Haptically Enhanced Emergency Recovery Operations

General Aviation Safety

Team Name: H.E.R.O.

Supporting Academic Institution
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA 0213

Contact Information:
michaelh@mit.edu
Michael Heiman
516-524-4553

Supervisor Contact Information:
Col. Peter W Young
pwyoung@mit.EDU
(617) 253-5340

Massachusetts Institute of Technology
Room 33-240
77 Massachusetts Avenue
Cambridge, MA 02139

Team Members [1]
Isabel Bernal, Junior, Aerospace Engineering, Human Factors and Outreach
Michael Heiman, Junior, Aerospace Engineering, Project Manager
Craig Morales, Senior, Aerospace Engineering, Hardware Design and Construction
Bo Shi, Sophomore, EECS, Software Development and Integration

[1]Thanks to Col. Peter Young, Dr. Conrad Wall III, Dr. Jeffrey Hoffman, Kathy Sienko, Franck Billarant, Dr. Braden McGrath for all their help.

Abstract

In unstable flight, especially in instrument flight rules (IFR) conditions, pilots must trust their instruments to make a safe recovery. In a standard general aviation aircraft, these instruments are visual in nature. The artificial horizon, altimeter, vertical speed indicator, and heading indicator must all be individually scanned by the eye and then interpreted by the pilot before action may be taken. In unstable flight, when the vestibular and somatosensory systems may provide false information regarding the direction of gravity, while visual cues convince the pilot that he or she is flying right-side-up, this process may prove to be difficult, if not impossible.

The purpose of this project will be to study the effects of haptic display integration on unstable flight recovery. Test subjects will be required to recover from simulated unstable flight conditions in micro-gravity with varying levels of haptic interface to their flight instruments. The purpose of micro-gravity is to safely recreate the disorientation experienced by a pilot during unstable flight.

Contents

4 Hypothesis

A novice pilot who finds him or herself flying in IFR conditions can become spatially disoriented when attempting to perform emergency maneuvers. A haptic feedback system will augment the information provided by the pilot's visual instruments and enhance the pilot's ability to recover to a desired flight condition.

5 Purpose of Research

The purpose of conducting this experiment in micro-gravity is to safely recreate the disorientation experienced by a pilot during unstable flight. Use will also be made of the intervals in which the test subjects will experience 2Gs of gravitational acceleration, again to simulate the extreme environment of unstable flight.

5.1 Background

5.1.1 Spatial Disorientation

Humans obtain information about their position and motion with the aid of the central nervous system. The central nervous system works by integrating redundant information from multiple sensory channels (visual cues, vestibular system, and the somatosensory system) and combining them into a single accurate reading of the surroundings. In the accelerated environments faced by pilots these systems may provide a false sense of what is actually happening. For instance, the vestibular and somatosensory systems may provide false information regarding the direction of gravity, while visual cues convince the pilot that he or she is flying right-side-up (varying gravitoinertial force fields can produce visual illusions of motion and position). Given these adverse situations and conflicting information, it is normal for a seasoned pilot and even more so for a novice to experience disorientation. For this reason, it is desirable to test a tactile interface that acquires veridical information about roll and pitch through a gyro-stabilized attitude indicator and then clearly maps this information onto the torso of the test subject using a matrix of tactile vibrators, or "tactors". This device will allow the test subject to be continuously aware of the aircraft's attitude without the aid of visual cues and by using a sensory channel that normally only works on the subconscious level. Although originally developed to aid pilots, this device has many other possible applications, such as: simulation and training, non-visual tracking of targets, environments where there are minimal somatosensory cues (diving) [7], environments where there are minimal gravitational cues (space), patients with problems in the vestibular system, and patients recovering from ablative inner ear surgery.

5.1.2 Effects of Spatial Disorientation on Pilots

Spatial disorientation has been identified as a major cause of accidents in both civil and military environments. Surveys indicate that 4 to 10% of Class A mishaps and 10 to 20%

of fatal accidents over the past 30 years and spanning all branches of the United States military were directly caused by spatial disorientation (SD) [6]. The United States Air Force alone calculates an average cost of $140 million per year due to SD [1]. A non-visual method of conveying aircraft attitude information is desirable, especially in the military environment where a pilot's attention is divided among a multitude of tasks.

Spatial disorientation has remained largely a military concern over the past half-century. This situation stems in part from the fact that only 2.5% of all civil aviation accidents are caused either directly or indirectly by spatial disorientation [2]. This statistic is misleading, however, and the true dangers of SD come to light when examining fatal aviation accidents in particular. According to a 1978 study of National Transportation Safety Board (NTSB) records from 1970 through 1975 [2], 90% of all accidents that were caused, entirely or in part, by SD were fatal. The same study also found that SD is the third leading cause in all fatal accidents (16%), after failing to maintain/obtain flight speed (26.3%), and initiated or continued visual flight rules (VFR) flight into adverse weather (22.2%). Furthermore, SD was found to be closely associated with accidents caused by continued VFR flight into adverse weather.

An important result of this study is that it indicates that 85% of all fatal accidents that in some way involved SD also involved non-instrument-rated pilots. These pilots were unable to react properly when the information given to them was based solely on visual instrumentation. It is clear that any device which improves the ability of a pilot to fly under IFR conditions could potentially reduce a large portion of the fatalities due to SD.

A final vital piece of information that results from the aforementioned study, is that far more SD related accidents occurred in small fixed-wing aircraft than in any other type of civil flight vehicle. For this reason, the current experiment was designed around the piloting of a small fixed-wing aircraft.

5.1.3 Standard Recovery Procedures

This study will attempt to use recovery performance as a measure of pilot ability. Two of the most common unstable flight conditions are stalls and spins.

Stall occurs when an aircraft reaches its critical angle of attack. At this point, airflow over the wings becomes turbulent, and lift is dramatically reduced. Control surfaces become ineffective, and if proper action is not taken, a spin may develop. Four types of stalls commonly practiced in General Aviation training are power off, power on, accelerated, and crossed-control [13]. Power off stalls simulate a stall on approach and landing, while power on stalls are taught to simulate a stall on takeoff. Accelerated stalls refer to stalls at higher airspeeds than usual, and crossed-control stalls are associated with cross-controlled conditions: rudder opposite aileron. Cross-controlled approaches are commonly used in cross-wind landing conditions.

According to the Jeppeson Private Pilot's manual, stall recovery consists of three steps:

1. Decrease angle of attack

2. Apply throttle

3. Recover and adjust power.

If stalls are not corrected in a timely manner, a spin can develop. Described by Jeppeson as "an aggravated stall which results in the airplane descending in a helical, or corkscrew, path," spins are more dangerous and more difficult to recover from than stalls. Spins develop when wings are unevenly stalled. The wing with less lift drops before the other, and the nose tends to yaw towards the stalled wing. stalled. The wing that is creating less lift will drop before the other, and the nose tends to yaw towards the stalled wing.

Spins are the result of uncoordinated flight, which is often caused by pilot distractions. According to Jeppeson, preoccupation with situations inside or outside the cockpit, maneuvering to avoid other aircraft, and maneuvering to clear obstacles during takeoffs, climbs, approaches, or landings" can initiate spins.

There are three types of spins:

1. Erect: yaw and roll in the same direction

2. Inverted: yaw and roll in opposite directions

3. Flat: yaw only

The flat spin is the most dangerous because it allows for the least flow over aircraft control surfaces. As a result, recovery is difficult if not impossible. Fortunately, this maneuver does not usually apply to general aviation aircraft because of center of gravity location and weight and balance considerations.

There are three phases of a complete spin maneuver. The first is the incipient spin. This is the time between a stall and fully developed spin when the aircraft has an increasing rate of rotation. The second phase is a fully developed spin which is characterized by constant rates of angular rotation, airspeed, and vertical speed. A typical rate of altitude loss for a small, general aviation aircraft in this phase is 500 feet per 3 second turn. The third phase of a spin is recovery; forces are applied to stop the spin, rotation and angle of attack decrease, and stable flight is achieved. In a general aviation aircraft, recovery should take place in 1/4 to 1/2 of a turn.

The Jeppeson steps for spin recovery are as follows:

1. Idle throttle

2. Neutralize the ailerons

3. Determine direction of rotation (use turn coordinator)

4. Apply full opposite rudder.

5. Elevator- neutral to full forward (depends on aircraft)

6. Rotation stops-neutralize rudder.

7. Elevator- gently back and level off

5.1.4 Medical Applications

Dizzyiness and disorientation are caused by problems with the human vestibular system. Statistics have shown that 6.2 million Americans report chronic dizziness [12]. Medical causes of vestibular disfunction include congenital defects, ototoxic drugs, injury, disease, ablative surgery of the inner ear, and the decay of the vestibular system due to age [12]. Another well documented cause of disorientation is gravitational variation.

The otolith organs that comprise the inner ear work like a "carpenter's plumb" in the sense that they keep track of the total sum of accelerations acting at any given time [14]. As a result, they cannot distinguish between the effects of gravity and induced forces due to linear acceleration.

Disorientation is gravitational variation. The human vestibular system actively accounts for the force of gravity in a 1g environment. In the microgravity environment of space, this substantial force vector is removed, and the vestibular system usually takes 3-5 days to adjust. On re-entry, the problems of disorientation can resurface. Professor Charles Oman, director of the M.I.T. MVL, states:

> As the force of gravity reasserts itself, crew members discover that normal head movements now cause a prominent vertigo. Shuttle pilots must be particularly cautious while flying the vehicle manually. Some find that tilting their head to one side produces an illusion of translation in the opposite direction, exactly what one would expect if they had learned to interpret otolith cues as indicating acceleration rather than tilt. [5]

In order to replace lost vestibular function, researchers are developing prosthetic devices. There are two kinds of vestibular prosthesis on the drawing board: implantable and non-invasive. Implanted devices directly stimulate the central nervous system, with the added advantage of replacing lost vestibular function [12]. The inherent risks of surgery, however, give added appeal to non-invasive methods such as a vibrotactile display. The non invasive measures, however, will not serve to cure the symptoms of vestibular disfunction. Rather, they can provide cues that bypass their vestibular systems to help patients maintain balance. In this manner, vibrotactile displays are comparable to the walking dogs that commonly assist the blind.

5.1.5 Previous Research

A wide array of solutions have been investigated in order to compensate for vestibular illnesses, ranging from subsensory mechanical noise applied to the feet [8] to an array of electromechanical tactors that is worn around the waist [10], to proposals for balance prostheses that will bypass the faulty vestibular organs and send balance information directly to the brain [9]. One of the reasons for tactile feedback's popularity is the fact that it acts on a relatively low level of consciousness, which allows for a fast response from the body. It is for this reason that the current experiment is being conducted using tactile feedback.

Research into the application of tactile feedback to military piloting has been performed for several years through the Naval Aerospace Medical Research Laboratory (NAMRL) located in Pensacola NAS, FL. Specifically, the design of a haptic feedback device which provides aircraft attitude information to the pilot has been developed and flight tested [3]. The device used was a vest covered in electromechanical tactile motors, or tactors, which was worn beneath the pilot's flight suit. Results included the ability of a pilot to fly a loop while deprived of vision outside of the craft, and using only the feedback system as an instrument. Other applications that were explored included the use of a tactile feedback system as a non-visual targeting system. NAMRL's research continues with investigation into the use of electromagnetic tactors located in the aircraft seat and seat back, and other possibilities for size reduction of the haptic system.

The search for better interfaces between pilot and craft has been going on since the beginning of flight and continues even now. National Research Council, Canada's Flight Research Laboratory, is studying the effects of different attitude indicator shapes and layouts in an attempt to find better unusual attitude recovery systems [4]. This is just one of a vast number of approaches that can be used to help solve the problems associated with spatial disorientation.

5.1.6 Other Applications

Prolonged exposure to microgravity impairs basic human functions that aid in posture, gaze, and balance. Other negative side-effects of space flight are re-entry and landing vertigo, severe space motion sickness, and in-flight spatial orientation. The cause of all these unfavorable reactions can be closely linked to problems with the visual, somatosensory, and vestibular systems. Therefore, a possible use for a tactile interface is as an aid for astronauts that are experiencing some or all of the symptoms described above.

A possible application of haptic feedback that is being explored by NAMRL is for Navy SEAL divers. In this application, feedback was used to guide a diver through a predefined course in shallow water conditions [7]. The diver was given a tactile warning each time he deviated from the course. Not only was the diver able to navigate the course more easily, but he was able to do so while a strong current was added to the simulation. This application has possibilities for application in rescue and recreational diving.

5.2 New Information Expected

NAMRL's research is focused on experienced naval pilots. This experiment will build on their work by testing the applications of the technology in other areas, especially to determine the usefulness of haptic feedback for relatively inexperienced civilian pilots. Ground based trials (with and without forced disorientation) will provide information that can be compared with in-flight data.

6 Statistical Analysis

Flight data will be logged into an Excel importable text file. The flight simulator will feed the data to the log file during each trial for later analysis.

Particular interest will be taken in the following values:

recovery time the time required for the test subject to fly the plane into final specified flight conditions

change in altitude the loss or gain of altitude while performing recover maneuvers

error between final flight conditions and final specified flight conditions

RMS of pitch and roll

The number of test subjects will be either 2 or 4. Selection will be based on:

1. Difficulty of switching test subject with investigator in flight
2. Subject Pilot Skill
3. Demonstrated subject Piloting Consistency

7 Rationale for use of Human Subjects

Human subjects are required for this research study to test the haptic feedback device in order to determine how it enhances pilot ability to recognize and recover from unstable flying conditions. In order for the data to be useful and applicable to the hypothesis, testing must be performed on human subjects.

8 Research Plan and Schedule

8.1 Objective

The main objective of this research is to evaluate the effects of a haptic feedback system on the emergency response performance of an novice pilot.

8.2 Specific Goals

The experiment is designed to allow a quantitative analysis of the pilot's performance with a haptic feedback system versus his or her performance without one. Specific performance measurements will include recovery time, loss of altitude, and the root mean square values of the aircraft pitch and roll. Special interest will be taken in the recovery time and the root mean square values, as they are the most direct measurements of the pilot's performance.

8.3 Simulator and Feedback System Training

Both the test subject and the test controller will require training before they will be able to perform any trials. The test subjects will need to be familiar with the flight simulator interface and will have to be experienced enough pilots that they are comfortable flying in VFR conditions. The controller will require training and experience working with the interface that will be created with the flight simulator. They will be responsible for setting up each adverse condition and for beginning the data collection for each trial. Due to the time restraints while on board the KC-135, the controller will have to be able to set up each new trial within a few seconds of the previous one. This ability will require much practice on the part of the controller. Also during the experiment the controller will be responsible for the safety of his or herself and that of the test subject.

Both the controller and the test subjects will require training in the use of the haptic feedback system, both for ease of use and to avoid possible injuries due to the system.

8.3.1 Data Collection

Preliminary data collection will include an evaluation of each potential test subject's baseline flight abilities, an evaluation of the haptic system, and a comparison of ground-based disorientation techniques. Test subjects will be selected in part according to their basic flight abilities. Desired subjects have enough experience to comfortably fly in VFR conditions, while being inexperienced enough that they are not IFR qualified. It is believed that subjects of this level of ability will benefit the most from a haptic feedback system.

The exact haptic system that will be used has yet to be determined. It is possible that a tactor vest can be obtained through the generosity of the Naval Aerospace Medical Research Lab. If so, the vest will require testing to ensure that it is in proper working order and has not suffered any damage during transport. Also, it will be desirable to know the exact response characteristics of the tactor system. If the vest cannot be borrowed from NAMRL, a device will be constructed using low-cost pager motors. This unit must comply with all safety regulations outlined in the TEDP in order to ensure adequate safety.

Finally, several disorientation techniques will be researched and compared in order to select the method most appropriate for the ground-based disoriented trials. Advice on and equipment for these techniques may be obtained through the Massachusetts Eye and Ear Infirmary and the M.I.T. Manned Vehicle Laboratory.

8.3.2 Pilot Training

The purpose of this experiment is to determine the influence of a tactile feedback system on the performance of VFR qualified pilots. Therefore, it will be necessary for all team members to take a private pilots ground school course or its equivalent. All test subjects will receive at least 40 hours of simulator training, corresponding as closely as possible to lessons in an FAA certified course.

Activity	Date	Duration
COUHES Application Due	October 30	Milestone
COUHES Review Date	November 20	Milestone
Build & Test Hardware	January	1 Month
Baseline Data Collection	January	3 Months
MVL Testing	March	1 Month
Outreach	January	7 Months

Table 1: Tentative schedule for the next few months

8.4 In-Flight

8.4.1 Simulation Procedure

One test subject and one controller will be on each flight. The controller will set up each simulation and troubleshoot any problems that may occur. For each simulation, the controller will instruct the test subject of the desired final flight conditions. The software will handle all logging of flight data and time data. The test subject will inform the controller when (s)he believes that the task has been completed and the controller will then kill the timer and simulation and move on to the next simulation.

8.4.2 Videotaping Plan

Subjects will be videotaped along with the controller throughout the course of the experiments. For ground testing, this will exclude possible time spent on a centrifuge or any other device meant to cause disorientation in the test subject. While on-board the KC-135, videotaping will last for the entire duration of the experimental portion of the flight. The videos will provide an extra source of information regarding the reactions of the test subject. This plan is tentative and may be reduced to videotaping only certain trials under each test condition due to the cost restrictions of taping a large number of preliminary trials.

8.5 Research Plan and Schedule

8.5.1 Dates and Milestones

Table 1 shows the proposed activity schedule.

8.5.2 Subjects

This experiment will be using two subjects between the ages of 19-22 who are members of the M.I.T. flight team. Screening for eligibility will take place during the baseline data collection period of the experiment. The two test subjects will have to be proficient using the flight simulator. In order to determine proficiency, each team member will be trained in using the flight simulator and then tested by the other team members and advisors. This experiment is designed to help novice pilots: it would be useless to use test subjects not apt to fly properly. Another screening will take place during the baseline testing regarding motion sickness. All four team members will undergo several runs on the MVL (Manned Vehicle Lab) facilities centrifuge at M.I.T.. The team members that can best perform better under these conditions and who give the most consistent flight data will be chosen as the test subjects. It is understood that there is no direct correlation between motion sickness induced by ground based techniques and the KC-135. However, the team feels that data derived from ground tests in the centrifuge will still be a viable measure of a team members' potential as a test subject.

8.6 Facilities and Performance Sites

M.I.T. All equipment will be built/prepared at M.I.T.. Once this has been completed, baseline testing will begin.

MVL Facilities at the MVL will be used to perform disorientation procedures to further conduct the baselines testing described in section 8.0.

JSC We will purchase a chair and assemble all the pieces and run mock experiments to ensure everything is running smoothly. In flight experiments will take place at this facility.

8.7 Data Privacy and Confidentiality

All in-flight recorded data will be stored in text format on the laptop and will only be accessible by investigators and collaborating parties. Any information identifying the test subject will be stripped from the data. All data will ultimately be stored at M.I.T. in the Andrew File System. This information will not be shared without written consent from the test subjects. When this study has been completed, all data will be archived.

8.8 Injury and Anonymous Data

All subjects will be monitored for at least 24 hours after all tests for adverse effects. If deemed necessary, medical attention will be requested without hesitation. In the event of unexpected medical conditions resulting from this study, COUHES (the Massachusetts Institute of Technology Institutional Review Board) will be informed through their office. Contact information is: (617) 253-6787, mede@med.mit.edu.

9 Experimental Protocols and Equipment

9.1 Equipment and Protocol Design

Equipment that will be obtained 'off the shelf' will be the laptop and the controllers for the flight simulator. These include a joystick, throttle, rudder pedals and an accelerometer and a chair to mount the controls for the flight simulator. The two pieces of custom equipment are the software and the haptic system.

Two options exist for the flight simulator. We are leaning toward the use of FlightGear as the simulator to customize for our purposes. FlightGear is a mature Open Source flight simulator. Furthermore, as an open source project, it allows the team greater flexibility and access to all the flight telemetry data. Modifications to FlightGear to make the simulation dump flight data to standard out have been completed as a proof of concept. Microsoft Flight Simulator is the other option. Microsoft has a better graphics engine and the scenery in the simulation looks better. Unfortunately, we have no access to Flight Simulator source code and would require other programs such as FSUIPC to extract the data out of the simulation. FlightGear provides us with a cleaner solution.

NAMRL has given us access to quite a few models of their vests. The vests have an update rate of around 100hz; this is more than enough for use in real time. Their better models use a mixture of pneumatic and electromagnetic tactors. One of their main challenges has been managing the weight of the tactors. As a consequence, they have integrated the tactile feedback systems into the cockpit rather than on the uniforms of the pilots in some models. There are 3 or 4 full body suits each containing a 12x6 grid of tactors on the suit. Their underarmor suits (made of lycra or some other compression material) use pager motors, which are much cheaper than the pneumatic or electromagnetic tactors used in the flight systems and the lab systems.

We have opted to attempt to build our own haptic vest because the process of doing so would be very educational and because we would be able to more effectively troubleshoot any last minute problems that may come up. Troubleshooting in particular would be difficult with third party hardware such as what NAMRL has offered – never the less, NAMRL has kindly offered to advise and collaborate with us in building the vest. Should we encounter major problems, we will fall back to using a loaned vest.

A pager motor system will be used to generate haptic feedback due to the relatively low price of pager motors. The vest will be assembled from some close fitting garment (such as a wet-suit or shark-suit). After the wiring and circuitry has been completed for the tactors, they will be sewn onto the vest.

The vest and simulation will communicate via a standard serial port (EIA232 standard, previously called RS232) communication. EIA232 is quite an old protocol, but it supports everything necessary for simulation/vest communication. Newer protocols such as USB were considered, but we did not require the multitude of features and furthermore, those features complicate the programming of the vest's controller and the simulation code considerably.

9.2 Samples

No samples will be collected, biological or otherwise.

9.3 Procedure

In order to test the hypothesis each test subject will be asked to recover from an unstable flight condition to a specific recovery condition. Once the subject reaches what he or she believes is the recovery condition, he or she will end the simulation. Each unstable condition will be flown twice, once with the aid of the haptic system and once without it. Conditions will be encountered randomly in order to avoid the possibility of the subject improving his or her performance through repetition and practice. As a control, one flight condition will be straight and level flight. Flight data including aircraft attitude, altitude, heading, and simulation time will be recorded continuously throughout each flight.

The experiment will proceed as follows:

1. Test subject is disoriented either forcibly (ground-based) or by exposure to changing gravitational conditions (KC-135).

2. Controller specifies an unstable condition and a desired recovery condition and initializes the simulation.

3. Test subject recovers to what he or she believes is the specified recovery condition. Once in this condition the subject ends the simulation by pressing a preassigned key or button.

4. The controller specifies a new condition and desired recovery condition and initializes the simulation.

5. Steps 3 and 4 are repeated until all of the trials have been run.

9.4 Pre-Flight Training and Baseline Data Collection

Preflight training will include instruction in the use of the haptic system for regular flight in order to allow the test subjects time to grow accustomed to the system. Once each test subject is proficient in the use of the haptic system, trials will be run without disorienting the test subjects. An initial number of 5 to 10 adverse conditions will be tried by an initial number of 4 test subjects. Each subject will fly a total of 40 repetitions of each adverse condition, 20 without the haptic system, and 20 with the haptic system. This initial data will allow the number of adverse conditions to be reduced, according to the repeatability of the results from each condition.

Subjects will then proceed to run the trials using the chosen adverse conditions after being forcibly disoriented. Again, each subject will fly 20 repetitions of each adverse condition while using the haptic system, and 20 repetitions without it. This extra data will help to broaden our statistical analysis by adding repetitions, and will again aid in choosing only those adverse conditions which provide the most repeatable and consistent data. Only these conditions will be run while on the KC-135, due to the time constraint.

One more result of this preliminary data will be to narrow down the number of test subjects to 2. Only these subjects will fly the simulations while on-board the KC-135, again due to limited flight time. The subjects will be selected based on the consistency of the data that they provide and also based on their ability to sustain repeated disorientation.

9.5 In-Flight Data Collection

Simulation parameters will be determined before the flights begin. See section 9.4 for details.

We will have a total of 40 periods of 0G and 40 periods of 2G available to us. We should be able to run *at least* one simulation during each of those periods. There will be two test subjects, one per day, so each test subject will be able to run through at least twenty simulations in 0G and 2G situations.

10 Safety Reviews, Hazard Analysis, and Safety Precautions

10.1 Safety Review Procedure

10.1.1 M.I.T. COUHES

The Massachusetts Institute of Technology's Institutional Review Board, the Council On the Use of Humans as Experimental Subjects (COUHES), regulates all M.I.T. related research that involves the use of humans as subjects. The council holds monthly meetings to review all applications for human research. For studies that involve minimal risk, annual renewal is required. All investigators involved in a study are required to take and pass a training course that covers the ethical and legal guidelines for human subjects studies.

COUHES also requires that IRB approval be issued from all collaborating institutions. This means that full COUHES approval is dependent on both the Reduced Gravity and Navy Institutional Review Boards accepting the terms of this proposal.

10.1.2 NASA Approval

As outlined in the Samples and Examples document provided from the RGSFOP web page, there are multiple steps involved in getting approval from NASA. The first occurs in the proposal stage, where hardware and safety are evaluated by Ellington Field Test Directors. Projects are rated either Red, Yellow, or Green. Projects that receive a Red rating are ineligible for the program. Yellow rated projects must correct indicated safety issues or risk being permanently grounded. In addition, the CPHS will examine proposed hardware and report any unanticipated safety issues.

A Test Equipment Data Package (TEDP) will be submitted no later than April 9, 2004. The purpose of this document is to provide Test Directors a final description of test hardware and protocols. JSC safety rules and guidelines, outlined in the TEDP Requirements Guidelines AOD 33896 document, will be followed.

On arrival at Ellington Field, equipment will be inspected by test directors and compared to the submitted TEDP. All relevant JSC organizations will review the experiment and ensure its compliance to regulations. On the Monday of flight week, the experiment will undergo a final Test Readiness Review. Flight test clearance is dependent on passing this final review.

10.2 Hazard Analysis

10.2.1 Structural Hazards

Hazard Number 1 Title : sharp edges/edges/protuberances

Description : Subjects and Investigators may come into contact with sharp edges, protrusions, and protuberances that can cause abrasions, cuts, lacerations, bruising, punctures, and penetrations.

Cause(s) :

- Exposed sharp edges on experimental equipment
- Equipment not properly secured

Control(s) :

- Eliminate sharp edges with a durable blunting material
- Preflight inspect for loose objects and missed sharp edges

Hazard Number 2 :

Title : Pinch Points

Description : Investigators' and subjects' extremities may become caught in pinch points, leading to crushing injuries.

Cause(s) : Exposed and improperly designed joints and latches are potential pinch points.

Control(s) : Experimental equipment will be designed to minimize pinch points. If it is necessary to include a potential pinch point, it will be clearly labeled with a warning.

Hazard Number 3 :

Title : Inadequate Design/Structural Failure

Description : If the haptic system is incorporated into a seat/harness setup, inadequate design could result in structural failure. Test equipment would be lost, and test subject would be at risk of injury. In addition, structural failure could result in components becoming free and interfering with neighboring projects.

Cause(s) :

- Improper calculation of expected stresses and strains
- Lack of an adequate safety margin
- Use of materials weaker than required

Control(s) :

- Adequate safety margin incorporated into design
- Incorporate off-the-shelf flight proven hardware as the main load bearing structures
- Preflight simulation of expected flight stresses to verify structural integrity.

Hazard Number 4 :

Title : Wire entanglement

Description : Multiple sets of cables are required by the current experiment design to power and operate the tactile feedback system. Loose lengths of wire may become entangled with each other, test equipment, subjects, and investigators. Entanglement may create excess stress on the wires, which could cause fracture, thereby creating a potential shock hazard.

Cause(s) :

- Wires not bundled, clamped, and secured properly.
- Excess wire length.

Control(s) :

- Cables will be bundled and secured.
- The number of separate cable bundles will be minimized.
- A clearly marked emergency kill switch will be used in the event of an entanglement.

10.2.2 Electrical Hazards

Hazard Number 5 :

Title : Electrical Shock

Description : Subjects and investigators come into contact with surfaces at a significantly different electrical potential than their own. The resulting voltage gap induces a potentially harmful current through his or her body.

Cause(s) :

- Exposed control and power wires
- Improperly grounded equipment
- Overloaded power supply
- Use of improper wire gauge

Hazard Control(s) :

- All test equipment power will be run through a fuse or circuit breaker.

- Load tables, as described in document AOD 22896, will be completed for each electrical component requiring an external power source.
- Test equipment will be grounded to prevent charge buildup.
- Wire gauge will be selected based on maximum current expected.

10.3 Medical Safety Precautions

The proposed study will not require direct supervision from a physician. Test subjects will be performing relatively simple cognitive tasks that require no biological sampling, medications, or invasive procedures. As a result, there are no plans for physician supervision during or after the study other than test subjects' and investigators' regularly scheduled visits with their primary care providers.

Human subjects will not be permitted to take motion sickness medications, medications that cause drowsiness, or drink alcohol within 48 hours of any experimentation. These drugs may influence the performance of test subjects, thereby invalidating all comparisons to ground based tests and rendering results inconclusive.

11 Possible Inconveniences or Discomforts to Subjects

The microgravity inducing maneuvers performed on the KC-135 mission are intended to disorient test subjects. All subjects and investigators will be subjected to the symptoms of motion sickness, which may include dizziness, nausea, and vomiting. If an investigator chooses to take motion sickness medication, he or she may experience drymouth.

Test subjects may experience chafing and irritation from being strapped into test apparatus. This will be minimized by requiring subjects to wear adequate clothing and constructing the apparatus of non-abrasive material.

During the construction phase of the experiment, investigators will be required to sew tactors onto fabric. As a result, there is the risk of puncture by needles if care is not taken.

12 Extent of Physical Examinations

There will be no additional medical requirements beyond the standard physical exam. This experiment focuses on general aviation safety, and therefore all test subjects must be physically qualified to operate as a pilot-in-command of an aircraft. Subjects will be screened based on the required flight physical, so there is no need to include additional medical requirements.

13 Availability of a Physician and Medical Facilities

Experimental procedures are non invasive, do not require subjects to take medications, do not cause subjects significant physical stress, and do not involve the use of hazardous materials. As a result, the investigators feel that these procedures will not increase subjects' risk of medical problems. Therefore, this experiment is considered to be of Level 3 or higher.

14 Informed Consent

14.1 Layman's Summary

I have been asked to participate in a research study conducted by Col. Peter Young, from the Department of Aeronautics and Astronautics at the Massachusetts Institute of Technology (M.I.T.) I was selected as a possible participant in this study because of my participation on the M.I.T. Reduced Gravity Student Flight Opportunities Program Team. I must read the information below, and ask questions about anything I do not understand, before deciding whether or not to participate.

14.1.1 PARTICIPATION AND WITHDRAWAL

My participation in this study is completely voluntary and I am free to choose whether to be in it or not. If I choose to be in this study, I may subsequently withdraw from it at any time without penalty or consequences of any kind. The investigator may withdraw me from this research if circumstances arise which warrant doing so.

14.1.2 PURPOSE OF THE STUDY

In unstable flight, especially in instrument flight rules (IFR) conditions, a pilot must trust his or her instruments to make a safe recovery. In a standard general aviation aircraft, these instruments are visual in nature. The artificial horizon, altimeter, vertical speed indicator, and heading indicator must all be individually scanned by the eye and then interpreted by the pilot before action may be taken. In unstable flight, when the inner ear of an unseasoned pilot is veritably screaming that something is wrong, this process may prove to be difficult, if not impossible.

The purpose of this project will be to study the effects of haptic display integration on unstable flight recovery. Test subjects will be required to recover from simulated unstable flight conditions in micro-gravity with varying levels of non-intrusive haptic interface to their flight instruments. The purpose of micro-gravity is to safely recreate the disorientation experienced by a pilot in unstable flight.

14.1.3 PROCEDURES

If I volunteer to participate in this study, I will be asked to do the following things:

I will be subject to special disorientation on the ground in a centrifuge and on-board a NASA KC-135 flying microgravity and hypergravity inducing maneuvers.

While disoriented, I will operate a flight simulator using a yoke, throttle, and pedals. In addition, I will receive tactile stimulations via an array of pager-strength vibrators. These vibrations will indicate my simulated aircraft's pitch and roll. I will receive training on the use of this array prior to experimentation.

I will be asked to participate at various times between December 2003 and July 2004 for ground-based and in-flight training. I will receive ample notification of when my presence is required and have the right to refuse to participate for any reason at any time.

Trials will be run in a series of approximately 20 flight simulations at a time. Each case will take approximately 30 seconds to complete. The location of tests will vary between the M.I.T. campus, the Massachusetts Eye and Ear Infirmary, Johnson Space Center, and the Gulf of Mexico on board a NASA KC-135. There will initially be 4 test subjects, including myself.

There is no requirement for follow-up examinations or studies, and there will be no limitations of my physical activities after this experiment is completed.

14.1.4 POTENTIAL RISKS AND DISCOMFORTS

Motion sickness due to special disorientation is almost certain. Common symptoms include (but are not limited to): dizziness, nausea, and vomiting.

There is also the risk of equipment malfunction, which could result in electric shock. This risk will be minimized by taking all necessary safety precautions. These include operating all electrical equipment well within manufacturer specifications.

Finally, there is the slight possibility of KC-135 in-flight mechanical failure. The risk is minimal due to the professionalism and experience of the NASA Reduced Gravity Program pilots and staff as well as the excellent safety record of the KC-135.

14.1.5 POTENTIAL BENEFITS

The Naval Aerospace Medical Research Laboratory (NAMRL) Tactile Situation Awareness System (TSAS) is one of the most advanced forms of tactile display technology in existence. The military is their chief customer, and as a result NAMRL has focused on development for high-performance military uses such as target acquisition and tracking, helicopter hovering, and enhanced situational awareness.

According to a 1978 Aviation, Space, and Environmental Medicine article entitled "Spatial Disorientation in General Aviation Accidents", spatial disorientation is the third leading cause of fatal aviation accidents. As such, there is an established need to enhance pilots' ability to remain spatially oriented. NAMRL test results and pilot testimony indicate potential for the TSAS system to enhance pilot awareness, especially in poor meteorological conditions. However, these are test pilots with many years of experience. How well will a tactile display system, specifically designed for general aviation economics, work for an inexperience pilot who finds him or herself unexpectedly in poor weather?

The ultimate goal of this project is to improve general aviation safety. If investigation results in significant pilot performance enhancement, then we have added yet another tool in the ongoing pursuit of aviation accident prevention. Ideally, manufacturers will one day consider incorporating such systems into their products.

14.1.6 PAYMENT FOR PARTICIPATION

I will not receive payment for my participation.

14.1.7 CONFIDENTIALITY

Any information that is obtained in connection with this study and that can identify me will remain confidential and will be disclosed only with written permission or as required by law.

Flight Physicals will be released only to the Reduced Gravity Student Flight Opportunities Program (RGSFOP) staff.

In-flight tests will be recorded on video-tape. I understand that I will also be photographed, and I give my consent for both of these activities.

I will be given a numerical identification code which will be used to identify all test data. Test data will only be referred to by this ID.

All electronic data will be stored on a secure distributed file system provided by M.I.T., and only investigators will have direct access. My personal information will not be shared without my express written consent. If the secure file system becomes unavailable due to student investigators' inevitable departure from M.I.T., test data will be summarily destroyed.

If any other uses of my data are to be considered, I will be notified before any action is taken. My written consent for the sharing of any non-coded data will then be obtained.

14.1.8 IDENTIFICATION OF INVESTIGATORS

If I have any questions or concerns about the research, I am encouraged to contact Col Peter Young: Principal Investigator, pwyoung@mit.edu, or the student investigators, hero@mit.edu.

14.1.9 EMERGENCY CARE AND COMPENSATION FOR INJURY AT M.I.T.

In the unlikely event of physical injury resulting from participation in this research I may receive medical treatment from the M.I.T. Medical Department, including emergency treatment and follow-up care as needed. My insurance carrier may be billed for the cost of such treatment. M.I.T. does not provide any other form of compensation for injury. Moreover, in either providing or making such medical care available it does not imply the injury is the fault of the investigator. Further information may be obtained by calling the M.I.T. Insurance and Legal Affairs Office at 1-617-253 2822.

14.1.10 NASA LEGAL INFORMATION

There will be no additional wage, salary, or other remuneration of any form paid, given, or in any manner delivered to the test subjects of this investigation where the subjects are National Aeronautics and Space Administration (NASA) employees or NASA contractor employees, and the terms of the contractors with NASA provided for participation as subjects in approved experiments.

If the human research subjects are NASA employees, NASA contractor employees or independent contractors, and the training/testing is part of their employment or contractual circumstances, NASA is responsible for compensation for injury, death, or property damage to the extent required by the Federal Employees Compensation Act or the Federal Tort Claims Act.

Since the KC-135 is considered to be a public aircraft within the meaning of the Federal Aviation Act of 1958, as amended, and as such does not hold a current airworthiness certificate issued by the Federal Aviation Administration, any individual manifested to board the KC-135 should determine before boarding whether his/her personal life or accident insurance provides coverage under such conditions.

14.1.11 RIGHTS OF RESEARCH SUBJECTS

I am not waiving any legal claims, rights or remedies because of my participation in this research study. If I feel I have been treated unfairly, or I have questions regarding my rights as a research subject, I may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E32-335, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253 6787.

14.1.12 SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

```
----------------------------------------
Name of Subject


----------------------------------------
Name of Legal Representative (if applicable)


----------------------------------------                --------------
```

Signature of Subject or Legal Representative Date

SIGNATURE OF INVESTIGATOR

In my judgment the subject is voluntarily and knowingly giving informed consent and possesses the legal capacity to give informed consent to participate in this research study.

-- --------------
Signature of Investigator Date

14.2 Subject Briefing

At the subject briefing session, the entire Layman's summary will be reviewed. The test subject will have the opportunity to ask any questions, and the investigator will highlight all important information. The briefing will be redundant information because in this case the investigators are simultaneously serving as subjects

The personnel present at the briefing will be the test subject, the principal investigator, and the student investigator who will be on board the KC-135 with the test subject. All test procedures, as outlined in section 9.0, will be thoroughly reviewed during the meeting.

Copies of the Layman's Summary and the JSC Human Research Subject Informed Consent forms are attached in section 17.

15 Research Performed at Off-Site Locations

All research that is not performed at JSC will not involve any JSC personnel as investigators or test subjects.

16 Other Funding Source

Funding for this project is anticipated from the M.I.T. department of Aeronautics and Astronautics, the Massachusetts Space Grant Consortium, and private industry.

17 Attachments to Life Sciences Research Protocol

17.1 University Human Subjects Committee Approval

The following application has been sent to the M.I.T. Council on the Use of Humans as Experimental Subjects. Once their approval is secured, a letter will be forwarded to the RGSFOP office.

17.2 Unsigned JSC Consent forms for each subject

17.3 Unsigned Layman's Summaries for each subject

Please note that the Layman's Summaries follow the same format as the MIT COUHES form entitled "CONSENT TO PARTICIPATE IN NON-BIOMEDICAL RESEARCH". This was done because COUHES required a standard format which was an excellent beginning for the JSC Layman's Summary document.

References

[1] Air Force Research Laboratory. Spatial Disorientation Countermeasures Homepage. [Website]. Ohio: Air Force Research Laboratory, Joint Cockpit Office, 2003 [cited 18 October 2003]. Available from the World Wide Web: (http://www.spatiald.wpafb.af.mil).

[2] Kirkham, W.R., W.E. Collins, P.M. Grape, J.M. Simpson, and T.F. Wallace. Spatial Disorientation in General Aviation Accidents. Aviation, Space, and Environmental Medicine 49(9): 1043-1154. 1978.

[3] McGrath, B.J., Tactile Instrument for Aviation, NAMRL - Internal Report. Copy available upon request.

[4] North, D.M., "Angle on Awareness." Aviation Week & Space Technology 04 08.2003: 41-43.

[5] Oman, Charles. "Neurovestibular adaptation to spaceflight: Research progress." Journal of Vestibular Research. vol 12 pp201-203. 2002/2003.

[6] Rupert, A.H., A. Mateczun, F.E. Guedry, Jr., 1990. Maintaining Spatial Orientation Awareness. Situational Awareness in Aerospace Operations = La perception de la situation au cours des operations aériennes : papers presented at the Aerospace Medical Panel symposium held in Copenhagen, Denmark, from from 2nd-6th October 1989. Neuilly Sur Seine, France: AGARD, 1990.

[7] Rupert, A.H., T.J. McTrusty, J. Peak, 1999. Haptic Interface Enhancements for Navy Divers. Proceedings of the International Society for Optical Engineering, April 1999, 246-252.

[8] Priplata, A., J. Niemi, M. Salen, J. Harry, L.A. Lipsitz, and J.J. Collins, 2002. Noise-Enhanced Human Balance Control. Physical Review Letters 89, 238101 (2002).

[9] Wall, C. 3rd, D.M. Merfeld, S.D. Rauch, F.O. Black, 2002. Vestibular Prostheses: The Engineering and Biomedical Issues. Journal of Vestibular Research 2002-2003; 12(2-3):95-113.

[10] Wall, C. 3rd, M.S. Weinberg, 2003. Balance Prostheses for Postural Control. Engineering in Medicine and Biology Magazine, IEEE, 22(2): 84-90 March-April 2003.

[11] Wall, Conrad et al. "Balance Prostheses for Postural Control." IEEE Engineering in Medicine and Biology Magazine. pp84-90 March/April 2003.

[12] Wall, Conrad et al. "Vestibular prostheses: The engineering and biomedical issues." Journal of Vestibular Research. vol 12 pp95-113. 2002/2003.

[13] Editor Pat Willits. Private Pilot Manual. Jeppesen Sanderson, Inc. Englewood, CO. 1997, 1998.

[14] Young, Laurence. Principles and Practice of Aviation Psychology. Lawrence Erlbaum Associates, inc. 2003.