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TECHNIQUES FOR OPTIMIZING HUMAN-MACHINE INFORMATION TRANSFER RELATED TO REAL-TIME INTERACTIVE DISPLAY SYSTEMS

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Abstract

In recent years the needs of ground-based researcher–analysts to access real-time engineering data in the form of processed information has expanded rapidly. Fortunately, the capacity to deliver that information has also expanded. The development of advanced display systems is essential to the success of a research test activity. Those developed at the National Aeronautics and Space Administration (NASA), Western Aeronautical Test Range (WATR), range from simple alphanumerics to interactive mapping and graphics. These unique display systems are designed not only to meet basic information display requirements of the user, but also to take advantage of techniques for optimizing information display. Future ground-based display systems will rely heavily not only on new technologies, but also on interaction with the human user and the associated productivity with that interaction. The psychological abilities and limitations of the user will become even more important in defining the difference between a usable and a useful display system. This paper reviews the requirements for development of real-time displays; the psychological aspects of design such as the layout, color selection, real-time response rate, and interactivity of displays; and an analysis of some existing WATR displays.

Nomenclature

MCC	mission control center
NASA	National Aeronautics and Space Administration
PC	personal computer
STM	short-term memory
WATR	Western Aeronautical Test Range

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Introduction

The success of NASA aeronautics programs is directly related to Western Aeronautical Test Range (WATR) ability to refine and advance techniques that support research flight and ground test requirements. Requirements to acquire, process, and display immense quantities of data will continue to challenge the development of real-time interactive display systems. Innovative system designs at Ames Research Center, Dryden Flight Research Facility have provided a capability for information display that will continue to push the limits of technology.

The primary mission of WATR is to provide the capability to conduct aeronautical research missions through the development and operation of tracking and data acquisition systems, real-time processing and display systems, and audio and video communications systems (Fig. 1). This support uses a combination of facilities in California: Ames Research Center, Moffett Field; Dryden Flight Research Facility, Edwards Air Force Base; and Naval Auxiliary Landing Field, Crows Landing, Patterson. In addition to these facilities, mobile research flight test support systems are available for use at remote locations.

The data resulting from flight and ground test missions are processed through a sophisticated computer system and is then sent to mission control center (MCC) facilities for display in real time. These real-time data displays are crucial to the safe and effective completion of various flight missions. This has led the WATR to continue its leadership role in the development and implementation of new display technologies appropriate for use in research flight and ground testing.

While many of the displays presented in this paper are oriented toward flight test, their basic design and function is relevant to a much broader range of applications. Thus, our discussion of this work will attempt to capture some of this breadth, rather than focusing on more specific applications.

Information Requirements

The implementation goal is to develop generic display systems capable of supporting a full range of test requirements for a variety of test missions. Consequently, these display systems must have the capability to present a variety of information and display formats. Ideally, all information required to determine the results and success of the test are transmitted to the display system in real-time, reducing postmission analysis requirements.

Display systems for support of research flight and ground testing can be divided into broad areas: safety of personnel, equipment, and the test article; productivity in test envelope expansion; real-time optimization of the research test; and maximum scientific return from the research test. The method of presentation, amount of information presented, and display interactivity have different characteristics depending on the purpose of the display.

The most important step in the development of new display technology is to have a clear understanding of the required test objective including the real-time and postmission analysis requirements. Figure 2 displays the evolution of requirements for WATR support. Real-time display requirements are analyzed to determine the appropriate approach for the desired information transfer. Only after completing this analysis is the new display capability developed.

Within the WATR well over 1500 missions, both ground tests and airborne research flight tests, are conducted each calendar year. Each of these tests has distinctive display requirements or classes of requirements. Schedules may require implementation of new displays within 2 days, while 6 months may be needed for the more complex. It is not practical or cost effective to develop an entirely new display capability for each test. A generic display capability that can interactively be customized by the user in real time would save both time and money in display development. The WATR development team must continually anticipate future display requirements to determine the path for development of new display systems.

Psychological Factors in Design

Test results must be displayed in a form that can be easily assimilated by the user in real time. To do otherwise places an unneeded mental processing burden on the user. This additional mental processing burden has the potential of making the researcher less efficient. A decrease in efficiency in one part of the information analysis system reduces the effectiveness of the entire test program.

Based on this need, there is an increasing requirement to design display systems that better fit the inherent information processing (psychological) capabilities of the user, rather than requiring that the user conform to the display portion of the system. This interest has been translated into an examination of how display design affects memory load and ease of learning. In addition, factors such as color perception and use, and cognitive processing ability are being examined in order to determine how they should influence display design.

Memory Load

Memory load can be a critical factor in the real-time environment of the MCC. The most critical form of memory in this setting is human short-term memory (STM).[1,2] The generally acknowledged storage capacity of STM is 7 ± 2 chunks of information. When combined with other attention-demanding tasks, as in the MCC, STM capacity will generally be towards the low end of this range. Once the capacity of STM is exceeded, some of the information stored in STM will be lost or forgotten. Depending on the nature of the forgotten information, this forgetting can produce anything from a minor inconvenience to a catastrophe.

The concern over memory load has become more relevant as aircraft design, system design, and research test programs have become more complex. Increased complexity has lead to increased demands on STM during research flight and ground testing. Thus, it has become necessary to redesign displays to reduce the load on STM.

Color Perception

With the inclusion of increasingly sophisticated displays that use color, color perception and color use need to be considered. It should be remembered that color perception is a psychological as well as a physiological process. The most obvious example of this involves cultural stereotypes for color use. In most western cultures red is used for warning or stop, while green is used for O.K. or go. Use of these colors in a manner that violates these norms will cause confusion and errors on the part of the user. Again, the nature of the information displayed will determine the cost of these errors.

While humans can discriminate a fairly large number of colors under laboratory conditions (approximately 200), this discrimination ability does not generally transfer to application utility.[3] The discrimination between two similar shades of the same color is fairly easy when those are the only two colors being displayed and they are adjacent to each other. In an application where these colors are separated by distance and other colors, this discrimination is very often beyond the perceptual capability of the typical human user. Thus, coding discrete information using similar colors will generally be ineffective.

Cognitive Processing

One must also be concerned with cognitive processing, or how people process the information they take in. This includes a number of seemingly different areas of concern. These differences include recognition and recall, alphanumerics and graphics, and how people learn. All of these factors and more fall under the heading of cognitive processing.

These factors, especially memory load and cognitive processing, combine to make formatting of the display an issue that needs to be considered. Formatting includes two primary factors. The first is the type of data display, alphanumerics or graphics. Depending on the type of information to be displayed, one of these will generally be superior to the other.

The second factor in formatting would be character density. The more characters that are included in the display, the longer it takes for a person to locate the information desired. Thus, unnecessary information on a display is not as harmless as is often thought.

One other design factor that must be considered in light of memory load and cognitive processes is the interactivity of the display device. With improving technology, the display devices presenting data to the researcher no longer need to be strictly passive. As seen later, many of these devices will allow the user to change display formats or change the information displayed during the actual testing phase. When properly implemented, this interactivity can be a boon to the researcher. By allowing the researcher to choose only relevant information, screen density can be reduced. However, this also brings with it the danger of the user producing inefficient displays, displays of high character density, or cognitive overload by thinking about changes during the testing program.

Without proper consideration for these human factors, the display systems can be designed in a manner that reduces the user's performance by presenting information in a manner not conducive to efficient and effective processing by the user.

Display Analysis

The creation of optimal displays requires that some form of analysis be performed. Four basic methods exist for determining the usefulness of a display design: judgment of the programmer, user feedback, expert opinion, and research. Information from the last three methods will generally be most useful when used in combination.

Expert opinion generally provides a reasonable initial display design. This opinion might be gained by use of an on-site expert, an outside consultant, or a set of printed guidelines. User feedback can enhance the design by noting major design flaws. Unfortunately, the user, while able to locate problems, will not always come forth with a usable solution to the design flaw. That brings us back to the expert, who must now make a judgment as to how the flaw should be corrected.

Research in the actual mission control center environment will further enhance this process in two ways. First, design flaws that would not be major enough for user comment could be uncovered. Second, expert opinion may be enhanced by allowing for the comparison of likely alternatives. This research, coupled with expert opinion and attention to user comments, should provide for the design of an optimal display. To review this design process, some existing WATR displays will be analyzed. Figure 3 shows a variety of displays in use in the WATR.

In general, any display can be analyzed for usability by considering several factors:

1. Is there sufficient information on the display?

2. Is there any excessive information on the display?

3. Would reformatting the information help?
4. Would graphics or some other presentation format be better?
5. Would color be useful for this display?
6. What is the appropriate use for color in this display?
7. Does the display place any unnecessary memory demands on the user?
8. Would interactivity benefit the user?

Any or all of these factors may need to be considered when developing or revising displays of engineering data or safety information.

The display depicted in Fig. 4 can be used as an example of how the design process might work. This fairly common alphanumeric display of engineering data is a usable display, though not optimal. It contains all the information necessary but not in a format well-suited for transfer to the user.

So how might this display be optimized? We can begin by soliciting user comments for this already functioning display. In this particular case, the display is not sufficiently bad to prompt many user comments.

The next step would be to solicit expert opinion. For this display, the immediate goal would be to reformat the upper half of the display so that character density is reduced, and quantities that need to be compared are placed next to each other. One such option for doing this can be seen in Fig. 5.

At this point, we can either go back to the users and see if there are any comments, or we can move into the laboratory to see if we have actually made any improvements. Since this particular display system has already been implemented, research will be our best option. This reduces the number of changes prior to final implementation.

Once the upper half of the screen has been considered, we may move to the lower half (Fig. 4). The purpose of this portion of the screen is to provide the user with information concerning behavior across time. This same information could be displayed more compactly and with less demand on human processing by using either graphics or moving averages (Fig. 6).

Finally, we can examine this screen for interactive compatibility. While the actual use of this display is currently a noninteractive one, there is no technological reason that the user should not be allowed to modify it. Modifications can be allowed in real time, or before the start of a given test program.

Interactivity could fail if the users lack understanding of human factors issues. The most likely failure would be users placing too much unneeded information on the screen, thus reducing the overall effectiveness of the display. Another possible negative result would occur if the user were allowed to override the established formatting conventions.

Once these display modifications have been fully implemented and tested in the laboratory, they can be used on a trial basis. Assuming that this trial implementation does not uncover any unforseen problems, final implementation can proceed.

Color use is another consideration in analyzing displays. Figures 7 and 8 illustrate two examples of color use. Figure 7 depicts a safety display that mimics important warning lights in the cockpit. This display makes significant use of color by indicating active or inactive systems status, as well as unsafe conditions. Whenever the status of a particular system changes, so does the color of the block associated with that system. Thus, color change, which is an attention-grabbing phenomenon, means that something important is happening. The safety officer can very quickly use this display to double check that all necessary systems are indeed operating by looking for the corresponding green lights. When one of the panels changes from green or gray to yellow or orange, the safety officer's only decision is who to inform of the problem.

Figure 8 is a color graphics display for engineering data. Color has been used in a number of cases where it fails to serve any functional purpose. In such a case color acts as a distractor. That is, it draws the user's attention away from what should be the focus of the display. This is because humans have learned to use color as a significant form of coding information (for example, traffic lights). In this case, the user will probably adapt and screen out the distractions. Because of this, two points need to be made. The first is that the screening process takes some level of mental processing ability away from an already demanding task. The second is that, should this type of color contamination appear in a display where color coding is informative, the user will tend to screen out the useful information right along with the useless. Color ends up becoming the proverbial boy who cried wolf.

For this display, real-time modifications by the user are allowed. Ideally, this will allow the user to add or eliminate individual plots and data displayed on the plots as the needs of the test program change across time. Of course, the possibility of the user trying to place too much information on the display still remains. This has been curbed somewhat by placing limits on how many plots may be on a single display. This limit will force the user to consider which information is truly useful.

Concluding Remarks

It is important that the WATR continue to push the limits of technology and innovation in order to keep pace with increasingly more complex aircraft, systems, and their test programs. This has already mandated the development of advanced techniques for optimizing information display systems. Future development must continue to incorporate techniques outlined in this paper and develop additional techniques to enhance the human-machine interface related to display technology.

Display system augmentations will include several options that are not yet considerations in display development. More processing capability will reduce some of the technological bottlenecks that exist in today's systems, while allowing for even more sophisticated display design. Greater interactivity may be allowed as technology improves and the benefits and limitations of interactivity become better understood. Introduction of PC systems with increased processing and display capability will not only allow interactivity, but also the ability of the users to provide their own off-the-shelf or customized display software. And finally, improved methods will network all the necessary hardware into a single, cohesive unit that is transparent to the user.

Development of advanced displays will continue to challenge the delicate balance between human and machine. Human-machine interaction needs to be clearly understood to design and develop display systems that will enhance the information transfer process. With efficient information transfer, real-time ground and flight test results can be obtained that are cost effective and productive.

Development of advanced real-time display systems is crucial for safe and effective completion of research ground and flight test activities. The WATR continues to emphasize the role that human-machine information transfer technology plays in this development. The formation of new techniques to enhance information transfer related to real-time interactive display systems is essential in development of new display technologies. The success of NASA's aeronautics programs is directly related to the WATR's ability to refine and advance techniques for support of research flight and ground testing.

References

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[2] Miller, George A., The Magical Number Seven, Plus or Minus Two: Some Limitations on our Capacity to Process Information, *The Psychological Review*, vol. 63, no. 2, 1956, pp. 81–97.

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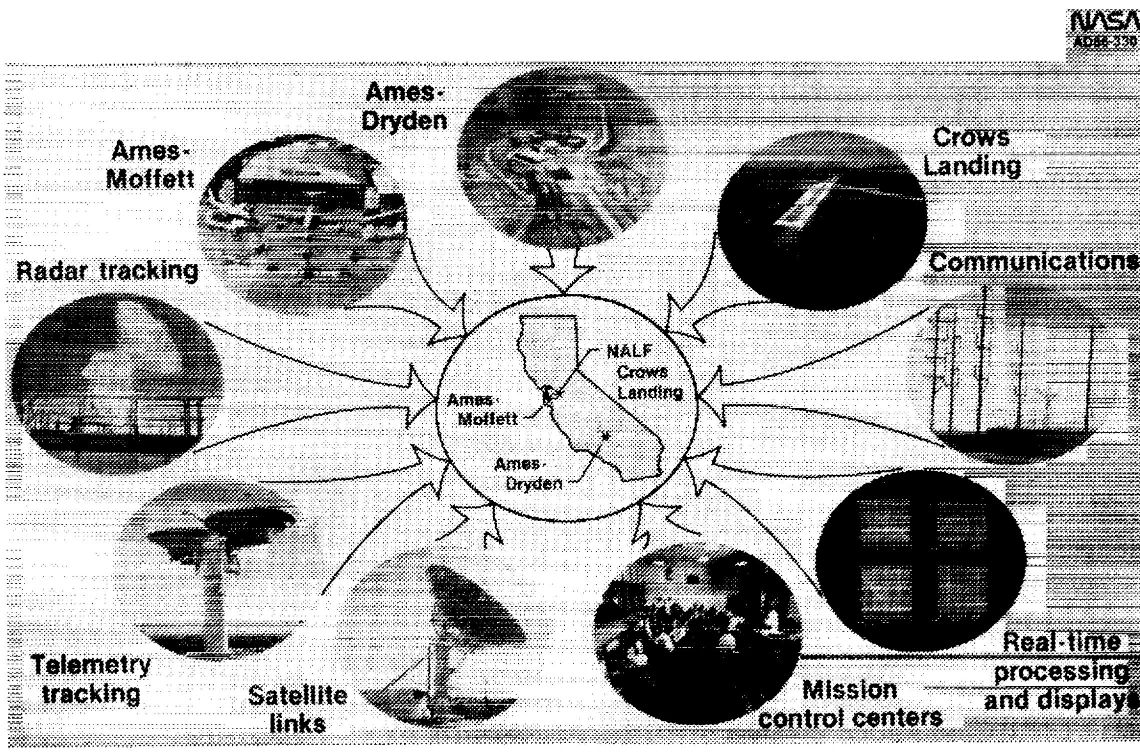

Fig. 1 Western Aeronautical Test Range.

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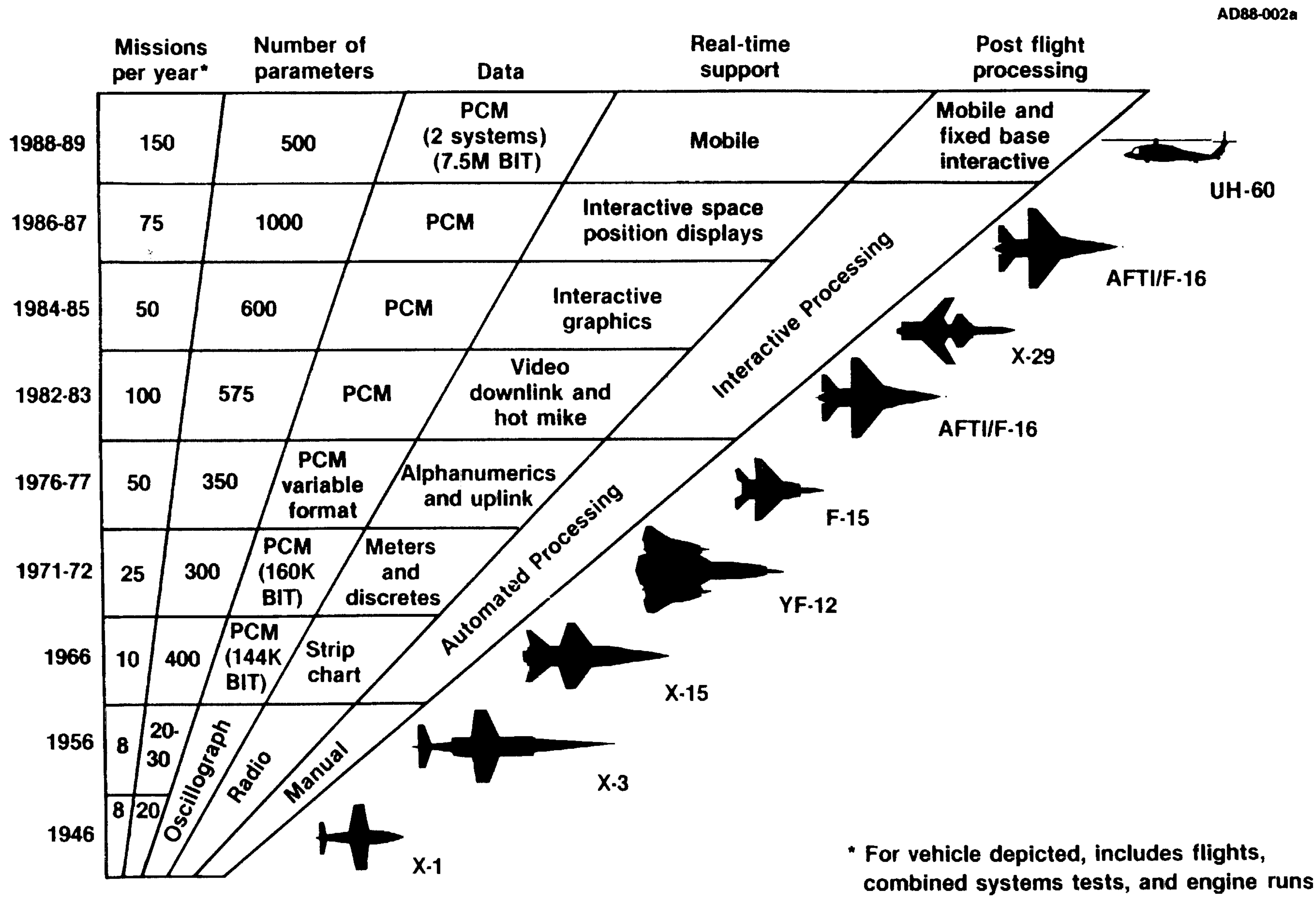

Fig. 2 Evolution of aeronautical program requirements.

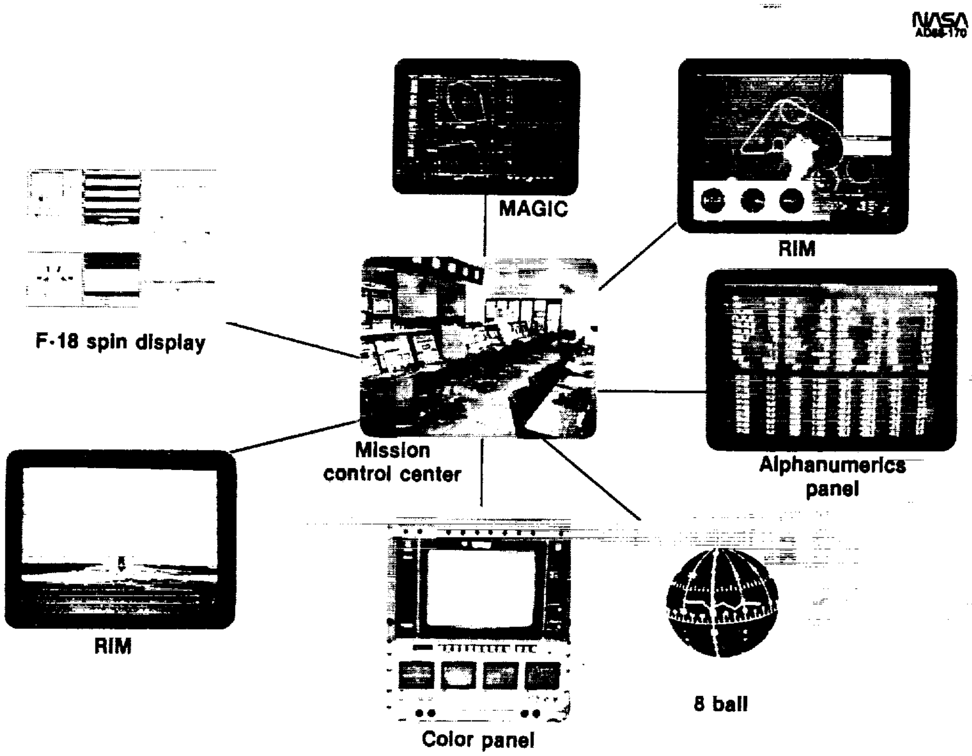

Fig. 3 Mission control room.

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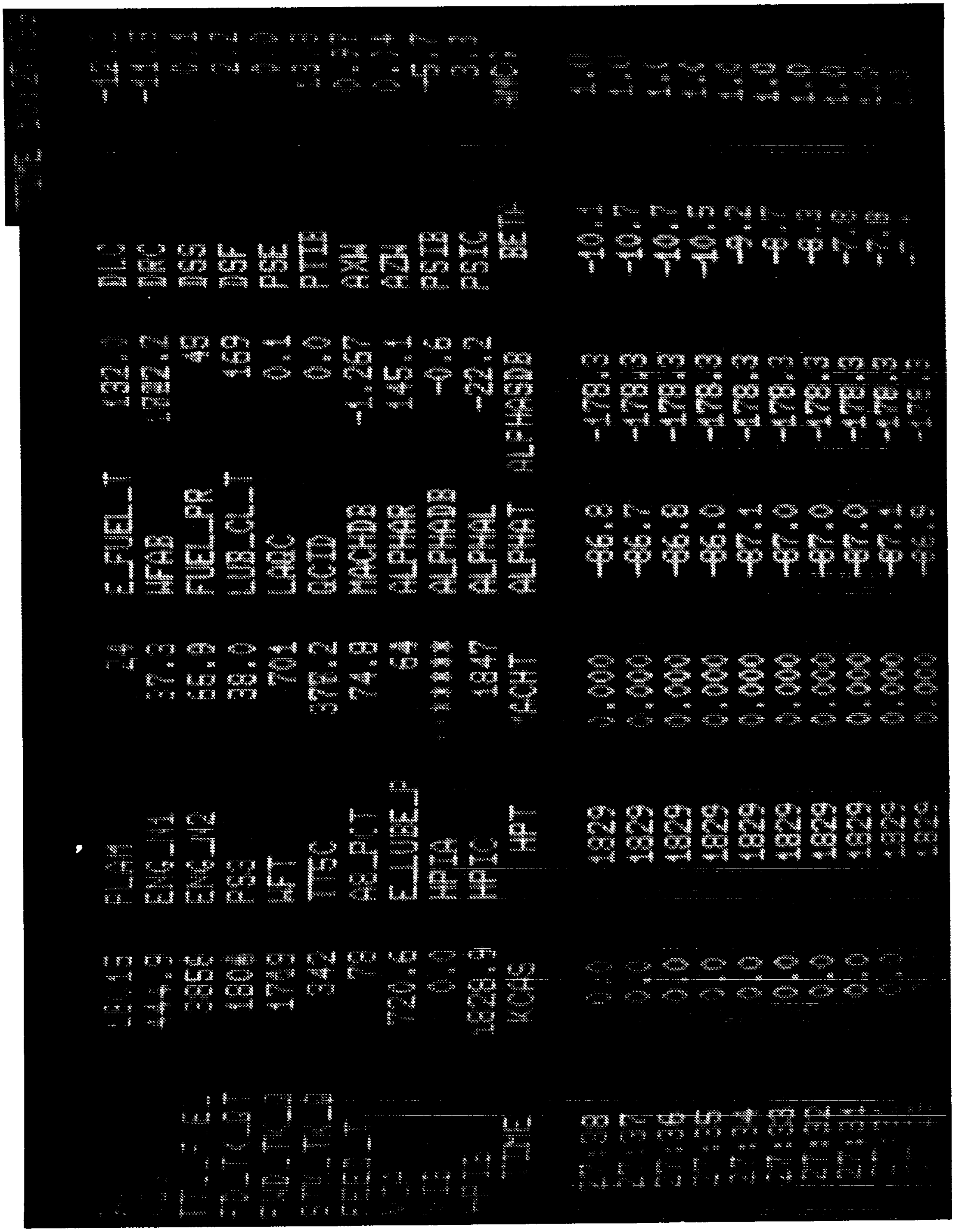

Fig. 4 Alphanumeric display.

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	LEFT	RIGHT		FBAYTMP	75	FQP	10790
EPR	1.147	1.204		TFCEU1	87	FQA	2793
TT5	744	714		THYPDO	161	DELTAF	7997
PLA	74	19		THYDUO	153	FDO11	14417
NOZPCT	0	0		ONGEAR	0	RSTICK1	0.0
N2HPCT	86	86		IDLE	1	INBRK	0
RPM	73	72		QIMPN	706		
PARMID				QIMPS	743	DFL	-0
TAPREM	-529	SYSTEM	PRIMARY	QBAR	614	DFT	2
TAPE	OFF	FLAPSW	RETRACT	MCPSEL	4		
TAPESPD	SLOW	TRIM		PFTSEL	1	WSPOS	26.0

TIME	HP	MINF	KCAS	ALPHA	NZ	CLCG	GWFQ
49:19	13452	0.831	439	3.7	1.0	28.5	72594
49:18	13540	0.832	439	3.6	1.0	28.5	72612
49:17	13640	0.832	438	3.6	1.0	28.4	72634
49:16	13719	0.834	439	3.6	1.0	28.5	72669
49:15	13806	0.834	438	3.6	1.0	28.5	72669
49:14	13895	0.835	438	3.7	1.0	28.4	72634
49:13	13984	0.836	438	3.7	1.0	28.5	72669
49:12	14071	0.836	438	3.7	1.0	28.5	72699

Fig. 5 Matching items in adjacent columns.

AFTI F111 CRT NO.1 TIME 09:49.19

	LEFT	RIGHT		FBAYTMP	75	FQP	10790
EPR	1.147	1.204		TFCEU1	87	FQA	2793
TT5	744	714		THYPDO	161	DELTAF	7997
PLA	74	19		THYDUO	153	FDO11	14417
NOZPCT	0	0		ONGEAR	0	RSTICK1	0.0
N2HPCT	86	86		IDLE	1	INBRK	0
RPM	73	72		QIMPN	706		
PARMID				QIMPS	743	DFL	-0
TAPREM	-529	SYSTEM	PRIMARY	QBAR	614	DFT	2
TAPE	OFF	FLAPSW	RETRACT	MCPSEL	4		
TAPESPD	SLOW	TRIM		PFTSEL	1	WSPOS	26.0

TIME 09:49:19

	MEAN	REL CHNG
HP	13600	-77.4
KCAS	438	.75
ALPHA	3.6	.5
NZ	1.0	0.0
CLCG	28.5	.5
GWFQ	72630	18.3

Fig. 6 Substituting moving averages for periodic updates.

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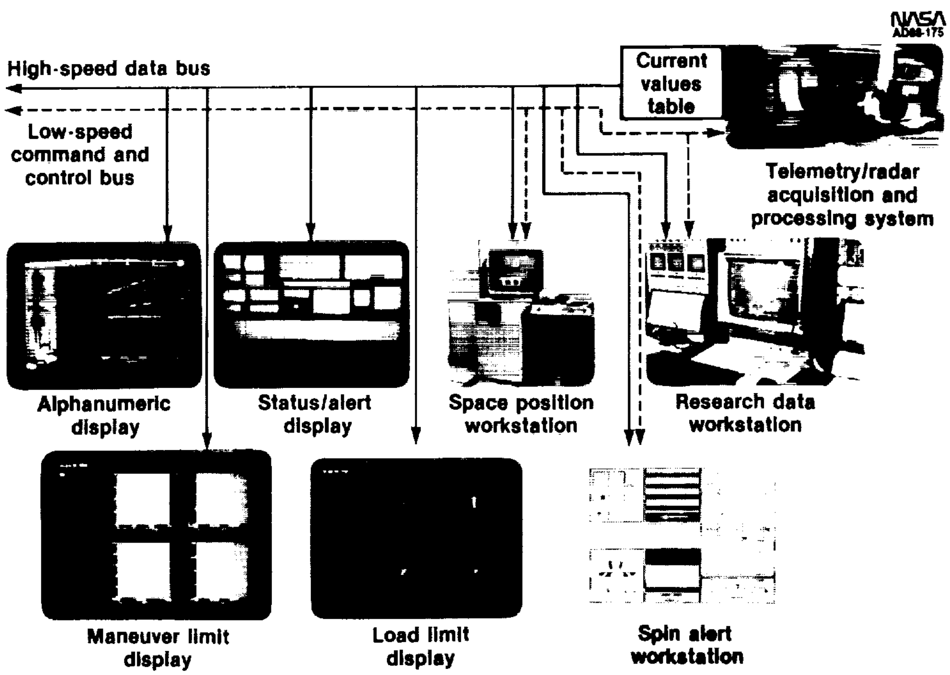

Fig. 7 Real-time data to mission control center displays.

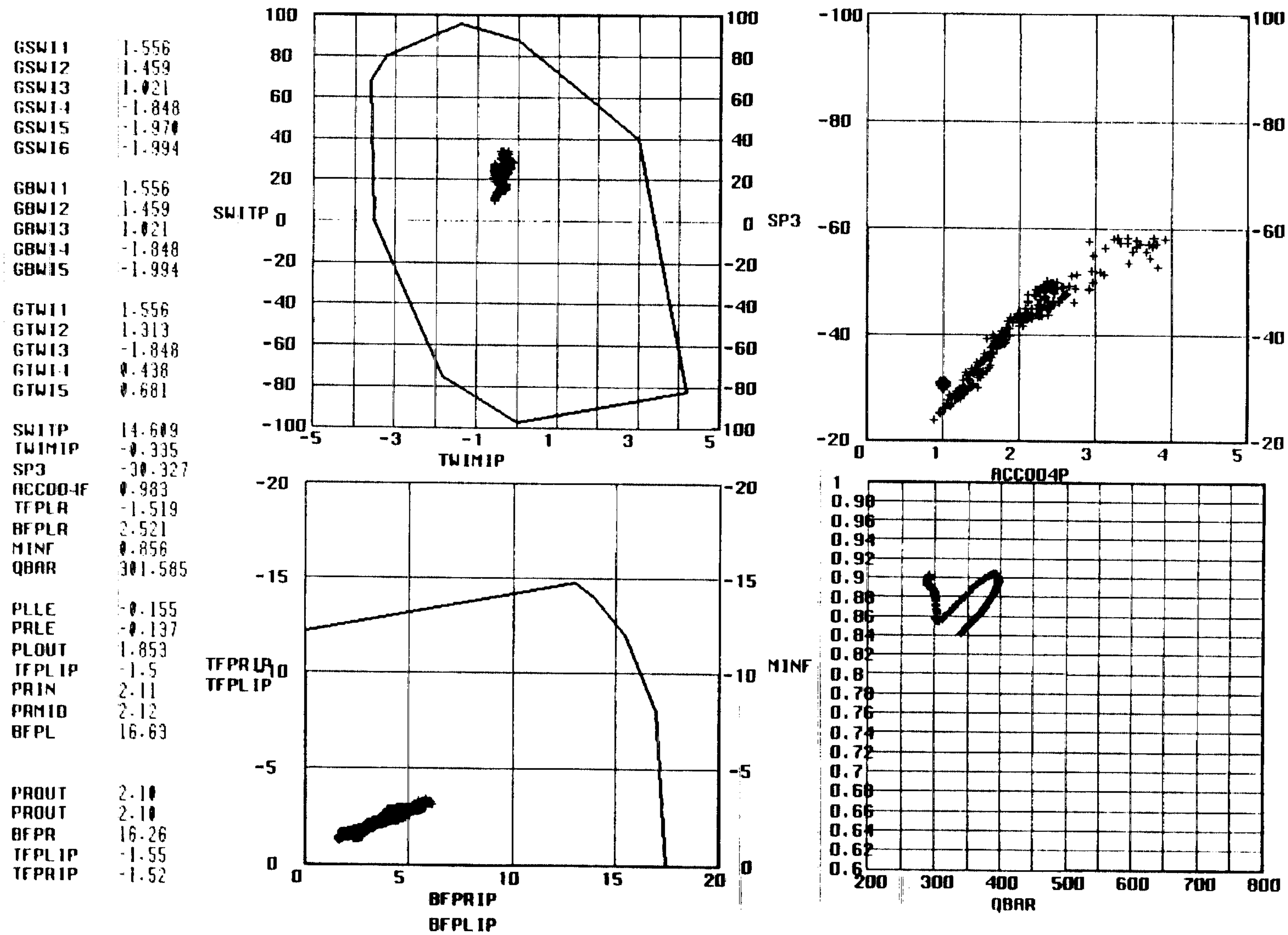

Fig. 8 Master graphics interactive console display.

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