The Human Interface Elements of System Safety in the Emerging Small Aircraft Transportation System

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ABSTRACT

Accident data indicates that 80 percent of general aviation accidents are attributable to pilot error. NASA's Small Aircraft Transportation System vision involves a revolutionary leap in air transportation that combines new aircraft and engine technologies with advanced avionics and communications to provide near all weather operations at thousands of existing general aviation airports with improved safety. The operators of the new SATS aircraft will expand well beyond the existing pilot community to include men and women of all ages and professions trained in entirely new ways and who are comfortable flying in visual or instrument flight conditions. This "SATS vision" is creating a demand for new research into safety and human factors for the general aviation community.

GENERAL

Accident data indicates that 80 percent of general aviation accidents are attributable to pilot error. Technology is often seen as the solution to pilot error problems such as controlled flight into terrain, loss of situational awareness, loss of control, and inadvertent flight into weather. Emerging technologies in aircraft and engine design, global positioning system applications, aircraft avionics, digital communications and data link systems, and flight management systems do offer significant technological solutions to improved aviation safety but changes go far beyond the man-machine interface. Changes are already entering the aviation community that will impact all elements of the SHELL (Software, Hardware, Environment, Liveware, and Liveware) human factors model.

AVIATION SAFETY

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Occasionally a fatal general aviation accident claims the live of a well known personality such as John Kennedy Jr or John Denver and raises the public's interest in the safety of general aviation. Most Americans however, do not relate to the general aviation community, the financial impact of general aviation on their communities, or the tragically high number of fatal general aviation accidents evey year. Although the fatal accident rate per 100,000 flight hours has declined over the past 25 years, it has remained "relatively constant over the past 16-17 years (AOPA, 2000, p.8)". Figure 1 presents the U.S. general aviation fatality rate trend between 1975 and 1997.

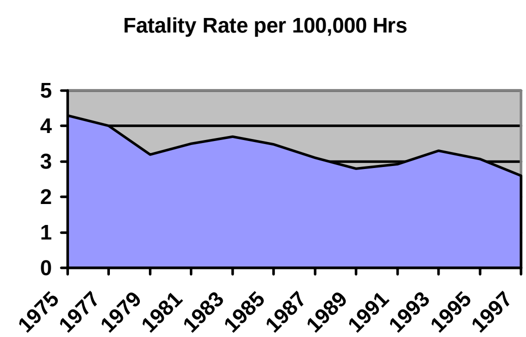

Figure 1: General Aviation Fatality Rate 1975-1997
Source: BTS, 1999, p. 89

The fifty percent decline in actual total annual fatalities between 1970 and 1998 is notable yet the resurgence in general aviation aircraft sales presents the same problem facing commercial aviation. A stable accident rate applied to ever increasing numbers of aircraft and total flight hours (more than one million additional flight hours in 1997) equates to ever increasing numbers of fatalities if nothing is done to eliminate the most common sources of accidents.

Personal flights in general aviation aircraft remain the most dangerous within the community. "An estimated 43 percent of all flying is done for personal reasons and results in almost three-quarters of the fatal accidents (AOPA, 1998, p.3)" This trend has not changed noticably over time and offers the greatest potential for reducing the GA accident rate through technology.

Weather Related Accidents

Rather that concentrating on the aggregate fatalities, a more informative way to view the general aviation safety record is to examine the specific causes of fatal accidents. "With an overall fatality rate of 83.1 percent, weather accidents remain the deadliest of all" (AOPA, 1999, p. 20). The majority of accidents involving weather were the result of controlled flight into terrain (CFIT), spatial disorientation, or pilot-induced structural failure of the aircraft. Table 1 presents a summary of 1998 accidents involving an interaction between time of day and the weather. Clearly, inadvertent flight into weather has a disproportional percentage of fatal accidents.

Table 1
Accident By Light And Basic Weather Conditions

Conditions	**Total**	**Fatal**	**% Fatal**
Day VMC	1216	139	11.4%
Night VMC	75	18	24.0%
Day IMC	58	37	63.8%
Night IMC	19	13	68.4%
All	**1679**	**341**	**20.3%**

AOPA, 1999, p21

Figure 2 presents the accident rates for various weather/light possibilities. Figures above the average Total Accident and Fatal Rates indicate higher than average rates under the indicated conditions. Both categories involving flight into instrument conditions are significantly highter than the average fatality rate. This is particularly notable since flights in Instrument Meterorological Conditions produce nearly 20 percent fewer total accidents per 100,000 flight hours but over four times the rate of fatal accidents as VMC conditions. Synthetic vision offers the potential of making every flight the equivalent of a daylight operastion.

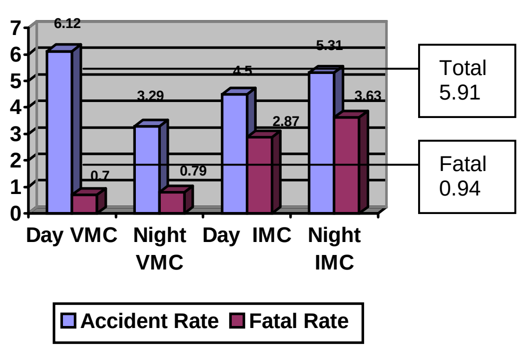

Figure 2: Weather/Light Conditions
AOPA, 1999, p. 21

Spatial Disorientation Accidents

Spatial disorientation can occur anytime a pilot is deprived of visual references to determine the aircraft's orientation in three-dimensional space. Some common phenomena that can deprive a pilot of visual references include clouds, fog, darkness, rain, snow, haze, darkness, and indistinct contrasts between the terrain and sky. Although experienced commercial airline pilots can fall victim to spatial disorientation, it is much more common, and much more likely to result in serious consequences for the general aviation pilot. "In a detailed analysis of accidents over a ten-year period (1987-1996) with an emphasis on spatial disorientation as a cause or significant contributory factor reveals . . . there was an average of almost 37.6 accidents per years, of which 33.9 were fatal" (AOPA, 1999, p. 21). While the average spatial disorientation accident in General Aviation involves non-instrument rated pilots who encounter IMC conditions, instrument rated pilots are not immune.

SMALL AIRCRAFT TRANSORTATION SYSTEM

General aviation has historically lagged behind commercial aviation in at least three respects that have impacted safety. These factors include aircraft technology, pilot training and credentials, and the operating environment. An industry revitalization exemplified by the efforts of the Advanced General Aviation Transport Experiments (AGATE) and the General Aviation Propulsion (GAP) programs have demonstrated that general aviation can provide many of the advanced technology features of large commercial aircraft for the GA community. The SATS aircraft will be four-to-six place aircraft, personally operated or with hired pilots. These revolutionary vehicles will include:

- "Highway in the Sky" graphical flightpath operating systems to permit flights in marginal weather to all nearly all runway ends and helipads,
- Flight Information Services (FIS) to include Traffic Informations Services (TIS) and Automatic Dependent Surveillance (ADS-B),
- Near all weather air and ground operations at non-towered airports without radar surveillance,
- New quiet engines with single-lever power controls, intuitive diagnostics, and longer Time-Between-Overhauls,
- Crashworthy composite airframes, including airbags and, in some vehicles, whole aircraft parachutes,

- Speeds of at least 200 knots for piston and 300 kts for turbine propulsion engines,
- HITS graphical flight path operating systems, including navigation, terrain, weather, airspace depictions, traffic, and autopilots to relieve pilot workload and to provide backup in times of emergency.

Technology

New aircraft such as the proposed low-cost, entry-level Eclipse business jet and the production model Lancair Columbia 300, are initial steps in providing safe, affordable SATS aircraft. The Lancair, in particular, has demonstrated significant improvements in safety through design with an improved cockpit safety cage, whole aircraft parachute, and in-flight characteristics. "For all its speed, the plane (Lancair Columbia) is so docile that the Federal Aviation Administration had certified it as being unable to spin" (Stephes, 2001, p 1).

Two technolgy breakthroughs have made the prospect of affordable HITS technolgy for the general aviation market are Global Positioning System (GPS) receivers and the production of inexpensive graphic display systems capable of providing real-time HITS predictions in the cockpit. GPS is not a new technology for military aircraft but the availability of small, inexpensive, and accurate systems for non-military aircraft is essential for HITS to become successful.

HITS is a major specification for the future generations of SATS aircraft however, critical questions remain to be answered on the safety and effectiveness of these displays in single piloted general aviation aircraft. Probably the greatest unanswered question remaining is how well an average GA pilot can maintain situation awareness while flying with HITS and transitioning between day and night or VMC and IMC conditions. The military has extensive experience with heads up displays and flight path markers in high performance aircraft and with highly skilled pilots but the human interface boundaries that would include low flight hour, less well trained general aviation pilots is not known.

Some early research on the impact of HITS displays on pilot situational awareness has been completed on the ability of pilots of varying ages and experience to interpret HITS data. This early data indicated that training in the specific HITS display could be more important that the specific type of HITS display. Age also appeared to be a factor in the successful use of HITS with older pilots experiencing more difficulty with the displays.

Pilot Training

General aviation pilots tend to operate at higher risk while flying than their commercial or military counterparts because of wide variations in pilot qualifications and training, the airports they use often are non-towered and have fewer facilities to aid the pilot, and because they have more individual responsibility for the safety of their flight.

The goal of SATS is to provide a simplified and affordable pilot training through advanced technologies including:

- Unified instrument-private pilot training,
- On-board embedded training capabilities,
- Internet-based and simulation-enhanced training systems,
- Pilots flying 50 hours per year area able to maintain all necessary competencies and proficiencies for IFR HITS operations

Embry-Riddle Aeronautical University has already developed a trial unified instrument-private pilot training curriculum in cooperation with Jepperson Sanderson. Results from the initial training involving 70 volunteer subjects were used to develop a follow-on modified Integrated Curriculum. This one critical improvement in decades old pilot training promises safety improvements for the entire pilot community, but especially for the future of SATS. The true test of this training and its potential however, will have to wait for production aircraft with HITS and other "SATS vision" technologies to determine the actual impact on pilot proficiency.

Operating Environment

SATS envisions an operating environment that utilizes much of the emerging technology designed to make commercial aviation operations safer. Flight Information Services, Traffic Information Services, Automatic Dependence Surveillance Broadcasts, GPS navigation and approaches, free flight, and weather avoidance systems all have safety implications for new SATS aircraft and the airports serving the general aviation and business aviation communities.

SATS PROOF OF CONCEPT

NASA has been provided funding for SATS with a primary mandate to "prove that SATS works". A five-year proof of concept research effort is planned to develop the key technologies needed for an initial set of SATS operating capabilities. The program would culminate in a joint NASA/FAA demonstration of the SATS operational capabilities.

The SATS proof of concept is framed within a set of hypotheses to guide the investigation of technology options. A key hypothesis is that the public can *safely operate a SATS vehicle in three dimensions, in near all weather, including abnormal operations*. To prove the hypotheses of SATS, Dr. Holmes (May 16, 2000) identified three capabilities that would comprise the integrated technology demonstration:

- Virtual Visual Meteorological Conditions (VMC) for routine Instrument Meteorological Conditions (IMC) operations. Prove that cockpit displays, automated systems, and virtual terminal procedures can enable non-commercial aircraft operators to conduct VMC-like approaches, departures, and missed approaches in IMC.

- High Density Operations. Prove that SATS automation-aided airborne-based technologies have the potential to enable user-preferred trajectories with sequencing and separation including applications in non-towered, no radar airspace in near all-weather conditions. Establish the potential for seamless, non-interfering interoperability at and around facilities in Class B airspace.

- Automotive Synergies. Prove that automotive design and manufacturing technologies have the potential for application to easy to use SATS vehicles while satisfying the public need for safety, energy efficiency, and environmental acceptability.

IMPLICATIONS FOR RESEARCH

Partnerships between NASA, the FAA, industry, states, and research enclaves are already pursuing research efforts designed to develop and demonstrate the SATS operating capabilities. Many other candidate areas of research exist such as bio-medical and human factors, maintenance and manufacturing, airport environment, pilot education/accident prevention, air traffic control, and maintenance and manufacturing.

REFERENCES

AOPA Air Safety Foundation (2000). NALL report 1999: General aviation accident trends and factors for 1998. Frederick, MD: Author.

Hampton, S. (1999). Technology and training issues associated with the Advanced General Aviaiton Transport Experiment (AGATE) and Small Aircraft Transportation System (SATS) programs.

Holmes, B. (1999, January). NASA aeronautics enterprise national general aviation roadmap for pillar II: Revolutionary leaps for goal #7. Presented at the National Research Council Transportation Research Board, Washington, DC.

Holmes, B. (2000, May 16). Future of aviation. Testimony before Subcommittee on Transportation and Infrastructure, House of Representative. Washington, DC.

Stephens, M. (2001, January 29). The Lexus of the skies. *Forbes Lifestyle.com*. Retrieved February 17, 2001, from the World Wide Web: http://www.Forbes.com/2001/01/29/0129feat.html

U.S. Department of Transportation Bureau of Transportation Statistics (1999). Transportation statistics annual report 1999. Washington, DC: Author.