Collaboration on Upgrades to the Space Shuttle Cockpit

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The NASA Academy of Program and Project Leadership (APPL) Masters Forum

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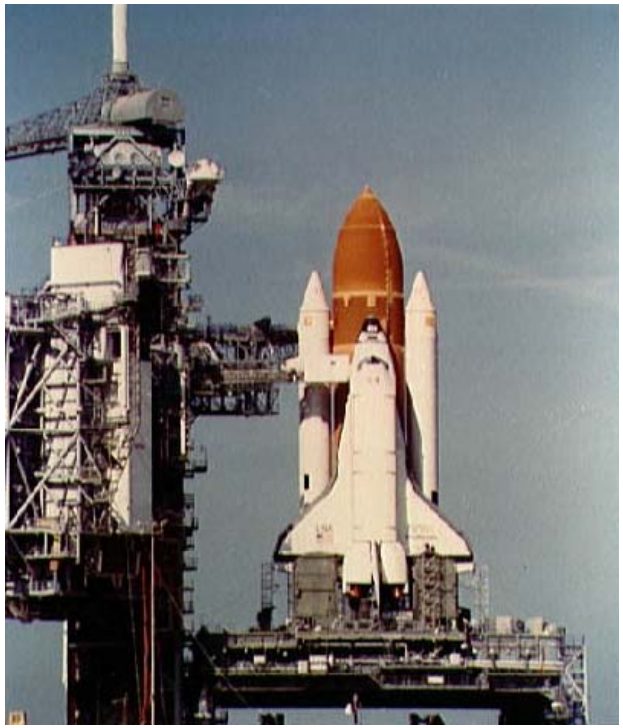
The Space Shuttle Cockpit Avionics Upgrade (CAU) Project is based at NASA Johnson Space Center with support from other organizations such as NASA Ames Research Center.

Background

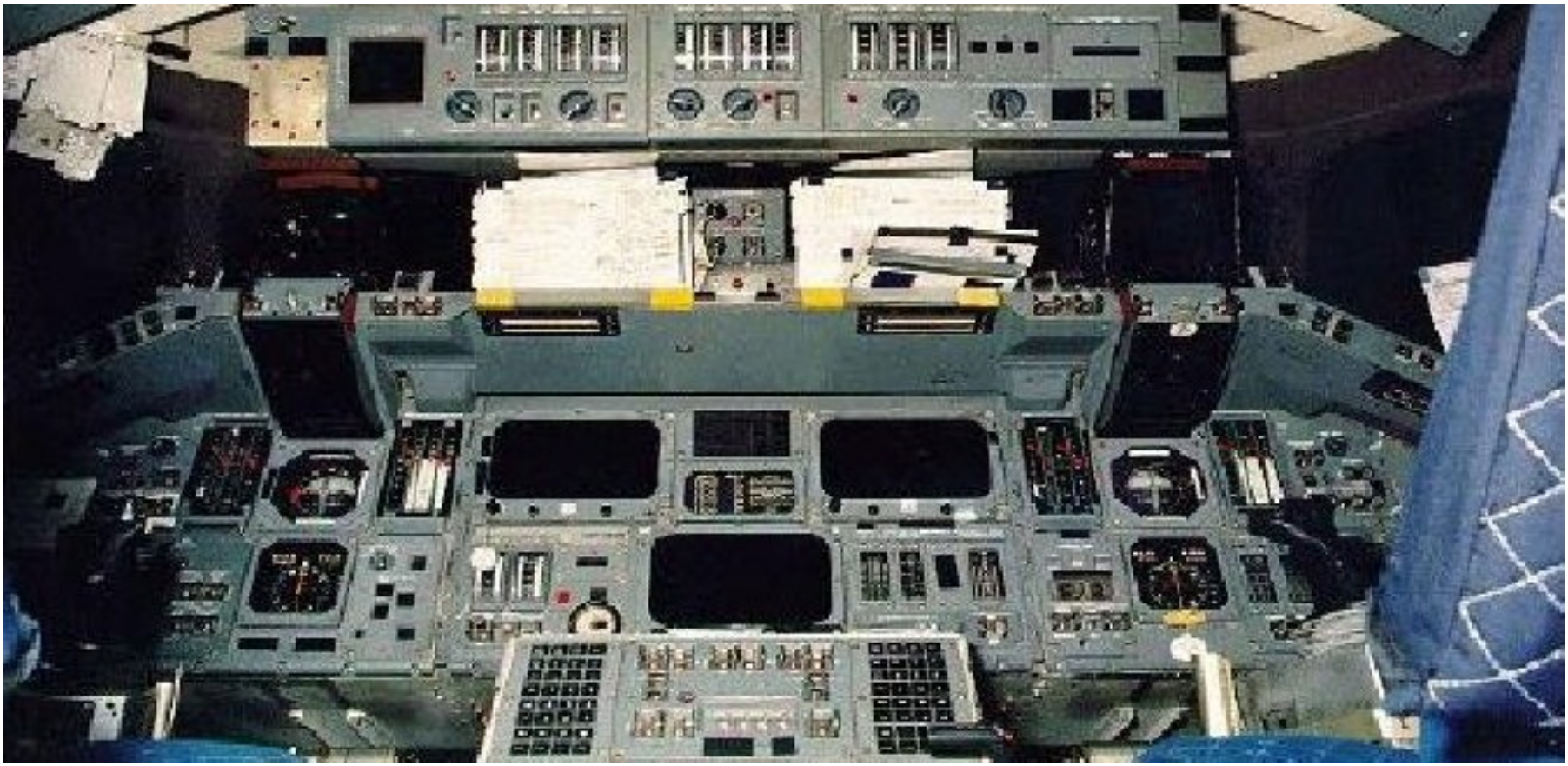
Overview



- First flight in 1981
- Arguably the most complex flying machine ever
  - Launch rocket for 8½ minutes
  - Orbital spacecraft for approximately 2 weeks
  - Hypersonic plane for an hour
  - Subsonic glider for about 5 minutes

Original Shuttle Cockpit (1981)

Multifunction CRT Display System (MCDS)



Original Shuttle Cockpit (1981)

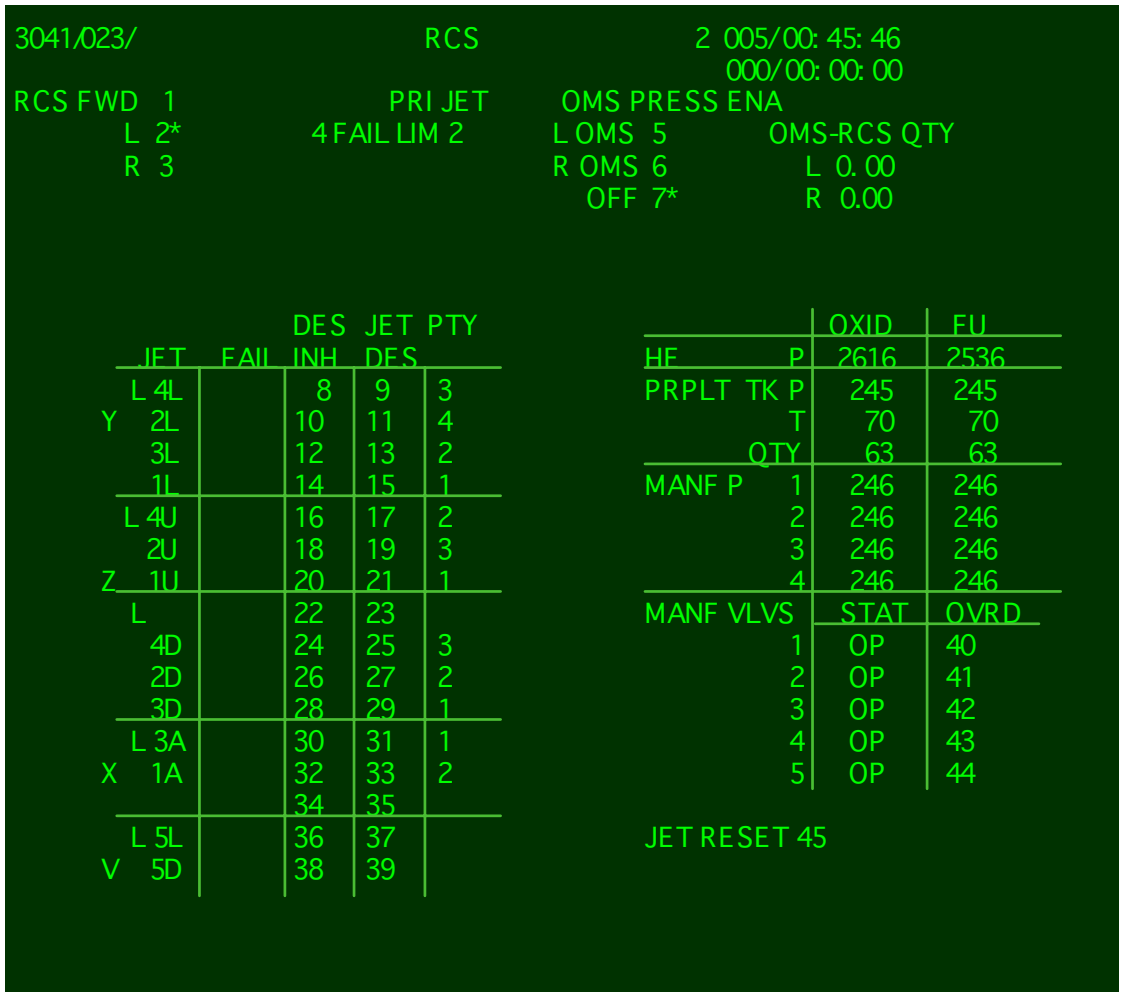
Multifunction CRT Display System (MCDS)

Drawbacks:

- Some gauges are needed only for a brief portion of the mission.
- Only three CRTs are available in the forward section to show display formats.

Original Shuttle Cockpit (1981)

Multifunction CRT Display System (MCDS)

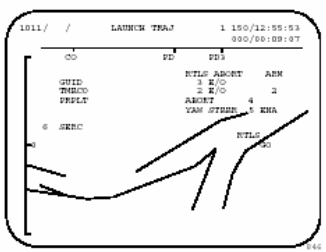


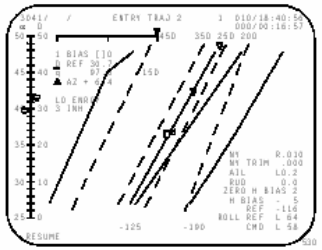
Drawbacks:

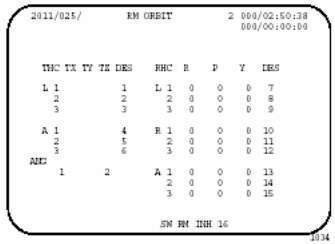
- Information is monochrome text.
- Information is not well consolidated.
- Each display title must be memorized according to its number. (Example: This is a SPEC 23.)

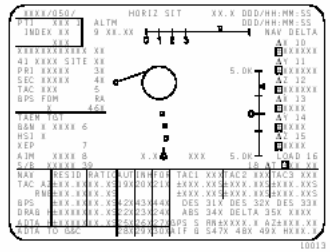
Original Shuttle Cockpit (1981)

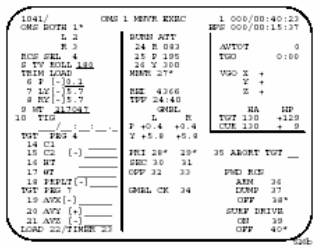
Multifunction CRT Display System (MCDS)

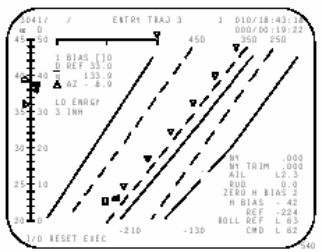


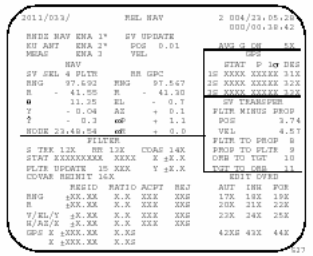


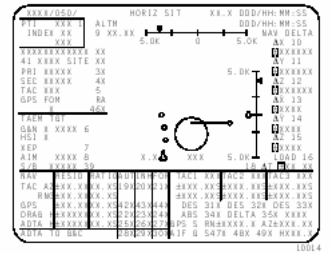


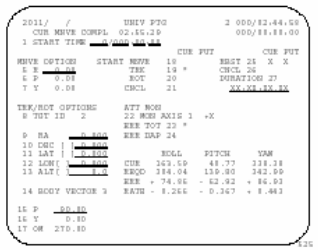


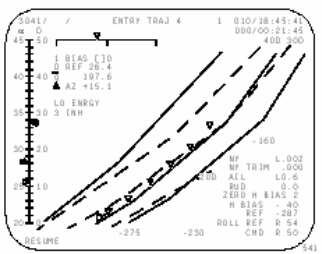


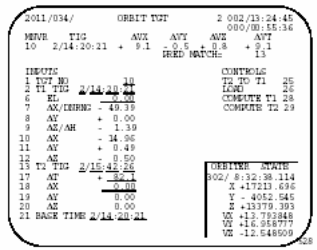


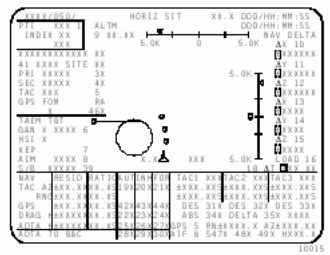


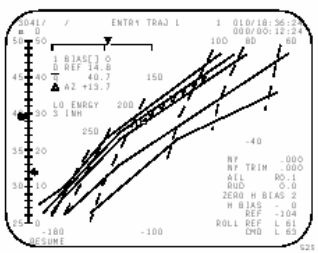


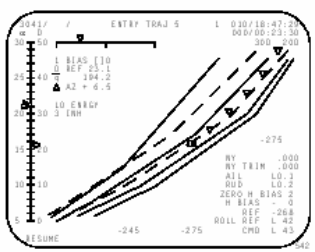


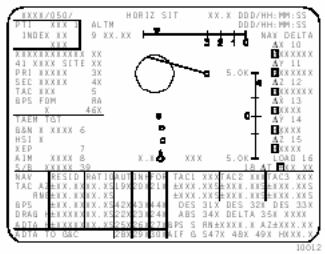


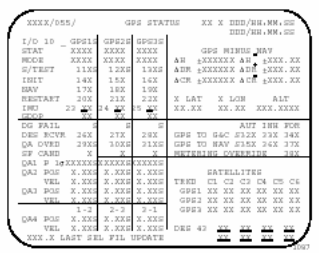












In 1981 ...

The five onboard computers had 128K of RAM.

In 1981 ...

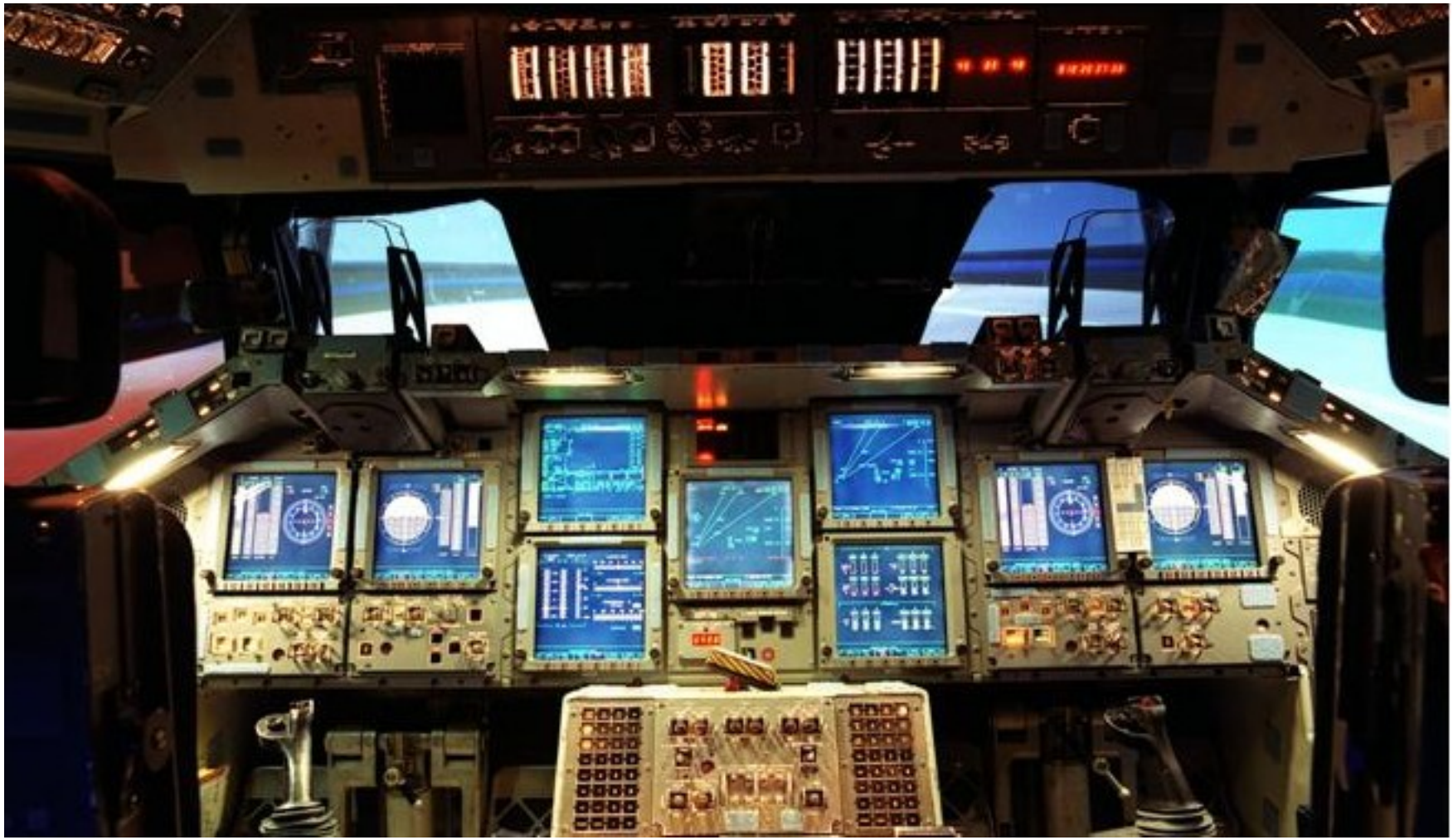
The five onboard computers had 128K of RAM.

IBM PC had 64K RAM.


Windows
An exception 06 has occured at 0028:C11B3ADC in VxD DiskTSD(03) +
00001660. This was called from 0028:C11B40C8 in VxD voltrack(04) +
00000000. It may be possible to continue normally.
* Press any key to attempt to continue.
* Press CTRL+ALT+RESET to restart your computer. You will
lose any unsaved information in all applications.
Press any key to continue

Current Shuttle Cockpit (2000)

Multifunction Electronic Display System (MEDS)



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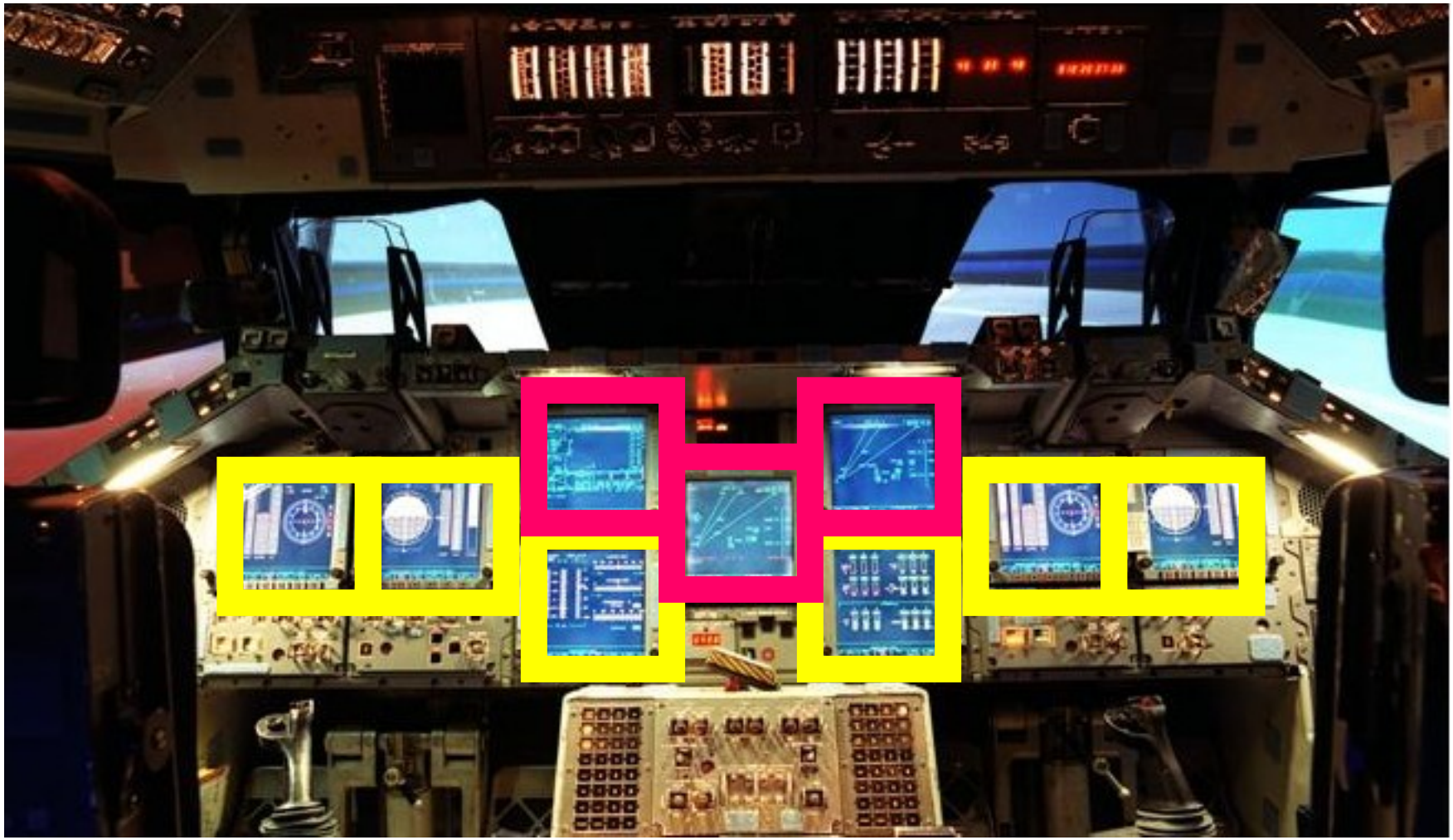

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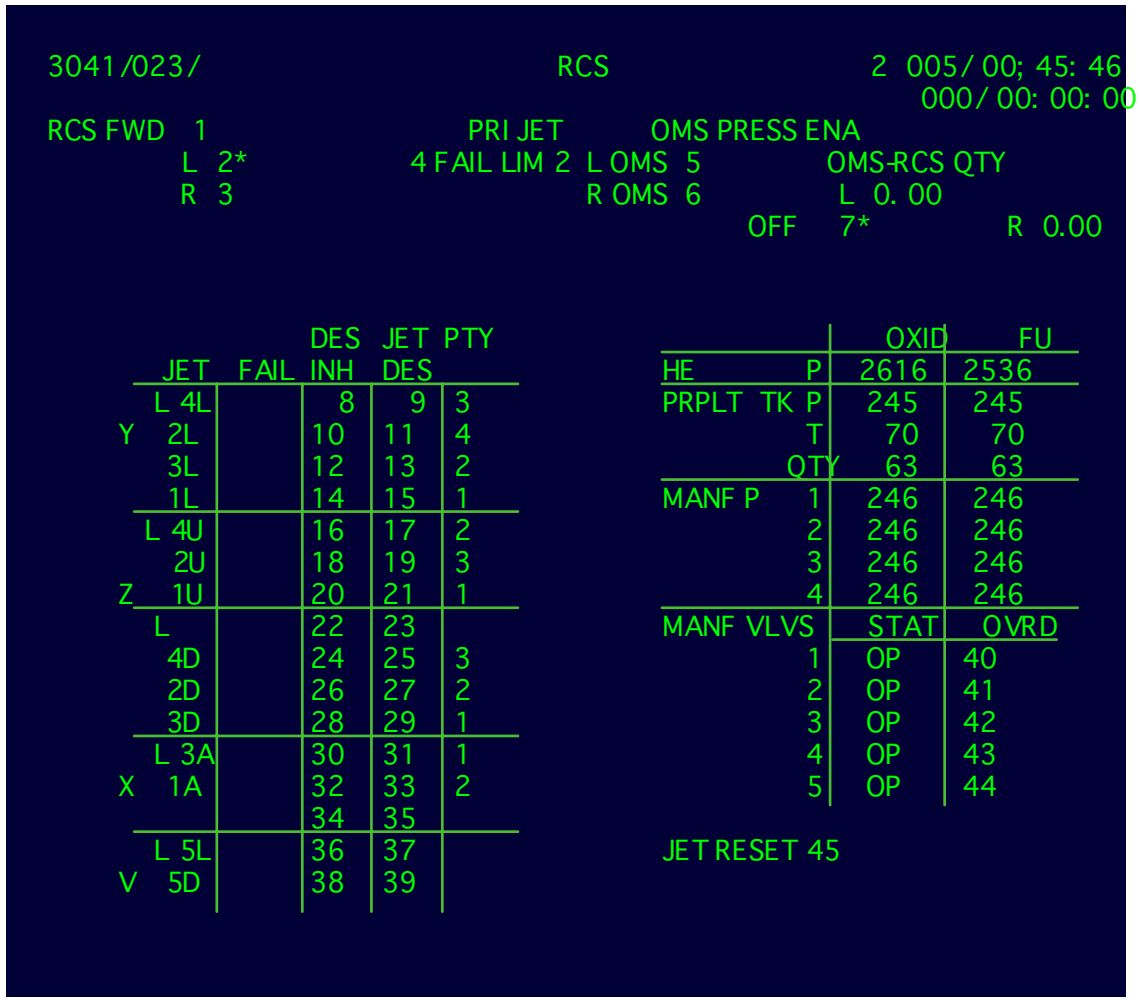


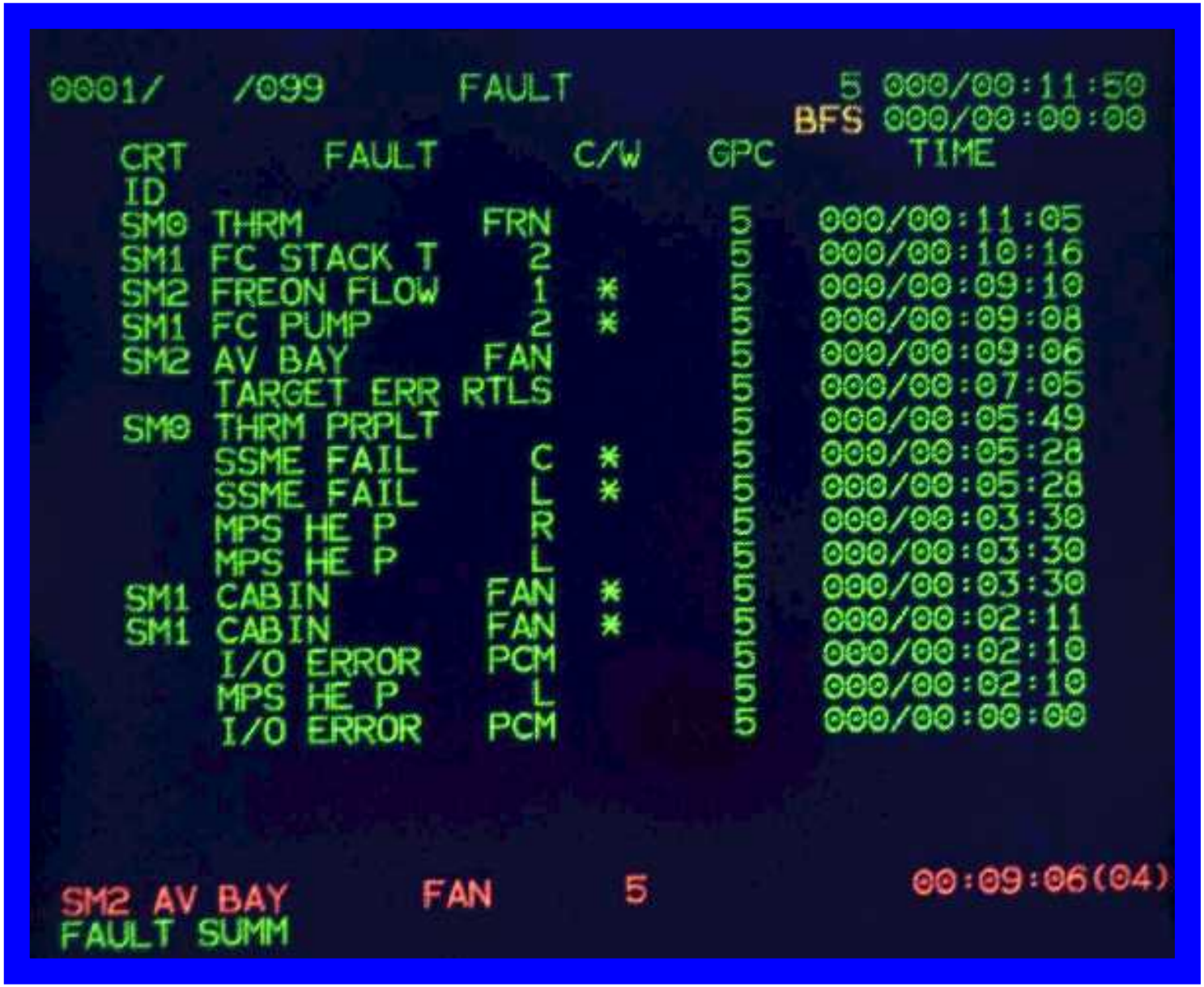
It is far better to adapt the technology to the user than to force the user to adapt to the technology.

- Larry Marine

It is far better to adapt the technology to the user than to **force the user to adapt to the technology**.

- Larry Marine


1031/
ASCENT TRAJ 2
5 000/00:04:18
BFS 000/00:00:00
+200
25
CO
26
ΔḢ
Ḣ 681
R R00
P D00
Y L00
60
0
RTLS
3
T 104
TMECO 08:26
g's
2
-200


0001/ /099 FAULT
5 000/00:11:50
BFS 000/00:00:00
CRT ID
FAULT
C/W
GPC
TIME
SM0 THRM FRN 5 000/00:11:05
SM1 FC STACK T 2 5 000/00:10:16
SM2 FREON FLOW 1 * 5 000/00:09:10
SM1 FC PUMP 2 * 5 000/00:09:08
SM2 AV BAY FAN 5 000/00:09:06
TARGET ERR RTLS 5 000/00:07:05
SM0 THRM PRPLT 5 000/00:05:49
SSME FAIL C * 5 000/00:05:28
SSME FAIL L * 5 000/00:05:28
MPS HE P R 5 000/00:03:30
MPS HE P L 5 000/00:03:30
SM1 CABIN FAN * 5 000/00:03:30
SM1 CABIN FAN * 5 000/00:02:11
I/O ERROR PCM 5 000/00:02:10
MPS HE P L 5 000/00:02:10
I/O ERROR PCM 5 000/00:00:00
SM2 AV BAY FAN 5 00:09:06(04)
FAULT SUMM


0001/ /078 SM SYS SUMM 1 5 000/00:08:39
BFS 000/00:00:00
SMOKE 1/A 2/B
CABIN 0.0
L/R FD 0.1 0.1
AV BAY 1 0.0 0.1
2 0.1 0.1
3 0.1 0.1
CABIN
PRESS 14.8
dP/dT -.00
BU/EQ +.00 -.00
PPO2 3.24 3.24
FAN ΔP 5.85
HX OUT T 49
O2 FLOW 0.0L 0.0L
N2 FLOW 0.0L 0.0L
IMU FAN ΔP 4.66
ΔV FC1 FC2 FC3
SS1 25 28 28
SS2 15 19 10
SS3 16 20 20
TOTAL AMPS 680
KW 20
SYS SUMM
DC VOLTS 1/A 2/B 3/C
FC 30.7 30.4 30.7
MAIN 30.5 30.4 30.5
CNTL AB 28.6 28.6 28.6
BC 28.7 28.7 28.7
CA 28.7 28.7 28.7
ESS 29.2 29.2 29.2
AC
VOLT ΦA 117 117 117
ΦB 117 117 117
ΦC 117 117 117
AMPS ΦA 4.1 8.8 4.1
ΦB 3.8 8.8 4.3
ΦC 5.0 10.1 5.4
FUEL CELL PH
AMPS 216 241 222
REAC VLV OP OP OP
STACK T +205 +205 +205
EXIT T 150 150 150
COOL P 61 61 61
PUMP


0001/ /079
SM SYS SUMM 2
5 000/00:09:45
BFS 000/00:00:00
CRYO TK 1 2 3 4 5 MANF1 MANF2
H2 PRESS 244 244 245 245 245 244 244
O2 PRESS 860 860 861 861 861 861 861
HTR T1 -248 -248 -248 -248 -248
T2 -248 -248 -248 -248 -248
APU 1 2 3
TEMP EGT 945 945 945
B/U EGT 945 945 945
OIL IN 212 212 213
OUT 222 222 224
GG BED 511H 511H 511H
INJ 1274 1271 1274
SPEED % 118 117 115
FUEL QTY 80 81 80
PMP LK P 14 14 14
OIL OUT P 45 45 45
FU TK VLV
A T 65 65 66
B T 65 65 66
AV BAY 1 2 3
TEMP 108 108 84
FAN ΔP 0.00L 0.00L 3.89
HYD 1 2 3
PRESS 3064 3064 3064
ACUM P 3080 3080 3080
RSVR T 114 123 123
QTY 72 73 71
W/B
H2O QTY 79 79 79
BYP VLV BYP BYP BYP
THERM CNTL 1 2
H2O PUMP P 24 63
FREON FLOW 578L 2384
EVAP OUT T 38 41
00:09:06(02)
SM2 AV BAY FAN 5
SYS SUMM


1041/ /018 GNC SYS SUMM 1
5 000/00:07:17
BFS 000/00:00:09
SURF POS MOM
L OB
IB
R IB
OB
AIL
RUD
SPD BRK
BDY FLP
DPS 1 2 3 4
MDM FF
FA
PL
FCS CH 1 2 3 4
MPS L C R
HE TK P 2840 2880 2880
REG P A 746 750 744
B 747 749 744
dP/dT 30 30 30
ULL P LH2 12.0 12.0 12.0
LO2 0.0 0.0 0.0
GH2 OUT P 440 420 410
GO2 OUT T- 143 - 161 - 134
NAV 1 2 3 4
IMU
TAC
ADTA
MPS PNEU HE P
TK 2850
REG 751
ACUM 747
MANF P LH2 0
LO2 19
SYS SUMM


GNC SYS SUM1 2
OMS AFT QTY L R
OXID 38.5 38.5
FU 38.5 38.5
FU INJ T 287 212
OMS L R
TK P HE 3388 3298
OXID 249 249
FU 244 244
N2 TK P 2398 2398
REG P 325 325
P VLV OP OP
ENG IN P
OXID 171 172
FU 282 197
VLV 1 97 97
2 96 97
RCS OXID FU JET FAIL ISOL VLV
FWD HE P 3368 3288
TK P 263 259
QTY 83 81
MANF 1 P 264 256
2 P 264 268
3 P 266 262
4 P 268 268
5
AFT HE P 3646 3649
L TK P 259 265
QTY 181 181
MANF 1 P 194 206
2 P 196 210
3 P 196 210
4 P 196 212
5
HE P 3646 3646
R TK P 261 262
QTY 181 181
1 P 196 264
2 P 196 264
3 P 196 266
4 P 194 264
5
SYS SUM1

TOP

HOOK

ASCENT PROCEDURES

OMS 1 TGTING

R180	LVLH
.90M	√P_c → 72%
1.20M	√P_c → 104%
P_c < 50+5 s	√SRB SEP (Backup AUTO SEP 2:21)
	√TMECO
	* If NOT STABLE (10 sec): *
	* NO COMM – CSS & MAN THROT *
MM103+10 s	√OMS assist
	Close suit O2, open visor
3:00	√EVAP OUT (T < 60)
	* If Systems ABORT reqd: *
	* RTLS at 3:40 or *
	* TAL Select prior to 23000 *
	* Otherwise Manual MECO 23700 *
Vi = 13.2K	√Roll Heads Up
	* If Man Throttle (3 eng): *
	* Man Shutdn at 25810 *
	* If 1 eng: *
	* TRAJ √SERC ON *
	* When MPS PRPLT = 2%: *
	* MAN THROT, P_c → 67% *
	* Man Shutdn at C/O mark *
MECO	√V_I = 25928
MECO+18 s	√ET SEP
	* If 'SEP INH': *
	* ET SEP – MAN *
	* OPS 104 – PRO (√BFS 104) *
	* If Rates > .7, .7, .7: *
	* Null rates *
	* ET SEP – SEP *
	* If Rates < .7, .7, .7: *
	* Assume Feedline Fail *
MM104+2 s	If HA > 156:
	+X xlation for 11 sec
	√TGTS
	√ASC PKT for failures
	If OMS 1 not reqd:
	OMS ENG (two) – OFF
	Go to POST OMS 1

TOP
BACK OF 'EMERGENCY EGRESS'

PILE

BAILOUT EGRESS

SYS FLIGHT RULES

	RTLS	TAL
OMS – 2 He TKs		
– 1 OX & 1 FU TKs (diff pods)		X
– 2 OX or 2 FU TKs		X
APU/HYD – Impending loss of all capability	X	X
CABIN LEAK – (–EQ dP/dT > .15)	X	X
CRYO – All O2(H2)	X	X
2 FREON LOOPS ↓ [Accum Qty (↓ and decr) and/or Flow (↓)]	X	X
2 MAIN BUSES ↓	X	
THERMAL WINDOW PANE	X	

NO COMM MODE BOUNDARIES

NEG RETURN (104)	8200
PRESS TO ATO (104)	9600
SE OPS 3 ZZA (109)	12000
SE ZZA (104)	13600
PRESS TO MECO (104)	14700
SE PRESS (104)	18500
NEG BEN (2 @ 67)	18500
NEG MRN (2 @ 67)	19900
LAST PRE MECO TAL	23000
LAST TAL	
YQX	20200
YJT	20900
INN	24000
FFA	24200
ESN	24900
ZZA	25000
KKI	25100
JDG	25200

2 ENG ZZA (104)	5800
ABORT TAL ZZA (4)	
EO VI	
SE OPS 3 ZZA (109) (14)	
SE ZZA (104) (4)	
2 ENG MRN (104)	5700
ABORT TAL MRN (3)	
EO VI	
SE OPS 3 MRN (109) (13)	
SE MRN (104) (3)	
2 ENG BEN (104)	5700
ABORT TAL BEN (2)	
EO VI	
SE OPS 3 BEN (109) (12)	
SE BEN (104) (2)	


1031/
ASCENT TRAJ 2
5 000/00:04:18
BFS 000/00:00:00
+200
25
CO
26
ΔḢ
Ḣ 681
R R00
P D00
Y L00
60
0
RTLS
3
T 104
TMECO 08:26
g's
2
-200


α
9.3
KEAS
255
R 318
P 346
Y 000
Ḣ
-222
H
22 K
20
15
5
0
250
260
270
160
180
200
240
260
280
300
24
23
22
21
20K
19
0.57
M/VI
1.31
ACCEL
2g
1g
PRI
121
SEC
24
ΔAZ 5°
ASCENT/ENTRY FLIGHT INSTRUMENT MENU
P1*
S2
UP
ADI/
AVVI
HSI/
AMI
COMP
ADI/HSI
DATA
BUS
MEDS
MSG ACK
FC2
AUT

Example: Electrical Power System failure (3 phase motor stall)

- Alarm occurs.
- Signature recognition: 30-45 seconds
- Determine appropriate book/procedure location
- Execute the procedure: 3-4 imbedded “do” loops + multiple displays/switches
- Confirm problem is mitigated: Delta P’s come back
- Determine impacts/recovery actions required: reference data
- Determine next worst failure: Interpreted from ref data/cockpit cue cards
- Situation awareness: Lost
  - 5 displays required, 1 display available (avionics architecture limitation)
  - Pilot focused on failure exclusively for about 4 minutes
  - Commander has no insight into navigation/trajectory monitoring

My Story

NASA Johnson Space Center

Proposed Shuttle Cockpit (2006)

Command and Data Processor System (CDPS)

Goal: Develop new display formats with:

- Consolidated information
- A better use of graphics
- A better use color

The anticipated benefits are:

- An increase in the crew's situational awareness
- A reduction in the crew's workload
- An improvement in the crew's performance

Solution: Team Effort in Designing Display Formats

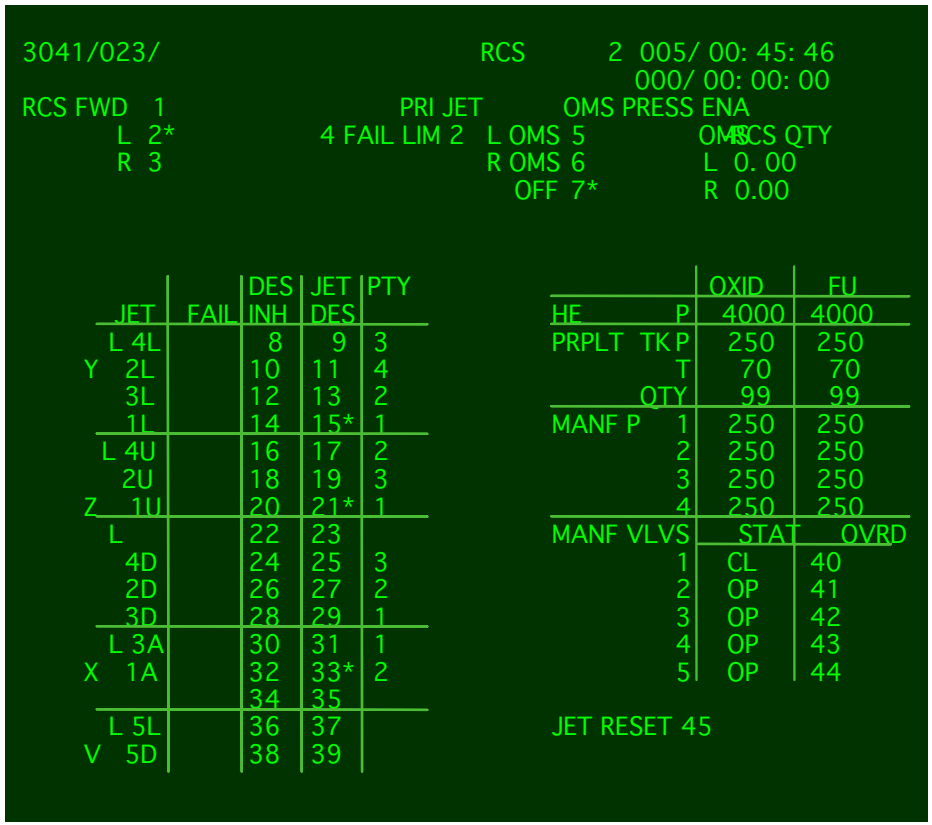
- Teams are assigned to each of the ~70 display formats.
- Each team typically has 5-10 people:
  - 1-2 astronauts
  - 1-2 engineers
  - 1-2 astronaut trainers
  - 1-2 Mission Control representatives
  - 1-2 human factors scientists
- Teams generally met 1-2 times per month for several months from 1999-2003.

You can use an eraser at the drafting table or a sledge hammer at the construction site.

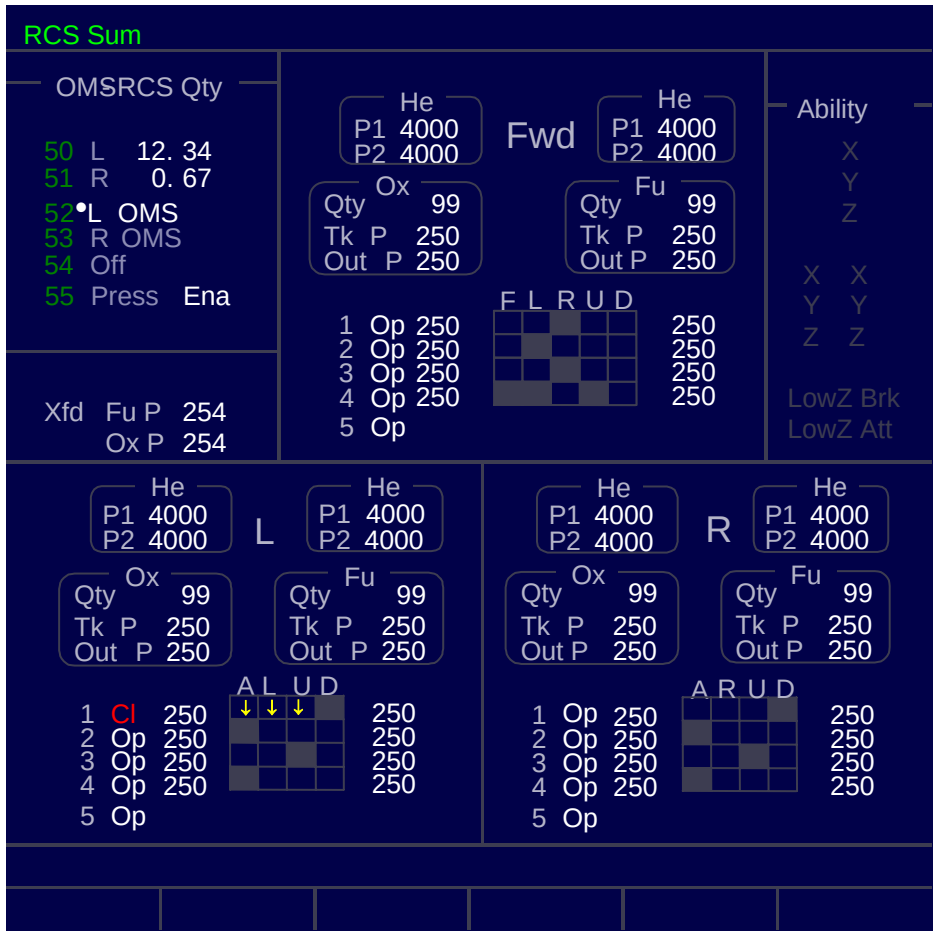
- Frank Lloyd Wright

Comparison of Reaction Control System (RCS) Display Formats

Current RCS Display



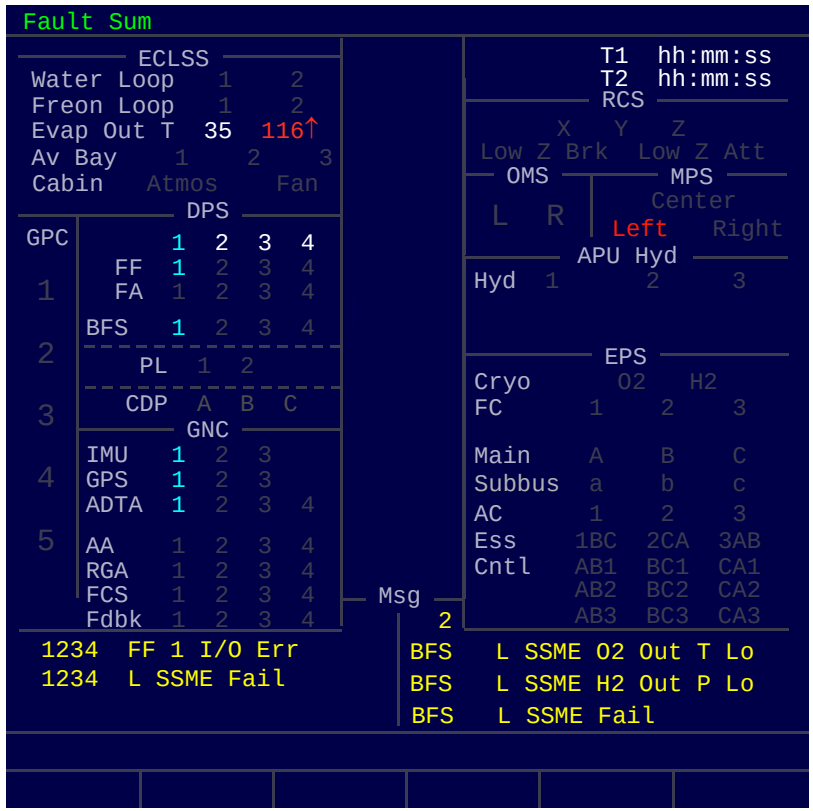
Proposed RCS Display



Comparison of Fault Summary Display Formats

Current Fault Sum Display

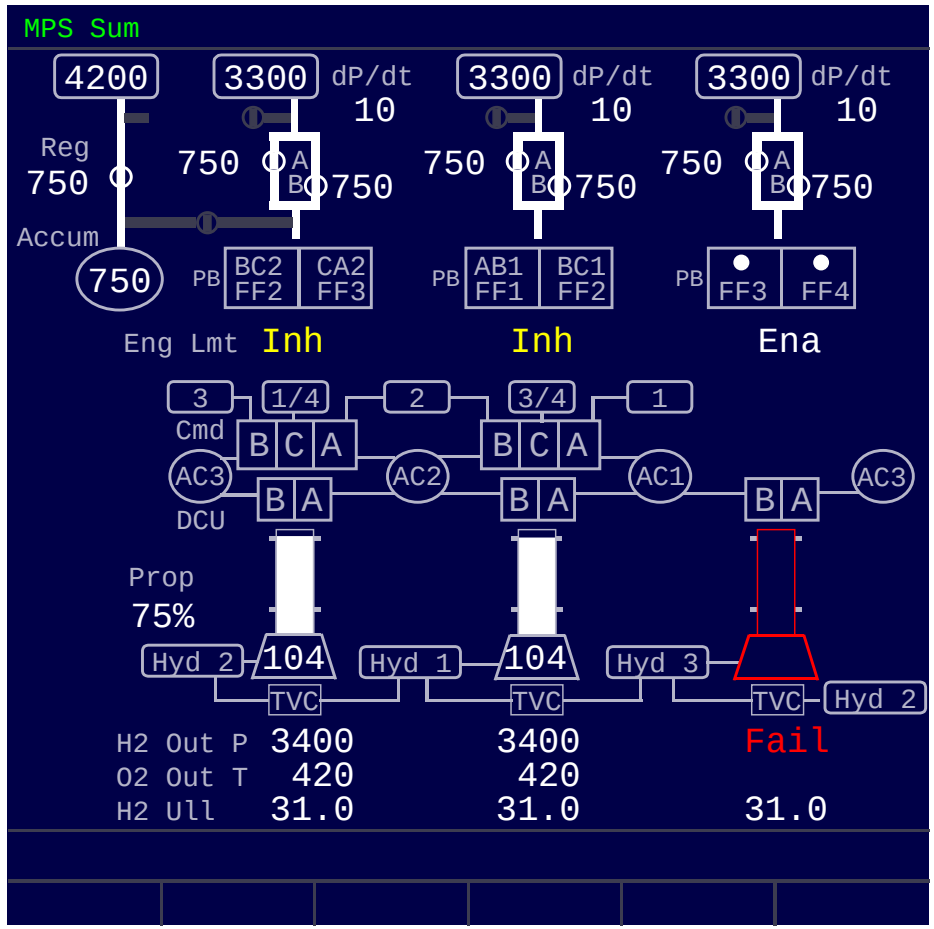
Proposed Fault Sum Display



Comparison of Main Propulsion System (MPS) Display Formats

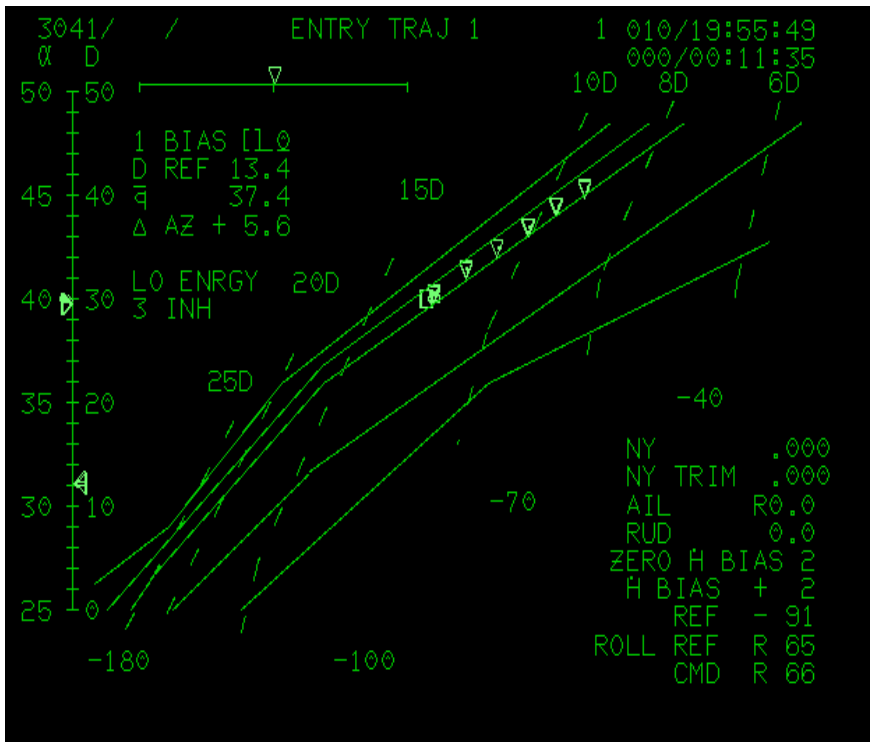
Current MPS Information

Proposed MPS Display

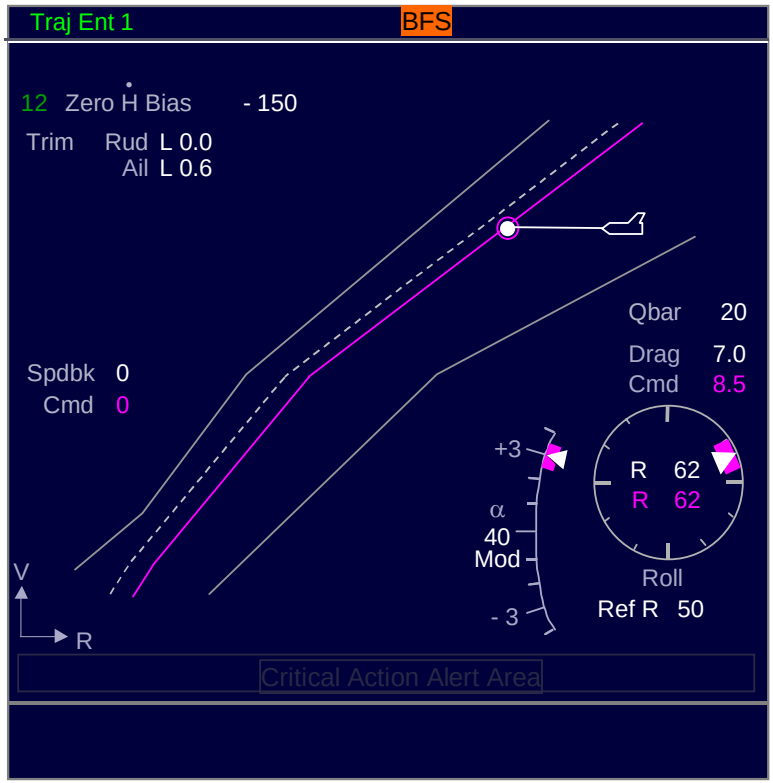


Comparison of Entry Trajectory Display Formats

Current Entry Traj Display



Proposed Entry Traj Display



Key Constraint

- Formal evaluation in the Shuttle Mission Simulator cannot occur until the design is nearly finalized.

Will the upgraded displays be implemented?

Arguments against:

- The funding is not available.
- Crews can be adequately trained on the original displays.
- The displays will only be flown a handful of times before the shuttle is retired.

Arguments in favor:

- The new displays are a safety upgrade.
- The new displays give us a foundation for cockpit development of the Crew Exploration Vehicle.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