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SPACECRAFT
REDUNDANCY AND
ENVIRONMENTAL TESTS
AN HISTORIC EVALUATION

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)REWORD

his study originated because concern was expressed by government space system lanners that the potential capabilities of the space shuttle may not be fully xploited in future space systems.

'hese space shuttle capabilities are expected to provide the following:

1. On-orbit mating of components, subassemblies and assemblies.
2. Satellite retrieval and return to earth.
3. On-orbit satellite check-out, repair, refueling and testing.

Because the shuttle has these capabilities it was postulated that reliability and test requirements might be reduced for the entire acquisition cycle for spacecraft.

The original paper was given at the Sixth Aerospace Testing Seminar at Los Angeles on March 11 - 13, 1981, and covered spacecraft designed built and tested by LMSC and flown using expendable launch vehicles over a ten-year period through 1978. Today's paper is an update and an abbreviated summary of that earlier paper. It covers additional history through 1981.

PURPOSE

The purpose of the study is to answer the following questions:

1. In the shuttle era, is it necessary and cost effective to provide highly redundant spacecraft since they can be retrieved from orbit?
2. Are extremely extensive environmental tests still necessary at the system level?

The experience of LMSC's many spacecraft over a 12-year historical period can be extremely useful in providing data to help assess the value of redundancy and systems test programs.

BASIS OF STUDY

The study analyzed the history of 67 spacecraft over a 12-year period. Each of these were looked at in two different ways. For each spacecraft the following assumptions were made:

1. Redundancies but no environmental system acceptance testing. The study estimated what the duration of spaceflight operating time would have been without environmental system testing but with the redundancies of the actual spacecraft.

2. Environmental systems acceptance testing but no redundancies. The study estimated the duration of spaceflight operating days with the systems environmental test performed but with the assumption that all redundancies had been removed.

TESTING PROGRAM

Each of the spacecraft reviewed were subjected to comprehensive system environmental acceptance tests in accordance with MIL-STD-1540 as amended by contractual documents. A typical sequence is as follows:

1. Serial System Test (verify component capability)
2. Baseline integration
3. EMC
4. Functional
5. Acoustic
6. Functional
7. Pyro shock
8. Functional
9. Mechanical Release Systems check
10. Functional
11. Pressure leak
12. Functional
13. Booster compatibility
14. Functional
15. Weight and CG
16. Alignment
17. Functional
18. Thermal Vacuum Cycling

    2 temperature cycles minimum at $+10^{o}F$ to $+100^{o}F$ in a vacuum, 10^{-5} Torr.

    First 4 days, thermal balance

    (a) Verify equipment thermal design
    (b) Verify analytical thermal models
    (c) Verify heating and cooling system performance margins for hot and cold extremes for both primary and back-up circuits.

19. Functional
20. Antenna deployment
21. Final functional
22. Mechanical preparations
23. Confidence tests
24. Shipping preparations
25. Ship

NOTE: During thermal vacuum testing redundant equipment is exercised separately (an together if applicable), and, components are not allowed to exceed acceptance test temperature levels.

In addition to the system tests, each component received an acceptance test prior to being installed in the spacecraft. A typical test sequence is as follows:

1. Functional
2. Random vibration (3 axes)
3. Functional
4. Thermal vacuum cycling (5 cycles, 75 hours) at $-10^{o}F$ to $+140^{o}F$
5. Functional
6. Leak
7. Functional
8. Burn-in thermal cycling (30 cycles, 330 hours) at $-10^{o}F$ to $+140^{o}F$
9. Final functional

<u>Ground Rules of Study</u> (See typical methodology chart)

Case 1. <u>Redundancy but no environmental testing</u>. Each spacecraft history was reviewed to determine the number of days in system <u>environmental</u> acceptance testing until a critical equipment repetitive failure occurred. (Ambient system test operating time was not counted because we assumed it would be done even if no environmental testing were performed). If no second failure occurred in system test the spaceflight operating time was counted up to the second failure.

Case 2. <u>Environmental testing but no redundancies</u>. Each spacecraft operating history was reviewed to determine the point at which the first mission critical failure occurred on a redundant pair. The number of successful spacecraft operating days would have ended at this time if no redundancy was aboard.

CONCLUSIONS

Significant reductions in the number of achieved days would have occurred without system testing or redundancies. The following is tabular summary:

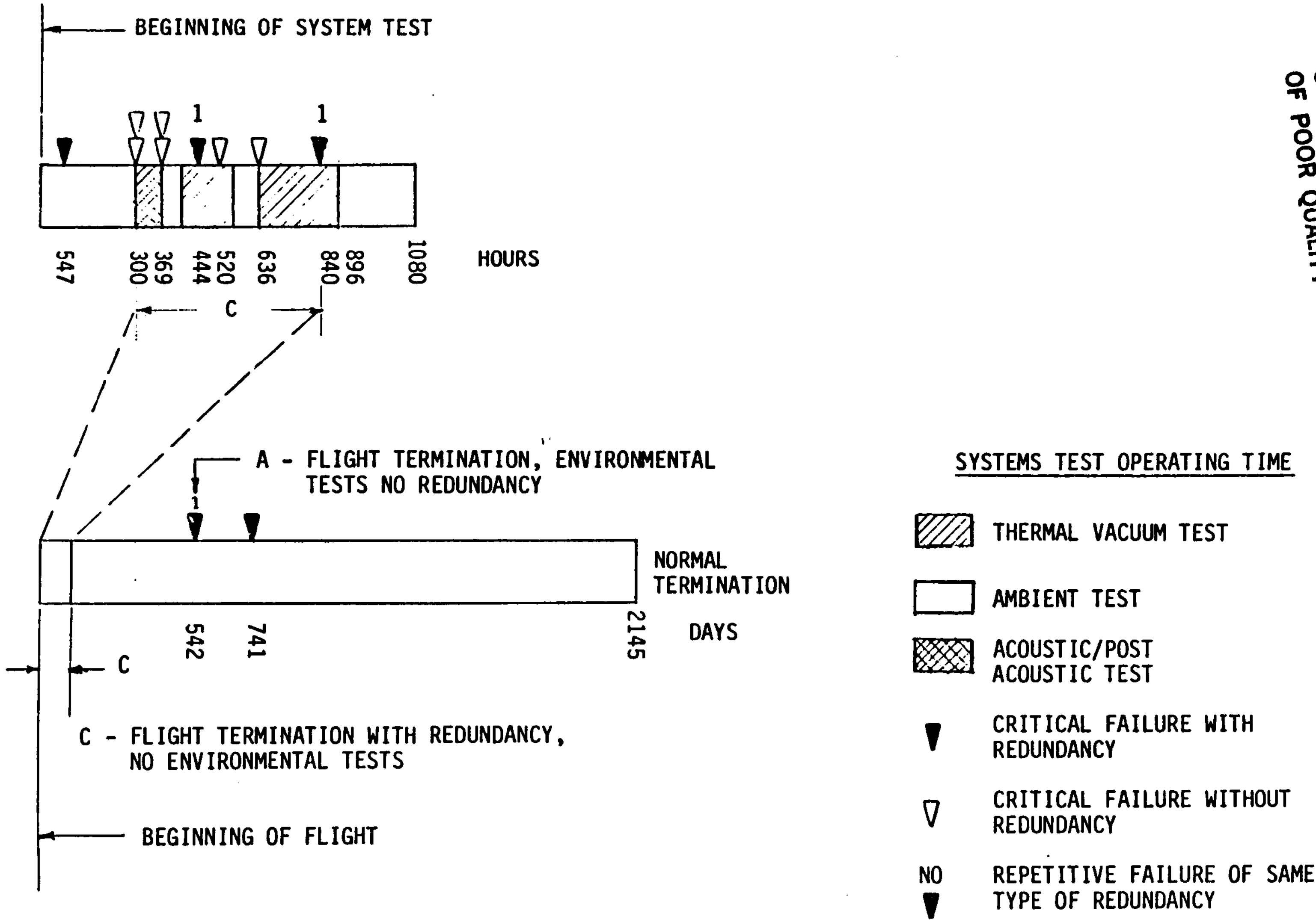
67 SPACECRAFT	CUMULATIVE TOTALS
ACHIEVED DAYS	29,270 ACTUAL
REDUNDANCY ONLY (NO ENVIRONMENTAL TESTING)	5,584 EST.
ENVIRONMENTAL TESTING ONLY (NO REDUNDANCY)	8,812 EST.
TOTAL SYSTEM FAILURES	357
TOTAL FLIGHT FAILURES	119

From the above it can be concluded that--

1. Spacecraft with the same redundancies as used in the past, but eliminating systems environmental acceptance testing would have to be delivered at 19% of the current cost to provide the same effective on-orbit days.
2. Spacecraft without redundancies, but subjected to the current systems environmental acceptance testing would have to be delivered at 30% of the current cost to provide the same effective on-orbit days.
3. Environmental testing appears to be more effective than redundancy in increasing on-orbit mission days.
4. The present practices of providing redundancy of critical components and environmentally testing the spacecraft are cost effective and should be continued into the shuttle era.
5. 357 potential on-orbit failures which could have been mission critical were detected during systems environmental acceptance testing.
6. In the shuttle era, these spacecraft would need to be retrieved for repair 3 to 5 times more often if they did not have redundancy or system environmental testing. This would be a significant economic impact in addition to the potential mission time value loss that cannot be estimated in dollars.

The final result of this study is that LMSC is convinced of the significant value of redundancy in spacecraft and systems environmental testing and such techniques should be carried forward into the shuttle era.

METHODOLOGY - TYPICAL



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DATA BASE

- ANALYZED SYSTEMS TEST AND FLIGHT DATA FOR SIX PROGRAMS TOTALING 67 SPACECRAFT OVER A 12 YEAR PERIOD

- ANALYZED SYSTEM TEST FAILURE DATA AND DETERMINED SYSTEMS TEST OPERATING HOURS

- ACCUMULATED A TOTAL OF 29,270 FLIGHT OPERATING DAYS (80 SPACECRAFT YEARS)

REFERENCE: PROCEEDINGS - INSTITUTE OF ENVIRONMENTAL SCIENCES, SIXTH AEROSPACE TESTING SEMINAR, 11-13 MARCH, 1981

PURPOSE OF STUDY

- EVALUATE VALUE OF REDUNDANCY
- EVALUATE NECESSITY FOR SYSTEM ENVIRONMENTAL TESTS
- DETERMINE: IS ELIMINATION OF REDUNDANCY OR SYSTEM ENVIRONMENTAL TESTING A SOUND, COST-EFFECTIVE MEASURE ?

ACCEPTANCE TEST REQS

PARTS

- ACTIVE: JANTXV AND CLASS B SCREENING OR BETTER
- PASSIVE: E-REL SCREENING

BOXES (LATER BOXES RECEIVED MORE TEMP CYCLES & BURN-IN)

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- VIBRATION: RANDOM, 3 AXIS
- THERMAL VACUUM: 1 TO 15 CYCLES
- BURN-IN: HI TEMP, 100 TO 500 HRS, LAST 100 HRS FAILURE FREE

ALL ITEMS PREVIOUSLY QUALIFIED AT HIGHER ENVIRONMENTAL LEVELS

SYSTEM TEST

PROGRAM	ACOUSTIC	PYRO DEPLOY	HI PRESS	T/V (MINIMUM)
A	1M		X	32H 2~
B	1M	X	X	X
C	X	X	X	200H 6~
D	2M		X	20D 8~
E	1M	X	X	7D
F	1.5M	X	X	14D

D = DAYS
M = MINUTES
H = HOURS
~ = CYCLES

FUNCTIONAL FAILURES ONLY

ELIMINATED FROM DATA BASE:

- TEST FAILURES TRACED TO TEST EQUIPMENT
- TEST FAILURES TRACED TO PROCEDURES
- TEST FAILURES TRACED TO HUMAN ERROR
- NON-CRITICAL EQUIPMENT FAILURES
- UNVERIFIED FAILURES
- DEGRADING/NON-CATASTROPHIC FAILURES
- HYDRAULIC/PNEUMATIC LEAKS

ACCOUNTABLE FAILURES:

- ALL OTHERS

BASIS FOR REDUNDANCY/TEST RATIONALE

CASE 1: <u>REDUNDANCY BUT NO ENVIRONMENTAL TESTING</u>

A. THE NUMBER OF DAYS IN SYSTEM TEST UNTIL A CRITICAL EQUIPMENT <u>REPETITIVE</u> FAILURE OCCURRED

B. IF NO REPETITIVE FAILURES OCCURRED DURING SYSTEM TEST, CONTINUED THE SEARCH INTO THE FLIGHT PERIOD

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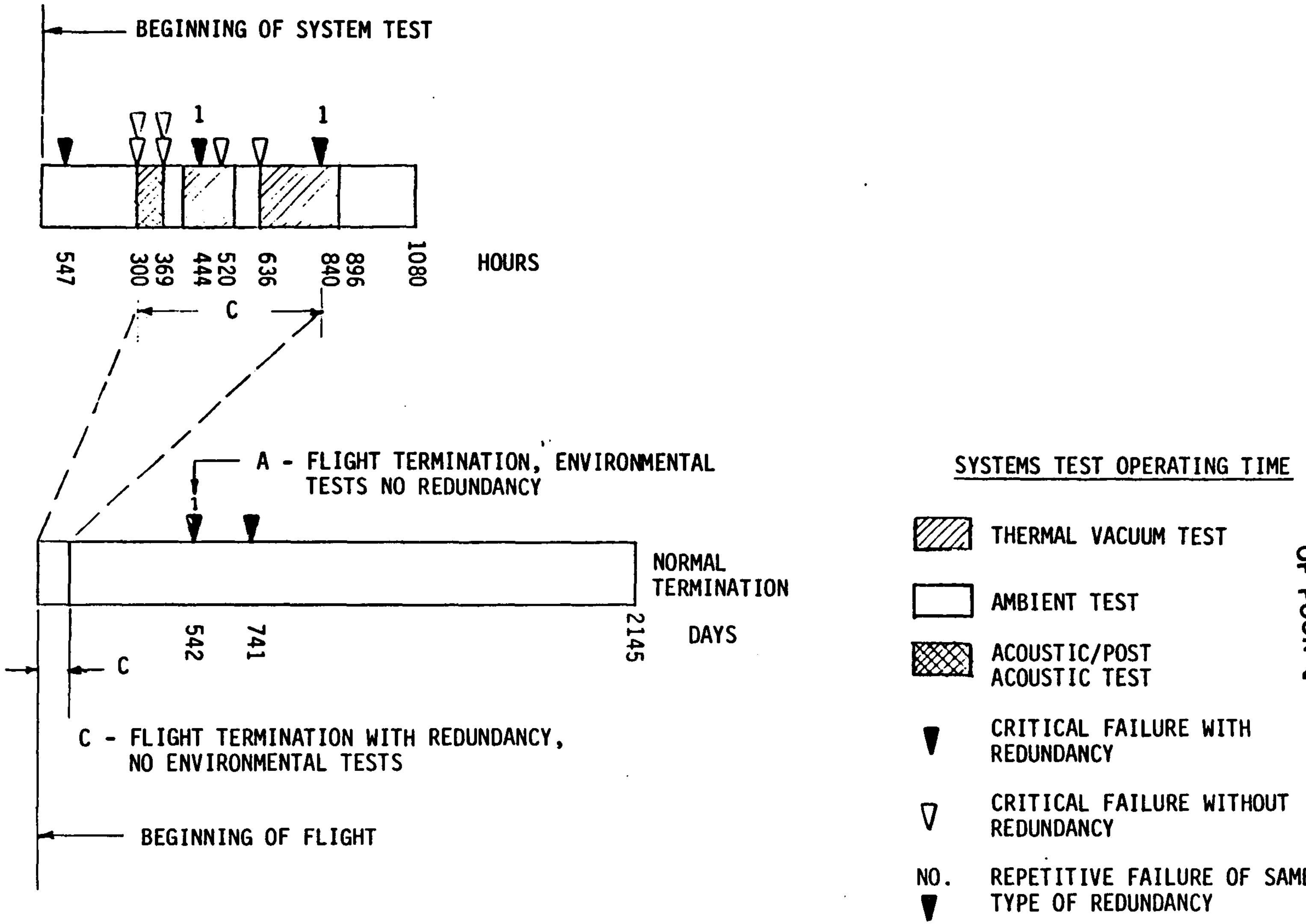
CASE 2: <u>ENVIRONMENTAL TESTS BUT NO REDUNDANCY</u>

THE NUMBER OF SPACE FLIGHT DAYS BEFORE THE FIRST REDUNDANT EQUIPMENT FAILURE OCCURRED.

NOTE: SINGLE REDUNDANCY (ONE BACKUP BOX) ONLY WAS EVALUATED. IN ACTUAL PRACTICE, SOME EQUIPMENTS HAVE MULTIPLE BACKUPS.

METHODOLOGY - TYPICAL



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SUMMARY OF STUDY RESULTS

S/C OPERATING DAYS THAT WOULD HAVE BEEN ACHIEVED UNDER THE ASSUMED CONDITIONS

	DAYS
ASSUMPTION	
o REDUNDANCY BUT NO SYSTEM ENVIRONMENTAL TESTS	5,584
o ENVIRONMENTAL TESTING BUT NO REDUNDANCY	8,812
ACTUAL LENGTH OF S/C OPERATING TIME	29,270
TOTAL NUMBER OF SYSTEM TEST FAILURES	357
TOTAL NUMBER OF FLIGHT FAILURES	119

ON-ORBIT TIME RATIOS

REDUNDANCY, NO ENVIRONMENTAL TEST = $\frac{5584}{29,270}$ = 19%

ENVIRONMENTAL TEST, NO REDUNDANCY = $\frac{8,812}{29,270}$ = 30%

EFFECTIVENESS

$$\text{ENVIRONMENTAL TEST} = \frac{29{,}270}{5{,}584} = 5.24$$

$$\text{REDUNDANCY} = \frac{29{,}270}{8{,}812} = 3.32$$

$$\text{SYSTEM TEST EFFECTIVENESS} = \frac{357}{119 + 357} = 75\%$$

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CONCLUSIONS

THIS HISTORICAL EVALUATION HAS CONVINCED LMSC OF THE SIGNIFICANT VALUE OF REDUNDANCY IN S/C AND THE NEED FOR A RIGOROUS ENVIRONMENTAL SYSTEMS TEST.

IN THE SHUTTLE ERA, REDUNDANCY & SYSTEM TESTING WILL EXTEND THE TIME BETWEEN RETRIEVALS BY FACTORS OF 3 TO 5.