NASA/TM–2013-218000

Identification of Crew-Systems Interactions and Decision Related Trends

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May 2013

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1. INTRODUCTION

1.1 Purpose of Study

The goal of the Vehicle System Safety Technology (VSST) project within NASA's Aviation Safety Program (AvSP) is to "enable a reduction in accidents and incidents through enhanced vehicle design, structure, systems, and operating concepts" (ref. 1). The VSST project is composed of three key Technical Challenges (TCs):

(1) Improve Crew Decision-Making and Response in Complex Situations (CDM)
(2) Maintain Vehicle Safety between Major Inspections (MVS)
(3) Assure Safe and Effective Aircraft Control under Hazardous Conditions (ASC)

VSST project management uses systems analysis "to identify key issues and maintain a portfolio of research leading to potential solutions to these challenges". To assist management in accomplishing these objectives, several systems analysis related milestones have been specified in the VSST project plan. The systems analysis milestone for fiscal year (FY) 2013 is focused on the CDM Technical Challenge. The goal of CDM is to "develop and demonstrate new capabilities that enable pilots to better understand and respond to complex situations". The expected research outcome of the CDM TC is the set of five research products listed in Table 1.

Table 1. CDM List of Research Products

IMPROVE CREW DECISION-MAKING AND RESPONSE IN COMPLEX SITUATIONS (CDM)		
CDM-1	**Advanced Displays for Terminal Area and Surface Operations**	Advanced displays and decision support concepts that improve situation awareness and provide hazard protection during terminal area and runway /surface current-day and NextGen operations
CDM-2	**Flight Deck Countermeasures for Spatial Disorientation and Loss-of-Energy State Awareness**	Displays, decision support tools, and Crew Resource Management (CRM) concepts to help crews avoid, detect, mitigate, and recover from the loss-of-aircraft attitude and energy state awareness
CDM-3	**Crew System Monitoring And Management System (CSMMS)**	These technologies offer the capability of identifying and quantifying the current physiological, workload, and attentional state of the crew and these data may be used to ensure and adapt to the crew's and/or automation system's readiness to respond in potentially hazardous situations.
CDM-4	**Flight Deck Information Management Systems for Integrity and Awareness**	The primary objective of this technology is the creation of integrated flight deck information management systems that assure the information needed by flight crews to make critical decisions is complete and not misleading.
CDM-5	**Revised Pilot Proficiency Standards for Manual Handling and Automation Interactions**	This technology will result in the creation of data and guidelines to support revised pilot proficiency standards and training associated with manual handling, automation interactions, and reverting from automated to manual handling.

As detailed in the VSST Project Plan, the CDM TC is described as follows:

> "*CDM research develops flight deck capabilities that enable pilots to make more informed decisions when confronted with complex situations. From a review of recent accidents, pilots are increasingly faced with complex, multi-faceted situations. Prior emphasis on responding to an individual failure with a targeted checklist may not always apply. Given the complexities of current-day operations and future trends toward greater levels of automation and information, technologies must be developed that help pilots assess these situations and execute an informed course of action. CDM research focuses on low altitude terminal area operations since this phase of flight is at greatest risk due to its operational complexity and time criticality*. "

A summary of the goals, objectives and products for the CDM TC are graphically depicted using an objectives tree format (ref. 2) in Figure 1.

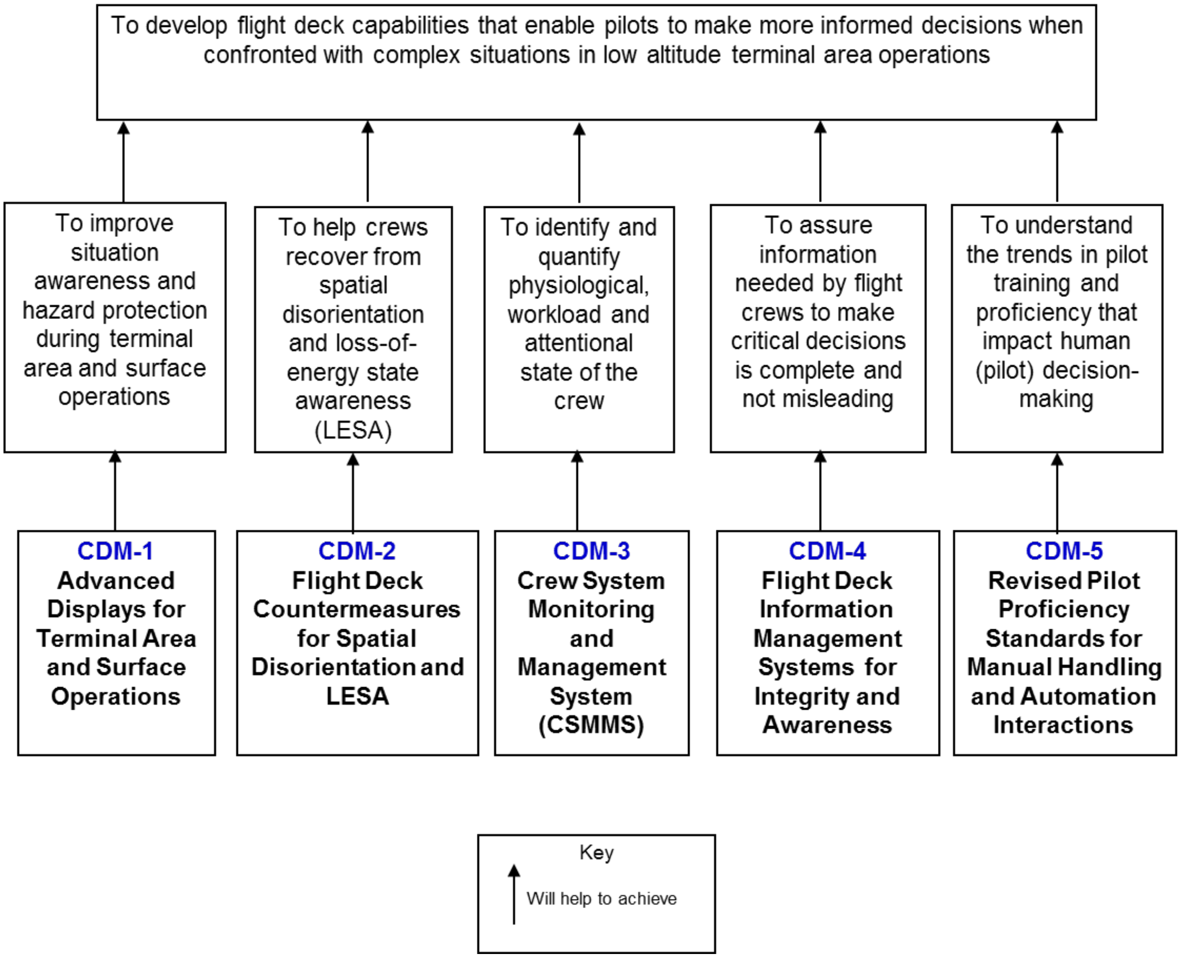

Figure 1. CDM Objectives Tree

The specific CDM related FY13 systems analysis milestone is stated below:

(1) *"Deliver analysis of trends in aviation as related to crew systems interactions & decisions by reviewing the most current statistical and prognostic data available about accidents and incidents related to crew systems research areas*
(2) *Deliver assessment of future directions in aviation technology related to crew systems research areas through review of literature from academia, industry and other government agencies to establish requirements for future work in crew systems"*

1.2 Overview of Study Contents

The expected outcomes for this study are addressed in sequential order. Outcome 1 is addressed in section 2, which contains a summary of statistical analyses of accident and incident data that have been conducted by NASA researchers. Outcome 2 is the focus of section 3, which is a summary of crew systems issues and future research needs that were derived from literature reviews, databases and aviation subject-matter experts. Finally, discussion and the conclusions that have been drawn are provided in section 4.

2. SUMMARY OF NASA STATISTICAL STUDIES

Systems analysis personnel within the NASA Aviation Safety Program have recently conducted several statistical analyses of accident and incident data (ref. 3 and 4). This section summarizes the results of these analyses that are related to the CDM Technical Challenge.

2.1 Analysis of NTSB/FAA Data

In 2011, a study (ref. 3) was conducted to identify trends in aviation accidents and incidents that were related to the three VSST Technical Challenges (TCs) as they were defined at that time:

1. Vehicle Health Assurance
2. Effective Crew-System Interactions and Decisions in All Conditions
3. Aircraft Loss-of-Control Prevention and Mitigation

For the “Vehicle Health Assurance” and “Aircraft Loss-of-Control Prevention and Mitigation” TCs, historical aviation accidents were examined, using the National Transportation Safety Board (NTSB) Aviation Accident and Incident Data System (restricted to 1989-2008), and incidents, using the Federal Aviation Administration (FAA) Accident/Incident Data System (restricted to 1989-2006). The rationale was that these two TCs mapped easily to specific Commercial Aviation Safety Team/International Civil Aviation Organization (CAST/ICAO) (ref. 5) categories of accidents and incidents. The “Vehicle Health Assurance” was mapped to system/component failures/malfunctions (SCFM) and non-impact fires, and “Aircraft Loss-of-Control Prevention and Mitigation” TC to the “loss of control-inflight” category.

However, the “Effective Crew-System Interactions and Decisions in All Conditions” TC, which is now the current CDM TC, was mapped to select categories of causal factors because it could not be associated with a particular accident category. Given that the NTSB coding process does not use terms such as “crew-system interaction”, the Aviation Safety Analysis and Functionality Evaluation (ASAFE) program (ref. 6) was used because it contains a taxonomy that maps specific causal factor codes used by the NTSB to more general error types based upon an expanded human factors analysis and classification system (HFACS) (ref. 7). For example, there are fourteen categories of errors specific to each of flight crew, ground personnel, air traffic control and maintenance. By using the ASAFE taxonomy, events with “flight crew decision errors” and “skill-based errors” could be selected and mapped to the “Effective Crew-System Interactions and Decisions in All Conditions” TC.

In order to better understand the ASAFE taxonomy with respect to the two types of errors chosen for this analysis, the NTSB database was searched. This search revealed that the most frequently cited flight crew skill-based errors were the following:

- failure to maintain aircraft control or directional control
- inadequate compensation for wind conditions
- inadvertent stall
- inadequate preflight preparation
- inadequate visual lookout

In addition to the more generic errors of inadequate or poor pre-flight or in-flight planning or decisions, the most frequently cited specific decision errors were as follows:

- selection of an inappropriate takeoff or landing site
- failing to refuel the aircraft

- failing to perform an aborted landing or aborted takeoff
- selection of the wrong runway
- excessive airspeed
- inappropriate use of certain controls (usually brakes, carburetor heat or landing gear extension)

The accidents with flight crew skill-based errors and flight crew decision errors were selected if the error was considered either a cause or a factor (but not a finding) in the accident report. Causes are actions or events that are the direct source of the accident, while factors are actions or events that contributed to the accident (ref. 8). Each accident can have multiple causes and factors. Findings are actions or events that occurred in conjunction with the accident, but were not determined to have contributed to the accident.

The ASAFE taxonomy cannot be applied to the incident data because the level of causal factor coding is far less detailed. Each incident has been assigned a general cause in one of three categories: individual person (pilot, maintenance crew or ground crew), operational deficiency (mostly non-maintenance related system component failures) or environmental (weather or terrain conditions). Thus we are only able to report the proportion of incidents caused by pilot action or inaction, without specifying the type of pilot error.

Results

A summary of the accidents affected by the two selected types of pilot error can be found in Tables 2 and 3. Denominators are included in many lines for clarification, specifically with respect to fatal accident percentages. There are two types of fatal accident percentages, and both are of interest: the percentage of all fatal accidents that included a particular type of pilot error, and the percentage of accidents marked by the particular pilot error in which there was a fatality. The numerators in these percentages are identical (fatal pilot error accidents) but the denominators are different.

More than half of the accidents and fatal accidents in Part 135 and Part 91 were caused in part by a flight crew skill-based error (Table 2), compared with less than one quarter of Part 121 accidents. Part 121 accidents with skill-based errors also were less likely to be fatal (7%) than accidents in other operations (22%-30%).

Table 2. Summary of Flight Crew Skill-Based Error (SBE) Accidents by Operation Category (1989-2008)

	Part 121	Part 135—Scheduled	Part 135—Non-Scheduled	Part 91
Total Flight Hours	317,999,117	24,446,927	61,751,000	507,516,000
Total Accidents	738	219	1,202	26,922
Accidents with SBE	174 (23.6%)	123 (56.2%)	631 (52.5%)	17962 (66.7%)
SBE Accidents per million flight hrs	0.547	5.031	10.218	35.392
Total Fatal Accidents	67	48	307	5214
Fatal SBE Accidents out of All Fatal Accidents	12/67 (17.9%)	29/48 (60.4%)	190/307 (61.9%)	3892/5214 (74.6%)
Fatal SBE Accidents out of All SBE Accidents	12/174 (6.9%)	29/123 (23.6%)	190/631 (30.1%)	3892/17962 (21.7%)
Total Fatalities	1956	309	745	10,109
Fatalities in accidents with a Skill-Based Error (SBE)	122 (6.2%)	150 (48.5%)	431 (57.9%)	7531 (74.5%)

Decision errors (Table 3) were noted as the cause of fewer accidents overall (13%-30%) than skill-based errors, but for most operation categories, a slightly higher percentage of them include at least one fatality (13%-29%). The differences in percentages between operational categories are less striking for decision errors than for skill-based errors.

Table 3. Summary of Flight Crew Decision Error (DE) Accidents by Operation Category (1989-2008)

	Part 121	Part 135—Scheduled	Part 135—Non-Scheduled	Part 91
Total Flight Hours	317,999,117	24,446,927	61,751,000	507,516,000
Total Accidents	738	219	1,202	26,922
Accidents with DE	96 (13.0%)	53 (24.2%)	363 (30.2%)	7306 (27.1%)
DE Accidents per million flight hrs	0.302	2.168	5.878	14.395
Total Fatal Accidents	67	48	307	5214
Fatal DE Accidents out of All Fatal Accidents	12/67 (17.9%)	14/48 (29.2%)	104/307 (33.9%)	1694/5214 (32.5%)
Fatal DE Accidents out of All DE Accidents	12/96 (12.5%)	14/53 (26.4%)	104/363 (28.7%)	1694/7306 (23.2%)
Total Fatalities	1956	309	745	10,109
Fatalities in accidents with Decision Errors	341 (17.4%)	52 (16.8%)	266 (35.7%)	3259 (32.2%)

Figures 2-5 display the percentage of accidents in each time period with the two types of pilot error as a cause or factor in the accident for each of the operational categories. In Part 121 accidents (Figure 2), decision errors have declined substantially over time, but skill-based errors have consistently been a factor in twenty to twenty-five percent of accidents.

Among Scheduled Part 135 accidents (Figure 3), the percentage of accidents with skill-based errors dropped during 1999-2003, but rose again in the latest time period, while decision errors reached a peak during 1999-2003.

Among Non-Scheduled Part 135 accidents (Figure 4), skill-based errors have declined, and the percentage of accidents with decision errors has remained fairly steady.

Among Part 91 accidents (Figure 5), there has been a decrease in the percentage of accidents with decision errors, but there has been little change in the percentage of accidents with skill-based errors.

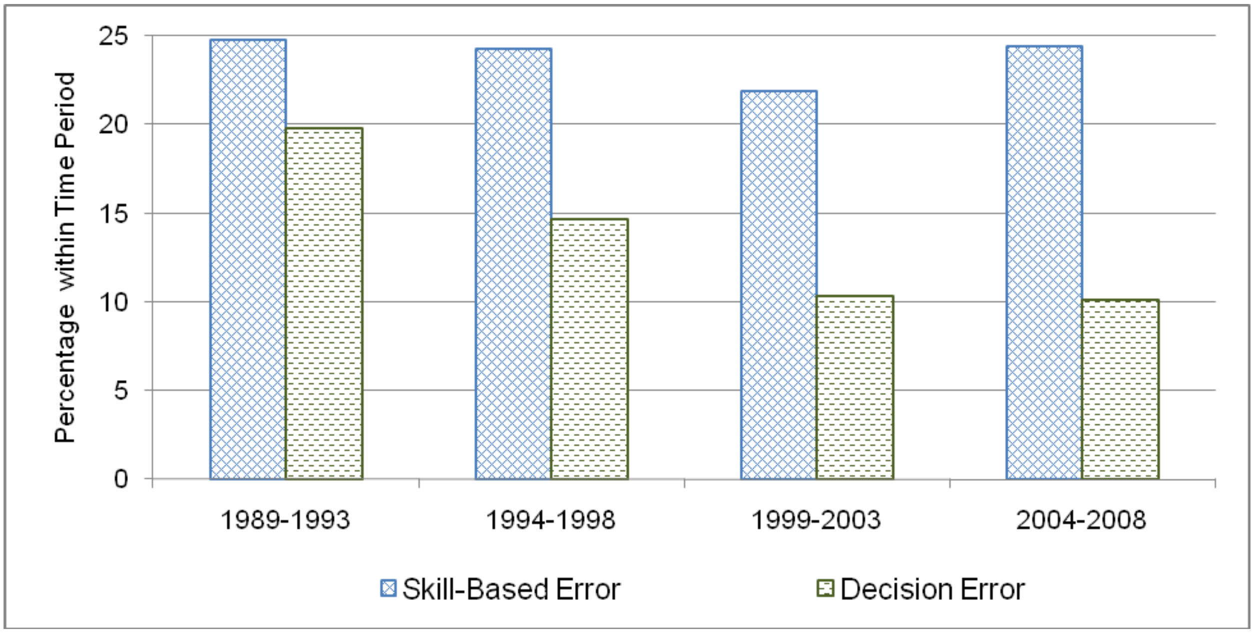

Figure 2. Percentage of Part 121 Accidents with the Specified Error Type Across Four Time Periods.

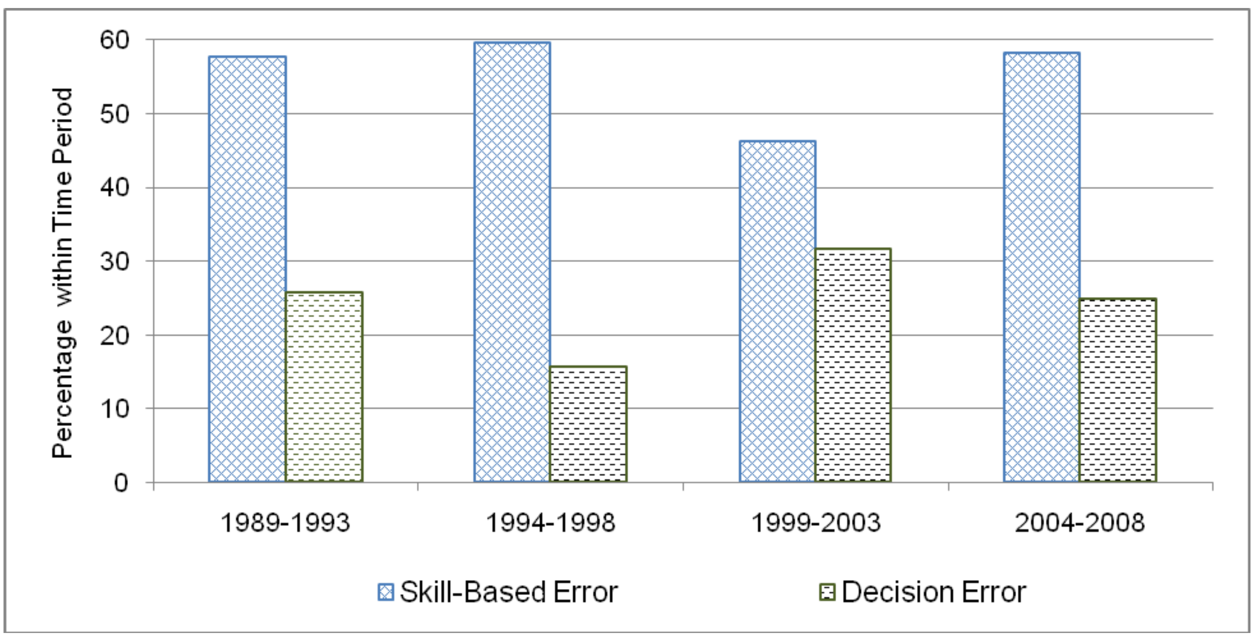

Figure 3. Percentage of Scheduled Part 135 Accidents with the Specified Error Type Across Four Time Periods.

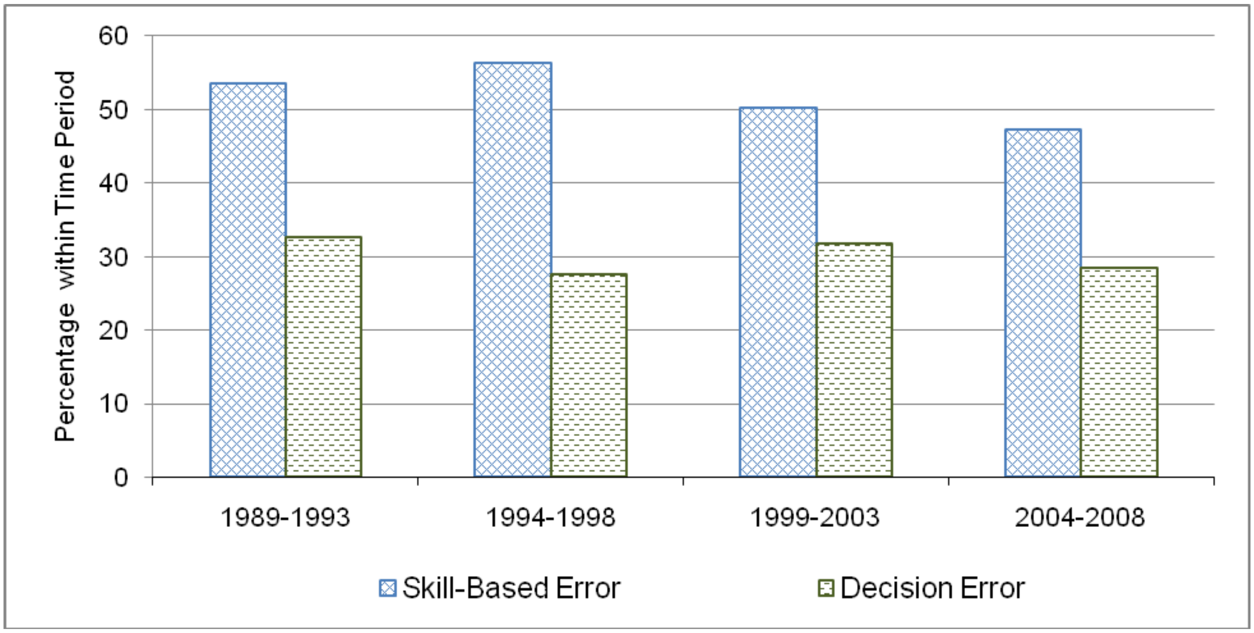

Figure 4. Percentage of Non-Scheduled Part 135 Accidents with the Specified Error Type Across Four Time Periods.

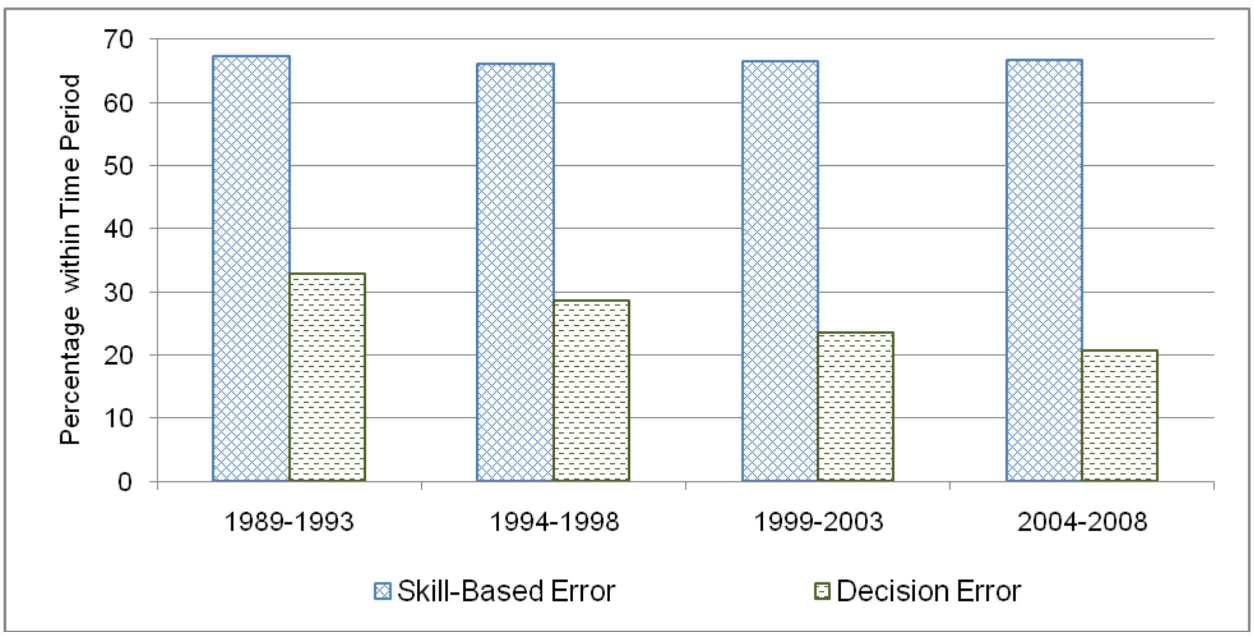

Figure 5. Percentage of Part 91 Accidents with the Specified Error Type Across Four Time Periods.

The incident data in general are not as detailed as the accident data, and that is particularly true with regard to causal factors. Only a single general cause is recorded for each incident, although for some incidents the cause is shared (e.g., pilot and maintenance, pilot and ground crew). Table 4 shows the percentage of incidents for which the pilot was assigned blame, either solely or in part.

The percentage of incidents caused by any pilot error ranges from 13 percent (Part 121) to 56 percent (Part 91). In general, pilot error rates for Part 91 are roughly double those for Non-Scheduled Part 135, which in turn are roughly double those for Scheduled Part 135. Part 121 incidents invoving pilot error were always less frequent than the other flight operational categories with one exception; errors by ground crew and pilot, which are highest in Part 121. This is not surprising, since Part 121 flights are far more likely than those in other flight categories to require the assistance of ground crew.

Table 4. Summary of Incidents Caused by Pilot Error by Operation Category (1989-2006)

Incident Cause	Part 121	Part 135—Scheduled	Part 135—Non-Scheduled	Part 91
Total Incidents	7647	1921	2189	27,919
Pilot Error Only	714 (9.3%)	221 (11.5%)	470 (21.5%)	11961 (42.8%)
Pilot Error plus Ground Crew	167 (2.2%)	23 (1.2%)	16 (0.7%)	72 (0.3%)
Pilot Error plus Maintenance	79 (1.0%)	38 (2.0%)	57 (2.6%)	1142 (4.1%)
Pilot Error plus Weather	72 (0.9%)	41 (2.1%)	102 (4.7%)	2402 (8.6%)
Any Pilot Error	1032 (13.5%)	323 (16.8%)	645 (29.5%)	15577 (55.8%)

Figures 6-9 display the percentage of incidents in each time period with the cause of the incident determined to be pilot error only or pilot error plus an additional factor (ground crew, maintenance or weather).

Among Part 121 incidents (Figure 6), the overall percentage of incidents for which pilot error was the cause has decreased since 1998. It should be noted that there was a slight increase in the 2004-2006 time period. The percentage of incidents in which the pilot shared blame with the ground crew, maintenance or weather has generally increased over time.

Among Scheduled Part 135 incidents (Figure 7), the proportion of incidents caused by pilot error alone has been substantially higher since 1998 than it was prior to 1998.

Among Non-Scheduled Part 135 incidents (Figure 8), the percentage of incidents with the single cause of pilot error has increased consistently until the last time period of 2004-2006, just as the percentage of pilot plus caused incidents has decreased

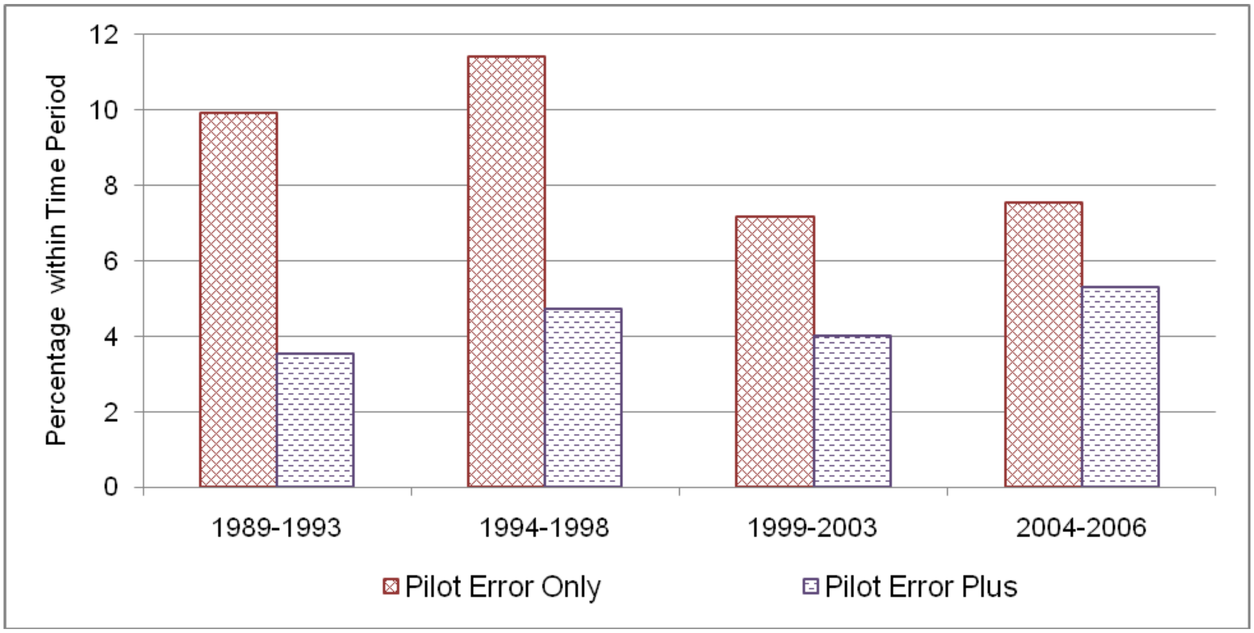

Figure 6. Percentage of Part 121 Incidents with Pilot Error Across Four Time Periods (1989-2006)

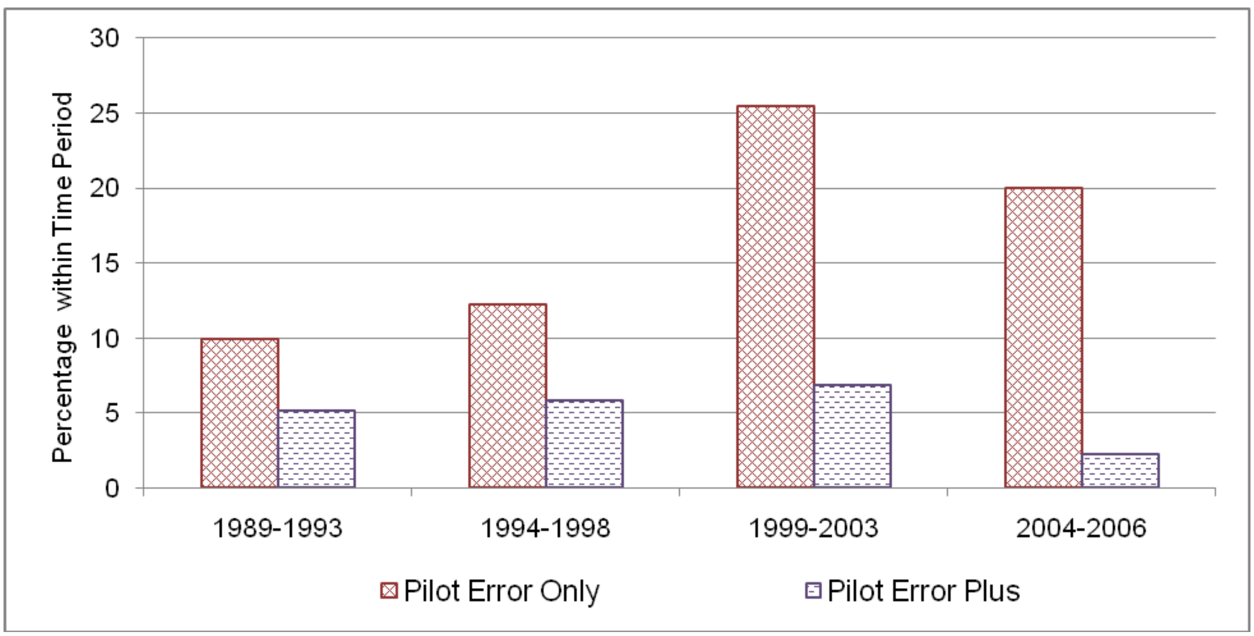

Figure 7. Percentage of Scheduled Part 135 Incidents with Pilot Error Across Four Time Periods (1989-2006)

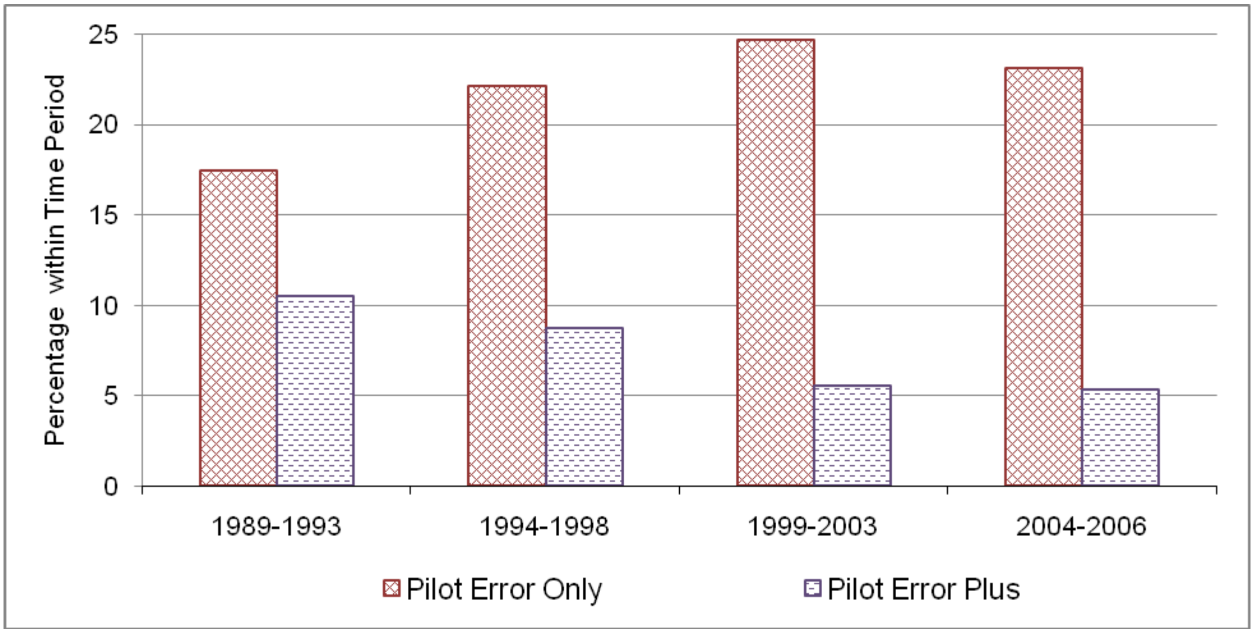

Figure 8. Percentage of Non-Scheduled Part 135 Incidents with Pilot Error Across Four Time Periods (1989-2006)

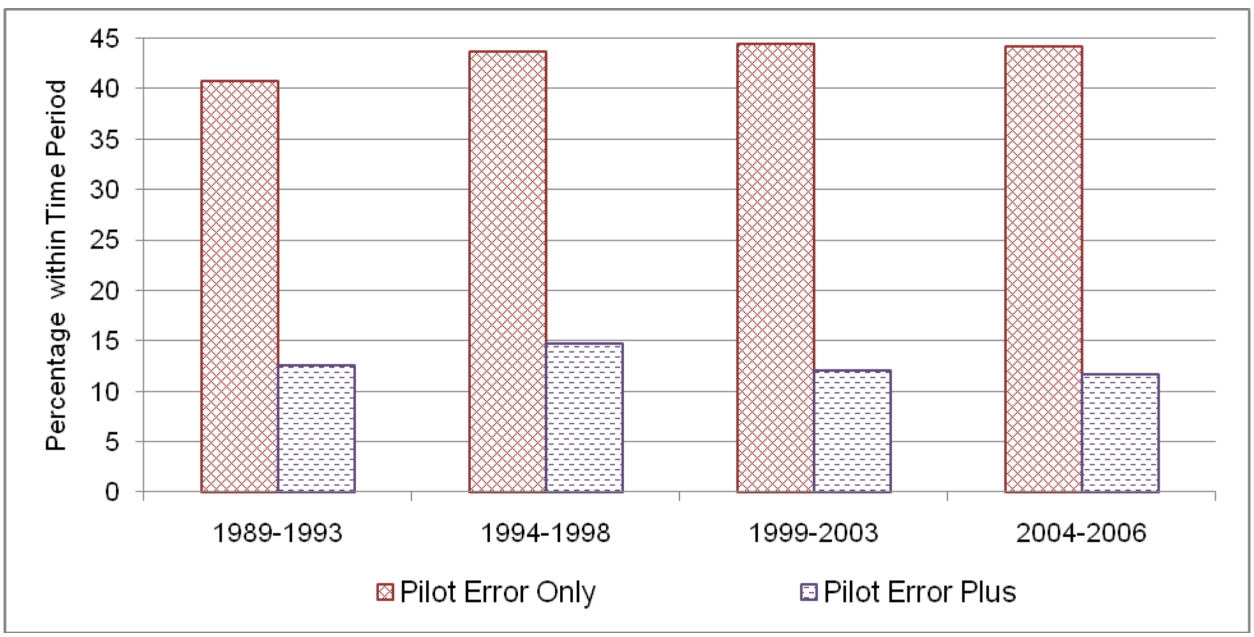

Figure 9. Percentage of Part 91 Incidents with Pilot Error Across Four Time Periods (1989-2006)

Among Part 91 incidents (Figure 9), both pilot error percentages have remained relatively steady over time.

2.2 NASA Analysis of ASRS Data

In 2011, AvSP systems analysis personnel completed a study (ref. 4) of Aviation Safety Reporting System (ASRS) data. The human factors related incidents were analyzed because the system analysis personnel believed these incidents were applicable to the “Effective Crew-System Interactions and Decisions in All Conditions” (currently known as CDM) TC. In response to the systems analysis team’s request for incident reports involving human factor related incidents during the time period January, 1993 through January, 2011, the analysts at ASRS provide a dataset of 2,243 incidents for Part 121, 135, and 91 operations. The category of human factors is a new category added to the search criteria for the ASRS data and is only available from May, 2009, instead of January, 1993. The data prior to this most likely also has human factor information in it, but this information would require using a free text search string or by reading through each report.

Information provided included the incident report number, date of incident, phase of flight, aircraft make/model, SCFM, and human factors. The human factor categories used in the analysis are the following, in alphabetical order:

1. Communication Breakdown
2. Confusion
3. Distraction
4. Fatigue
5. Human-Machine Interface
6. Other / Unknown
7. Physiological-Other
8. Situational Awareness
9. Time Pressure
10. Training / Qualification
11. Troubleshooting
12. Workload

The human factors category can list more than one human factor involved for each incident report. A more in depth analysis of this raw data set was conducted to look at the conditions present when human factor incidents occurred. This information may be useful to researchers in determining areas of future research.

Results

The result of breaking the data into the human factor categories can be seen in Figure 10. In many of the reported incidents there were multiple human factors listed. There were 2,152 reports that listed the specific human factor, with a total of 5,949 human factors listed in those 2,152 reports. Situational Awareness was the tallest pole (with 1,309 incidents), followed by communication breakdown (844 incidents), confusion (757 incidents) human-machine interface (510 incidents), and distraction (506 incidents). Fatigue and physiological-other had the fewest reports with 95 and 84 incidents respectively.

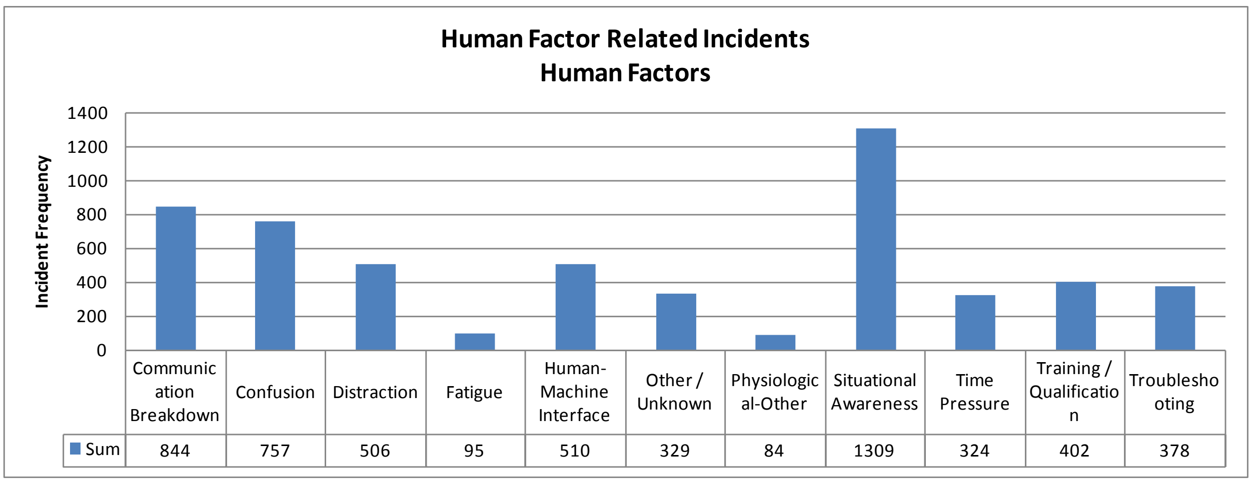

Figure 10. Human Factor Frequency for Human Factor Related Incidents

Forty four percent of the human factors related data, or 977 incidents, have an aircraft system component failure listed. The remaining 1266 human factor incidents did not list an SCFM. Figure 11 shows the results for the SCFM breakdown. The SCFM tall poles are navigation at 155, propulsion systems at 139, and monitoring and management at 121.

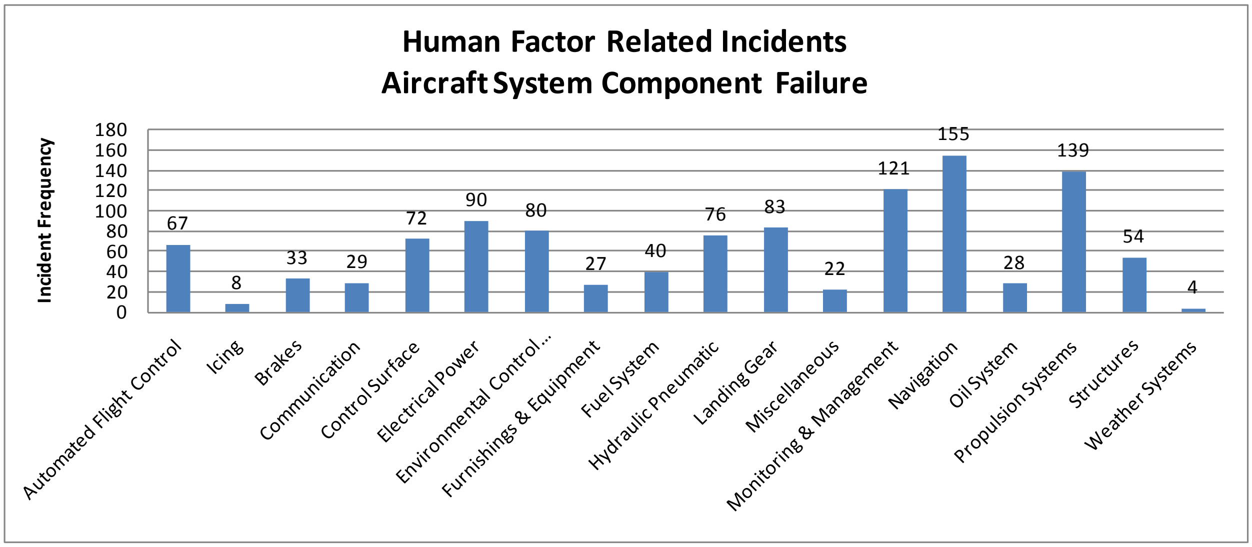

Figure 11. SCFM Frequency for Human Related Incidents

The human factors per phase of flight were then broken down into FAR parts. Table5 displays the results for FAR part 121. The categories with more than 60 incidents are highlighted for emphasis. The largest categories were in the parked phase of flight: communication breakdown with 171 incidents and situational awareness with 168. Of the Part 121 incidents, the parked phase of flight had the most tall poles, and the situational awareness human factor had the largest number of tall poles. The human factors of fatigue and physiological-other had the fewest incident reports for all phases of flight: for the different phases of flight, the final approach and landing categories had the fewest incident reports for all of the human factors categories.

Table 5. Frequency of Part 121 Human Factor per Phase of Flight for Human Factor Related Incidents

Human Factor	Phase of Flight - Part 121									
	Taxi	Take Off	Initial Climb	Climb	Cruise	Descent	Initial Approach	Final Approach	Landing	Parked
Communication Breakdown	76	36	24	42	72	52	40	20	19	171
Confusion	67	41	32	58	50	57	37	27	21	104
Distraction	43	28	26	34	59	34	36	24	12	55
Fatigue	5	3	0	6	3	2	13	6	2	24
Human Machine Interface	16	43	28	52	54	39	32	24	11	26
Other / Unknown	8	12	13	24	44	29	18	11	16	30
Physiological-Other	4	6	4	9	18	10	6	3	7	12
Situational Awareness	101	79	47	77	113	84	74	42	46	168
Time Pressure	12	29	19	22	39	22	20	9	10	59
Training / Qualification	23	30	16	26	45	14	21	5	6	65
Troubleshooting	15	29	21	42	73	19	14	7	2	63
Workload	21	20	29	34	56	30	29	9	10	43
Number of Incident Reports	136	130	82	148	210	144	112	70	71	259

Table 6 contains the results of the FAR part 135 human factor per phase of flight analysis. Confusion during initial climb was the largest reported incident with 11, followed by situational awareness during initial climb and cruise, both with 9 incidents. The phase of flight with the most tall poles was the initial climb, and the category of human factors with the most tall poles was situational awareness. Many categories had no incidents or only one incident for part 135.

Table 6. Frequency of Part 135 Human Factor per Phase of Flight for Human Factor Related Incidents

Human Factor	Phase of Flight - Part 135									
	Taxi	Take Off	Initial Climb	Climb	Cruise	Descent	Initial Approach	Final Approach	Landing	Parked
Communication Breakdown	2	2	7	2	2	2	1	3	1	3
Confusion	1	3	11	2	5	1	2	3	3	3
Distraction	1	2	5	4	4	0	1	1	2	2
Fatigue	0	0	0	0	0	2	0	0	0	1
Human Machine Interface	1	3	6	3	0	2	0	0	0	1
Other / Unknown	0	0	0	0	3	0	0	0	0	0
Physiological-Other	0	0	0	0	3	0	0	0	0	0
Situational Awareness	3	3	9	8	9	1	2	5	5	5
Time Pressure	1	1	4	3	3	0	1	1	1	3
Training / Qualification	0	0	4	1	1	0	0	0	0	0
Troubleshooting	1	2	2	3	1	0	0	0	0	2
Workload	1	1	8	2	4	2	1	1	2	0
Number of Incident Reports	3	7	17	8	12	2	2	6	5	7

FAR part 91 human factors per phase of flight results are shown in Table 7. It had two tall poles both in situational awareness, one during cruise with 71 incidents and the other during landing with 61 incidents. For human factors, there was a higher concentration of tall poles in situational awareness. In the area of phase of flight the tall poles were more heavily concentrated during cruise. Fatigue, physiological-other, and other/unknown had the fewest human factor incidents per phase of flight for part 91. The phase of flight for human factors with the fewest incidents was the parked phase of flight.

Table 7. Frequency of Part 91 Human Factor per Phase of Flight for Human Factor Related Incidents

Human Factor	Phase of Flight - Part 91									
	Taxi	Take Off	Initial Climb	Climb	Cruise	Descent	Initial Approach	Final Approach	Landing	Parked
Communication Breakdown	15	16	26	12	33	19	22	17	27	7
Confusion	20	12	27	13	24	17	18	20	20	6
Distraction	8	10	15	12	30	13	17	13	19	3
Fatigue	0	3	0	1	0	0	1	2	2	0
Human Machine Interface	6	9	25	11	28	12	20	10	19	1
Other / Unknown	3	3	3	4	11	6	3	3	12	0
Physiological-Other	1	2	1	0	2	1	1	1	1	0
Situational Awareness	31	33	40	22	71	28	35	27	61	9
Time Pressure	9	6	8	4	15	9	3	6	9	0
Training / Qualification	9	13	14	10	22	10	7	12	35	7
Troubleshooting	4	7	7	7	31	6	6	4	9	3
Workload	4	3	15	12	21	16	9	8	16	0
Number of Incident Reports	40	44	57	34	102	41	48	37	92	12

3. REVIEW OF CREW SYSTEMS ISSUES AND FUTURE RESEARCH NEEDS

Subject-matter experts and researchers have conducted a number of studies that included recommendations for improving the safety of the air transportation system. This section contains a review of these safety priority lists, information databases and other documented references pertaining to aviation crew systems issues and future research needs.

3.1 CAST Safety Enhancements Reserved for Future Implementation (SERFIs)

The Commercial Aviation Safety Team (CAST) was formally established on June 23, 1998 (ref. 9). Its mission is to provide government and industry leadership to develop and focus implementation of an integrated, data-driven strategy to improve commercial aviation safety. The members of CAST are a variety of stakeholders, including representatives from government, industry, pilot groups, air traffic controllers, and others. The Joint Implementation Monitoring Data Analysis Team (JIMDAT) is a working group with CAST. The JIMDAT monitors the implementation of the Safety Enhancements (SEs) in the CAST plan and suggests modifications and changes to CAST (ref. 10).

In addition the current set of SEs in the CAST plan, there are number of SEs that could be added in the future. These SEs are referred to as “Safety Enhancements Reserved for Future Implementation” or SERFIs (ref. 11) for short. Table 8 contains a list of SERFIs that could possibly fall within the charter of the CDM TC. The SERFIs highlighted in the following table may not be currently funded by the NASA Aviation Safety Program. Detailed descriptions of each CDM related SERFI can be found immediately after Table 8.

Table 8. CDM Related CAST SERFIs

SE #	Title	LOOSEC	NASA Role
22	Flight Deck Equipment Upgrades – Existing Type Designs (4-5)	FAA AIR-1	S
35	Displays and Alerting Systems – Existing Designs	AIA	
36	Basic Airplane Design – Mode Confusion (1-2)	NASA	L
61	Aircraft/Vehicle Upgrade and Installation – Part 121/135 Cockpit Moving Map Display	FAA AVR-1	S
62	Aircraft/Vehicle Upgrade and Installation – Vehicle Moving Map Display	FAA ARP	S
63	Aircraft/Vehicle Upgrade and Installation – Non-121 Aircraft Moving Map Display	FAA AVR-1	S
71	Graphical Displays – Carry On	NASA	L
72	Graphical Displays – Panel Mounted – New Production	NASA	L
110	Cockpit Moving Map Phase 1	FAA AVR-1	S
111	Cockpit Moving Map Phase 1 & 2	FAA AVR-1	S
112	Cockpit Moving Map Phase 1, 2, & 3	FAA AVR-1	S

	LEGEND
L	NASA has a Leading role: NASA is the Lead Overall Organization for Safety Enhancement Completion (LOOSEC), or the Lead Organization for Output Completion for one or more SE Outputs, or is assigned a specific action in an Output
S	NASA has a Supporting role: NASA is shown as a contributing Resource in the SE or has Current Related Aviation Activities listed in the SE, but has no specific assigned actions
	NASA is not listed anywhere in the SE as a contributing organization
	SE falls within charter of CDM. Does not necessarily mean that work is currently funded by AvSP

SE022: Flight Deck Equipment Upgrades – Existing Type Designs

This safety enhancement ensures altitude awareness and accomplishment of checklist items. This will be accomplished through the development of guidelines and procedures for flight deck smart alerting system design and supporting operational procedures and training based upon:

1. *The installation of equipment to provide automatic aural altitude alert call-outs on final approach or other such altitude alerting systems.*
2. *The installation of automated or mechanical checklist devices to provide a positive means for checklist completion.*
3. *Research and assessment of existing technology in flight deck smart-alerting system design.*

SE035: Displays and Alerting Systems – Existing Designs (R-D)

This safety enhancement outlines research and development (R&D) topics needed to evaluate display and alerting systems in existing type designs to provide:

1. *Graphic speed trend information*
2. *A pitch limit indication*
3. *Bank angle limits to buffet*
4. *Barber poles and amber bands on primary airspeed indications*
5. *Detection and annunciation of conflicting attitude, airspeed and altitude data information*
6. *Detection and removal of invalid attitude, airspeed and altitude data information (i.e.. from an internal fault)*
7. *Detection and removal of misleading attitude, airspeed and altitude data information (e.g., from an external sensor fault) to the extent feasible*
8. *Information to perform effective manual recovery from unusual attitudes using chevrons, sky pointers, and/or permanent ground-sky horizon on all attitude indications*
9. *Salient annunciation of autoflight mode changes and engagement status changes (e.g., blinking/colored/boxed mode information)*
10. *Effective sideslip information and alerting of excessive sideslip (e.g., split trapezoid on attitude indicator)*
11. *Clear annunciation of engine limit exceedances and significant thrust loss.*

SE036: Basic Airplane Design – Mode Confusion (R-D)

This safety enhancement outlines research and development (R&D) topics aimed at reducing fatal accidents due to mode confusion leading to loss of control. Information regarding observed instances of flight crew mode confusion (by airplane model) should be disseminated to operator training departments, manufacturers, and the aviation human factors research community.

SE061: Cockpit Moving Map Display

The purpose of this Safety Enhancement is to reduce runway incursions by improving pilot situational awareness using cockpit/vehicle moving map technology in commercial aircraft. The requirements for the moving map implementation are organized into four phases. Phase 1 will address development and installation of cockpit moving map (airport) displays with own-ship position enabled by GPS. Phase 2 will add display functionality for data-linked traffic, ground and air, utilizing ADS-B and TIS-B. Phase 3 will add functionality for runway occupancy advisory systems. Phase 4 will add functionality for data-linked taxi routes and clearance limits. Each phase will also address heads-up guidance display systems (HUDs). Each phase will require the continuing development and certification of cockpit display equipment and the formation of standards, guidelines and procedures for use of the equipment

SE062: Airport Vehicle Moving Map Display

The purpose of this Safety Enhancement is to reduce runway incursion incidents by improving ground vehicle operator situational awareness using airport moving map technology.

SE063: General Aviation Aircraft Moving Map Display

The purpose of this Safety Enhancement is to reduce runway incursion incidents by improving pilot situational awareness using cockpit moving map technology in general aviation (GA) aircraft.

SE071: Turbulence Displays - Carry-on Equipment

The purpose of this Safety Enhancement is to provide improved, real-time turbulence information to pilots, ground operations personnel, and forecasters for turbulence avoidance decisions and for input to turbulence forecasts. This will be accomplished through the improvement of automated airborne turbulence measurements; new flight deck displays of turbulence information; improved or new on-board look-ahead turbulence detection capabilities; and upgraded flight crew procedures for use of the improved information to avoid turbulence.

SE071 assumes equipage with electronic flight bag (EFB) or other carry-on displays. The enhancement provides first-generation turbulence displays for these products via integration of up-linked information on existing carry-on displays.

SE072: Graphical Turbulence Displays – Panel Mounted – New Production
The purpose of this Safety Enhancement is to provide improved, real-time turbulence information to pilots, ground operations personnel, and forecasters for turbulence avoidance decisions and for input to turbulence forecasts. This will be accomplished through the improvement of automated airborne turbulence measurements; new flight deck displays of turbulence information; improved or new on-board look-ahead turbulence detection capabilities; and upgraded flight crew procedures for use of the improved information to avoid turbulence.

SE072 recommends panel-mounted graphical turbulence displays for new production airplanes.

SE110: Moving Map Display with GPS Own-Ship Position
The purpose of this Safety Enhancement is to reduce runway incursions by improving pilot situational awareness using cockpit/vehicle moving map technology in commercial aircraft. The requirements for the moving map implementation are organized into four phases. SE110 includes Phase 1 to address development and installation of cockpit moving map (airport) displays with own-ship position enabled by GPS.

SE111: Moving Map Display with Own-Ship and Traffic Enabled by ADS-B/ TIS-B
The purpose of this Safety Enhancement is to reduce runway incursions by improving pilot situational awareness using cockpit/vehicle moving map technology in commercial aircraft. The requirements for the moving map implementation are organized into four phases. SE111 builds upon SE110 by adding display functionality for data-linked traffic, ground and air, utilizing ADS-B and TIS-B to Phase 1, which addresses development and installation of cockpit moving map (airport) displays with own-ship position enabled by GPS

SE112: Moving Map Display with Own-Ship, Traffic, and Runway Occupancy Advisory System
The purpose of this Safety Enhancement is to reduce runway incursions by improving pilot situational awareness using cockpit/vehicle moving map technology in commercial aircraft. The requirements for the moving map implementation are organized into four phases. SE112 builds upon SE110 and SE111 by adding functionality for runway occupancy advisory systems to Phase 1 (own-ship position enabled by GPS) and Phase 2 (data-linked traffic enabled by ADS-B/TIS-B).

3.2 Flight Deck Automation Issues (FDAI) Study

The Flight Deck Automation Issues (FDAI) website (ref. 12) contains the results of a study conducted by principal investigators from Oregon State University, Research Integrators, Inc and Honeywell. The study (ref. 13) was funded by the FAA, Office of the Chief Scientific and Technical Advisor for Human Factors (AAR-100). The study, which was conducted over a ten year period (1997-2007), contained two phases: (1) identification of possible problems and concerns related to flight deck automation and (2) compilation of evidence related to flight deck automation issues. Two taxonomies of flight deck automation problems and concerns were developed based on the information obtained in phase one of the study. The “primary taxonomy” organizes the perceived problems and concerns into three major categories; reason for automation existence, automation design, and automation use. In the “alternative taxonomy” of flight deck automation problems and concerns, the 2,428 citations of 114 issues were divided into five distinct categories (Figure 12). The two largest of these categories, “Pilot Centered Problems and Concerns” and “Automation-Centered Problem and Concerns” can be furthered divided into the subcategories shown in Figures 13 and 14. Of the 19 sub-categories identified, “pilot/automation interface” was the most frequently cited problem/concern (13%).

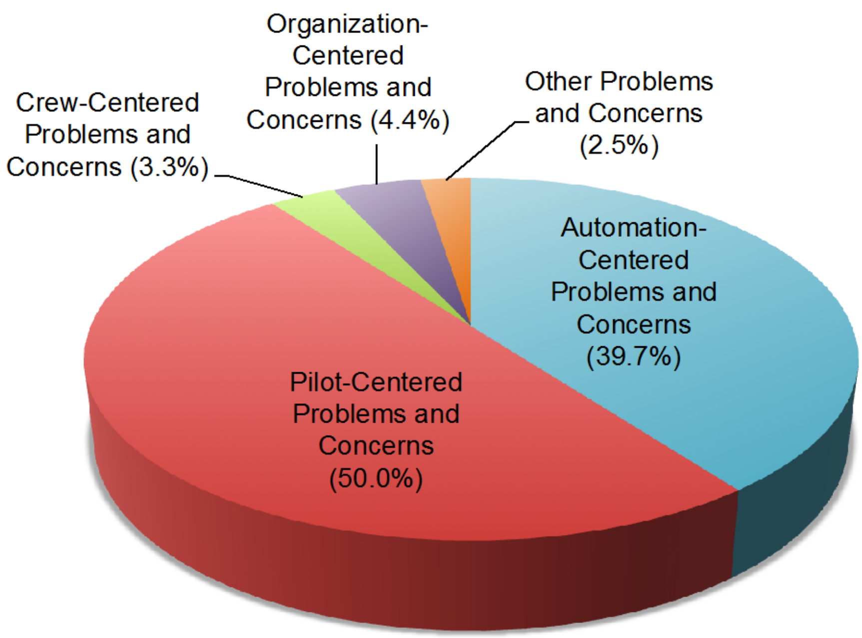

Figure 12. Percentage of Total Citations Related to the FDAI Alternative Taxonomy of Flight Deck Automation Problems and Concerns

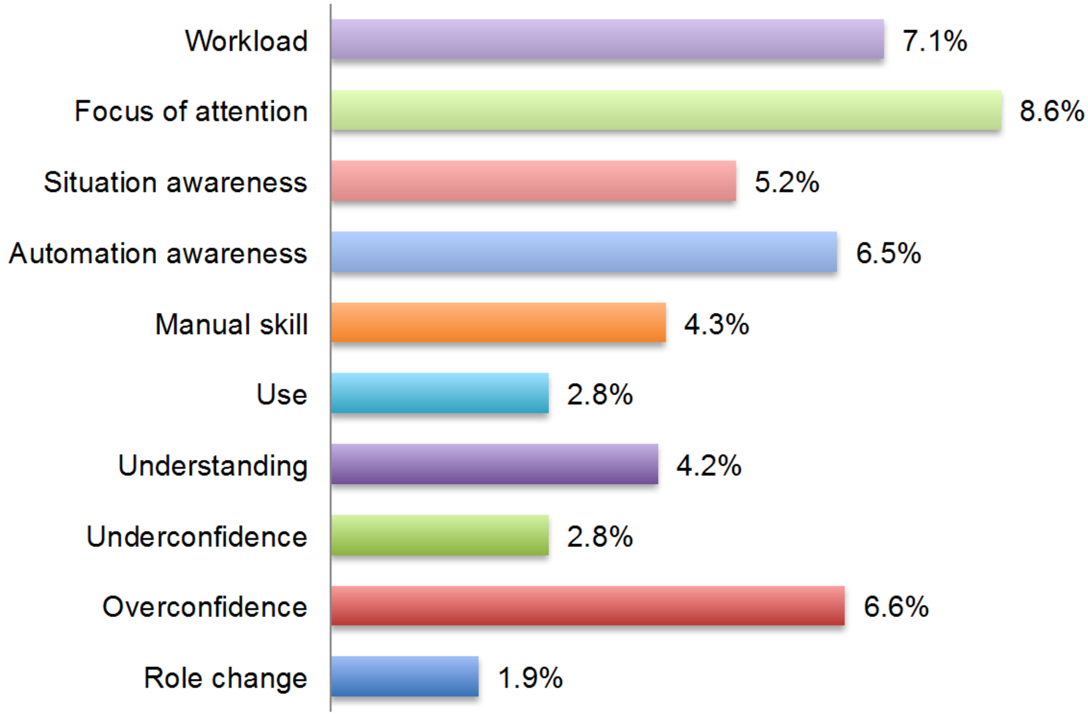

Figure 13. Percentage of the Total Citations Related to the FDAI Pilot-Centered Problems and Concerns Subcategories Taxonomy

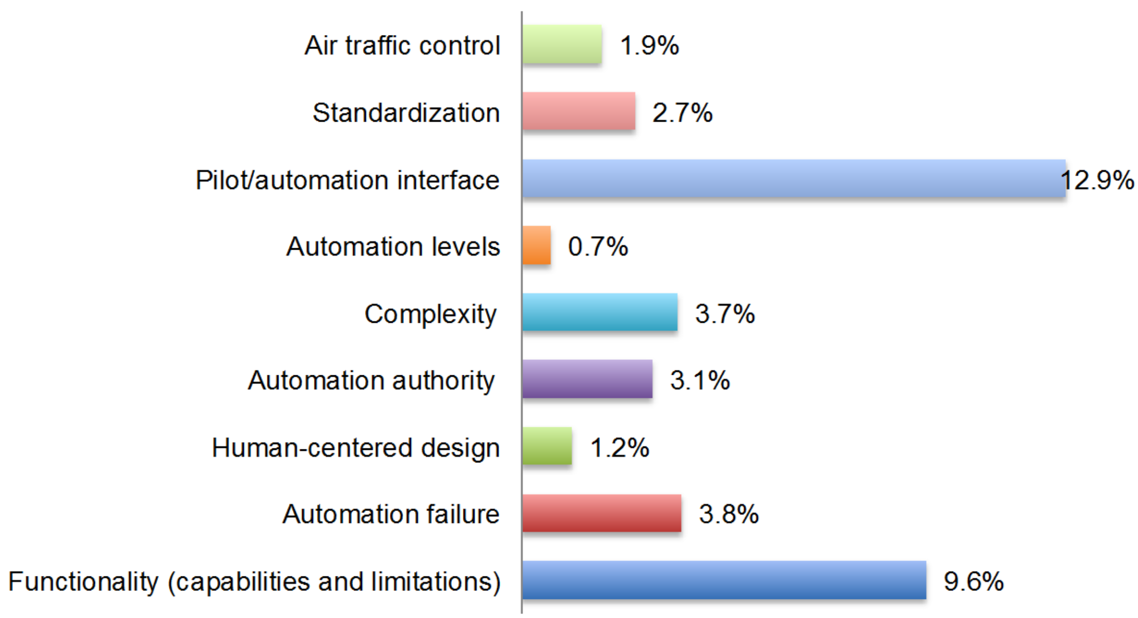

Figure 14. Percentage of Total Citations Related to the FDAI Automation-Centered Problems and Concerns Subcategories Taxonomy

3.3 NTSB Most-Wanted List

Every year the NTSB publishes a list of the most-wanted transportation safety improvements for various modes of transportation (e.g., highway). Although most of the research conducted in the NASA AvSP is directed toward commercial aircraft operations, a portion of the work in CDM may be applicable to the issue of “Improving General Aviation Safety”, which is currently on the NTSB’s Most Wanted List (ref. 14). Specific recommendations to address this Most Wanted issue include:

- “*Adequate education and training and screening for risky behavior are critical to improving general aviation safety. For example, guidance materials should include information on the use of Internet, satellite, and other data sources for obtaining weather information*
- *Training materials should include elements on electronic primary flight displays, and pilots should have access to flight simulators that provide equipment-specific electronic avionics displays.*
- *Knowledge tests and flight reviews should test for awareness of weather, use of instruments, and use of "glass" cockpits.*
- *Need for a mechanism for identifying at-risk pilots and addressing risks so that both the pilot and passengers can safely fly.*”

In addition, the NTSB also issues safety recommendations as a result of accident investigations and other safety concerns that arise. Some recent open recommendations that could possibly be related to CDM research are listed in Table 9.

Table 9. Recent NTSB Recommendations Related to CDM Issues

Recommendation #	Recommendation
A-11-092	Require principal operations inspectors to review flight crew training programs and manuals to ensure training in tailwind landings is (1) provided during initial and recurrent simulator training; (2) to the extent possible, conducted at the maximum tailwind component certified for the aircraft on which pilots are being trained; and (3) conducted with an emphasis on the importance of landing within the touchdown zone, being prepared to execute a go-around, with either pilot calling for it if at any point landing within the touchdown zone becomes unfeasible, and the related benefits of using maximum flap extension in tailwind conditions.
A-11-039	Require that role-playing or simulator-based exercises that teach first officers to assertively voice their concerns and that teach captains to develop a leadership style that supports first officer assertiveness be included as part of the already required crew resource management training for 14 Code of Federal Regulations Part 121, 135, and 91 subpart K pilots.
A-11-028	Actively pursue with aircraft and avionics manufacturers the development of technology to reduce or prevent runway excursions and, once it becomes available, require that the technology be installed.
A-10-037	Require all manufacturers of certified electronic primary flight displays to include information in their approved aircraft flight manual and pilot's operating handbook supplements regarding abnormal equipment operation or malfunction due to subsystem and input malfunctions, including but not limited to pitot and/or static system blockages, magnetic sensor malfunctions, and attitude-heading reference system alignment failures.

4. DISCUSSION AND CONCLUSIONS

The CDM TC, does not address a specific CAST/ICAO occurrence category, but instead addresses specific causal factors which lead to accidents: flight crew skill-based errors and flight crew decision errors. Skill-based errors were a causal factor in more than half of all Part 135 accidents, two thirds of Part 91 accidents, and almost one quarter of Part 121 accidents. For all operational categories, accidents involving skill-based errors have not decreased appreciably during the study time period. Accidents involving decision errors have decreased for all operational categories except in Scheduled Part 135 operations. Even though more accidents are caused by skill-based errors, those accidents involving decision errors are more likely to be fatal than those accidents with skill-based errors. In Part 121 accidents, decision error resulted in more fatalities than those accidents with skill-based errors.

The human factor related incidents analysis of ASRS dataset resulted in 2,243 reports. It is important to note that the category of human factors in the ASRS data set has only been added since May, 2009 and that previous data within ASRS probably has human factor related incidents in it but that they are not categorized as such. A larger time frame would be helpful to better understand the causes of human error in the incident data. The data was analyzed in four ways: FAR part (121, 135, and 91), 10 phases of flight, 18 SCFM categories, and 12 human factors. There were 2,243 phase of flight incident reports, 1,966 FAR part 121, 135, and 91 incident reports, 977 SCFM listings, and 2,152 with specific human factors categories. When analyzing the human factors, FAR parts, and phase of flight, situational awareness was the top problem for all the FAR part categories. Communication breakdown and confusion also had higher frequencies than the other human factor categories. There was no one phase of flight that had the majority of problems. The fewest human factors were seen in fatigue and physiological-other. Analyzing human factors and SCFMs per FAR part also showed situational awareness as being the largest incident issue. In the future more analysis needs to be done in the area of situational awareness to determine what the biggest issues are in that human factors category.

A review of crew systems related issues in safety priority lists, information databases and other document references identified a number of areas related to the CDM TC. Out of the 47 SERFIs that have been identified by the CAST, 11 of these Safety Enhancements could possibly fall within the charter of the CDM TC. In addition, many of the crew related issues identified by in the FDAI study and in published literature are closely related to the CDM goals and products (Figure 1). For example, the top three automation-center problems identified in the FDAI study, “pilot/automation interface”, “functionality (capabilities and limitations)” and “automation failure” are all being addressed by researchers within CDM. Although the current CDM products primarily focuses on crew related technologies and capabilities, modifications can be made in the future so that more of the CDM portfolio addresses the NTSB’s general aviation recommendations.

One of the upcoming tasks of the AvSP systems analysis personnel is to develop a Bayesian model similar to the one created for loss of control (ref. 15, 16, 17), that examines the role of increasing complexity and reliance on automation in the future National Airspace System. This model will be used by AvSP management for identifying any gaps in its research portfolio and also to evaluate the impact of its research products on reducing the risk of an aviation accident in the future. The FDAI “alternative taxonomy” was selected as a foundation for organizing automation related issues in the “complexity and reliance on automation” Bayesian model currently under development. However, the FDAI "alternative taxonomy" was lacking some characteristics needed for the modeling the effort such as time-dependencies (e.g., latent vs. active causes), a further breakdown of automation-centered issues, etc. Therefore, the AvSP systems analysis personnel combined the FDAI "alternative taxonomy" with other related research pertaining to human factors, automation and flight deck design (ref. 18, 19, 20), to create the list of automation issues outlined in Table 10.

Table 10. Summary of Automation Issues

Automation Centered Issues	Operations	Pilot Centered Issues	Organization-Centered Issues	Automated Aircraft/ATC Interaction-Centered Issues
Flight Crew Interface/Design ▪ Development process ▪ Pilot/automation interface ▪ Human-centered design **General Automation Design** ▪ Functionality ▪ Complexity ▪ Levels of automation ▪ Automation failure **Underlying Philosophy of Automation** ▪ Standardization ▪ Pilot/automation responsibility and authority ▪ Pilot role	**Crew Performance** ▪ Crew coordination ▪ Performance ▪ Use of automation **Awareness** ▪ Situation/energy awareness ▪ Automation awareness **Workload** ▪ Attention ▪ Workload	▪ Skill ▪ Confidence/trust ▪ Understanding of automation ▪ Crew personnel factors	▪ Company automation philosophies, policies , and procedures ▪ Pilot selection, training, and evaluation	▪ ATC conflicts

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

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
01- 05 - 2013	Technical Memorandum	

4. TITLE AND SUBTITLE Identification of Crew-Systems Interactions and Decision Related Trends	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Jones, Sharon M.; Evans, Joni K.; Reveley, Mary S.; Withrow, Colleen A.; Ancel, Ersin; Barr, Lawrence	**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-20255
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-2013-218000

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

13. SUPPLEMENTARY NOTES

14. ABSTRACT
NASA Vehicle System Safety Technology (VSST) project management uses systems analysis to identify key issues and maintain a portfolio of research leading to potential solutions to its three identified technical challenges. Statistical data and published safety priority lists from academic, industry and other government agencies were reviewed and analyzed by NASA Aviation Safety Program (AvSP) systems analysis personnel to identify issues and future research needs related to one of VSST's technical challenges, Crew Decision Making (CDM). The data examined in the study were obtained from the National Transportation Safety Board (NTSB) Aviation Accident and Incident Data System, Federal Aviation Administration (FAA) Accident/Incident Data System and the NASA Aviation Safety Reporting System (ASRS). In addition, this report contains the results of a review of safety priority lists, information databases and other documented references pertaining to aviation crew systems issues and future research needs. The specific sources examined were: Commercial Aviation Safety Team (CAST) Safety Enhancements Reserved for Future Implementation (SERFIs), Flight Deck Automation Issues (FDAI) and NTSB Most Wanted List and Open Recommendations. Various automation issues taxonomies and priority lists pertaining to human factors, automation and flight design were combined to create a list of automation issues related to CDM.

15. SUBJECT TERMS
Aircraft accidents; Aircraft safety; Flight crews; Human factors; Statistical analysis

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)
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	35	(443) 757-5802

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18