A Summary of Unmanned Aircraft Accident/Incident Data: Human Factors Implications

Kevin W. Williams
Civil Aerospace Medical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

December 2004

Final Report

U.S. Department
of Transportation

**Federal Aviation
Administration**

NOTICE

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents thereof.

Technical Report Documentation Page

1. Report No. DOT/FAA/AM-04/24	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A Summary of Unmanned Aircraft Accident/Incident Data: Human Factors Implications		5. Report Date December 2004
		6. Performing Organization Code
7. Author(s) Williams KW		8. Performing Organization Report No.
9. Performing Organization Name and Address FAA Civil Aerospace Medical Institute P.O. Box 25082 Oklahoma City, OK 73125		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Office of Aerospace Medicine Federal Aviation Administration 800 Independence Ave., S.W. Washington, DC 20591		13. Type of Report and Period Covered
		14. Sponsoring Agency Code

15. Supplemental Notes

Work was accomplished under approved task AM-HRR-521.

16. Abstract

A review and analysis of unmanned aircraft (UA) accident data was conducted to identify important human factors issues related to their use. UA accident data were collected from the U.S. Army, Navy, and Air Force. Classification of the accident data was a two-step process. In the first step, accidents were classified into the categories of human factors, maintenance, aircraft, and unknown. Accidents could be classified into more than one category. In the second step, those accidents classified as human factors-related were classified according to specific human factors issues of alerts/alarms, display design, procedural error, skill-based error, or other. Classification was based on the stated causal factors in the reports, the opinion of safety center personnel, and personal judgment of the author. The percentage of involvement of human factors issues varied across aircraft from 21% to 68%. For most of the aircraft systems, electromechanical failure was more of a causal factor than human error. One critical finding from an analysis of the data is that each of the fielded systems is very different, leading to different kinds of accidents and different human factors issues. A second finding is that many of the accidents that have occurred could have been anticipated through an analysis of the user interfaces employed and procedures implemented for their use. This paper summarizes the various human factors issues related to the accidents.

17. Key Words Unmanned Aerial Vehicle, Accidents, Human Factors		18. Distribution Statement Document is available to the public through the Defense Technical Information Center, Ft. Belvior, Va. 22060; and the National Technical Information Service, Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 17	22. Price

Form DOT F 1700.7 (8-72)   Reproduction of completed page authorized

A Summary of Unmanned Aircraft Accident/Incident Data:
Human Factors Implications

INTRODUCTION

Available reports regarding unmanned aircraft (UA) reliability have noted that the accident rate for UA is, in general, much higher than that of manned aircraft (DoD, 2001; Schaefer, 2003; Tvaryanas, 2004). An understanding of the causal factors associated with these accidents is important if the goal is to improve the reliability of these aircraft to a level comparable to manned aircraft.

Human factors are consistently cited as a major cause of manned aircraft accidents. Estimates of the percentage of accidents that implicate human error range from 70% to 80% (Wiegmann & Shappell, 2003). In addition, over the past 40 years, the percentage of accidents attributable to human error has increased relative to those attributable to equipment failures (Shappell & Weigmann, 2000).

The review and analysis of UA accident data can assist researchers in the identification of important human factors issues related to their use. The most reliable source for UA accident data currently is the military. The military has a relatively long history of UA use and is diligent in accurately recording information pertaining to accidents/incidents. The purpose of this report is to review all currently available information on military UA accidents to determine to what extent human error has contributed to those accidents and to identify specific human factors involved in the accidents.

Nomenclature

Designations for unmanned aircraft are almost as varied as the aircraft themselves. The most common term for these aircraft is Unmanned Aerial Vehicle (UAV). They have also been called Uninhabited Aerial Vehicles (also UAVs), Remotely Operated Vehicles (ROVs), and Remotely Piloted Vehicles (RPVs). In addition, the military has some special categories of unmanned aircraft that require additional nomenclature. These categories include Tactical UAVs (TUAV), Combat UAVs (UCAV), Unmanned Combat Armed Rotorcraft (UCAR), and "drones." Some agencies have problems with the use of the term "vehicle" for aircraft. So there also exist designations like Remotely Operated Aircraft (ROA), Robotic Aircraft (RA), Remotely Piloted Aircraft (RPA), and Unmanned Aircraft (UA). The term "Unmanned Aircraft" (UA) will be used in this paper to designate the large population of remotely piloted, operated, and/or monitored aircraft.

Military Accident Classification System

Military accidents are classified based on monetary damage and/or severity of injury to personnel. All military branches have similar accident classification schemes. The most severe accident classification is Class A. Table 1 shows the accident classes for the Army.

Table 1. Army accident classes (Department of the Army, 1994a).

Class A	Class B	Class C	Class D
An accident in which the resulting total cost of property damage is $1,000,000 or more; an Army aircraft or missile is destroyed, missing, or abandoned; or an injury and/or occupational illness results in a fatality or permanent total disability.	An accident in which the resulting total cost of property damage is $200,000 or more but less than $1,000,000; an injury and/or occupational illness results in permanent partial disability, or when three or more personnel are hospitalized as inpatients as the result of a single occurrence.	An accident in which the resulting total cost of property damage is $20,000 or more but less than $200,000; a nonfatal injury that causes any loss of time from work beyond the day or shift on which it occurred; or a nonfatal occupational illness that causes loss of time from work or disability at any time.	An accident in which the resulting total cost of property damage is $2,000 or more but less than $20,000.

The Air Force and Navy definitions of Class A, B, and C accidents are very similar to the Army definitions. However, both the Navy and Air Force classify their mishaps/accidents into only the three categories of A, B, and C. They do not have a category D.

Data Sources

To collect UA accident data, personnel from the Safety Centers of the Army, Navy, and Air Force were contacted. Requests were made for all data related to UA accidents, mishaps, and incidents from each of the Safety Centers. Personnel from military research laboratories were also contacted for information and reports summarizing accident data. In addition, an Internet search was conducted to identify and download accident information.

Army Data

Two primary sources of accident information were collected from the Army. The first source was a report entitled "The Role of Human Causal Factors in U.S. Army Unmanned Aerial Vehicle Accidents" (Manning, Rash, LeDuc, Noback, & McKeon, 2004). The report was produced by the U.S. Army Aeromedical Research Laboratory and is a summary of 56 UA accidents that occurred between January 1995 and February 2003. The accident data were obtained from the U.S. Army Risk Management Information System (RMIS), maintained by the U.S. Army Safety Center (USASC), Fort Rucker, Alabama. The accidents were summarized using two taxonomies, a modified version of the Human Factors Analysis and Classification System (HFACS; Shappell & Weigmann, 2000), and the Army accident investigation and reporting taxonomy, DA PAM 385-40 (Department of the Army, 1994b).

The second source of information was a direct query of the RMIS system. The query examined all UA accidents contained in the RMIS database that occurred between January 1980 and June 2004. A total of 74 accidents were identified, the earliest of which occurred on March 2, 1989, and the latest on April 30, 2004.

Navy Data

Information regarding UA accidents for the Navy was collected from the Naval Safety Center. A summary of UA mishaps occurring between 1986 and 2002 was received from the Naval UA Pioneer training command in Pensacola, Florida, via the Naval Safety Center (Kordeen Kor, personal communication). The summary lists 239 mishaps, including the mishap level, date, location, and a brief description. The brief description, while not providing much detail, allowed the general classification of the mishap, including whether the mishap was or was not related to human factors.

Air Force Data

Air Force accident/mishap information was collected from the Air Force Judge Advocate General's Corps Web site, http://usaf.aib.law.af.mil/. The Web site gives the executive summaries of Air Force Class A mishaps, organized by year. Lower-level mishaps were not available. A total of 15 Class A UA mishaps were retrieved from the Web site, covering the dates from December 6, 1999, to December 11, 2003. In addition to these executive summaries, a complete accident investigation board report of the December 6, 1999, accident was received electronically from Major Curtis McNeil of the Judge Advocate General's Corps office. Also, a summary of Air Force accidents and human factors issues related to UA was received electronically from Major Anthony P. Tvaryanas (Tvaryanas, 2004).

Data Reliability Issues

Unfortunately, the data regarding UA accidents are not usually as detailed as that surrounding manned aircraft. One reason for this lack of detail is that most UA used in the military are much less expensive than manned aircraft and so do not warrant the same level of analysis. In addition, the military does not release much of the detailed information regarding specific UA accidents to the general public.

There are also problems regarding the classification of UA in the military. The Army, for example, only recently has begun to classify UA as aircraft. Before, they were classified only as vehicles. Therefore, accidents involving Army UA were treated in the same fashion as ground vehicles. A similar situation existed until recently for the Navy. In effect, there are really no highly detailed accident investigations performed for UA accidents, with the exception of the Air Force. The Air Force, however, will not release detailed reports to the general public and puts restrictions on the writing of reports based on such detailed data. Consequently, much of the reported accident data collected for this report consists of summaries of several accidents or simple one-sentence statements regarding individual accidents.

Classification Procedure

Classification of the accident data was a two-step process. In the first step, accidents were classified into broad categories based on whether it was clear the accident was related to human factors or was a failure of an aircraft component. For some aircraft systems, other categories were included based on information specific to that aircraft. The category "Aircraft" included problems associated with the failure of a mechanical or electrical component of the airframe. An "Unknown" category was used if there were accidents with insufficient information

for categorization. A category of "Maintenance" was also included if there was evidence that an action by maintenance personnel contributed to the accident. An example would be a failure by a maintenance technician to check the oil level prior to a flight, leading to an engine failure during the flight. This category was separated from human factors because it did not involve a member of the flight crew and because UA maintenance is an important topic by itself that should be addressed separately. Note that accidents could be classified into more than one category. For example, an accident could be classified as both "Aircraft" and "Human Factors" if a mechanical failure was also accompanied by an inappropriate or inadequate display indication to the crew.

In the second step, those accidents classified as related to human factors were classified according to specific human factors issues that are commonly addressed in current research. These issues included alerts/alarms, display design deficiencies, procedural errors, and skill-based errors. Other human factors issues were included for a particular aircraft if evidence was available from the reports indicating it was an important factor in the accident. Classification was based on the stated causal factors in the reports, the expressed opinion of safety center personnel, and the personal judgment of the author.

RESULTS

Because of the enormous differences in the human interfaces of the various UA systems, it did not make sense to combine all of the accident data into a single analysis. Instead, each system will be looked at individually to see how their design approaches have influenced the types of human errors that have occurred.

There are five primary U.S. military UA in service currently. The Army's Hunter and Shadow, the Navy's Pioneer, and the Air Force's Predator and Global Hawk. Other systems are being developed and have undergone testing, such as the Mariner system for the Coast Guard and Navy, but sufficient accident data do not exist to warrant separate analyses of these airframes. A description of these five UA systems included in this analysis is provided in an effort to further understanding of the accident data associated with each.

U.S. Army
Human Causal Factors Report
Manning et al. (2004) looked at Army UA accident data using both the HFACS taxonomy and the DA PAM 385-40 analysis. A total of 56 UA accidents were analyzed, with 18 (32%) identified as involving human error. They did not perform an analysis separately for the Hunter and Shadow UA; however, they noted that 17 accidents

involved the Hunter and 10 involved the Shadow, but the report does not state how many of those involved human error. In addition, accident data were included in the analysis even if the UA type was only identified as a "drone," "trainer," or simply "UAV."

Regarding the HFACS analysis, the largest percentage of accidents involving human error (61%) was attributed to the category called Unsafe Acts. Unsafe Acts is broken down further into the subcategories of skill-based errors, decision errors, perceptual errors, and violations. Decision errors accounted for the highest percentage of human error accidents (33%), followed by skill-based errors (22%), perceptual errors (17%), and violations (11%).

The DA PAM 385-40 analysis divides accidents into the categories of individual failure, leader failure, training failure, support failure, and standards failure. For definitions of these categories the reader is referred to DA PAM 385-40. Sixty-one percent of the human-error accidents were attributed to individual failures, followed by standards failures (44%), leader failures (33%), training failures (22%), and finally support failures (6%). The percentages do not add to 100% because many of the accidents fell into more than one category.

One shortcoming of the summary by Manning et al. is that the analysis does not identify specific human factors issues associated with UA accidents. The use of the HFACS taxonomy helped in the identification of the importance of decision-making and the development of crew skills in the prevention of accidents but did not reveal specific design shortcomings of the various systems included in the data. For this reason, a second analysis was conducted of the accidents contained in the RMIS database. This analysis examined 74 UA accidents that occurred between March 2, 1989, and April 30, 2004.

These 74 accidents were separated into those related specifically to the Hunter (32 accidents), those involving the Shadow (24 accidents), and those concerning other types of UA (18 accidents). The Hunter and Shadow accidents were further analyzed to identify how many involved human factors issues and which issues were associated with a specific type of aircraft.

Hunter
The Hunter (see Figure 1) is a twin-engine, short-range (144nm) tactical aircraft, with a payload capacity of 200 pounds and endurance of up to 12 hours (Manning et al., 2004). The aircraft weighs 1600 pounds and has a 29-foot wingspan, a ceiling of 15,000 feet, a cruising speed of 100 kts and a cost of $1.2M (Schaefer, 2003).

The Hunter takes off and lands using an External Pilot (EP) standing next to the runway in visual contact with the aircraft, operating a controller that is very similar to ones used by radio-controlled aircraft hobbyists (see Figure 2).

Figure 1. U.S. Army Hunter (RQ-5) unmanned aircraft.

Figure 2. Controller for radio-controlled aircraft.

As shown in Figure 1, takeoffs can be assisted using a rocket bottle that releases from the aircraft shortly after takeoff. After takeoff and climb out, control of the aircraft is transferred to an Internal Pilot (IP), operating from a Ground Control Station (GCS). The IP controls the Hunter in a more automated fashion by selecting an altitude, heading, and airspeed for the aircraft using a set of knobs located within the GCS. For landing, control of the aircraft is transferred from the GCS back to an EP. A hook located below the aircraft is used to snag the aircraft on a set of arresting cables positioned across the runway.

Data from the Hunter program indicated that 15 of the 32 accidents (47%) had one or more human factors issues associated with them. Figure 3 shows the major causal categories for Hunter accidents. Note that the percentages add to more than 100% because some of the accidents were classified into more than one category.

Breaking down the human factors issues further, Table 2 shows how the number and percentage of the 15 human factors-related accidents are associated with specific human factors issues. Again, percentages exceed 100% because of some accidents being classified under more than one issue.

By far the largest human factors issue is the difficulty experienced by EPs during landings, with 47% of the human factors-related Hunter accidents occurring during this phase. An additional 20% of the accidents involved an error by the EP during takeoff. Control difficulties are at least partially caused because when the aircraft is approaching the EP, the control inputs to maneuver the aircraft left and right are opposite what they would be when the aircraft is moving away from the EP. This reversed-control problem is present for any UA operated by an external pilot via visual contact. Other research has also identified this problem as an important human factors issue related to UA (Gawron, 1998).

Besides EP control problems, other issues represented in the table include pilot-in-command issues, alerts and alarms, display design, and crew procedural error. A pilot-in-command issue is a situation where the authority of the controlling pilot is superceded by other personnel in the area, violating the principle that the pilot of the aircraft has the final decision-making authority during a flight. In contrast, alerts and alarms deal with situations where a non-normal flight condition (e.g., high engine temperature) is not conveyed effectively to the crew.

Display design issues typically manifest when not all of the information required for safe flight is conveyed effectively to the crew. In the instance referred to in Table 2, a ground crew member had toggled off the autopilot feature, and no display was available to the flight crew regarding the status of the autopilot. Since the autopilot is typically engaged when the IP is controlling the UA, the pilot failed to notice the status of the autopilot, thus contributing to an accident.

Finally, the crew procedural errors referred to here involved three occasions where the crew failed to properly follow established procedures. On one occasion an improper start-up sequence led to data link interference from the backup GCS. A second event occurred when the crew failed to follow standard departure procedures and the UA impacted a mountain. The third occasion
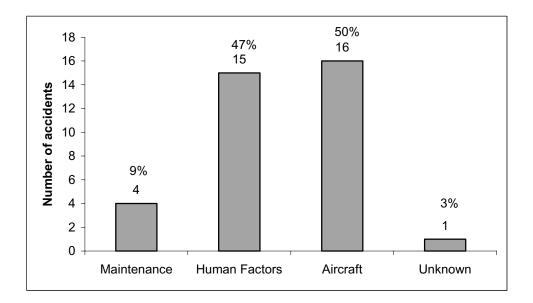
Figure 3. U.S. Army Hunter accident causal factors.

Table 2. Breakdown of human factors issues for Hunter accidents.

Issue	Number	Percent
Pilot-In-Command	1	7%
Alerts and Alarms	2	13%
Display Design	1	7%
External Pilot Landing Error	7	47%
External Pilot Takeoff Error	3	20%
Procedural Error	3	20%

was when an EP failed to complete control box checks prior to taking control of the UA and did not verify a box switch that was in the wrong position.

Shadow

Compared with the Hunter, the Shadow 200 (Figure 4) is a smaller (9 ft in length), and lighter (330 lbs) short-range surveillance aircraft, capable of operating at altitudes of 14,000 ft and carrying a payload of up to 60 lbs (Manning et al., 2004). The Shadow 200 has an operational range of 68nm, a cruising speed of 82 kts and a cost of $325,000 per aircraft (Schaefer, 2003).

Unlike the Hunter, the Shadow does not use an external pilot, depending instead on a launcher for takeoffs and an automated landing system for recovery. The landing system, called the Tactical Automated Landing System (TALS), controls the aircraft during approach and landing, usually without intervention from the GCS pilot. A cable system, similar to the one used for the Hunter, is used to stop the aircraft after landing. Aircraft control during flight is accomplished by the GCS pilot through a computer menu interface that allows selection of altitude, heading, and airspeed. It is interesting to note that during landing, the GCS personnel have no visual contact with the aircraft, nor do they have any sensor input from onboard sensors. A command to stop the aircraft engine is given by the GCS pilot, who must rely on an external observer to communicate that the plane has touched down.

The analysis of Shadow accidents shows a different pattern from that seen with the Hunter. In contrast to the Hunter, only 5 of the 24 Shadow accidents (21%) were attributed to human factors issues. Figure 5 shows the major causal factors for the Shadow accidents.

In addition to the four categories used for the Hunter accidents, an additional category was added for Shadow to include failures of the tactical automated landing system. While eliminating landing accidents potentially attributable to an EP, the use of TALS is not perfect, as shown from the data. Use of the launcher eliminated any EP takeoff errors for these aircraft.
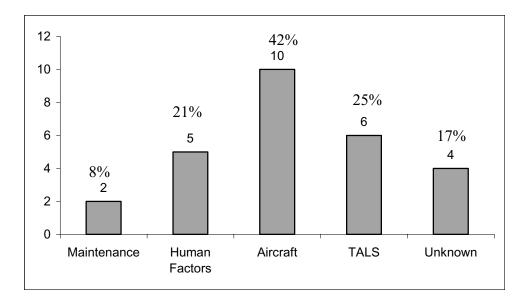
Figure 4. U.S. Army Shadow (RQ-7) unmanned

Figure 5. U.S. Army Shadow accident causal factors.

Table 3. Breakdown of human factors issues for Shadow accidents.

Issue	Number	Percent
Pilot-In-Command	2	40%
Alerts & Alarms	2	40%
Display Design	2	40%
Procedural Error	2	40%

Breaking down the human factors-related accidents, Table 3 shows the number and percentage of the five accidents related to specific human factors issues. As can be seen from the table, the distribution of issues is evenly divided across pilot-in-command, alerts and alarms, display design, and procedural errors.

For both the Hunter and Shadow, at least one accident involved the transfer of control of the aircraft from one GCS to another during flight, an activity unique to UA. In the case of the Shadow, two aircraft were damaged during a single mission. The first was damaged due to a TALS failure. After the accident, the GCS crew issued a command to the damaged aircraft to kill its engine, but because of damage to the antenna the command was not received. That same GCS was then tasked with controlling a second Shadow that was on an approach. Unfortunately, after taking control of the second Shadow, the aircraft received the "engine kill" command that was still waiting for an acknowledgment from the GCS software, causing the second Shadow to also crash. This accident was classified as both a procedural error (because the crew failed to follow all checklist items prior to the transfer of control of the second aircraft) and a display design problem (because there was not a clear indication to the crew of the status of the "engine kill" command that had been issued).

While not frequent, such accidents suggest the unique nature of problems that can arise with UA that would not be encountered with manned aircraft. As if to emphasize the point, on a recent Coast Guard operational test of an Altair UA, a problem was encountered during one of the flights while control was being transferred from one operator station to another (Randy Sundberg, personal communication). The second operator station apparently had a fuel control switch out of position, so that when control was passed over, the engine died. Luckily, in this instance, the aircraft was high enough that the engine was restarted without incident.

U.S. Navy

Pioneer

The longest serving UA in the military is the Pioneer (RQ-2), which has been used by the Navy and Marine Corps since 1985 and has logged over 20,000 hours of flight time (Schaefer, 2003). The Pioneer (see Figure 6) is a single-engine, propeller-driven aircraft. It is 14 ft long with a wingspan of 17 ft. It weighs 452 lbs and has a payload capacity of 72 lbs. It can fly for 5 hrs without refueling, has a ceiling of 15,000 ft, and a cruising speed of 80 kts. Each aircraft costs $650,000. Notably, in September 2002, the Navy discontinued operation of the Pioneer, leaving the Marine Corps as the only operator.

Figure 6. Pioneer RQ-2 unmanned aircraft.

Like the Army's Hunter UA, the Pioneer requires an EP for takeoff and landing. After takeoff, the aircraft can be controlled from a GCS in one of three modes. In the first mode, the air vehicle is operated autonomously, and the autopilot uses global positioning system (GPS) preprogrammed coordinates to fly it to each waypoint. In the second mode, the IP commands the autopilot by setting knobs (rotary position switches) to command airspeed, altitude, compass heading or roll angle, and the autopilot flies the UA. In the third mode, the IP flies the aircraft using a joystick. The Pioneer can be landed at a runway using arresting cables, but because it is a Navy/Marine-operated aircraft, it can also be landed on board a ship by flying into a net. There are plans for implementing an automated landing system for the Pioneer for ship-based landings.

A list of 239 Pioneer accidents was received from the Navy Safety Center. The accidents cover the period from 1986 until 2002. Although not providing much detail, the data did allow a general categorization of accidents into principal causal categories. Figure 7 shows the major causal factors for Pioneer accidents.

As can be seen from the figure, human factors-related issues were present in approximately 28% of the accidents. Also, a small number of mishaps (5) were attributed to enemy actions. Breaking down the human factors-related accidents further, Table 4 lists the number and percentage of the 68 accidents related to specific human factors issues.

As with the Army Hunter accidents, the largest percentage of human factors accidents (68%) was associated with the difficulty experienced by the EP while landing the aircraft. An additional 10% of the accidents were associated with takeoffs, although the primary means of taking off is through the use of a launcher (from ship-based aircraft). In addition to landing and takeoff errors, two other issues seen with the Pioneer were aircrew
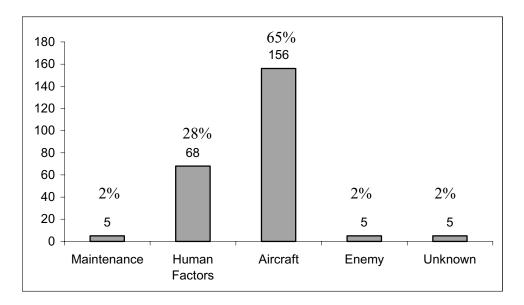
Figure 7. U.S. Navy Pioneer UA accident causal factors.

Table 4. Breakdown of human factors issues for Pioneer accidents.

Issue	Number	Percent
Aircrew Coordination	9	13%
Landing Error	46	68%
Take-off Error	7	10%
Weather	6	9%

Table 5. Specifications for the Air Force MQ-1 and MQ-9 (from Schaefer, 2003).

	MQ-1	MQ-9
Gross Weight	2,250 lbs	10,000 lbs
Length	28.7 ft	36.2 ft.
Wingspan	48.7 ft	64 ft
Ceiling	25,000 ft	45,000 ft
Radius	400 nm	400 nm
Endurance	24 + hrs	24 + hrs
Payload	450 lb	750 lb (internal) 3000 lb (external)
Cruise Speed	70 kts	220 kts
Aircraft cost (w/out sensors)	$2.4 M	$6 M
System Cost (4 Avs)	$26.5 M	$47 M

Figure 8. The U.S. Navy Fire Scout (RQ-8A).

Figure 9. Predator MQ-1.

Figure 10. Predator B MQ-9.

coordination, which includes procedural and communication type errors, and weather-related accidents, which deal with pilot decision-making. Unfortunately, details regarding these accidents were not sufficient to identify issues beyond this level.

Fire Scout

An additional accident for which information was available was the crash of a Navy-owned Vertical Take-off and Landing Tactical Unmanned Aerial Vehicle (VTUAV), called the Fire Scout (see Figure 8).

The Fire Scout air vehicle (RQ-8A) is based on the Schweizer Aircraft Corporation Model 330 manned turbine helicopter. The Fire Scout has a gross takeoff weight of 2,550 lbs, cruises at 110 kts, and is intended to loiter on-station at 110 nm for over 3 hrs (DoD, 2002).

The investigation of the accident, which occurred on November 4, 2000, revealed that human error, associated with damage to onboard antennas during ground handling, led to the accident. Because of the damage to the antennas, an incorrect signal was emitted, causing the radar altimeter system to incorrectly track the altitude. The antennas gave a false reading that indicated

that the Fire Scout was at an altitude of 2 ft above the ground when, in fact, it was hovering at an altitude of 500 ft (Strikenet, 2001). After the "land" command was given, the aircraft descended two ft to 498 ft AGL. The guidance and control system interpreted the incorrect altitude signal as an indication that the Fire Scout had already landed and, performing as designed, shut down the engine. Although the Fire Scout is not widely used, the accident is included here because it is another example of how unique approaches to automation and procedures with UA can lead to unique mishaps.

Air Force

Predator

The Predator made its first flight in June 1994. There are two Predator types, currently designated as MQ-1 and MQ-9, also called Predator and Predator B. Figures 9 and 10 show photos of the MQ-1 and MQ-9, respectively.

The specifications for both the MQ-1 and MQ-9 are presented in Table 5. The Predator aircraft is flown from within the GCS, similarly to a manned aircraft, using a joystick and rudder pedals and a forward-looking camera that provides the pilot with a 30-degree field of view. The

Figure 11. Predator ground control station layout.

Table 6. Breakdown of human factors issues for Predator accidents.

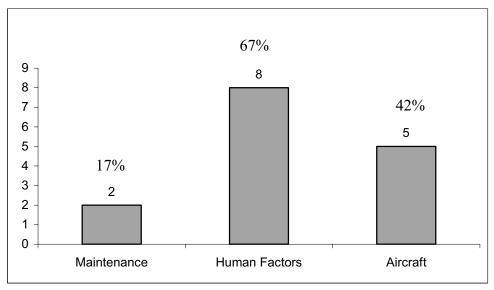| Issue	Number	Percent
Alerts & Alarms	1	13%
Display Design	2	25%
Landing Error	1	13%
Procedural Error	6	75%

Figure 12. Air Force Predator accident causal factors.

camera is used for both takeoffs and landings. Figure 11 shows a picture of the Predator GCS.

The Predator accident causal factors are shown in Figure 12. As can be seen from the figure, human factors encompass a higher percentage (67%) than aircraft-related causes, unlike the other aircraft examined thus far.

Table 6 shows a breakdown of the human factors issues associated with Predator accidents. The majority of human factors-related problems were concerned with procedural errors on the part of the flight crew. One of these accidents involved yet another problem with a handoff of the aircraft from one GCS to another. During the handoff, the mishap crew did not accomplish all of the checklist steps in the proper order, resulting in turning off both the engine and the stability augmentation system of the aircraft. The aircraft immediately entered an uncommanded dive and crashed.

A second procedural error of note occurred when the pilot accidentally activated a program that erased the internal random access memory onboard the aircraft during a flight. That this was even possible to do during a flight is notable in itself and suggests the relatively ad hoc software development process occurring for these systems (Tvaryanas, 2004). Predator pilots also have noted problems caused by the software interface (Hoffman, 2004). One example in particular from Hoffman (2004) was with the assignment of menu selections to function keys on the GCS keyboard. Hoffman noted that a particular order of pressing function keys that controlled the lights on the Predator was almost the same as an order for cutting off the engine.

The report by Tvaryanas (2004) on mishap epidemiology states that Human System Interface (HSI) issues are discussed in 89% of the Predator accidents and are cited

as a causal factor in 44% of those accidents. Tvaryanas cites four HSI issues involved with Predator mishaps: 1) design of the head-up display (HUD); 2) design of the head-down display (HDD); 3) alerts and alarms (Tvaryanas calls them "warnings and cautions"); and 4) functioning of the autopilot.

Specific problems cited for the HUD design are that the field of view (30 degrees) is too narrow, the attitude indicator is inadequate, the engine RPM indicator needs improvement, the symbology becomes obscured during low-link conditions, some of the symbology lacks sufficient contrast against the external view, and other symbology is inadequate. There is currently an effort to replace the Predator HUD with a new design based on fighter aircraft HUD designs. However, even the new HUD design does not address all of the problems listed above.

Four specific problems were cited for head-down display design. These were: 1) too many levels of pages to maneuver through to access information; 2) the unintuitive manner of information display; 3) critical commands were unprotected or unemphasized; and 4) operational ranges of values were inconsistent within the display. The lack of protection for critical commands was a key feature in the mishap cited above where the internal memory of the aircraft was erased during a flight.

The following deficiencies of alerts and alarms were noted: 1) alerts do not command attention; 2) audio warnings were insufficient or absent; 3) information provided was inadequate or poorly prioritized; 4) information was invalid; and 5) data that need to be compared are not always co-located on the same display page. Tvaryanas also states that the alerts and alarms on the Predator violate multiple human factors design principles.

Finally, four problems were cited by Tvaryanas regarding the functioning of the autopilot. The first is that there is no indication on the HUD of the status of the autopilot. The second problem is that the flight controls cannot control the aircraft while the autopilot is engaged (i.e., no override capability). In addition, the pilot must navigate through four separate menus on the HDD to deactivate the autopilot. This requires approximately 7 sec on average to accomplish. The third problem cited is that the autopilot functionality does not fully consider the capabilities of the aircraft, which results in the commanding of extreme maneuvers (unusual attitudes) and the possible overstressing of the aircraft by the autopilot. The final problem is that the autopilot functionality does not conform to Air Force standards, using pitch to adjust airspeed instead of power. This could result in the pilot not being fully aware of what changes were being made by the autopilot during maneuvering.

Figure 13. Air Force Global Hawk (RQ-4).

Global Hawk

The Global Hawk (see Figure 13), made by Northrop Grumman, is the largest and newest of the five military systems discussed. Global Hawk first flew in February 1998, and it became the first UA to cross the Pacific Ocean in April 2001 when it flew from the United States to Australia (Schaefer, 2003).

The specifications for the Global Hawk are listed in Table 7. The Global Hawk is the most automated of all the systems discussed. All portions of the flight, including landing and takeoff, are pre-programmed before the flight, and the basic task of the crew during the flight is simply to monitor the status of the aircraft and control the payload. While this makes flying the Global Hawk very simple, the mission planning process is unwieldy and requires a great deal of time to accomplish.

The following description of the mission-planning process for the Global Hawk is taken from an accident investigation board report dated February 2000:

Mission planning is a long and involved process where everything that the pilot and crew of a manned aircraft do in conjunction with a mission must be programmed

Table 7. Global Hawk specifications (from Schaefer, 2003).

	RQ-4A
Weight	26,750 lbs
Length	44.4 ft
Wingspan	116.2 ft
Ceiling	65,000 ft
Radius	5,400 nm
Endurance	32 hrs
Payload	1,950 lbs
Cruise Speed	345 kts
Aircraft Cost	$20 M
System Cost	$57 M

into the air vehicle. This process begins up to 270 days prior to flight in an exercise to negotiate agreement on the mission, targets, and flight routes. Mission planning involves people from many different organizations. Mission planners become actively involved 90 days prior to the flight. Once the target sets are finalized, it takes three to five weeks to write and validate a mission plan. Mission plans are generated using a mission planning system that consists of the standard core application and a Global-Hawk-specific module. Validation is scheduled to take 10 days, starting 18 days prior to the planned flight and includes any iterations necessary to finalize the plan.

Only three accident reports were available for the Global Hawk. Of these three reports, one did not provide sufficient information for classification, a second faulted a failure in a fuel nozzle, which led to an engine failure, and the third was a human factors issue centering on the complicated mission-planning process. In that accident, the mishap aircraft suffered an inflight problem with temperature regulation of the avionics compartment and landed at a preprogrammed alternate airport for servicing. After landing, the aircraft was commanded to begin taxiing. Unknown to the crew, a taxi speed of 155 knots had been inputted into the mission plan at that particular waypoint as a result of a software bug in the automated mission planning software in use at the time. The aircraft accelerated to the point it was unable to negotiate a turn and ran off the runway, collapsing the nose gear and causing extensive damage to the aircraft.

An analysis of human factors problems with the Global Hawk by Tvaryanas centers primarily on the high levels of automation involved with the system. The report suggests that system operators do not closely monitor the automated mission-planning software, resulting in lowered levels of situation awareness and a lowered ability to deal with system faults when they occur. In particular, status reports were difficult to interpret because they were coded in hexadecimal and provided no trend data to the operators.

CONCLUSIONS

Figure 14 summarizes the data reported in this report across each UA system. One conclusion apparent from the data reported here is that, for most of the systems examined, electrical and mechanical reliability play as much or more of a role in the accidents as human error. Mishaps attributed at least partially to aircraft failures range from 33% (Global Hawk) to 67% (Shadow) in the data reported here. A recent report by the Office of the Secretary of Defense (Schaefer, 2003) reviewed several factors affecting the electromechanical reliability of UA. The most critical factor cited is that cost savings are more important for UA than for manned aircraft. Unfortunately, cost-saving measures have a tendency to impact component reliability, system redundancy, and the inclusion of new component technologies. For example, cost-saving techniques such as the use of wooden propellers and less attention to watertight sealing leave some UA more vulnerable to precipitation than manned aircraft. In addition, the relatively smaller size of many UA also has an adverse effect on their response to both precipitation and icing. Schaefer points out that "a one-tenth inch accumulation [of ice] on a Pioneer's wings is equal to one inch on a Boeing 747" (p. 33).

An improvement in electromechanical reliability will probably come only through an increase in the cost of the aircraft. However, a reduction of human errors leading to accidents might not necessarily entail increased costs if suggested changes can be incorporated early in the design process. In the systems analyzed, human factors issues were present in 21% (Shadow) to 67% (Predator) of the accidents. These numbers suggest there is room for improvement if specific human factors issues can be identified and addressed.

In that regard, it is important to note that many of the human factors issues identified are very much dependent on the particular systems being flown, the type of automation incorporated, and the user interface
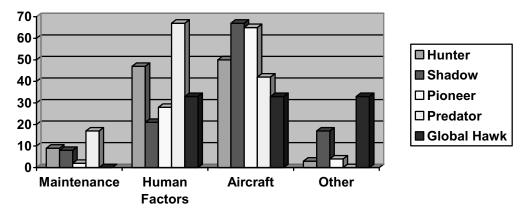

Figure 14. Summary accident percentages across aircraft systems.

employed. For example, both the Pioneer and Hunter systems have problems associated with the difficulty external pilots have in controlling the aircraft. For both of these systems, the majority of accidents due to human error can be attributed to this problem. However, the other three systems discussed do not use an EP and either use an IP (Predator) or perform landings using an automated system (Shadow and Global Hawk).

Notably, however, the use of automation to overcome human frailties does not completely solve the problem, as the automation itself can fail (as with the Shadow's TALS) and the automation can introduce other problems for the crew, such as the complicated mission planning process required for the Global Hawk. The effectiveness of automation is dependent on how it is incorporated within the interface (Parasuraman & Riley, 1997). There are current research efforts to understand the effect that automation has on UA pilot/operator workload, particularly if that automation is not completely reliable (Dixon & Wickens, 2004; Ruff, Calhoun, Draper, Fontejon & Guilfoos, 2004).

The design of the user interfaces of these systems are, for the most part, not based on previously established aviation display concepts. Part of the cause for this is that the developers of these system interfaces are not primarily aircraft manufacturers. Another reason is that these aircraft are not "flown" in the traditional sense of the word. Only one of the aircraft reviewed (Predator) has a pilot/operator interface that could be considered similar to a manned aircraft. For the other UA, control of the aircraft by the GCS pilot/operator is accomplished indirectly through the use of menu selections, dedicated knobs, or preprogrammed routes. These aircraft are not flown but "commanded." This is a paradigm shift that must be understood if appropriate decisions are to be made regarding pilot/operator qualifications, display requirements, and critical human factors issues to be addressed.

Besides the EP accidents, most of the other human factors-related accidents were unique in the sense that a problem that occurred for one type of aircraft would never be seen for another because the user interfaces for the aircraft are totally different. On the other hand, a common theme across many of the mishaps reported involved a problem with the command interface to the system. The issues reported in this paper regarding alerts and alarms, display design, and procedural problems are mostly associated with providing information to the pilot/operator about the commanded status of the aircraft.

If the aircraft is commanded to begin taxiing, there should be information available regarding the intended taxi speed. If the aircraft is being handed off from one station to another, the receiving station personnel should be aware of what commands will be transmitted to the aircraft after control is established. Interface development needs to be focused around the task of the pilot/operator. For most of these aircraft, that task is one of issuing commands and verifying that those commands are accepted and followed. Understanding this task and creating the interface to support it should help to improve the usability of the interface and reduce the number of accidents for these aircraft. This is especially important as these aircraft begin to transition to the National Airspace System, conducting civilian operations in among civilian manned aircraft.

REFERENCES

Department of the Army (1994a). Accident reporting and records. Washington, DC. Army Regulation 385-40.

Department of the Army (1994b). Army accident investigation and reporting. Washington, DC. Army Pamphlet 385-40.

Dixon, S.R. and Wickens, C.D. (2004). Automation reliability in unmanned aerial vehicle flight control. *Proceedings of the Human Performance, Situation Awareness and Automation Conference*, March 22-25, Daytona Beach, FL, 395-9.

DoD (2001). *Unmanned aerial vehicles roadmap, 2000-2025.* Office of the Secretary of Defense, Department of Defense, Washington, DC, April 2001.

DoD (2002). RQ-8A Firescout vertical takeoff and landing tactical unmanned aerial vehicle system (VTUAV). From the Director of Operational Test and Evaluation FY2001 Annual Report, Department of Defense. Downloaded on 6/16/2004 from URL http://globalsecurity.org/military/library/budget/fy2001/dot-e/index.html.

Gawron, V.J. (1998). Human factors issues in the development, evaluation, and operation of uninhabited aerial vehicles. *AUVSI '98: Proceedings of the Association for Unmanned Vehicle Systems International*, Huntsville, AL, 431-8.

Hoffman, J. (2004). The U.S. Air Force at the crossroads: Dealing with unmanned aerial vehicles human factors. Presented at the *Human Factors of Uninhabited Aerial Vehicles First Annual Workshop*, May 24-25, 2004, Chandler, AZ.

Manning, S.D., Rash, C.E., LeDuc, P.A, Noback, R.K., and McKeon, J. (2004). The role of human causal factors in U.S. Army unmanned aerial vehicle accidents. U.S. Army Aeromedical Research Laboratory Report # 2004-11.

Parasuraman, R. and Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human Factors*, *39*(2), 230-53.

Ruff, H.A., Calhoun, G.L., Draper, M.H., Fontejon, J.V., and Guilfoos, B.J. (2004). Exploring automation issues in supervisory control of multiple UAVs. *Proceedings of the Human Performance, Situation Awareness and Automation Conference*, March 22-25, Daytona Beach, FL, 408-412.

Schaefer, R. (2003). Unmanned aerial vehicle reliability study. Office of the Secretary of Defense, Washington, DC, February 2003.

Shappell, S.A. and Wiegmann, D.A. (2000). Human factors analysis and classification system - HFACS. Department of Transportation, Federal Administration: Washington, DC. DOT/FAA/AM-00/7.

Strikenet (2001). VTUAV P1 accident investigation board report. Downloaded on 4/15/2004 from URL http://www.strikenet.js.mil/pao/vtuav_crash_invest_news_release.html.

Tvaryanas, A.P. (2004). USAF UAV mishap epidemiology, 1997-2003. Presented at the *Human Factors of Uninhabited Aerial Vehicles First Annual Workshop*, Phoenix, AZ, May 24-25, 2004.

Wiegmann, D.A. and Shappell, S.A. (2003). *A human error approach to aviation accident analysis: The Human Factors Analysis and Classification System*. Burlington, VT: Ashgate.