

ROYAL AIRCRAFT ESTABLISHMENT

Technical Report 71172

August 1971

ORBITAL OPERATIONS HANDBOOK FOR THE X3 SATELLITE

by

V. W. Adams

CORRIGENDUM

<u>Page No.</u>	<u>4.2 Orbital Elements</u>																	
8	<p>The nominal orbital elements have been changed and are now as follows:-</p> <table> <tbody> <tr> <td>Apogee 1540 km</td> <td>Inclination 82.2°</td> </tr> <tr> <td>Perigee 550 km</td> <td>Eccentricity 0.0665</td> </tr> <tr> <td>Period 106 \pm1 min</td> <td>Longitude of ascending node 140°</td> </tr> <tr> <td></td> <td>Rate of change of ascending node -805° per day</td> </tr> <tr> <td></td> <td>Argument of perigee 337°</td> </tr> <tr> <td></td> <td>Mean anomaly 8.027°</td> </tr> <tr> <td></td> <td>Mean motion 4892° per day</td> </tr> </tbody> </table> <p>The nominal injection coordinates are now as follows:-</p> <table> <tbody> <tr> <td>Latitude -13.73°</td> </tr> <tr> <td>Longitude 137.95°</td> </tr> <tr> <td>Launch time 0400Z</td> </tr> </tbody> </table>	Apogee 1540 km	Inclination 82.2°	Perigee 550 km	Eccentricity 0.0665	Period 106 \pm 1 min	Longitude of ascending node 140°		Rate of change of ascending node -805° per day		Argument of perigee 337°		Mean anomaly 8.027°		Mean motion 4892° per day	Latitude -13.73°	Longitude 137.95°	Launch time 0400Z
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11	<p><u>Table 1</u></p> <p>The Baudot code for command number 32 should read 'OFIG' and not 'OAG'</p>																	
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 'DA02' under syllables 19, 35, and 51 of Rocket 3rd stage mode direct format and insert 'IRDT'.																	

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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

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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 aeriels are mounted 90° 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 telemetry 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

Command number	Address word (octal)	Baudot	Decimal	Command
		140 237	PT B LET	06.00 09.15
	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	OZ	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
36	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° .

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.

(d) The flux of micrometeoroids down to 0.1 micron or 10^{-14} g in size.

The experiments are detailed in the following sections.

4.4.1 Thermal control surfaces experiment

The purpose of this experiment is to measure the change due to the space environment, in the solar absorption and infra-red emittance of the experimental thermal control surfaces.

The values of absorption and emittance are calculated from calorimetric measurements employing gold plated sensor plates and thermistors.

Data from 96 channels is monitored when the data handling system is commanded into the surface mode.

The experimental thermal control surface units are mounted on the upper and equatorial facets of four satellite fillets.

4.4.2 Solar cell experiment

This experiment is designed to measure the performance and temperature of thin silicon solar cells. The short circuit current, current near the maximum power point and open circuit voltage are measured on three patches of cells. Short circuit current only is measured on a further three patches of cells which are irradiated with 10^{16} electrons cm^{-2} of 1 MeV energy before launch. In this way their performance should not change appreciably during the orbital lifetime so that any observed change may be attributed to the cell cover slips.

The solar cell patches are mounted on the equatorial facets of two diametrically opposite satellite modules, are thermally insulated from the modules and have their temperatures monitored.

The measurements are sampled when the data handling system is commanded to the solar cell mode.

4.4.3 Hybrid electronics experiment

This experiment, designed and made at the RAE, Farnborough, is to prove the performance in space of lightweight hybrid assemblies made up from film resistors, chip capacitors, and unencapsulated devices mounted on alumina substrates with conductor patterns. The experiment subsystem consists of a voltage to digital converter and an analogue multiplexer used to select calibration voltages from a potential divider. The multiplexer output is applied either to the experimental voltage to digital converter or the converter in the satellites data handling system. Comparison between the experimental and satellite systems will be made.

In order to monitor their behaviour, the voltage applied to the potential divider and the outputs from the two converters, are sampled.

4.4.4 Micrometeoroid experiment

This experiment measures the flux of micrometeoroids impinging on the spacecraft. A new detection method, which involves the measurement of charge released when a particle strikes a surface, is employed, and is expected to detect particles down to at least 0.1 micron diameter or 10^{-14} g mass. Electric currents of the order 10^{-5} amp are detected using particle multiplier techniques. The experiment is mounted close to the upper surface of the spacecraft and micrometeoroids enter through a port. Positive ions produced when a particle strikes a target plate are accelerated in an electric field to the first dynode of an electron multiplier which is at -2.5 kV with respect to the target. The multiplier has a current gain of the order 10^5 and is filled with dry argon at a pressure of half an atmosphere prior to launch. After launch, a vacuum tight flap opens under spring pressure when the ambient pressure falls to a predetermined value. The output signal of the multiplier is amplified, and spurious counts due to random noise or photo emission are masked by pulse amplitude and width discrimination. Two checks may be made in orbit on command from the ground. The first test produces a pulse of electrons from a UV source, which impinge on the first dynode, and in the second test a pulse is applied to the input stage of the amplifier.

4.5 Satellite tracking

During the launch and early-orbital stages the X3 spacecraft and launcher will be tracked by the following organisations:-

WRE Range Instrumentation Facilities and the Queensland Telemetry Station at Charters Towers.

Ministry of Defence.

During the normal orbital stage the spacecraft orbital elements will be provided by the MOD.

4.6 Command and data acquisition

Space Department, RAE will have primary responsibility for commanding the X3 spacecraft and acquiring data. The ESTRACK organisation will provide data acquisition support and will be required to send commands during the early part of the spacecraft's lifetime.

4.7 Orbit determination

The MOD will provide the orbit elements for the X3 satellite. Orbit predictions will be provided by DATA CENTRAL and the European Space Operations Centre (ESOC).

4.8 Spacecraft performance monitoring and control

Monitoring and operational control of the X3 spacecraft will be conducted from the RAE Control Centre, Space Department, RAE, Farnborough (DATA CENTRAL) supported by the ESTRACK network of ground stations, and the RAE Telemetry Station at Lasham.

5 OPERATIONS AND CONTROL

5.1 Introduction

The operations of the ESTRACK network and the RAE telemetry and command ground support facilities are the responsibility of ESRO and MOD(PE) respectively. All operations will be controlled from DATA CENTRAL either directly or through ESOC, Darmstadt. The organisation, facilities and operational procedures for discharging these responsibilities are specified below.

5.2 Launch and early orbit phases

The X3 spacecraft will be launched from the WRE range at Woomera, and the nominal sequence of events for the first 24 hours after lift-off is summarized opposite in Table 2.

5.2.1 Vehicle tracking and data acquisition

The launch vehicle will be tracked from lift-off to third stage separation and launch vehicle telemetry will be acquired to loss of signal. The launch data and flight telemetry will be reported from WRE to the RAE (DATA CENTRAL) for further reporting to all stations as soon as possible after launch.

5.2.2 Spacecraft tracking

During the early orbit phase the X3 spacecraft orbital elements will be provided by the MOD.

Table 2

Early orbit schedule

Notes:- Times are approximate and based on nominal orbit predictions.

Q/L 1, 2 or Auto refers to quick-look operations, see section 5.6.2 and section 5.6.1(a).

OMS 20 and OMS 28 are ESRO message numbers for quick-look and pass reports, respectively.

The following abbreviations are used in Table 2.

AOS - acquisition of signal
 ESOC - European Space Operations Centre
 FAL - Falkland Islands
 FBA - Fairbanks, Alaska
 LM - Lasham
 LOS - loss of signal
 MOD - Ministry of Defence
 NCW - Network Controller, Woomera
 Q/L - quick-look
 RAE - Royal Aircraft Establishment, Farnborough
 SPI - Spitsbergen
 T - Teleprinter
 T/C - Telecommand
 V - Voice

Orbit	T + time	Stn.	T/C No.	Q/L	Event	Comms.
	00.01				Approx. lift-off time NCW - RAE/MOD - ESOC	T
	00.10				Lift-off time NCW - RAE/MOD - ESOC	T
	00.10				Injection into orbit	
	00.14				Lift-off time RAE - Lasham	V
1	00.15				Injection report NCW - RAE/MOD - ESOC	T
1	00.15				Close NCW/RAE and RAE/ESOC voice links	V
1	00.15				Injection report NCW - RAE/MOD - ESOC	T
1	00.35	FBA			AOS	
1	00.37	FBA			S/C carrier modulated? FBA - ESOC - RAE - MOD/NCW	T
1	00.38	FBA			S/C carrier modulated? RAE - Lasham	V
1	00.39	FBA		1	Max Ele 25 ⁰	

Table 2 (Contd)

Orbit	T + time	Stn.	T/C No.	Q/L	Event	Comms.
1	00.42	FBA			LOS	
1	00.48	FBA			OMS 28: FBA - ESOC - RAE (RAE calculate spin)	T
1	00.55				OMS 20: FBA - ESOC - RAE	T
1	01.20	FAL			AOS	
1	01.22	FAL		1		
1	01.27	FAL	18		Replay on	
1	01.30	FAL			Orbit elements MOD - RAE - ESOC	T
1	01.31	FAL	17		Record mode	
1	01.34	FAL			LOS	
1	01.37	FAL			OMS 28: FAL - ESOC - RAE (RAE calculate spin)	T
1	01.54	FAL			OMS 20: FAL - ESOC - RAE	T
2	02.00				Nominal orbit RAE - NCW/ESOC	T
2	02.25	FBA			AOS	
2	02.26	FBA		1		
2	02.29	FBA	18		Replay on	
2	02.29	FBA	14		'Surfaces' mode on	
2	02.33	FBA	17		Record mode	
2	02.35	FBA			LOS	
2	02.41	FBA			OMS 28: FBA - ESOC - RAE (RAE calculate spin)	T
2	02.55	FBA			OMS 20: FBA - ESOC - RAE	T
3	04.17	FBA			AOS	
3	04.18	FBA		1		
3	04.21	FBA	18		Replay on	
3	04.21	FBA	13		'Normal' mode on	
3	04.25	FBA	17		Record mode	
3	04.33	FBA			LOS	
3	04.34	FBA			OMS 28: FBA - ESCO - RAE (RAE calculate spin)	T
3	04.53	FBA			OMS 20: FBA - ESOC - RAE	T
4	06.07	FBA			AOS	
4	06.09	FBA		1		
4	06.14	FBA	18		Replay on	

Table 2 (Contd)

Orbit	T + time	Stn.	T/C No.	Q/L	Event	Comms.
4	06.18	FBA	17		Record mode	
4	06.24	FBA			OMS 28: FBA - ESOC - RAE (RAE calculate spin)	T
4	06.25	FBA			LOS	
4	06.45	FBA			OMS 20: FBA - ESOC - RAE	T
4	07.00				Voice and time check, RAE/LM, Request Lasham checkout: RAE - LM	V
4					Lasham system checkout starts	
5	07.59	FBA			AOS	
5	08.00	FBA		1		
5	08.00				Request Lasham simulation Test: RAE/LM	V
5	08.03	FBA	18		Replay on	
5	08.03	FBA	14		'Surfaces' mode on	
5	08.07	FBA	17		Record mode on	
5	08.11	FBA			LOS	
5	08.15	FBA			OMS 28: FBA - ESOC - RAE (RAE calculate spin)	T
5	08.30				Confirm Lasham readiness: LM-RAE	V
5	08.31	FBA			OMS 20: FBA - ESOC - RAE	T
5	08.32	RAE/ LM			Start set up phase for Orbit 6	V
6	09.00				Close RAE/NCW/MOD Teleprinter link	T
6	09.25				Confirm Lasham readiness: LM - RAE	V
6	09.29	LM			AOS confirm LM - RAE	V
6	09.30	RAE		Auto		
6	09.31	RAE	18		Replay on	
6	09.35	RAE	17		Record mode on	
6	09.36	LM			Max Ele 49 ⁰	
6	09.37	RAE	13		'Normal' mode on	
6	09.45	LM			LOS confirm: LM - RAE	V
6	09.50	RAE			Start Q/L for Orbit 6	
6	10.30	RAE/ LM			Start set up phase for Orbit 7	V
7	11.20	LM			AOS confirm: LM - RAE	V

Table 2 (Contd)

Orbit	T + time	Stn.	T/C No.	Q/L	Event	Comms.
7	11.21	RAE		Auto		
7	11.22	RAE	18		Replay on	
7	11.26	RAE	17		Record mode on	
7	11.27	LM			Max Ele 31 ⁰	
7	11.27	RAE	14		'Surfaces' mode on	
7	11.34	LM			LOS confirm: LM - RAE	V
7	11.40				Start Q/L for Orbit 7	
8	13.22	SPI			AOS	
8	13.23	SPI		2		
8		SPI	18		Replay on	
8		SPI	17		Record mode on	
8	13.36	SPI			LOS	
9	15.10	SPI			AOS	
9	15.11	SPI		2		
9		SPI	18		Replay on	
9		SPI	17		Record mode on	
9	15.26	SPI			LOS	
10	17.00	SPI			AOS	
10	17.01	SPI		2		
10		SPI	18		Replay on	
10		SPI	13		'Normal' mode on	
10		SPI	17		Record mode on	
10	17.17	SPI			LOS	
	17.30				Request Lasham check out	V
10	18.00	RAE/ LM			Start set up phase for Orbit 11	V
11	18.55	LM			AOS confirm LM-RAE	V
11	18.56	RAE		Auto		
11	19.03	RAE	18		Replay on	
11	19.05	LM			Max Ele 38 ⁰	
11	19.07	RAE	17		Record mode on	
11	19.08	RAE	14		'Surfaces' mode on	
11	19.19	LM			LOS confirm LM - RAE	V
11	19.25	RAE			Start Q/L for Orbit 11	

Table 2 (Contd)

Orbit	T + time	Stn.	T/C No.	Q/L	Event	Comms.
11	19.45	RAE/ LM			Start set up phase for orbit 12	V
12	20.46	LM			AOS confirm LM-RAE	V
12	20.47	RAE		Auto		
12	20.50	RAE	18		Replay on	
12	20.54	RAE	17		Record mode on	
12	20.55	RAE	13		'Normal' mode on	
12	20.57	LM			Max Ele 76 ^o	
12	21.13	LM			LOS confirm LM-RAE	V
12	21.20				Start Q/L for Orbit 12	
12	21.40	RAE/ LM			Start set up phase for Orbit 13	V
13	22.37	LM			AOS confirm LM-RAE	V
13	22.38	RAE		Auto		
13	22.40	RAE	18		Replay on	
13	22.44	RAE	17		Record mode on	
13	22.45	RAE	14		'Surfaces' mode on	
13	22.47	LM			Max Ele 24 ^o	
13	22.58				LOS confirm LM-RAE	V
13	23.05	RAE			Start Q/L for Orbit 13	

5.2.3 Spacecraft data acquisition

Telemetry data acquisition during the launch and early orbit phases (3 weeks maximum) is the responsibility of the following stations and 24 hour coverage will be required.

(a) ESTRACK network stations:-

FAIRBANKS, ALASKA	(FBANKS)
FALKLAND IS.	(FALKIS)
REDU, BELGIUM	(REDUBE)
SPITSBERGEN	(SPITSB)

(b) RAE telemetry station at Lasham.

These stations will be scheduled by ESOC and DATA CENTRAL for data acquisition and quick-look operations. The telemetry carrier frequency is 137.560 MHz. All operations will be controlled from DATA CENTRAL via a teleprinter link with ESOC, Darmstadt and by direct link with Lasham.

Up to and including the fifth orbit, the spacecraft data will be acquired by the ESTRACK stations. After this phase, the main station will be Lasham with supporting facilities from the ESTRACK stations at FBANKS, FALKIS and SPITSB. The ESTRACK station at REDUBE will be required to acquire the spacecraft data during the first twelve orbits, and will be scheduled there-after only as a back-up (contingency) station.

During the launch and early-orbit phases, the RAE Control Centre (DATA CENTRAL) will control the spacecraft. Real-time telemetry data will be transmitted from Lasham to DATA CENTRAL during the pass, and quick-look operations will be performed at DATA CENTRAL both during and immediately following a pass.

(a) WRE Range (Woomera)

A check-out trailer will be manned during launch by the Spacecraft Operations Team, and the launch status of the spacecraft will be transmitted to DATA CENTRAL for information to all stations at T-6 minutes.

(b) Telemetry and telecommand support requests

The RAE Control Centre at DATA CENTRAL will request telemetry support and telecommand action in the form of 'Telemetry Support Request' messages. Requests will normally be sent weekly so as to arrive at ESOC/OFSO by mid-day Thursday and will include support requests for a period beginning Wednesday 0001Z and ending the following Tuesday 2400Z. A series of coded remarks will be listed,

headings added to the data columns and orbit numbers added at the end of the line. Alternative passes will be indicated by the use of 'equals' signs.

ESOC will inform DATA CENTRAL of the accepted passes by transmitting a message in the same format as the request, under the heading 'Confirm the following requests'. This notification will be sent by midday Sunday prior to the scheduled period.

(c) Short notice requests

Short notice requests for special telemetry and telecommand support will be in the same format as request messages and headed 'Short Notice Requests'. They will be transmitted to ESOC Control (INFO OFSO) 24 hours prior to the operations requested.

When commands are sent by ESTRACK stations, ESOC will supply a pass report as soon as possible in the normal ESRO format.

5.2.4 Command

The launch and early orbit phases will normally last a maximum of three weeks and during this period it is intended to command the replay mode once per orbit. In addition, it is intended that the spacecraft mode will be changed, as scheduled by DATA CENTRAL, by sending commands 13 and 14. The Birmingham Expt. EHT will be switched on (command 11) and the Birmingham expt. calibrations performed (command 12).

The X3 spacecraft is capable of accepting 37 commands, and the data acquisition stations listed in section 5.2.3 will be responsible for commanding X3 as requested by DATA CENTRAL.

WARNING

The Birmingham EHT ON/OFF command (No.11) is to be sent only from the station at RAE, and special care must be taken not to transmit this command. Unscheduled transmission from ESTRACK stations could result in the command being invalidated since ESTRACK commands are normally sent twice as a matter of routine.

(a) Command format

The format of a command frame consists of the following coded words: address, adress, execute, execute, execute, blank pulse period and a synchronisation pulse, where the first five words are each eight-bit words, as

shown in Fig.7. Each command is preceded by a one half second transmission of unmodulated RF carrier and a command is effected by the reception of any one valid address word and any one execute word in the same series of five words.

Command encoding is effected with a PDM signal which has four states:-

- (a) blank,
- (b) synchronisation,
- (c) logic 1,
- (d) logic 0.

Address and execute words have a similar structure, i.e., a blank pulse period, a synchronisation pulse followed by an eight-bit digital code consisting of logic 1'S and 0'S.

(b) Command transmission

All commands transmitted from DATA CENTRAL are normally automatically sent on request by the operator. All commands from ESTRACK stations will be transmitted, when possible, by using punched paper tapes except when instructed by the RAE Control Centre. The punched paper tapes will be verified for the correct command format prior to the start of a pass.

Punched paper tapes will be prepared in accordance with the command format definition given in section 5.3.4(a).

ESTRACK stations must not have punched tapes containing command No.11.

(c) Tape recorder play-back commands

Transmission of the playback command (No.18) will be timed to occur after the satellite data telemetry signal has been acquired and after the satellite has reached an elevation of 10 degrees. To avoid loss of play-back data, the stations should ensure that play-back data is obtained as soon as possible after transmitting the play-back command. The following procedure will be used for DATA CENTRAL:

(a) At the scheduled time, transmit a complete command 18 (play-back) as defined in section 5.2.4(a).

(b) Verify tape recorder play-back by ensuring play-back data is received. If signal does not appear within a predetermined time, a contingency procedure, to be defined will be followed. At T + 230 seconds after sending

Command 18 a record command (No.17) will be sent. If this command 17 is unsuccessful, it should be repeated once. The X3 spacecraft has a timer, that should return the tape recorder to record mode approximately four minutes after a play-back command is received.

(d) Satellite clock commands

In order to obtain useful data from the solar cell experiment it may be necessary to command a change of satellite clock frequencies (commands 19 and 20). This is necessitated by the need to overcome possible synchronism of the two opposite solar cell patches with the spin of the satellite. Synchronism occurs every $7\frac{1}{2}$ revolutions per minute from the nominal spin rate.

If required, a clock command (19 or 20) will be transmitted at the end of a play-back from the tape recorder.

(e) Birmingham experiment EHT ON/OFF Command

Command 11 switches the EHT supply to the Birmingham experiment either ON or OFF depending on the original state of this experiment. Since ESTRACK stations ordinarily send two commands as a matter of routine, the command No.11 must only be transmitted from the station at DATA CENTRAL.

5.3 Routine phase

The routine phase will begin when the spacecraft orbit has been determined, updated orbital predictions have been forwarded to all participating stations and the spacecraft has settled into routine operation. This phase should last for a period of 11 months.

5.3.1 Tracking

The MOD will provide tracking support during this stage, with limited contingency support from ESTRACK as requested by the RAE Control Centre.

5.3.2 Data acquisition

The RAE station at Lasham will provide primary data acquisition support, with limited support from ESTRACK as requested by the RAE Control Centre. It is proposed to monitor a total of 560 passes at the rate of about 50 passes per month. Sections 5.2.3(b) and 5.2.3(c) are also applicable to this section.

5.3.3 Command

During the routine phase it is intended to command the replay mode during every orbit monitored by the telemetry stations (i.e. 50 passes per month).

It is also anticipated that all the commands, in addition to the routine commands for replay, Birmingham cal. and mode change, will be transmitted at least once during this phase, as and when scheduled by DATA CENTRAL.

The sections 5.2.4(a) to 5.2.4(e) are also applicable to this section.

5.4 Equipment parameters

The equipment parameters to be used by the data acquisition stations are outlined in the following sections.

5.4.1 Telemetry receiving and recording

Set-up details for the equipment are listed below:

(a) Antenna parameters

Frequency band	137 to 138 MHz
Minimum gain	16 dB
Polarisation	circular

(b) Telemetry system

Frequency	137.560 MHz
Mode	phase lock
Loop noise bandwidth (double sided)	300 Hz*
AGC speed	1 to 3 ms.

(c) Magnetic tape recorder

Tape speed	7.5 ips
Track assignments for ESTRACK Stations,	see Table below.

Magnetic tape recorder track assignments

<u>Track</u>	<u>Record amplifier</u>	<u>Signal</u>
1	Direct	Voice annotation WWV telecommand
2	Direct	LTSS reference frequency
3	FM	Conditional RT and TT data
4	Direct	PCM data from Group 2 receivers
5	Direct	PCM data from Group 1 receivers
6	Direct	NASA 36 bit timecode on 1 kHz carrier
7	Direct	FM multiplex. Trigs 1, 3, 5, 6, 7, 8, 9, 10, 11, 12 and 12.5 kHz ref frequency.

* This figure refers to the Scientific Atlanta receivers used at Lasham. Receivers at other stations may have loop bandwidth defined in different terms. In this case bandwidth should be as low as possible consistent with reasonable ease of acquisition and maintenance of phase lock.

Note:- FM multiplex track 7 will contain the following:-

IRIG 1	non-coherent	AGC	R×1	Gp 1
3	"	"	R×2	Gp 1
5	"	"	R×1	Gp 2
7	"	"	R×2	Gp 2
8	"	"		Tracking error
9	"	"	R×1	Gp 1
10	"	"	R×2	Gp 1
11	"	"	X	Tracking error
12	"	"	Y	" "

NB IRIG 6 contains the ground command receiver AGC

5.4.2 Command configuration

The command equipment configuration is summarised below. A list of commands, with Octal, Baudot and binary codes for each command, is shown in Table 1 in section 4.3.5.

(a) Antenna

Frequency band	148 MHz
Minimum gain	9 dB
Polarization	left and right hand circular

(b) Transmitter

Carrier frequency	148.250 MHz
Modulation	PDM/AM/AM
Percent modulation of RF carrier	75%
Minimum output power	200 watts

(c) Command encoder

Type	Tone digital
Tone frequency	7000 Hz.

5.5 Real-time data transmission

5.5.1 Lasham

Lasham will be scheduled by the RAE Control Centre to transmit spacecraft telemetry data in real-time to the Control Centre via the data link.

Voice and data circuits will thus be required for each pass and these circuits should be scheduled for a period of up to one hour, beginning 20 minutes prior to the start of a pass.

5.6 Quick-look operations

Quick-look operations will be performed on all scheduled data acquisition passes during the early orbit phase. After this period, quick-look operations will be scheduled at the ESTRACK stations as requested by the RAE Control Centre.

Decommutation of the real-time data from Lasham will be carried out at the RAE Control Centre (DATA CENTRAL) and a limited number of parameters will be displayed. Immediately after the end of a pass over Lasham quick-look operations and limited data processing will be performed and print-outs produced on the line printer for distribution to experimenters and sub-system designers (see section 8.2).

5.6.1 DATA CENTRAL decommutation and displays

(a) Automatic operations

The real time data from Lasham will be decommuted and the following operations are computer controlled:-

A spacecraft mode check will be made and the appropriate bits (24, 25 of the Sync Work) will be printed out.

One of the following automatic status checks will be scheduled for each pass:-

- (a) A complete check and printout of all the status bits, i.e., all PGs from PG00 to PG37.
- (b) A complete check and printout of those status bits which indicate a change from the launch status.

In addition, one of the following automatic performance checks will be scheduled for each pass:-

- (a) A complete printout of all the performance parameters on the direct telemetry format, i.e., PPs from PP40 to PP83.
- (b) A complete limit check selected performance parameters and print-out of those parameters which are outside the stated limits.

(b) Manual operations

The real time data from Lasham will be decommutated and the following channels on the Data Distributor (EMR 2745) selected for each scheduled pass.

(a) Digital

Parameter	Word	Frame
ID count	03	0
PG0	53	0
PG1	53	1
PG2	53	2
PG3	53	3

(b) Analogue

Parameter	Word	Frame
PP42	42	0, 8, 16, 24, 32, 40, 48, 56
PP47	58	1, 9, 17, 25, 33, 41, 49, 57
PP52	10	3, 11, 19, 27, 35, 43, 51, 59
PP54	42	3, 11, 19, 27, 35, 43, 51, 59
PP55	58	3, 11, 19, 27, 35, 43, 51, 59
PP56	10	4, 12, 20, 28, 36, 44, 52, 60
PP58	42	4, 12, 20, 28, 36, 44, 52, 60
PP61	26	5, 13, 21, 29, 37, 45, 53, 61
PP62	42	5, 13, 21, 29, 37, 45, 53, 61
PP66	42	6, 14, 22, 30, 38, 46, 54, 62
PP71	58	7, 15, 23, 31, 39, 47, 55, 63
PP73	33	All
PP79	10	0, 8, 16, 24, 32, 40, 48, 56
PP80	40	All
PP82	51	All
PP83	56	All
BPUL	50	All
BEHT	18	All

5.6.2 ESOC decommutation and display

The ESOC stations will decommutate and display the following channels, and during the launch phase (up to the first five orbits) will send a quick-look report to RAE via ESOC as soon as possible after a pass.

Quick-look No.1

(a) Octal

Parameter	Word	Frame
AS03	37	8
AS03	38	8
AS04	45	8
AS04	46	8
Mode Id	03	0
PG0	53	0
PG1	53	1
PG2	53	2

} 8 consecutive values required

(b) Analogue

Parameter	Word	Frame
PP42	42	0, 8, 16, 24, 32, 40, 48, 56
PP54	42	3, 11, 19, 27, 35, 43, 51, 59
PP56	10	4, 12, 20, 28, 36, 44, 52, 60
PP61	26	5, 13, 21, 29, 37, 45, 53, 61
PP66	46	6, 14, 22, 30, 38, 46, 54, 62
PP73	33	All
PP79	10	0, 8, 16, 24, 32, 40, 48, 56
PP80	40	All
PP82	51	All
PP83	56	All

Quick-look No.2

After the first five orbits, the quick-look selection will be as above with the exception of parameters AS03 and AS04, unless scheduled by the RAE.

5.6.3 Quick-look operating procedures

A data acquisition station will decommutate the spacecraft real-time data for quick-look operations as scheduled by the RAE Control Centre.

A quick-look operation at an ESTRACK station will be as defined in the ESRO Mission Operations Plan for X3. The stations will submit a quick-look report to DATA CENTRAL via ESOC. For the first five orbits the quick-look reports will be relayed to DATA CENTRAL not later than fifteen minutes after the pass. Following the first five orbits through to the end of the mission quick-look messages will be relayed to DATA CENTRAL within one hour after the pass.

5.7 Tape mailing instructions

All telemetry magnetic tapes will be forwarded, in accordance with the standard tape shipping instructions, to the following address:-

Procurement Executive, Ministry of Defence,
Royal Aircraft Establishment,
Farnborough,
Hants,
England.

For the attention of Room 224, Space Department

6 COMMUNICATIONS

6.1 Introduction

The control centres at DATA CENTRAL and ESOC will provide the necessary communications links, teletype, voice and data transmission to satisfy the operational requirements of the X3 project. A temporary teletype link operating in a conference mode will be provided between the launch range at WRE Woomera, the MOD centre in London and DATA CENTRAL at Farnborough, for a 24 hour period commencing at T -8 hours.

6.2 Teletype communications

ESRO will utilize the existing network for all teletype communications between the ESTRACK stations and the ESOC. An exclusive teletype link will be used for the first month for all teletype communications between ESOC and DATA CENTRAL. Thereafter the public telex network will be used for communications between ESOC and DATA CENTRAL. Teletype communications and procedures will be in accordance with the ESRO Mission Operations Plan for X3 and section 34 of the Estrack Operations Manual.

6.2.1 Addressing traffic

All project-oriented traffic will be addressed to DATA CEN SPACE RAE. All traffic to ESOC will be addressed to ESOC CONTROL.

6.3 Voice communications

Voice communications will be provided between DATA CENTRAL and the LASHAM telemetry station. A temporary voice communication will be provided between the WRE launch range, DATA CENTRAL and the ESOC, for a period between T-6 hours and T +15 minutes.

6.4 Data transmission

The data link between LASHAM and DATA CENTRAL will be used to transmit spacecraft data in real-time.

7 ORBITAL COMPUTATIONS SUPPORT

7.1 Introduction

Data Central, the RAE Space Department Dynamics Division (SP5) and ESOC are responsible for prelaunch and postlaunch orbit determination during the X3 project.

7.2 Prelaunch operations

A predicted world map printout and station observations will be computed from data supplied by DATA CENTRAL. Station predictions will be required for LASHAM and all ESTRACK stations for a 3 day period 10 days prior to launch. If trajectory changes occur prior to launch, the predicted data will be recomputed.

Copies of the predicted observations and world map printout, for a 3-day period, will be distributed to:-

ESRO Control centre
Darmstadt, Germany.

Data Central,
RAE, Farnborough.

X3 Satellite Controller,
RAE.

RSRS,
Slough, Berks.
(Mr. Luscombe).

BDRSS,
WRE, Salisbury,
S.A.
(Mr. K. Smith).

7.3 Post-launch operations

Orbit elements will be provided by the MOD, and will be used to generate the predicted world map and station observations. DATA CENTRAL will send orbital elements to ESOC every time they are updated and in any case the latest elements must be available at ESOC not later than T-7 days for the scheduling week.

8 DATA PROCESSING8.1 Responsibility

RAE is responsible for evaluating the quality of the recorded data on the analogue tapes received from the telemetry stations, and is also responsible for processing the data.

8.2 Data evaluation

The station telemetry tapes will be received by DATA CENTRAL for evaluation and initial processing in order to provide digital magnetic tapes for subsequent computer processing in Mathematics Dept., RAE.

The digital magnetic tapes will contain formatted satellite data and identity blocks of the following form:-

- (1) 9999
- (2) YYMM
- (3) DDHH
- (4) ORBIT NO.
- (5) STATION NO.
- (6) ORIGINAL TAPE NO.

The station numbers to be used are as follows:-

FALKIS	0353
FBANKS	0352
REDU	0351
SPITS	0354
LASHAM (LTS1)	0001
LASHAM (LTS2)	0002

For passes over Lasham the ditital magnetic tape will be processed in DATA CENTRAL as soon as possible after a pass in order to provide the quick-look printout for distribution (section 5.6). This data will consist mainly of housekeeping parameters, as specified by the experimenters and sub-system designers.

9 COMPOSITE COUNTDOWN

The composite countdown is referenced to the nominal lift-off time and lists only those periods that involve or require action by the X3 project ground support elements. Abbreviations are as used in section 5.3.

COMPOSITE COUNTDOWN

Countdown	Message	TTY or voice	Responsibility from to
Between F -14 days and F -9 days	X3 F - days Dress rehearsal sim lift off = Y M D H MIN	TTY	{ NCW RAE ESOC } RAE/MOD ESOC STATIONS
Between F -14 days and F -9 days	X3 F - days Dress rehearsal sim lift off = Y M D H MIN (Note:- The dress rehearsal follows the same procedure as the launch countdown below, with times related to the simulated lift off. The rehearsal will be fast-timed where possible and communications with ESOC simulated. A rehearsal with ESOC will take place at F -3 days when communications with NCW will be simulated)	voice	RAE LASHAM
F -3 days	ESTRACK station readiness report	TTY	RAE
F -2 days	ESTRACK station readiness report	TTY	RAE
F -1 days	ESTRACK station readiness report	TTY	RAE
T -18 h	X3 T -18 h Nominal lift off = Y M D H MIN	TTY	{ NCW RAE } RAE/MOD ESOC
T -17 h 45 min	X3 Nominal lift off = Y M D H MIN	TTY	ESOC EASTRACK STNS
T -13 h	X3 T -13 h Request support status MOD	TTY	RAE MOD
T -12 h 50 min	X3 T -12 h 50 min MOD support status Green or Red (followed by qualification if Red)	TTY	MOD RAE
T -12 h 45 min	X3 T -12 h 50 min MOD support status Green or Red (followed by qualification if Red) (Note:- MOD is assumed to be able to support the mission after this time unless RAE is notified otherwise)	TTY	RAE NCW

Countdown	Message	TTY or voice	Responsibility from to
T -8 h	Open Satellite Network		RAE
T -8 hr	X3 T -8h Comms check, fox message (Note:- This message to be repeated approx every ½h)	TTY	NCW RAE RAE ESOC
T -7 h	X3 T -7 h Nominal lift off = Y M D H MIN	TTY	RAE/MOD ESOC
T -6 h 50 min	X3 Nominal lift off = Y M D H MIN	TTY	ESOC ESTRACK STNS
T -6 h 15 min	Request T -0.6.00 h station readiness report from ESTRACK stations	TTY	ESOC ESTRACK STNS
T -6 h	ESTRACK station readiness report	TTY	ESOC ESTRACK STNS
T -6 h	Open Voice links for a time check, close Voice Links	VOICE	RAE/ESOC
T -5 h 55 min (approx)	X3 nominal lift off is H MIN. Voice and time check. Request Lasham checkout	VOICE	RAE LASHAM
T -5 h 50 min to T -4 h 50 min	Lasham conducts system checkout		
T -4 h	Request simulation test	VOICE	RAE LASHAM
T -4 h to T -3 h 30 min	Lasham conducts simulation test with RAE		
T -3 h 30 min	X3 T -3 h 30 min Request status all stations	TTY	RAE ESOC
T -3 h 25 min	Request T -03.15 h station readiness report from EASTRACK stations	TTY	ESOC ESTRACK STNS