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22. On the Dependence of Information Display Quality Requirements Upon Human Characteristics and "Pilot/Automatics"-Relations

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INTRODUCTION

Basically, the title selected has to deal with the characteristics of, and relations between, many and complex components. Due to the short time available some of these contributing factors can only be touched and I am very aware of the risk of over-simplification. So I can only try to give a representative cross section.

Although this paper primarily offers generalized statements, these are based on operational and experimental flight and simulator experience, on literature- and some theoretical studies, and on an evaluation of a new display concept. Information on more specific results is, or will be, presented in other papers (refs. 1 through **4).**

Manual control e.g., of an aircraft landing would be (under the impression of the previous paper of Dr. Naish I should modify to: "seems to be) no problem, if best visual contact with the outside environment would be continuously available. In general, this is true even for poor aircraft dynamics.

Actual operating conditions, however, are more or less below optimum, down to absolute zero visibility. We all know that under these conditions aircraft control becomes critical as soon as solid objects in the environment of the aircraft severely restrict the use of one or more **of** the *six* degrees of freedom, especially when the speed is extremely low or high. Several remarks in literature try to base the "all" weather landing problems on limited human abilities in manual control. The pilot as a controller should be substituted by automatics, as shown by the quotes from reference *5*

> . . . even with the best available displays the pilot has not been able to control (the blind landing) with the precision required . . .

and reference *6*

> There is no doubt that in complex flying tasks like blind landing . . . automatics become essential . . .

Sometimes, certain limitations of man are reached and exceeded, indeed. For example, when a pilot tries to suppress high frequency oscillations. However, such critical flight characteristics do not prevail in the landing phase.

Of course, man cannot penetrate fog with his eyes; However, in order to remain consequent, it would be unreasonable to blame *him* for this fact. Otherwise, he should be considered to be blameworthy, too, because he needs tools, machines to carry heavy loads, artificial wings to fly, etc.

The characteristics of the aircraft, **of** the controls, and of the gust disturbances in principle do not change and the same human sensors remain active as soon as flight conditions change to IMC. **A** rigorous change happens in the type of information only. Therefore this and it's interference with basic human characteristics must be the main source of the problem. Furthermore, this suggests, that the substitutes for visual contact presently in operation are not yet equivalent, although visual contact itself has been shown to provide poor information in some respect, too (see paper **21** and (ref. **7)).**

Finally, the inevitable predominance of the automatic in landing control is justified only if the present information display concepts are approximately the best that can be achieved at all.

EVOLUTION OF THE DISPLAY PROBLEM

A quick look at the evolution of the display problem may help to emphasize the main "knots in the network" (fig. 1).

Some aspects of the field of aeronautics are composed here according to different applicable activities of man. However, let us concentrate on man in his role as a systems component, especially as a pilot. In his other activities within the whole, he has more or less direct, or secondary, influence with the central display problem. The other part of the "link systems" the controls are eliminated here, although their man-compatible outlay plays a remarkable role in the limitations of the total systems performance.

Aircraft performance increased rapidly under the powerful drive of basic human desires. On the other hand, the human "ability for unaided information pick-up" and "some desire" or, at least: "acceptance to perform difficult tasks" delayed the development of the artificial information sources. Economy and the desire for independence from day time and meteorological conditions partly provided for some accelerating as well as unfavorable inputs to the display development. The other part of this influence made use of the human "readiness to adapt to almost every demand." This combination of inputs necessarily led, via a "completion" of the information step by step, to the "logic" result, the additive display as we know it from present cockpits. The built-in "lag-mechanism," however, is responsible that even this simplest requirement for complete information relative to the demands of operation was fulfilled in rare cases only. It should not be surprising that there are still gaps to be filled. The following is quoted from reference 8.

> . . . None of the parameters . . . flare initiation, decrab, touch down point . . . are available on the instrument panel . . . (inusable form) . . .

The *visual switching* of man operates at a high performance level, when compared with other motion functions of the human body. The fact that basically the additive display—in whatever stage of maturity—does not allow the systems optimum to be reached has been obscured for some time:

Sinaiko (ref. 9) stated

> . . . man can perform several **kinds** of tasks simultaneously or in rapid succession and keep them all integrated.

This is true in normal every-day conditions. However, as soon as a complex riskful task has to be performed under severe time constraint, the opposite unfavorable side of the (minutely examined) organization principle of the human

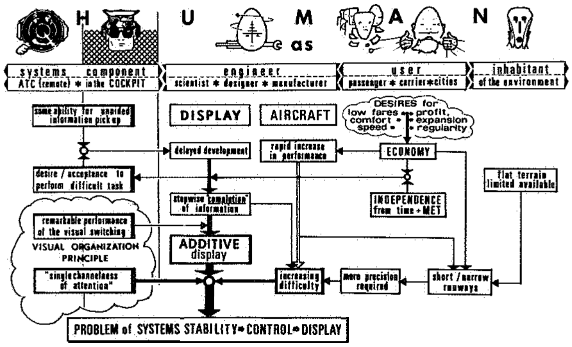

FIGURE 1.—Evolution of the display problem.

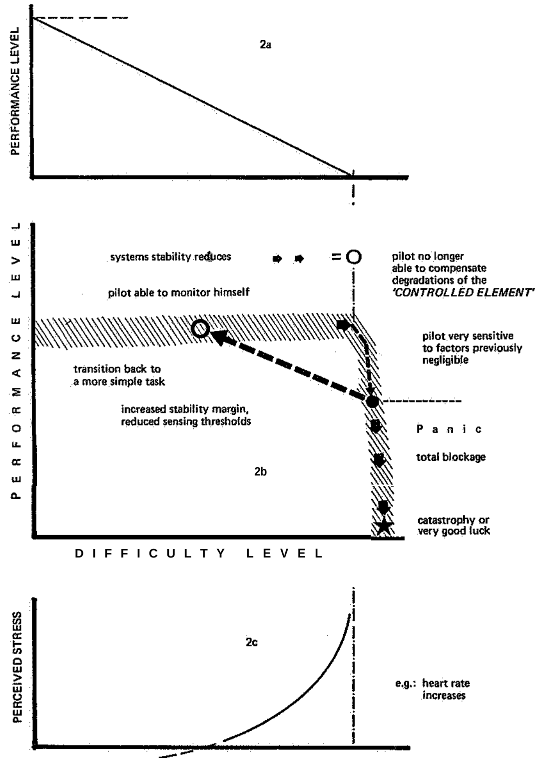

FIGURE 2.—Human performance behavior.

visual becomes apparent. Kelly in reference **10** mentions

> **The human operator can attend to only one thing at a time; he is a single channel device in this sense . . .**

The increasing performance of the aircraft, on the one hand, impaired the flight characteristics; but on the other hand, the step from circular grass airfields to narrow concrete runways was necessary and required a much more precise guidance.

The following is a translated remark in a **1935** paper by Schulz (ref. 11):

> **Landing in poor weather (dense fog included) is a problem, the main part of which is considered to be solved; within a few years the last difficulties will have been overcome.**

We know, the progress "by-passed the last difficulties," which grew in the meanwhile and was "baked" to be a very resistant problem now. After all, the "single channelness of attention" of man in a task of increasing difficulty made the manual control with information from an additive display critical. Operation under marginal conditions primarily became a stability problem.

Human Performance Behavior

We saw that the willingness of man to adapt had an unfavorable influence in the evolution process. This would have been avoided, if the "man in the loop" would allow the performance of the system to drop, e.g., linearly, with increasing difficulty (fig. 2(a)). He does not. Instead of this, he amplifies his effort and maintains the overall performance approximately constant (fig. 2(b)), as demonstrated by Henry Jex during this conference. Due to the raised effort man perceives stress as soon as a certain difficulty level is exceeded (fig. 2(c)).

Compensating the difficulty with effort necessarily reduces the reserves of man and thus of the system's stability. As soon as the human capacity is saturated, a steep break down occurs and either a simpler task is adopted or, if this is impossible, a catastrophy may result.

TRIED SOLUTIONS

Figure **3** shows a rudimentary diagram of known efforts to overcome a problem. Some impressions and knowledge of limitations as well as abilities of man and automatics, respectively, split the activity—some of which diverged into opposite directions. Not all of these are indicated here and two, the improved education and simplification of machine are mentioned only. Figure **3** concentrates on the trends towards display improvement for manual control and towards substitution of man by fully competent automatics.

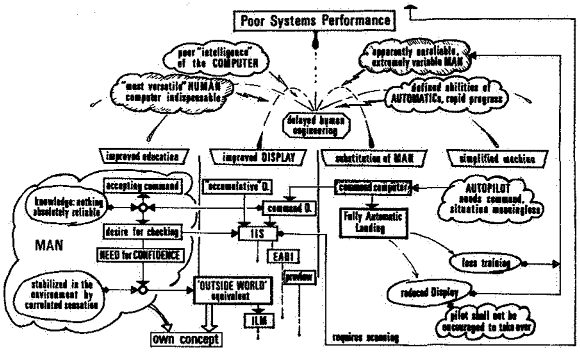

FIGURE 3.—Types of known solutions.

Improvement of Controllability by Displays

Display improvements have been achieved, for example, by compressing the distributed indicators into—I prefer to call it—"accumulative displays."

Steering commands, which combine the different separate variables are obligatory for automatic control. They were made available for the pilot, too, in the form of command displays, e.g., director needles.

While the first step, the accumulation, reduced information scanning, command should have completely eliminated this main destabilizer on the first superficial view.

What can be effected in terms of stabilization with a "fully integrated" display is symbolized in figure **4** by a simple mechanical model. In control tasks with "distributed information" the pilot has to stabilize (dependent upon the difficulty level) a more or less unstable system. Unstable, because too much relaxation in information scanning activity increases deviations from the desired conditions and thus the control diffi-

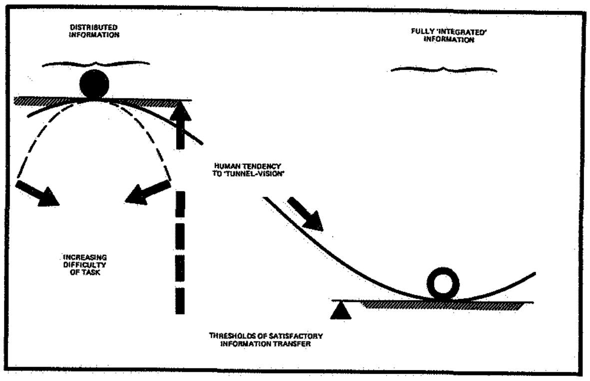

FIGURE 4.—Effect **of** tunnel-vision=function of display.

culties. This in turn, tends to further reduce the scanning frequency.

As soon as the stabilizing capability of man is exhausted, the information transfer runs "downhill" below the satisfactory threshold. If, on the other hand, the pilot is provided with fully integrated information, which has it's threshold of satisfactory information transfer at "the bottom of a valley" (fig. 4), the destabilizing scanning process is no longer required. It may be used to gather additional secondary or detail data; however, in cases where attention must be concentrated, man automatically returns to the main source of a continuous fully integrated flow of information. In this case, the information transfer would be inherently stable. In other words, since the pilot has a strong tendency to "tunnel-vision," it is reasonable not to fight against this but to give him the "tunnel."

Returning to figure 3 we can say that the pure command display already is some type of fully integrated information. However, pure imperative indications are not satisfactory. Although there are some pilots (and people) who accept or even like command, most of them feel a natural need at least to check its validity. So the accumulated situation indicators were combined with command in the so-called integrated instrument systems (IIS), which are the well known ADI/HSI-instruments, presently in wide use.

Progress in electronics has led to conversion of the ADI-display into the CRT-equivalent: the electronic attitude director indicator (EADI). Although to a lesser extent than before, the problems of single channelness of attention and information scanning and systems stability were adopted again with the IIS and EADI. Furthermore, in operations under marginal visibility it became obvious that the present state of the art does not cover, to a satisfactory extent, the human psychological need for confidence. The following observations **of** Stout and Naish (ref. 12) emphasize this:

> . . . pilots anxiety level increased at an alarmingly fast rate below 100 ft (altitude in true blind landings, manually controlled with a certain modern Flight Director).

Obviously, the conventional type of situation display, although sometimes provided with the term "pictorial," is not yet realistic enough. The following remark of Armitage (ref. 13) indicates a possible solution:

> There appears to be a great need for a real world-type display derived from . . . data of a source other than ILS.

TV- and infrared techniques and the recent progress in radar have made possible a picture of the runway during the final phase of a landing even through dense fog. In some displays this picture is combined with the EADI-Information. The independent landing monitor (ILM), a radar-image according to the statement of Armitage (ref. 13), is intended to be used not as an aid for manual control but as a separate 'confidence producer' for the pilot who supervises the automatic landing.

Another important type of outer loop-information, the preview-display, should, at least, be mentioned here. There is no instrumentation of this type in general use today.

Both, pure command or IIS, as well as pure contact analog, had been shown to be unsatisfactory, as has been presented in separate displays. In a paper presented at the AGARD Symposium in 1968 (ref. 14) we can find the following surprising remark of Douwes Dekker which shows that superimposition of different elements is undesirable :

> . . . Complete obedience to the HUD-director signals was required. This was best achieved with windshield blanked out, to prevent the pilot from being disturbed by the outside world. This most curious contradiction . . . indicates that FD-signals, having **no** direct relationship with the visual cues, should not be superimposed **on** the outside world.

AIMS FOR DISPLAY DESIGN

Obviously, the question is now, how we can achieve the desirable complete integration of quantitative indications, outer **loop** information and real-world display, in order to fulfil the requirements of controllability and confidence, respectively.

Gibson (ref. **15)** and Metager (ref. **16)** and probably other psychologists have shown the high extent which man is emotionally stabilized in his habitual fixed environment. This is primarily achieved by the realistic, and in motions quickly changing, the appearance of near-by objects which are reasonably distributed in the visual world, and, furthermore, by a very intense correlation of the inputs from all the affected human senses.

Since the natural environment of an aircraft is not filled with space-fixed objects, a simple copy of the real world has proven unsatisfactory. More or less abstract superimposed additives are undesirable. However, the useful part of the real world can be extended by suitable imaginary objects apparently fixed in space. Such a complex pictorial presentation can provide for each desired sensitivity.

The symbology of pictorial displays can be designed to provide for all necessary quantitative information content by pure pictorial means. It is a wrong assumption that pictorial displays in principle are less accurate and qualitatively only.

Furthermore, such pictorial displays which meet the aims mentioned before inherently contain some outer loop-information to a much higher degree than generally recognized. Separate indicators for command, preview, and flight path vector will thus be superfluous.

These display qualities are evaluated in detail in reference **17.**

The presentation until now has only touched the controllability and the confidence components of the problem area. However, the requirements for really advanced displays extend beyond these aims. Modern aircraft operation demands for a maximum of flexibility, e.g., for noise abatement — STOL-operation on small airfields which may be surrounded by high obstacles. We know that modern instruments do not allow an approach such as is possible in visual contact turning approaches (fig. *5)*. Present instruments require all dynamics of motion, except speed, to be suppressed in a 5 to 8 mile long straight-in approach in order to effect a safe landing. Straight approach suits the desire for comfort, yes. However, up to now not much more in terms of flexibility is possible.

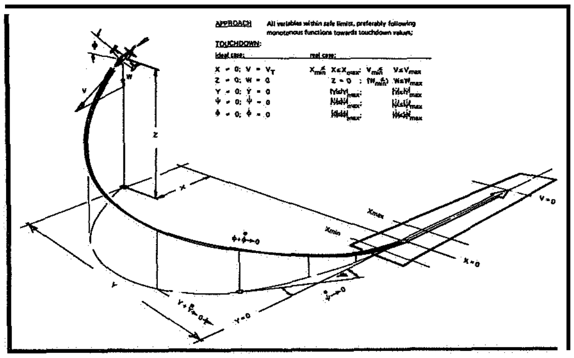

FIGURE 5.—Desirable flexibility in **landing approach.**

Turning approaches, contradictory as it may seem, are safer and easier to perform (ref. 18) and, therefore, are used by fighter pilots and recommended for space shuttle landing (ref. **19).**

A true precision task in terms of a tight control of all degrees of freedom prevails in relatively short phases of flight only—if at all. In general, the last **10** sec of a landing might be considered as such. But, more accuracy is required in close formation flight and flight refuelling. In spite of that, these tasks are performed with admirable perfection which indicates that landing cannot be too difficult a task for manual control if a suitable display is provided.

The proficiency of a pilot depends upon his training in precision control. Thus, presenting a display which continuously demands a reasonably high precision of guidance would raise the average manual skills to a remarkably higher level.

The ability of man to "differentiate" and "integrate" is much better than sometimes assumed; it can be raised to an artistical level as an overwhelming number of examples, even in every-day life, demonstrate. This should consequently be used for improvement of manual control of an aircraft by better display techniques.

The following summarizes the main aims of display quality requirements:

Controllability of the system:

(1) Not as easy as possible, when achieved by artificial task simplification only.

(2) According to demands of high performance activities of man

(3) Economic use of superb human dynamic capabilities.

Flexibility of the system:

(1) Free selection of safe flight trajectories

(2) Response to operational requirements.

Proficiency of the pilot:

(1) Raised beyond the present state

(2) Maximum use of human reflexes+intelligence

(3) Selection of the most suitable individuals.

Confidence of the pilot:

(1) In space orientation

(2) In his own ability as pilot in the loop

(3) In the overall situation

(4) In the functional reliabilities may be less important.

FINAL REMARKS

Let me add a further statement to confidence. My impression is that we cannot hope for any spontaneous confidence when we base it only on partly experienced, finally extrapolated, and believed or not believed high reliability of the equipment. The pilot needs a back-up by a confidence-immanent information display!

With respect to the acceptance of advanced automatics, we cannot derive that the automatic solution is near-optimum if pilots accept the role of a manager without being able to demonstrate true competence in manual control during each phase of flight. They must and probably will accept a dominating autopilot and reduced instead of improved displays, if no convincing alternative is in sight; otherwise, they will probably lose their job. The extreme tendency of man to adapt allows him to develop a fatalistic type of confidence. On the other hand, a pilot will like to delegate the complete landing even to a less reliable automatic if the display enables him to chose and perform alternative decisions in case of not only an overshoot but a take over.

Two examples of our approach to solve the problem are shown in figure *6*, 7, and 8.

The main display element is a channel or a tunnel, which has been developed by consequently applying the street-shaped symbol for lateral and vertical guidance in all flight phases. This concept is described in more detail in references **5** and 17.

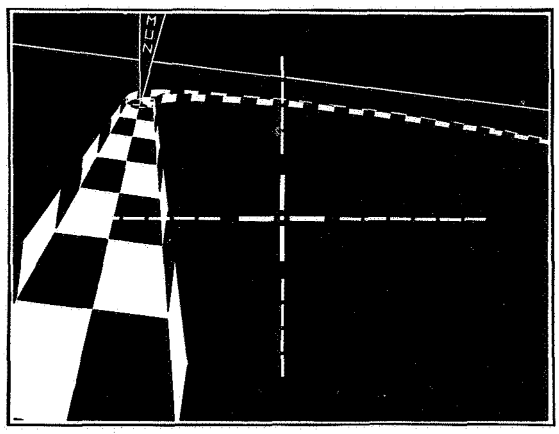

FIGURE 6.—Entering MUN holding pattern.

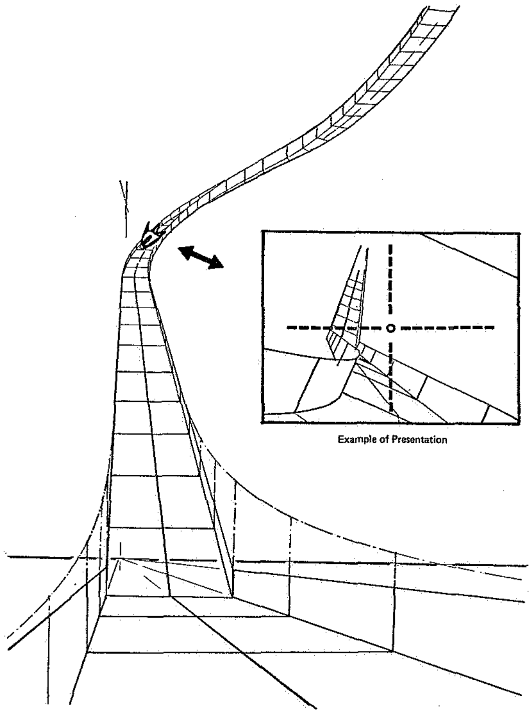

FIGURE 7.—A channel for unpowered landings; glide angle variability, wind, and flare capability have been accounted for.

We feel sure that we can meet the requirements of controllability, flexibility, and proficiency. We believe that we have a good chance to fulfil the confidence-requirement, too. However, we are aware that this is very difficult to demonstrate.

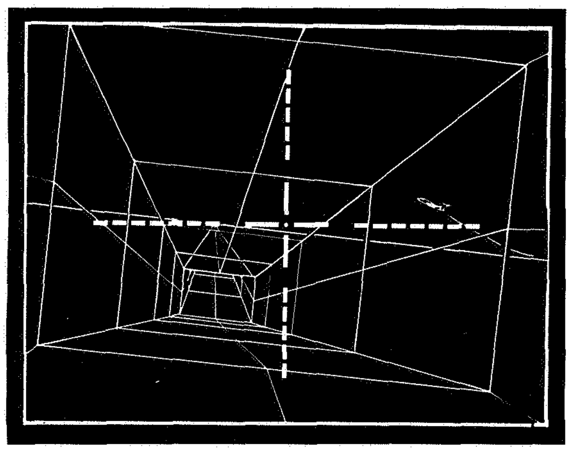

FIGURE 8.—Channel information for collision avoidance.

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