



AAR-100

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Project Report: *Certifying Head-Up Displays* (M. Zuschlag, Volpe NTSC)
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Purpose: A research project is underway to provide the FAA with empirically based guidelines for certifying head-up displays (HUDs) for use in civil air transports. The purpose of this document, as part of this project, is to support this research by summarizing the existing literature on HUDs, providing the current knowledge and research directions for developing the certification guidelines.

HUDs are being installed in air transports in order to allow manual approaches, landings, and takeoffs in poor visibility, down to and including Category IIIA conditions. Through the course of certifying these HUDs, FAA experts have identified 22 HUD design issues each representing a potential adverse impact of a HUD design on pilot performance. In order to improve the consistency and validity of the certification process of HUDs, the FAA needs to know better, exactly how pilot performance is affected.

Display Information Accessibility Issues

Eight issues concerned the location and format design of flight information. Designers must choose what to display on the HUD, where, and how. On the one hand, pilots will have maximal accessibility to information that is displayed in the center of the HUD. On the other hand, excessive information in the HUD center or on the HUD at all likely represents clutter that slows perception of a particular information unit of interest. In order to limit clutter, the designer may simplify the appearance of a given indicator (e.g., airspeed) by omitting such elements as scale labeling, tick marks, and analog components. However, such omissions reduce the information provided by the indicator, which may lead to misperceptions.

Thus, for each unit of information, the designer must make a tradeoff between maximizing access to the information and minimizing interference with other units of information, including that presented by the underlying out-the-window (OTW) view. The literature presents no precise means to decide this tradeoff. The following rules of thumb are available for designers and certifiers:

- Only the most absolutely necessary indicators should be on the HUD.
- Keep at least the central 10 degrees of the HUD field-of-view (FOV) as clear as possible.

- All the guidelines and requirements regarding tick marks and scales that apply to the analogous head-down primary flight reference (PFR) indicators should be applied to the HUD.
- It is sufficient for a HUD to merely get the pilot's attention regarding a warning or caution while other displays describe the problem, with the exception of warnings that relate directly to aircraft attitude or control.

Further research is needed to provide more precise guidelines than above. For example, there is no technique or calculation available now, other than flight testing, that would allow a designer or certifier to evaluate systematically a proposal to locate a specific indicator at a specific location using a specific format. There does not appear to be any research indicating the degree traditional indicators can be diminished when the HUD presents unconventional indicators, such as the flight path marker and speed worm. Research on the phenomenon of attention trapping is subject to competing interpretations of the experimental data that must be resolved before design guidelines can be provided. There is virtually no research on the degree the HUD affects the likelihood of the pilot noticing important events on the head-down displays (HDDs) including cautions and warnings, although, possibly, this is not really a problem for HUDs.

Task-Display Compatibility Issues

Four issues concern the display's effectiveness to support the intended tasks. Among these, certifiers need to determine the effectiveness of the uses of symbology attributes (such as brightness, ghosting) in representing various states and values. For example, certifiers need to determine if the display adequately indicates and distinguishes commanded values and limits in altitude and speed displays, and if an indicator is out of range or has failed. According to research, X's or other overlays are preferred to removal or ghosting an indicator to show an indicator failure. Ghosting is becoming an effective de facto convention for representing an out-of-range indicator. The best use of flashing probably is purely to capture the attention of the pilot.

Regarding target values, limits, and alerts, it would seem reasonable that HUDs be subject to guidelines analogous to that applied to HDDs. Study is needed to develop guidelines for evaluating a monochrome convention for representing limits and alerts. The guidelines should identify those conventions associated with pilot performance comparable to the use of red and yellow on HDDs.

Two issues concern evaluating a HUD's effectiveness in displaying and guiding recovery from unusual attitudes. The pitch ladder symbology used in most HUDs has features that make sky-ground discrimination difficult. As a result, several differences in the positive and negative pitch ladder rungs may be necessary for a HUD to match an HDD for sky-ground recognition. Ultimately, the best approach to evaluating a HUD in this regard is flight testing.

Questions have been raised regarding the appropriateness and adequacy of various instrument formats (tape, pointer, drum, counter) in HUDs. Operational experience with HDDs suggests that to the degree that tapes have become acceptable for HDDs, one may regard them as adequate for HUDs even though counter-pointer formats may be better. Analog indicators have performance advantages over simple counters but counters alone may be appropriate when minimal clutter is necessary.

Display-Display Consistency and Discrimination Issues

Five issues concern the consistency and discriminability of HUD symbology. These concern the consistent use of coding and attributes within the HUD, discriminability of cautions from warnings in the HUD, and consistency with the formats and conventional positions of HDD indicators. There is little research relevant to these issues. While there is consensus that inconsistency should be minimized, the literature, however, does not provide guidance for deciding between two different forms of inconsistency when total consistency cannot be achieved without causing other problems.

Flight experience implies that the vertical position of the heading indicator relative to the attitude indicator can be safely varied between HUD and HDD, but no hard research supports this or other deviations from the “Basic-T” positions of indicators. Similarly, flight experience suggests it is acceptable to mix a fixed-pointer tape indicator with a round-dial moving pointer indicator. However, there are untested theoretical reasons to surmise that certain combinations of formats could cause confusion.

As mentioned earlier regarding Task-Display Compatibility Issues, study is needed to develop guidelines for monochrome conventions for representing cautions and warnings. Such guidelines may address issues concerning distinguishing cautions from warnings and avoiding inconsistency with HDD alerts.

Physiological Stress Issues

Four issues concern the pilot physiological stress that may be associated with HUD optical design. These issues lack adequate research. For example, anecdotes suggest that the eye strain effects of HUDs are a possibility, although currently they are unsubstantiated. Published sources do not provide any guidance on the dimensions or characteristics of HUD optics that are related to strain or fatigue. Some research implies that pilots may shift focus when transitioning between the HUD and the OTW view. Limitations of this research preclude any operational or design advice. HUD optics require that the pilot keep his or her head within a specific volume in order to see all flight indications. However, despite the attention applied to this issue, no one knows the normal amount of pilot head movement that would define the minimum dimensions of this volume.

Research Programs

The following research programs are proposed to aid in resolving the issues for which there is currently insufficient knowledge to provide precise guidelines for certification:

- **Visual Scanning.** The purpose of this research program is to develop a means to determine if a HUD adequately balances clutter against providing sufficient and easily accessible information to the pilot.
- **Conformity vs. SLS.** This program seeks to resolve concerns regarding attention trapping through experiments to determine if it is caused by non-conformal symbology or relative motion. Follow-up studies shall develop a measurement for a HUD’s propensity to induce attention trapping.

- **Alert Coding.** Through subject matter expert workshops, technology surveys, and experiments, this program seeks to develop guidelines for evaluating monochrome coding convention for cautions and warnings in order to resolve various issues regarding consistency, discrimination, and task compatibility.
- **Internal Consistency.** This program seeks to develop a quantitative measure of display consistency that predicts human performance.
- **HDD-HUD Consistency.** This program determines the pilot performance cost (if any) associated with making the transition between a HUD and HDD when each use different formats or locations of indicators.
- **HUD Strain.** This program uses surveys and experiments to determine the presence, effects, and mitigation of strain from HUD usage.
- **Head Motion.** This program uses field tests to determine the range of normal head motion exhibited by pilots in non-HUD equipped aircraft to provide volume guidelines for cockpit head motion.

Charting the Next Century of Flight: On the 99th anniversary of the Wright Brother's flight, the Administrator helped kick off a year-long celebration leading to the 100th anniversary of powered flight. In a message to employees, Administrator Blakey pointed out that "This commemoration has a special meaning for the FAA because this agency and its predecessor agencies have helped chart the course of aviation for more than three quarters of a century -- a role that began in 1926, just 23 years after the Wright Brothers first flight at Kitty Hawk and a year before Charles Lindbergh first flew to Paris. It continues to this day as we work with the aviation community to shape aviation's second century. The theme we have chosen to celebrate the FAA's role in this continuum is "Charting the Next Century of Flight," because it aptly captures, I believe, the agency's historical and future role -- charting the highways of the sky and envisioning and plotting the future course of aviation." (T. Kraus, AAR-200)

CPDLC: On Tuesday, December 17, David Knorr, Metrics Manager (AOZ-40) and his group visited the William J. Hughes Technical Center's Research and Development Human Factors Laboratory to collect data on time to complete CPDLC tasks on the DESIREE CPDLC Build 1A simulator. Laboratory researchers participated in the data collection and developed output files which will collect time-stamped data for AOZ. (E. Stein, WJHTC)

AQP: In December 2002, Officials at Gulf Air (Kingdom of Bahrain) requested FAA assistance as they transition to the Advanced Qualification Program (AQP). If approved, AFS-230 (Air Transportation Human Factors) will provide the latest functional software and other materials, and human factors researchers at Battelle Memorial Institute, the University of Central Florida, and the University of New Mexico will help with the transition. (E. Edens, AFS-230)

Cognitive Performance in Aviation Training and Operations: Researchers at NASA-Ames are studying the cognitive processes that underlie the performance of pilots, air traffic controllers, and other skilled professionals. This research involves a combination of well-controlled laboratory studies of basic cognitive mechanisms, theoretical modeling, flight simulation studies, field observations, and analysis of accident reports. They are currently

focusing on the cognitive processes involved in (1) prospective memory -- remembering to perform an intended action that must be deferred, and (2) attention to and management of concurrent tasks. Other research includes field studies involving interruptions and distractions in concurrent task performance, devising ways to evaluate crew performance of complex tasks, and teaching crews to critically analyze their own performance. They work closely with airline training departments and try to provide a bridge between research and aviation operations. Research findings are currently being reviewed for inclusion in AC 120-71 (SOPs) and the next revision to 120-51 (CRM training). (E. Edens, AFS-230) <http://human-factors.arc.nasa.gov/ihf/flightcognition/>

More information on human factors research can be found at the FAA Human Factors (AAR-100) web site: <http://www.hf.faa.gov>

Mark D. Rodgers
FAA (AAR-100)



January 6-9, 2003 - 41st AIAA Aerospace Sciences Meeting and Exhibit at the Reno Hilton, Reno, Nevada. For more information, visit [Event Website](#)

January 12-16, 2003 – Transportation Research Board 82nd Annual Meeting in Washington, DC
<http://www4.trb.org/trb/annual.nsf>

January 13-17, 2003 – SAE S-18 Airplane Safety Assessment Committee, Salt Lake City, UT
<mailto:lemon@sae.org>

January 14-16, 2003 – SAE Aircraft Seat Committee, San Diego, CA <mailto:elizd@sae.org>

January 16-17, 2003 – National Research Council, Committee on Human Factors, The National Academies, Wash, DC http://www7.nationalacademies.org/bcsse/BCSSE_Meetings.html

January 27-30, 2003: Annual Reliability and Maintainability Symposium (RAMS), Tampa, FL
<http://www.rams.org/>

January 27-31, 2003 – SAE G-10 Aerospace Behavioral Engineering Technology Committee, Melbourne, FL <mailto:lemon@sae.org>

February 4-6, 2003 – SAE North American Aviation Safety Conference, Atlanta, GA
<http://www/sae.org/calendar/aeromtgs.htm>

February 9 – 11, 2003 - Heli-Expo 2003, Dallas, Texas. Contact: www.rotor.com

February 11 – 16, 2003 - Australian International Air Show, Melbourne, Australia. Contact: www.pacific2002.net.au

February 25-26, 2003 – FAA Research, Engineering and Development Advisory Committee, Subcommittee on Human Factors Meeting, FAA Headquarters, Room 932
<mailto:gloria.dunderman@faa.gov>

March 3-6, 2003 – SAE 2003 World Congress, Cobo Center, Detroit, MI
<http://www/sae.org/congress/index.htm>

March 5-6, 2003 – ASPA/ICAO Seminar on Cross-Cultural Issues in Aviation Safety, Mexico City, Mexico <mailto:dmaurino@icao.int>

March 18-19, 2003 - 28th FAA Commercial Aviation Forecast Conference at the Renaissance Washington DC Hotel, Washington, DC. For more information, visit [Event Website](#)

March 17-19, 2003 – 15th Annual European Aviation Safety Seminar presented by the Flight Safety Foundation and European Regions Airlines Association, Hotel Intercontinental Geneva, Geneva, Switzerland <http://www.flightsafety.org/seminars.html>

March 24-28, 2003 – SAE Airplane Safety Assessment Committee, Lisbon, Portugal
<mailto:lemon@sae.org>

April 2-8, 2003 – Sun ‘n Fun EAA Fly In, Lakeland, FL <http://www.sun-n-fun.org>

April 5-10, 2003 –CHI 2003 Conference on Human Factors in Computing Systems, Broward Convention Center, Ft. Lauderdale, FL <http://www.chi2003.org/>

April 7-27, 2003 – Aviation World’s Fair, Newport News/Williamsburg, VA
<http://www.worlds-fair.com/> or <http://aviation-worlds-fair.com/>

April 9-11, 2003 – SAE Aircraft Environmental Systems Committee, Dayton, OH
<mailto:elizd@sae.org>

April 22-23, 2003 – 48th Annual Corporate Aviation Safety Seminar, presented by the Flight Safety Foundation and the National Business Aviation Association, Westin Diplomat Resort and Spa, Hollywood, FL <http://www.flightsafety.org/seminars.html>

April 27-30, 2003 – Symposium on Interactive 3D Graphics, Monterey Marriott, Monterey, CA
<mailto:Pausch@cmu.edu>

May 3-10, 2003 – International Conference on Software Engineering, Hilton Portland, Portland, OR <mailto:ldillon@cse.msu.edu>

May 4-9, 2003 – 74th Annual Scientific Meeting of the Aerospace Medical Association, Convention Center, San Antonio, TX <http://www.asma.org/>

May 6 – 8, 2003 - AHS International 59th Annual Forum and Technology Display, Phoenix Civic Plaza, Phoenix, AZ. [General Information](#) - [Call for Papers](#) - [Exhibitors](#)

May 12-17, 2003 - 2003 IEEE International Conference on Robotics and Automation, The Grand Hotel, Taipei, Taiwan <http://www.icra2003.org/>

June, 2003 – SAE Digital Human Modeling for Design and Engineering, Location TDB <http://www.sae.org/calendar/aeromtgs.htm>

June 15-22, 2003 – 45th Paris Air Show le bourget <http://www.paris-air-show.com/index3.htm>

June 22-27, 2003 – 10th International Conference on Human-Computer Interaction, Institute of Computer Science Foundation, Research and Technology, Science and Technology Park of Crete, Heraklion, Crete, Greece <mailto:info@hciei2003.gr>

June 23-25, 2003 – Human Systems Integration Symposium “Enhancing Human Performance in Naval and Joint Environments”, Sheraton Premier Hotel, Tyson’s Corner, VA <http://www.navalengineers.org/Events/HSIS2003/HSIS.html>

July 7-10, 2003 – SAE 33rd International Conference on Environmental Systems, The Westin Bayshore Resort and Marina, Vancouver, Canada <http://www.sae.org/calendar/aeromtgs.htm>

July 14-17, 2003 – AIAA/ICAS International Air & Space Symposium and Exposition, Dayton Convention Center, Dayton, OH <http://www.flight100.org/>

July 21 – 23, 2003 - 4th Australian Pacific Vertiflite Conference on Helicopter Technology, Melbourne, Victoria, Australia. Contacts: [Dr. Arvind K. Sinha](#) and [Mr. Raden Kusumo](#)

July 29-August 4, 2003 – 51st Annual AirVenture, Oshkosh, WI <http://airventure.org/>

August 7-10, 2003 – 111th Convention of the American Psychological Association, Toronto, Ontario, Canada <http://www.apa.org/convention>

September 9-11, 2003 – SAE Aerospace Congress and Exhibition, Palais des Congrès, Montreal, Quebec, Canada <http://www.sae.org/calendar/aeromtgs.htm>

September 15-17, 2003 – FAA/TCA/CAA Safety Management in Aviation Maintenance Symposium, Toronto, Canada

September 16-18, 2003 - 1st International Congress on Health and Safety in Transportation. Paris, France <http://www.biomedicale.univ-paris5.fr/LAA/eindex.htm>

September 16 – 18, 2003 - 29th European Rotorcraft Forum, Friedrichshafen, Germany. Contact B. Gmelin at bernd.gmelin@dir.de

September 18-19, 2003 – National Academy of Engineering 2003 Frontiers of Engineering Symposium, Irvine, CA [Welcome to the National Academy of Engineering \(NAE\)](#)

October 6 – 9, 2003 - NATO Research and Technology Agency, Applied Vehicle Technology Panel (AVT) will present "The Vehicle Propulsion Integration Symposium" in Poland. For more information contact cheynes@rta.nato.int

October 7 – 9, 2003 - National Business Aviation Association Annual Meeting & Convention, Orlando, Florida. Contact: www.nbaa.org

October 13-17, 2003 – Human Factors and Ergonomics Society 47th Annual Meeting, Adams Mark Denver Hotel, Denver, CO <http://www.hfes.org/>

January 11-15, 2004 – Transportation Research Board Annual Meeting, Washington, DC <http://www4.trb.org/trb/annual.nsf>

January 21 – 23, 2004 - AHS 4th Decennial Specialists' Meeting on Aeromechanics, Fisherman's Wharf, San Francisco, CA. For more information contact the Technical Chairman, Tom Maier at tmaier@mail.acr.nasa.gov

April, 2004 – SAE General Aviation Technology Conference and Exhibition, Century II Convention Center, Wichita, KS <http://www/sae.org/calendar/aeromtgs.htm>

May 6-8, 2004 - AHS International 60th Annual Forum and Technology Display, Virginia Beach, VA. Contact Staff@vtol.org

July 27-August 2, 2004 – 52nd Annual AirVenture, Oshkosh, WI <http://airventure.org/>

May 2-7, 2004 – 75th Annual Scientific Meeting of the Aerospace Medical Association, Egan Convention Center, Anchorage, AK <http://www.asma.org/>

July 28 – August 1, 2004 – 112th Convention of the American Psychological Association. Honolulu, Hawaii <http://www.apa.org/convention>

September 20-24, 2004 – Human Factors and Ergonomics Society 48th Annual Meeting, Sheraton New Orleans Hotel, New Orleans, LA <http://www.hfes.org/>

Note: Calendar events in Italics are new since the last Newsletter



Comments or questions regarding this newsletter?

Please contact Bill Berger at (334) 271-2928
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