ROYAL AIRCRAFT ESTABLISHMENT

Technical Report 71172

August 1971

ORBITAL OPERATIONS HANDBOOK FOR THE X3 SATELLITE

by

V. W. Adams

CORRIGENDUM

Page No.	
	4.2 Orbital Elements
8	The nominal orbital elements have been changed and are now as follows:-

Apogee 1540 km	Inclination 82.2°
Perigee 550 km	Eccentricity 0.0665
Period 106 ±1 min	Longitude of ascending mode 140°
	Rate of change of ascending mode -805° per day
	Argument of perigee 337°
	Mean anomaly 8.027°
	Mean motion 4892° per day

The nominal injection cordinates are now as follows:-

Latitude -13.73°
Longitude 137.95°
Launch time 0400Z

11	Table 1
	The Baudot code for command number 32 should read 'OFIG' and not 'OAG'
35	Last line - 'section 5.3' should read 'section 5.2'
45	Add - 'IRDT Motor Pressure' to list of Rocket third stage data.
Fig.4	Delete 'DAO2' under syllables 19, 35, and 51 of Rocket 3rd stage mode direct format and insert 'IRDT'.

UDC 629.19.085 : 629.195

ROYAL AIRCRAFT ESTABLISHMENT

Technical Report 71172

August 1971

ORBITAL OPERATIONS HANDBOOK FOR THE X3 SATELLITE

by

V. W. Adams

SUMMARY

The purpose of this Handbook is to provide general information to those concerned with X3 orbital operations. For detailed information on the ground stations and the RAE Control Centre (DATA CENTRAL) the reader is referred to the relevant ESRO and RAE support documents.

Departmental Reference: Space 378

CONTENTS

CONTENTS (Contd)

CONTENTS (Contd)

1 INTRODUCTION

The X3 satellite, the first technological spacecraft in the British National Space Programme, is scheduled to be launched on a Black Arrow vehicle in late 1971.

The spacecraft carries experiments to investigate performance of solar cells, characteristics of thermal surfaces, micrometeoroid flux and performance in orbit of a hybrid electronics package: section 4.4 gives details.

In addition newly developed data, telemetry, telecommand and power system will be tested in orbit. The micrometeoroid flux experiment has been contributed by the University of Birmingham, England.

2 RESPONSIBILITIES

2.1 Project management

The Procurement Executive, Ministry of Defence is responsible for project management of the spacecraft and launch vehicle systems. Arrangements for a Black Arrow launch at Woomera are made with the cooperation of the Weapons Research Establishment (WRE).

2.2 Spacecraft

The MOD(PE) is responsible for the design of the spacecraft and its support systems, integration, pre-launch testing and spacecraft-launcher integration.

The contractor responsible for the spacecraft mechanical construction and handling is the British Aircraft Corporation (BAC). Marconi Space and Defence Systems are responsible for the spacecraft electrical and communications systems, assembly, integration and test. They also supply the Operations Team for the spacecraft.

2.3 Tracking, data acquisition and spacecraft control

The MOD will provide orbital elements for the spacecraft's lifetime and ESRO will provide contingency tracking facilities.

The Satellite Control Centre and Telecommand Station at the Royal Aircraft Establishment, Farnborough, (DATA CENTRAL), the MOD(PE) VHF telemetry station at Lasham, RAE, and the European Space Tracking and Telemetry Network (ESTRACK) will provide primary data acquisition support for the lifetime of the spacecraft.

2.4 Orbital calculations

The RAE Satellite Control Centre and the ESRO Control Centre have responsibility for computing the orbit of the X3 spacecraft and for generating predictions to participating stations.

2.5 Data processing and reduction

The processing and reduction of the X3 telemetered data are the responsibility of the RAE (Space Dept.), (MOD(PE)).

2.6 Data analysis

The individual experimenters and sub-system designers involved in the X3 project will be responsible for the final analysis and interpretation of data.

3 ORGANISATION PROCUREMENT EXECUTIVE, MINISTRY OF DEFENCE

The following sections summarise the major responsibilities of MOD(PE) personnel assigned to support the X3 project.

3.1 Project Manager

Mr. R. Mawson of Space 3(b), MOD(PE) is the Project Manager and represents the Ministry in all activities pertaining to the Black Arrow X3 project.

3.2 Project Officer

Mr. B.W. Jacobs of Space Department, RAE, is the Head of the X3 Project Office.

3.3 Head of Spacecraft Operations

Mr. D.D. Hardy of Space Department, RAE is responsible for coordinating the activities of the various organisations involved with the project operations. He is also the network controller Woomera (NCW) during the launch period.

3.4 Satellite Controller

Mr. V.W. Adams of Space Department, RAE is responsible for specifying all spacecraft control requirements and all Telemetry and Telecommand support needed to fulfil the project.

3.5 Control Centre Operations

Mr. E.A.R. Anstey of Space Department, RAE is responsible for the operations at DATA CENTRAL. Mr. E. Jones of Space Department is responsible for the routine running and organisation of DATA CENTRAL.

3.6 Telemetry Station at RAE Lasham

Mr. M.J. Hammond of Space Department, RAE is responsible for the operation of the Telemetry Data Acquisition Station at Lasham.

3.7 Orbit Operations Team

The Control Centre at DATA CENTRAL and the telemetry station at Lasham will be manned by personnel from Space Department, RAE and Spembly Electronics Ltd.

4 IMPLEMENTATION

4.1 Launch vehicle

The X3 satellite will be launched by a three-stage Black Arrow vehicle, shown in Fig.1. Westland Aircraft is the main vehicle contractor and Rolls Royce supply the first and second stage motors. The third stage solid apogee motor designated 'Waxwing' has been developed by The Rocket Propulsion Establishment, Westcott, using a tube and nozzle manufactured by Bristol Aerojet.

4.2 Orbital elements

The X3 satellite will be launched from the WRE range at Woomera, Australia (longitude 136.5° E) into an eccentric near-polar orbit. A plot of the sub-satellite ground trace is shown in Fig.2. The nominal orbit parameters are as follows:-

Apogee	1850 km	Inclination 82.1°
Perigee	550 km	Eccentricity 0.085509
Period	109 ±1 min	Longitude of ascending node 140°
		Rate of change of ascending node 0.761° per day
		Argument of perigee 337°
		Mean anomaly 7.5207°
		Mean motion 5450° per day.

The nominal injection coordinates are as follows:-

Latitude	13.66°
Longitude	138.02°
Launch time	0430Z

4.3 Spacecraft

X3 is a spin-stabilised spacecraft with an external shape similar to a pumpkin. Its equatorial diameter is approximately 1.2 metre and its height approximately 0.7 metre. The spacecraft weighs about 70 kg and will be spin-stabilised at about 180 rev/min.

The general configuration is shown in Fig.3. For a full description see the Operations Manual for Black Arrow X3 Satellite, volume I, published by MSDS Ltd.

4.3.1 Configuration and structure

The spacecraft structure is built round a central box assembly comprising four panels, internal and external corner angles, and top and bottom corner fittings, all of which are bonded and bolted together. The bottom fittings form the separation plane of the craft, and provide attachment to the third stage electronics bay. The main four panels of the central box are used as mounting platforms for telemetry, command, storage battery, power control and experiment equipment. Eight large segments, designated modules, and eight small segments,designated fillets, comprise the outer structure of the satellite and are attached to the outer edges of the top and bottom fittings.

The modules which are hinged at their upper ends to provide access to the spacecraft interior carry the power generating solar cells, the experimental solar cells and associated aspect sensors. The fillets carry the thermal control surface units with experimental surface finishes. Two of the fillets have nutation dampers fitted to their inside surfaces.

Four telemetry aerials are mounted 90^{o} apart on the base of the spacecraft.

4.3.2 Power supply system

An array of silicon solar cells is the main power source for X3. Power during solar eclipses is provided by a storage battery consisting of twelve nickel-cadmium cells, each with a 6 ampere-hour capacity. Auxilliary equipment includes battery charging circuitry, a dc to dc converter, voltage regulators and a power distribution system.

The solar array comprises 3360 silicon solar cells mounted on the eight satellite modules in patches of 42 cells each. Four alternate modules carry four patches on each of their three facets whereas the remaining four modules carry four patches on their upper and lower facets only.

4.3.3 Telemetry system

The X3 satellite employs a PCM/PM split phase code telemetry system, with data time-multiplexed into an 8 bits per syllable, 64 syllables per minor frame, 64 minor frames per major frame format. The telemetery format is shown in Figs.4-6.

Real time data is transmitted at a rate of 2048 bits/second after being encoded by a high speed encoder. A low speed encoder with 1/32 sampling rate of the high speed encoder enables real time data to be recorded on a magnetic tape recorder which will record approximately 120 minutes of data. Sixteen seconds after receipt of a command signal, the tape recorder changes from the record mode to the playback mode which lasts approximately four minutes at 32 times the speed of the record mode. The recorded data is erased after the tape passes the playback head, and the recorder automatically reverts to the record mode at the completion of playback if record mode has not been commanded.

(a) Telemetry transmitter

The PCM output from either the high speed encoder or the tape recorder phase modulates a crystal controlled transmitter operating at a frequency of 137.56 MHz. Two transmitters are provided, and either one may be selected on a command signal from the ground. The RF power output from either transmitter is 300 mW. The RF signal bandwidth is about 8 kHz and 25% residual power is left in the carrier for tracking purposes.

4.3.4 Antenna system

The spacecraft antenna is omnidirectional, circularly polarised with a minimum gain of -5 dB. The antenna system is used for both telemetry transmitters and command receivers; a hybrid and filters provide the necessary isolation. The on-board transmission loss is -2 dB.

4.3.5 Command system

The X3 spacecraft utilises a PDM/AM/AM tone digital command system to NASA standards with a capacity of 40 commands. Table 1 gives a command list. The command carrier (148.25 MHz) is 75% modulated by a pulse modulated audio tone (7.0 kHz). The audio tone is pulse duration modulated by the coded digital command.

Two command receivers are simultaneously in use and the receiver with the larger input signal overrides the other. The output from the command receivers is coupled to two command decoders each with a separate address code. The decoder outputs are combined so that whichever one is addressed, the command is executed.

4.3.6 Stabilisation and attitude measurement

The X3 spacecraft is spin stabilised, and in support of the solar cell and thermal control surfaces experiments, sun and earth sensors are used to determine the spin axis orientation.

Table 1

Telecommands

	Address word (octal)	Baudot	Decimal	Command
	140	PT	06.00	Decoder A
	237	B LET	09.15	Decoder B
Command number	Execute word (octal)			Command
1	360	LETT	15.00	Hybrid electronics experiment OFF
2	314	MM	12.12	Hybrid electronics experiment ON
3	303	MW	12.03	Thermal control surfaces experiment OFF
4	017	T LET	00.15	Thermal control surfaces experiment ON
5	063	WW	03.03	Transmitter OFF
6	074	WM	03.12	Transmitter ON
7	252	GG	10.10	Transmitter A
8	251	GB	10.09	Transmitter B
9	246	GP	10.06	Not allocated
10	245	GY	10.05	Not allocated
11	232	BC	09.10	Birmingham EHT ON/OFF
12	231	BB	09.09	Birmingham test pulse
13	226	BP	05.06	Command 'normal mode'
14	125	YY	05.05	Command 'surfaces mode'
15	126	YP	05.06	Command 'rocket third stage mode'
16	131	YB	05.09	See below between commands 36 and 37
17	132	YG	05.10	Command tape recorder to record
18	145	PY	06.05	Command tape recorder to playback
19	146	PP	06.06	Clock A
20	151	PB	06.09	Clock B
21	116	HV	04.14	HS divider A
22	123	YW	05.03	HS divider B
23	134	YM	05.12	LS divider A
24	143	PW	06.03	LS divider B
25	152	PG	06.10	HS (parallel to serial converter OR gate and Bi-phase-C converter) A
26	154	PM	06.12	HS (parallel to serial converter OR gate and Bi-phase-C converter) B
27	161	QZ	07.01	LS (parallel to serial converter OR gate and Bi-phase-C converter) A
28	162	QL	07.02	LS (parallel to serial converter OR gate and Bi-phase-C converter) B
29	164	QH	07.04	A-D converter, A on HS and B on LS
30	170	QO	07.08	A-D converter, A on LS and B on HS
31	207	OQ	08.07	HS parallel digital multiplexer A output gates
32	213	OAG	08.11	HS parallel digital multiplexer B output gates
33	215	OX	08.13	LS parallel digital multiplexer A output gates
34	216	OV	08.14	LS parallel digital multiplexer B output gates
35	223	BW	09.03	Data switching gates A on
36	225	BY	09.05	Data switching gates B on
16	131	YB	05.09	A-D converter A switching gates on
37	234	BM	09.12	A-D converter B switching gates on
38	243		10.03	Not allocated
39	254		10.12	Not allocated
40	261		11.01	Not allocated

(a) Spin rate

The third stage of the Black Arrow launcher spins up the spacecraft to 20 rad/s and this spin rate decays throughout the lifetime of the satellite.

(b) Nutation control

A nutation damping system is used to reduce the effects of spacecraft oscillation about the spin axis. This system consists of two tubes, one on the inside of each of two opposite fillets, filled with fluid. The motion of a ball inside each tube produces frictional forces tending to cancel the nutation effects.

(c) Attitude measurement

Two attitude sensor units are mounted on the equatorial facets of two diametrically opposite spacecraft modules, to provide redundancy. Each attitude sensor is a combination of two sun sensors and one earth horizon sensor. When stimulated, the pulses from the sensors start and stop counters driven from one of the satellite clocks, and the position of the spin axis can be determined to better than 1^{o}.

4.3.7 Heat balance and temperature control

A thermal design for the X3 satellite was developed in order to meet the temperature limits for the on board equipment. The internal ambient temperature is controlled by the use of bare metal surfaces, black painted surfaces and insulating blankets on the outside, and white paint on the inside, of the spacecraft.

Twelve thermistors are located on the spacecraft structure and thirteen are located on various units, for monitoring temperatures.

4.4 Experiments

The purpose of the experimental equipment on board the X3 spacecraft is to investigate and monitor the following:-

(a) The performance of thermal control surfaces.

(b) The performance of thin silicon solar cells and solar cell covers in space.

(c) The performance of lightweight satellite electronic systems in space, designated the hybrid electronics experiment.