APOLLO 13 WHERE'S WALDO GAME

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Also available at http://www-iwse.eng.ohio-state.edu/homepages/nasaproject/0.html
Warning: screens have black backgrounds, so printing this uses a lot of ink!

On the night of April 13, 1970, several NASA engineers were following the flight of Apollo 13 from a rooftop observatory. Against a backdrop of distant galaxies, they saw a tiny flare of light and a glowing cloud that resembled an exploding star.

You saw the movie, now you play the controller! Look at the actual Mission Control screens and see if you can find the oxygen tank explosion that crippled the Apollo 13 spacecraft. The challenge is to locate the data values in a screen filled with numbers, like finding Waldo* in the popular children's book.

1. Eight minutes before the explosion
2. Moment of the explosion
3. Four seconds after the explosion
4. Four minutes after the explosion
5. The answer

Now that you've done it the hard way, see how much easier it would be to see the explosion with a better display! This display is based on representation principles that can be found in CLARE, an online library at NASA Johnson Space Center for the reuse and exchange of software development ideas.

1. Depicting relationships in a frame of reference
2. Putting data into context
3. Highlighting events
4. But there's not enough space!

* Hanford, Martin. (1987) Where's Waldo. Boston. Little, Brown.

Eight minutes before the explosion

LM1839		CSM ECS-CRYO TAB					0613
CTE 055:46:51 ( )		GET 055:46:53 ( )					SITE GDS09
------------LIFE SUPPORT--------				--------PRIMARY COOLANT------			
GF3571	LM CABIN P	PSIA		CF0019	ACCUM QTY	PCT	34.4
CF0001	CABIN P	PSIA	5.1	CF0016	PUMP P	PSID	45.0
CF0012	SUIT P	PSIA	4.3	SF0260	RAD IN T	°F	73.8
CF0003	SUIT ΔP	IN H2O	-1.68				
CF0015	COMP ΔP	P PSID	0.30	CF0020	RAD OUT T	°F	35
CF0006	SURGE P	P PSIA	891	CF1081	EVAP IN T	°F	45.6
	SURGE QTY	LB	3.67	CF0017	STEAM T	°F	64.9
O2	TK 1 CAP ΔP	PSID	21	CF0034	STEAM P	PSIA	.161
O2	TK 2 CAP ΔP	PSID	17	CF0018	EVAP OUT T	°F	44.2
CF0036	O2 MAN P	PSIA	105	SF0266	RAD VLV 1/2		ONE
CF0035	O2 FLOW	LB/HR	0.181	CF0175	GLY FLO	LB/HR	215.0
CF0008	SUIT T	°F	50.5				
CF0002	CABIN T	°F	65	-----SECONDARY COOLANT----			
CF0005	CO2 PP	MMHG	1.5	CF0072	ACCUM QTY	PCT	36.8
---------------H2O-----------------				CF0070	PUMP P	PSID	9.3
CF0009	WASTE	PCT	24.4	SF0262	RAD IN T	°F	76.5
	WASTE	LB	13.7	SF0263	RAD OUT T	°F	44.6
CF0010	POTABLE	PCT	104.5	CF0073	STEAM P	PSIA	.2460
	POTABLE	LB	37.6	CF0071	EVAP OUT T	°F	66.1
CF0460	URINE NOZ T	°F	70	CF0120	H2O-RES	PSIA	25.8
CF0461	H2O NOZ T	°F	72	TOTAL	FC CUR	AMPS	67.58

-------------CRYO SUPPLY-----------------			O2-1	O2-2	H2-1	H2-2
SC0037-38-39-40	P	PSIA	913	908	225.7	235.1
SC0032-33-30-31	QTY	PCT	77.63	01.17	73.24	73.03
SC0041-42-43-44	T	°F	-189	-192	-417	-416
	QTY	LBS	251.1	260.0	20.61	20.83

Moment of the explosion

LM1839 CSM ECS-CRYO TAB 0613

CTE 055:54:52 (55.914) GET 055:54:54 (55.915) SITE GDS09

------------LIFE SUPPORT--------

GF3571	LM CABIN P	PSIA	
CF0001	CABIN P	PSIA	5.1
CF0012	SUIT P	PSIA	4.3
CF0003	SUIT ΔP	IN H2O	-1.72
CF0015	COMP ΔP	P PSID	0.30
CF0006	SURGE P	P PSIA	891
	SURGE QTY	LB	3.67
O2	TK 1 CAP ΔP	PSID	-12
O2	TK 2 CAP ΔP	PSID	105
CF0036	O2 MAN P	PSIA	103
CF0035	O2 FLOW	LB/HR	0.181
CF0008	SUIT T	°F	50.5
CF0002	CABIN T	°F	65
CF0005	CO2 PP	MMHG	1.5

---------------H2O-----------------

CF0009	WASTE	PCT	24.8
	WASTE	LB	13.9
CF0010	POTABLE	PCT	104.1
	POTABLE	LB	37.5
CF0460	URINE NOZ T	°F	72
CF0461	H2O NOZ T	°F	72

--------PRIMARY COOLANT-----

CF0019	ACCUM QTY	PCT	34.4
CF0016	PUMP P	PSID	46.0
SF0260	RAD IN T	°F	73.8
CF0020	RAD OUT T	°F	35
CF1081	EVAP IN T	°F	46.2
CF0017	STEAM T	°F	64.9
CF0034	STEAM P	PSIA	.161
CF0018	EVAP OUT T	°F	44.2
SF0266	RAD VLV 1/2		ONE
CF0175	GLY FLO	LB/HR	214.6

-----SECONDARY COOLANT----

CF0072	ACCUM QTY	PCT	37.5
CF0070	PUMP P	PSID	9.3
SF0262	RAD IN T	°F	76.5
SF0263	RAD OUT T	°F	46.2
CF0073	STEAM P	PSIA	.2460
CF0071	EVAP OUT T	°F	66.3
CF0120	H2O-RES	PSIA	25.8
TOTAL	FC CUR	AMPS	71.58

------------CRYO SUPPLY-----------------

			O2-1	O2-2	H2-1	H2-2
SC0037-38-39-40	P	PSIA	879	996	224.2	233.6
SC0032-33-30-31	QTY	PCT	76.83	47.04	73.24	74.03
SC0041-42-43-44	T	°F	-190	-329	-417	-416
	QTY	LBS	248.5	260.0	20.61	20.83

Four seconds after the explosion

LM1839 CSM ECS-CRYO TAB 0613

CTE 055:54:56 (55.915) GET 055:54:58 (55.916) SITE GDS09

------------LIFE SUPPORT--------

GF3571	LM CABIN P	PSIA	
CF0001	CABIN P	PSIA	5.1
CF0012	SUIT P	PSIA	4.1
CF0003	SUIT ΔP	IN H2O	-1.64
CF0015	COMP ΔP	P PSID	0.30
CF0006	SURGE P	P PSIA	891
	SURGE QTY	LB	3.67
O2	TK 1 CAP ΔP	PSID	-109
O2	TK 2 CAP ΔP	PSID	-872
CF0036	O2 MAN P	PSIA	105
CF0035	O2 FLOW	LB/HR	0.181
CF0008	SUIT T	°F	50.8
CF0002	CABIN T	°F	65
CF0005	CO2 PP	MMHG	1.5

----------------H2O------------------

CF0009	WASTE	PCT	24.8
	WASTE	LB	13.9
CF0010	POTABLE	PCT	104.1
	POTABLE	LB	37.5
CF0460	URINE NOZ T	°F	72
CF0461	H2O NOZ T	°F	72

--------PRIMARY COOLANT------

CF0019	ACCUM QTY	PCT	34.4
CF0016	PUMP P	PSID	46.7
SF0260	RAD IN T	°F	73.8
CF0020	RAD OUT T	°F	35
CF1081	EVAP IN T	°F	45.9
CF0017	STEAM T	°F	64.4
CF0034	STEAM P	PSIA	.161
CF0018	EVAP OUT T	°F	44.2
SF0266	RAD VLV 1/2		ONE
CF0175	GLY FLO	LB/HR	214.6

-----SECONDARY COOLANT----

CF0072	ACCUM QTY	PCT	36.8
CF0070	PUMP P	PSID	9.1
SF0262	RAD IN T	°F	76.5
SF0263	RAD OUT T	°F	46.2
CF0073	STEAM P	PSIA	.2460
CF0071	EVAP OUT T	°F	66.3
CF0120	H2O-RES	PSIA	25.8
TOTAL	FC CUR	AMPS	81.45

-------------CRYO SUPPLY-----------------

			O2-1	O2-2	H2-1	H2-2
SC0037-38-39-40	P	PSIA	782	19	224.2	233.6
SC0032-33-30-31	QTY	PCT	78.04	47.04	73.64	74.03
SC0041-42-43-44	T	°F	-190	84	-417	-416
	QTY	LBS	252.4	260.0	20.72	20.83

Four minutes after the explosion

LM1839 CSM ECS-CRYO TAB 0613

CTE 055:58:24 (55.930) GET 055:58:26 (55.974) SITE GDS09

------------LIFE SUPPORT--------				--------PRIMARY COOLANT------			
GF3571	LM CABIN P	PSIA		CF0019	ACCUM QTY	PCT	35.6
CF0001	CABIN P	PSIA	5.1	CF0016	PUMP P	PSID	46.9
CF0012	SUIT P	PSIA	4.1	SF0260	RAD IN T	°F	56.4
CF0003	SUIT ΔP	IN H2O	-1.60				
CF0015	COMP ΔP	P PSID	0.30	CF0020	RAD OUT T	°F	34
CF0006	SURGE P	P PSIA	891	CF1081	EVAP IN T	°F	44.6
	SURGE QTY	LB	3.67	CF0017	STEAM T	°F	64.4
O2	TK 1 CAP ΔP	PSID	-514	CF0034	STEAM P	PSIA	.162
O2	TK 2 CAP ΔP	PSID	-872	CF0018	EVAP OUT T	°F	44.0
CF0036	O2 MAN P	PSIA	105	SF0266	RAD VLV 1/2		ONE
CF0035	O2 FLOW	LB/HR	0.181	CF0175	GLY FLO	LB/HR	211.9
CF0008	SUIT T	°F	50.5				
CF0002	CABIN T	°F	65	-----SECONDARY COOLANT----			
CF0005	CO2 PP	MMHG	1.5	CF0072	ACCUM QTY	PCT	36.8
---------------H2O-----------------				CF0070	PUMP P	PSID	9.3
CF0009	WASTE	PCT	25.6	SF0262	RAD IN T	°F	76.8
	WASTE	LB	14.3	SF0263	RAD OUT T	°F	47.4
CF0010	POTABLE	PCT	104.1	CF0073	STEAM P	PSIA	.2460
	POTABLE	LB	37.5	CF0071	EVAP OUT T	°F	65.7
CF0460	URINE NOZ T	°F	73	CF0120	H2O-RES	PSIA	25.8
CF0461	H2O NOZ T	°F	76	TOTAL	FC CUR	AMPS	61.29

-------------CRYO SUPPLY------------------			O2-1	O2-2	H2-1	H2-2
SC0037-38-39-40	P	PSIA	377	19	228.7	236.6
SC0032-33-30-31	QTY	PCT	74.81	-103	74.05	-1.24
SC0041-42-43-44	T	°F	-195	-329	-417	-427
	QTY	LBS	241.9	260.0	20.84	-0.35

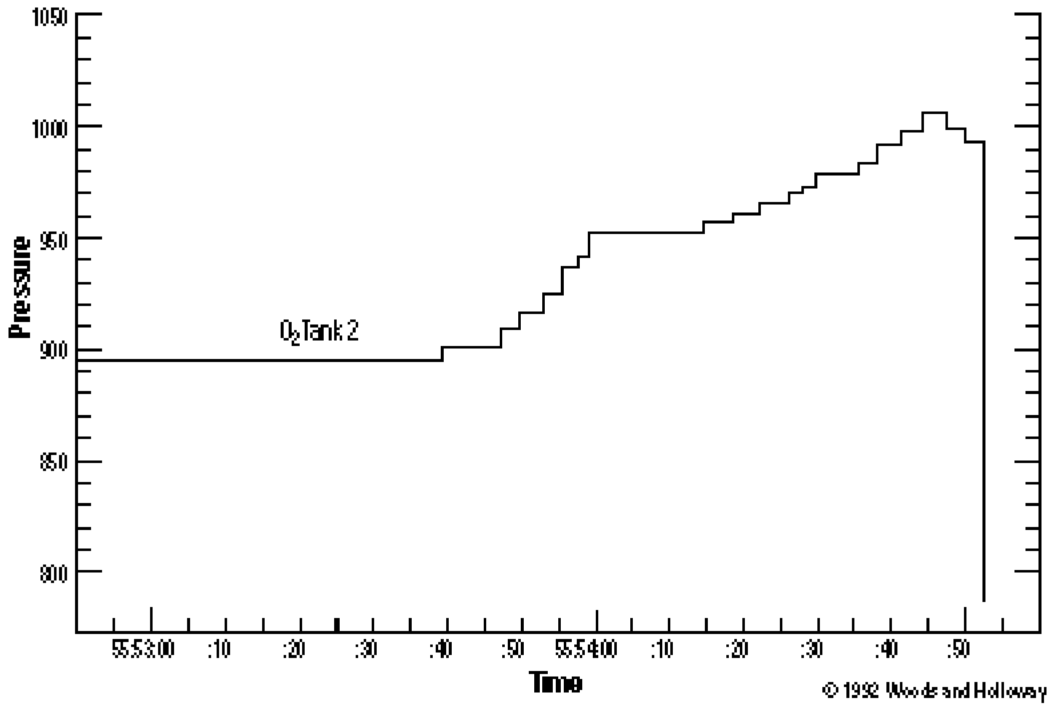
What's wrong with this display?

The pressure value for oxygen tank number two is located on the fourth line from the bottom, third column from the right. It reads 906 psi (pounds per square inch) in the first screen, rising to 996 psi eight minutes later at the moment of the explosion. Four seconds later it has dropped to 19 psi, where it remains four minutes later.

It is easy to see that this display would be difficult to monitor. Why is this? For one thing, it lacks data history. It is not possible to easily check whether values are different from several seconds before. In addition, the values require intensive training to understand - you need to know the normal pressure range during this part of the flight, and the maximum pressure the tank can withstand before bursting. A better visualization of this information could be designed by keeping the following three principles in mind:

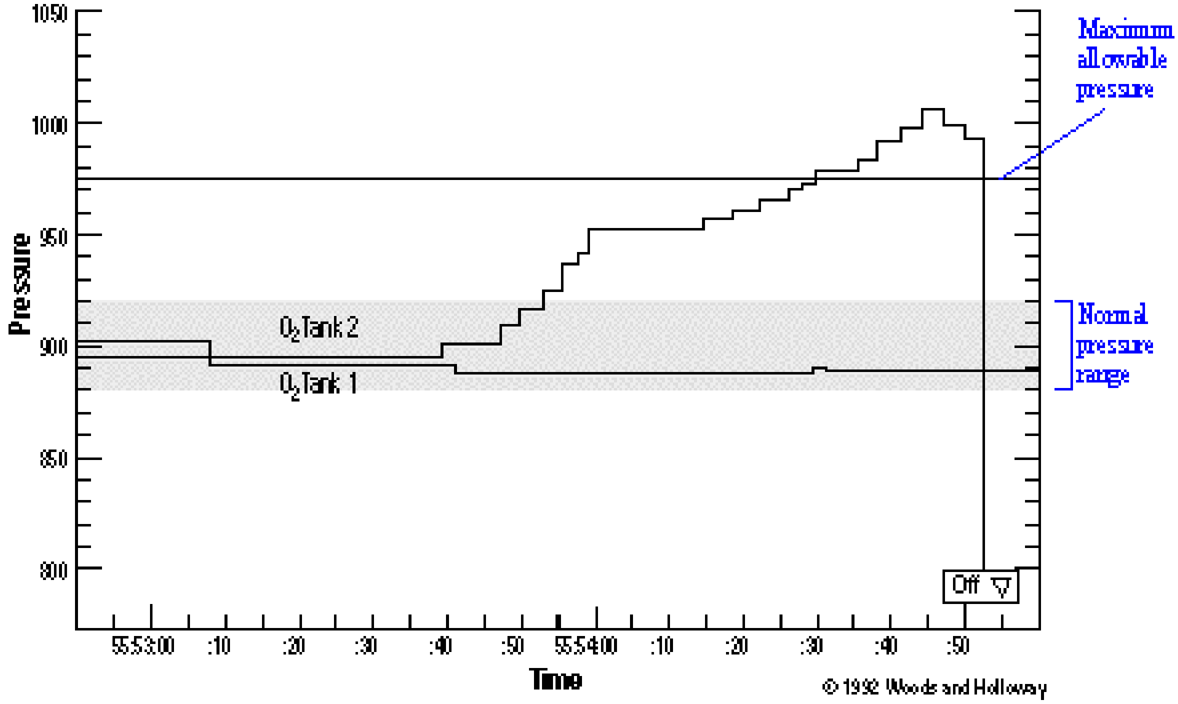
· Depict relationships in a frame of reference
· Put data into context
· Highlight events

Depicting relationships in a frame of reference



The original data screen groups data under the responsibility of the mission controller, organized around an Apollo subsystem. The raw data is displayed in a labeled column format independently of an organizing frame of reference. In order to go beyond displaying raw data values, the information should be visualized against a frame of reference or several coordinated frames of reference. The selected frame of reference should be one that best highlights events and contrasts. Notice how this representation tells the story of the explosion much more clearly - it contains the same data, but plots it over time.

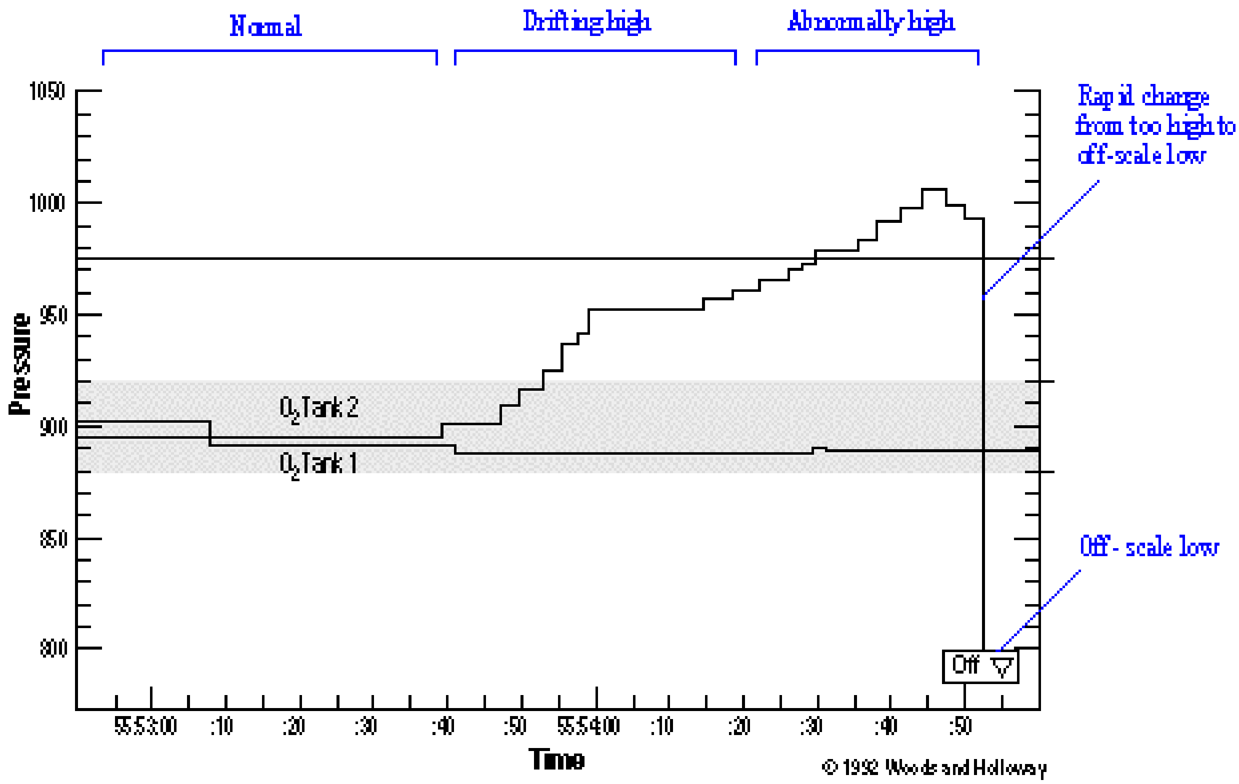
Putting data into context



In the original display, expectations of how the data should behave are contained entirely in the head of the controller. The data only becomes informative when it is known that:

- Both oxygen tanks should be reading approximately the same value
- The pressure in this part of the flight should be approximately between 880 and 920 psi
- A value of 19 psi is offscale low, meaning that the tank is holding no oxygen

Highlighting events



The critical event in the Apollo 13 incident was the rapid depressurization of the oxygen tank. This representation graphically highlights the changes between the different "states" of the system, such as normal, drifting high, and abnormally high. The event of rapidly changing from abnormally high to off-scale low is very salient.

But there's not enough space!

One drawback of this representation is its demand on screen real estate. It is important to understand the tradeoffs involved in choosing to annotate data values vs. placing every value in context. At one extreme, annotating raw data values requires the user to keep the data history and expectations in the head. At the other extreme, displaying every value in a graphical format over time requires the user to navigate between many displays. Balancing these tradeoffs is a difficult design challenge. For a more detailed discussion on the annotation vs. navigation issue, see the CLARE library at the NASA Johnson Space Center (see http://tommy.jsc.nasa.gov/~clare/issues/index.html).