AIRCRAFT MAINTENANCE RESEARCH: THE NASA PROGRAM

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Some of the Maintenance Human Factors research activities sponsored by the NASA Aviation Safety Program (AvSP), and their historical precursors are described. With the goal of developing interventions that reduce human error and enhance safety and effectiveness in maintenance operations, four key product areas include: 1) human factors task/risk analysis tools, 2) models and tools for enhancing procedures, 3) recommendations for Maintenance Resource Management skills, training and evaluation, and 4) advanced display technologies for training and job aiding.

INTRODUCTION

Human error in aircraft maintenance is notorious for its ability to remain undetected and seemingly harmless over indeterminate periods of operational use. By the time an error become operationally "visible" the event chain may have become long, complicated and difficult to trace. Information to critical links and the contexts in which they occurred may be irretrievably lost from records and memory.

Over the lifetime of the error event chain, multiple, interrelated factors will have exerted their influence. Some factors may be relatively easy to assess, such as workplace conditions or adequacy of resources, while others are indirect and more diffuse in their effect, such as organizational culture and communication barriers. Corresponding to an error history of complex, inter-related events, the process of managing such errors likewise involves careful implementation of complex, inter-related interventions.

Maintenance human factors issues also arise from today's ever-changing operational and economic conditions. As companies rise to economic challenges, changes in the roles and responsibilities of the workforce, as well as changes in regulations, and company policies create new tensions in maintenance organizations. Cutbacks in resources and downsizing of personnel may result in an increased dependence on a contract labor force, and the associated problems of standardization, accountability, and training following a transition. While process improvements and new technologies simultaneously streamline operations, there is often an associated process loss in terms of communication and training required that create an uneasy trade-off.

To understand that serious maintenance human factors issues exist is a progressive step. However, an appreciation for the degree to which maintenance human factors underlies flight safety as well as ground safety is critical. Maintenance operations are integral to every flight. As such they can both enhance and undermine safety of flight and therefore contribute to global aviation safety metrics such as those described below.

The world-wide commercial aviation major accident rate (as judged by hull losses per million departures) has been nearly constant over the past two decades. While the rate is very low, increasing traffic over the years has resulted in the absolute number of accidents also increasing. The world-wide demand for air travel is expected to increase even further over the coming two decades: more than doubling by 2017 and requiring over $1 trillion in new aircraft deliveries. Without an improvement in the accident rate, such a traffic volume would lead to 50 or more major accidents a year -- a nearly weekly occurrence (Figure 1). Given the very visible, damaging, and tragic effects of even a single major accident, this situation would clearly be an unacceptable blow to the public's confidence in the aviation system. As a result, the anticipated growth of the commercial air-travel market would not reach its full potential.
AvSP L.1.Plan V6.0DRAFT (1998)

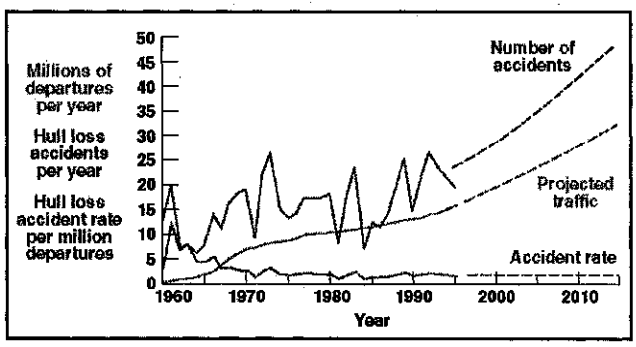

Figure 1.
Air travel projected to double by 2017. Without improvement in accident rate, traffic volume would lead to 50 or more major accidents per year. (Source: Boeing Company)

NASA Aviation Safety Program (AvSP)

In February, 1997, President Clinton announced a national goal to reduce the fatal accident rate for aviation by 80% within 10 years. In order to define the appropriate research to be conducted by the Agency, NASA responded by forming the NASA Aviation Safety Investment Strategy Team (ASIST), which sponsored four industry and government-wide workshops to define the most critical research needs. The ASIST workshops involved industry, government and academic organizations and shaped Phase 1 of the NASA Aviation Safety Program (AvSP) which runs from FY2000 through FY2004 and focuses primarily on the 10-year national goal. In the Aviation Safety Program, NASA works in partnership with the Federal Aviation Administration (FAA) in implementing the program and maintains close coordination with the Department of Defense (DoD) and other government agencies. Additionally the program works across the full range of commercial, rotorcraft, and general aviation industry manufacturers, suppliers, and operators in implementing the effort. Langley Research Center (LaRC) is the Lead Center and works closely with program personnel at Ames (ARC), and Glenn Research Centers (GRC).

The NASA AvSP consists of six elements: 1) Aviation System Monitoring and Modeling, 2) System-Wide Accident Prevention, 3) Single Aircraft Accident Prevention, 4) Weather Accident Prevention, 5) Accident Mitigation, and 6) Synthetic Vision. Within the System-Wide Accident Prevention (SWAP) element research activities are pursued in Human Error Modeling, Maintenance Human Factors, and Training.

As a "focused program", Maintenance Human Factors will stress the development of products that immediately support improved maintenance operations and a reduction in maintenance error. For example, document design tools provide a direct defense against procedural errors by aiding maintenance engineers and managers in systematically evaluating and enhancing maintenance procedures and by providing maintenance technicians a means of feeding back improvements to the organization. Maintenance Resource Management (MRM) training guidance and tools help industry to establish standards and performance metrics for MRM training and to focus and direct the development of training materials that address high priority human factors domains that are critical to maintenance safety.

Maintenance human factors research has not had a long history. Although recent technology advances are found in many areas of maintenance operations, rarely have these innovations been accompanied by corresponding human factors development. The FAA's Human Factors in Aviation Maintenance and Inspection program has been a pioneer in this area, but even this effort has a limited history. Thus, one particular challenge to the AvSP is to help build an established research foundation of results, methods and metrics from which to continue to grow. Technology transfer from other aerospace domains holds potential, but requires substantial adaptation for maintenance operations.

Maintenance Human Factors Program

The general approach to maintenance human factors research shown in Figure 2, consists of four steps: 1) Identify human error problems and safety needs, 2) Design and application of methods and analyses, 3) Development of human factors interventions and, 4) Validation of products in operational field sites.

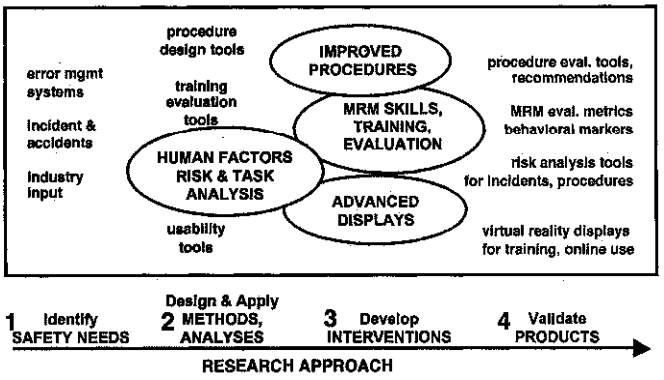

Figure 2.
Maintenance human factors research approach and project areas

The specific research elements are motivated by a history of limited research, and a current industry atmosphere characterized by copious economic, technical, and organizational changes. Because maintenance error is not yet sharply delineated, it is critical that research projects maximize customer involvement so that the most important human error problems are identified. In coordination with other human factors initiatives, the general approach will systematically analyze high priority issues through task analysis tools in order to define human factors requirements. These requirements will form the basis for developing human factors interventions. Finally, interventions will be rigorously validated in operational settings so that maximum benefit will be assured

Also shown in Figure 2 are the four areas of research activity comprising the Maintenance Human Factors: 1) Human Factors Risk and Task Analysis, 2) Improved Procedures, 3) Maintenance Resource Management (MRM) Skills, Training and Evaluation and 4) Advanced Displays. As the Roadmap depicts, these research areas are built into the middle of the research approach. They presume the identification of safety needs; they build upon each other throughout the design and application of methods and analyses as well as the intervention development phases; they culminate in products to be validated in an operational setting.

Collaborative Approach

The general implementation strategy for maintenance human factors products is to follow the phased approach described above, and to conduct research and development in close collaboration with industry partners. In the early development phases this means that members of the aerospace community will help to identify the highest priority human factors needs in the activity area. Later, FAA requirements, company policies, and standards developed by industry groups (Air Transport Association (ATA) Maintenance Human Factors Subcommittee, Society of Automotive Engineers (SAE) documents, unions, etc.) must be accommodated. Subsequently, prototypes will be developed and tested in an operationally relevant setting, thus requiring the participation of maintenance organizations (e.g., airline maintenance, repair stations, shuttle processing). Collaborative participation at this stage greatly facilitates later implementation.

A partnering/teaming strategy is essential to overcome the technology challenges described earlier. The phased research approach provides opportunity for industry participation at various stages. In addition, it is critical to partner with other research organizations in order to leverage our separate human factors efforts. Sharing of results, methods and metrics can enhance all research in these areas. Since research is often obtrusive to operations, coordination of research logistics can be useful in minimizing disruption to customer operations. Table 1 indicates some of the research/industry partnerships currently established in the AvSP Maintenance Human Factors program.

Table 1
Some AvSP Researchers and Industry Partners

AvSP Researchers	Industry Partners
▪ NASA Ames Research Center	▪ ATA, FAA, NTSB, Unions
▪ Clemson Univ	▪ Continental Airlines
▪ Naval Postgraduate School	▪ Naval Fleet Supply Squadrons
▪ Northwestern Univ	▪ DeltaAirlines
▪ Santa Clara Univ	▪ Southwest Airlines
▪ San Jose State Univ	▪ Hewlett Packard
▪ Univ of Idaho	▪ United Airlines
	▪ USAirways

Research Objectives and Products

It is not possible to give complete descriptions of all current projects in the NASA AvSP Maintenance Human Factors program (although many of the projects are represented at this conference). One of the basic activities based on the research approach is the Identification of Safety Needs. This is accomplished in a variety of ways including: analyses of Aviation Safety Reporting System (ASRS) incident reports (see Nord & Kanki, 1999), analyses of National Transportation Safety Board (NTSB) accident reports, industry data collection through organizations such as the ATA or SAE, within-company analyses of safety data. This program depends on this preliminary research in order to keep priorities current and focused. The following provides short summaries of the objectives and products associated with each of the four research areas:

Human Factors Risk and Task Analysis. Risk and task analysis tools can be used for a variety purposes. For instance these tools can be used in incident analysis so that high-risk trends can be identified. It is also a method for linking incidents to re-mediation strategies. Risk and tasks analysis tools are also useful in assessing and re-designing procedures. It provides an objective system for considering many of the known human error vulnerabilities. Risk analysis tools are also usefully applied in the area of maintenance inspection. For example, one AvSP project (University of Idaho) focuses on the development of an Inspection Decision Tool which addresses the following questions: Is an inspection step needed in the maintenance task? What level of inspection is needed? How do varying levels of inspection affect risk? As regulators and organizations assess their rules, policies and procedures for how inspection is accomplished, systematic risk-based analyses can help to make more informed decisions.

Improved Procedures. Projects focusing on improved procedures are facilitated by both the identification of safety needs (e.g., characterization of most prevalent procedural errors), and by human factors analysis tools such as the risk and task analysis tools described above. In several of procedure re-design projects, we are considering the ways in which human factors can be incorporated in order to improve situational awareness, and to enhance team, time and resource management both within and across maintenance teams. While hardware and software constraints impose limitations on re-design proposals, organizational and process constraints often pose the more difficult challenge. Nevertheless, the development of procedure evaluation tools can be used for improving procedure structure, content, and format. In addition, they can be used for comparing and standardizing procedures such as those across facilities within a company or when procedures are outsourced to an outside repair station. AvSP researchers from Northwestern University are specifically focusing on outsourcing issues and take a task-analysis approach to procedural comparisons.

Maintenance Resource Management (MRM) skills, training and evaluation. Many organizations have introduced Human Factors Training or MRM in their maintenance organizations. In doing so, they are building an industry experience base of great value. (see ATA Specification 13). However, there are areas in which researchers can provide some help, namely in providing tools for assessing MRM needs, providing tools for evaluating short and long term effects of training, and establishing industry baselines so that organizations can evaluate their internal progress (Taylor, & Patankar, 1999). Finally, AvSP research is focused on the development of action approaches to MRM training--that is, the incorporation of MRM concepts into practical Human Factors skills beyond the awareness and "classroom" solution. A full range of metrics are considered from individual survey

responses, to observations and interviews to operational performance metrics. AvSP researchers from the Naval Postgraduate School are developing behavior-based performance indicators of risk through collaborative activities with Logistics Fleet Support Wing squadrons.

Advanced Displays. In the area of advanced displays, the objective for AvSP is to develop and demonstrate advanced displays for maintenance training and task aiding. Our initial focus is to extend the capabilities of the FAA-sponsored ASSIST, computer-based inspection training/job-aid tool (see Gramopadtye et al. 1998) in order to develop a prototype virtual reality (VR) inspection environment. With a VR inspection simulator, supplemental inspector training materials can be developed to enhance existing on-the-job training experiences, and controlled studies can be conducted in order to develop human performance metrics. Although the product is initially an inspection tool, we will also consider its on-line task aiding potential.

Summary

In summary, the Maintenance Human Factors Research program is dedicated to goals of the NASA Aviation Safety Program. In order to achieve these goals, a plan has been developed for building a research foundation in four areas: Risk and Tasks Analysis, Improved Procedures, MRM Skills, Training and Evaluation, and Advanced Displays. The program is coordinated with the FAA, DoD, industry and research communities, and is based on collaborative partnerships with maintenance organizations. We invite continued industry feedback, customer involvement in all phases of research, and technology transfer opportunities across all maintenance and ground processing operations.

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