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OPERATIONAL IMPLICATIONS OF AUTOMATION IN ADVANCED TECHNOLOGY FLIGHT DECKS

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INTRODUCTION

1.   This digest presents the Human Factors implications of automation and advanced technology flight decks. The purpose of the digest is to identify operational and training issues, and to provide an understanding of the problems in the interface between humans and automation, with emphasis on the way in which automation affects human performance. It is primarily directed to training managers and operational personnel, but pilots and other operational personnel will also benefit from this digest, as will regulatory authorities.

2.   This digest has an operational orientation, and it does not address issues of equipment design and certification. A special digest on flight deck and systems design will be published later, and it is expected that these two digests will contribute to the understanding of the problems faced by operational personnel when new technology is introduced.

3.   Automation has been gradually introduced in flight decks (and in the aviation system) over time. Flight deck automation has made aircraft operations safer and more efficient (a one per cent reduction in fuel consumption translates into annual savings of $100 000 000 for the IATA carriers of one particular State) by ensuring more precise flight manoeuvres, providing display flexibility, and optimising cockpit space. In the interest of flight safety, however, this digest focuses on actual and potential problems and issues. This is because of the need to define and understand these problems, and it is not intended to be a reflection on the technology itself. To keep a proper perspective, it must be unequivocally stated that, in the long run, the benefits of automation far outweigh the problems.

4.   Although there is still no international consensus regarding the proper use of automation, there is no question that the reduction in accidents related to human error can, in part, be explained by the introduction of automation on the flight deck. However, the record also shows that failures of automatic equipment, and, more frequently, mismatches at the human-equipment interface, remain as crucial links in the causal chain of accidents and incidents.

5.   One of the reasons for the introduction of automation was the elimination of human error. So far, it has been successful in the elimination of certain type of errors. But in other cases, what has taken place is a displacement of error. Experience indicates that while automation may eliminate small errors, it may increase the potential for large errors. These are examples of the messages which this digest attempts to convey.

6.   This digest comprises the following:

  – Chapter 1 presents the history of automation in aviation, proposes a definition of automation, addresses the evolutionary nature of automation, and stresses the need for an automation philosophy.
  – Chapter 2 addresses some of the problems of automation and illustrates what worked and what did not with regard to the expectations for automation.
  – Chapter 3 refers to the training of operational personnel with special emphasis on flight crew training.

     –   Chapter 4 refers to management techniques and coping strategies, other than training, which have been or can be employed to solve automation problems.

     –   Appendix 1 includes the field studies in automation completed to the present date.

     –   Appendix 2 presents the Automation Principles elaborated by Wiener and Curry in 1980.

     –   Appendix 3 presents an example of automation philosophy, as proposed by one operator.

     –   Appendix 4 presents a list of recommended reading.

7.   This digest was produced with the assistance of the ICAO Flight Safety and Human Factors Study Group, and especially of its advisor Prof. Earl L. Wiener of the University of Miami and NASA Ames. Additional sources of information included the Report of the NASA/Industry workshop "Flight Deck Automation: Promises and Realities" (Susan Norman and Harry Orlady, editors; August 1988), and the document "Training for Advanced Technology Aircraft", by Study Group advisor Capt. Harry Orlady, July 1988.

8.   Four other Human Factors digests have been published by ICAO:

     –   Digest No. 1 — *Fundamental Human Factors Concepts* (Circular 216);

     –   Digest No. 2 — *Flight Crew Training: Cockpit Resource Management (CRM) and Line-Oriented Flight Training (LOFT)* (Circular 217);

     –   Digest No. 3 — *Training of Operational Personnel in Human Factors* (Circular 227); and

     –   Digest No. 4 — *The Proceedings of the ICAO Human Factors Seminar at Leningrad* (Circular 229).

Chapter 1

AN INTRODUCTION TO AUTOMATION

1.1   The Oxford dictionary defines automation as "automatic control of manufacture of product through successive stages; use of automatic equipment to save mental and manual labour." For the purpose of this digest, the following definition of flight deck automation is proposed: "the assignment to machinery, by choice of the crew, of some tasks or portion of tasks performed by the human crew to machinery. Included in this definition are warning and alerting systems that replace or augment human monitoring and decision-making (this may not be at the choice of the crew, but preassigned, such as systems monitoring, flight status monitoring, fire detection)."

1.2   Automation was initially aimed at stabilizing aircraft attitude through the control of aerodynamic surfaces. This need was met with gyroscopic devices, which were used in the maintenance of attitude for all spatial axes (aircraft inner loop control[1]) for many years. During World War II, vacuum-driven gyroscopes, which also provided information on heading and attitude in the flight deck, were intensively used to provide better information, alleviate fatigue, and reduce manual control requirements.

1.3   Progress was fast after the war. Electrical systems and electronic amplifiers replaced vacuum-driven gyros. The introduction of very high frequency omnidirectional radio range (VOR) transmitters and the instrument landing system (ILS) permitted the coupling of autopilots to the output signals of this equipment and track radials, localizer and glide slope beams. Precise data regarding external references, integrated into the autopilot system, enhanced outer loop control[1]. This was the prevailing state of the art when commercial jet transports were introduced in the late 1950s.

1.4   The increase in speed and altitude capability of these new transports required a more accurate inner loop control — especially at high altitudes — as well as more precise flight instruments. Yaw dampers, to damp oscillations as well as to prevent the tendency to yaw away from banked turns, and Mach trimmers to counteract the tendency to pitch down at high Mach numbers, were introduced during this period, and are good examples of automatic devices used without crew intervention. The introduction of flight directors[2], which integrated attitude and navigational information into a single instrument, provided better inner loop control, but at the same time raised concerns about pilots losing sight of the 'raw data' from which the information was derived.

1.5   Advances in solid-state electronics during the 1960s fostered the appearance of autopilot and flight director systems which made automatic landings possible, and allowed the integrated control of power and flight path through autothrottle systems. Reported difficulties by flight crews in learning to operate the more complex aspects of these systems led to the requirement to demonstrate proficiency in their use during pilot certification, whereas previous requirements emphasized the ability to operate without these aids. The

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1. There are two levels of systems management which must be considered in flight deck design: *aircraft control* (inner loop, exercising psychomotor skills), and *aircraft monitoring* (outer loop, demanding cognitive abilities).
2. Flight directors gave, for the first time, "command information". The raw data were available to the pilot, but it was not always used as a check or monitor of the integrated information presented by the flight director.

ground proximity warning systems (GPWS), and, more recently, the airborne collision avoidance system (ACAS/TCAS) represented a further extension of the concept of 'automated commands' advising the pilot to manoeuvre the aircraft, rather than using automation merely to maintain aerodynamic or navigational control. This philosophy of automated pilot advisory/warning prevails today in wind shear advisory and collision avoidance systems. The introduction of area navigation (RNAV) and four-dimensional flight management systems integrated with the autopilot increased the level of automation complexity prevailing in civil transport aircraft. It also expanded the capability of aircraft and air traffic control (ATC) to use airspace more effectively.

1.6　　　　Economics, including the goal of reducing flight deck workload to permit safe and efficient utilization of two- rather than three-person crews, was a major driving force behind the next major step in flight deck automation: electronic cathode ray tube (CRT) displays and automated system management devices. (The relationship between automation and workload has yet to be established, however, and it is incorrect to accept as a general statement that automation reduces workload, since there are conditions under which the very opposite occurs.) The reduction of human error by monitoring the human management of aircraft systems and flight control was another major objective, as were optimizing flight performance and managing fuel consumption. Operationally, the new systems enabled vertical and horizontal automated navigation and guidance, as well as completely automatic thrust management. Yet the implications of this new technology were only beginning to be understood. As these aircraft were introduced, it was soon evident that the ATC system was not adaptive enough to permit full use of the capabilities of the newer aircraft flight management systems (FMS).

1.7　　　　The recently introduced new aircraft (747-400; MD-11; A320) are equipped with advanced forms of automation, whose control systems incorporate logic to prevent the aircraft from exceeding its safe operating envelope. Through microprocessor technology, navigational tasks and aircraft system management have been automated, making the flight crew more peripheral to the actual operation of the aircraft. Pilots who at one time had direct authority over all aspects of aircraft control and management have now become responsible for the management of complex hardware and software interfaces, through which they are required to direct the operation of the aircraft (see Figure 1). These technological advances, however, have given rise to new forms of error. Questions have arisen about the complexity of control and display units (CDU), and elimination of the CDU keyboard data entry has been considered, although it might be difficult to find a suitable replacement.

1.8　　　　Furthermore, latest generation aircraft include drastic evolutions in the field of information exchange between crew and aircraft. The amount of information exchanged has increased considerably: for example, more than 200 checklist items can be displayed on the Electronic Centralized Aircraft Monitor (ECAM) CRT of an A320. At the same time, crew/aircraft interfaces have been highly concentrated and integrated, with the same interface unit now shared by crew and aircraft to exchange immense quantities of very diverse information. CRT displays in electronic flight instrument systems (EFIS) technology have allowed multiple source information to be combined and displayed in a highly synthesized form, presenting four basic pictures of aircraft status: primary flight path control; navigation; engines and flight controls monitoring; and systems monitoring. The conventional control wheels, throttles, knobs and buttons have been replaced as the primary means of information transfer between aircraft and crew. Their function has been assumed by a flight control unit for short-term, real-time (tactical) instructions and a control display unit for long-term (strategic) data input.

EVOLUTION OF TRANSPORT AIRCRAFT AUTOMATION

Increasing peripheralization of the pilot
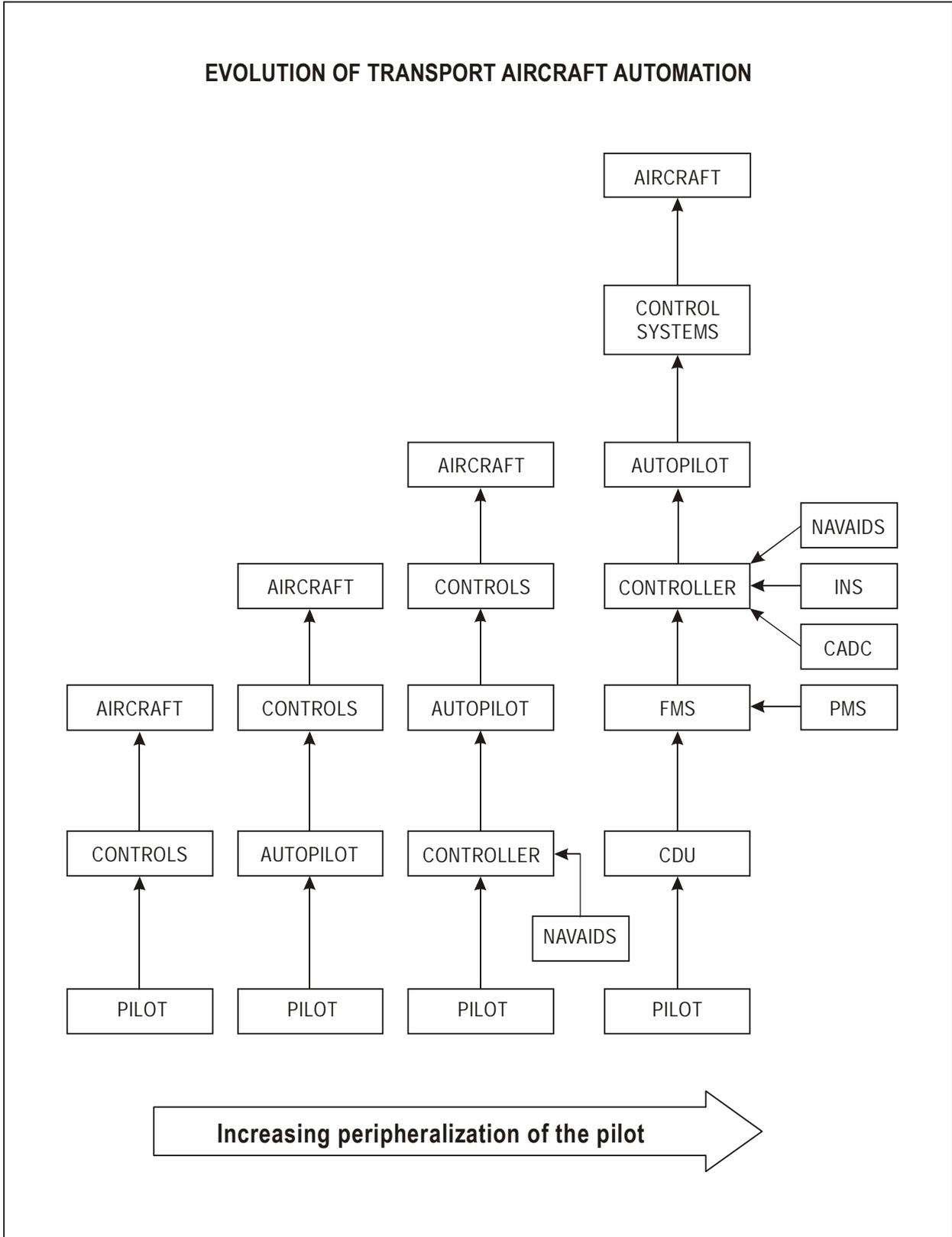
Figure 1

1.9   Although this last step in flight deck evolution does not fall within the scope of the definition of automation presented in paragraph 1.1, it is associated with the issues discussed in this digest. Indeed, it is often difficult — and rather artificial — to separate automated processes from their related processes of information exchange. Furthermore, advanced or 'glass cockpit' technology tends to generate Human Factors-related problems similar to those encountered in automation (over-reliance, human displacement, etc.)

1.10   Some mention of the reasons behind flight deck automation has already been made in the preceding paragraphs, and the subject can be expanded as follows:

- *The availability of technology,* mainly through the explosive growth of microprocessor technology. The increased speed and capabilities of jet aircraft, the growth in air traffic, the costs of an accident (in terms of human life and liability), and the recognition of human limitations are some of the reasons for which machine assistance was sought. It is worth noting that while some of the promises of automation were soon realized, many of its problems have only recently been recognized.

- *A continued concern for safety*, as a consequence of the persistence of human error in accident and incident reports. The goal was to remove error at its source — to replace human functioning with device functioning (Figure 2). However, the devices have to be monitored by humans, and humans are at best poor monitors. The interface between humans and devices has the potential to generate errors which can result in accidents, and in some cases the automated devices have succeeded only in relocating error rather than in eliminating it. The extent to which over-all safety has been improved is thus still debated in many circles.

- *The goal of enhanced economy*, through improved navigation and over-all flight and fuel consumption management. *Reliability and ease of maintenance* can be included under this heading. Generally these have been quite impressive in the new generation aircraft.

- *The attempt to reduce workload and thus crew complement*, allowing the introduction of wide-body aircraft requiring only a two-pilot crew. Automation was seen as one way to reduce flight deck workload, but experience suggests that, while a reduction in manual workload has been achieved, mental workload has not been reduced by the same amount. In fact, it may have been increased. Operational experience also suggests that automation may not always reduce workload in those phases of flight in which it is usually high, for example, arrivals and landings at busy terminals.

- *The goal of economy of cockpit space,* by taking advantage of the flexibility in displays and controls allowed by digital systems. More information can be made available to both the flight crew and ground stations.

1.11   One conclusion of relevance is apparent for operational personnel: the implementation of automation has been incremental in nature (or *evolutionary*), rather than following a global or systems level design strategy (*revolutionary*). This means that the development of independent components led to their

Boeing Flight Deck Design Committee

Examples of accident data reviewed

• Subsystem management accidents – world-wide air carriers 1968-1980

Accident-related cause	*Design*
• Crew omitted pitot heat	• Auto on with engine start
• Wrong position of standby power switch	• Automated standby and essential power
• Flight engineer and captain conducted unauthorized troubleshooting	• Simplified systems delete maintenance functions
• Electrical power switching not co-ordinated with pilots	• Auto switching and load shedding — no crew action required
• Flight engineer shut off ground proximity	• Shut off on forward panel in full view of both pilots
• Faulty fuel management	• Auto fuel management with alert for low fuel, wrong configuration and imbalance
• No leading edge flaps on take-off	• Improved take-off warning with digital computer
• Confusion over correct spoiler switch position	• Dual electric spoiler control
• Crewman did not follow pilot's instruction	• Full-time caution and warning system
• Mismanaged cabin pressure	• Dual auto system with auto switchover

Allocation of 747-200 flight engineer's duties to 747-400 flight crew
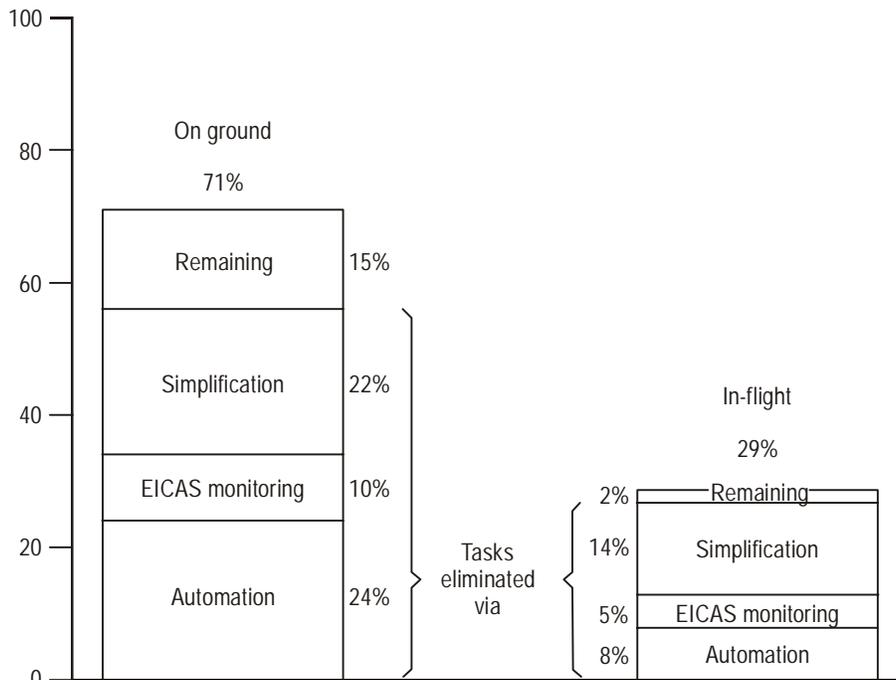
Figure 2

progressive introduction into the flight decks when they were available, slowly building up to present-day level of automation. When progress in gyroscopic stabilizer technology enabled attitude control, for instance, this piece of automation was introduced into the flight deck, surrounded by non-automated instrumentation and controls. When control and fuel management through systems became possible, performance data computers/control systems were retrofitted to electro-mechanical flight decks. When development of ground-based systems enabled it, automated navigational control (e.g. the autoland system) was duly introduced; finally, when microprocessor and CRT technology allowed it, 'glass cockpits' were introduced. Presently, efforts are being directed to the integration process discussed in paragraph 8 (Figure 3).

1.12   In academic terms the above is known as a *technology-centred approach*, as opposed to a *human-centred approach*. In a human-centred design the human is the central element in control and management of the system, and automation is present to assist the crew. To a considerable extent, the value of automation is the degree to which it just does that. This difference between the human-centred and the technology-centred approaches has relevance, because there is no co-ordinated philosophy of flight deck automation. Experience suggests that many problems associated with the introduction of advanced technology onto the flight deck of commercial aircraft arise from the lack of a consistent, co-ordinated philosophy (Figure 4). Such a philosophy would consist of device-independent guidelines, so that each new device, operating technique, doctrine or training programme can be held against a 'template', rather than designed, implemented and defended anew.

MD-11 Cockpit Automation

TYPICAL AIRCRAFT SYSTEM	*MD-11 SYSTEM*
• Autopilot • Flight director • Auto throttle	• Auto flight system
• Compass system (slaved) • Auto nav – lateral • Auto nav – vertical • Performance (auto speed)	• Flight management system
• Altitude director indicator • Horizontal situation indicator • Engine instruments • Aircraft alerts	• Electronic flight instrument system
• Fuel system • Hydraulic system • Environmental system • Electrical system	• Aircraft system controllers

Figure 3

1.13   Particular operational issues associated with the introduction of automation will be discussed in some detail in Chapter 2. When considering the advantages and disadvantages of the evolutionary nature of the introduction of automation as compared with a hypothetical revolutionary introduction, it can be argued that changes in the task of piloting an aircraft have been of an evolutionary nature throughout the history of commercial aviation. The problems emerging from automation could then be dealt with by the traditional training and operational resources, adapted to cope with this particular demand. (This subject will be discussed extensively in Chapter 3.) On the negative side, one of the assumptions behind a technology-centred approach is that automation will reduce or eliminate certain skill requirements. This is not always the case, and experience indicates that because of the change in the human role, what takes place is a change in rather than a reduction of the skills required. These skills are frequently more demanding: for example, more diagnostic and fault-finding tasks have appeared, and more alternative selection is required. A further possibility is that the skills required by universal automation are simply additional skills.

1.14   There is an established tendency to compare the human and machine, in terms of the functions for which the human is superior to the machine versus the functions for which the machine is superior to the human. The proponents of this comparison argue that in order to plan, design and operate complex systems, human and machine functions should be described using the same set of parameters. This means describing human functions in mathematical terms comparable to the terms used in describing mechanical functions. The fallacy in this contention is that any time human functions can be reduced to a mathematical formula, a machine can be built which can perform the functions better than the human.

PERSPECTIVE

- **Automation** can improve the efficiency, capacity and dependability of the national aviation system

    — BUT —

- **Humans** will manage, operate and assure the safety of the next generation system

    — THEREFORE —

- **Human-centred automation** is the key to system effectiveness

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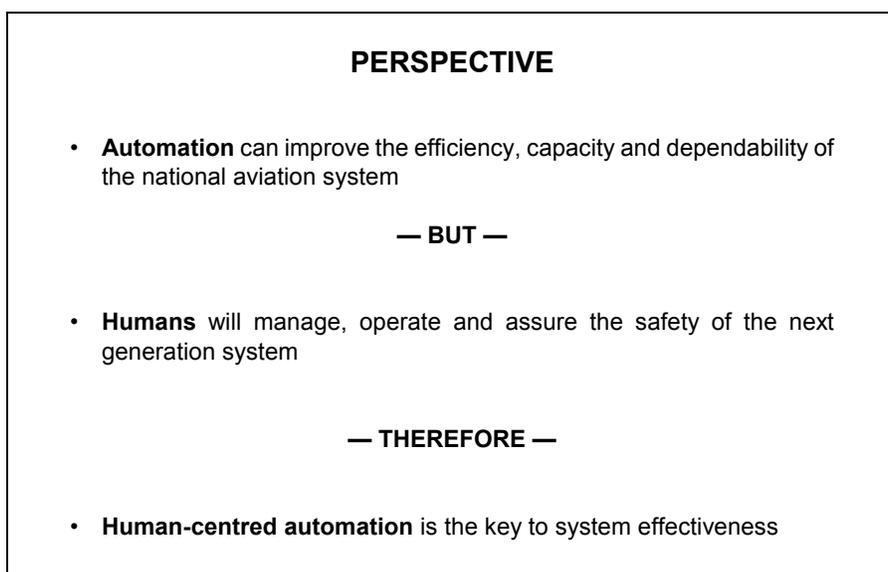
Figure 4

1.15   This digest does not endorse any comparisons, and supports the notion that human and machines are not *comparable* but are *complementary*. Rather than compare the abilities of humans and machines to accomplish a task, one must think about how the human and the machine can complement each other to accomplish the task. Automation should function to *supplement*, not to *supplant*, the human management and control function in civil air transport. The proposal is, then, to humanize Human Factors engineering.

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Chapter 2

ISSUES AND CONCERNS IN AUTOMATION

2.1   There is enough information, both from safety deficiencies information systems and from accident reports, to illustrate the impact of the technology-centred approach to automation. In 1985, the Society of Automotive Engineers (SAE) Human Behavioural Technology Committee (G-10) established a subcommittee to consider flight deck automation. The G-10 comprises pilots, engineers and Human Factors specialists representing airlines, Federal Aviation Administration (FAA), National Aeronautics and Space Administration (NASA), United States Air Force (USAF), Department of Transportation (DOT), National Transportation Safety Board (NTSB) and aircraft manufacturers.

2.2   The G-10 subcommittee on automation held several meetings, during the course of which more than 60 concerns relating to automation were identified. These concerns were grouped into nine categories:

- situation awareness
- automation complacency
- automation intimidation
- maintenance of the captain's command authority
- design of the crew interface
- pilot selection
- training and procedures
- the role of the pilot in automated aircraft
- other issues

2.3   What follows is a further elaboration of this basic list, with special emphasis on those issues which are relevant to operational personnel. An exception is made with the item 'training and procedures', which will be dealt with in detail in Chapter 3.

- **Loss of situational awareness** occurs when a pilot develops, and fails to recognize, a lack of perception or an erroneous perception of the state of the aircraft and its relationship to the world. Shortly after the introduction of commercial jet transports, a Boeing B-707 flying at 35 000 feet over Newfoundland experienced an autopilot disconnect and began a downward spiral. The crew did not detect the uncoupling of the autopilot until well after an initial loss of control had taken place. The crew recovered the aircraft at about 6 000 feet above the Atlantic. About 15 years later, the crew of a Lockheed L-1011 was attempting to diagnose a landing gear unsafe warning light, when an autopilot disconnect occurred — probably because one of the crewmembers bumped the control column — and the aircraft slowly descended from 2 000 feet to crash into a swamp area. The crew was never aware of what was actually happening until it was too late.

- **Loss of systems awareness** occurs when a pilot is unaware of the basic capabilities and limitations of automated systems, or develops erroneous ideas of how systems perform

in particular situations. In 1985, a Boeing B-747 flying at 41 000 feet over the Pacific suffered a partial loss of power in its number 4 engine. The crew took no action, and when the authority of the autopilot to correct the yaw was exceeded, the aircraft first rolled, almost inverted, to the right, then the nose fell through the horizon into an almost vertical dive. The aircraft was recovered at 9 500 feet. The crew initially believed that the unusual attitude shown in their instruments was due to instrument failure. It might be worth noting that the aircraft stayed at an altitude it was unable to maintain on three engines for approximately two and a half minutes before it went out of control. The following report from the Aviation Safety Reporting System (ASRS) data bank also illustrates this kind of problem:

"On take-off roll in Newark, the autothrottles were armed and take-off power was set. Departure control told us to level off at 4 000 feet, which I did. I expected the autothrottles to reduce the power upon level off. They did not. I retarded them manually but they once again advanced to climb power. While fighting a battle with the throttles, ATC told me to turn to a heading of 230 degrees and intercept the 335 radial of Colts Neck VOR, which I did. At this time I disconnected the autothrottles by means of a button on the side of the throttles. This action caused a bright red light on the instrument panel to begin flashing. It is necessary to push the light to extinguish it. While trying to push the light, I accidentally and unknowingly pushed the light adjacent to the flashing red one. This was the Omega Nav system engage switch and it immediately caused the VOR needle to centre. When I saw the needle centred, I made a left turn to intercept what I thought to be the radial 335 of Colts Neck. Shortly thereafter, departure control questioned this action, informed me that I was in LaGuardia's airspace …"

- **Poor interface design**, which results from the system having the capability to adapt to a change in the operational condition (i.e. a change in assigned landing runway), with such a complicated and time-consuming human-machine interface that the system's usefulness is limited when it could be most effective. Poor interface design may combine with the time required for the human to take over from automation (takeover transient) and may become an important factor, by reducing the quality of execution or practice of an event due to lack of warmup. If combined with a lack of situational awareness to create an unsafe condition. Humans normally require the establishment of an appropriate mental set and proper neuromuscular condition to perform at peak effectiveness. The relative inactivity induced by automation reduces human readiness and initial skilled performance. Consider the following ASRS report:

"The autothrottle did not respond (it was armed) to speed decrease when set to IAS/Mach mode. The aircraft levelled off in ALT HOLD mode, but the throttles did not advance, and the airspeed decayed in the length of time that it took me to try and get into VERT SPEED mode (which did not work). I disconnected the autopilot and at about the same instant the stick shaker activated. I manually advanced the power and hand flew the aircraft back on to the glide slope …"

It is interesting to note that it was not necessary to disconnect the autopilot; a manual increase of engine thrust would have been enough.

- **Reversion to manual control** arises from the understandable fear in some pilots of automated aircraft that they will lose basic flying skills. Many pilots elect to fly their aircraft manually in order to maintain these skills. In other cases, however, there may be a reluctance to take over from automatic systems resulting from the fear of having lost the necessary skills. The adequacy (or inadequacy) of training in new airplanes, and of procedures and company philosophy, have an impact in this item. It will be further discussed in Chapter 3.

- **Automation-induced crew co-ordination changes** have occurred because many of the functions previously performed by the crew (observable human behaviour), have been transferred to the computers (hidden, and hard to observe, machine behaviour). A case for the need for improved crew communication can thus easily be sustained. This subject will be expanded in Chapter 3 under CRM and LOFT training. The following report from the ASRS illustrates the point where programming a system took precedence over basic navigation and position awareness:

  "Using Flight Management System navigation direct to DQO, we were cleared to turn left 15 degrees and enter a hold west of PAILS on J42 … while finding PAILS on the chart and writing the hold into the Flight Management Computer the hold was overrun …"

- **Attitudes towards automation** expressed by some pilots indicate a frustration over the operation of automated systems in a non user-friendly environment, although improvements in the human-machine interface would probably reduce this feeling to some extent. This frustration might be best summarized by a question put by pilots: "who is in command, the aircraft or me?" Automation has not been uncritically accepted by the crews, nor should it be. Some aspects of automation are accepted while others are rejected; in some cases because pilots did not operate the equipment acceptably in the real world environment. This was especially true, for example, in some early versions of autothrottles. Some pilots have accepted automation as a whole while others have rejected it. Generally pilots state that they enjoy flying modern aircraft, but still express a concern for safety, because of the opportunities for error introduced by automation. The ASRS example provided under the heading "loss of system awareness" above is also applicable here.

- **Motivation and job satisfaction** involves problem areas such as loss of the pilot's feeling of importance, the perceived loss in the value of professional skills, and the absence of feedback about personal performance. Much has been said about the changing role of the pilot; however, many believe that the basic task of flying passengers and freight safely from A to B remains unchanged, and that automation simply represents additional tools to assist in achieving the task. It should be clear that this issue cannot be solved by using only a series of operational orders or bulletins.

- **Over-reliance** on automation occurs because it is easy to become accustomed to the new automated systems' usefulness and quality — when things go wrong, there may be a reluctance by the crew to disconnect automation (some contend that there is also an element of complacency here). There is also a tendency to use automation to cope with rapidly changing circumstances, even if there is not enough time to enter new data into

the computer. In 1984, a DC-10 overran the runway at New York JFK and came to rest in the mud. The aircraft landed long and fast (touched down at the 4 700 foot point of the 8 000 foot runway) following an automatic approach during which the crew allowed the autothrottle system to maintain a speed 40 knots above the approach reference speed. There were valid airspeed indicators within inches of the limited fast-slow indicator that was being monitored. Overreliance was also identified as a factor in the case of the B-747 high-altitude upset previously described. As another example, a DC-10 stalled while climbing to cruise altitude, in 1979. In this case, the autopilot had been programmed for vertical speed rather than in airspeed mode. Maintaining constant rate of climb, airspeed diminished until engine thrust became insufficient to maintain flying speed, and the airplane entered stall buffet. This was misidentified as vibration in No. 3 engine, which was subsequently shut down. The airplane then stalled, rolled to its right, and lost 11 000 feet before the crew recovered. Consider also the following pilot report from the 1989 Wiener study:

"Captain flying late at night, FL 410 on top of severe weather. EPR malfunction on right engine caused autothrottle to slowly retard throttle. Left engine very slowly went to maximum continuous, but speed dropped off. I noticed speed 20-25 knots below bug speed and advised the captain. Came very close to a stick shaker/stall over a thunderstorm. Need to maintain scan even at cruise."

•   **Systematic decision errors**. Humans may depart from optimal decision practices, particularly under time pressure or other stress. The existence of human biases may further limit the ability of humans to make optimal decisions. One approach to reduce or eliminate biased decision-making tendencies is to use automated decision-making aids at the time decisions are required. In such a system, humans adopt one of two strategies: accept or reject the machine recommendation. The evidence to date suggests that such machine-human decision systems often worsen, rather than improve, decision perform-ance. The inadequate design of procedures may also lead to systematic errors. The crash of the B-737 on take-off from Washington National Airport because of ice buildup on the wings has been used to illustrate a variety of classic human decision-making limitations.

•   **Boredom and automation complacency** may occur because some portions of the flight are so completely automated that pilots are lulled into inattention and are either bored or complacent. In the particular case of complacency, humans are likely to become so confident that the automatic systems will work effectively that they become less vigilant and/or excessively tolerant of errors in the execution of the desired performance. Their alertness may at times falter (see Figures 5 and 6). It is desirable to secure pilot involve-ment and understanding in all phases of the flight, while still maintaining the efficiency of flight that automation provides. Keeping pilots in the control loop, even just at frequent intervals, is better than requiring them to simply monitor the system's operations over long periods of time. Consider the following pilot report from the 1989 Wiener study:

"Relying on VNAV (vertical navigation) to bug back the speed at 10 000 feet automatically leads to complacency. When FLCH (flight level change) is used for descent, I have been substantially below 10 000 before realizing that I am still at 300 knots."

TWO DIMENSIONS OF AUTOMATION: CONTROL AND MONITORING

Piloting an aircraft (and many other tasks in modern systems) involves both control and monitoring. This figure depicts the possibility of different levels of automation in these subtasks (from Wiener and Curry, 1980, p. 1004).

Figure 5

- **Automation intimidation** results in part because of an increase in system components. The result is a reliability problem, since the more components there are, the more likely it will be that any one will fail. However, some pilots remain reluctant to interfere with automated processes, in spite of some evidence of malfunction. This is partly due to inadequate training and partly because of management pressure. The captain's decision to accept and maintain an excessive airspeed, derived from the autothrottle control system during approach, caused a DC-10 to land about 2 800 feet beyond the displaced threshold

of the 9 191-foot, water-contaminated runway at Boston Logan. It overran the departure end of the runway and slid into shallow water. Consider also the following pilot report from the 1989 Wiener study:

*"First Officer was going to land threshold minus 10 knots decreasing, nose up 12 degrees increasing – because it was a practice autoland. We would not only have gotten the tail, but probably would have wiped out. When I told him to take it around he said it was an autoland. I took over and made it from about five feet. An EEC on the right was faulty, which we found out at the gate. **The big factor was his attitude that some computer would do it all and he didn't have to observe the [company's recommended] seven degrees nose up and threshold speed** [emphasis added]. The autosystem is great, but we pilots are the 'break glass' if all else fails and we must put out the fire …".*
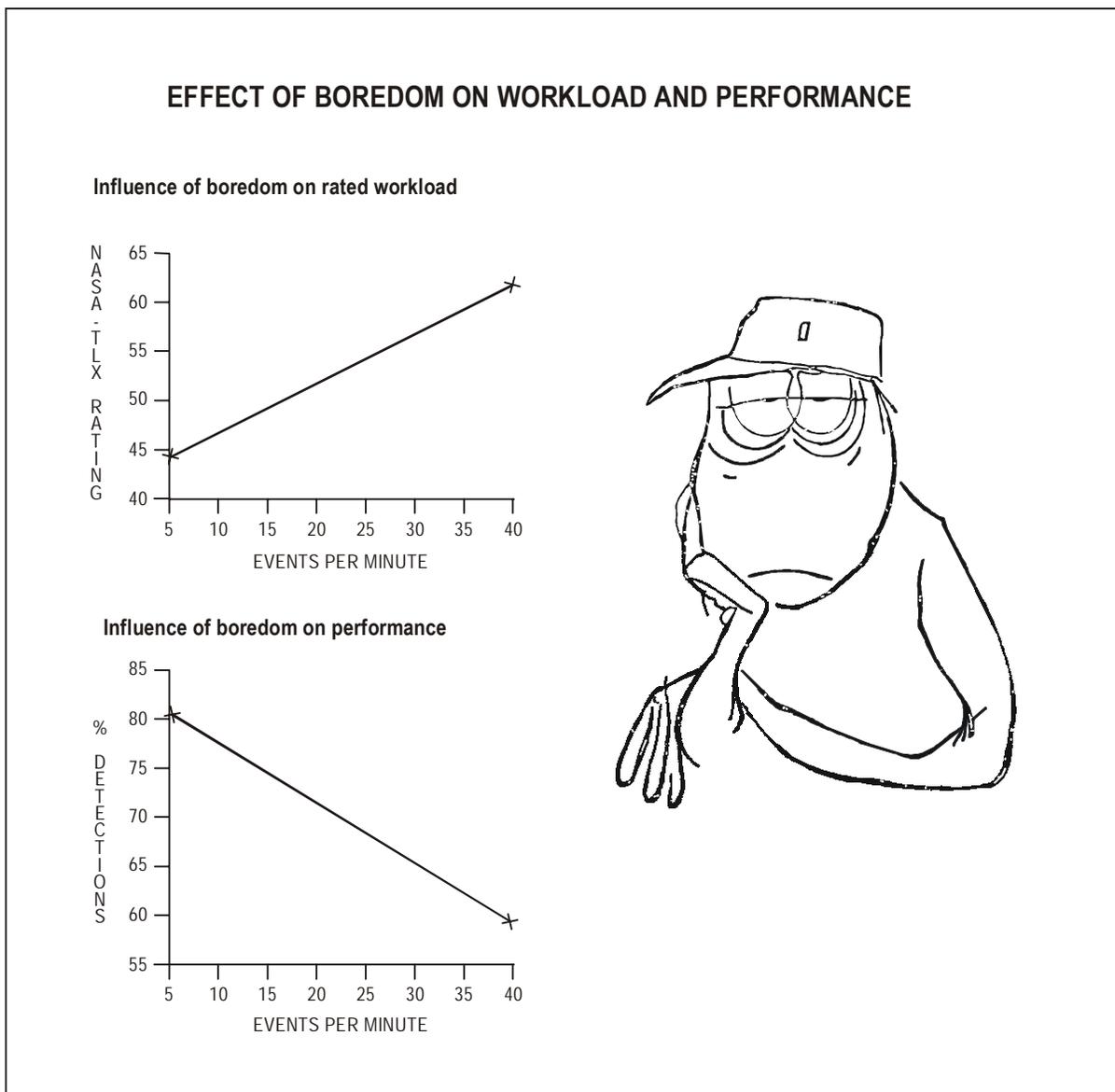
Figure 6

- **Distrust,** because the assessment of a particular situation by the human differs from the automated system. If the system does not perform in the same manner as a human would do, or in the manner the crew expects, or if the human is not properly trained, it would lead to either inappropriate action or concern on the part of the human. This is aggravated by flaws in system design which lead to nuisance warnings, like those which plagued the first generation of Ground Proximity Warning Systems (GPWS).[3]

- **Pilot selection procedures** will need to be re-examined regarding the relative value of flight experience and flying hours. Some contend that automation will lead to less concern for crew selection. In reality, more attention will have to be devoted to selection procedures because of automation in advanced flight decks. Allocations of functions between human and machine will have to be made, based on the knowledge of the implications underlying these allocations. An important aspect of these implications is the set of prerequisites that the pilot must bring to the job so as to fulfil the defined role. This implies the necessity for a re-evaluation of existing selection criteria, or the development of more advanced and specific criteria, to properly screen and recruit the most suitable candidates for advanced technology flight decks. Careful and systematic approaches using validated selection procedures will translate into reduced flight training and into increased operational safety and efficiency.

- **Mode confusion and mode misapplication** are results of the many possibilities offered by automation, as well as by inadequate training. It is possible with the new computer technology for the crew to assume that the aircraft is operating under a certain control mode when in fact it is not. This can also be a training or procedures problem. Mode status and mode changes must always be clearly annunciated to the crew. The number of modes available should not be too great nor should the difference between modes be too subtle. This report from the ASRS data bank illustrates the point:

"The aircraft was climbing to FL 410 with the right autopilot and the throttles engaged and controlling the aircraft. At approximately FL 350 the airspeed was observed to be below 180 knots and decaying. The autopilot was disengaged and the pitch attitude was decreased. At this point the stick shaker activated and a small buffet was felt. Application of full power and a decrease in pitch attitude returned the airspeed to normal. Remainder of the flight was uneventful.

During the climb portion of the flight I believed the autopilot was in the Flight Level Change Mode (max climb power and climbing while maintaining a selected airspeed/Mach). Looking back now I feel the autopilot must have been in the Vertical Speed mode, and not Flight Level Change. If this were the case with 2 500/3 000 feet per minute up selected, then the airspeed would be near normal to about FL 300 at which point the airspeed would bleed off as the autopilot maintained the vertical speed …"

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3. Distrust is one of the biggest factors in system design. If a system is designed so that it will always do what the pilots think it should do, and *never* does what the pilots think it should not do, it is probably a good design (see Wiener-Curry principle No. 1, Appendix II). This point should be kept in mind by certification test pilots, who should not compromise when evaluating a system and its operation.

- **Interface with the existing ATC system** is easily done as long as there are no flight plan changes. However, when changes are required — as they are in every flight — the data entry may take more time than the ATC environment allows, particularly at lower altitudes. The controllers need to understand the capabilities of the newer generation of aircraft (as well, pilots need to understand controllers' dilemmas). With modern aircraft, a course change may not be immediate, because the crew first enters new course data into the flight management computer rather than immediately executing the requested course change. There are also differences between different advanced technology airplanes (A320, MD-11, B-747-400, etc.). System design should permit rapid and easy course changes or direct pilot input for heading, altitude and airspeed changes. The following example, presented by Dr. Wiener (*Cockpit Automation Issues in CRM and LOFT Training*, 1989) illustrates this point:

  "After taking off from SJC and completing the first part of the LOUPE FIVE departure, the following clearance was issued: after Wilson Creek, direct 37 degrees 45 minutes north, 111 degrees 05 minutes west, direct Farmington as filed. When the crew attempted to enter this into the system, they found that the sequence of the clearance did not conform with the format required by the system. After considerable frustration, they found the correct format (on another CDU page) and used it as a model. Why ATC felt the need to issue a lat and lon waypoint instead of a bearing and distance of a nearby VOR (which is easy to enter) is not known."

- **Vulnerability to gross error** due to the fact that automation tunes out small errors and creates opportunities for large ones. A simple example illustrates this point: the digital alarm clock. It can be set very precisely but, unlike the analog alarm clock, it operates on a 24-hour cycle, so a wakeup time can mistakenly be set for p.m. instead of a.m. With the introduction of a digital system, a precise blunder was born: the precise 12-hour error. With increased automation in transport aircraft, most of the gross errors involve improper digital data insertion and monitoring of the FMCS.

- **Workload management**, because workload, especially on the monitoring pilot and particularly at low altitudes in terminal areas, can be very high. Workload may go rapidly from underload to overload, since systems do not necessarily degrade slowly. The advance of automation has been based partly on the assumption that workload would be reduced, but there is evidence to suspect that this goal has yet to be achieved. In effect, data from some of the studies in automation indicate that the pilots' perception is that automation does not reduce workload, since it involves greater monitoring. In the words of one pilot, "… a lot of times we just click it off and go back to manual if the load becomes heavy".

- **Heads-down time** is something that must be studied. It refers to the activities that direct the crew attention inside the flight deck, like instrument scanning, computer programming, chart consultation, etc. These activities prevent the crew from looking at the external surrounding environment. There is concern about the amount of such time spent by pilots, particularly when the aircraft is below 10 000 feet in a terminal area. Significant heads-down time (and workload) is associated with runway reassignments, deviations from

standard arrivals and standard instrument departures, speed changes, and crossing restrictions. All of these are a normal part of today's environment, and all have training, procedural and automation implications.

- **Suitability of the supervision of training**, which raises — among many others — questions about the selection or deselection of automatic devices as the trainee sees fit during training, or as specified by the examiner during verification. It has been proposed that present regulations are not fully responsive to the technical and operational requirements of contemporary operations, and that a review is needed.

2.4   One of the most controversial issues in automated flight decks concerns the role of the pilot. Some argue that the main job of the pilot has changed from being primarily a manipulator of flight controls to a systems manager, while others believe that the basic task of safely flying passengers and freight has remained unchanged, and that all changes have simply been evolutionary. ICAO believes that the latter view is closer to the truth. Today's pilots simply have available additional tools in automation. These new tools clearly represent new challenges.

Chapter 3

TRAINING FOR AUTOMATION

3.1   Pilot training is very important and it is also very expensive. There is no argument regarding its importance, but there is not always agreement on the kind and amount of training required to enable pilots to operate new and different airplanes safely and efficiently.

3.2   The controversy regarding the effect of automation on training is an entirely separate issue. Some claim that automation requires additional skills, while others propose that automation reduces training costs and also reduces the level of traditional flying skills required in older (conventional flight deck) aircraft; in contrast, others propose that one of the greatest misconceptions about automation is that it reduces training requirements. Notwithstanding these conflicting opinions, there is little doubt about the importance of training. The interface between transport aircraft and the pilots who operate them is of great importance, as are the interfaces between the pilot and the manufacturer, procedures, Standard Operating Procedures and company operating philosophies. The purpose of this chapter is to identify some issues that have been raised regarding training in advanced flight deck technology aircraft.

3.3   One controversial issue already mentioned has been the changing role of the flight crew in automated flight deck aircraft. It comprises at least two basic questions:

- Is the pilot a control operator, a systems manager, or both?
- If a difference exists, is it in the pilot's role, or in the elements of that role?

Analysis suggests that the primary role of the transport pilot has not changed at all: since the *goal* is (as it has always been) to complete the planned flight safely and efficiently and with a maximum of passenger comfort, the *role* is to achieve that goal — to fly safely and efficiently from point A to point B. The *functions* still include monitoring, planning, and making decisions in reference to the operations, and the *tasks* are those traditionally performed (communicating, navigating and operating). The question is how best to train pilots for advanced technology aircraft.

3.4   The consensus seems to indicate that, as a general approach, automation should take a greater role in maintaining basic stability and control of the aircraft. Higher-level functions, such as flight planning/pre-planning, system status management and decision-making, should be performed primarily by humans with the help of automation. Training should reflect the increased emphasis on the pilot's decision-making, knowledge of systems, monitoring and crew co-ordination. One point is clear, however: automation has not reduced the need for the basic airmanship skills and knowledge which have always been required of airline pilots. The importance of those fundamentals should be emphasized in the early phases of training, and general aircraft instruction should always precede detailed instruction in automatic features. The training should be sensitive to the varying needs of a pilot population that differs widely in areas such as total flight experience, corporate experience, recency of last transition training, computer literacy, etc.

3.5   One of the lessons learned regarding advanced technology aircraft is that *assessment of training requirements* should be made when a new aircraft type is designed. Determination of the general training requirements needed to enable pilots to operate new equipment safely and efficiently should be

considered an integral part of the design process. These requirements need not be — and probably should not be – very detailed. They should clearly indicate what the designer of the system believes the pilot should know in order to operate that system safely and efficiently. The next occasion to do this would be when the new type is introduced. This gives an opportunity to introduce operational changes, but any inefficient practices existing at the time of introduction will tend to endure. This is the time to appreciate and understand the manufacturers' design and operating intents, since they heavily influence training and operational issues. Those responsible for the introduction of new types, or charged with the responsibility of training development, should possess more background information with regard to the basic design philosophy than was needed in the past. This is important since most of the existing training programmes for new technology aircraft were originally developed for conventional aircraft.

3.6   Careful considerations should be given to the **adequacy of the transition training programme**. The complexity of many of the systems may require a higher level of initial understanding and operational skill than was required with previous aircraft. The basic question is: do pilots, after completing their transition training, have sufficient skills, knowledge and understanding to operate these aircraft safely and efficiently? Although some believe that the traditional high level of manual skills will be required to a lesser extent, greater demands are placed on intellectual or mental skills due to the complexity of the systems and the environment in which they are operated. There is also evidence that routine operation of automatic modes may not provide adequate training opportunities. Flight deck observations have shown that pilots use only a few of the features available to them, because of incomplete knowledge about how to use other features. This says much about the inadequacy of the training and the complexity of the systems and modes.

3.7   **The depth of training** should ensure that pilots thoroughly understand systems interdependencies. This understanding may no longer be intuitively obvious even to highly experienced pilots. Training must provide more specific information about systems than was previously required when systems interdependencies were much less pronounced. The following examples, proposed by Jean-Jacques Speyer, with Airbus Industrie, illustrate this point:

> *"The link between A320 nosewheel steering and the Air Data Inertial Reference System (ADIRS) would have been impossible to achieve in previous design generations. Yet, the conceptual advantage – nosewheel steering sensitivity as a function of aircraft speed — is quite straightforward. As with most automation concepts, however, the benefits are often counterbalanced by an increased need for an in-depth operational understanding which may not be intuitive. A pilot experiencing difficulties with nosewheel steering may need to work through the operation of the steering, the ADIRS and their interactions in order to understand and cope with the anomaly. Similarly, the advantage of linking both pressurization computers with both Flight Management and Guidance Computers (FMGCs) and all three ADIRs on the A320 is that planned and actual flight profiles can be continuously compared for adequate pressurization control in any phase of flight. However, the pilot is then placed in the position of having to understand the interactive system functioning in order to exercise the ultimate accountability function."*

Training time devoted to aircraft operation with the automated system(s) failed would increase pilot confidence in taking manual control early and effectively.

3.8   It must also be remembered that "surface" competence during the normal operation of a new system may well differ considerably from "real" competence which can withstand high stress and high workload. To withstand such pressures, skills need to be overlearned. This is basic knowledge which does not seem to be always applied in practice. In order to obtain the necessary intensive hands-on training, *the value and applicability of part-task trainers* has been recognized. These devices include a high-fidelity simulation of a particular system (or even the actual piece of equipment) which allows the student to concentrate on it without the extra load and distractions which might be imposed by a full flight simulator. They are less elaborate, and can range from large photographs which emulate the flight deck around the simulated system, to sophisticated desk-top computer-assisted training (CAT) devices. Part-task trainers can be highly cost-effective in developing the skills required for efficient system operation. The major drawback of some of these devices — as presently designed — appears to be a lack of functional realism (e.g. at a given point of any exercise, there may be only one allowed sequence of responses, whereas in the real system much more freedom is available).

3.9   *The use of home computers* to fulfill training requirements and for voluntary self-instruction should be explored. There is potential for misuse here, but there is also a considerable potential for fulfilling the needs and desires of pilots, management and authorities. Although implementation may be a particular challenge, experience indicates that some basic computer literacy (i.e. being comfortable with an alphanumeric keyboard) will make transition to new technology flight decks easier.

3.10   *The time elapsed since the last transition training* is an important factor when considering pilots' needs. Flight guidance systems and other automated systems are certainly more complex than in previous aircraft, yet it has been noted that quite often some pilots making the transition to these aircraft had not been to ground school for periods as long as 15 years. This may have contributed to the difficulties of some of these pilots, for whom transition training to new technology may not always go smoothly and may involve higher than expected training costs. *A lack of meaningful operating experience* (which can be quite different than total flight time) should be expected for the period immediately following training. One way to solve this problem may be to expose the flight crews to highly realistic flight situations in high-fidelity simulators. In many countries this is called LOFT (Line-Oriented Flight Training)[4]. Because of the sophisticated equipment, the variety of situations that can be simulated, and the highly technical training methods now available, it enables pilots to gain flight experience (in addition to training) that in some cases may be even better than actual flight.

3.11   Specific issues also related to transition training include the *transition from electromechanical instruments to electronic flight instrument systems*; *training for the loss of all the electronic displays* (the aircraft would be controlled on standby instruments which are essentially the same as those in previous generation aircraft, but the step down in data available is much greater); and the *use of the autopilot, flight management system and mode control panel*. The manner in which these systems allow the flight to be conducted enables the pilot to become detached from the immediate state of the aircraft (position, speed, height, etc.) Crew procedures and training methods must ensure that no automation complacency is fostered by this process, and that the pilot maintains a satisfactory level of situational awareness. The training should be hands-on and line-oriented, and should stress sound practices.

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4. For a complete discussion on LOFT, refer to ICAO Circular 217.

3.12   *Guidelines on the use of automation* should be provided. They should indicate to the crew when to use automation, and, more importantly, when *not* to use it. Even when guidelines are available (usually through company policy or standard operating procedures), they reflect preferred practices in the context of particular operational environments. The existence of such guidelines does not necessarily mean that they are universally applicable, nor is the purpose of this digest to provide them. The objective of this paragraph is only to identify this issue, and Appendix 3 provides an example of one airline's approach to a philosophy of automation.

3.13   In line with the well established practice of programming wind-shear profiles as part of flight simulator training, it might be worthwhile to explore the benefits of *replaying* incidents or accidents where automation has been considered a factor. The flexibility of contemporary simulator-computer systems and the information available from safety reporting systems makes this possible. Similarly, some contend that there is a need to include and review problems and incidents encountered in day-to-day operations.

3.14   The need to monitor should be constantly reinforced, both during training and proficiency checking. The vast literature on vigilance shows, however, that humans are not uniformly effective monitors, and frequently miss system faults or wrong set-ups. This trait is sometimes aggravated by *operations in a low stimulus environment*, such as that found in long-range, "back-of-the-clock" operations. The possibility of more or different training has been raised as a remedy, although it seems difficult to achieve consistent gains in this way. Some attention has been directed to placing more emphasis on creating the sort of stimuli (displays, procedures, additional meaningful tasks) that enhance the pilot's ability to monitor them. It is also a fact that pilots can do specific kinds of monitoring very well – for example, monitoring pilot flying performance during an approach from outer marker to touchdown. Many believe, however, that the influence of systems design must be investigated as an alternative to alleviate the problem.

3.15   *The adequacy of "differences" training* must be considered when a new aircraft is considered "common" with an older aircraft. It is not unusual for some operators to have not only several different flight deck configurations for the same basic airplane model, but also different computers and software. When such a situation is coupled with mergers and fleet integration, the pilots can be exposed to quite different flight deck arrangements in quick succession. Also, *prolonged absence from advanced technology aircraft* may result in a marked diminution of skill. This has been demonstrated to have a greater impact on piloting proficiency than a similar absence from the flight deck of an older technology aircraft. This loss of proficiency is directly related to the operation of the flight guidance system.

3.16   *Requalification training*, when a pilot is returning to a less automated aircraft, must be very thorough. A major training consideration should be deprogramming the pilot's expectations: for example, automatic altitude capture and level off, a common feature of automated flight decks, may not be available on older technology aircraft. Evidence from field studies in automation (see Appendix 1) indicates that pilots are also concerned about the degradation in their cognitive (mental) skills due to the ease of navigation and maintenance of situational awareness using electronic maps. Management should be aware of the potential hazards of these reassignments.

3.17   The need for *standardization and simplification* of all aspects of operation of two-person crew automated aircraft should be given a high priority. Standardization is one of the foundations of safety, and its importance has been accentuated by the appearance of aircraft leasing organizations, airline mergers, consolidations, etc. Flight crews may be faced with different names for the same item, different procedures to operate the same systems, different symbology to display the same information, and all of

this often under demanding conditions. Such problems may also be due in part to the constant improvements in aircraft, their systems and flight deck symbology. Standardization of symbology is receiving considerable and well deserved attention these days. Symbols should be intuitive and their meanings consistent from one system design to the next. Standardization should be emphasized, and this emphasis should be extended to flight operations and equipment manuals, operating procedures and checklists.

3.18   ***Operational procedures and checklists*** should be carefully examined with particular attention to the workload required to perform them. In their operation of two-person crew aircraft, many operators have not reflected the advances that have been made in flight deck technology and in the understanding of flight crew behaviour. Special training considerations should be given to flight crew members making the transition to automated two-person crew airplanes from a three-person crew airplane. The use of Line-Oriented Flight Training as a tool to demonstrate heavy workload conditions is proposed in the following paragraphs. More importantly, LOFT can be an ideal tool to identify workloads which are a product of inappropriate policies or procedures, as considerable flight crew workload can be created by having to perform non-operational tasks at inappropriate times (calls for passenger connections, meal requirements, wheel chairs, etc.). This is not a new problem, but it is more critical in the automated environment and with the proliferation of high density operations. (Some aspects of this problem are being met on many of the new airplanes with separate communication facilities for the cabin crew.)

3.19   It has previously been assumed that **Cockpit Resource Management (CRM)[5] *training programmes*** are model-independent. However, there is increasing evidence that at least some aspects of crew co-ordination and communication in the automated flight decks are qualitatively different from the flight decks of older aircraft. Recent experiments suggest, for instance, that there is a trend towards less verbal inter-pilot communication as the degree of flight deck automation increases. If this hypothesis can be confirmed through research, then customized modules of CRM training programmes should be developed to deal with such differences. These customized modules should also take account of the nature and the needs (culture) of the organization. The following areas of concern in CRM of automated aircraft are the result of observations during actual flights. They indicate that highly automated flight decks may require special scrutiny in the areas of crew co-ordination and resource management, both in the assignment of tasks and the standardization of their performance.

•   *Compared to traditional models, it is now physically difficult for one pilot to see what the other is doing.* For example, in previous generation aircraft the autopilot mode control panel was easily observable by both pilots; in automated flight decks the selections are made in the control display unit (CDU), which is not visible to the other crewmember unless the same CDU page is selected. Proper procedures and intra-cockpit communication appear to be the answers to this problem.

•   *It is more difficult for the captain to monitor the work of the first officer, and vice-versa.* New or revised procedures and intra-cockpit communication are again the apparent answer.

•   *Automation can induce a breakdown in the traditional roles of the controlling pilot and monitoring pilot*, and there is a less clear demarcation of who does what. This is particularly relevant, since it has already been mentioned that standardization is one of the

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5. For a full discussion of CRM, refer to ICAO Circular 217.

foundations of safety. The answer to this problem might be found in procedures and standard operating procedures (refer also to Chapter 4, paragraph 9).

- *Automated flight decks can produce a redistribution of authority from the captain to the first officer*. This is unintended, and is a product of an apparently greater proficiency of some first officers in CDU data entry compared to that of the captains, plus the delegation of these duties to the first officer. Particularly in times of high workload, the captain may surrender some responsibility to the first officer in order to accomplish the task. A somewhat shallower trans-authority gradient[6] may be the result, although captains, recognizing the superior CDU skills of their first officers, may follow good CRM principles and use them to their advantage.

- *There is a tendency of the crew to help each other with programming duties when workload increases, which can dissolve a clear demarcation of duties*. This seems to be computer-induced behaviour, since no similar situation is observed in traditional aircraft.

3.20   Although little is known about **the implications of automation for the design and conduct of Line-Oriented Flight Training**, some particular issues can be highlighted. The automated flight deck offers new opportunities for scenario design. In conventional flight decks it was necessary to introduce system failures to elevate the workload and stress of the crew in a realistic manner, but the automated flight deck has enough built-in stressors to do this job, especially in the area of ATC instructions. The "glass cockpit" presents new opportunities for scenario design that do not require abnormal conditions or emergencies — difficult problems at the human-automation interface will suffice. There now exists the opportunity to design scenarios that will address the problems and opportunities of working in automated flight decks, where their peculiar characteristics can be stressed and where CRM principles can be easily exercised. For example, an ATC instruction including an unexpected, non-depicted holding pattern over a fix defined by a radial/DME value, provides considerable opportunities to practice CRM principles without the necessity of introducing any system failure.

3.21   **Aircraft manufacturers are giving more importance to human performance issues in automated flight decks**. At least one of them has joined efforts with a training development company to integrate present and future training programmes in Cockpit Resource Management into the transition training courses for its aircraft. The manufacturer's instructor pilots will receive CRM training. Current training courses for pilots and maintenance technicians will also incorporate CRM programmes. This particular manufacturer claims that CRM courses to be developed will be airplane-tailored, with a different CRM course for each specific model of aircraft in the production line. The justification for this decision is based on the need to align training with longer-term behavioural education, as well as to concentrate on the assigned duties and responsibilities of the flight crews. Most importantly, it is the tacit recognition that Human Factors education is no longer an exclusive responsibility of the operators, but an integral part of present-day system operations.

3.22   **Adequate instructor/check pilot training is necessary**, and must be emphasized, since some instructors may have only a little more meaningful (i.e. operational) experience and knowledge than

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6. Trans-cockpit authority gradient is the authority relationship between captain and first officer. The term was first introduced by Prof. Elwyn Edwards. For example, in the case of a domineering captain and an unassertive first officer, the gradient will be steep. If two captains are rostered together, the gradient may be shallow.

the students. A strong case can be made for practical experience input to instructor and student training. The need for more emphasis on behavioural issues (CRM and LOFT training) has also been suggested. Though the Human Factors profession has recognized the problem, the issue of instructor training in relation to automation has not yet been properly addressed, and training specialists have no source to consult for guidance on the question of training for automation. Instructor selection and training continues to be determined by the same time-honoured methods and criteria applied for conventional flight decks, although the training issues are quite different on automated flight decks.

3.23 ***The role of the regulatory authority*** in the development of training programmes and instructor training must not be overlooked. During the certification process, the regulatory authority evaluates information presented by the manufacturer. These certification data must be delivered to the operator, since it provides the foundation upon which to build the training programmes. By knowing, for example, the manufacturer's design intent, the operator can develop procedures in which tasks can be properly identified. The training programmes thus defined must then be validated based on the same sources of information, closing the manufacturer-regulatory authority-operator loop. Training should be part of the integral system design, and it must be contemplated as part of a systems engineering approach.

Chapter 4
MANAGEMENT TECHNIQUES AND COPING STRATEGIES

4.1   It has been proposed that every accident, no matter how minor, results from a failure of the organization. The implication of this proposition in operational management is clear. Despite this, management's role has often been overlooked. In automation-related issues, **management impact is vital**. This is because we are still in the implementation phase, and going through the "shakedown" period which always accompanies change. Many decisions have yet to be made — and others have to be modified — related to equipment design, configuration and selection, establishment of proper procedures and policies, and training strategies. At the systems level, the benefits of management involvement will surpass those which might be obtained addressing the individual operator.

4.2   A basic requirement for flight operations management is ***to develop an unambiguous understanding of the way flight operations are to be conducted,*** for example, by fully explaining the degree to which the crew is expected to use the automated equipment available in the flight deck. This understanding must be stated clearly and unequivocally, and these intentions must then be communicated effectively to flight crews. Equally important, training/check pilots, supervisory pilots, and higher levels of flight operations management should follow the rules and procedures which have been adopted. This should foster a proper management climate and indicate the necessary commitment, which can be further enhanced by proper pilot selection procedures and adequate training packages.

4.3   ***Management support is also essential in the production and use of operational media***. Flight manuals, aircraft operations manuals, checklists, equipment manuals, operational bulletins and — in automated flight decks — software are all important means of communication that reflect a particular operating philosophy. However, it takes more than simply issuing manuals or directives to communicate effectively with pilots. A permanent contact with the pilots, with a maximum exchange of information, views and policies, is essential, and procedures, equipment and rules should be discussed and justified. Pilots can then understand the reasons for the selection of equipment or procedures, and interest and involvement in their consistent use can be expected. The importance of pilots' involvement in the decision and on design of procedural guidelines also relates to motivation, self-satisfaction, etc.

4.4   ***Operational management and pilots must be involved in the acquisition of equipment (hardware)***. Advanced technology aircraft incorporate changes which represent considerable achievements; they have also created considerable controversy. The cost of any design flaw which is not corrected at the stage of design or acquisition will be paid for, many times over, throughout the entire operational life of the equipment, be it a display, a computer, its hardware or software. Sensible, properly designed training and procedures which cannot be properly implemented because of design mismatches lead to more problems than they solve. At the same time, there is no consensus on how much adjustment to less-than-optimum design can reasonably be expected of professional pilots.

4.5   It is hardly surprising that ***training and procedures*** were highlighted as problem areas in early surveys of the operation of advanced technology aircraft. In the same way as it was recognized that improper design hinders the implementation of proper training and procedures, it must also be recognized that even the best designed system will not be operated optimally if the training and procedures that accompany it are inefficient. **The establishment of a feedback loop** between operational personnel and the training department is essential, since training precedes and affects flight operations. In regard to

automation, there is some evidence that flight crews might not be receiving the amount of training, or the amount of information in manuals and other sources, that they need to understand the systems that they are expected to operate.

4.6   **Differences in training for two- and three-person crew operations.** It may be important to give pilots in two-person crew operations more systems training in their initial and periodic training than was given for predecessor aircraft with three-person crews. The change from three- to two-person flight crews results in a significant change, requiring a different approach to flight deck resource management, in standard operating procedures and in checklists. For example, pilots transitioning from the older models B-747 or DC-10 to the newer MD-11 or B-747-400 not only need to master new navigation and autoflight techniques, but also need to learn the command and communication relationships of a two-person rather than three-person flight deck. This might be especially difficult for those pilots who transition to modern aircraft late in their careers; it might also be difficult for operational management which has not recognized these problems. This was expressed by one pilot who reported to the ASRS:

> *"We have traditionally been a 3-man airline and we are still using 3-man procedures with a 2-man crew. The problems are in our procedures and checklists, not in the airplanes …"*

The B-767 which ran out of fuel while at cruising altitude and eventually came up to a successful dead-stick landing at Gimili, in Canada, is a good example of this problem.

4.7   **Pilot promotion policies and scheduling practices** create additional problems. Promotion policies are usually based on collective bargaining agreements and on seniority considerations, and a pilot who has been flying as co-pilot in automated flight deck airplanes might go back to an older jet in order to be promoted to captain. In such a case, it is recommended that additional "back to basics" refresher training be provided. As another example, certain operators' practices include scheduling flight crews in the DC-9 series and the MD-80 series at the same time, based on commonality of ratings, since some authorities have ruled that some of these derivatives are essentially the same airplane and can be operated with a common type rating. This practice needs to be carefully monitored by pilots, operators and authorities, and eventually re-examined and changed. Automated flight deck and conventional airplanes may need to be given a separate status and the fleets isolated for scheduling purposes. Separation of the fleets, which might be regarded as an economic burden for the operators, is a definite plus for safety, and hence a long-term economic gain.

4.8   **Controlling pilot and monitoring pilot duties must be clearly delineated and tasks properly allocated,** with particular emphasis on the role of the monitoring pilot. For the monitoring pilot case, a significant operational anomaly is normally preceded by a preventive monitoring failure; from a systems safety standpoint, this monitoring failure is as critical as the failure of the controlling pilot. Existing data base evidence suggests that risk increases when the captain is performing monitoring duties, since a number of accidents/incidents have occurred when the co-pilot is flying. The problem in part is the ambiguous role played by the captain while monitoring. The argument on this issue goes beyond, but is certainly included in automation.

4.9   In order to relieve boredom and maintain a proper level of vigilance and monitoring during periods of low activity, some have proposed the inclusion of meaningful extra work during these periods (see Chapter 3). Recently, consideration has been given to the concept of **embedded training** as one of the several ways to achieve this objective; it involves the use of the on-board computers to provide training. It must be clearly stated that the subject of this paragraph is not vigilance, but the ways to use inactive time. As a word of caution, very little guidance is available on resolving the conflict between the maintenance of effective situational awareness and the achievement of valid "embedded training".

4.10   In many parts of the world, **the development of ATC** has not kept pace with advances in flight deck capability. The present ATC system, which is a compromise, is not cordial to the advanced capabilities of new aircraft, since it is essentially designed to accommodate jet transports of the generation of DC-8/9, B-737-100/200, B-727 and similar airplanes. Conversely, the latest jet transports are too sophisticated to operate easily and effectively in today's ATC environment, and the crews cannot exploit their advanced features. The flight guidance and display systems of modern airplanes are impressive: vertical navigation (VNAV) and lateral navigation (LNAV) capabilities, advanced autothrottles, inertial reference system (IRS) navigation, and IRS navigational displays have become familiar equipment. They are ideal for operations in complex environments, but in trying to conform with ATC instructions, they present problems to the flight crews. To some extent, the lack of controller familiarity with the capabilities of new aircraft is considered an issue, as is the lack of pilot familiarity with ATC problems. Experience has demonstrated that ATC service does improve, however, as controllers become familiar with the new generation aircraft. Familiarization trips on these aircraft present ATC personnel with the opportunity to understand the capabilities of the modern flight decks.

4.11   Mention has been made of **a company environment which provides documentary support to flight crews** (flight plans, weight and balance computations, weather, etc.), and which establishes a feedback loop between operational (flight planning, operations centre, etc.) and training (while this is not model-independent, it is more critical in automated flight decks). The importance of feedback can be best illustrated with the following example, presented by Dr. Wiener during the ICAO Human Factors Seminar in Leningrad (1990):

> *"The flight crew of a B-757 received a flight plan in which a waypoint was written simply as "CLB" (Carolina Beach), making it appear to be a VOR. When the pilots typed it on the Route page, they continued to obtain "not in database" error messages. The problem was that Carolina Beach is a non-directional beacon (NDB), and to be consistent with the Flight Management Computer (FMC), the flight plan should have listed it as "CLBNB".*

An established feedback loop will allow operators to re-examine their checklists, procedures and all documentation to make certain that they are appropriate for modern flight decks and their particular operations.

4.12   It has been suggested in Chapter 3 that considerable crew workload can be created by **the requirement to perform non-operational tasks** at inopportune times (for example, calling ahead for passenger connections, meal requirements, wheelchairs and other passenger service items). While this is not a new item, it has become more critical due to the increased workload of two-pilot aircraft in congested, high-density operations in terminal areas. While training solutions might include guidelines to establish priorities and reduce workload, management should establish policies which reassign or eliminate of these tasks. These policies should address the cockpit/cabin crew interface, making it very clear that there are issues in this relationship which are relevant to the two-person crew, and which were not present in three-person crew flight decks. Some managements have recognized this problem, and require separate radio communication facilities for the cabin crew for non-operational communications.

4.13   **The establishment of an international reference system**, for collecting and disseminating information on items like selection of the optimum level of automation and other operational procedures, is desirable. This system would refer to existing accident and incident reporting systems. There is considerable evidence that some of the problems associated with automation may well be the product of these differences in training and in procedures. The establishment of this reference system might be a medium-term goal, and this Human Factors digest is intended as a step in that direction.

Appendix 1
FIELD STUDIES IN AUTOMATION

1.   Field studies are a window on the real world. The several established safety deficiencies reporting systems are another window on the real world. Through them, important lessons can be learnt about the operation of the world. Since it is not the intention to duplicate existing documentation, this appendix provides only an overview of existing field studies in automation. The Secretariat will assist those interested in obtaining more detailed information in securing such information at its source.

2.   Field studies are important for several reasons:

- Flight crews are the ones who see and know the way airplanes are operated in the real world. They are actually involved, and their experience and advice should be sought.
- Problems often do not appear until after line experience has been accumulated. Line flying is the real test of design, since that is where the equipment is used under a variety of conditions. It is the acid test. An additional focus of field and reporting studies is to provide feedback from the operational world to those who are not in the operational world.
- Field studies allow for impartial evaluation of the system, since researchers conducting the study are not involved in design, sales or operation of the aircraft, or enforcement of regulations. Field studies can provide important feedback to designers and operators, as well to other researchers.

3.   The basic sources of information in field studies are questionnaires for use with volunteer crews and structured "callbacks" made in volunteer reporting systems. Face-to-face interviews are also used, involving instructor pilots, management pilots, simulator instructors and ground school instructors. Researchers may also attend ground school training for the aircraft type involved, and make observation rides in the flight deck. To the present date, three of the major published field studies in automation are:

- The Introduction of New Cockpit Technology: A Human Factors Study, by Renwick E. Curry, 1985, in reference to crew transition to Boeing B-767 aircraft.
- Human Factors of Cockpit Automation: A Field Study of Flight Crew Transition, by Earl L. Wiener, 1985, in reference to crew transition to Mc Donnell — Douglas MD-80 aircraft.
- Human Factors of Advanced Technology ("Glass Cockpit") Transport Aircraft, by Earl L. Wiener, 1989, in reference to error analysis, crew coordination, training, and workload in Boeing B-757 aircraft.

These three studies were sponsored by NASA, and they are available from NASA Ames. Another major survey was conducted by one operator in the Airbus A-310 cockpit systems. Recently, the Civil Aviation Authority of the United Kingdom has started an automation questionnaire to survey the current opinions of pilots in the UK on cockpit automation, and to identify areas which might benefit from more research or study. In addition, individual operators and organizations have conducted internal surveys or pilot questionnaires aimed at identifying particular shortcomings applicable to their specific operations.

THE INTRODUCTION OF NEW COCKPIT TECHNOLOGY:
A HUMAN FACTORS STUDY

4.   The objectives of this study were:

- to identify any adverse reactions to the new technology,
- to provide a "clearinghouse" of information for the airlines and pilots on experiences during the introductory period of the B-767,
- to provide feedback on airline training programmes for the new aircraft, and
- to provide field data to NASA and other researchers to help them develop principles of human interaction with automated systems.

Three airlines and more than one hundred pilots agreed to participate in the study. The data were taken during the early introduction of the B-767 and the conclusions apply only to that period.

5.   The conclusions of this study were:

- Most pilots enjoy flying the B-767 more than they enjoy flying the older airplanes (This conclusion must be interpreted as a generic observation. It reflects the pilots' appraisal of an ADVTECH airplane rather than a specific type).
- The pilots accept the new technology, and they choose to use it because they find it useful.
- The pilots are aware of the possible loss of flying skills with the presence of automation, and they hand-fly (usually with flight director) to prevent this loss. The data collected in this study do not indicate any loss of skills.
- The primary points of confusion or surprise were autothrottle/autopilot interactions; the autopilot turning the "wrong way" or not capturing the course; and achieving (or not achieving) desired results with the Flight Management System/Control Display Unit (FMS/CDU).
- The pilots felt training for the FMS/CDU could be improved, and they specially wanted more "hands-on" experience. More training on the mode control panel, and more hand flying were mentioned.
- Information, especially "techniques", may not always be getting from the system designers to the line pilots.
- Flying any aircraft with sophisticated equipment and high levels of automation allows distractions that cause a loss of monitoring performance.
- Pilots should be trained to "turn it off" and not try to "program" their way out of an anomalous situation.
- These field data confirm some existing Human Factors principles, suggest some new principles, and raise questions requiring further research.

HUMAN FACTORS OF COCKPIT AUTOMATION:
A FIELD STUDY OF FLIGHT CREW TRANSITION

6.   This was a field study involving two groups of airline pilots (from the same airline) over a two-year period to determine what factors affected their transition from traditional airline cockpits to a highly automated version (DC-9/10/30/50 to MD-80). The conclusions of the study were as follows:

- The MD-80, its Flight Guidance System and other automatic features are generally viewed by the pilots who fly it as well conceived and well designed, and are held in high regard.

- Pilots expressed a favourable overall view about automation. However, even the more enthusiastic defenders of automation expressed concern over the increasing degree of monitoring required by automatic equipment. Some concern was also voiced about the pilots being "out of the loop" or "along for the ride".

- There was overall high usage of automatic features, but with large variations in individual degree of usage. Pilots felt that automation should be provided by the company, but that it should be left to each individual to determine when and under what circumstances he would choose to use or not use the automatic features.

- After an initial period of concern about the reliability of the automatic equipment, most crews felt that the equipment was highly reliable. The major concern voiced was that it required a degree of monitoring that was beyond what they had been accustomed to in the earlier DC-9's.

- There were mixed feelings on the subject of workload reduction. The consensus was that if a number had to be placed on workload reduction, it would be around 15 per cent, far short of the expectations for the MD-80.

- Pilots were unanimous in reporting that compared to the DC-9, the automation and cockpit configuration of the MD-80 did not allow any additional time for extra-cockpit scanning.

- Most pilots did not see any safety advantage to the automatic features. Their attitude towards the safety aspects of automation was essentially neutral.

- This study did not provide solid evidence on questions relating to loss of proficiency due to overreliance on automation. Even when some concern was expressed, none saw this as a serious problem. This may be in part because, at the beginning of the study, crews were flying mixed blocks of MD-80 and traditional DC-9 time.

- During the period of the study, a "separate status" between conventional and advanced models was established. Pilots impacted by this status reported that transition was made considerably smoother by the opportunity to fly only the MD-80 during the initial period of exposure to the new cockpit.

- Learning to control a new technology flight deck requires a new approach to training. It is inefficient to use a whole-task simulator for training in programming and cognitive (mental) skills. What is needed is a family of dynamic, interactive training devices which are capable of demonstrating to the pilot trainee in real time the dynamics of the aircraft systems and the consequences of his actions. It is a significant comment on the quality of training that crews repeatedly mentioned that whenever the slightest unexpected event occurred, such as a change in runway, they would "click it off" (go to a manual mode).

- Continuing attention must be paid to basic and traditional Human Factors problems in the design of cockpits: control design, keyboard entry devices, warning and alerting systems, and cockpit lighting. The effective employment of new technology in the flight deck depends on time-honoured Human Factors principles.

- The study did not find signs of automation-induced psychosocial problems such as negativity toward flying as an occupation, or loss of self-esteem.

HUMAN FACTORS OF ADVANCED TECHNOLOGY
("GLASS COCKPIT") TRANSPORT AIRCRAFT

7.   This is a report of a three-year field study of airline crews at two major airlines who were flying an advanced technology aircraft, the Boeing 757. The two previous studies concentrated on initial transition of the flight crews and their early experience. This report concentrates in four major topics: training for advanced automation; cockpit errors and error reduction; management of cockpit workload; and general attitudes towards cockpit automation. The conclusions of the study are:

- *General findings.* Pilots exhibit a high degree of enthusiasm for the aircraft, their training and the opportunity to fly state-of-the-art transport aircraft. It is more difficult to summarize the pilots' attitudes towards automation in general, an area in which "mixed feelings" predominate. Strong reservations were expressed in two critical areas: safety (pilots feel that they are often "out of the loop" and lose situational awareness); and workload (pilots feel it increases during phases of the flight already characterized by high workload, and decreases during periods of low workload). Pilots tend to revert to manual modes of flight guidance ("click it off") in times of high workload.
- *Equipment.* Pilots report satisfaction with the general layout of the cockpit, and few problems in the area of traditional Human Factors. The warning and alerting systems of the 757 deserve high praise in the view of most pilots.
- *Training.* Training for the 757 at both airlines in this study was generally considered well planned and well conducted. The most common criticism is an over-emphasis on automation to the exclusion of basic airplane knowledge and skills. The need for computer-based, part-task simulation devices is evident.
- *Cockpit errors.* The study did not provide evidence to assert whether high or low automation aircraft generate more crew errors. Altitude deviations, one area of great concern, are usually more often traceable to human error than to equipment failure.
- *Crew coordination.* Compared to traditional models, it is physically difficult for one pilot to see and understand what the other is doing. There is a less clear demarcation of "who does what" than in traditional cockpits; this is due to the tendency of the crew to "help" each other with programming duties when the workload increases. The modern cockpit also seems to produce an unintended redistribution of authority from the captain to the first officer.
- *Workload.* The study does not demonstrate that a clear case for automation bringing an overall reduction in workload can be made, especially during phases of high workload when that reduction is most needed. Positive evidence was obtained, however, that some automatic features placed in the aircraft in the hope of reducing workload, are perceived by the pilot as workload inducing. The conclusion is that the present generation of advanced technology aircraft has failed to realize its potential for workload reduction for both internal reasons, and reasons external to the hardware and software design.

- *Air Traffic Control.* The present ATC system does not allow full exploitation of the flight guidance capabilities of automated aircraft. It seems that aircraft and ground-based ATC systems were designed, developed, and manufactured almost as if they were unrelated and independent systems.

8.   In its conclusion, this study offers the following recommendations:

- Research should continue on human-automation interfaces.
- Research into making the ATC system more receptive to the capabilities of advanced aircraft should be conducted on a priority basis before the new generation ATC systems are placed on line.
- Training departments should reexamine their training programmes, syllabi, training equipment and support materials to be certain that they have been responsive to necessary changes brought by the new aircraft.
- Operators of modern, two-pilot aircraft should reexamine their procedures, checklists, flight plans, weather information, fuel slips, manuals, and company demands on the flight crew for opportunities to reduce workload and operational errors by providing optimal support material, and eliminating unnecessary procedures.
- Research should be launched into crew resource management as it may differ in advanced versus traditional cockpits.
- Authorities should reexamine certification procedures with the goal of carefully evaluating the Human Factors aspects of new models. Human Factors other than merely estimates of workload should be considered, making use of error-predictive techniques.
- Agencies should encourage research into error-tolerant systems and other methods of exploiting machine intelligence to prevent, trap, or make more apparent errors made by the flight crew.
- Manufacturers and users should standardize terminology and designations of navaids across the CDU, charts and computer-produced flight plans.
- In general, future cockpits should be designed to provide automation that is human centred rather than technology driven.

LUFTHANSA COCKPIT SYSTEMS SURVEY: A-310

9.   This operator uses cockpit surveys to obtain up-to-date information and feedback from their flight crews as a basis for cockpit specifications. The selected tool is an anonymous questionnaire, which comprises two parts: cockpit layout, general handling qualities and airplane systems, and electronic crew interfaces (ECAM, EFIS, AFS, and FMS). Part 2 (electronic interfaces) of the survey was subdivided into four main topic areas according to a standard human-machine interface model:

- *Physical interface (reach and see)* — control location, reach and handling, display location, readability, colour and lighting, etc.
- *Interface dialogue or operational considerations (understanding)* — ease of understanding of operational rules, display rules, interlocks, and amount and kind of required training.
- *Interface tools (usability)* — general usefulness, adequateness and importance of features.

- *Organizational aspects of the interface (appropriateness in the operational environment)* — factors like reliability, logistics, ATC constraints, etc.

10.   These four main topic areas were surveyed in the Electronic Centralized Aircraft Monitoring (ECAM), Electronic Flight Instrument System (EFIS), Autoflight System (AFS), and Flight Management System (FMS). The conclusions of the survey were:

- Overall, pilots surveyed like automation.
- Flying with automatics must be as good or better than flying manually.
- Some problems do occur with automation: "keeping the pilot in the loop" is a mandatory requirement for any automated function.
- FMS and ECAM are both well liked, however, both systems are not yet optimally designed. Initial development of the FMS was promoted and tested by a relatively small group of pilots. Further development should be based on a broad (international) range of airline experience.
- Advanced flight management systems must incorporate an improved crew interface, higher computational performance, and a better fit to the ATC environment.

Appendix 2
AUTOMATION PRINCIPLES FROM
WIENER AND CURRY (1980)

CONTROL TASKS

1.   System operation should be easily interpretable or understandable by the operator, to facilitate the detection of improper operation and to facilitate the diagnosis of malfunctions.

2.   Design the automatic system to perform the task the way the user wants it done (consistent with other constraints such as safety); this may require user control of certain parameters, such as system gains (see Principle No. 5). Many users of automated systems find that the systems do not perform the function in the manner desired by the operator. For example autopilots, especially older designs, have too much "wing waggle" for passenger comfort when tracking ground based navigation stations. Thus, many airline pilots do not use this feature, even when travelling coast-to-coast on non-stop flights.

3.   Design the automation to prevent peak levels of task demand from becoming excessive (this may vary from operator to operator). System monitoring is not only a legitimate, but a necessary activity of the human operator; however, it generally takes second priority to other, event-driven tasks. Keeping task demand at reasonable levels will ensure available time for monitoring.

4.   For most complex systems, it is very difficult for the computer to sense when the task demands on the operator are too high. Thus the operator must be trained and motivated to use automation as an additional resource (i.e. as a helper).

5.   Desires and needs for automation will vary with operators, and with time for any one operator. Allow for different operator "styles" (choice of automation) when feasible.

6.   Ensure that overall system performance will be insensitive to different options, or styles of operation. For example, the pilot may choose to have the autopilot either fly pilot-selected headings or track ground-based navigation stations.

7.   Provide a means for checking the set-up and information input to automatic systems. Many automatic system failures have been and will continue to be due to set-up error, rather than hardware failures. The automatic system itself can check some of the set-up, but independent error-checking equipment/procedures should be provided when appropriate.

8.   Extensive training is required for operators working with automated equipment, not only to ensure proper operation and set-up, but to impart a knowledge of correct operation (for anomaly detection) and malfunction procedures (for diagnosis and treatment).

MONITORING TASKS

9.   Operators should be trained, motivated, and evaluated to monitor effectively.

10.   If automation reduces task demands to low levels, provide meaningful duties to maintain operator involvement and resistance to distraction. Many others have recommended adding tasks, but it is extremely important that any additional duties be meaningful (not "make-work") and directed toward the primary task itself.

11.   Keep false alarm rates within acceptable limits (recognize the behavioural impact of excessive false alarms).

12.   Alarms with more than one mode, or more than one condition that can trigger the alarm for a mode, must clearly indicate which condition is responsible for the alarm display.

13.   When response time is not critical, most operators will attempt to check the validity of the alarm. Provide information in a proper format so that this validity check can be made quickly and accurately and not become a source of distraction. Also provide the operator with information and controls to diagnose the automatic system and warning system operation. Some of these should be easy, quick checks of sensors and indicators (such as the familiar "press to test" for light bulbs); larger systems may require logic tests.

14.   The format of the alarm should indicate the degree of emergency. Multiple levels of urgency of the same condition may be beneficial.

15.   Devise training techniques and possible training hardware (including part- and whole-task simulators) to ensure that flight-crews are exposed to all forms of alerts and to many of the possible conditions of alerts, and that they understand how to deal with them.

Appendix 3
STATEMENT OF AUTOMATION PHILOSOPHY,
DELTA AIR LINES (1990)

The word "automation", where it appears in this statement, shall mean the replacement of a human function, either manual or cognitive, with a machine function. This definition applies to all levels of automation in all airplanes flown by this airline. The purpose of automation is to aid the pilot in doing his or her job.

The pilot is the most complex, capable and flexible component of the air transport system, and as such is best suited to determine the optional use of resources in any given situation.

Pilots must be proficient in operating their airplanes in all levels of automation. They must be knowledgeable in the selection of the appropriate degree of automation, and must have the skills needed to move from one level of automation to another.

Automation should be used at the level most appropriate to enhance the priorities of Safety, Passenger Comfort, Public Relations, Schedule, and Economy, as stated in the Flight Operations Policy Manual.

In order to achieve the above priorities, all Delta Air Lines training programs, training devices, procedures, checklists, aircraft and equipment acquisitions, manuals, quality control programs, standardization, supporting documents and the day-to-day operation of Delta aircraft shall be in accordance with this statement of philosophy.

Appendix 4
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ICAO TECHNICAL PUBLICATIONS

The following summary gives the status, and also describes in general terms the contents of the various series of technical publications issued by the International Civil Aviation Organization. It does not include specialized publications that do not fall specifically within one of the series, such as the Aeronautical Chart Catalogue *or the* Meteorological Tables for International Air Navigation.

International Standards and Recommended Practices are adopted by the Council in accordance with Articles 54, 37 and 90 of the Convention on International Civil Aviation and are designated, for convenience, as Annexes to the Convention. The uniform application by Contracting States of the specifications contained in the International Standards is recognized as necessary for the safety or regularity of international air navigation while the uniform application of the specifications in the Recommended Practices is regarded as desirable in the interest of safety, regularity or efficiency of international air navigation. Knowledge of any differences between the national regulations or practices of a State and those established by an International Standard is essential to the safety or regularity of international air navigation. In the event of non-compliance with an International Standard, a State has, in fact, an obligation, under Article 38 of the Convention, to notify the Council of any differences. Knowledge of differences from Recommended Practices may also be important for the safety of air navigation and, although the Convention does not impose any obligation with regard thereto, the Council has invited Contracting States to notify such differences in addition to those relating to International Standards.

Procedures for Air Navigation Services (PANS) are approved by the Council for world-wide application. They contain, for the most part, operating procedures

regarded as not yet having attained a sufficient degree of maturity for adoption as International Standards and Recommended Practices, as well as material of a more permanent character which is considered too detailed for incorporation in an Annex, or is susceptible to frequent amendment, for which the processes of the Convention would be too cumbersome.

Regional Supplementary Procedures (SUPPS) have a status similar to that of PANS in that they are approved by the Council, but only for application in the respective regions. They are prepared in consolidated form, since certain of the procedures apply to overlapping regions or are common to two or more regions.

The following publications are prepared by authority of the Secretary General in accordance with the principles and policies approved by the Council.

Technical Manuals provide guidance and information in amplification of the International Standards, Recommended Practices and PANS, the implementation of which they are designed to facilitate.

Air Navigation Plans detail requirements for facilities and services for international air navigation in the respective ICAO Air Navigation Regions. They are prepared on the authority of the Secretary General on the basis of recommendations of regional air navigation meetings and of the Council action thereon. The plans are amended periodically to reflect changes in requirements and in the status of implementation of the recommended facilities and services.

ICAO Circulars make available specialized information of interest to Contracting States. This includes studies on technical subjects.