BETTER MACHINES – OR BETTER HUMANS?

by Paul C Schutte – NASA Langley Research Centre

We all make mistakes – after all – to err is human. But we often seem to forget this when it comes to aircraft pilots, or so it would seem when one considers the fact that over 70% of all aircraft accidents are blamed on pilots. We often design flight deck instrumentation for humans who will not make mistakes; we seem to expect humans to stop being human when they set foot inside a flight deck. It is my belief that what we call human error is actually the negative consequences of normal human behaviour that is not accounted for in design. In other words, we know that humans make mistakes and we know the types of mistakes they are likely to make; therefore, we should design flight decks to accommodate such mistakes.

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One reason that we have not done so is that we have lacked the technology to develop a more human-tolerant flight deck – but technology has now advanced to the point where this is no longer the case. We now can complement a human's natural abilities – compensating for the weak points and accentuating the strong points. I call this 'complementation' as opposed to automation. However, it requires a somewhat radical departure from the current approach to design.

With good reason, designers tend to evolve flight deck designs in small steps, changing only one aspect at a time and leaving the rest constant. This approach can sometimes lead to an evolutionary dead end and modern flight decks may be approaching such a point. Within the constraints of today's interface conventions (e.g. glare shield, flight management system, primary flight display), designers must force-fit innovations into existing designs. For example, a designer may add another display page to a multi-function display or use the flight management system (FMS) cockpit display unit (CDU) to input information not directly associated with the FMS tasks. Evolutionary changes such as these, while leaving intact what pilots already know, can add considerable – and often unnecessary – complexity that may make the system more susceptible to human error.

I believe that what is required is a quantum leap away from today's technology. By 'technology-centred' I simply mean that the design capitalised on the best that technology had to offer and left the human to cover what the technology could not. In contrast, a human-centred approach capitalises on the best that humans have to offer and leaves the technology to cover what the human cannot. However, due to evolutionary constraints, a human-centred design calls for a 'clean slate' approach that removes the shackles of previous designs while retaining lessons learned from previous successes.

Researchers at the NASA Langley Research Centre have been working on just such a design. One goal of this work is to create a design based on human-centred principles that is traceable from a design decision back to principles and guidelines that support it. When a design decision is changed (and it will be changed due to the ceaseless march of technological process), the effect of that change on the whole design can be better assessed by tracing that design decision back to its foundation principles. The design centres on guidelines developed at Langley, as described in Table 1. In order to be successful, the flight deck must be consistent, useful,. usable and upgradable. This article will provide a glimpse of the design in progress. This is a dangerous thing to do at this point because only high-level concepts have been developed and the reader might develop a bad first impression. However, the value of early feedback is worth the risk. The graphics shown are rough sketches intended to demonstrate an idea and should not be viewed as a final control or display for a flight deck. The reader is reminded that this is nowhere near its final form both in depth and breadth and that it will require considerable evaluation and refinement.

WHY IS THE HUMAN THERE?

I believe that the only unassailable reason for having a human at the controls is to deal with unexpected situations – that is, situations that the designer did not or could not anticipate. It can be argued that in terms of accuracy and efficiency, automation is the winner over humans, but it is difficult for the designer to anticipate (and therefore for the automation to handle) every situation. In addition, because they are human, designers, manufacturers, information providers, maintenance personnel and operators can also make er-

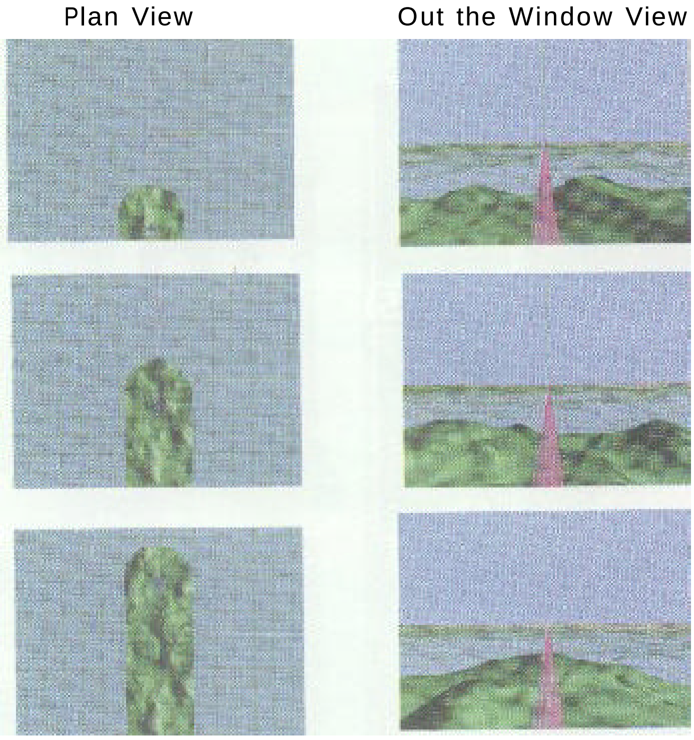

Figure 2 Information on the actual displays must be of a high degree of certainty. With modern GPS and terrain databases it is tempting to provide a rich graphical depiction of the outside world. However, such displays can become overly compelling, leading to a false perception that they represent the real world. For the displays in this design, the terrain displays are simplified to a wireframe depiction to indicate a lower level of certainty. It is only when onboard systems (such as radar) confirm the information that it is depicted as photorealistic.

rors that unless caught by the pilot, cannot be remedied. In these cases the human is often called onto assess the situation and deal with it appropriately. In some cases the human has to act as a backup to a system. In short, the pilot is the last best defence.

However, pilots cannot instantly take on the task of dealing with unanticipated situations. To deal with these types of situations they must have an appropriate picture (situation awareness) of what is going on. If the technology-centred approach is continued, the machine will be able to perform more and more activities, leaving the pilot less and less involved. The less involved in the flight, the harder it is for humans to maintain situation awareness, so to compensate for this fact and to accentuate the human's abilities to deal with the unexpected, it may be necessary to have the pilot perform some tasks that the machine might actually do better.

Another aspect of being human is the need to be doing something of worth, so involvement must be meaningful otherwise the human will feel trivial or patronised. Another aspect of the human dealing with the unexpected that is important for design is the fact that the human may require more detailed information about the aircraft and the airspace system. A current trend is to train only how to nominally fly the aircraft and

Table 1 – Human-centred design guidelines

Team member

- The design should facilitate human operator awareness of his or her responsibilities and the responsibilities of the other human operators and automated flight deck systems, in fulfilling the current mission objectives.
- The design should facilitate the communication of activities, task status, conceptual models, and current mission goals among the human operators and automated flight deck systems.
- The design should support they dynamic allocation of functions and tasks among multiple human operators and automated flight deck systems
- The design should assure that team limitations are not exceeded.
- Co-operative team capabilities; e.g. use of collected resources and co-operative problem solving) should be used to advantage when necessary.
- The design should facilitate the prevention, tolerance, detection and correction of both human and system errors, using the capabilities of the human operators and the flight deck automation.

Commander

- The human operator should be appropriately involved in all functions and tasks that have been assigned to him.
- Different strategies should be supported for meeting mission objectives.
- The human operator should have final authority overall dynamic function.
- The human operator should have the final authority to exceed known system limitations when necessary to maintain the safety of flight.

Individual operator

- The human operator should be appropriately involved in all functions and tasks that have been assigned to him.
- Different strategies should be supported for meeting mission objectives.
- The content and level of integration of information provided to the human operator should be appropriate for the functions and tasks being performed and the level of aiding or automation being used.
- Methods for accomplishing all flight crew functions and tasks should be consistent with mission objectives.
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- Procedures and tasks with common components or goals should be distinct across systems and mission objectives.
- The design should facilitate the development by the human operator of conceptual models of the mission objectives and system functions that are both useful and consistent with reality.
- Fundamental human limitations (e.g. memory, computation, attention, decision-making, biases, task timesharing) should not be exceeded.
- Fundamental human capabilities (e.g. problem solving, inductive reasoning) should be used to advantage.
- Interference among functions or tasks that an operator may perform concurrently should be minimised.

Occupant

- The needs of the flight crew as humans in a potentially hazardous work environment should be supported.
- The design should accommodate what is known about basic human physical characteristics.
- Peripheral activities that are indirectly related to the mission objectives should be supported.
- The design should accommodate cultural norms.

From 'A Crew-centred flight deck design philosophy' by Palmer, Rogers, Press, Latorella and Abbott

not go in to the details of how it works. But in dealing with unanticipated situations, this knowledge may be the difference between life and death. However, today's aircraft are (and will probably remain) far too complex for the pilot to be trained as they were in the "good old days". Human-centred complemation uses the machine to assist the pilot in overcoming these weaknesses.

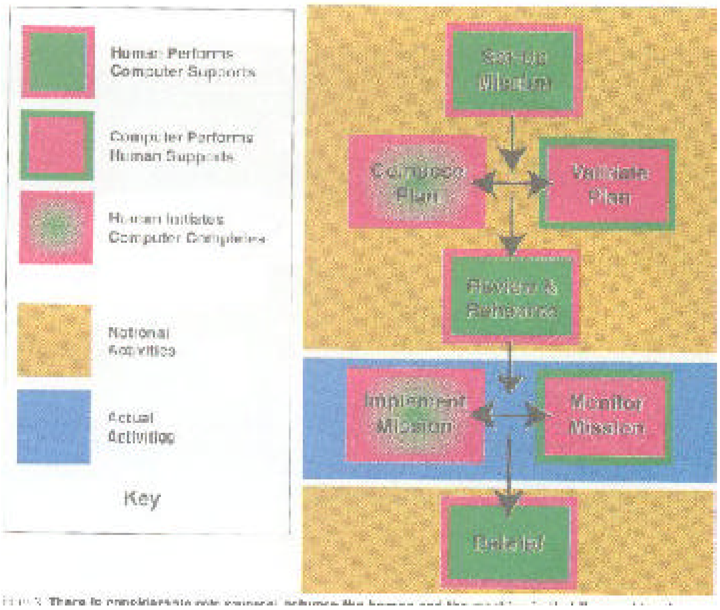


Figure3 There is considerable role reversal between the human and the machinein that the machine does most of the monitoring and validating. The human is involved with the outer-loop initiation of tasks and actions.

ALL THE WORLD'S A TASK

One of the first steps for the flight deck design was to establish a paradigm that was consistent with human nature and flight. The classic paradigm of aviate, navigate, communicate and manage systems was selected with one addition – manage tasks. Task management was added because many typical human errors involve erroneous omissions or commissions of tasks. Also inappropriate task workload is often a precursor to human errors. Modern flight decks often have nearly bipolar levels of workload where there is either too much or too little to do. The new paradigm gives task management a prominent place in the organisation of the flight deck. Every action, procedure, communication or activity is viewed by the flight deck as a task that can be created, deferred, delegated or cancelled. Just as a "file" is the dominant entity in computing environments, "task" is the dominant entity that is manipulated in the flight deck environment. Any new "application" would capitalise on this convention so that the pilot will always have some familiarity with the new device.

IS THIS REALITY?

Another major distinction in the mind of the pilot is the difference between tactical behaviour and strategic behaviour. Rigorously defining this distinction across the flight deck can be problematic. The most common discriminator between these two behaviours is time and distance, but selecting the appropriate levels is highly context and task dependent. For example, 15 minutes may be considered tactical information for weather, but strategic information for air traffic avoidance. The discriminator that we have chosen is based on reality and certainty – namely what is actually happening (actual) and what is predicted, planned or hypothesised to happen (notional).

When you create a flight plan, you are moving a notional aircraft through time and space. The aircraft exists only on paper, in a computer or in your mind; the real one is sitting on the tarmac. This notional representation is not constrained by time, space. This notional representation is not constrained by time, space or detail. You can develop detailed plans about what to do in one situation and vague plans about what to do in another situation. Weather forecasts are generally notional in that you are not really certain that they are true until you get there, that is, until you actually experience the weather at that time.

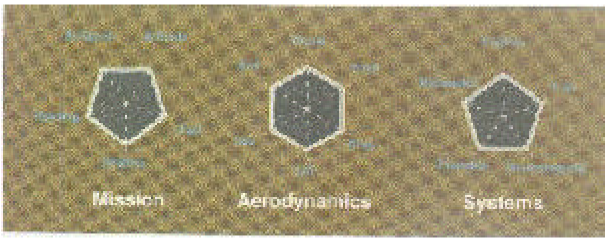
In actual mode, you are really moving the aircraft; it is not a notional representation but the real thing. There is little confusion or uncertainty and what you see is what the aircraft is doing and what the environment really looks like.

Current flight deck designs often confuse actual and notional information and control. One might consider the FMS to be a notional (strategic or planning) device, but with the autopilot fully coupled to the FMS it becomes an actual (tactical) device by which the pilot can move the aircraft. Multiple routes can be stored in the FMS and there is a possibility that the pilot could make a change in a non-active (notional) route thinking that it is the active (actual) route. Given the fact that the glareshield can also serve as an actual or a notional device, it is not surprising that pilots can become confused regarding whether the aircraft will execute a change that they make.

In the new design there is a strict distinction (separate controls and displays) between actual and notional control and information. A change made or information presented on an actual display really is what the aircraft is doing or is just about to do. There is a high threshold of certainty in an actual display that must be met before information can be presented. Thus forecast weather information might not be available on an actual display. Instead, the pilot must look to the notional display to se what might happen in the future. Long-range plans, contingency plans and "what-if" scenarios can be developed on the notional controls and displays but they can only be actualised using the actual controls and displays. The actual controls and displays can be used to "grab" a particular notional plan, and use it as the actual guidance, but it immediately becomes displayed on the actual displays and it is the only guidance present there.

DEFINING THE MISSION

At this point in the discussion, it is time to take a closer look at a generic mission and how it fits into the design. The first step in a mission is to determine the overall objectives. This means



Normal

Abnormal

Figure 4 Machines are extremely vigilant and can readily detect problems. the monitoring and status information must be quickly transmitted to the human. The use of regular geometric shapes is used here to depict normality. Abnormalities are represented by irregular or smaller shapes. Each vertex denotes a system or quality of the overall health of the mission. The pilot can quickly scan the shapes to determine if there is anything out of sorts and then direct attention to the appropriate display for more details.

setting the origin and destination airports, departure and arrival times, and so on. Once the overall mission constraints are set, the pilot can compose the mission – setting more of the details such as altitudes and airspeeds. During this process the mission plan must be checked for compliance with rules of the airspace and performance characteristics of the aircraft. The pilot should develop contingency plans and explore what-if situations. When the composition is complete, the pilot should review the planned route and perhaps rehearse some aspects of the flight (note that this review and rehearsal can occur during the flight). The next step is the actual flight, which involves implementing the plan and monitoring the progress and the environment. When the mission is complete, the pilot should look over the flight (i.e. debrief) to explore any curiosities and improve on performance.

Mission set up, plan composition and checking, review and rehearsal, and debriefing are all notional tasks; only implementation and monitoring are actual tasks. Notional activities do not have to take place on the aircraft. The software and displays for notional activities should be implemented on a portable device, such as a PDA or a laptop, as well as on the flight deck.

Part of the approach to complemation is to use the machine to compensate for human weaknesses. Two such weaknesses are limited memory recall and poor monitoring of reliable systems. In this new flight deck design, the machine takes on the major brunt of these burdens. The human is not expected to monitor the machine (as is the case in many modern systems), but rather the machine performs the primary monitoring function (including monitoring the human). Likewise, the machine takes on a large portion of memorisation. Facts about regulations, performance charts, previous states and system operation and configuration are “remembered” by the machine. The human can quickly recall or bring to the foreground the relevant information for the current situation. In many cases this will cue the human’s own memory.

While the machine takes on more of the monitoring and memory burden, the human will be more involved in the outer loop control of the aircraft. There is no execution of pre-programmed flight plans and the flight plan created in the notional phase is used only as guidance. The aircraft is extremely stable on a flight vector, so the pilot can fly hands-off for extend periods of time, but only the pilot can change that vector. This increases pilot involvement in the task during periods of flight that are currently low workload and helps maintain pilot proficiency. Again, the machine will monitor the human’s actions (and physiological state) to ensure that the flight is proceeding as planned. This should help eliminate the so-called automation surprises.

TRAINED IN THE ART

Any flight deck will require training and this one will be no exception. Initial training will be in the art of flying itself rather than interacting with the systems. Since the human is in the flight deck to deal with potential problems and unforeseen circumstances it is important that they know the basics of how to fly, as one of those unforeseen occurrences could be a failed piece of flight guidance. This leads to training on how to plan a flight (not how to interface with the system on the aircraft). Finally they will be taught some basic knowledge about physical systems.

If the overall design concept is successful, the step from this training to actual flying will be short. In other words, if they know about flight, they will easily learn how to fly this aircraft

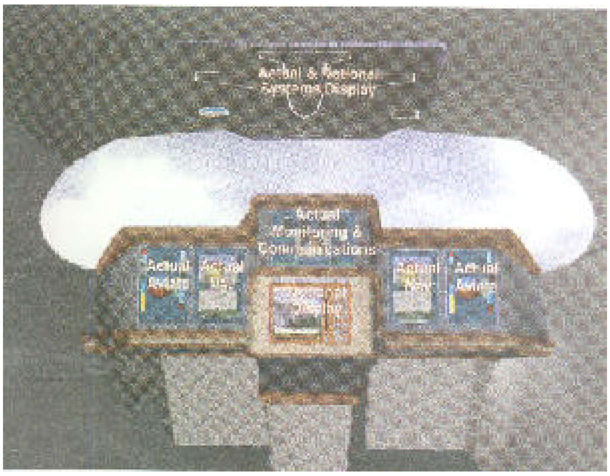


Figure 5 The actual display s are physically located in different places fromthe notional displays. Thus the pilot can trust any information on the actual displays to be the true state of the world and the aircraft.

because there will be a one-to-one relationship between the flight deck controls and displays and the pilot's knowledge. Additional training will then be provided (on a recurring basis) in troubleshooting and problem solving – the purpose of the human on the flight deck. In addition, the machine will capitalise on the fact that it is doing the monitoring to passively watch for areas in need of improvement and then focus on those areas during the debriefing session. Likewise if the pilot gets into an unusual situation, it can be reconstructed later on the ground in a safe environment rather than on-the-job learning in the sky. In summary, the design is set to focus training on pilot proficiency in safe flying and troubleshooting rather than on learning how to operate the interfaces.

I have not mentioned what type of aircraft this design is intended for; this is because it is intended for a generic aircraft. Since the design is top-down it is intended that all aircraft regardless of their mission could use this design paradigm. As flight decks become more specialised for specific missions, it is hoped that they will still be able to conform to the overall design decision, so moving from one aircraft type to another will not require much training. It is probably most appropriate for high-end business jets since they have some of the most advanced flight deck innovations in use. However, it is unlikely that any flight deck will use this final design as is. Rather, this design may offer new ideas, goals and targets that can be used in directing evolutionary designs away from their potential dead ends.

BETTER MACHINES OR BETTER HUMANS?

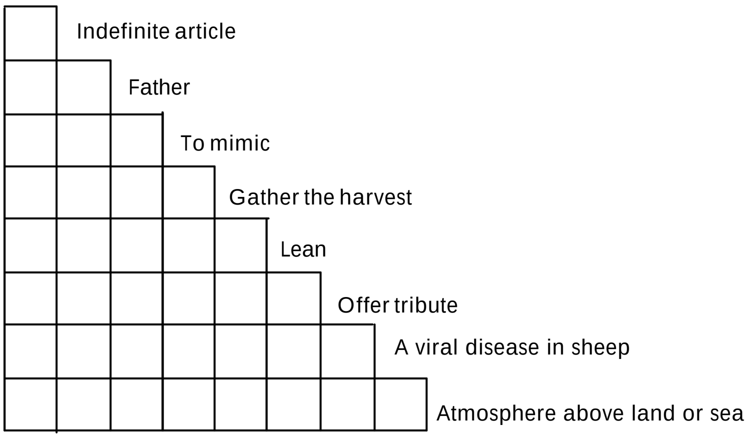
In conclusion, I would like to stress again the idea of complemation over automation. Complemation will lead to humans that are more capable due to their augmented selves. Complemation leads to a world where we do things better rather than simply having things done for us. Automation could lead to creating machines that may one day be better than humans without humans being at the centre; humans may make themselves obsolete. In aviation as well as in other domains, I feel that complemation offers a better and ultimately safer alternative.

SCROLEX

by Hadi Risvi

is a unique word game puzzle. It combines vocabulary testing and unscrambling of word puzzles with the fun and lateral thinking of croswords. The name itself is the best description.

SCR	Scramble
CRO	Crossword
SCROL	Scroll
LEX	Lexicon
EX	Exercise



RULES

Clues are given for a word on each line.

Each word must contain all the letters from the word above it plus one more letter.

No word must begin with the same letter as the word above it

Plurals ending with an "s" and proper nouns are not permitted.

Slang words, spelling variants, dialect words and common usage shortened forms are not permitted.

Scrolex has been devised by Captain Hadi Rizvi, a senior pilot with PIA and member of PALPA-Pakistan. He began flying at 16 and now has over 10,000 hours of flying experience. Flying is his "passion" but he lists puzzels and poetry as his major interests. In his "spare" time Hadi goes into reflective and philosophical frame of mind where he perpetually seeks to broaden his horizons. He has just completed a law degree and is now moving into the arena of aviation law.

Hadi has used his multi-talents to devise this ingenious word game, whcih combines the letter-block, vocabulary testing principle of Scrabble with the clue-guessing lateral thinking concept of a crossword puzzle.

This game took Hadi many years to devise and is now being seen on a regular basis in newspapers and in-flight magazines (including that of PIA).

Solution
a/pa/ape/reap/spare/praise/scrapie/airspace