IUE Spacecraft Operations: Critical Issues and Important Lessons for the Future

Jeffrey L. Linsky
JILA/University of Colorado and NIST

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ESO Garching
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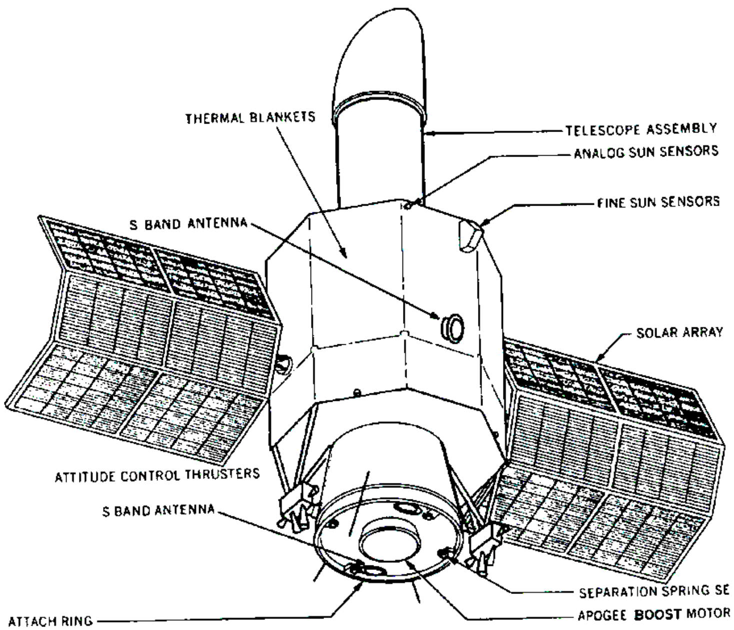
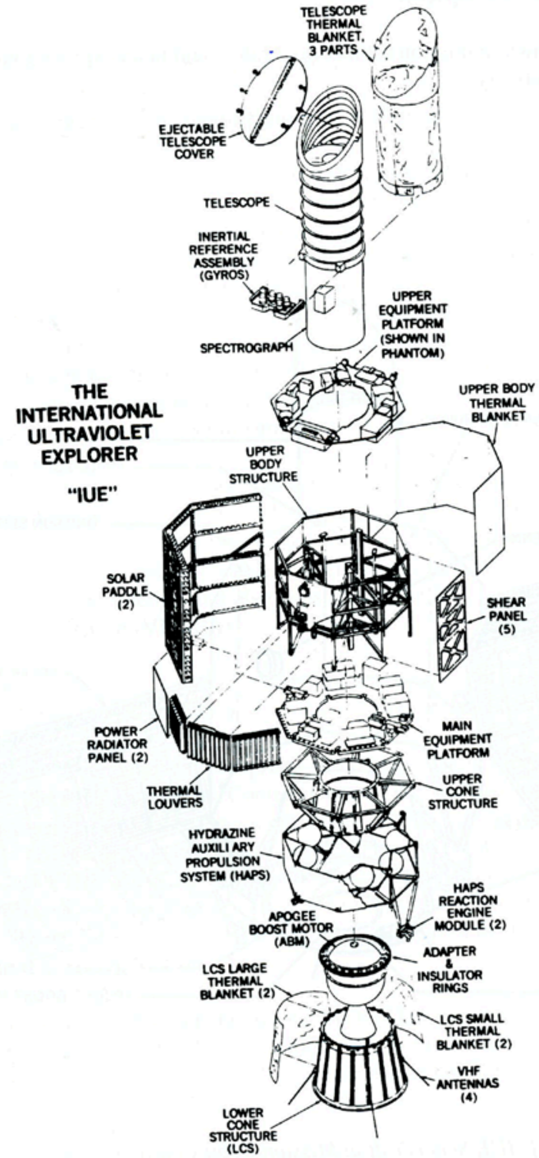
Those who do not remember the past are condemned to repeat it.

George Santayana

IUE spacecraft (external and exploded views)





IUE Spacecraft Parameters and Timeline

Characteristics	Description
Spacecraft Weight	312 kg
Scientific Instrument Weight	122 kg
Apogee Motor Weight	237 kg
Launch Vehicle Adapter Weight	29 kg
Total Launch Weight	700 kg
Launch Vehicle	Delta 2914
Life	3 - 5 years
Orbit (Mission)	Elliptical Geosynchronous (28.6° inclination)
Power Required (Spacecraft & Experimentation)	210 watts average
Array Capability (Beginning of Life)	424 watts at beta equal to 67.5° 238 watts at beta equal to 0° and 135°
Batteries (2)	6 ampere-hour NiCad (17 cells each)
Telemetry Bit Rate	1.25 kbit/sec to 40 kbit/sec with fixed and reprogrammable formats
Command	PCM/FSK/AM, 800 bits/sec
Stabilization and Control	Spinning during transfer orbit, 3 axis stabilized with better than 1 arc-second control for mission orbit.

Launch: January 26, 1978

End of mission: September 30, 1996

Mission duration: 18 years, 8 months, 4 days

Pluses and minuses for selecting a 24 hour orbit

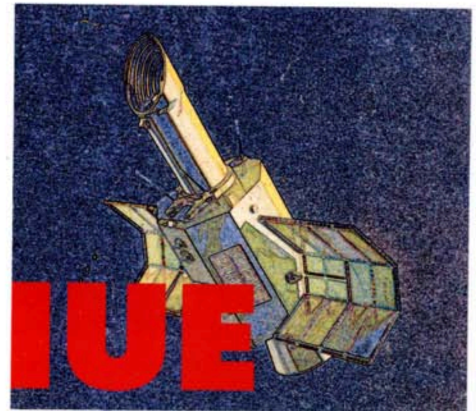
- Long continuous observing programs possible
- Minimal Earth occultation means simpler scheduling
- Minimal Doppler corrections
- Can observe most of the sky at any time
- More benign thermal environment

- Less weight means smaller telescope and fewer instruments.
- Harsh radiation environment in HEO
- Telemetry constraints

esa

SP-1215

September 1997



Spacecraft Operations

Final Report

European Space Agency
Agence spatiale européenne

NASA PPARC

Some critical issues of spacecraft operations that kept IUE alive and scientifically productive for 18 years

- Orbit
- Electrical power (solar arrays, batteries, eclipses)
- Operate with less than 3 gyros
- Work around component failures
- Work around computer failures (patching)
- Work around detector problems and radiation damage
- Work around fine guidance problems

Spacecraft orbit and ground trace

Figure 4-11. Ground trace at 01/30/1978.

Figure 4-12. Ground trace at 01/01/1980.

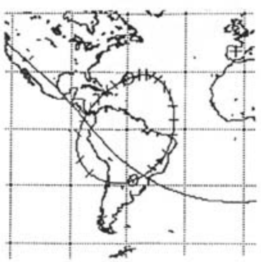


Figure 4-13. Ground trace at 01/01/1982.

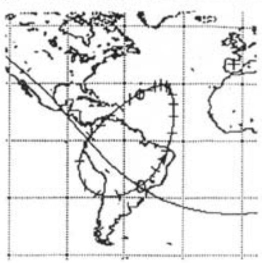


Figure 4-14. Ground trace at 01/01/1984.

Figure 4-15. Ground trace at 01/01/1986.

Figure 4-16. Ground trace at 01/01/1988.

	Predicted	Actual
Semi-Major axis (a):	42164 km	42156 km
Eccentricity (e):	0.250	0.239
Inclination (I):	28.7 degr.	28.63 deg
Argument of perigee (ω):	257 degr.	257.04 degr.
Period (P):	23.93 hrs	23.927 hrs
Perigee height (Pe):	25230 km	25669 km
Apogee height (Ap):	46340 km	45887 km

Need fuel to correct the orbit so that IUE is within sight of ground stations. Hydrazine fuel amount was much more than needed for a 5 year mission.

Delta-V orbital corrections to compensate for the westward drift of IUE induced by the ellipticity of the Earth.

Electrical power issues

- Solar arrays degraded 2.8%/yr, but 9.7%/yr at solar max. (radiation damage).
- Power positive criterion decreased viewing angles with time.
- During eclipses must turn off gyros and heaters. Gyro 5 never restarted.
- Batteries degraded with time.

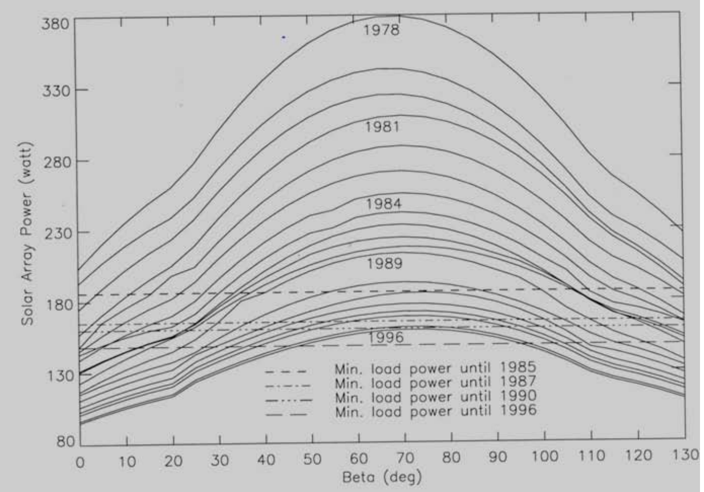
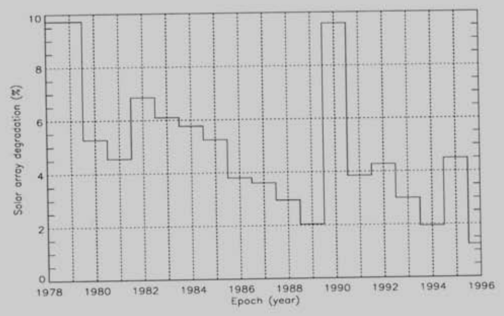


Figure 5-3. History of average solar array output.

The annual degradation computed at beta 67° is shown in the figure 5-4. The degradation h
lways been under the pre-launch expected value of 10% per year.



Beta angle (from anti-Sun direction) restrictions with time

Year	Beta Range	S/C load (watt)
1978-1984	24° - 120°	186
1985	25° - 115°	186
1986	25° - 121°	165
1987	25° - 120°	165
1988	24° - 120°	160
1989	28° - 112°	160
1990	30° - 112°	160
1991	31° - 113°	148
1992	31° - 112°	148
1993	30° - 109°	148
1994	35° - 103°	148
1995	41° - 102°	148
1996	41° - 102°	148

Operate with less than 3 gyros

- Initially 6 gyros: #6 did not start after shadow turn-off (1979), #1 failed (1981), #2 failed (1982), #3 failed (1985), #5 failed because of conflicting commands (1996).
- 2-gyro + FSS tested (3/1983) and implemented (8/1985).
- 1-gyro + FSS tested (10/1990) and implemented (3/1996).
- 4 reaction wheels but only 3 ever used.
- Fine Error Sensor anomalies after radiation belt passages.

Work around component failures

- Panoramic Attitude Sensor (PAS) failed on day 3. Redundant PAS work for 18 years.
- In first 9 months 6 instrument subsystem failures including the SWR camera.
- Command Decoder #1 failed in 1980, but #2 worked for rest of mission.
- Command Relay Unit (CRU) anomalies and often both on producing confusion.
- Radiation damage to COS/MOS chips produced data corruption.

Work around computer malfunctions

- A partial list of OBC crashes due to high temperatures and other unknown causes.
- Each crash required manual intervention, and lost observing time.
- Uploaded 18 patches to the OBC code.
- This was an old computer with large chips (more radiation hard than modern tiny chips)

OBC crashes	Date	Remarks
	March 11, 1978	It appeared to be related to the high OBC temperature.
	November 15, 1978	The OBC halted during a test whilst running on 40 kbps. Operations were limited to 20 kbps.
	December 3, 1978	It seemed to be related to the high OBC temperature.
	February 1, 1979	It seemed to be related to the high OBC temperature.
	July 18, 1979	The OBC crashed during a maneuver due to a data block 10 incorrect scaling.
	August 18, 1979	The OBC crashed and s/c began to drift in pitch and roll direction. The stabilization was achieved when it was commanded into sun acquisition mode.
	October 9, 1979	The OBC crashed at 20:52 UT, but the spacecraft was stabilized in 3-axis again with the 4K back-up computer at 20:57 UT.
	October 23, 1979	It was thought to be caused by a high OBC temperature.
	May 7, 1980	The OBC halted at 04:09 UT which caused the spacecraft lost attitude.
	January 21, 1981	The spacecraft attitude was lost when the OBC halted at 04:25 UT.
	February 1, 1981	The OBC halted due to an interrupt 14 anomaly.
	March 1, 1981	The OBC halted due to an interrupt 14 anomaly.
	May 2, 1981	The OBC halted due to an interrupt 14 anomaly.
	May 11, 1981	The OBC halted due to an interrupt 14 anomaly.
	June 20, 1981	The OBC halted due to an interrupt 14 anomaly.
	February 20, 1982	The OBC halted due to an interrupt 14 anomaly.
	February 21, 1982	The OBC halted due to an interrupt 14 anomaly.
	November 25, 1982	At 15:20 UT the OBC crashed during a maneuver. The spacecraft was stabilized using the 4K back-up system.

Work around detector problems and radiation damage

- 4 SEC cameras (SWP, SWR, LWP, LWR)
- SWR had an electrical failure during inflight checkout (2/1978).
- Microphonics noise in the other 3 cameras induced by roll wheel spin changes during manoevers.
- SWP enhaced noise (pings) when camaera head too hot.
- Radiation damage to COS/MOS chips.
- Occasional data corruption from Data Multiplexer Units.

Work around fine guidance problems

- Fine Error Sensors (FES) were star trackers to position the star in the aperture.
- FES#2 occasionally gave false count rates after passage through the radiation belts.
- FES#2 developed scattered light anomaly after 1/1991 with uncertain cause.
- FES streak anomaly at certain roll angles after 9/1992).

Important lessons for the future

- Perverse acronymology
- Redundant components may not provide redundancy.
- The environment in space is very harsh (radiation, thermal, optical contamination, etc.)
- Preplan responses to failures
- Own the command and operations software
- Designers must closely supervise the builders (hardware and software)
- Thorough systems engineering is essential
- Guest observers often find and correct the flaws
- We live in an age of hacking

A very partial list of acronyms

A/D	analog to digital
ABG	gyro measured body angle
ABM	apogee boost motor
ac	alternating current
ACS	attitude control subsystem
AM	amplitude modulation
ANC	automatic nutation control
AS	analog sub-commutator
BLT	Greenbelt tracking station
BOL	beginning of life
CCIL	Control center Interactive Language
CEA	control electronics assembly
CEB	control electronics box
CEM	camera electronics module
CHM	camera head module
CPM	central processing module
CPU	central processing unit
CRU	command relay unit
CSIM	camera supply interface module
CSIU	camera system interface unit
CSS	coarse sun sensor
DAC	digital to analog converter
dc	direct current
DDPS	Digital Data Processing System
DEC	Digital Electronics Corporation
DET	Direct Energy Transfer
DKLP	camera deck near longwave prime temperature
DKSP	camera deck near shortwave prime temperature
DMA	direct memory access
DMU	data multiplexer unit
DS	digital sub-commutator
DWG	digital word gate
ECU	electronics control unit
EDS	experiment display system
EEA	experiment electronics assembly
EOL	end of life
ESA	European Space Agency
ESTEC	European Space and Technology Centre
EV	engine valve
EVCL	engine valve command logic
FES	fine error sensor
FM	frequency modulation
FOD	Flight Operations Directive
FOV	field of view
FPM	flux particle monitor