, takeoff and landing	1003
Navigation	Determination of the position on or above the surface of the Earth; also collision avoidance including navigation around other aircraft and avoidance of terrain	988
Electrical/power	Includes power generation, distribution protection, and storage	933
Hydraulics/pneumatics	Any systems using a fluid or gas to transmit force; includes actuators	671
Automated flight control	Automated means of flight control	543
Structures	The fuselage, empennage, wings; the control surfaces and landing gear have been subcategorized	543
Fuel	Any portion of the fuel system	414
Miscellaneous	Anything that does fit into any of the other categories	404
Communication	Connects the flight deck to the ground and the flight deck to the passengers	362
Oil	Oil lubrication and components	337
Brakes	Landing gear braking system	287
Furnishings and equipment	Aircraft seats, cargo, entertainment, etc.	263
Icing	Anti-icing or deicing systems	140
Weather	Weather radar/information and lightning detectors	36

Monitoring and Management

The monitoring and management category is of particular importance to the IVHM Project because of its focus on the health management of aircraft components and systems. This category includes any component or system that monitors the aircraft status and functions and relays them to the pilots as well as centralized control of complex systems including health monitoring. While hardware features have extensive background research and testing of failures, monitoring and management failures may be harder to predict and test. Information given by United Airlines in reference to Boeing 777 aircraft indicates that health monitoring significantly reduces mechanical problems, but increases software problems (Ref. 6). More research is needed to ensure that mechanical problems are not replaced by software problems (Ref. 6).

Included in Table 12 are the top 20 most frequent specific component failures of the monitoring and management system. This category contains 75 different types of component failure. These failures account for 64 percent of all monitoring and management system failures.

TABLE 12.—TOP 20 MOST FREQUENT SYSTEM/COMPONENT FAILURE/ MALFUNCTIONS (SCFMs) OF MONITORING AND MANAGEMENT SYSTEM COMPONENTS

Component	SCFM frequency
Landing gear indicating and warning	142
Landing gear indicating system	98
Fire/overheat warning	95
Cargo compartment fire/overheat warning	86
Door warning system	83
Fuel quantity pressure indication	81
Powerplant fire/overheat warning	77
Oil pressure indication	65
Air data computer	57
Altimeter	52
Airspeed indicator	39
Flight and navigation systems indicating and warning	39
Pneumatic system indicating and warning	39
Fuel system indicating and warning	37
Primary flight display	29
Oil contents indication	28
Attitude indicator	26
Engine pressure ratio indication	26
APU fire/overheat warning	25
Engine indications	25

Propulsion

The propulsion system category contains SCFMs of 82 different components and systems. Shown in Table 13 are the top 20 most frequent specific component failures of the propulsion system. These failures account for 88 percent of all propulsion SCFMs. The turbine engine and engine components account for 58 percent of all the cited propulsion SCFMs. Again, these components skew the results because of lack of detail in the reports. The rest of the propulsion SCFMs were actually remarkably specific and diverse. Without engine and turbine engine, most of the propulsion components do not fail a significant amount of the times.

TABLE 13.—TOP 20 MOST FREQUENT SYSTEM/ COMPONENT FAILURE/MALFUNCTIONS (SCFMs) OF PROPULSION SYSTEM COMPONENTS

Component	SCFM frequency
Turbine engine	752
Engine	259
Compressor	73
Throttle/power level	69
Cowling	50
Turbine assembly	48
Turbine engine thrust reverser	31
Engine air starter	27
Compressor bearing	26
Reciprocating engine assembly	24
Thrust reverser control	24
Fan blade	23
Turbine assembly blade	23
Engine air	22
Engine-driven pump	22
Reverser actuator	16
Compressor blade	15
Propeller autofeather system	15
Fan reverser	12
Propeller blade	11

Control Surfaces

The control surface system category contains SCFMs of 33 different components and systems. Shown in Table 14 are the top 20 most frequent specific component failures of the control surface system. These failures account for 94 percent of all control surface SCFMs. The flap/slat control system, trailing edge flap control, and trailing edge flap components account for 40 percent of all the cited control surface SCFMs.

TABLE 14.—TOP 20 MOST FREQUENT SYSTEM/ COMPONENT FAILURE/MALFUNCTIONS (SCFMs) OF CONTROL SURFACES SYSTEM COMPONENTS

Component	SCFM frequency
Flap/slat control system	175
Trailing edge flap control	170
Trailing edge flap	124
Rudder control system	82
Leading edge slat	77
Horizontal stabilizer trim	73
Aileron control system	50
Elevator control system	49
Elevator trim system	43
Speedbrake/spoiler	42
Spoiler system	41
Leading edge flap	32
Horizontal stabilizer control	26
Rudder	22
Rudder trim system	19
Elevator	18
Elevator feel system	15
Aileron trim system	14
Aileron	13
Horizontal stabilizer	10

Environmental Controls

The environmental control system had the fourth highest impact on the incidents reported from 1993 to 2008. The environmental control system category contains SCFMs of 16 different components and systems shown in Table 15. The pressurization system, air conditioning and pressurization, pressurization control system, and air conditioning distribution system components account for 74 percent of all the cited environmental controls SCFMs.

TABLE 15.—SYSTEM/COMPONENT FAILURE/MALFUNCTION (SCFM) OF ENVIRONMENTAL CONTROLS SYSTEM COMPONENTS

Component	SCFM frequency
Pressurization system	351
Air conditioning and pressurization	192
Pressurization control system	162
Air conditioning distribution system	130
Aircraft cooling system	76
Oxygen system/crew	52
Pressurization outflow valve	49
Air conditioning compressor	40
Oxygen system/passenger	19
Aircraft heating system	17
Fire extinguishing indication system	14
Fire protection system	10
Aircraft auto temperature system	6
Oxygen system/portable	5
Oxygen system/general	3
Other fire extinguishing system	1

Landing Gear

The landing gear system also contributed to a significant number of failures. The landing gear system category contains SCFMs of 23 different components and systems. Shown in Table 16 are the top 20 most frequent specific component failures of the landing gear system. The gear extend/retract mechanism, main gear tire, and nose gear components account for 47 percent of all the cited landing gear SCFMs .

TABLE 16.—TOP 20 MOST FREQUENT SYSTEM/ COMPONENT FAILURE/MALFUNCTIONS (SCFMs) OF LANDING GEAR SYSTEM COMPONENTS

Component	Frequency of failure/malfunction
Gear extend/retract mechanism	174
Main gear tire	165
Nose gear	128
Nose wheel steering	90
Main gear	68
Main gear door	58
Landing gear	44
Nose gear tire	37
Gear down lock	34
Nose gear door	33
Wheels/tires/brakes	26
Gear up lock	24
Tires	23
Main gear wheel	22
Gear lever/selector	19
Emergency extension system	18
Nose gear wheel	16
Supplemental landing gear	12
Wheel assemblies	5
Gear ski	2

Failure Modes and Effects Analysis

FMEA is a method that systematically examines individual system components to assess risk and reliability. It is a bottom-up approach and follows an inductive logic to determine critical component failures and their consequences. The FMEA starts with decomposition of the system into subsystems and finally into individual components. Ways in which each component can potentially fail, called failure modes, are then recorded and evaluated separately to determine what effect they have at the component level and the system level.

As part of the system analysis task, FMEA data from literature has been examined to identify and document failure modes of aerospace components/subsystems as they relate to the adverse conditions documented in the adverse events table. In most cases, the actual FMEA data and quantitative values regarding criticality were not included in the reviewed literature documents due to the sensitivity of the information. However, we have captured critical failure modes regarding a number of aerospace components and subsystems. Examples include component failure mechanisms in wiring components such as wire chafing, stalling in turbomachinery, solder or joint problems for electronic components, and spalling of engine bearings. Where appropriate, this information is incorporated into the adverse events table (Table 17).

Adverse Events Table

The purpose of the adverse event type table is to provide focus to the direction of the IVHM Project. As the IVHM Project matures and future technologies and trends become clear, this initial set of adverse event types and candidate examples will change. These adverse event types are categorized into five classes based on the overall remaining useful life of the affected system, subsystem, or component: incipient failures, slow-progression failures, intermittent faults, cascading faults, and fast-progression failures.

The systems analysis team has updated the initial adverse events table by collecting data gleaned from findings within the ASRS and NTSB databases, in addition to FMEA abstracts. The intent was to call attention to damage conditions that occur frequently while providing insight on their severity and detectability. Depending on the nature of the damage condition, there are scenarios in which they may apply to more than one adverse event type. For example, a software fault could lead to a fast-progression fault as in the case of a stack overflow, or a slow-progression fault, as in the case of a memory leak. In addition, improper maintenance is a key issue that was omitted from the table but is applicable within all event types. Primarily, the majority of the accidents were derived from the NTSB database, and the incidents were extracted from the ASRS database.

Because the IVHM Project does not address maintenance issues, and Landing Gear and Hydraulic systems accidents are usually not fatal, the focus of research should be those SCFMs that occur in the engine/fuel and flight control/structures systems as well as power systems. Some examples of damage conditions for these systems can be found in the Adverse Events Table (Table 17). Of particular interest are

- Icing conditions in propulsion systems
- Turbine engine bearings failures
- Fatigue cracks on metallic airframe structures
- Delamination in composites
- Ball-jam in electromechanical actuator (EMA)
- Aileron, rudder or control surface faults
- Fuel system faults
- Engine stall/faults in turbomachinery
- Power electronics/power system faults

TABLE 17.—ADVERSE EVENTS AND EXAMPLE DAMAGE CONDITIONS WITH SEVERITY AND FREQUENCY

Adverse event type	Example damage condition	Severity (frequency)
Incipient Fault: Hard to detect and differentiate due to extremely slow degradation in performance	1. Icing conditions in propulsion system	1. Accident (6)
	2. Fault of power electronics • Power drivers • Power supplies • Switching transistors • Electronics packaging • Electronic circuit boards	2. Accident (11) Incident (417)
	3. Turbine engine bearings • Fatigue spallation	3. Accident (4)
Slow Progression Fault: Very hard to detect and gradual degradation in performance	4. Fatigue cracks on metallic airframe structure	4. Accident (13) Incident (343)
	5. Delamination in composites	5. Accident (2)
	6. Ball-jam in EMA • Hydraulic actuator failures	6. Accident (18) Incident (516)
	7. Air conditioning and pressurization faults	7. Incident (408)
	8. Oil and lubrication system failures	8. Incident (463)
Intermittent Fault: Fault does not degrade but instead is a recurring hard fault that comes and goes, for example, a signal conducted via a loose connector	9. Wire chafing resulting in an electrical short due to an unexpected ground path	9. Accident (9)
Cascading Fault: Faults that may have a single root cause yet progress to create faults in other systems, subsystems, or components	10. Power system faults resulting in wide-spread systemic issues • Electrical distribution problems	10. Accident (10) Incident (738)
	11. Aileron, rudder, or control surface (elevator) faults	11. Accident (22) Incident (620)
	12. Instrumentation, communication, and navigation	12. Accident (5) Incident (1278)
	13. Fuel system faults	13. Accident (20) Incident (349)
Fast Progression Fault: Limited precursor signature but rapid degradation	14. Engine stall/faults in turbomachinery	14. Accident (52) Incident (2312)
	15. Landing gear faults • Gear extension/retraction	15. Accident (97) Incident (2057)
	16. Brake/anti-skid system faults	16. Accident (22) Incident (423)
	17. Lightning- and radiation-related avionics faults	17. Accident (1)

Discussion and Conclusion

Of the 370 National Transportation Safety Board (NTSB) accidents affected by system/component failure/malfunction (SCFM) in the study period of 1988 to 2003, 48 percent involved the engine or fuel system, 31 percent involved landing gear or hydraulic failure and malfunctions, 9 percent involved flight control or structural failure and malfunctions, and 11 percent involved all other SCFMs. A total of 35 percent of all the SCFM accidents were caused by improper maintenance. The leading causes of engine or fuel SCFM were maintenance related (39 percent), component failure (35 percent), component fatigue (23 percent), component separation (14 percent), manufacturing/design (11 percent), and component disconnected (11 percent). For flight control or structural failure events, the leading causes of SCFM were maintenance related (46 percent), component failure (29 percent), and manufacturing/design (20 percent). The leading causes of landing gear or hydraulic SCFM were component failure (48 percent), maintenance related (28 percent), and component fatigue (18 percent), For the "other" category (electrical, instrumentation/communication/navigation, anti-ice/deice system, auxiliary power unit (APU), cargo fire, galley, heating, oxygen, pressurization, warning systems, vacuum pump, and unknown), the leading causes of SCFM were maintenance related (32 percent), electrical failure (17 percent), wire chafed/arcing (15 percent), and electrical short (12 percent).

A total of 7732 FAA database incidents were affected by SCFM. Of these, 33 percent involved the landing gear or hydraulics, 33 percent involved the engine and fuel system, while 11 percent involved the flight control or structural systems.

Ninety-three percent of the aircraft primary problem incidents found in Aviation Safety Reporting System (ASRS) were attributed to equipment problems. The most frequent component failures were turbine engine, pressurization system, hydraulic main system, flight management system/flight management computer, and engine. The data was further categorized into aircraft systems. The monitoring and management system accounted for 14.1 percent of the system failures, the propulsion system accounted for 13.7 percent, the control surfaces accounted for 9.1 percent, and the environmental control accounted for 8.8 percent. Unfortunately, the propulsion system failures and malfunctions often were not clearly defined in the reports.

Appendix.—Acronyms

ACN	incident report number
APU	auxiliary power unit
ASIAS	Aviation Safety Information and Analysis Sharing
ASRS	Aviation Safety Reporting System
ATC	air traffic control
AvSafe	Aviation Safety Program
EMA	electromechanical actuator
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FMEA	failure modes and effects analysis
GPWS	ground proximity warning system
IVHM	Integrated Vehicle Health Management
MEA	measurement and inspection technologies
NASA	National Aeronautics and Space Administration
NTSB	National Transportation Safety Board
SCFM	system/component failure/malfunction

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REPORT DOCUMENTATION PAGE					*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
01-03-2011

2. REPORT TYPE
Technical Memorandum

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Causal Factors and Adverse Events of Aviation Accidents and Incidents Related to Integrated Vehicle Health Management

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Reveley, Mary, S.; Briggs, Jeffrey, L.; Evans, Joni, K.; Jones, Sharon, M.; Kurtoglu, Tolga; Leone, Karen, M.; Sandifer, Carl, E.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
WBS 284848.02.01.03.04

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E-17593

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

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

11. SPONSORING/MONITORING REPORT NUMBER
NASA/TM-2011-216967

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Category: 03
Available electronically at http://www.sti.nasa.gov
This publication is available from the NASA Center for AeroSpace Information, 443-757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Causal factors in aviation accidents and incidents related to system/component failure/malfunction (SCFM) were examined for Federal Aviation Regulation Parts 121 and 135 operations to establish future requirements for the NASA Aviation Safety Program's Integrated Vehicle Health Management (IVHM) Project. Data analyzed includes National Transportation Safety Board (NSTB) accident data (1988 to 2003), Federal Aviation Administration (FAA) incident data (1988 to 2003), and Aviation Safety Reporting System (ASRS) incident data (1993 to 2008). Failure modes and effects analyses were examined to identify possible modes of SCFM. A table of potential adverse conditions was developed to help evaluate IVHM research technologies. Tables present details of specific SCFM for the incidents and accidents. Of the 370 NTSB accidents affected by SCFM, 48 percent involved the engine or fuel system, and 31 percent involved landing gear or hydraulic failure and malfunctions. A total of 35 percent of all SCFM accidents were caused by improper maintenance. Of the 7732 FAA database incidents affected by SCFM, 33 percent involved landing gear or hydraulics, and 33 percent involved the engine and fuel system. The most frequent SCFM found in ASRS were turbine engine, pressurization system, hydraulic main system, flight management system/flight management computer, and engine. Because the IVHM Project does not address maintenance issues, and landing gear and hydraulic systems accidents are usually not fatal, the focus of research should be those SCFMs that occur in the engine/fuel and flight control/structures systems as well as power systems.

15. SUBJECT TERMS
Flight safety; Aircraft safety

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			STI Help Desk (email:help@sti.nasa.gov)
U	U	U	UU	32	**19b. TELEPHONE NUMBER** *(include area code)* 443-757-5802