CONCLUSIONS AND RECOMMENDATIONS

Managers responsible for maintenance of the U.S. air carrier fleet continuously strive for an efficient and error-free operation. Factors that might contribute to lessened workforce productivity or to error in aircraft maintenance and inspection must be understood and controlled. There are many such features including communications, equipment characteristics, training level of workers, management relations, and the environment in which the work takes place. This report addresses the last topic, the work environment. "Work environment" is defined broadly here and encompasses all factors, including the physical plant, the social environment, the organizational structure, and the many technical aspects that impact the performance of a workforce.

Features of the work site and ways in which work is structured can be quite important in determining the quality of worker output. A review by Miller and Swain (1987) discusses the ways in which proper design of the work setting can serve to reduce error rate. The authors note that whereas traditional industrial thinking puts the burden for human error on the worker and his or her presumed lack of competence, newer approaches examine the task demands, equipment, and work environment for characteristics that predispose a worker to errors.

The incentives for production quality and error control in air carrier maintenance are many. One certainly is cost. As noted during the meeting, the increase in air carrier maintenance costs in the two-year period from 1987 through 1989 approaches $2 billion. Of possibly greater importance than the dollar volume is the fact that during this period maintenance cost increased as a percentage of total operating costs from 11.2 to 11.8 in 1989. Had these costs remained at 11.2 percent, the savings to industry would have been about $165 million. This fact alone provides a powerful incentive to examine workforce productivity and, in turn, those factors that influence productivity. The work environment in which maintenance is conducted certainly is one such factor.

A second, and possibly even more important, incentive for examining the quality of workforce performance is flight safety. Many studies (review by Miller and Swain, 1987) have shown that work situations in which ergonomics are poor make errors more likely to occur. Such situations make demands on workers that are not compatible with their capabilities, limitations, experience, attitudes, and goals. The design of a maintenance workplace, just as the design of an aircraft flight deck, can make errors less likely or more likely.

Attendees at this meeting represent all segments within the air carrier industry, including airline operators, manufacturers, maintenance managers, union representatives, regulators, safety experts, industrial hygienists, and others. Formal presentations given during the two days covered a variety of topics related to different features of the broadly-defined work environment that affect the performance of aviation maintenance technicians. Recommendations for better understanding and management of the work environment were offered during formal presentations, during ensuing discussions, and during a final session directed specifically to conclusions and recommendations. The following recommendations represent a grouping and synthesis of broad topics considered important by attendees, with specific recommendations included within each topic.

Physical Parameters

The term "work environment" most readily brings to mind the physical features of the work setting such as lighting conditions, noise levels, ambient temperatures, vibration sources, and atmospheric composition. In air carrier maintenance, the three considered most important for worker proficiency are lighting, noise, and temperature.

While a perfect work environment would be desirable, the nature of aircraft maintenance means that certain features of the workplace will be less than optimum. Maintenance takes place, for the most part, in large hangar facilities that must hold aircraft, test stands, and maintenance equipment. Since aircraft must be moved in and out of a hangar from time to time, environmental control can never be perfect. In addition, some maintenance, particularly at line stations, must be conducted outside where technicians are at the mercy of the elements.

Maintenance managers recognize that the environmental conditions under which maintenance is conducted are not perfect and work on programs of continuing improvement. All airlines have individuals responsible for safety conditions. Larger air carriers maintain safety departments and participate with unions on safety committees. Discussions may include topics such as heating problems, use of proper job clothing, and any other matters designed to minimize problems with the physical environment. Nonetheless, the nature of the work and the environment mean that certain problems remain.

Lighting Conditions

Inasmuch as maintenance is conducted on maintenance benches, at test stands, on external surfaces of the aircraft, within the aircraft hull, and beneath aircraft wings means that lighting conditions vary dramatically. An FAA audit of major air carriers included a survey of lighting conditions and found a variety of lighting systems in use, including mercury vapor, metal halide, and high-pressure sodium lights. Although these lights differ in color rendition, the principal problem was with level of illumination. For work performed on upper and lateral surfaces of the aircraft, illumination levels were deemed adequate. These levels average to 66 foot candles (ft-c) during the day and 51 ft-c for night maintenance work. For work conducted below wings, inside the fuselage, and in cargo areas, illumination is poor and use of supplemental lighting systems was noted. However, these frequently were placed too far from the work being performed and were too few in number. The result was that illumination levels in shielded regions ranged, on occasion, from one to about 10-14 ft-c. In terms of recommended minimum illumination levels for aircraft repair and inspection tasks established by the Illuminating Engineering Society, these levels are not adequate. A minimum level of 75 ft-c is recommended for repair tasks.

Recommendation

1. The adequacy of illumination may well be the most important environmental issue affecting maintenance performance. This is particularly true for maintenance tasks which must be conducted within relatively inaccessible parts of the airplane. Further studies should be made to determine the significance of current illumination levels and to identify optimum lighting procedures for use within and under aircraft. Recommended solutions should be equally feasible for major air carriers and for the smaller regional/commuter airlines.

Noise

Noise levels during air carrier maintenance generally are quite acceptable. Average levels within hangar areas, measured by the FAA Audit Team noted above, were found to range typically from 70 to 75 dBA. This is acceptable for an industrial environment and does not require hearing protection. However, when riveting or other pneumatic tools were being used, levels about 90 dBA were recorded and levels in excess of 110 dBA can be produced. Exposure at this last level, without hearing protection, should not exceed 12 minutes in an eight-hour day.

Excessive noise is a concern for additional reasons at regional/commuter airlines. In the regional industry, geared engines with propellers are the mainstay of the fleet. These aircraft operate at a high decibel level and can increase the possibility for hearing impairment when aircraft taxi and run-up operations are conducted near the maintenance hangar.

Recommendation

1. Work in air carrier maintenance areas generally does not require hearing protection. Noise as an environmental stressor does not typically impact maintenance proficiency. However, under those conditions, particularly in regional airline maintenance, where noise levels can exceed 85 dBA, care should be taken to ensure that appropriate hearing protection is provided and used. There are two reasons. First, proper protection will allow the work to be done more comfortably and possibly more accurately. Second, the technician will not have a history of being exposed to noise sources in excess of 85 dBA. Claims for hearing loss suffered in industrial operations represent a leading category of claims under workmen's compensation and a major cost item for industry.

Work Support Systems

The term "work support systems" refers principally to a variety of structures used by technicians to gain access to different parts of the airplane. These structures include the maintenance hangar itself and proceed through scaffolds, ladders, stools, and "cherry pickers." The underlying purpose of all of these systems is to allow direct access to aircraft components and, hopefully, to make the work easier and safer. Some structures are sophisticated and allow on-the-spot adjustments in height and lateral position. Some major airlines use massive scaffolding systems that move and essentially enclose a large aircraft, thereby allowing direct and safe access to parts such as the vertical stabilizer.

There are problems with existing work support systems. In some instances, a workstand will require a technician to work in an awkward position, thus tending to produce increased fatigue. The cherry pickers have the problem of inherent instability which becomes a safety concern and also increases the difficulty of detailed visual inspection. The application of torsional forces during maintenance also can be a problem when working from a platform of diminished stability.

Recommendation

1. The procurement of work support systems by air carriers, including majors and regional/ commuters, would benefit from a set of human factors standards for these systems. The standards should address stability requirements, use of proper anti-skid work surfaces, the need for and recommended features of worker harnesses and restraints, and the inclusion of emergency warning and escape features. A careful review should be made of accident data supplied to the Department of Labor (USDOL) and the Occupational Safety and Health Administration (OSHA) as the standards are developed. The human factors standards should be reviewed and approved by representatives of the air carriers before being adopted as industry standards.

Workplace Variables

Changing Nature of Maintenance

Aircraft coming on-line with both major carriers and smaller airlines are different in many dimensions from those entering service 10 to 20 years ago. A major difference is in the growing use of composite materials. These materials use reinforcing fibers or filaments embedded in a resin matrix and offer both increased strength and lighter weight over the more common metal structures. While composites have been used in aviation for almost 20 years, newer aircraft such as the Boeing 757 and 767 and the AirBus A310, are expanding the use.

Inspection and repair procedures for composite materials differ from those used with metals. There is no single propagating crack as in metals. Instead, the damage is characterized by matrix cracking, fiber breakage, and delamination, all of which contribute to component failure. Inspection procedures and inspection equipment developed for metal failure modes must be changed significantly for use with composites.

Another change in maintenance practices arises from the broad use of digital electronics in aircraft systems. Digital electronics no longer are concentrated in avionics components such as the autopilot, navigation, and communications systems. In a discussion of the AirBus A320 aircraft, the observation was made that "One can say there is no more purely mechanical system on this aircraft. Mechanical forces are translated into electronic bits from the command to the actuator; there is no more lever or command which is not connected to a computer." Further, these digital systems were described as being so interconnected that troubleshooting must be accomplished on a system-wide basis rather than as a simple isolated task.

Features incorporated into aircraft such as the A320 are very important for maintenance practices and philosophies. The distinction between aviation mechanics and avionics technicians is becoming blurred. Aviation maintenance technicians (AMTs) now must extend their skills well into the field of avionics if they are to be able to do their job with greatest proficiency. Indeed, in the future mechanics and avionics technicians will tend more and more to do the same job. This has great implications for training, job design, and personnel management.

Recommendations

1. The occupational specialty of aviation maintenance technician must change as the requirements underlying maintenance and inspection of new and advanced aircraft change. As new job requirements evolve, those responsible for the training of maintenance technicians and those responsible for regulatory oversight of maintenance must work from a different script. To remain apace of these changes, the Federal Aviation Administration (FAA) should maintain a continuing review and update process for Parts 147 and 65 of the Federal Aviation Regulations (FARs). These parts cover the curricula for technical training schools and the certification of mechanics and repairmen, respectively.
2. Blending the skills of maintenance technicians and avionics technicians raises the skill requirement for the individual technician. This increase in requisite skill level may serve to lessen the supply of candidates. This fact, coming at a time when analyses of population dynamics shows the supply of technician candidates may be minimal in any event, could have serious and negative impact on the ability to staff air carrier maintenance operations. For this reason, the recommendation made at the conclusion of the Fourth Human Factors Meeting on "The Aviation Maintenance Technician" is reaffirmed. This recommendation states that "Some organizations such as the Professional Aviation Maintenance Association (PAMA) or the Future Aviation Professionals of America (FAPA) should undertake, with blessings from the FAA and financial support for the airline industry, a detailed manpower modeling study of the aviation maintenance technician occupation as it is likely to change over the next decade."

Work Schedules

The nature of airline operations, with the heaviest demand for aircraft during daylight hours, necessarily means that considerable aircraft maintenance must be done at night. The questions arises, will maintenance done by those on the night shift be of comparable quality to that done by day workers? Research findings tell us that night shift workers inevitably sleep less than those working during the day. This leads to a chronic sleep deprivation condition and one would predict an increase in fatigue, accidents, production defects, worker dissatisfaction, health issues, and other problems. However, measures of subjective fatigue show no differences between night workers and day workers. Laboratory performance tests, on the other hand, show that day shift workers perform better than night shift workers.

The above findings indicate that the performance of those working on the night shift may not match the performance of day workers. However, the difference may be slight and may not be noticed, either by management or by the workers themselves. Considering the number of quality checks routinely applied to maintenance operations, a slight decline in proficiency at night may be of no operational significance. However, management should be aware that it probably exists.

Recommendation

1. Research conducted on the efficiency of industrial shift work shows that differences do exist between the quality of day work vs. night work. However, no fixed guidelines are available for determining the best shift work arrangement. If problems seem to exist, the best solution is one in which management and workers examine the issue together, outline available options, and decide on the best course of action. In any event, any changes made in shift work and work schedules should be evaluated periodically. The simple fact of a change may produce temporary benefits, but a real evaluation will require some months.

Paperwork Requirements

The Federal Aviation Administration must rely on recordkeeping as an essential index of the adequacy of maintenance in commercial air carrier operations. This is true for the major carriers; it is equally true for air taxi operators. Records maintained by air carriers must be available and up to date. From the FAA perspective, proper recordkeeping must rank in importance with proper maintenance of the aircraft itself.

Aviation maintenance technicians view recordkeeping somewhat differently than does the FAA. While technicians recognize the need for and importance of documenting maintenance procedures, they question the burden imposed by paperwork and the serious amount of time spent in meeting paperwork require- ments. In one example described at the meeting, an aircraft ready for release for a 7:30 a.m. flight was delayed in its release until 10:30 a.m. by the requirement to complete paperwork prior to release. This is not efficient.

The simple volume of paperwork also constitutes a problem. In one instance described at the meeting, approximately 80 pages of paperwork were generated to accomplish two AD notes concerning the tailcone release on the DC- 9 and the DC-9-80 aircraft. The result was that technicians were unable to deal with the many instructions within these 80 pages and finally discarded them and proceeded with the work. When the work was completed, a non-routine card was written stating "Accomplished project per the maintenance manual." This defeats the purpose of generating the maintenance data.

Recommendations

1. The issue of the volume of paperwork required to support air carrier maintenance has been raised a number of times. This issue in all likelihood will never be resolved completely since the interests of the FAA on one hand and the aviation maintenance community on the other differ significantly. However, improvements can be made. Consideration should be given to introducing more flexibility into current procedures. Unless compelling reasons exist not to do so, mechanics might be authorized to release an aircraft on their own signature with a fixed deadline following this for completion of required paperwork. Airline operations would benefit.
2. The management of maintenance paperwork would benefit through increased standardization. The FAA should consider developing a standard set of paperwork requirements for each airplane. This would remove differences associated with paperwork identified by individual airlines and with the need to conform to the requirements of each individual FAA region.
3. Much of maintenance recordkeeping now is being processed through computers. While this increased automation carries many benefits, it does present problems. One is that maintenance technicians now must spend considerable time inputting information into the computer. A study of the technician/computer interface is recommended to develop procedures for minimizing the time required for data input.

Automation

A program of continuing improvement in maintenance requires increasing use of automation. Automation supports maintenance proficiency and leads to improved performance and availability of aircraft. Automation can bring significant economic benefits. The major air carriers are developing automated systems as rapidly as feasible. These systems cover everything from writing manuals, revising manuals, handling AD notes, specifying repair processes, and assessing the technology of new aircraft. Computer data bases now store and supply technical information required for all phases of aircraft maintenance. Computer-aided drawings in a three-dimensional format now can be incorporated into maintenance text.

Automation makes synchronized maintenance production more achievable. One presentation at this meeting described development of a "focused repair center" in which different engine parts are handled within one shop with all activities carefully coordinated. In this system, all tooling and equipment used for refurbishing components is under computer control. All completed components come together as required for reassembly. Studies show a dramatic reduction in maintenance costs through use of this type of automated repair center. Another benefit is a continuous flow rather than a segmented routing time, which results in reduced cycle time. Also, since one group of technicians is responsible for the entire process, a sense of ownership in the process is developed.

Recommendation

1. Increased automation in air carrier maintenance benefits everyone. Means should be explored, possibly through committees of the Air Transport Association (ATA), to ensure that the technology being developed at this time at major air carriers can flow freely and expeditiously to regional/commuter carriers. The ATA committee should also work to develop means whereby major carrier technology can be applied at the regional/commuter level without tremendous expense.

Worker Productivity

Work Teams

Considerable research has been done to determine those variables in industrial operations that affect both individual and organizational productivity. Progress has been made in defining organizational variables that do influence productivity. One of these is *team identification.* A presentation by Major General Albert G. Rogers, entitled "Organizational Factors in the Enhancement of Aviation Maintenance," addressed this topic at the Fourth Human Factors Meeting. Presentations at the present meeting elaborated on this theme.

Team identification is a form of decentralized management. Team members participate in the development of production goals, to the extent feasible, and make decisions concerning the best ways to achieve these goals. Goal interdependence means that the team has a clearly defined mission and individual team members feel that their individual goals and the group goals are consistent. There also is workload sharing. While everyone needs to pull his/her own weight, there must be a mechanism to ensure an equitable distribution of workload. Studies in the military and in industry indicate that the development of production teams and team identification does result in increased productivity.

Recommendation

1. Air carrier maintenance managers should review maintenance operations to determine the extent to which work teams exist now and ways in which this concept might be fostered. To the extent that work teams can be defined and team identification established, maintenance productivity could be enhanced. Use of the team concept, however, involves delegation of certain authority to the team as well as a large measure of responsibility for its success.

Safety and Health in the Workplace

Safety and Health Initiatives

Recognition of the need for proper safety and health procedures in the workplace is very important. Congress did so in 1970 through passage of the Occupational Safety and Health Act (OSHAct). Just prior to the formation of OSHA, there was one fatality for each 6,000 people at work. By 1988, the rate of fatalities had fallen to one for each 19,000 workers. This is an impressive improvement but the record of U.S. industries in safety and health still is not perfect.

Violations of good safety and health practices do more than simply add additional expenses to industry and to the country. Workers who are injured or ill cannot perform and organizational productivity decreases. A maintenance work shift not fully staffed slows the tempo and can adversely affect flight operations and, in turn, company revenue. There are many reasons to work toward a safe and healthy workforce.

Major air carriers maintain industrial hygiene departments to oversee safety and health policies and practices. Regionals generally have smaller groups or individuals responsible for these matters. For all of these programs to be effective, however, employees must "buy into" industrial hygiene programs. Training and procedures designed to reduce the likelihood of injury or illness will not be used or followed if employees do not have proper safety attitudes. Management should maintain continuing educational programs to stress the need for proper safety and health practices. Employees should: (1) use protective equipment; (2) read information on chemical hazards; (3) ask questions when in doubt; and (4) keep informed on changing conditions.

Recommendation

1. Every airline, of whatever size, should have a standard operating policy which establishes a joint management/labor health and safety committee. This committee should meet on a regularly scheduled basis and have appropriate authority to review health and safety issues in the workplace and to mandate changes as necessary.

Reference

Miller, D.P. & Swain, A.D. Human error and human reliability. In G. Salvendy (Ed.), *Handbook of Human Factors.* New York: John Wiley & Sons, 1987.