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HUMAN FACTORS ASPECTS OF REMOTELY PILOTED AIRCRAFT

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Abstract

Use of remotely piloted aircraft (RPA) has expanded rapidly, driven by the need to improve utility for airborne vehicles in both civil and military sectors. These vehicles are operated similar to conventional aircraft except that a ground stationed pilot provides flight path control through auxiliary sensory channels onboard the aircraft. Recent experience in operating these vehicles has highlighted a need to better understand human factor interfaces to provide safe control throughout the flight envelope. Results from current RPA operation indicate a reduced capability to provide completely satisfactory control since the information content to provide accurate operator feedback can be degraded by using intermediary channels. The purpose of this paper is to highlight certain aspects of RPA operation to provide a clearer understanding of the human systems interface needed to improve safety and utility under remote control conditions. Of the various sensory cues available to the pilot, visual factors either from onboard instrumentation or by a video down link are most important to avoid loss of control.

Introduction

Operation of RPAs is increasing rapidly because of unique mission requirements which can be fulfilled by airborne vehicles in both civil and military arenas. Remote control of aerial vehicles dates back thousands of years when kites were flown in China via a data link consisting of a string attached to the lifting surface. The first large-scale use of RPAs occurred in the 1950s by military reconnaissance vehicles.(1) Operation was unique in that these aircraft were rail-rocket launched, flown by preprogrammed automatic control, and recovered by parachute. Recently, the requirement for operation at very high altitudes and for extended duration has stimulated the use of RPAs for civil airborne science programs. For the most part, these vehicles are operated similar to conventional aircraft except that a ground stationed pilot provides flight path control through auxiliary sensory channels onboard the aircraft.

Recent experience in operating these vehicles has highlighted a need to better understand human factor interfaces to provide safe control throughout the flight envelope. Taking the pilot out of the aircraft to a ground station can complicate the pilot's control role since knowledge of the environment and state of the aircraft has shifted from a direct feedback system to one where information has to be sensed, communicated to a control station, and displayed in a manner that will effectively substitute for the lack of sensory cues used by a pilot in real aircraft. Results from current RPA operation indicate a reduced capability to provide completely satisfactory control since the information content to provide accurate operator feedback can be degraded by using intermediary channels.

The purpose of this paper is to highlight certain aspects of RPA operation to provide a clearer understanding of the human systems interface needed to improve safety and utility under remote control conditions.

The scope of the paper includes a discussion of the human systems interface used in RPA operation and the relative importance of sensory cues used for control. A review of operational experience of several RPAs is used to establish the state-of-the-art and future needs for aerial vehicles.

Discussion

Human System Interface

An important link for RPA operation is the ground control station (GCS) which serves as the primary interface between the RPA and the simulator operator. Depending on the vehicle configuration and mission requirements, the degree of sophistication of the GCS can vary in terms of the equipment and the number and type of personnel. Two methods of control are used. In an autonomous system, the vehicle is controlled through the autopilot using stored information obtained through the mission planning system with the operator making minor autopilot adjustments such as altitude, heading, and airspeed. Instead of aircraft-like controls, knobs can be used to command flight parameters. Other systems, designed to be manually flown, use a cockpit layout with a stick, power control (throttle), rudder pedals, and conventional displays including some form of head-up display (HUD) where symbology is overlaid on an out-the-window scene provided by the aircraft nose camera. An excellent example of a modern manual system equipped with a sophisticated HUD is used for the X-36 aircraft.(2)

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For the majority of RPA operations conducted thus far, the manual system uses an operator, preferably with real aircraft piloting experience. The rationale is that although anyone can be trained to operate an RPA, a real pilot can handle emergencies and unexpected flight path departures more expeditiously by drawing on past experience from real life exposure.

Relative Importance of Sensory Cues

In the foregoing description, it may be noted that some sensory cues such as motion, aural, visual, and tactile may not be available or are considerably degraded or different from that experienced in manned aircraft. As a result, a pilot/operator for RPAs may have difficulty in maintaining controlled flight for lack of adequate information. The need for information is crucial for providing correct timing and content in the human operator response loop. An example of the consequences of a lack of information is discussed later for the Raptor remotely piloted vehicle (RPV).

An information gap is generally distressing for the operator, who tries to collect as much information as possible by means of all available sensors.(3) (This is why solitary confinement is so oppressive for prisoners.) Lacking information, the pilot/operator creates some by thinking about something else, which usually results in vigilance loss. An example is a situation where a driver is stopped by a red light. The driver is not able to keep his eyes on the red light for more than five seconds, because the steady red light does not give any information. The driver then is inclined to look for other surrounding information. He may note the density of cars in the cross traffic lane to provide information as to when his turn may come. When the light changes to yellow, the driver looks again at the red light because it is possible to forecast that it will turn green in less than five seconds. This forecasting ability makes the waiting bearable; however, if it takes more than the expected time to turn green, his mind directs the eye to look elsewhere for other information.

Understanding the use of cues and the interaction between different cues is important to obtain satisfactory pilot/operator behavior. The following is an example of the interrelationship between cues (motion and visual). In manned aircraft, when encountering a vertical gust, the pilot has learned to instinctively apply nose-down stick pressure to reduce the flight path divergence. A glance at an attitude indicator shows the pilot that the deviation in pitch is decreasing in magnitude. In a fixed based cockpit, the pilot is alerted to a flight path disturbance by a display which indicates that pitch attitude is diverging. Again a forward (nose-down) stick pressure is required to decrease the divergence. Thus, without the motion cue (pitch rotation and/or "g") there is a delay in initiating a response, and a less precise return to the original flight condition can occur.

Visual Factors

Control of real aircraft is not possible without visual cues. Even birds cannot maintain controlled flight when blind. The following visual factors are important to the pilot/operator:

- Optical quality—definition, resolution, texture
- Depth of field—focus
- Brightness and contrast
- Color—realism, registration
- Field of view (FOV)
- Dynamic perspective—motion smoothness, linearity
- Angular and linear limitation of display

This is a formidable list and no attempt will be made to prioritize these factors since the ordering is not generally known. An effort will be made to select those factors that are significantly different in operating an RPA compared to actual manned flight.

Foremost in visual factors is FOV, which is most important in approach and landing. In real aircraft the pilot has approximately 130 degrees of vision on either side of the flight path. In most visual systems used on RPVs, such as video, the FOV is limited to less than ±45 degrees. Experience has indicated that a wide FOV is desired to initiate turn entry from base leg to final approach, particularly when operating at high approach speeds.(1) A wider FOV is desired also when operating with low stability margins and when damping is low in pitch and roll. This can occur when operating at high altitude where air density is lower. As a result, control of flight path can deteriorate when FOV is restricted.

Another factor related to optical quality is texture, which is important for height judgment when operating near the ground. In real life, as the ground is approached, the resolution and definition of objects steadily improve. With most RPA visual (video) systems, visual clarity remains unchanged or deteriorates due to difficulty in obtaining an adequate depth of field inherent in the lens system of cameras. Realistic impressions of rate of closure and range may suffer also. Factors involved include retrieval disparity and convergence. In real life views of landing, near points exhibit retinal disparity while far points do not.

A common pilot complaint when operating without motion is that the visual scene appears to move past the aircraft, this being most noticeable in rolling maneuvers. It is a normal human reaction in the absence of proper cues to assume that when a viewed object is displaced relative to the observer, it is the object that has moved, not the aircraft. An adaptation to this disparity must be learned to achieve desired results in flight path control.

In summary, several features of visual information are of special interest relative to control when operating an RPV. The visual system—whether by instruments, video, or a combination—is the only source of reasonably accurate position information, without which controlled flight is impossible. Visual information can be multichannel, and in contrast to motion cues, it requires attention or concentration

Auditory Cues

Although less important for RPV operation, lack of auditory cues can be a source of pilot stress and make the environment unrealistic. In addition to creating realism, auditory cues can be helpful as a substitute for missing cues, primarily motion. In takeoff and landing, auditory cues alert the pilot/operator when the aircraft has left the ground or arrived on the runway, so that configuration changes can be made at the correct time. Engine noise can be a helpful cue to alert the pilot/operator that thrust changes for air speed control may be needed or to alert for an impending compressor stall.(2) Airflow noises are noticeable and useful in real flight, not only as a rough measure of airspeed, but also to indicate a breakdown of streamline flow to indicate incipient stall or direction and magnitude of side-slip angle.

RPA Operational Problems

Next, a brief review is made of operation of several RPAs where mishaps occurred that illustrate the importance of some of the human factors previously discussed. In each case emphasis is placed on "lessons learned" rather than finding fault for each mishap.

Raptor Aircraft

This RPA (see Figure 1) powered by a Rotax reciprocating engine was developed by the Scaled Composites Company in Mojave, California, as an intermediate altitude long-duration vehicle primarily for reconnaissance missions. The vehicle operated from a typical ground station with several operators to provide long-term endurance capability. Takeoff and landing were conducted by manned operation using direct visual inputs at the ground station. There was no onboard video down link. In cruise flight, attitude was controlled by two separate, but not completely redundant, autopilot control systems. The flight control system (FCS) used a variety of support systems including navigation computers, transponders, data down link transmitters, etc. The key components of each FCS were a vertical gyro and a flight control computer. The pilot/operators in the ground station had controls to switch between "A" and "B" systems.

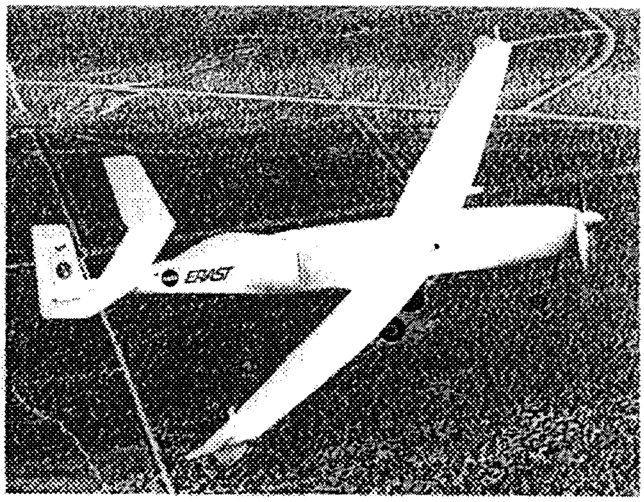

FIGURE 1 - Raptor Aircraft

The RPA crashed in the desert close to the GCS while in its 32nd hour of a planned 60 hour endurance demonstration mission. The following is a summary of events. The vehicle had experienced "noise" and dropouts in the down link data in the first day with the B system. The B system was only used occasionally to check wing fuel transfer status. On the first day of operation, the switchover worked satisfactorily.

The second time the B system was selected, the attitude indicators at the ground station "froze." After 16 seconds, the pilot switched back to the A system to regain accurate attitude display information. In spite of the disparity that had occurred, the crew elected to continue the flight with the A system to avoid a night landing. The next morning a switchover to the B system was made with no problems in the transfer.

The flight then continued on the A system until nightfall approached, at which time a switchover to the B system was made to check again fuel transfer status (equal fuel load in left and right wing fuel tanks). After selection of the B system FCS, the pilot in command (PIC) noted that the horizon bar indicated a rapid left roll. Assuming that the display was receiving "bad" data, a switch back to the A system was ordered. The displays locked up at this time and no down link signal was received for either channel to indicate vehicle status. Following emergency checklist procedures, local air traffic control (ATC) was contacted requesting information on the location of the vehicle. ATC said there was no aircraft signature on their radar screen. The PIC then ordered activation of the flight termination system hoping to safely recover the RPA by parachute. Unknown to the GCS crew, the vehicle had departed from controlled flight and was destroyed by ground impact.

The sequence of events leading up to the crash is the following: When the pilot switched to the B system, erroneous attitude information was given to the FCS because of a faulty bearing in the vertical gyro. As a result, a violent roll departure occurred and in attempting to return to "trim" (1 g) flight, wing structural failure occurred due to excessive g loading.

This example points out several problems related to human factors previously discussed. Foremost was the lack of information needed for a status check of both the A and B systems. When the operator first received information that the B system was faulty, no attempt was made to determine why, since a good A system was available. What was lacking in the information logic loop was the seriousness of a potentially large attitude departure from wings level flight and the consequences of trying to recover using the "good" A system. In addition, the operator accepted the need to check fuel load asymmetry even though that required switching to a faulty gyro system. The point to be made is that if a system is so critical that redundancy is required, flight rules should require the mission to be aborted as soon as safe landing can be made. In addition, a clearer understanding of limits on survivable attitude excursions using a video down link is necessary to help avoid a "point of no return" situation.

Perseus A Aircraft

A second example of RPA operation resulting in an accident has the following scenario. The Perseus A (see Figure 2) was being flown on its 16th mission by its builder, Aurora Flight Sciences Corporation, under contract to NASA. The flight plan included the intention to climb to an altitude over 50,000 feet to establish a new altitude record for RPA operation. Because of large turbulence levels and poorer-than-expected rate of climb at 36,000 feet, a crew decision was made to return to base in a normal glide (engine power reduced) at Edwards Air Force Base, California. Shortly after gliding flight commenced, the onboard video camera showed yawing oscillations and uncontrolled pitch changes. As a result, the flight director ordered all the autopilots turned off except for the airspeed hold autopilot. Sixteen seconds later, while in descending flight, the aircraft experienced moderate up-and-down pitch excursions and then a large roll-off from which the aircraft appeared to recover. Next the aircraft was observed to pitch down more steeply, increasing airspeed to a point where dynamic pressure was large enough to cause wing failure. The flight termination system was activated and the aircraft descended by parachute in a level attitude to the ground.

From the human factors standpoint, the loss of the aircraft resulted from a lack of information needed to establish the true state of the aircraft. When the aircraft was observed by the onboard video camera to depart from controlled flight, the autopilots were turned off under the assumption that a vertical gyro failure was causing the problem. However, because of a lack of information on the magnitude of upset, the airspeed hold autopilot was turned back on with the hope that airspeed would not increase sufficiently to cause structural failure. This was faulty reasoning because the airspeed autopilot also received its "hold" information from the faulty vertical gyro.

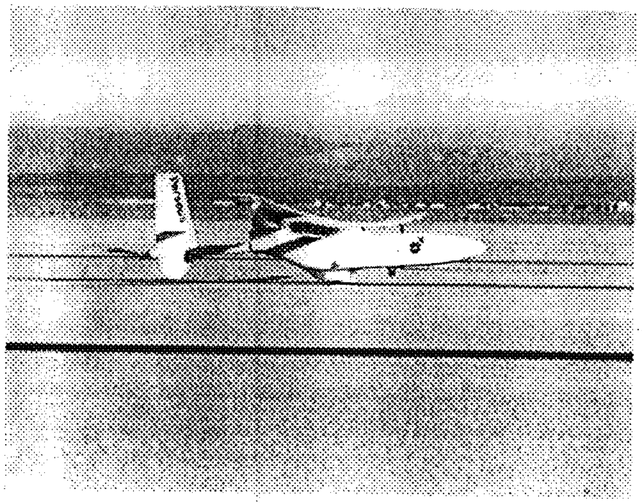

FIGURE 2 - Perseus A Aircraft

In summary, from the human factors standpoint, the ground crew did not have enough information from current or past experience to understand the absolute need for a stable vertical gyro reference. It is doubtful that the aircraft could be safely controlled manually in turbulence at high altitude when inherent angular rate damping is greatly reduced.

Perseus B Aircraft

Another example of an RPA accident relating to human factors errors is discussed next. The aircraft, a Rotax engine propeller-driven vehicle, was constructed and test flown by Aurora Science Corporation. The Perseus B aircraft (see Figure 3) had been flying about two hours on a test flight at Edwards AFB when loss of thrust resulting from a failure in the propeller drive shaft prompted a forced landing. Following normal emergency procedures, the engine was shut down and the airspeed hold autopilot was turned off for landing. The RPA was being flown over Rodgers Dry Lake, a hard surface sandy area routinely used for test flights. The plan was to glide to the concrete runway adjacent to the lake bed. However, because of the less-than-expected glide performance, the aircraft could not reach the runway and had to be landed on the lake bed. A "hard" landing sheared off the nose and main gear, and the aircraft slid to a stop on the fuselage with only moderate damage.

This mishap clearly illustrates a lack of good "situation awareness" and reasoning. First, when thrust was lost at 17,000 feet near the lake bed runway, the crew was content to plan for a normal "dead stick" landing, even though this

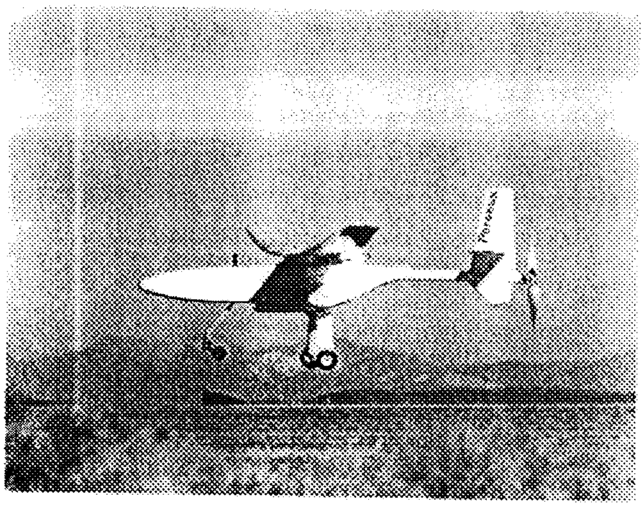

FIGURE 3 - Perseus B Aircraft

had not been done before. There were two factors in the chain-of-events loop that would interfere with and block correct action in the "motor loop" for a satisfactory approach and flared landing. First was the fact that the windmilling propeller in the cruise pitch setting resulted in a very high drag (low lift-to-drag ratio) condition that increased rate of descent such that a glide to the runway could not be made. The crew was not aware of the true rate of descent because of a system design error. The digital rate of descent display had reached a limit value of 1000 feet per minute. In addition, approximately three minutes from touchdown, the crew (pilot) inadvertently turned off the airspeed hold autopilot, which in the control loop limited the amount of nose-up pitch control available.

From the human factors standpoint, there are three areas in the motor control loop that should be examined: The pilot must (1) have a clear mental image of the required approach and landing geometry (perspective), (2) mentally compute the time and distance required to make the necessary flight path angle changes, and (3) perform an execution phase to position the aircraft for a safe touchdown. With these points in mind, consider the following: The pilot did not fully appreciate and understand the seriousness of the drive shaft failure. The brain was content to assume that from 17,000 feet enough altitude and airspeed could be made available to allow a safe flared landing. What was missing in the stored brain memory circuit was information which would indicate that the restricted amount of nose-up pitch control may not be enough to flare the aircraft when the rate of sink was unusually high. Finally, full nose-up pitch control must be available at all times to deal with an unknown flight path angle change requirement. Had the true conditions been rationally evaluated, the action part of the control loop would have been successful.

Concluding Remarks

In the foregoing, certain aspects of RPA operation have been reviewed to provide a better understanding of the human factors interface related to improving safety and utility of these vehicles under remote operating conditions. Understanding the use of sensory cues and the interaction between cues is very important to obtain satisfactory pilot/operator behavior. Of the various sensory cues available to the pilot, visual factors either from onboard instrumentation or by a video down link are most important to avoid loss of control. Next, lack of information regarding vehicle state and a clearer understanding of allowable attitude excursion limits can help avoid a "point of no return" situation. In the mishaps reviewed, limited or incomplete information resulted in poor situation awareness with a resultant loss of control.

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