PRESENTATION 4.3.10

"PROPULSION SYSTEM GROUND TESTING"

BY

CHARLES C. WOOD

JUNE 27, 1990

OBJECTIVE

TO PROVIDE MANAGEMENT VISIBILITY RELATIVE TO THE ROLES OF SIMULATION AND PROPULSION SYSTEM TESTING FOR FUTURE DEVELOPMENT PROGRAMS THROUGH ASSESSMENT OF CURRENT PROPULSION RELATED SIMULATION CAPABILITIES AND REVIEW OF CONTRIBUTIONS FROM PROPULSION SYSTEM TEST PROGRAMS.

BASIS FOR PRESENTED DATA

CONTENT	SOURCE
• DEVELOPMENT STATIC FIRING DATA	SPACE SHUTTLE MAIN PROPULSION SATURN STAGES
• ANALYTICAL CAPABILITY	JUDGEMENT
• PROGRAMATICS DATA (ROCKWELL)	ORBITER SATURN S-11 APOLLO CSM GEMINI
• PROPULSION SPECIALISTIC SURVEY	RESPONSE TO SURVEY

REPORT

"ADVANCED NSTS PROPULSION SYSTEM VERIFICATION STUDY FINAL REPORT" - JULY 31, 1989

SIMULATION CAPABILITY ASSESSMENT

(NO PROPULSION SYSTEM TEST)

EVALUATION CRITERIA	VEHICLE FLIGHT CATASTROPHE RISK	MISSION LOSS RISK	LAUNCH DELAY RISK	LAUNCH COMPLEX RISK	SYSTEM TEST PROVIDES DATA	REMAINING RISK AFTER 20 SECOND FRF
"Wrong" Component Verification	Very High	Very High	High	High	Yes	Low
Instrumentation Failure	Moderate	Moderate	Very High	Very High	Yes	Minor
Hazardous Fluid Leakage	High	High	Very High	Very High	Yes	Moderate
POGO Failure	Moderate	High	Minor	Minor	Can	Moderate
Thrust Vector Control Failure	Low	Low	Low	Minor	No	Minor
Propellant Loading Procedures/Operations	No	No	Very High	High	Yes	No benefit
Clustered Engine Performance	Minor	Minor	Minor	Minor	Yes	Minor
Performance Margin Uncertainty	Minor	High	No	No	Yes	Moderate
Stored Gas Mass, Loading, Operations	Minor	Minor	Minor	Moderate	Yes	Minor

SIMULATION CAPABILITY ASSESSMENT

(NO PROPULSION SYSTEM TEST)

EVALUATION CRITERIA	VEHICLE FLIGHT CATASTROPHE RISK	MISSION LOSS RISK	LAUNCH DELAY RISK	LAUNCH COMPLEX RISK	SYSTEM TEST PROVIDES DATA	REMAINING RISK AFTER 20 SECOND FRF
Pressurization System Performance	Moderate	High	Minor	Minor	*Yes	Moderate
Propellant Mass Uncertainty	Minor	Moderate	Very High	Minor	Yes	Low
Low Level Cutoff Sensor	Minor	Minor	Moderate	No	Yes	No benefit
Engine/Feed Systems Chill	Minor	Minor	High	Minor	*Yes	Minor
Tank Insulation	Minor	Minor	High	Minor	*Yes	Minor
Hardware Thermal Control	Minor	Minor	High	Moderate	*Yes	Minor

* Mission Dependent

SIMULATION CAPABILITY ASSESSMENT SUMMARY

(NO PROPULSION SYSTEM TEST)

RISK, DEGREE	VEHICLE FLIGHT CATASTROPHE RISK	MISSION LOSS RISK	LAUNCH COMPLEX RISK	LAUNCH DELAY RISK	REMAINING RISK AFTER 20 SEC
	RISK CATEGORY				
VERY HIGH	1	1	0	4	0
HIGH	1	4	2	4	0
MODERATE	3	2	2	1	4
LOW ₹	10	8	11	6	11

- HAZARDOUS FLUID LEAKAGE
- POGO
- PRESSURIZATION SYSTEM PERFORMANCE
- PERFORMANCE MODEL UNCERTAINTY

ADVANCED VEHICLE SIMULATION CAPABILITY ASSESSMENT

(NO PROPULSION SYSTEM TEST)

EVALUATION CRITERIA	SHUTTLE	ADVANCED VEHICLE WITH SMALLER VOLUME, COMMON BULKHEAD	
	FLIGHT CATASTROPHIC/ LAUNCH DELAY RISK	ALTITUDE START	ORBITAL START
		RISK	RISK
Pressurization Systems Performance	Moderate/ Minor	Much Higher/ Same	Significantly Higher/Higher
Propellant Mass Uncertainty	Minor/ Extremely High	Higher/Same	Much Higher/Same
Engine/Feed System Chill	Minor/High	Higher/Same	Significantly Higher/Higher
Tank Insulation	Minor/High	Higher/Same	Much Higher/Same
Hardware Thermal Control	Minor/High	Higher/Same	Significantly Higher/Higher

Note: Risk relative to shuttle.

SIMULATION ASSESSMENT

CONCLUSIONS

- SIMULATION WITHOUT PROPULSION SYSTEM TESTING RESULTS IN A HIGH RISK PROGRAM.
- WITHOUT PROPULSION SYSTEM TESTING:
  - FLIGHT CATASTROPHE/LAUNCH DELAY AND OTHER RISKS ARE UNACCEPTABLY HIGH.
  - 20 SECOND FRF REDUCES RISK.
  - ORBITAL/ALTITUDE ENGINE START REQUIREMENT INCREASES RISK SIGNIFICANTLY RELATIVE TO SHUTTLE TYPE PROPULSION SYSTEM.
- THE COMPLEXITY OF INTERACTIVE CHARACTERISTICS OF VARIOUS SUBSYSTEMS DEFIES ACCURATE SIMULATION. SYSTEM TESTING PROVIDES FOR MODEL BASING AND ENHANCES SIMULATION.

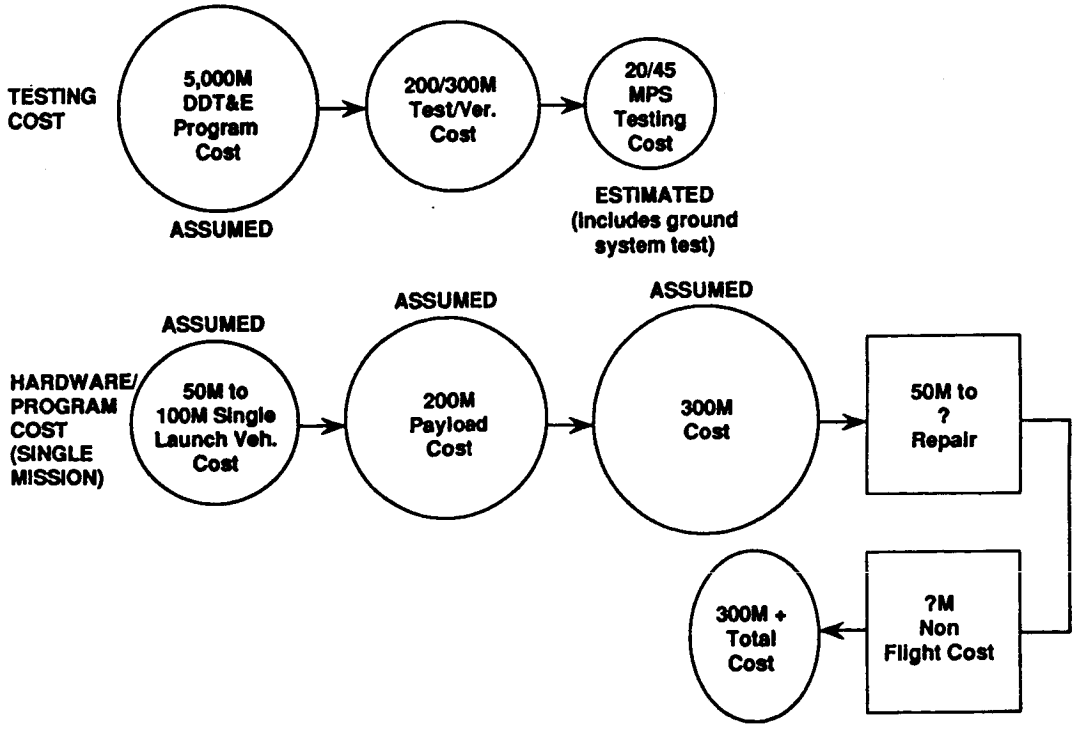
EMPIRICAL COSTING RELATIONSHIPS

RELATIONSHIPS			SOURCE
AVERAGE TEST/VERIFICATION COST NON RECURRING DDT and E Cost (ALL DISCIPLINES)	→	Approximately 4.9 Percent	(4.2%) Gemini S-II Apollo CSM (5.2%) STS Orbiter
MPS TEST COST MPS DDT and E Cost	→	Approximately 8.3 Percent	STS Orbiter Excluding SSMEs
MPS TEST COST Average Test and Verification Cost (All Disciplines)	→	10 to 15 Percent	Deduction

NOTE: Excludes Government Furnished

- Facilities
- Equipment
- Other

ECONOMICS OF TESTING



CONCLUSION: ONE VEHICLE LOSS PREVENTED BY MPS TESTING IS COST EFFECTIVE.

SYSTEMS TESTS IDENTIFIED EVENTS

STAGE	CATASTROPHE		UNWORKABLE		TOTAL PER STAGE**
	FLIGHT	PREFLIGHT	FLIGHT	PREFLIGHT	
SHUTTLE	3	3	5	17	40
S-1C	4	0	3	3	13
S-II	2	0	8	8	21
S-IVB	8	0	6	3	20
S-I/IB	5	1	4	2	15
S-IV*	2	0	3	1	6

* Incomplete

** Includes Categories not included

EXAMPLE

SHUTTLE
- SSME NOZZLE STERN HORN RUPTURE - H_2 DUMPED.
- MARGINAL STABILITY CHARACTERISTICS - ET/ORBITER 17" O_2 DISCONNECT.

SAT V
- F-1 ENGINE TO STAGE BOLTS STRUCTURAL FAILURES
- S-II ENGINE THRUST CHAMBER CHILL FAULTY - ENGINE STALL POTENTIAL

MPTA Hardware Replacement and Repair

MPTA Test Number	Pumps	Major Valves	EIU/MDMS	Other	LH2 Recirculation System, Pressurization System	Valves	Sensors	LH2 Diffuser, Feed Line Screens, Other
	← ENGINE →				← VEHICLE →			
1-002				1	4	5	4	1
2							1	2
3				1		1	1	2
4							1	1
5-A	12	9		1			4	3
5			1		4	2	4	
6-01		9	1	1			2	
6-02/3	1	7		2	3		5	1
6-04			1	5			4	
7-01		1						
7-02		2			2		4	
8		2			5	1		
9-01	1						4	
9-02	4		1		1	1	2	
10		4	10	3	1		2	
11-01	2	7			4	6	2	
11-02				3	6	4		
12				3		1		
Total	**20**	**41**	**15**	**20**	**30**	**21**	**40**	**10**

Note: Hardware changes made prior to designated test number

Rockwell International

MPTA TESTING EVALUATION

ATTEMPTED FIRINGS/ABORTS	INERTING PURGE USAGE	FIRE WATER USAGE (EXTERNAL)	ABORT SOURCE
21/9	5K - 12 System 30K - 3 System	6	Vehicle 2 Engine 8

MPTA TESTING EVALUATION

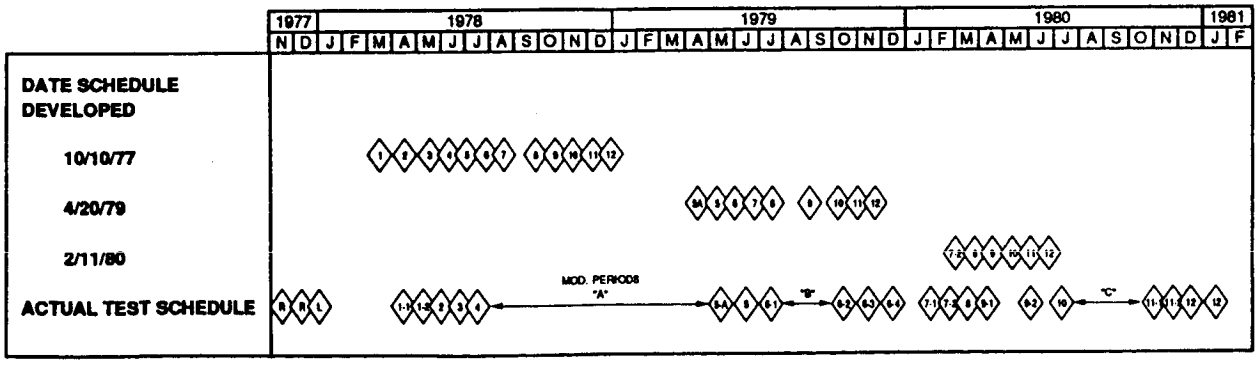
CONTINUED

ABORT CAUSE			
FAULTY INSTRUMENTATION	ENGINE REDLINE VIOLATION	ENGINE HARDWARE FAILURE	EXTENDED PROGRAM DELAYS
3	3	3	2

SATURN V, IB, I TESTING EVALUATION

DEVELOPMENT STAGES					FLIGHT STAGES	
VEHICLE	TEST NUMBER	ABORTS	TEST INADVERTENTLY "CUT"	TEST STAGE DESTROYED	ACCEPTANCE TESTED	DESTROYED IN TEST
SIC "ALL SYSTEMS"	15	5	3		15	1
S-11 BATTLESHIP ALL SYSTEMS	54 9	29 6	1	1	15	
SIV B	21	-	-	1	27	1
SI/IB	23	6			22	

MPTA TEST SCHEDULE



NOTE: R/L - RESONANT/LOADING TESTS

CONCLUSIONS

- PROPULSION SYSTEM TESTING IDENTIFIED MANY ISSUES HAVING THE POTENTIAL FOR THE FOLLOWING CONSEQUENCES:
  - CATASTROPHE; BOTH FLIGHT AND PREFLIGHT
  - MISSION LOSS
  - SIGNIFICANT LAUNCH DELAY
  - SIGNIFICANT LAUNCH COMPLEX DAMAGE
- SHUTTLE PROPULSION SYSTEM TESTING WAS REDUCED VS. SATURN AND CAN BE FURTHER REDUCED FOR SIMILAR FUTURE PROGRAMS.
- ELAPSED TIME SPAN FOR MPTA TESTING WAS EXCESSIVE AND CAN BE REDUCED.

PROPULSION SPECIALIST "SURVEY"

REQUEST: SUMMARIZE YOUR OPINION OF THE ROLE OF "ALL-UP" SYSTEMS TESTING IN VERIFICATION OF A NEW PROPULSION SYSTEM PRIOR TO FIRST LAUNCH.

REQUEST RESPONDENTS: SIXTY SIX ROCKET/SPACE VEHICLE DESIGNERS AND MANAGERS.

RESULTS: OVERWHELMINGLY SUPPORT PROPULSION SYSTEM TESTING.

RESPONSE EXAMPLES: "WERE I SCHEDULED TO RIDE ON A NEW LAUNCH VEHICLE, SYSTEM TESTING WOULD BE A PRIMARY REQUIREMENT."

"IF ANY ITEM IS GOING TO FAIL, HAVE IT FAIL ON THE GROUND WHERE IT CAN BE DIAGNOSED AND FIXED BEFORE FLIGHT."

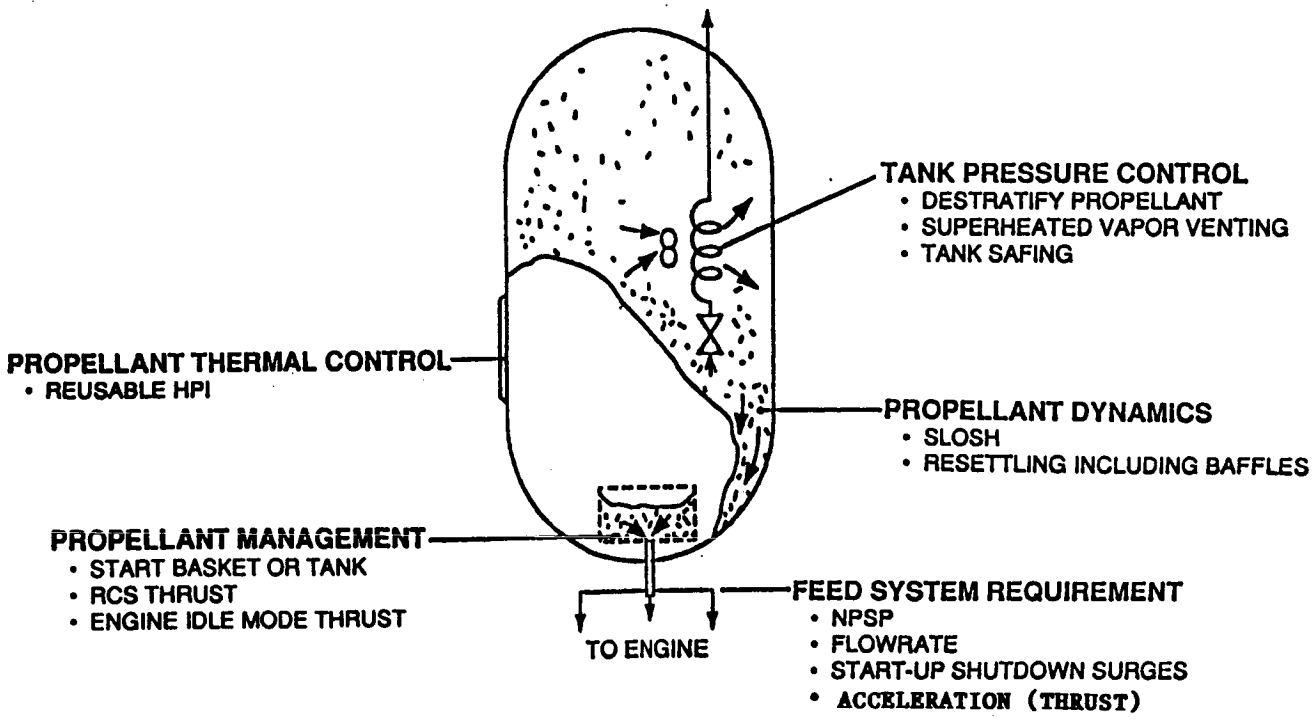
"SPECIAL" VEHICLE SIMULATION ISSUES

(PROPULSION RELATED)

VEHICLES IN THE SPACE ENVIRONMENT HAVE ADDITIONAL DESIGN/ OPERATIONAL REQUIREMENTS:

- PROPELLANT MANAGEMENT
- PROPELLANT THERMAL CONTROL
- TANK PRESSURE CONTROL
- PROPELLANT DYNAMICS
- PROPELLANT RESUPPLY

"SPECIAL" VEHICLE ISSUES



"SPECIAL" VEHICLE ISSUES

(PROPULSION RELATED)

SIMULATION ASSESSMENT:

FOR SOME ISSUES –

- NECESSARY TECHNOLOGY DOES NOT EXIST
- DEMONSTRATION OF TECHNOLOGY NECESSARY
- ORBITAL EXPERIMENTAL DATA NECESSARY
- DEVELOPMENT STAGE GROUND TEST POSSIBLE/DESIRABLE
- SPECIAL DEVELOPMENT GROUND FACILITIES REQUIRED

SUMMARY

- THE COMPLEXITY OF INTERACTIVE CHARACTERISTICS OF VARIOUS SUBSYSTEMS/DISCIPLINES DEFILES ACCURATE ANALYTICAL REPRESENTATION. SYSTEM TESTING PROVIDES DATA FOR MODEL BASING AND ENHANCES ANALYSIS.
- HISTORICALLY SYSTEM TESTING HAS PREVENTED CATASTROPHE AND MISSION LOSS FAILURES, LAUNCH DELAYS AND LAUNCH COMPLEX DAMAGE.
- PROPULSION SYSTEM TESTING IS COST EFFECTIVE IF ONE VEHICLE LOSS IS PREVENTED.
- ADVANCED/"SPECIAL" VEHICLES HAVE AN EQUAL/GREATER REQUIREMENT FOR PROPULSION SYSTEM TESTING.
- PROPULSION SYSTEM TESTING IS A SIGNIFICANT CONTRIBUTOR TO MISSION SUCCESS ASSURANCE.