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JPL's Real-Time Weather Processor Project (RWP)

Metrics and Observations at System Completion

Build 3

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This presentation is an update to the November 1988 GSFC First Ada Symposium presentation which provided preliminary data reflecting the RWP Project at the Build-3 Preliminary Design Review. This presentation is based upon the completion of the RWP Build-3 development and the associated Metrics Report draft. The RWP Build-3 Metrics Report will be completed in March 1991 and will be submitted for public release which may take 3-5 months. Because this presentation is based on the draft Metrics Report, prior to complete validation of all the data, minor corrections may result after the Final Metrics Report is completed.

The development of the RWP System is sponsored by the Federal Aviation Administration (FAA). The RWP is one of several weather information programs the FAA has identified in the FAA's National Airspace System (NAS) Plan, which describes all programs planned for modernizing and improving air traffic control and airway facilities services by the year 2000.

An integral part of the overall upgraded NAS, the objective of the RWP is to improve the quality of weather information and the timeliness of its dissemination to system users. To accomplish this, an RWP will be installed in each of the Center Weather Service Units (CWSUs), located in 21 of the 23 Air Route Traffic Control Centers (ARTCCs). The RWP System is a Prototype System. It is planned that the software will be GFE and that production hardware will be acquired via industry competitive procurement.

The ARTCC is a facility established to provide air traffic control service to aircraft operating on Instrument Flight Rules (IFR) flight plans within controlled airspace, principally during the en route phase of flight. Beginning in 1993, and continuing

to 1998, the ARTCCs will be reconfigured to include both en route and approach control functions. The reconfigured facilities will be called Area Control Facilities (ACFs).

RWP will process up to 27 Next Generation Radar (NEXRAD) weather data simultaneously in real-time and create mosaic displays. The processed NEXRAD data is disseminated directly to meteorologists and FAA aircraft controllers. This information is updated every three to five minutes.

The RWP project was started in November of 1987 which resulted from the descoping of the Central Weather Processor Project (CWP). At the time of the descoping the CWP was in detailed design and planned for the "C" programming language development environment. RWP is following DOD-STD-2167A and the software will be coded in the DOD standard ADA programming language. RWP is composed of 3 incremental development builds (Build-1, Build-2 and Build-3). Build-3 contains all of the capabilities specified in the RWP System Specification. There was one Preliminary Design Review (PDR) for the entire system and an individual Critical Design Review (CDR) for each Build. The Coding and Unit Testing (CUT) was completed in February 1990. System Testing was completed in June 1990. FAA Prototype (FAA Users) Test & Evaluation (PT&E) was completed in July 1990. Following PT&E several changes were made to improve the Man-Machine Interface and System Reliability. This was followed by the FAA Formal System Acceptance Test (FSAT) completed in October 1990. Final as-built documentation and the FSAT Test Report are scheduled for mid January 1991.

The system is composed of one CSCI developed by JPL that has 704 Computer Software Units (CSUs) and is composed of 97,687 Ada Statements, number of semicolon ";" delimiters, (or 213,961 Source Lines of Code ((SLOC)), carriage return delimiters less comments and blanks, but including specifications and data, type, declarations). In addition it has 4,330 of "C" SLOC.

In addition to the software developed by JPL there are two areas where Commercial-Off-The-Shelf (COTS) software is used:

- Communications Protocols
- Man-Machine Interface (DECWindows and DECs Forms Management System)

Following are some of the metrics and observations.

<u>Requirements Metrics and Observations</u>

The RWP System Specification contains a total of 223 requirements within 70 pages of the document. On the average there are about 3 requirements per page. This does not include the specification of the external RWP System-to-System interfaces. These are contained in a series of Interface Control Documents (ICDs). The System Specification was approved May 1988. Any System Specification questions, clarifications, or additions were reviewed and negotiated by the RWP System Design Teat (SDT) which was composed of key technical lead staff from each area (Project Office, System Engineering, Software Development, Hardware Development, Test and Operations, Product Assurance and Configuration Management). Results of these

meetings were processed using Project Configuration Management procedures and documented in the SDT minutes as "Open Issues." During the development 222 Open Issues were discussed by the SDT and approximately 40% were external system interface issues relating to ICDs. The 222 Open Issues resulted in 52 Engineering Change Requests (ECRs) and 34 Request for Deviation/Waivers, (RDWs) to the System Specification. RDWs were used as the interim method for correcting wording in the RWP System Specification.

Approximately 2/3 of the Open Issues were generated by the Test and Operation Organization (TOO) resulting primarily from the preparation of the System Integration and Test Descriptions and Procedures. The other 1/3 were generated by the Software Development Organization (SDO).

The 52 ECRs and 34 RDWs caused a significant rework impact late in the development life cycle.

The conclusion we have drawn is that if the System Integration Test Descriptions and Procedures had been prepared earlier in the life cycle, most of the Open Issues would have been initiated and resolved before much of the development was completed or even started and the amount of rework would have been minimized (significantly less).

SPFR Metrics and Observations

1,266 Software Problem Failure Reports (SPFRs) were generated which were based upon requirements (Priority 1,2,3); see DOD-STD-2167A error classification.

SPFRs reflect all errors reported during software (CSCI) or system related requirements testing. The only exception is that any errors found during Coding and Unit Testing and CSC Integration Testing still outstanding at the start of CSCI Requirements Testing were turned into SPFRs at that time.

Most notable is the small number of SPFRs (18%) that existed at the start of CSCI Requirements Testing and the large % (40%) of SPFRs found during System Integration and Testing (SIT). Because of schedule pressures the CSCI Requirements Testing (9% of errors) was deleted for the third incremental Build. This explains the small number of errors found (9%) during CSCI Requirements Testing and likely contributed to the large number found during system level testing (SIT, FSAT-1, FSAT-3 = 51%).

While there are no specific comparisons or conclusions we are prepared to make on the SPFR code growth. It may serve as an important point of reference to note the code growth per SPFR for embedded systems where the memory utilization and margin is critical. Our experience over six interim error correction Builds is that we had approximately 8.4 Ada statements of increase for each SPFR corrected. This does not provide any detail of number of specific amounts of code deleted, changed and added; only the net result.

During SIT there were 5 errors reported per 1000 Ada statements. A more useful number is the error density per SLOC which allows for comparison to numerous density reports on previous other developments. It is typical in this phase to see

error density rates in the 3 to 10 errors per thousand range with the median falling around 5-6 errors per thousand. Comparing the RWP Project error densities with other Fortran, "C" type developments it is our observation that there were fewer (approximately 50%) errors during the RWP, SIT that some previous projects. Some of this probably is due to the use of Ada. However, other factors also contributed such as quality of staff, low attrition of staff, etc.

Based upon the number of work years of effort for CSCI Requirements Testing versus the number of work years for SIT, SIT was 51% more productive in error generation. This is probably exaggerated somewhat due to the deletion of the Build-3 CSCI Requirements Testing.

The metrics of the number of work days to fix an SPFR is between 1.9 and 2.3 work days. The average is 2.1 work days per SPFR correction. This includes any design, coding, unit testing, CSU and CSC integration and delivery of the code to the Project Software Library.

The % of SPFRs fixed that were incorrect or created other problems attributable to the fixed code was 3% or less. This allowed us to use the 4-6 week period prior to release of Builds for various system level tests (SIT, FSAT, PT&E) to continue to be used SPFR correction rather verification of the SPFRs fixed. With 2-3 months centers for Build deliveries and version updates, it provided us with 1/3 more time to fix SPFRs and a higher overall SPFR correction productivity rate given a fixed period.

Ada Portability Metrics and Observations

Ada portability was established as a Project high priority design goal. The object was to minimize the various code constructs that may need to changed using the same programming language and software design but different hardware. The following specific design decisions were made to meet the portability goal:

- Ada Programming Language & Standard
- Ada Tasking to minimize Operating System function uniqueness
- DEC Windows (X-windows subset) to minimize the Man-Machine Interface rework
- Object Oriented Design Methodology to localize external interface dependencies and rework
- Other Engineering Principles and Standards to minimize rework

A tool was developed and used by the Product Assurance staff to analyze the code to identify each non-portable construct and provide summary statistics. Because of the still less than stable industry standards on X-windows the tool produced the portability results both with DECWindows portable and non-portable.

Portability can be measured any number of ways. One of the most useful is to measure the number of specific code constructs that run a risk of needing to be modified for execution on a different computer than that used for the RWP

system (i.e., DEC). This measure could then be compared to the number of code constructs existing in the developed RWP software. The tool does provide the number of non-portable constructs (i.e. 12,267). However there is no measurement of the number of total code constructs in the RWP developed code. There is a count of the number of Ada statements (i.e. 97,687). There may be 1 or more constructs per Ada statement but it is still a useful number to quantify the ratio or metric of % portable. If we divide the total Ada statements into the non-portable constructs we get the answer approx. 12.5%. Therefore, on a construct basis, the RWP system is at least 87.5% portable. This does not include any changes needed to accommodate word size or reformatting to accommodate storage devices that are unique. It should be cautioned that using the difficulty classification to compute work hours to port the system should not be done. Since many of the porting changes for one type of construct is mechanically repeatable and represents a single instance, worst case, the estimation of porting effort needs to consider repeatability. In addition, not all of the constructs identified as a porting risk may need to be ported.

However, the metrics and analysis should set an industry reference point for specifying design requirements for portability.

VIEWGRAPH MATERIALS

FOR THE

R. LOESH PRESENTATION

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REAL-TIME WEATHER PROCESSOR (RWP) PROJECT

RWP

RWP METRICS AND OBSERVATIONS AT SYSTEM COMPLETION (BUILD-3)

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NOVEMBER 28, 1990

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RWP METRICS AND OBSERVATIONS

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- o DATA IS PRELIMINARY
- o MINOR CORRECTIONS MAY RESULT AFTER VALIDATION PROCESS
- o METRICS REPORT TO BE COMPLETE IN MARCH 1991
  - WILL START PROCEDURE FOR PUBLIC RELEASE OF METRICS REPORT
  - RELEASE MAY TAKE 3 - 5 MONTHS

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RWP METRICS AND OBSERVATIONS

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AGENDA

- o WHAT IS THE RWP SYSTEM?
- o REQUIREMENTS ISSUES
- o TESTING EFFECTIVENESS
- o ERROR DENSITY AND DISCOVERY RATE
- o ADA ERROR CORRECTION RATES
- o PORTABILITY ISSUES

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WHAT IS THE RWP SYSTEM?

- SPONSOR: FEDERAL AVIATION ADMINISTRATION (FAA)

- PROTOTYPE DEVELOPMENT; EVENTUALLY PART OF NATIONAL AIRSPACE SYSTEM UPGRADE

- RWP WILL PROCESS WEATHER DATA IN REAL-TIME BY CREATING A MOSAIC DISPLAY OF UP TO 27 RADARS SIMULTANEOUSLY. THE DATA WHICH IS DISSEMINATED DIRECTLY TO THE FAA AIRCRAFT CONTROLLERS AND METEOROLOGISTS IS UPDATED EVERY THREE TO FIVE MINUTES

- PROJECT MILESTONES:
  - PROJECT START - NOVEMBER 1987
  - CODING COMPLETE - FEBRUARY 1990
  - SYSTEM TESTING COMPLETE - JUNE 1990
  - FAA OPERATIONAL TEST AND EVALUATION - JULY 1990
  - FAA FORMAL SYSTEM, ACCEPTANCE TEST - OCTOBER 1990

- 1 RWP SYSTEM AT 21 OF 23 AREA CONTROL FACILITIES; 7 EXTERNAL INTERFACES

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WHAT IS THE RWP SYSTEM? (CONT'D)

o S/W INTENSIVE; H/W OFF-THE-SHELF

- 1 COMPUTER S/W CONFIGURATION ITEM

  • DEVELOPED BY JPL: 97,687 (ADA STATEMENTS)
  213,961 (CARRIAGE RETURNS (COMMENTS AND BLANKS))
  4,330 (C SLOC)

  • COMMERCIAL OFF-THE-SHELF: 280,238 (C SLOC)

    -- COMMUNICATIONS PROTOCOLS
    -- DEC-WINDOWS
    -- DEC FORMS MANAGEMENT SYSTEM

- ADA, DOD-STD-2167, REVISION A: TAILORED

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WHAT IS THE RWP SYSTEM? (CONT'D)

- DISTRIBUTED H/W ARCHITECTURE
  - 10 MICRO VAX IIS, 3 MICRO VAX 3600S, 1 MICRO VAX 3200
  - VAXELN AND VAX/VMS OPERATING SYSTEMS, DECNET, ISO PROTOCOLS
- THE RWP SYSTEMS ARE SCHEDULED TO BE INSTALLED IN THE FAA CONTROL CENTERS BY 1994 BY A FAA SYSTEM CONTRACTOR WHO IS SCHEDULED FOR SELECTION IN 1992. JPL IS PLANNING TO PROVIDE TECHNICAL SUPPORT TO THE FAA THROUGH 1994 FOR THE INSTALLATION OF THE FIRST THREE OF 23 SITES.

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REQUIREMENTS ISSUES

- o SYSTEM SPECIFICATION (WRITTEN BY JPL AND FAA)
  - 205 FUNCTION AND PERFORMANCE REQUIREMENTS
  - + 18 PERFORMANCE (COUNTED AS 1)

    223
- o SYSTEM SPECIFICATION FUNCTIONAL AND PERFORMANCE REQUIREMENTS PAGES = 70 APPROXIMATELY 0.3 PAGES/REQUIREMENT
- o PROJECT SYSTEM DESIGN TEAM (SDT) ADDRESSED REQUIREMENTS ISSUES AT WEEKLY MEETINGS
- o ISSUE RESOLUTIONS WERE DOCUMENTED IN DESIGN TEAM MINUTES AND PROCESSED VIA CONFIGURATION MANAGEMENT:
  - ENGINEERING CHANGE REQUESTS (ECRs) TO SRS, ICDs AND SYSTEM/SEGMENT DESIGN DOCUMENT
  - REQUEST FOR DEVIATION/WAIVER (RDW) TO SYSTEM SPECIFICATION

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REQUIREMENTS ISSUES (CONT'D)

- o 222 OPEN ISSUES DISCUSSED AT DESIGN TEAM
  - APPROXIMATELY 40% WERE INTERFACE (ICD) ISSUES
- o RESOLUTION RESULTED IN:
  - 52 ECRs TO ICDs, SRS AND SSDD
  - 34 RDWs TO SYSTEM SPECIFICATION
- o APPROXIMATELY TWO-THIRDS OF OPEN ISSUES CAME FROM SIT STAFF DOING STT DESCRIPTIONS AND PROCEDURES (SITD/P)
- o MOST ECRs AND RDWs RESULTED IN SOFTWARE, DOCUMENT AND TEST PROCEDURE AND DATA <u>REWORK</u>

<u>WRITE INITIAL VERSION OF SYSTEM TEST PROCEDURES AS EARLY AS POSSIBLE</u>

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SPFR COUNT
(BY PHASE)

- TOTAL APPROXIMATELY 2,100 SPFRs TO DATE
  - 1,452 RWP CSCI RELATED
  - 1,266 PRIORITY 1 - 3

PHASE	SPFR COUNT	PERCENT
SYSTEM INTEGRATION TESTING	508	40%
CSCI REQUIREMENTS TESTING	117	9%
CSC INTEGRATION TESTING	231	18%
CODE AND UNIT	6	0%
FSAT-1	98	8%
FSAT-2	35	3%
BUILD	172	14%
OTHER	98	8%
	1,266	100%

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RWP METRICS AND OBSERVATIONS

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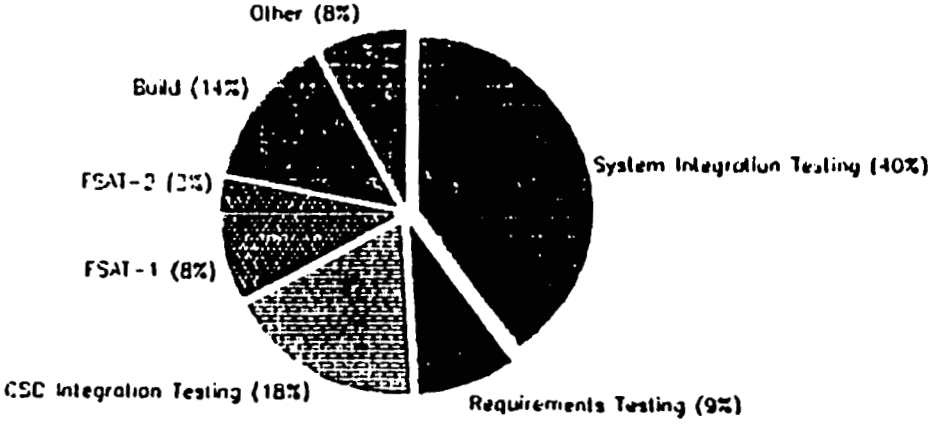
RWP SPFR DISTRIBUTION



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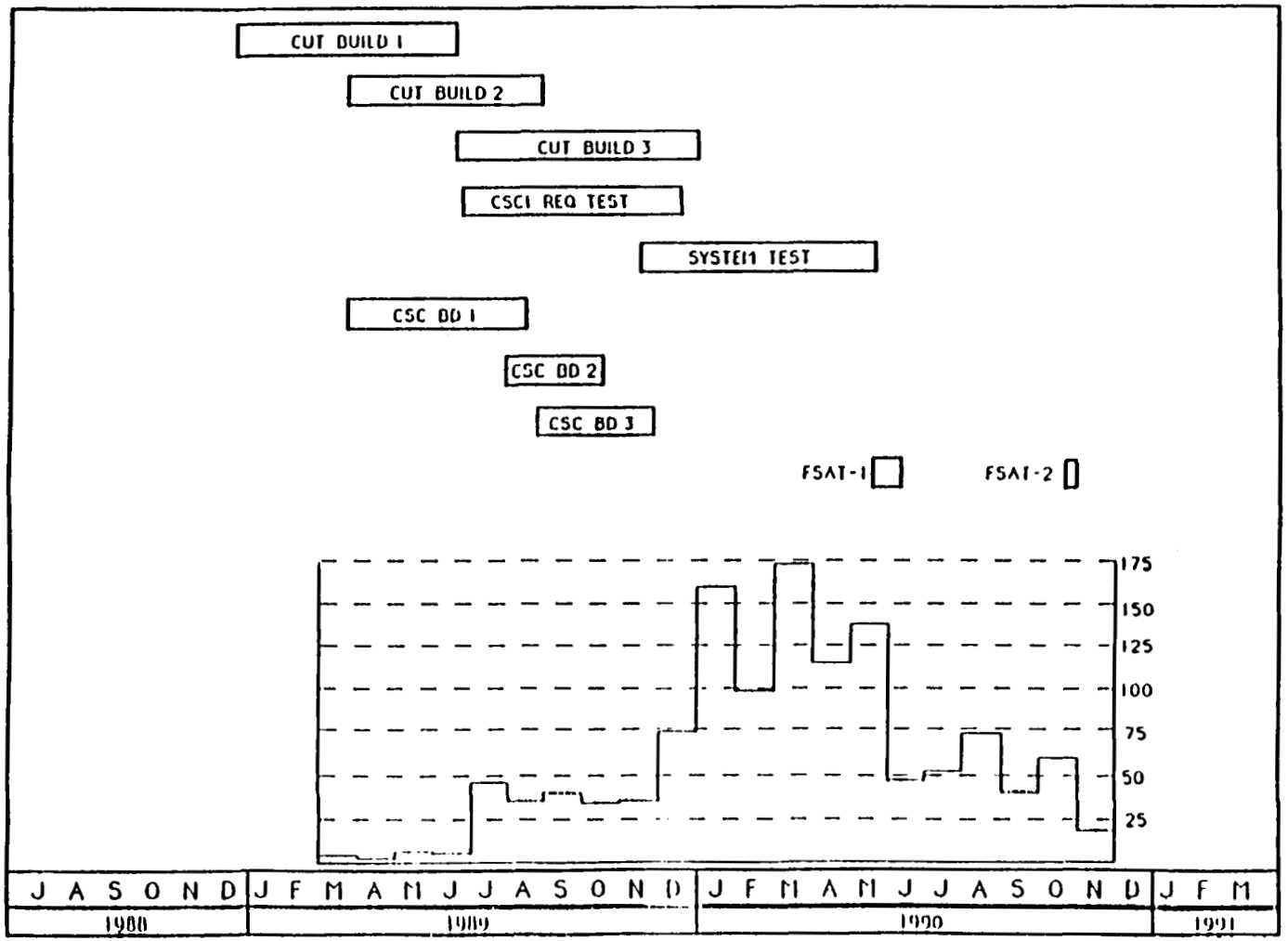
RWP SPFR DISTRIBUTION (BY PHASE)



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SPFR DENSITY

BUILD	CARRIAGE RETURNS	SEMI-COLONS	Δ FROM PREVIOUS BUILD (CARRIAGE RETURNS)	Δ FROM PREVIOUS BUILD (SEMI-COLONS)	SPFRS FIXED
3.8	401,544	94,886	---	---	128
3.9	405,537	95,613	3,993	727	55
3.10	408,895	96,214	3,358	601	80
3.11	409,362	96,308	467	89	18
3.12	414,546	97,687	5,164	1,379	78
3.13	420,804	99,288	6,258	1,601	135
3.14	418,433	98,748	-2,371*	-504*	95
TOTAL 6 BUILDS (3.9 - 3.14)			16,889	3,857	461

SEMI-COLONS PER SPFR 8.4

CARRIAGE RETURNS PER SPFR 36.6

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ERROR DENSITY AND DISCOVERY RATES

- o CSCI REQUIREMENTS TESTING
  - STOPPED FOR BUILD-3: SCHEDULE AND RETURN ON INVESTMENT
  - MOVED TO SDO FOR BUILD-4
    - PRODUCTIVITY: LESS OVERHEAD TO ERROR PROCESSING
    - EMPHASIZE REQUIREMENTS RESPONSIBILITY OF SDO STAFF

- o SYSTEM INTEGRATION AND TESTING (SIT)
  - NINE MONTHS TEST EXECUTION PERIOD
  - RESET AFTER THREE MONTHS TO ACCOMMODATE LATE SOFTWARE DELIVERY
  - 40% OF ERRORS FOUND DURING SIT

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ERROR DENSITY AND DISCOVERY RATES (CONT'D)

- o FORMAL ACCEPTANCE SYSTEM (FSAT)
  - FAA TEST WITNESS
  - 11% OF SPFRs FOUND DURING FSAT
  - TWO FSATs
    - FSAT-1: APPROXIMATELY THREE WEEKS: 98 SPFRs (8% SPFRs)
    - FSAT-2: APPROXIMATELY ONE WEEK: 35 SPFRs (3% SPFRs)

- o 95+% SYSTEM FUNCTION AND PERFORMANCE REQUIREMENTS FULLY VALIDATED

- o SIT METRICS AND OBSERVATIONS
  - APPROXIMATELY 5 ERRORS PER 1000 ADA STATEMENTS
  - APPROXIMATELY 2.3 ERRORS PER 1000 CARRIAGE RETURNS

APPROXIMATELY 1/2 LESS THAN TYPICAL FORTRAN

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ERROR DENSITY AND DISCOVERY RATES (CONT'D)

- o SIT VERSUS CSCI REQUIREMENT TESTING (NOTE-1)
  - CSCI REQUIREMENTS TESTING APPROXIMATELY 19.5 ERRORS/TEST WORK YEAR
  - SYSTEM INTEGRATION AND TESTING APPROXIMATELY 29.5 ERRORS/TEST WORK YEAR

SIT APPROXIMATELY 51% MORE PRODUCTIVE THAN CSCI REQUIREMENTS TESTING

<u>NOTE-1</u>: SYSTEM = 1 CSCI

RWP METRICS AND OBSERVATIONS

ADA ERROR CORRECTION RATES

NUMBER OF SPFRs IN BUILD	WORK DAYS PER/SPFR	
108	1.5	
128	2.2	- 2 - 3 WEEKS/BUILD
55	2.1	
80	1.9	- 8 BUILDS OVER 6 MONTHS
98	2.6	
78	2.3	- EXPERIENCED RWP/ADA STAFF
135	2.3	
95	1.9	
	16.9	= 2.1 AVERAGE WORK DAYS/SPFR CORRECTION

o TYPICAL WORK DAYS PER SPFR APPROXIMATELY 1.9 TO 2.3

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ADA ERROR CORRECTION RATES (CONT'D)

- 96+% OF CORRECTIONS WERE VALID:
  - ∴ WE WERE ABLE TO MAKE ONE ADDITIONAL BUILD PRIOR TO FSATs TO INCREASE RELIABILITY

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ADA PORTABILITY METRICS AND OBSERVATIONS

- PROJECT ESTABLISHED PORTABILITY AS DESIGN OBJECTIVE EARLY
- PERFORMED ANALYSIS USING THREE TOOLS AND LIMITED HUMAN ANALYSIS
  - ADA COMPILER
  - JPL DEVELOPED TOOL:
    - * SEE PAPER BY BORIS SHENKER AND HERNAN GUARDA
      AN AUTOMATED TOOL FOR PORTABILITY ANALYSIS OF ADA CODE OF THE
      REAL-TIME WEATHER PROCESSOR PROJECT
      PRESENTED AT MINNOWBROOK WORKSHOP, JULY 1990
  - ADA-MAT: FOR VALIDATION

- PORTABILITY HAS THREE LEVELS OF RISK:

	EFFORT TO CONVERT
- LOW	0 - 2 WORK HOURS
- MEDIUM	2 - 8 WORK HOURS
- HIGH	OVER 8 WORK HOURS

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ADA PORTABILITY METRICS*

	X-WINDOWS	NON-PORTABLE
TOTAL UNITS	704	100%
PORTABLE UNITS	455	65%
NON-PORTABLE UNITS	249	35%
UNITS WITH HIGH RISK CONSTRUCTS	145	21%
UNITS ONLY WITH LOW RISK CONSTRUCTS	41	6%
TOTAL ADA STATEMENTS (;)	97,687	
TOTAL NON-PORTABLE CONSTRUCTS:	12,267	100%
- HARDWARE	1,192	10%
- OPERATING SYSTEM**	2,290	19%
- ADA COMPILER	5,220	42%
- COMMERCIAL OFF-THE-SHELF (COTS)	3,565	29%

* DOES NOT INCLUDE DATA ISSUES (E.G. WORD SIZE, STORAGE ISSUES)

** DOES NOT INCLUDE PARAMETER SETTINGS

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ADA PORTABILITY METRICS

	X-WINDOWS PORTABLE	% DIFFERENCE
TOTAL NON-PORTABLE CONSTRUCTS	11,444	7%
- HARDWARE	1,192	0
- OPERATING SYSTEM**	2,290	0
- ADA COMPILER	5,220	0
- COTS	2,742	5%

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