Keynote Address (2): The Evolution of Human Factors Applied to the Cockpit Interface

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INTRODUCTION

When considering the general theme of the symposium, which is Critical Design Issues for the Human Machine Interface, it is perhaps appropriate in the 100th anniversary year of the Wright brothers' first flight to assess how the cockpit interface has changed and developed over the past century. From there, we can then evaluate those aspects of the cockpit design that have improved and the areas within Human Factors applied to cockpit design where we still need to progress. Whilst this is an 'air' biased look, I believe that the Human Factors issues that arise are also relevant across the land, sea and space domains.

For the benefit of those readers who may not work within the Human Factors field, throughout this paper I take the discipline of Human Factors to encompass the following domains:

- Safety
- Geometry and layout
- Egress and mobility
- Crew systems
- Displays and moding
- Warning systems
- Lighting
- Noise and vibration
- Temperature and humidity
- Comfort and fatigue
- Performance and human error
- Workload and situational awareness
- Selection and training
- Maintainability

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THE LAST ONE HUNDRED YEARS

As aircraft have evolved since the Wright Brothers made the first sustained controlled flights in their Flyer 1 aircraft in December 1903, so to have the cockpits associated with these aircraft and with each new generation the designers have faced new and different challenges at the Human Machine Interface.

The Sopwith Pup entered service in the UK in 1916. This is a First World War generation aircraft and, as can be seen from Figure 1, the cockpit interface is extremely rudimentary.

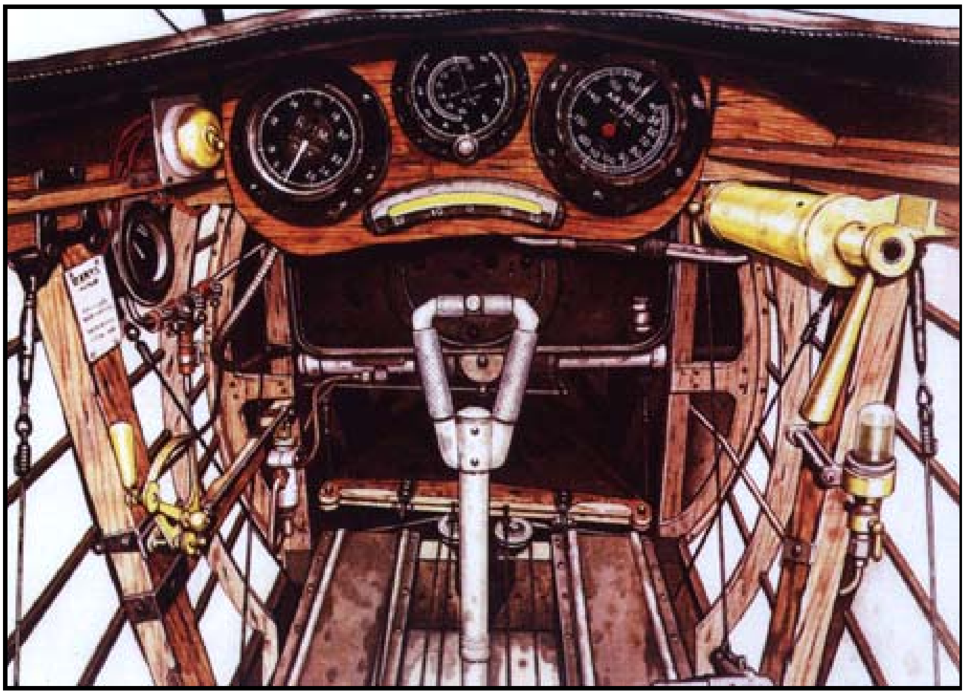

Figure 1: Sopwith Pup Cockpit.

The interface of such aircraft was developed, very much with the user, but with the primary considerations being flying. This was a very manoeuvrable little aircraft, but it was open to the elements and some of the main considerations were the physical protection of the pilot from those elements. This aircraft undertook the first carrier landing, and in such conditions that physical protection of the pilot became all important. At this standard of cockpit interface there was very little information available for the pilot: there is airspeed, an altimeter and some engine data, but altogether only about five information elements. Flying the Pup was very much more ‘seat of the pants’ rather than through the use of instruments. It is interesting to note that we can see an early instance of the use of Commercial Off The Shelf (COTS) equipment – the lighting switch in the top left of the picture is a typical Edwardian domestic lighting switch used in the home!

Moving on to the Second World War generation, the example that I have chosen is the Spitfire. The first Spitfire prototype flew in 1936 and it is estimated that there were ultimately over 22,000 of them that served during and after the war. By reference to the photograph in Figure 2, we can see that an obvious development here, beyond the Sopwith Pup, was the introduction of a canopy. With the canopy the external environmental considerations became less of an issue for the pilot, but the introduction of the canopy brought about its own problems. The canopy fitted to the early Spitfires had a flat top and, presumably, at the factory that provided adequate accommodation for the designer. Unfortunately, when the aircraft entered service and larger aircrew were exposed to the cockpit they could not sit in the cockpit with the canopy closed. This necessitated a re-design which resulted in a domed canopy, which is characteristic of the Spitfire as most people would know it today. In addition, the pilots were not able to see the touchdown point from the normal seating position. This resulted in the crew flying ‘zig zag’ approaches to enable them to see where they were going to land. Whilst accommodation problems can still arise today, the basic approach now adopted throughout industry, of giving due consideration to the anthropometric population requirements, whether this be via the use of traditional or 3D Anthropometric techniques, removes many such fundamental mistakes.

Figure 2: Spitfire Cockpit.

The Spitfire also provides an interesting example concerned with the problems associated with the introduction of new technology. This aircraft had a retractable undercarriage which, for the majority of the pilots who were flying it, was a new feature. A warning Klaxon was included to warn the crew to lower the undercarriage but this often proved to loud and was switched off by the crew. This resulted in many crashed landings with the undercarriage up. Unfortunately, whilst we are now aware of the necessity to consider the audio environment, issues surrounding inappropriate audio levels still persist in many aircraft today.

We also see with the Spitfire some of the early lessons in coping with population stereotypes. The Spitfire throttles would move forward to open, which all seems quite sensible and normal by today’s standards, but when some of the allied air forces started to fly the aircraft they were used to throttles operating in the opposite sense and again several crashes resulted from inadvertent de-powering of engines! Population stereotypes can still present challenges to cockpit designers today, even more so with multi national projects and aircraft geared towards the export market.

In terms of displays and controls, the quantity of information presented in the Spitfire increased when compared with the Pup, but the interface is still aimed primarily at providing basic flying information. It is interesting to note the introduction of an early artificial horizon (the 2nd instrument from the left).

Moving into the 1950s, with the Hunter, we have now entered the jet age. With the higher speeds and altitudes that this aircraft was capable of, jumping over the side of the cockpit in an emergency was no longer a viable escape option, and the Hunter included one of the first generation ejection seats, a Martin Baker Mk 3. There still seem to have been cockpit geometry problems. There was a fairly low canopy and cramped cockpit space that was quite challenging for the larger pilots. Whilst the aircraft seems to have been well liked by those that flew it, the cockpit layout has been described as disorganised with no rationale behind it. We are still in an era of cockpit design evolving as a by product of aircraft design, rather than being an especially planned 'system'. This is particularly interesting at this time in history, as it was towards the end of the Second World War and during the post war years that Ergonomics, or Human Factors, established itself as a separate discipline. In the U.K. there was Prof. Bartlett undertaking his work on Human Performance and in the States Chapanis and Fitts in the 40s starting to look at Human Engineering. As can be seen from Figure 3, we clearly have more complexity of information in the Hunter, compared to what we have seen, but it is still in a dedicated presentation format and still a quite manageable number.

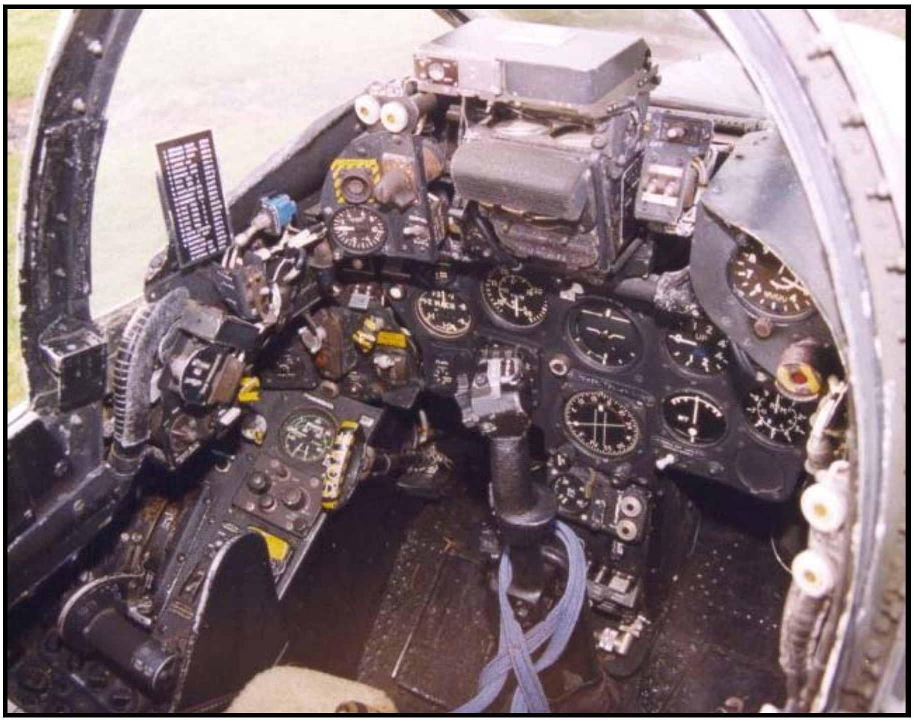

Figure 3: Hunter Cockpit.

The 1960s and the Harrier saw some new challenges, with its ability to undertake vertical landings. The take off and landing phases are always relatively high workload periods, but now the pilot had a nozzle lever to also contend with and the landings, in particular, were quite hazardous and very high workload. From a geometry perspective it was cramped, the cockpit being located between the two intakes, and there was poor external visibility. We still have the airframe totally driving the cockpit space. There is a Head Up Display (HUD), but as can be seen from the photograph of an early generation Harrier, presented at Figure 4, the majority of the information at this standard is fixed.

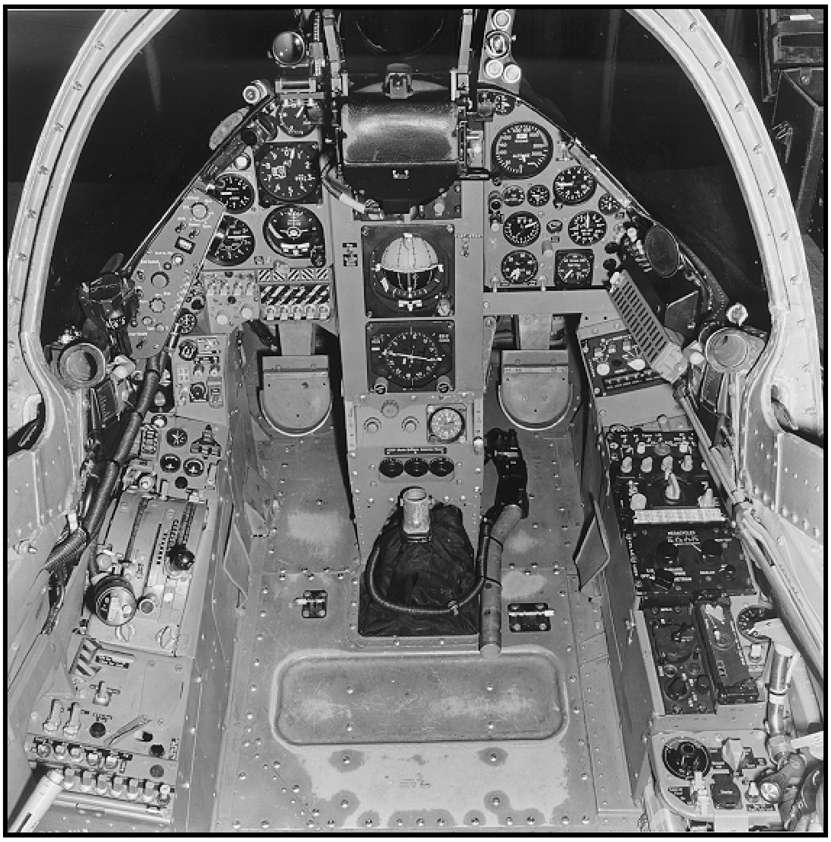

Figure 4: Early Harrier Cockpit.

The example that I have chosen from the 1970s is the Tornado, designed and manufactured jointly by the UK, Germany and Italy. This is a two seat aircraft and, by comparison with the other aircraft we have looked at, is a positively cavernous cockpit, very wide. The design process for the Tornado saw the extensive use of a mock-up to develop the geometry and layout, lighting simulations and displays simulations to develop the displays and moding. The utilisation of these mock-ups involved aircrew and so we see the start of a more user centred design process. There was still though a fairly strong element of design by committee. By reference to Figure 5, which shows the Air Defence Variant (ADV) of the Tornado, we see multi function displays starting to play a part, both with the HUD and the two head down displays.

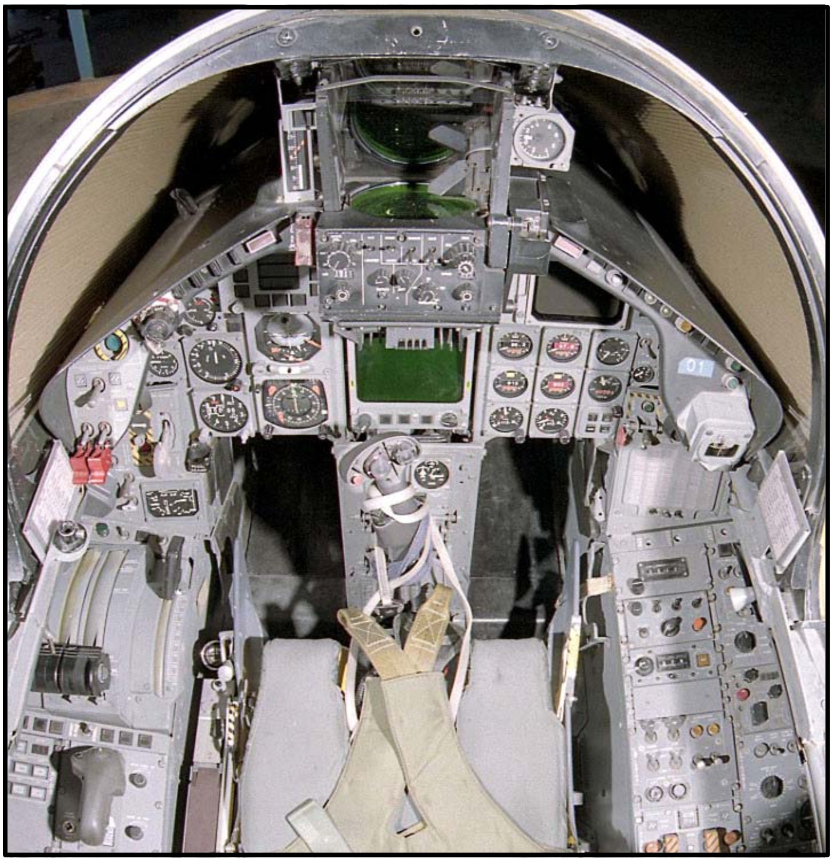

Figure 5: Tornado ADV Cockpit.

If we move into the 1980's generation, with the Eurofighter aircraft, the most noticeable difference here (see Figure 6) is that this interface appears so much cleaner than those previous generations. This is definitely now dominated by the new technology. The cockpit itself is very small, compared with the Tornado, and is single crew, so we now have workload as a primary consideration. But there is a lot of automation behind the scenes. One of the nice aspects of this cockpit, from a design point of view, is the bespoke nature of the majority of the cockpit displays and controls. This gives the design and ultimately the HF much greater flexibility, but I am afraid that in today's environment we will not again have this luxury. Now whilst the interface appears clean and uncluttered, the multi-function displays and controls hide the quantity of possible information, and in reality the information available for presentation to the pilot soared when compared to the previous generation of aircraft.

Figure 6: Eurofighter Typhoon Cockpit.

If we now look at the aircraft reviewed above and assess how the level of information presented to the pilots changed through the generations, we can see an interesting and predictable trend. The graph in Figure 7 illustrates along the x axis the different aircraft generations and the y axis indicates the number of information elements that are present in each cockpit. The most significant increases begin with the 1970's and then more than double with the 80's and the Eurofighter. This has been possible through newer technology and more sophisticated and complex systems, a point we will return to.

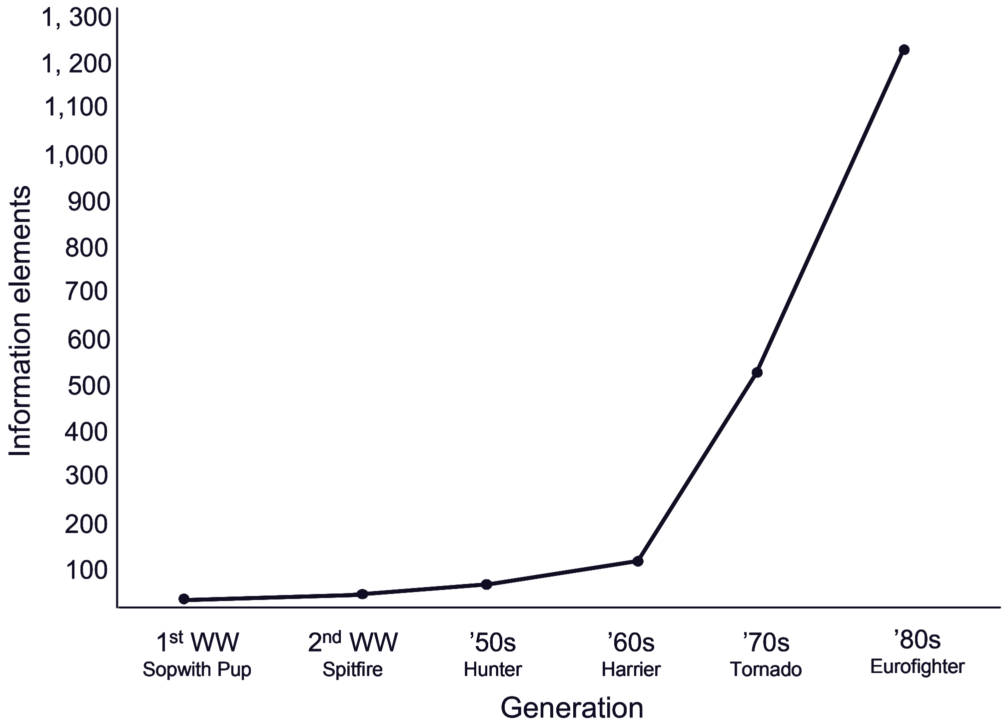

Figure 7: Change in Information Elements Available.

A similar picture exists if we look at the number of control functions available to the pilots in these same aircraft. Figure 8 reflects this information.

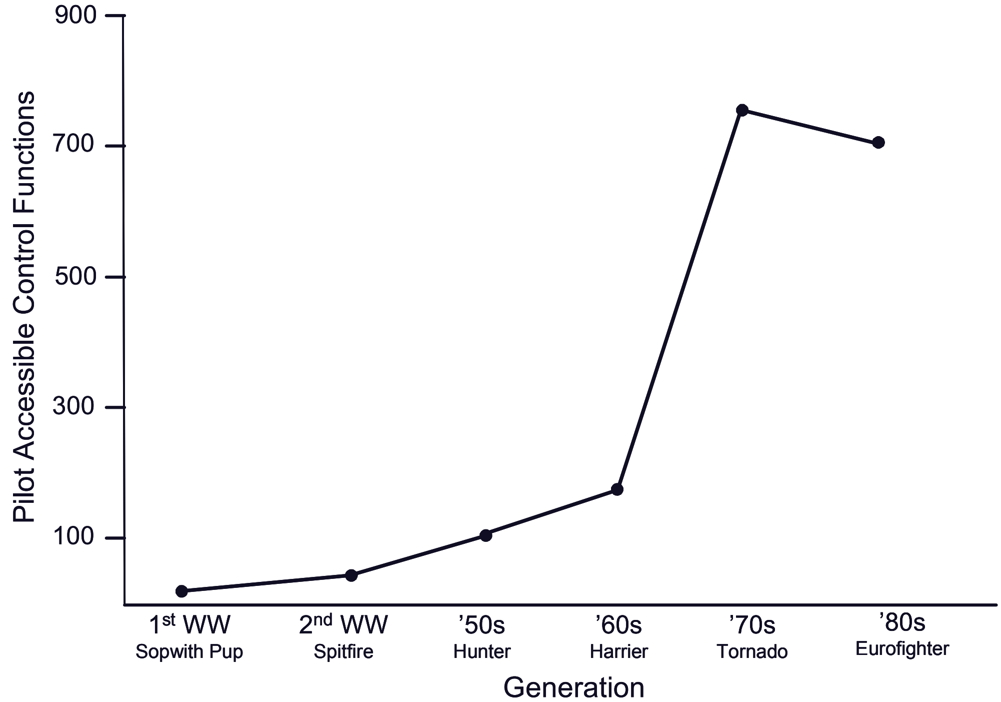

Figure 8: Change in Control Functions Accessible.

Again we have a slow but steady increase through the first and Second World War generations, but it is not until the 70's that we see a marked increase. The interesting trend that we see here, when we go from the Tornado to the Eurofighter (the 70s to the 80s), is a slight decrease in pilot accessible control functions. This can be attributed to mainly by the increase in automation that comes with aircraft of the Eurofighter generation. However what is perhaps even more interesting is that if you predict what the decrease should be, based upon the level of automation introduced, the actual reduction in control functions falls short of this. What is coming into play here is a degree of reluctance to 'hand over' completely to automation, retaining a degree of manual back up for extra confidence.

However, judging complexity, and hence usability, is not just about the counting up of control and information functions, it is about how we manage their implementation into the interface. But this is perhaps where, with the assistance of technology, we can become too clever.

If we take the Eurofighter stick and throttle tops. The stick has 10 dedicated controls and the throttle 12 dedicated controls. That is a reasonable number, but with clever physical design we can provide an interface that can be operated by the required anthropometric range: and by this I mean that each control can be uniquely identified and each discriminated from the others. But perhaps the issues may come with what we then do with this physical interface. These 10 dedicated controls on the stick top actually control 70 functions, and the 12 Throttle top controls are responsible for 51 functions. That is over 120 functions controlled just by the inceptors. That is engineered by having a 'shift' control that acts as a role change of other controls, by having short and long presses and by moding the switches as a function of such things as weapon or radar mode selected or other systems moding. For me the issue here is not any longer one of having a pilot that is physically able to cope with the number of controls, but one of his brain and cognitive functioning being able to cope.

HUMAN FACTORS IMPROVEMENTS

So, from a Human Factors perspective, what has improved and potentially got worse over time? The latest statistics produced by Boeing [1], regarding commercial jet airplane accidents, considered all aircraft on worldwide operations, between the years 1959-2001. These show significantly lower accident rates for current generation aircraft, when compared to first and second generation aircraft (where current generation aircraft are such platforms as the 747-400, 777, A330 / 340). However the same study shows that Flight Crew were identified by the investigating authority as the primary cause in 66% of accidents between 1992 and 2001. That can be compared with the first world war when 66% of accidents were due to aircraft failures. So, as the complexity has increased the ratio of human error to technical faults seems to have reversed. That is an extremely high percentage and one which will be at the fore front of the minds' of most people working within the Human Factors area.

However, there has definitely been a lot of improvement, so we should consider that.

Firstly, there is now the potential for **great flexibility for information presentation and control**. As I think we have seen, this has to be managed effectively, but whilst the wealth of available data is endlessly increasing, we can tailor this and present it in appropriate ways, such that we have ***information***, rather than just ***data***.

We have also improved with respect to the fact that we can now automate so much of the general housekeeping tasks and the complex, data rich, tasks, leaving the operators to be the 'managers' of the platform. As with so many strengths however, such strengths can also be weaknesses, and we have to be so careful here that the automation does not take away the operator's understanding of what is going on, his Situational Awareness.

I think that the **attention paid to the Human Factors** of the interface is ever increasing. In terms of future investment into Human Factors, there is a wealth of research monies put into all sorts of aspects and they are often concentrating on some of the real important issues that face the development of the Human Machine Interface. However, I do have a concern that perhaps a lot of it may stop at the research end and not manifest itself in products. We have all seen all too often noble research objectives dropped at a project stage and true Human Factors application dismissed as too theoretical. My experiences of the Eurofighter programme are of a programme that demonstrated a very strong commitment to the Human Factors interface. Throughout that programme there have generally been about 30-40 Engineers working on the Human Factors aspects of the interface, as well as the pilots who were involved in the design process.

Also, fundamental to most Human Factors processes is a **User Centred Design process**. The involvement of the user is crucial. But this should not just be a single or a few users, due to the risk of reaching a biased, personalised design, but as many as possible with as diverse a variety of backgrounds and experiences as possible. On the Eurofighter we have had the benefit of the experiences of getting on for 200 pilots, from the four nations involved. To me this is excellent; we can reap the benefits of their flying experiences from aircraft cockpits from around the world, and equally expose the design to a real cross section of abilities and mind sets.

Another great asset that we have in helping us to develop the Human Factors interface, is the availability of some very **sophisticated simulation facilities**. This ability to rapid prototype and realise the design before flight is crucial. Again, using the Eurofighter as an example, we have been able to develop that cockpit design by prototyping it in a simulator and exposing the emerging design to these 200 pilots during in excess of 5,000 hours of simulator flight.

CRITICAL DESIGN ISSUES

From all of this some, what for me are critical, issues emerge.

We undoubtedly have an information explosion at the interface. By reviewing the papers presented at this Symposium, this is not limited to the aircraft cockpit, but something that is of concern to Naval and Army platforms as well. These papers take many different approaches to dealing with this issue, but they generally focus around appropriate utilisation of automation, by considering Situational Awareness in *partnership* with automation and by distinguishing between *data* and *information*.

I think that as designers and operators we also have to become better at forgoing what we can have for the sake of what we can effectively use. In my experience this is an extremely difficult decision, or in fact what may at times seem to be a sacrifice, to make.

I would also highlight the potential loss of basic ergonomic design principles that comes with the introduction of some ‘modern’ technology. This ranges from the obvious push buttons that do not move and into the real danger zones of ‘we can do it so we should’. And this is where I feel that we have some real gaps in our Human Factors tool-set. This is in terms of being able to predict and even measure some of our basic abilities. I am a firm believer in simulation and a rigorous involvement of operators in the design process, but I believe that this has to be complemented with a stronger objective knowledge of what the operators will be able to undertake under all conditions. An important responsibility of the Human Factors specialist is to review the users’ capabilities and ensure that the design will be suitable for the majority of the users, always paying specific attention to the ‘weakest links’. If we are to start to address this 66% Human Factors attributable accident rate, we have to be more objective in understanding the likely causes of human error in the design that we are producing and be rigorous in our analysis of this, both pre, during and post design.

Whilst I firmly believe that a user centred type of approach is absolutely correct, I still have some residual concerns regarding the processes that we use in the evaluation of the design, and this brings me on to what I see as another critical area: how we undertake the decision process regarding when we have finished the design and when a change is necessary rather than just a 'good idea'. I have recently worked on the Nimrod programme where a great deal of attention was paid to determining and agreeing with our customer acceptable performance metrics. These ranged from the truly objective measures of performance to the more pseudo-objective measures of workload and situational awareness. One of the issues that existed on that programme was the establishment of red line data for acceptability. When is the workload acceptable, when is it borderline and when does it become unacceptable? If there are alternative design solutions and for each there is some measure of workload, most techniques will only allow comparison of these alternatives relative to each other. What we really need to know however is whether any of the alternatives satisfy an acceptable level – choosing the option that is 'better' than the others may not be the most efficient option, but choosing one that elicits a lower workload rating may still be acceptable. There is a lot of information regarding techniques, but very little on determining that elusive red line.

I would also say, from what I have seen around the world, at least within the air sector, that a critical issue is one of getting what we know we should do with respect to Human Factors, from the labs and into the real product environment. We understand from a Human Factors perspective the design processes that we should be following, what we must do is get them integrated with the project main stream engineering processes and demonstrate their worth.

We have to try and move our Human Factors approach over into the objective realm and be able to demonstrate the advantages and benefits from both safety and cost conscious perspectives. In this respect a user centred design process to me is not about the user doing the design, but about capitalising upon the experiences and domain knowledge of the users and ensuring that this is appropriately considered, from a Human Factors perspective, throughout the design process.

These experiences and issues will help to take us forward to the next generation of Human Factors challenges that will face us when we now look towards Uninhabited Air Vehicles and wider command and control issues. For all of these developments will retain a human operator at their core, perhaps with a different skill set and with different training requirements. They may be land bound, but the issues still prevail, and I do not think that so much has been solved to put us all out of a job, just yet.

REFERENCES

[1] Statistical Summary of Commercial Jet Airplane Accidents: Worldwide Operations 1959 – 2001; Airplane Safety, Boeing Commercial Airplane, June 2002.