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COMPUTER TECHNOLOGY ASSOCIATES, INC.

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INTEGRATED COMMAND, CONTROL, COMMUNICATION AND COMPUTATION SYSTEM DESIGN STUDY

Summary of Tasks Performed
(NAS5-26689)

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FOREWORD

This document has been prepared by Computer Technology Associates, Inc., Englewood, Colorado as a data requirement in the performance of the Integrated Command, Control, Communication and Computation (IC4) System Design Study Contract NAS5-26689 for NASA Goddard Space Flight Center.

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1.Ø INTRODUCTION

1.1 Purpose

This document provides a chronological summary of the tasks performed on the Integrated Command, Control, Communication and Computation (IC4) System Design Study (Contract NAS5-26689).

1.2 Scope

The IC4 System Design Study was awarded to Computer Technology Associates, Inc. in September, 1981. This study was conducted in three tasks, as follows:

a. Task 1: TDRSS Era Command and Control System Study
b. Task 2: Automating Real-Time Operations Study
c. Task 3: Image Processing Work Plan Study

The results of the TDRSS Era Command and Control System Study were documented in References 1 and 2. The results of the Automating Real-Time Operations Study were documented in Reference 3. The Image Processing Work Plan Study was added to the IC4 contract at the request of NASA Headquarters. The results of this task were transmitted to NASA Headquarters and are not included in this document. This report provides a brief synopsis of the activities and results of the three study tasks. For specific details concerning the individual tasks, refer to the referenced documents.

1.3 ACRONYMS AND ABBREVIATIONS

DOC	Data Operations Control
DSM	Data System Modernization
ERBS	Earth Radiation Budget Satellite
FY	Fiscal Year
GSTDN	Ground Station and Tracking Data Network
H/W	Hardware
IC4	Integrated Command, Control, Communications and Computation
MMI	Man-Machine Interface
MSOCC	Multi-satellite Operations Control Center
NASCOM	NASA Communications
NEEDS	NASA End-to-End Data System
POCC	Project Operations Control Center
R-T	Real-Time
SME	Solar Mesospheric Explorer
SMM	Solar Maximum Mission
STOL	System Test and Operations Language
S/W	Software
TDRSS	Tracking Data Relay Satellite System
TELOPS	Telemetry On-Line Processing System
TIPIT	TDRSS Interface Preprocessor Into TELOPS

2.0 APPLICABLE DOCUMENTS

1. GSFC Command and Control Functional Analysis Report, Computer Technology Associates, Inc., October 31, 1981.

2. NEEDS Phase 3 Technology Efforts Report, Computer Technology Associates, Inc., October 31, 1981.

3. Recommendations for Automating Real-Time Operations, Computer Technology Associates, Inc., November 8, 1982.

4. IC4 System Design Study Progress Reports.

5. IC4 System Functional Architecture, Computer Technology Associates, Inc., August 17, 1981.

6. Mitchell, Chris, "Human-Machine Interface Issues in the Multi-Satellite Operations Control Center-1", NASA Technical Memorandum 83826, August 1981.

7. Automated MSOCC-1 DOC System Study Task Summary Report (B83-D-17400-04), June, 1981.

8. Minutes for Operations Planning Preliminary Design Review, DSM Project.

9. Computer Program Product Specification for DSM/Commanding Computer Program.

10. Computer Program Product Specification for DSM/Mission Control Complex Management Computer Program.

11. DSM Operations Concept.

12. Computer Program Product Specification for DSM/Display Management Computer Program.

13. Computer Program Product Specification for DSM/Common Services Computer Program.

3.0 TASK 1 RESULTS: TDRSS ERA COMMAND AND CONTROL SYSTEM STUDY

The purposes of this task were as follows:

a. Define the GSFC TDRSS era command and control system functions.

b. Determine potential areas for introduction of automated technology, alternative procedures and alternative design which will improve performance and reduce cost of the command and control process.

c. Recommend specific technology efforts to be pursued during NEEDS Phase 3.

This task was conducted in two subtasks. In Subtask 1, a functional breakdown of the command and control system was provided, and cost and performance factors were applied to this functional structure. In Subtask 2, the NEEDS Phase 3 technology effort in the command and control area was defined. The results of these two subtasks are summarized below.

3.1 COMMAND AND CONTROL SYSTEM FUNCTIONAL STUDY

The GSFC Command and Control System Functional Study was performed to define the TDRSS era command and control system functional breakdown and to apply cost and performance factors to this functional structure. The purpose of this activity was to determine the major command and control cost drivers and to specify functions requiring further analyses and development within the NEEDS Phase 3 arena. As summarized in Reference 1, command and control costs (FY 1983 projections) were examined for the following GSFC institutional and project related aras:

a. Project Mission Operations.

b. Mission and Data Operations.

c. Networks.

The following information was provided as part of the analysis for each of these areas:

a. Total cost of each function for FY 1983.

b. The percentage of cost allocated to command and control for that function.

c. The actual command and control cost.

d. Development or one time only costs versus recurring costs.

Project Mission Operations costs were analyzed for three GSFC missions (DE,SMM,ERBS) to determine the number of personnel supporting command and control functions. Mission and Data Operations costs were provided for the following areas:

a. Mission Operations.

b. Programming, Computation and Analysis Operations.

Command and control costs were also provided for the following Network areas:

a. GSTDN Operations.

b. TDRSS Operations.

c. Laser Tracking Subnet.

d. Operational Support Computing.

e. NASCOM Operations.

Cost data for each of these areas and cost data summaries are summarized in Reference 1. The results of this analysis indicated that relative to command and control costs, GSTDN operations and Mission Operations are the major cost drivers. However, it was felt that relative to NEEDS GSTDN operations were adequately being addressed by Code 800. Consequently, the emphasis within the NEEDS command and control area was centered primarily around Mission Operations as summarized in Section 3.2 below.

3.2 RECOMMENDED NEEDS PHASE 3 TECHNOLOGY EFFORTS

The purpose of this subtask was to analyze cost, performance and mission drivers to determine the recommended emphasis of the NEEDS Phase 3 technology efforts in the command and control area. Reference 2 summarized the results of this subtask and completed the TDRSS Era Command and Control System Study.

In Reference 2, the following command and control tasks were recommended:

a. Operations Concept for Automating Real-Time Operations.

b. Operations Concept for Command Generation.

c. Operations Concept for Scheduling TDRSS Support.

d. User-Computer Interaction Demonstration System.

e. Ground-Space Control Trade-Off Study.

f. Project Management Guidelines for Prelaunch Test and Integration.

For each of these tasks, the purpose, number of phases (or subtasks), phase description, output, and level-of-effort were defined. The detailed task descriptions are contained in Reference 2.

4.0 TASK 2 RESULTS: AUTOMATING REAL-TIME OPERATIONS STUDY

As a result of the TASK 1 effort, the IC4 contract was redirected to analyze real-time command and control operations to identify and recommend functions suitable for automating. The effort to conduct this task centered around two areas of activity. One, to evaluate the real-time operations, information was obtained that was useful for the GSFC Human Factors Working Group, particularly on the ERBS project, and this data was presented to the Human Factor Working Group and at the Human Factors Workshop held at GSFC in May, 1982. The second area included the actual analysis of real-time operations to recommend functions suitable for automation, as defined in the Statement of Work. These two areas are summarized separately in Sections 4.1 and 4.2 below.

4.1 HUMAN FACTORS WORKING GROUP SUPPORT

To analyze ERBS real-time operations, technical interchange meetings were conducted with ERBS personnel. The purpose of these discussions was to review the ERBS command panel and the ERBS contact events. As a result, an ERBS contact scenario was developed and presented to the Human Factors Working Group. Appendix A of this document contains this scenario which defines real-time events, displays, and manual (operator 1 and 2) and automatic actions. In addition to the contact scenario, a critique of the ERBS command panel was generated. This critique is contained in Appendix B.

In support of the Human Factors Workshop held May 26, 1982, a presentation entitled "A Case Study of a System Engineered for Control by Humans" was delivered. Appendix C contains the report summarizing this presentation. In brief, the recommendation is made that future operations be system engineered to implement a real-time health and safety operational philosophy called the "watchman concept". The essence of this concept is to provide information that identifies problems, not data, and to provide on-board safing to protect hardware and contain the problem to the failed component. An operator friendly approach to contingency design is recommended where information is presented in a format that the less experienced operator can readily recognize and react to system problems. An approach to displaying information is presented in the form of a star icon. This type of display presents information which provides "the watchman" type operator with a clear indication of a problem and provides a second level of information detail as to the nature of the problem.

4.2 RECOMMENDATIONS FOR AUTOMATING REAL-TIME COMMAND AND CONTROL FUNCTIONS

The purpose of this effort was to analyze real-time mission operations, identify functions currently being performed, and define real-time functions suitable for automating. Three missions (SMM, ERBS, and SME) were selected as example missions to use in conducting the analysis. The following eight operational areas were defined and examined in detail for the three missions:

a. Routine spacecraft status and monitoring.
b. Presenting alarms to the operator.
c. Response to alarms.
d. Real-time science data monitor and response.
e. On-board spacecraft accommodation.
f. Pre-pass preparation.
g. Pass operations.
h. Post-pass operations.

For each of the major areas, a one-to-one comparison of functions was generated to define the current or planned mode of operation for each mission. Based on this comparison, considerations for automation were identified for each operational area. Potential techniques for implementing the automation were then identified, and cost, performance and personnel issues were addressed for each function. Based on this analysis, recommendations for automating real-time functions were generated.

Key automation considerations identified as a result of the SMM-ERBS-SME analysis include:

a. Provide real-time trend plotting and analysis programs to support routine spacecraft status and monitoring. With this feature the operator would have the capability in real-time to request plots of any telemetry point or to execute on-line analysis programs.

b. Provide automatic response to selected anomalies by transmitting precanned commands upon detection of the anomaly by the ground system. Allow the acceptable set of automatic responses to increase as the mission matures.

c. Provide the capability to pre-define branch points in the uplink process and to automatically select and execute the appropriate branch based on the downlink telemetry data. This capability supports real-time science data monitor and response and spacecraft pass operations.

d. Provide the capability to add automated functions on-board as a mission progresses. Candidates for on-board automation would include automatic responses to selected anomalies where the automatic response has been occurring on the ground but with confidence in its execution the automatic response to the anomaly is placed on-board the spacecraft.

e. Provide the capability to automatically execute the pass plan with operator intervention in event of anomalies or as required for selected pass activities.

The capability currently exists or is used (anticipated) for many of the automation considerations identified. However, certain characteristics are inherent in the current system that affect the amount of automation that will be incorporated in future operations. For example,

a. The operator is always in the loop to make decisions and take action. In many cases operator action is essential to spacecraft command and control operations. However, in selected instances, the ground system could make the decision based on telemetry data and automatically take the appropriate action.

b. With the operator always in the loop, there is the potential for operator errors. For routine operations where the ground system can make the proper decisions and take action, the chance for errors could be minimized.

c. The potential of over-loading the real-time system may limit automated capability or imply need for increased computing capability.

d. Many projects incorporate selected automation but these innovative ideas and implementation techniques are not necessarily shared between missions.

e. Operational costs often exceed development costs. For long term missions, system life cycle costs could be reduced by increasing the amount of operational automation (ie,software) and ultimately development costs, but over the life cycle of the mission the costs would be reduced.

As a result of the IC4 analysis, the following recommendations are made relative to automation in the future:

a. Develop and test an automated pass plan that controls execution of all pass functions. Incorporate expert system/decision aid technology to implement this system to provide the automation considerations, to provide capability to increase automation as a mission progresses, to allow user interaction where necessary and to provide consistent capabilities between missions. Evaluate high order languages as a means of providing the user/operator interface with the automated pass plan.

b. Provide real-time science/subsystem user interaction to select pre-canned commands or pre-defined branch points in the uplink operations. Evaluate remote user operations for interacting with the real-time system.

c. Evaluate and develop expert systems to support anomaly investigations and to ultimately support real-time spacecraft evaluations.

Based on these automation recommendations, the following options are suggested as the logical continuation of the IC4 effort:

a. Perform a detailed requirements analysis for automated operations. This analysis would include generation of an Operations Concept and Requirements Document summarizing the operations philosophy for implementing automated operations. It is recommended that two techniques for implementation be analyzed in depth as part of this effort: a STOL based implementation and an expert system/decision aid implementation using a high order language for the user interface.

b. Evaluate the technique for implementing automated operations whereby a "front-end" processor provides the user interface and analysis without impact to the current real-time system. This processor could provide the automation using either of the implementation techniques described in item (a) above.

5.0 TASK 3 RESULTS: IMAGE PROCESSING WORK PLAN STUDY

In July, 1982, a third task was added to the IC4 contract at the request of NASA Headquarters. The purpose of Task 3 was to develop a work plan and schedule for defining critical image processing needs at the Jet Propulsion Laboratory, for assessing alternatives means of meeting these needs, and for supporting design and development of a recommended image processing system. The results of this task were transmitted to NASA Headquarters.

APPENDIX A

CONTACT SCENARIO HUMAN INTERFACES

TIME	EVENT	DISPLAY	OPERATOR ACTION/AUTOMATIC ACTION
T-30 MIN.	INITIALIZE COMMAND PANEL µPROCESSOR	• COMMAND PANEL DISPLAY (CMD PANEL µ PROC. CRT)	• OPERATOR 1 TOUCHES "PASS PLAN ENTER" BUTTON ON COMMAND PANEL • PASS PLAN ENTER "BUTTON" ON COMMAND PANEL DISPLAY TURNS GREEN
T-29 MIN.	CONSTRUCT PASS PLAN	• COMMAND PANEL DISPLAY • IDT 2000 DISPLAY OF CMD MGMT. INFORMATION	AUTOMATIC MODE • OPERATOR 1 TOUCHES "MICRO INPUT" BUTTON ON COMMAND PANEL • MICRO INPUT "BUTTON" ON COMMAND PANEL DISPLAY TURNS GREEN TO SIGNIFY FUNCTION INVOKED • OPERATOR 2 CONFIGURES ERBS µ PROCESSOR FOR CMD. MGMT PROGRAM ACCESS • PASS PLAN IS AUTOMATICALLY GENERATED BASED ON CMD. MGMT PROGRAM INPUTS • OPERATOR 1 REVIEWS PASS PLAN MATRIX ON CMD. PANEL DISPLAY
		• COMMAND PANEL DISPLAY	MANUAL MODE • OPERATOR 1 TOUCHES "KEYBOARD INPUT" BUTTON ON COMMAND PANEL • KEYBOARD INPUT BUTTON ON COMMAND PANEL TURNS GREEN • OPERATOR 1 ENTERS PASS PLAN VIA CMD. PANEL µ PROC. KEYBOARD • OPERATOR 1 REVIEWS PASS PLAN MATRIX ON CMD. PANEL µ PROC. CRT.

TIME	EVENT	DISPLAYS	OPERATOR ACTION/AUTOMATIC ACTION
T-20 MIN.	EXECUTE PASS PLAN	• COMMAND PANEL DISPLAY	• OPERATOR 1 TOUCHES "PASS PLAN EXECUTE" BUTTON ON COMMAND PANEL - ENABLES CMD. PANEL SELECTION AUTHORITY • PASS PLAN EXECUTE "BUTTON" ON CMD. PANEL DISPLAY TURNS GREEN TO SIGNIFY FUNCTION INVOKED • PASS PLAN ENTER BUTTON TURNS WHITE
	VERIFY APPLICATION PROCESSOR READY	• MSOCC-I SYSTEM STATUS DISPLAY	• OPERATORS 1 & 2 MONITOR MSOCC-1 STATUS DISPLAY
T-19 MIN	INITIALIZE MSOCC-1 RESOURCES & DISPLAYS	• COMMAND PANEL DISPLAY • MSOCC-1 SYSTEM STATUS DISPLAY • ERBS μPROC. STATUS DISPLAYS (IDT 2000)	• OPERATOR 1 TOUCHES "PROC-SETUP" BUTTON ON COMMAND PANEL • "PROC-SETUP" TURNS BLUE TO INDICATE BUTTON INVOKED • ALL PROC CONTROL BUTTONS TURN BLUE • OPERATOR 1 TOUCHES "START" BUTTON TO INVOKE PROCEDURE • "START" BUTTON TURNS GREEN WHEN TOUCHED • WHEN THE PROC IS COMPLETE "START" BUTTON TURNS BLUE "PROC= SETUP BUTTON TURNS GREEN • OPERATORS 1 & 2 MONITOR MSOCC-1 STATUS DISPLAY TO VERIFY GROUND SYSTEM READY TO SUPPORT PASS • OPERATOR 2 VERIFIES ERBS μ PROCESSOR DISPLAY INITIALIZATION VIA IDT 2000 STATUS DISPLAY

TIME	EVENT	DISPLAYS	OPERATOR ACTION/AUTOMATIC ACTION
T-5 MIN	SEND USER PERFORMANCE DATA REQUEST MESSAGE TO NCC TO BRING UP REQUIRED RESOURCES	• COMMAND PANEL DISPLAY • NCC STATUS DISPLAY (MSOCC-1 CRT)	• OPERATOR 1 TOUCHES "PROC=NCINIT" BUTTON ON COMMAND PANEL • PROC=NCINIT "BUTTON" ON COMMAND PANEL DISPLAY TURNS BLUE TO INDICATE BUTTON INVOKED (PROC CONTROL BUTTONS ARE STILL BLUE) • OPERATOR 1 TOUCHES "START" BUTTON ON COMMAND PANEL TO INVOKE PROCEDURE • "START" BUTTON TURNS GREEN • WHEN THE PROC IS COMPLETE "START" BUTTON TURNS BLUE "NCINIT" BUTTON TURNS GREEN • OPERATOR 2 VERIFIES NCC INTERFACE VIA NCC INTERFACE VIA NCC STATUS DISPLAY • OPERATOR 1 MONITORS NCC STATUS MESSAGES ON COMMAND PANEL DISPLAY • DISCREPANCIES IN NCC/TDRSS REQUESTS ARE FLAGGED TO OPERATOR 1 VIA RED FLASHING NCC/TDRSS ALARM "BUTTON" ON COMMAND PANEL DISPLAYS (OPERATOR 1 TOUCHES "NCC/TDRSS ALARM" BUTTON TO RESET IT TO WHITE • DISCREPANCIES ARE FLAGGED TO OPERATOR 2 VIA ALARM MESSAGES ON NCC STATUS DISPLAY OR ANY DISPLAY ON MSOCC-1 CRT

TIME	EVENT	DISPLAYS	OPERATOR ACTION /AUTOMATIC ACTION
T-O	MONITOR ACQUISITION SEQUENCE	• COMMAND PANEL DISPLAY • NCC STATUS DISPLAY (MSOCC-1 CRT)	• OPERATOR 1 MONITORS COMMAND PANEL DISPLAY – TDRSS FAILURE TO ACQUIRE S/C CAUSES "NCC/TDRSS ALARM" TO FURN RED & FLASH ON COMMAND PANEL DISPLAY, ALARM MESSAGE TO APPEAR ON NCC MESSAGE LINE – TO RESET OP-1 TOUCHES ALARM BUTTON WHICH THEN TURNS WHITE • OPERATOR 2 MONITORS NCC STATUS DISPLAY
T + '30 SEC TO T + '1.5 MIN.	VERIFY ERBS HEALTH AND STATUS	• S/C TM DISPLAYS (MSOCC-1 CRT) • DOC STATUS DISPLAY (MSOCC-1 CRT) • S/C ANALYSIS DISPLAYS (IDT 2000)	• OPERATOR 2 MONITORS S/C TM DISPLAYS: ALARM CONDITIONS WILL APPEAR ON ALL DISPLAYS • OPERATOR 2 MONITORS DATA QUALITY & FRAME SYNC DATA ON DOC STATUS DISPLAY • OPERATOR 2 MONITORS S/C TREND DATA, PLOTS, ETC. ON IDT 2000 DISPLAYS • OPERATOR 1 MONITORS COMMAND PANEL DISPLAY: "RED S/C ALARMS ARE PRESENTED TO OPERATOR 1 – SPACECRAFT ALARM "BUTTON" FLASHES ON COMMAND PANEL DISPLAY – VOICE SYNTHESIZER CAUSES ALARM MESSAGE TO BE OUTPUT • OPERATOR 1 TOUCHES "SPACECRAFT ALARM" BUTTON TO RESET TO WHITE • OPERATOR 1 HAS CAPABILITY TO MONITOR S/C TM DISPLAYS • OPERATOR 2 CONFIRMS S/C HEALTH & STATUS WITH OPERATOR 1 VIA VOICE NET

TIME	EVENT	DISPLAYS	OPERATOR ACTION/AUTOMATIC ACTION
T + '1 MIN. TO T + '2 MIN.	INITIATE MEMORY LOAD	• COMMAND PANEL DISPLAY • COMMAND VALIDATION DISPLAY (MSOCC-1 CRT)	• OPERATOR 1 TOUCHES "CMD= RFZNRX" BUTTON ON COMAND PANEL TO SELECT RECEIVER TO ZENITH & SELECT ESSA OR OMNI ANTENNA • "CMD=RFZNRX" BUTTON TURNS BLUE TO INDICATE BUTTON INVOKED • ALL CMD CONTROL MATRIX BUTTONS TURN BLUE & ALL PROC CONTROL MATRIX BUTTONS TURN WHITE • OPERATOR 1 TOUCHES "ENTER" BUTTON (CMD CONTROL MATRIX • "ENTER" BUTTON TURNS GREEN & THEN BACK TO BLUE • OPERATOR 1 TOUCHES "SEND" BUTTON • "SEND" BUTTON TURNS GREEN & THEN BACK TO BLUE • "CMD=RFZNRX" BUTTON TURNS GREEN WHEN COMMAND IS SENT • OPERATOR 2 VERIFIES COMMANDS RECEIVED AND ACCEPTED BY SPACECRAFT VIA COMMAND VALIDATION DISPLAY • COMMANDING DISCREPANCIES ARE FLAGGED TO OPERATOR 1 BY – RED & FLASHING "REJECT" BUTTON ON COMMAND PANEL DISPLAY – VOICE OUTPUT VIA VOICE SYNTHESIZER • OPERATOR 1 RESETS "REJECT" BUTTON BY TOUCHING IT WHICH CAUSES IT TO TURN WHITE • OPERATOR 1 HAS CAPABILITY TO MONITOR COMMAND VALIDATION DISPLAY ON MSOCC-1 CRT.

TIME	EVENTS	DISPLAYS	OPERATOR ACTION/AUTOMATIC ACTION

			• OPERATOR 1 TOUCHES "MODE=DCDR=B" BUTTON TO SELECT DECODER
			• "MODE=DCDR=B" BUTTON TURNS BLUE
			• ALL PROC CONTROL MATRIX BUTTONS TURN BLUE: ALL CMD CONROL MATRIX BUTTONS TURN WHITE
			• OPERATOR 1 TOUCHES "START" BUTTON "START" BUTTON TURNS GREEN
			• WHEN PROC IS COMPLETED:
			  – "START" BUTTON TURNS BLUE
			  – "MODE=DCDR=B" BUTTON TURNS BLUE
			• COMMANDING IS VERIFIED PER ABOVE
			
			• OPERATOR 1 TOUCHES "CMD=CSMBDM" BUTTON TO SELECT CSM
			• "CMD=CSMBDM" BUTTON TURNS BLUE
			• ALL CMD CONTROL MATRIX BUTTONS TURN BLUE: ALL PROC CONTROL BUTTONS TURN WHITE
			• OPERATOR 1 TOUCHES "ENTER" BUTTON (CMD CONTROL MATRIX)
			• "ENTER" BUTTON TURNS GREEN & THEN BACK TO BLUE
			• OPERATOR 1 TOUCHES "SEND" BUTTON
			• "SEND" BUTTON TURNS GREEN & THEN BACK TO BLUE
			• "CMD=CSMBDM" BUTTON TURNS GREEN WHEN COMMAND IS SENT
			• COMMANDING IS VERIFIED PER ABOVE
			
			• OPERATOR 1 TOUCHES "CMD=TDUI" BUTTON TO SELECT TDU MODE
			• "CMD=TDUI" BUTTON TURNS BLUE (ALL CMD CONTROL MATRIX BUTTONS ARE STILL BLUE)
			• OPERATOR 1 TOUCHES "ENTER" BUTTON (CMD CONTROL MATRIX)
			• "ENTER" BUTTON TURNS GREEN & THEN BACK TO BLUE
			• OPERATOR 1 TOUCHES "SEND" BUTTON
			• "SEND" BUTTON TURNS GREEN & THEN BACK TO BLUE
			• "CMD=TDUI" BUTTON TURNS GREEN WHEN COMMAND IS SENT
			• COMMANDING IS VERIFIED PER ABOVE

TIME	EVENTS	DISPLAY	OPERATOR ACTION/AUTOMATIC ACTION
			• OPERATOR 1 TOUCHES "PROC=LOADB" BUTTON TO TRANSMIT MEMORY LOAD • "PROC=LOADB" BUTTON TURNS BLUE • ALL PROC CONTROL MATRIX BUTTONS TURN BLUE; ALL CMD CONTROL MATRIX BUTTONS TURN WHITE • OPERATOR 1 TOUCHES "START" BUTTON • "START" BUTTON TURNS GREEN • WHEN PROC IS COMPLETED: – "PROC=LOADB" BUTTON TURNS GREEN – "START" BUTTON TURNS BLUE • COMMANDING IS VERIFIED PER ABOVE • OPERATOR 2 CONTINUES TO MONITOR S/C HEALTH AND STATUS

TIME	EVENTS	DISPLAYS	OPERATOR ACTION/AUTOMATIC ACTION
	DUMP/MEMORY VALIDATE MEMORY LOAD	• COMMAND PANEL DISPLAY • COMMAND LOAD VALIDATION DISPLAY (MSOCC-1 CRT)	• OPERATOR 1 TOUCHES "PROC=DUMP" BUTTON ON COMMAND PANEL TO DUMP THE COMMAND MEMORY • "PROC=DUMP" BUTTON TURNS BLUE (ALL PROC CONTROL BUTTONS ARE STILL BLUE) • OPERATOR 1 TOUCHES "START" BUTTON • "START" BUTTON TURNS GREEN • WHEN THE PROC IS COMPLETED: – "START" BUTTON TURNS BLUE – "PROC=DUMP" BUTTON TURNS GREEN • COMMANDING IS VERIFIED AS DESCRIBED ABOVE • AP AUTOMATICALLY VALIDATES ON-BOARD MEMORY DOWNLINK AGAINST PREDICTED MEMORY IMAGE • OPERATOR 2 MONITORS COMMAND LOAD VALIDATION DISPLAY FOR DISCREPANCIES IN THE CSM.

TIME	EVENT	DISPLAYS	OPERATOR ACTION/AUTOMATIC ACTION
T + '10 MIN.	CONFIGURE FOR TR DUMP	• COMMAND PANEL DISPLAY • COMMAND VALIDATION DISPLAY • TIPIT DISPLAY • NCC STATUS DISPLAY	• OPERATOR 1 TOUCHES "PROC=TRISET" BUTTON ON COMMAND PANEL TO INITIATE GCMR DIRECTIVES TO NCC TO SWITCH FROM TDRSS NON-COHERENT TO COHERENT MODE, TO RECONFIGURE RETURN LINK PARAMETERS FOR HIGHER DATA RATE ON THE Q-CHANNEL, TO INHIBIT DOPPLER COMPENSATION, AND COMMENCE RANGE & RANGE RATE TRACKING • "PROC=TRISET" BUTTON TURNS BLUE (ALL PROC CONTROL BUTTONS ARE STILL BLUE) • OPERATOR 1 TOUCHES "START" BUTTON • "START" BUTTON TURNS GREEN • "WHEN PROC IS COMPLETE "START" BUTTON TURNS BLUE "PROC=TRISET" BUTTON TURNS GREEN • S/C COMMANDING VERIFIED • OPERATOR 2 MONITORS NCC STATUS DISPLAY TO VERIFY NCC INTERFACE • OPERATOR 1 MONITORS COMMAND PANEL DISPLAY TO VERIFY NCC INTERFACE: DISCREPANCIES FLAGGED BY FLASHING NCC/TDRSS ALARM "BUTTON", NCC MESSAGE OUTPUT & VOICE SYNTHESIZER OUTPUT • OPERATOR 2 MONITORS TIPIT DISPLAY TO DETERMINE THAT NETWORK HAS LOCKED ON 32 KBPS TR PREAMBLE • WHEN LOCK OCCURS, OPERATOR 2 NOTIFIES OPERATOR 1 VIA VOICE NET

TIME	EVENT	DISPLAYS	OPERATOR ACTION/AUTOMATIC ACTION
T + 11.75 MIN. TO T + 12.3 MIN.	INITIATE TR DUMP	• COMMAND PANEL DISPLAY • COMMAND VALIDATION DISPLAY • TIPIT DISPLAY • ERBE HEALTH & STATUS DISPLAY (MSOCC-1 CRT) • DOC STATUS DISPLAY • IDT 2000 (ERBE H&S DISPLAY	• OPERATOR 1 TOUCHES "PROC=RCIDMP" BUTTON ON COMMAND PANEL • "PROC=RCIDMP" BUTTON TURNS BLUE (ALL PROC CONTROL BUTTONS STILL BLUE) • OPERATOR 1 TOUCHES "START" BUTTON • "START" BUTTON TURNS GREEN • WHEN PROC COMPLETED: – "START" BUTTON TURNS BLUE – "PROC=RCIDMP" TURNS GREEN • COMMANDING VERIFIED PER ABOVE • OPERATOR 2 MONITORS TIPIT DISPLAY & DOC STATUS DISPLAY FOR TR DUMP QUALITY ASSESSMENT • OPERATOR 2 MONITORS ERBE INSTRUMENT HEALTH AND STATUS DISPLAYS (IDT 2000 & MSOCC-1 CRT) • OPERATOR 1 & 2 CONTINUE TO MONITOR UNTIL COMPLETION OF DUMP & PASS
T + 33 MIN.	TERMINATE PASS (MESSAGE TO NCC)	• COMMAND PANEL DISPLAY • NCC STATUS DISPLAY	• OPERATOR 1 TOUCHES "PROC=TERM" BUTTON ON COMMAND PANEL • "PROC=TERM" BUTTON TURNS BLUE • OPERATOR 1 TOUCHES "START" BUTTON • "START" BUTTON TURNS GREEN • WHEN PROC COMPLETED : – "START" BUTTON TURNS BLUE – "PROC=TERM" BUTTON TURNS GREEN • OPERATOR 2 MONITORS NCC STATUS DISPLAY TO VERIFY NCC INTERFACE • OPERATOR 1 MONITORS COMMAND PANEL DISPLAY TO VERIFY NCC INTERFACE
T + 38 MIN.	ISSUE POST EVENT REPORT TO NCC/ QUICK LOOK ASSESSMENT	INFORMATION THE OPERATOR KEYS IN	• OPERATOR 1 TYPES IN FREE FLOWING MESSAGE (POST EVENT REPORT) • OPERATOR 1 PUSHES SOME BUTTON ON KEYBOARD TO CAUSE MESSAGE TO BE SENT

TIME	EVENT	DISPLAYS	OPERATOR ACTION/AUTOMATIC ACTION
T + 39 MIN.	TERMINATE PASS PLAN	• COMMAND PANEL DISPLAY	• OPERATOR 1 TOUCHES "PASS PLAN TERMINATE" TO CEASE INTERFACE WITH AP • "PASS PLAN TERMINATE" BUTTON TURNS RED • "PASS PLAN EXECUTE" BUTTON TURNS WHITE
	RUN ANALYSIS PROGRAMS	TBD	TBD

APPENDIX B

ERBS COMMAND PANEL
FUNCTIONAL DESIGN CRITIQUE

APRIL 1982

PREPARED BY

COMPUTER TECHNOLOGY ASSOCIATES

DENVER, COLORADO

Foreword

This critique of the ERBS Command Panel Functional Design has been prepared by Computer Technology Associates, Inc., Denver, Colorado, under the IC^4 System Design Study Contract, NAS5-26689 for NASA Goddard Space Flight Center (GSFC).

1.0 Introduction

1.1 Purpose

This critique is for use as an evaluation tool in the human factors analysis being conducted by the Human Factors Group of GSFC.

1.2 Scope

This critique is a brief assessment of the advantages and disadvantages of the current ERBS Command Panel Functional Design as documented in "Command Panel Functional Specification," BFEC, March 1982. In addition, clarification of technical details was accomplished in informal interchange meetings with Mr. Steve Miles of BFEC on March 5, 10 and 30, 1982.

2.0 Critique

2.1 Advantages

The salient advantages of the command panel concept are the retively simple man-machine interface provided and the consolidation of many indications into a single work station/terminal.

2.1.1 Man-Machine Interface

The command panel concept allows the use of graphics techniques, colors, and positive operator selection authority to optimize human factors considerations for the man-machine interface. Graphics techniques are employed in the command panel for the matrix layouts and alpha-numerics, yielding a flexible format capability with variable line weights, type styles and sizes, and scrolling for the pass plan matrix. Colors are used to represent selections, alarms and status throughout. The light emitting diode (LED) matrix overlay requires the physical interruption of the beams in the matrix to cause a selection to be made.

2.1.2 Single Work Station/Terminal

Many indications normally dispersed throughout several display pages in a traditional MSOCC environment are incorporated into the command panel. Alarm indications are provided for spacecraft and NCC/TDRSS anomalies and a command reject indication responds to application processor detected rejects. Several lines at the top of the display are reserved for a STOL syntax printout of the procedure in progress, and two lines at the bottom are reserved for interactive NCC messages.

2.2 Disadvantages

As currently defined, the command panel lacks tactile feedback, has an extremely high density layout, offers no improvement over MSOCC standard capabilities for unplanned contingencies and/or backout operations, and due to its singularity in the ERBS application, raises reliability/maintainibility/availability concerns.

2.2.1 Tactile Feedback

The LED Matrix arrangement offers no tactile feedback to the operator. The color change of the "button" selected provides the only indication of the activation. This could be supplemented by the voice synthesizer of other audible cue, but these are not considered optimum for routine operations. Also, dependent on the resolution of the LED fields, inadvertent selections could result from an unsteady operator action or parallax error.

2.2.2 Layout

The organization of the command panel is cluttered, particularly when considering the multiple colors in the high density layout. This could lead to confusion or fatigue in operational scenarios, especially when stress is a factor.

2.2.3 Contingency/Backout Procedures

Under nominal operational conditions the advantages of the command panel (Section 2.1 above) can be exploited. In the event of an unplanned contingency (one not supported by a procedure in the contingency procedures matrix) or a backout operation (one calling for KILLPROC, and subsequent directives) the operator reverts to normal MSOCC/STOL practices. In these circumstances the command panel has not enhanced the level of automation available to the operator, and in fact, requires him to either reconfigure the command panel (invoke "STOL") or switch to a different (MSOCC) terminal.

2.2.4 Reliability/Maintainability/Availability (R/M/A)

A failure in the command panel system, be it the mircrprocessor, terminal, or LED matrix causes an abrupt reversion to normal MSOCC practices. The R/M/A statistics for these equipments must be analyzed to determine the level of training required to counter the risks associated with a rapid turnaround to MSOCC practices, and to establish a maintenance and sparing philosophy commensurate with the determined criticality of the equipments.

3.0 Conclusions

Since the command panel is a new development effort in itself, other options should be explored prior to full-scale implementation of the command panel concept. The areas deserving of further study are:

a. Alternative Graphics: Use of menus, or other illustrative representations for information currently contained in the five matrices and alarm/reject indicators.

b. Operator Input/Output: Use of track ball, light pen, "mouse," membrane panel or other selection media. The track ball and "mouse" are cursor positioning methods, the light pen and membrane panel are direct selection methods.

c. Enhanced automation: Since the command panel is microprocessor based, an investigation of additional tasks that could be performed automatically (ex: "stepping" to the next procedure in the nominal pass plan upon successful execution of the preceding procedure). Also, this should include studying shifting of tasks between the ERBS microprocessor, applications processor, and command panel microprocessor for load leveling, process streamlining (ex: reduced I/O) or other advantages.

APPENDIX C

A Case Study of a System Engineered for Control by Humans

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Historically, NASA/GSFC unmanned spacecraft command and control and health and safety operations have been data and people intensive. The increase in spacecraft complexity and the resulting increase in data required to establish the spacecraft status have made the traditional people intensive command and control operation both costly and a higher risk. The increased use and capability of on-board computers provides us with the opportunity to examine alternatives to the traditional concepts for real-time health and safety operations.

The pitfalls of the conventional contingency planning for health and safety are highlighted in Figure 1. The Solar Maximum Mission (SMM) contingency planning and operations provide one step in the evolution from this conventional people intensive health and safety operation toward a "night watchman" mode of operations. The SMM spacecraft health and safety operations were budget constrained to the point that one week after launch one operator was responsible for the health and safety of the entire spacecraft. The spacecraft was a protoflight with new subsystem configurations, software and procedures. To manage the risks associated with this one man SMM health and safety operation, real-time contingency planning and operations centered around unambiguously identifying a system level problem and reactively safing components susceptible to unrecoverable damage. The methodology applied to both analyzing and implementing this approach for SMM is shown in steps I-V below:

STEP I. Identify spacecraft and experiment hardware damage susceptibility to unpredicted system level states.

i.e. -Mispointing

-Unpredicted vehicle rates

-Computer failure

-Short on the power system.

As a general rule all lower level failures or operator errors will manifest themselves into one or more system level anomalies.

FIGURE 1- TYPICAL CONTINGENCY OPERATIONS PROBLEMS

LARGE CONTINGENCY PLAN IS UNMANAGEABLE

- -TRAINING VERSUS RETENTION
- -PUTS UNFAIR RESPONSIBILITY ON THE HUMAN OPERATOR
- -REQUIRES LARGE COMBINATION OF DATA AND DISPLAYS
- -GENERALLY DOES NOT COVER OPERATOR ERRORS

MOST FAILURES ARE NOT COVERED IN THE CONTIGENCY PLAN

TIME AVAILABLE TO RECOGNIZE PROBLEM RANGES FROM LIMITED TO NONE

STEP II. Identify the minimum information and limit values required to unambiguously identify system level problems.

i.e. -P/Y and R position

Hardware/software

-S/C rates

Hardware/software

-S/C currents.

These may be directly in the data stream or computed prior to display.

STEP III. Identify and allocate the functions and time response necessary to contain hardware damage (safe system).

i.e. -On-board command response

-Control center command response time (prime and backup).

Allocation is based on operational on-board capability; time allowed from identification until damage irreversible.

Level of safing is dependent on recovery complexity.

i.e. -Turn off all instruments

-Leave computer running but disable command function.

STEP IV. Establish operations policy, procedures and displays for health and safety monitoring and contingency actions.

i.e. -Monitor these 20 parameters

-Get vehicle and instruments safe

-Issue procedure XYZ anytime mispointed.

The operator should not be required to assume risk. He should be provided with the tools to recognize a problem and conservatively respond. Where one time science is involved "what if planning" and backup personnel should be provided.

STEP V. All other subsystem and benign system-level anomalies should be categorized and operator responsibilities defined.

i.e. -Unexpected configurations

-Thermal limits

The results of this analysis led to providing the SMM health and safety operations monitor three levels of anomaly criticality, a clear policy, and approximately twenty-nine parameters on two displays within which he maintained spacecraft safety. The levels of SMM anomaly criticaly and the SMM contingency operations policies are provided below.

Category I Contingency Actions

- o Safe hardware
- o Analyze problem
- o Stabilize vehicle
- o Notify in-depth analysis

Category II Contingency Actions

- o Notify in-depth analysis
- o Analyze problem
- o Prepare to safe hardware

Category III Contingency Actions

- o Notify in-depth analysis

The two displays provided to monitor the twenty-nine parameters are shown in Figures 2 and 3. The Flag column would provide the operator with an indication of a category 1,2, or 3 severity. But more importantly, the operator has instant cognition of a problem by simply noting an entry in the flag column. Simple unambiguous safing procedures which could be issued safely under any conditions were A clear cut simple contingency plan shown in Figure 4 was the prime reference for operator safing response.

The second result from the contingency analysis was the indentification of those safing actions that were so time critical they must be initiated by the on-board computer. These were incorporated into the software applications processors.

FIGURE 2 - SMM CATEGORY 1 REAL-TIME CONTINGENCY MONITOR (1 of 2)

ORB:04094 SYS: C02	ROLL: 0000.00	FLARE: 0000	CMD CNT:244		GMT-317:20:11:46	
PRI: MIL QUAL:NONE	PTCH:244.1915	ATP PT: 0182	CNTR:OBC227		SCT-317:17:49:47	
SRCE:0000	YAW :-220.101	CLK:17475557	OBC:	HALT	FRAME LOCK:02584	
P 22 OBC HOLD CAT CHECKOFF		LR	LY	HY	HR	FLAG
FPSS1 Y-POSN(P)	244.19* ARCS	-1440	-1K	1K	1440	
FPSS1 Z-POSN(Y)	-220.1* ARCS	-1440	-1K	1K	1440	
DAYNIT FPSS	DAY					
SUN CEN OFSET-P	252.18* ARCS	-1440	-1K	1K	1440	
SUN CEN OFSET-Y	-225.4* ARCS	-1440	-1K	1K	1440	
PSUN CEN-AE1(2)	3.9341* ARCS	-100	-15	15	100	
YSUN CEN-AE1(3)	.0 * ARCS	-100	-15	15	100	
FILTANG ERRR-AB1	2.7362* ARCS	-720	-100	100	720	
ERRP-AB2	.04072* ARCS	-100	-5	5	100	
ERRY-AB3	-.1475* ARCS	-100	-5	5	100	
FILT RATE R(RB1)	-.1967* AS/S	-25	-5	5	25	
P(RB2)	-.0983* AS/S	-15	-1	1	15	
Y(RB3)	-.0491* AS/S	-15	-1	1	15	
SRW PTCH-TCRATE2	-274.5* RPM	-2K	-1K	1K	2K	
YAW-TCRATE3	-297.2* RPM	-2K	-1K	1K	2K	

FIGURE 3 - SMM CATEGORY 1 REAL-TIME CONTINGENCY MONITOR (2 of 2)

ORIGINAL PAGE IS OF POOR QUALITY

OBP:04094 SYS: C02 ROLL: 0090.90 FLARE: 0003 CMD CNT:244 GMT-317:20:11:28
PRI: MIL QUAL:NONE PTCH:244.1915 ATP PT: 0182 CNTR:0BC227 SCT-317:17:49:47
SRCE:0000 YAW :-220.101 CLK:17475557 OBC: HALT FRAME LOCK:02594

P 21	POWER CAT CHECKOFF	**LR	**LY	**HY*	**HR	FLAG
FSS 1 SUN PRES	DAY					
LD BUS VOLTAGE	31.519* VDC	25.1	25.5	32.1	32.4	
BATT VOLTAGE 1	31.359* VDC	25.1	25.6	32.1	32.4	
BATT VOLTAGE 2	31.359* VDC	25.1	25.6	32.1	32.4	
BATT VOLTAGE 3	31.359* VDC	25.1	25.5	32.1	32.4	
BATT HIGH CURR 1	.79998* AMPS	-13	-10	25	31	
BATT HIGH CURR 2	.79998* AMPS	-13	-10	25	31	
BATT HIGH CURR 3	.79998* AMPS	-13	-10	25	31	
QUIET LD BUS CUR	4.79[illegible]* AMPS	0.3	2.0	8.7	10	
PULSE LD BUS CUR	.19123* AMPS	-----	-----	2	3	
HTR BUS CURRENT	1.1952* AMPS	-----	-----	8.7	10	
SCCU/MPS CURRENT	4.8799* AMPS	1.2	1.4	6.4	8.4	
MACS CURRENT	3.8399* AMPS	2.3	3.4	8.5	12	
CDH CURRENT	3.6799* AMPS	2	2.5	6	8	
TOTAL LD BUS CUR	18.235* AMPS	5.0	9.0	29	34	

FIGURE 4 - REAL-TIME OPERATIONS CONTINGENCY PLAN

PROBLEM	DEGREE	IMMEDIATE ACTION	USING...	COMMENTS
OBC CRASHED	SAFE HOLD A PROPERLY HOLDING OR NULLING.	1. SAFE ALL INSTRUMENTS.	C146	
	SAFE HOLD A NOT WORKING PROPERLY.	1. SAFE ALL INSTRUMENTS. 2. SWITCH TO SAFEHOLD B.	C146 A204	PROBABLE FAILURE OF PRIME HARDWARE.
	SAFE HOLD B NOT WORKING EITHER.	1. CHECK TORQUERS, RATS WHEELS/DRIVERS.		PROBABLE FAILURE OF PRIME ACTUATOR.
EXCESSIVE MISPOINTING OBC STILL RUNNING	ON MAIN BODY OF SUN.	1. CANCEL SLEWS.	A356 B572	MAY BE BAD SLEW TABLE. CANCEL SFT.
	NEAR LIMB, OR JUST OFF SUN. (±1500 SEC).	1. SAFE C/P & UVSP. 2. CANCEL SLEWS.	X010 A356 A303	NEAR DANGER ZONES FOR C/P AND UVSP.
	FAR OFF SUN.	1. SAFE C/P & UVSP. (SUN PRESENCE) $< 2^0$ (SUN PRESENCE) $> 2^0$ (NO SUN PRESENCE)	X010 A336 A338 A356	THERMAL RESTRICTIONS.
EXCESSIVE DRIFT OBC STILL RUNNING	HIGH P OR Y DRIFT.	1. SAFE C/P & UVSP. 2. P,Y NULL-AX.	X010 A303 B767	
	PURE ROLL DRIFT.	TAKE NO IMMEDIATE ACTION.	----	NOT CAT-1 SEVERITY.
EXCESSIVE WHEEL SPEED	WITH OBC STILL RUNNING. FOR SAFEHOLD CASE, SEE "OBC CRASHED" ABOVE.	1. SAFE ALL INSTRUMENTS. 2. HI-RATE MAG DETUMBLE TO CSS NULL. 3. TAKE NO OTHER IMMEDIATE ACTION.	C146 CONT. A206	OBC COULD CRASH. RE-ACQUIRE SUN, UNSAT WHEELS. NOT CAT-1 FOR WHEEL ITSELF.
EXCESSIVE DRAIN INTO BATTERY	1 OR 2 BATTERIES.	1. ISOLATE FAILED BATTERY(S). 2. REDUCE EXPERIMENT POWER.	LOOK UP GRP. C146	ISOLATE FAILURE, REDUCE POWER, ANALYZE CAPABILITY.

The successful results of the SMM contingency planning and operations implementation provide the basis for further simplification of spacecraft health and safety--the "watchman concept." The basic signal to the SMM monitor that a problem existed was his observation of a flag in the last column of the two displays shown in Figures 2 and 3. One could easily envision extending this concept to elimination of everything on the display except the flag column.

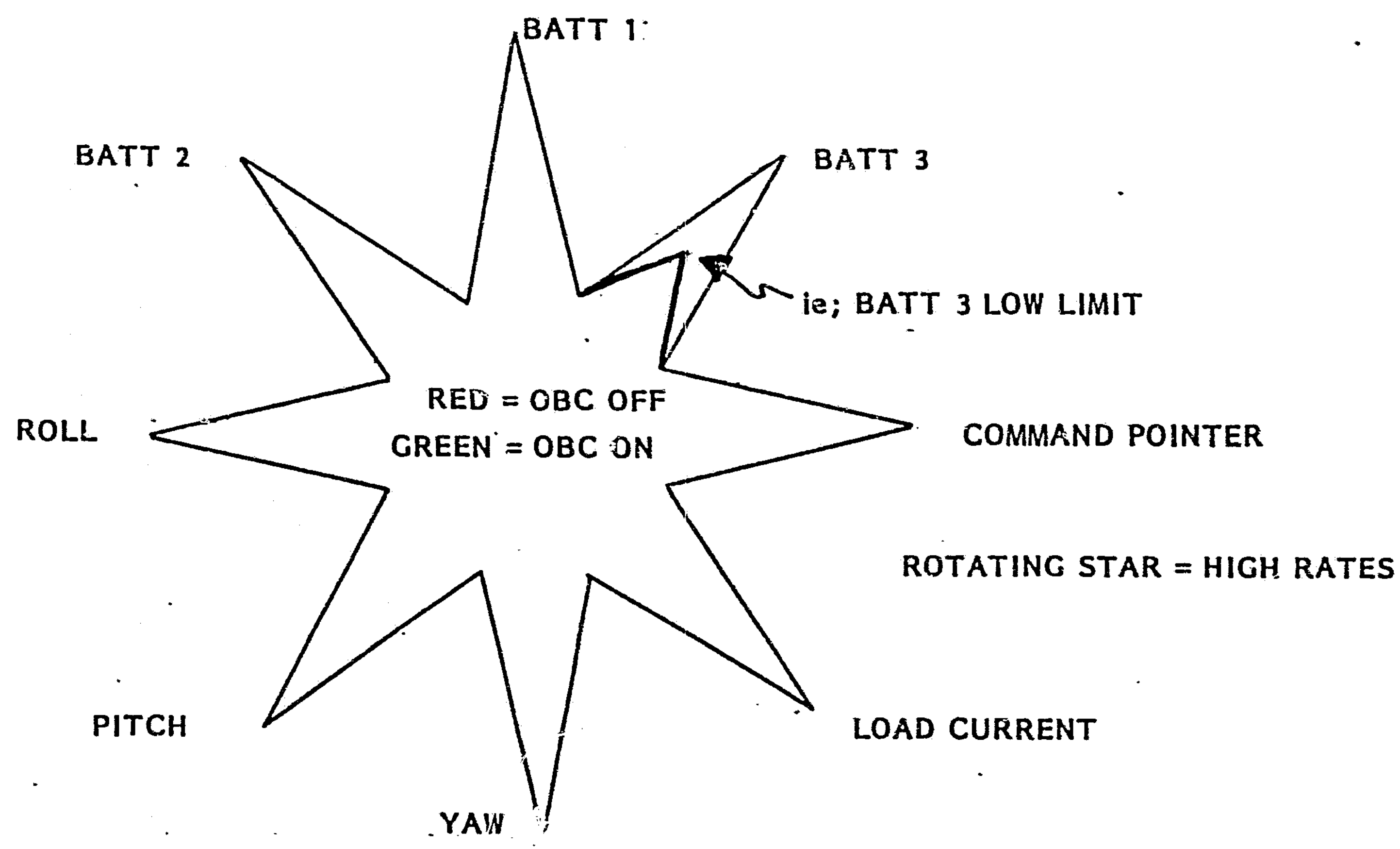
The experience gained on SMM coupled with increasing operations cost and increased use of flight computers, TDRSS, and ground system graphics provide the opportunity to re-evaluate health and safety operations. The historical evolution of the personnel assigned to monitoring spacecraft health and safety presents another consideration. Traditionally the "experts" at launch are off to their next project and are replaced by pure monitors by six months after launch. The personnel exposed to contingency training and familiar with the documentation are generally no longer around.

Cost, technology and personnel considerations lead to a suggestion that future operations be engineered to implement a different real-time health and safety operational philosophy, the "watchman concept." The essence of this concept is to provide information that identifies problems, not data, and on-board safing to protect hardware and contain the problem to the failed component.

Systems engineering for the human function in health and safety should consider the operator likely to be in place for the routine operation. We need to provide both an operator friendly approach to contingency design as well as the information in a form that the less experienced operator can readily recognize and react to system problems. The star icon in Figure 5 illustrates one approach to displaying information which could provide both "the watchman" type operator with a clear indication of a problem and the experienced operator with the same indication. It also however provides a second level of information detail as to the nature of the problem. Either ground or on-board automated responses could take the initial safing step. Any change in symmetry, color or stability of the star would readily be detected. The sample points shown in fact represent those category 1 flags shown in the SMM displays of Figures 1 and 2.

Once the concept of information display is accepted and readily recognizable forms of display are developed, the real-time health and safety monitoring for many spacecraft simultaneously by a "watchman" could be a realizable operations goal for NASA. As with today's operations the watchman would call "the expert" as soon as he detects an anomaly.

FIGURE 5 – THE WATCHMAN DISPLAY CONCEPT



SHAPE, COLOR AND ICON MOTION CAN READILY ALERT
THE TRAINED OR LAYMAN TO SYSTEM PROBLEMS

The idea can be extended throughout operations. The center director could have a bank of screens or even a composite icon which at a glance gives him operational spacecraft status. Remote experimenters could be given status information in the same fashion. Sometime in the future, night and weekend health and safety operations monitoring may even be able to be added to the security guards checklist.