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HUMAN FACTORS IN ELECTRONICS

Keynote Address by

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The exploration of Space has become a human challenge that will require the application of mankind's knowledge collected through 3,000 years of civilization. This knowledge and its resulting technology have been hoarded thoughts winnowed and sifted through millions of minds, living and dead, to guide us on our way in the design and fabrication of space systems and equipment needed to explore the Universe. It seems as if so much has been accomplished in the last few decades that there is hardly any basis for comparison with what man has done in the preceeding centuries. But it must be emphasized that the successful manned space flights are only the manifestations of the underlying body of technical and scientific knowledge accumulated and recorded throughout man's history.

There is so much discussion regarding Human Factors in the Space System Effort that it would appear as if it were only recently discovered. We tend to forget that it is older than recorded history itself. Man has always attempted to devise methods, techniques and equipment to extend his capacities and capabilities. It has only been within the last few years however, that we have seen a great acceleration in the complexity, speed, and the capacity of machines and equipment. We now appear to be crowding the human limits of understanding the complexities, reacting to the exigencies brought about by the speed, and withstanding the physical stresses brought about by the conditions of aerospace flight. This has put us in the position of having to engineer in the human factor solutions prior to construction of equipment and systems, instead of waiting for the previous slow trial and error methods of solutions. The human factor solutions also rests upon the research conducted in previous days and years. The intellectual activity of human research of today derives vigor and freshness from the motivation of the completed systems. For continued progress there is a coupling between the two and the absence of one produces sterility in the other. The life blood of any complex system is information. We must understand that information and the communication of it is a rather sutle affair which we are only beginning to understand in any exact sense. Since humans enter into a system whether it be manned or unmanned, we have an introduction of man's capabilities, capacities, and limitations placed into a feed back loop in the overall system. Because man and his equipment are imperfect, the assumed straightforwardness of information is contaminated with what we have been calling "noise". This then illustrates a fundamental property of information that is, in any system, be it physical, biological, or combinations of both, information is never available without some noise or error. In memory of Professor Norbert Weiner, to whom I would like to dedicate this presentation, I might say that the greatest contribution that the combined fields of human factors and electronics can make is to the area of cybernetics. Much credit for todays science of cybernetics must go to Professor Weiner. The essence of the electronics and the so called human factors combination really reduced themself to the fact that we must first understand what the human brain really is and what is actually does. As W. Ross Ashby has pointed out, this knowledge is essential both to those who must decide what the aim of cybernetics research shall be, and to the workers who must carry it out. It is clear that to obtain a better understanding of the human brain and in turn the whole human system will require the interdisciplinary approach of a new type of systems engineering.

In the last few years we have taken it for granted that large-sc... scientific research and development are the necessary conditions for advancement in science and technology. We also assume that the large government and industrial support of R and D will continue in the future. It is becoming increasingly more obvious that we must be in a position to show that the research and development is required and that it is being accomplished in a more efficient manner.

The main job of NASA Advanced Research and Technology Management these days, aside from the usual dealings with manpower, budgets, schedules and other functions is to establish the methods or blue prints which helps them ask the right question, find the right researcher to accomplish the research and to apply the information into the design and fabrication of advanced aerospace systems.

The scientific research today not only determines the progress in the space programs it contributes to our health, our standard of living and our economics. Researchers can no longer work in a cloistered laboratory. We must move about obtaining a systems viewpoint if we hope to compete financial support. We must be familiar with related research and technology already accomplished. To give you an idea of the magnitude of the problem, the number of research articles published runs in the tens of thousands per week. With this large volume of recorded data, it becomes obvious that rapid information handling and processing is required. But more important, some measure or yardstick of effectiveness of the accomplished R and D has to be established. For example the number of current pieces of work, including contract and in-house human factors research in NASA and the Department of Defense alone totaled several thousand individual tasks for this past year. This may not seem at first glance a large number, however, if you take related efforts by other government, industrial, University and Hospital researchers, the total number of research tasks in the human factors field alone, during the current year, totals in the tens of thousands. This current work in conjunction with that which has been accomplished in the past gives you some indication of the magnitude of the enterprise. It has become obvious to those who manage large Research and Development programs that some method must be developed to sift and reduce the bulk of information into undimensional areas of interest which can be used and assimilated by the researcher.

The first preliminary steps are being taken between NASA and DOD to accomplish this by first of all exchanging current Life Sciences Research Task information in the general field we call life sciences. This information has been abstracted and put on magnetic tape for quick retrival of all current work in a particular area of effort i.e. radiation. This method has given the program managers a tool or blue print by which they can assess what is on-going within a specific area of interest and who is doing the work. Technical working groups are being established to review and coordinate on going research down to the experimenter level. This effort is an effective tool for the program managers of the particular agency to determine just how much and what kind of research should be supported in relation to the constraints of the missions, the resources and the time available.

We, in many cases, underestimate man's capabilities in being able to perform certain tasks. We launch into extremely expensive development programs to automate systems to perform desired functions. With a little added analysis on determining the specific requirements and functions of the system, we could have been able to accomplish the desired results with only specialized training and better utilization of the man. An appropriate analysis would have resulted in a saving of the cost of procuring and operating the automatic equipment. In turn, a great deal of research and exploratory development, which has little general application, could have been eliminated. There may be many capabilities of man that we over-estimate. Consequently, automated devices would have increased the reliability of the system and possibly the safety. In the case of the former, I would like to bring to your attention the confinement problem of extended manned space flights. The rather startling accomplishment of a young lady named Mauri Rose Kirby, who on March 14, 1959, at the age of 17 established a new world title for flag pole sitting of 211 days and 9 hours. Miss Kirby braved 75 mile per hour winds, sub-zero temperatures, and even a tooth ache while perched on an enclosed yard square atop a 71 foot pole. Other discomforts included two small fires that broke out when rains short circuited a small heater she used to keep warm. She extinguished the fires by stamping them out with her feet. After being lowered to the ground, she said she wanted to dance so she could use her legs for the first time in several months. She then staggered and weaved into a nearby drive-in for an examination by a physician. It should be obvious from such an experience that man or woman have a tremendous capacity for braving danger, and have a capability of improvising even in very restricted conditions, to survive without any apparent ill effects for many months.

I mention Miss Kirby because at times we over-emphasize and over-elaborate research and related simulation techniques for relative straight forward conditions on situations that cannot be duplicated here on earth.

The question of how much research should be supported is always a question of the most efficient and economical way to obtain the needed information. There are even times when, because of the relative unimportance of the solution in comparison to the cost of obtaining it through research, we may consider it best just to accept the best estimate. We realize, of course, that there are dangers in this, particularly in the fact that we may not recognize the importance of certain problems. It is important, however, for all human factors scientists and engineers (in and outside of government) to realize that in laying a research and technology base to obtain the most efficient advanced aerospace systems for NASA, we must consider the cost of obtaining the information necessary to design them; that we cannot afford, from the country's or our own standpoint, to support any and all research and exploratory development one might want to do.

We need quantitative information for engineering purposes. When this statement is made, everyone agrees but we often find that they are not thinking about the same thing. The type of information that is needed for engineering purposes is what one might best describe as mathematical formulations of functional relationships between different variables. The important factor here is this functional relationship, one the basis from which predictions can be made. Very precise measurements of isolated points tell us little or nothing about functional relationship. The point is that we must have tools by which we can predict, with some degree of accuracy, what will happen in a situation that we have not been able to observe in the past.

Most life scientists or human factor specialists, have been trained not as engineers but as scientists. They think more in terms of the exact correctness of their data than in terms of their applicability. In fact, it has been said that to be concerned about applicability of data is to be non-scientific. Consequently, the literature in the field of human factors is full of information that is apparently very correct but which represents only one point on what should have been, to be useful, a curve showing how one variable is functionally related to another. However, seldom, if ever, are we faced with a design problem with conditions that exactly duplicate the laboratory situation. We are desperately in need of what one might call mathematical models for describing human behavior as they relate to equipment design problems. Of course the more refined these advances are, the better, but the refinement can follow as we go along. This is no different from what happens in the rest of the field of engineering. Much of the present data we use are trend data. We often wish such data were better, but even so they are better than none at all. In our opinion, human factors engineering is being held back more by this deficiency than any other, and there is as much to be gained at the present by attempting to put the data that are now available into the form of such meaningful functional relationships as there is collecting new refined points. We are attempting to do this so we will be able to use the data at the time we need it most--before the aerospace system is designed. The system includes integrating the man, his equipment and life support into one functional package.

The major effort in human factors engineering must be accomplished while the system is undergoing its initial planning and design phase. In one sense, this approach needs little emphasis; everyone is aware of it. At the same time, though, we do not think that anyone would say that this activity is being accomplished adequately today. We are emphasizing this practice in NASA, and so is the Department of Defense. It is a must, not only because we cannot afford costly redesign and retrofits, but also from a time standpoint it is often impossible to make basic changes after the system has been designed. Some of the primary decisions concerning manual versus automatic functions and manned versus unmanned systems stem from the amount of applicable man-machine data available, and can be made and incorporated in the system only in the early design stage.

We would like to point out certain limitations of which we must be aware. It is never possible to answer all of the detailed questions at the beginning of the design process. The design of a system is a continuous process of refinement of approximations--from the gross to the detailed. You cannot afford to wait until you are 100% certain that your decisions are correct before you start the design process; be it the design of a research tool, instrument, subsystem (e.g. life support, pressure suit), or the total advanced aerospace system, including the necessary ground support equipment. We know it is difficult to make predictions about human capabilities in the operation of some advanced system when only very gross ideas or estimates of the system or mission are available. But someone must do so. The human factors scientists and engineers should be in the best position to accomplish this aspect.

Engineers who specialize in specific areas, such as propulsion, controls, electronics, etc., sometimes have difficulty accepting decisions that seem to be contrary to their recommendations. Human factors specialists are no different. It is difficult for all of us to see beyond our own areas of special concern. Sometimes we forget that it is the total system that is important. Design decisions, however, must be based upon the overall effectiveness and cost of the system. You must consider not only what we might gain but also what we might lose. Increased performance in one subsystem might cause decreased performance somewhere else. In other words, human factors recommendations, just as others, must be considered and should be stated in terms of the potential effects upon total system effectiveness.

This brings us to the least glamorous but one of the most important considerations in Human Factors--the whole area of ground support.

In the last ten years or so considerable progress has been made in the field of human factors engineering. The major portion of this has been directed towards problems of the so-called "operators": astronaut, the pilot the navigator, or the controller in ground systems such as air defense or air traffic control. Even in the quite recent past many people have cast rather critical glances at the build-up in human factors groups because they have said we are moving more and more toward unmanned systems and that, therefore, the requirement for this type of effort will soon be eliminated. Fewer people are making those statements today. We are rapidly beginning to realize that the trend toward increased automaticity is by no means decreasing the requirement for human factors engineering. Instead it seems to be greatly increasing this requirement. Missiles engineers perhaps belatedly but nonetheless certainly have become well aware of this fact.

We all are becoming aware of the fact that when you take the man out of the actual operation of the system you magnify the support responsibility many fold. Requirements for accuracy are greatly increased. Errors that might have been insignificant in a manned system might well be catastrophic in an unmanned system. The human being readily corrects his errors but only the most sophisticated machine can accomplish this activity and then to only a very rudimentary degree. We are not suggesting here that we have gone too far toward automated systems. The requirements for greater precision and higher performance leave no other course. We are saying only that with this increase in complexity of systems have come increased demands for human factors engineering in the various support activities. As we see it, one of the biggest voids in human factors research today and one which must be met in the near future is that imposed by the need for greater efficiency and accuracy in the performance of various ground support activities.

In a complicated Human Factors System situation complete knowledge is never at hand, and the applied research and engineering approaches are as necessary as the basic research approach. In reality, within our program, we are trying to strike the appropriate balance between the two. We are therefore, in the very precarious position of being responsible for a significant aspect of the biomedical research, as well as the necessary technology to insure man's usefulness and safety in advanced aerospace flight. It is woefully apparent that our "ink well" of basic biomedical knowledge as it pertains to healthy normal people (as contrasted to clinical patients) has been seriously depleted. We are not only attempting to refill the "ink well," but to build up a reservoir of basic research information in conjunction with the appropriate engineering biotechnology that will be useful in the future for whatever space ventures this country may undertake to maintain and demonstrate its pre-eminence in space.

The Human Factors Systems Program is very important to the overall achievements of NASA's aeronautical and astronautical goals. The sooner we get Human Factors Systems data away from the laboratories, and into the design of our advanced aerospace systems, the better off we will all be.

We are being forced to operate at the limits of human understanding, capabilities, stress and perception in practically everything we undertake for the future. We must be able to apply continuously greater scientific and engineering finesse in the Human Factors field to continue our progress in the overall fields of engineering, and especially the advanced aerospace systems of the future. We need more basic information from ground based and flight research and we must be in a position to make it available for application rapidly to our ever more complex practical day to day problems.

The scientific and engineering community involved in Human Factors Systems research and technology are invited to participate in this program. Constructive criticism and assistance to the Biotechnology and Human Research program office will be appreciated in any way which will help our country attain its future aerospace goals.

In conclusion, I would like to say a little about the future of human factors systems research. Here I must speak somewhat critically.

It seems to me that some of the past and present work is highlighted more by the complexity and finesse of its technique than by the soundness of its requirement or goal. Sophisticated modern electronic tools are being used to attack problems that are trivial or already solved a long time ago. Information in the literature is not being exploited fully. The situation can be cured, by a closer scrutiny of all proposed research, be it fundamental, applied or developmental to insure that a goal is clearly defined and past work considered. We can no longer proceed in a random fashion.

There is no lack of good research problems.

There is a great need today for simplification through a more fundamental understanding of phenomena we take for granted. Mathematical theories to aid in simplification and a better understanding of the cosmos around us are needed. Specifically in Electronics we need to re-examine our traditional complex circuitry and the logic behind it, so we can make even more rapid strides in solid state physics and electronics without imposing old circuit theory and wiring diagrams on new active elements. In 50 years an electron tube as we know it, will be an archaic museum piece.

The greatest need in Human Factor research is a better understanding of man, his capabilities and limitations. The study of human brain mechanisms promises the greatest rewards to science and technology and in turn to the betterment of mankind. We need more cross fertilization between neuro- and psycho-physiologists and electronic engineers, through a new educational tool "Systems Engineering" that includes the human element.

As mentioned earlier, we can expect progress in research and we can attempt to devise a cost effectiveness yard stick for said research, but only if we recognize that both require human judgement at all levels, from top government, Industry, and University officials through to the laboratory bench workers. I conclude by making a plea to each of you to join in our crusade to apply your unique talents to obtain a better understanding of man and his brain mechanisms in analyzing and making decisions, in order to arrive at some methods to calculate and measure human reliability in advanced aerospace systems.