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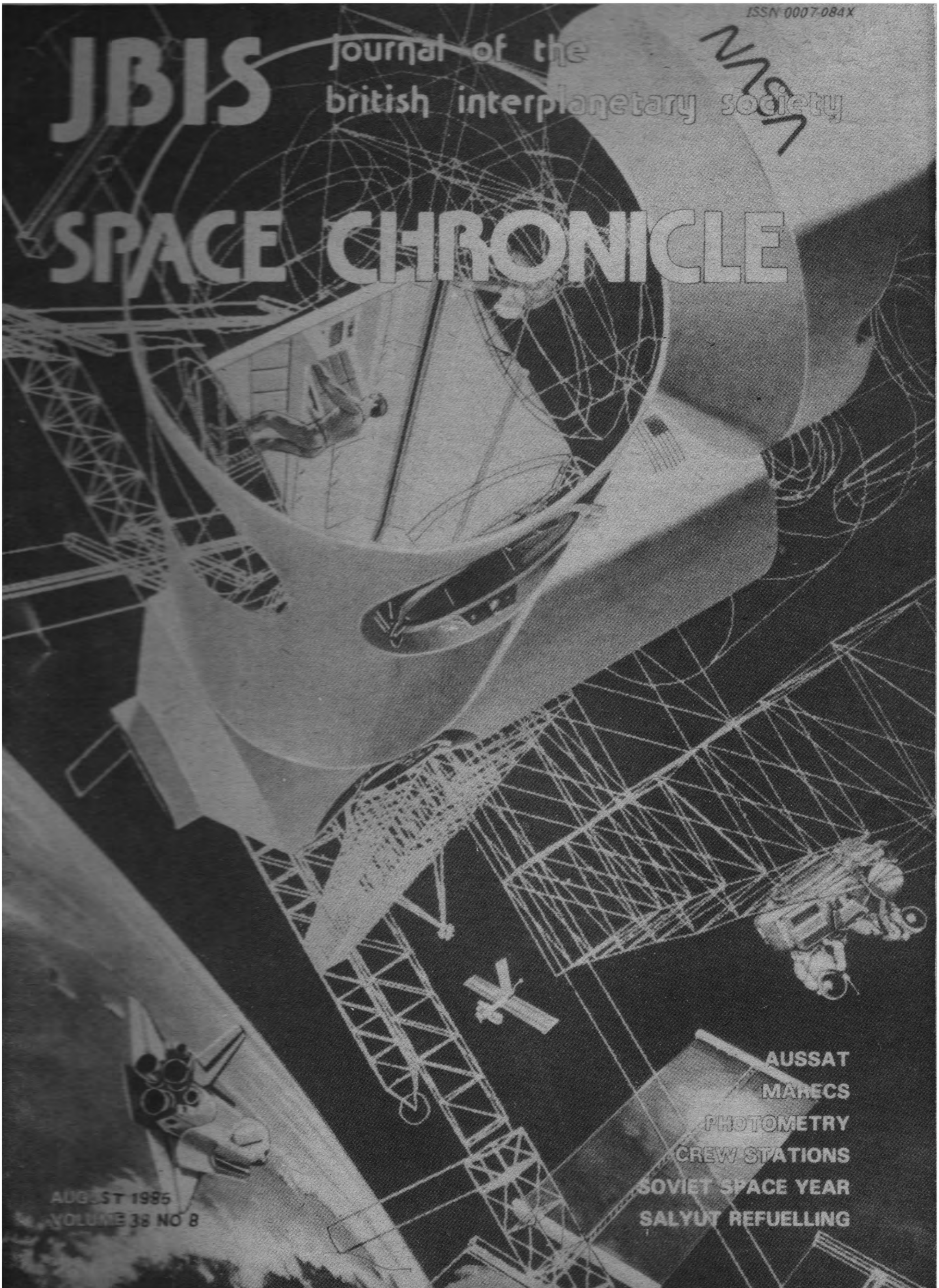
SPACE CHRONICLE



AUSSAT
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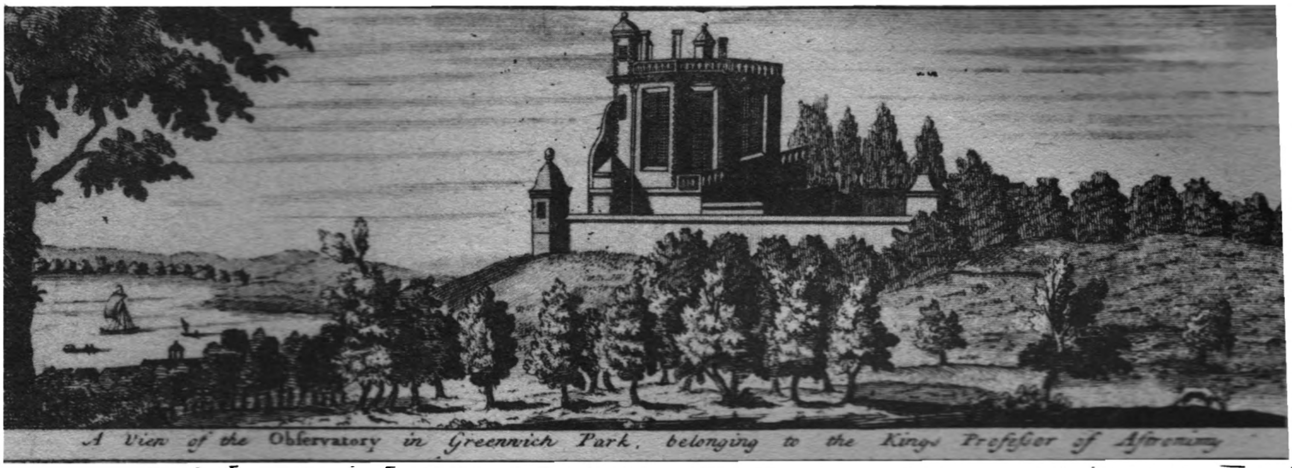
SOVIET SPACE YEAR
SALYUT REFUELLING

AUGUST 1985
VOLUME 38 NO 8

A PIECE OF ASTRONOMICAL HISTORY



James Bradley, Third Astronomer Royal, might have been the mystery owner of the Society's copy of the Bayer Atlas. Above is the Royal Greenwich Observatory as Bradley would have known it.

As interesting articles in Spaceflight (March and June 1985) have related, the Society is fortunate to possess a unique copy of an early important astronomical star atlas and, in view of its importance, plans to issue facsimile copies in limited edition.

The Uranometria (Atlas of the Heavens) first appeared in the year 1603. Its author was a Bavarian lawyer, Johannes Bayer (1572-1605). It was such a boon to astronomers that it continued as a major work of reference throughout the 17th and 18th centuries.

Basically, it consisted of a finely-engraved frontispiece with 51 copper-engraved star maps recording the approximate positions and magnitudes of some 500 stars observed by Bayer himself, in addition to those that had formed the renowned catalogue of the Danish astronomer, Tycho Brahe, only a year or two earlier.

The Society's copy is even more important than this. The Bayer star maps are interspersed with sheets of carefully-catalogued handwritten observations identifying the exact position of each star shown for Epoch 1747. It is apparent that this is the work of a dedicated astronomer of high calibre. Research is still continuing to identify who this mysterious observer might be but early candidates have included James Bradley (Third Astronomer Royal) and George Parker (Earl of Macclesfield), among a host of outstanding historical figures.

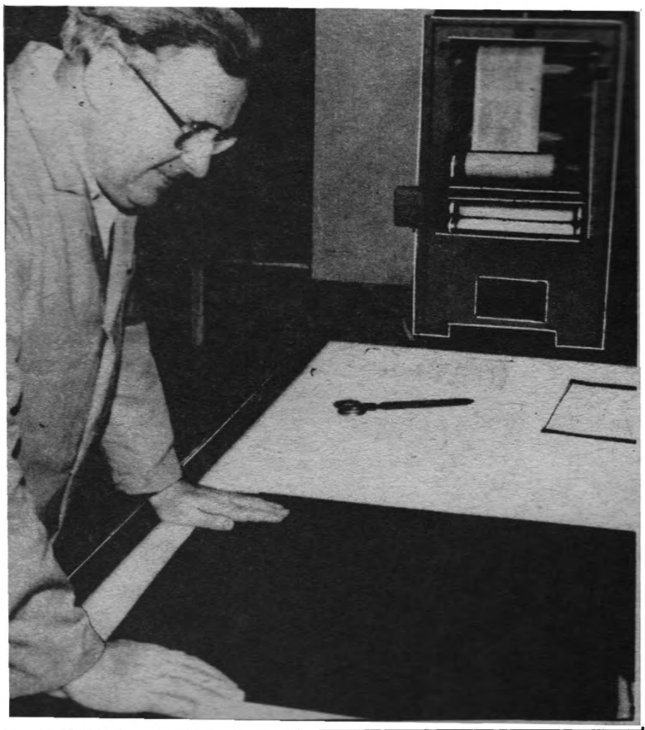
The Bayer large-scale maps and accompanying writings will be reproduced, using the photographic plates carefully prepared in the initial stages of the investigations.

Only 500 copies will be made. Two versions will be available, one bound in Buckram (£160) and the other in calf vellum (£250). They will be identical in all respects except for the binding. Members interested in securing copies at a special pre-publication price should apply to the Executive Secretary at HQ.

Currently only a few good copies of the first edition of Uranometria are on the market. Their cost averages about £4,500 each though one auctioned in 1980 reached £6,500. These consist solely of the star maps with Latin wording on the reverse of each. Later editions are slightly cheaper, with one in good condition costing about £2,500.

These prices, of course, disregard the fact that our own facsimile, although with a slightly damaged frontispiece, has been more than doubled in size by the inclusion of page after page of additional observations. The enormous labour that went into making these observations underlines the outstanding character of the book.

Preparing plates of the Society's Bayer Atlas for printing



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EDITOR: A. WILSON

Editorial Office: The British Interplanetary Society, 27/29 South Lambeth Road, London, SW8 1SZ, England. (Tel: 01-735 3160).

VOLUME 38 No 8 AUGUST 1985

CONTENTS

COVER

An artist's concept of the US Space Station of the 1990's. Two astronauts perform an EVA while two others work inside the pressurised modules. A co-orbiting platform is visible in the background.

McDonnell Douglas

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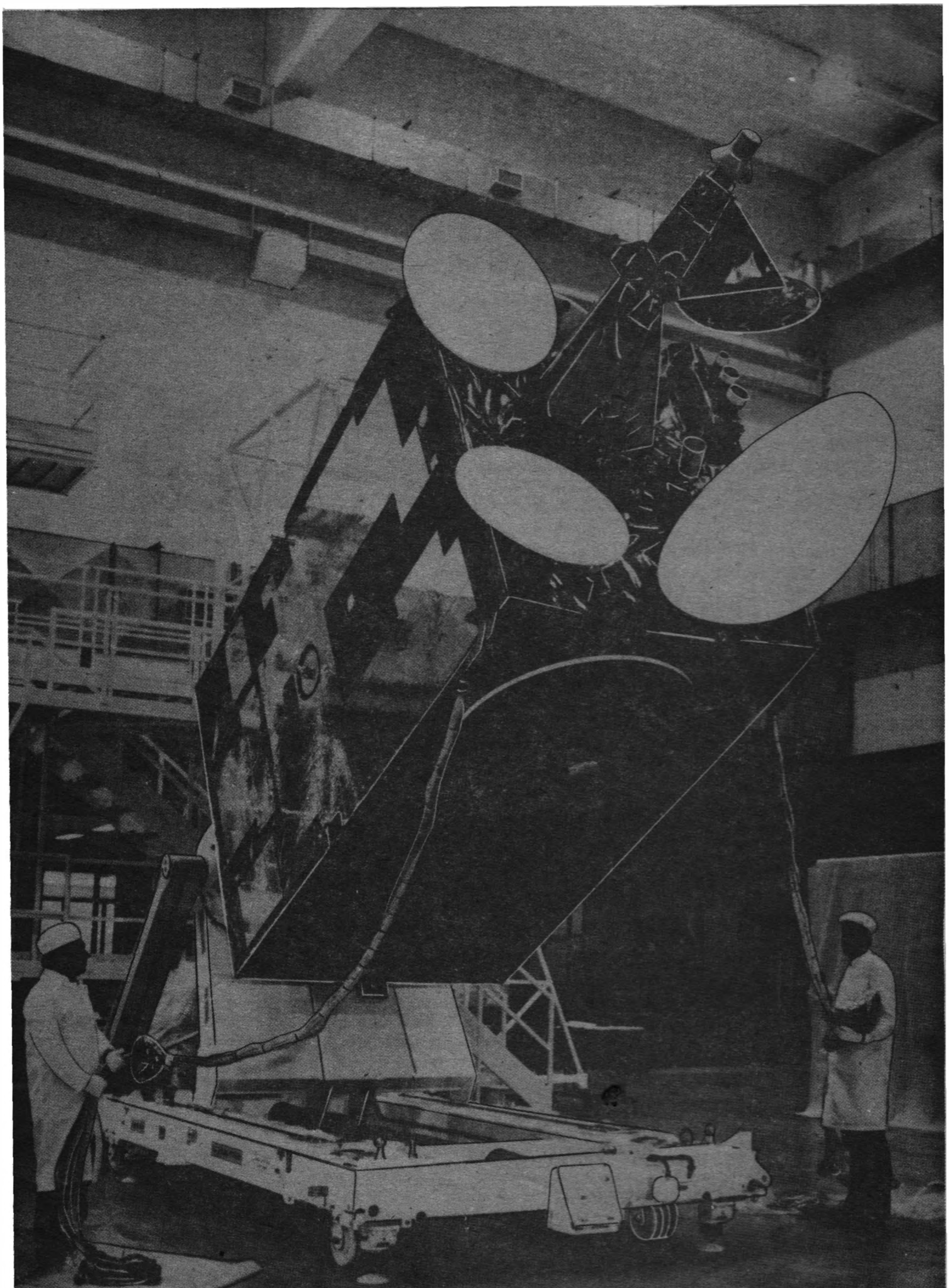

Olympus communications satellite structural model.

ESA

Journal of the British Interplanetary Society, Vol. 38, pp. 339-353, 1985.

THE SOVIET SPACE YEAR OF 1984

P. S. CLARK
Lee, London.

The Soviet Union continued its high rate of satellite launches during 1984. While many existing programmes continued as expected, there were some unusual space missions that are still not fully analysed. This paper reviews Soviet activity during 1984, looking at both the manned and unmanned programmes.

1. INTRODUCTION

During 1984, the Soviet Union made 97 launches that attained Earth orbit; two subsequently attained Earth escape trajectories. The launches represented 75% of all the national launches (129) for the year.

Following the set-backs in 1983, the manned programme regained its confidence with the crew launched on Soyuz T-10 establishing a new manned duration record, remaining in orbit for eight months. Additionally, there were two shorter "visiting" manned missions while the T-10 crew were aboard Salyut 7: the first was an eight-day Soviet-Indian mission, and the second was a 12-day flight with two men and a woman.

Of the unmanned programmes, most publicity was given to the launches of the two Vega probes that will fly past Venus before approaching Comet Halley in 1986. Less publicised was the re-introduction of the nuclear-powered Rorsat after the failure of Cosmos 1402 in late 1982.

While none of the expected new launch vehicles made a flight in 1984, the Proton booster was publically revealed with the Vega 1 launch, after 19 years of use. A new upper stage combination for the Proton was flown as Cosmos 1603 (the mission still requires a definitive analysis).

2. THE MANNED PROGRAMME

The Salyut 7 space station continued in use throughout 1984, playing host to three manned visits. To support the resident crew launched in February, five unmanned Progress re-supply craft were launched and at the end of the year a further test flight of the Soviet mini-shuttle test vehicle took place. There was no flight of the heavy Cosmos module similar to Cosmos 1443 of 1983.

Table 1 provides data for all the launches in the manned programme, while Fig. 1 shows the launch and landing activity for the year. The figure can be compared with that previously published as a "forward look" to 1984 [1].

2.1 Independent Flight of Salyut 7

After the Soyuz T-9 crew left Salyut in November 1983, the station was allowed to decay until January 1984. Table 2 is a summary of all the manoeuvres completed either by Salyut 7 itself or by spacecraft while docked with it. It can be seen that in the middle of January and at the beginning of February some orbital adjustments were made, the resulting low orbit in February being indicative of a forthcoming three-man launch to Salyut.

2.2 Launch of Soyuz T-10

The launch of a new manned expedition to Salyut 7 came on 8 February, and three men were placed in orbit. As had been anticipated the "core" two-man crew consisted of L. D. Kizim and V. A. Solovyov – they had been brought together as back-up cosmonauts for the Franco-Soviet T-6 mission, and had acted as back-ups for Soyuz T-10-1, the launch abort of September 1983. They were joined by O. Y. Atkov, a graduate of the Moscow Sechneov Number 1 Medical Institute in 1973. Atkov acted as a research student, specialising in cardiology, and his inclusion in the T-10 crew suggested that a long flight could be expected. He became a cosmonaut in 1977, the first man to fly from a new group of scientist-cosmonauts.

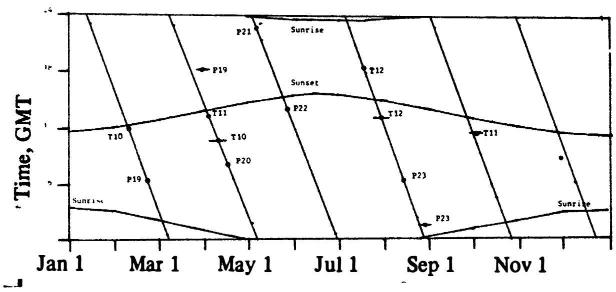

Fig. 1. The launch and landing windows for Salyut 7 during 1984. The sloping lines show the nominal launch times for each day, with the times of sunrise and sunset over the landing site indicated (converted to GMT). Soyuz T missions are shown as "T" followed by the mission number, while Progress missions are shown as "P" followed by the mission number. Launches are shown as a dot, while landings (or de-orbits for Progress) are shown as a dot with a bar. The de-orbit times were not announced for Progresses 20, 21 and 22.

This was to be the first serious attempt to extend the manned duration record beyond six months, established in 1979 by the Soyuz 32 (launched) crew. In 1980 the Soyuz 35 (launched) crew flew for 185 days, but since the duration did not exceed the existing record (185 days) by 10% the new duration was not officially recognised as a record. In 1982 the T-5 (launched) crew remained in orbit for 211 days, establishing a new record but, according to Lebedev who flew the mission, it should have been six months long, but was extended as the planned recovery date drew close.

Soyuz T-10 with its crew approached Salyut 7 at the front docking port the day after launch, and the spacecraft successfully docked at 14.43 GMT (all times in GMT). The crew immediately began to reactivate Salyut and expressed their thanks to the T-9 crew for leaving it in such good condition.

2.3 Flight of Progress 19

The first unmanned re-supply mission to the T-10 crew was launched on 21 February and the Progress craft docked at

TABLE 1. Launches in the Manned Space Programme.

Launch Date and Time	Mission	Launch Vehicle	Mass kg	Epoch 1984	Perigee km	Apogee km	Lifetime d.hh.mm		Comments
Feb 8.12.07	Soyuz-T 10	SL-4	6,850 ?	Feb 8.56	198	219	62.22.43	Craft	Cdr - L D Kizim
				Feb 8.80	227	270	236.22.50	Crew	FE - V A Solovyov
				Feb 10.12	289	296			RE - O Y Atkov
Feb 21.06.46	Progress 19	SL-4	7,015 ?	Feb 21.34	186	245	40.11.32		Unmanned cargo ferry
				Feb 21.70	205	325			
				Feb 22.52	272	327			
				Feb 24.02	281	286			
				Apr 1.14	190	204			
Apr 3.13.09	Soyuz-T 11	SL-4	6,850 ?	Apr 3.60	195	224	181.21.48	Craft	Cdr - Y V Malyshev
				Apr 3.91	227	270	7.21.41	Crew	FE - G M Strekalov
				Apr 4.10	222	271			RE - R Sharma
				Apr 4.78	287	298			
Apr 15.08.13	Progress 20	SL-4	7,015 ?	Apr 15.40	186	260	22		Unmanned cargo ferry
				Apr 15.83	183	246			
				Apr 16.63	232	276			
				Apr 16.88	237	270			
				Apr 18.25	278	290			
				May 7.04	187	312			
				May 7.29	186	304			
May 7.22.47	Progress 21	SL-4	7,015 ?	May 8.13	190	243	19		Unmanned cargo ferry
				May 8.31	243	277			
				May 10.24	276	317			
May 28.14.13	Progress 22	SL-4	7,015 ?	May 28.65	188	244	48		Unmanned cargo ferry
				May 28.89	204	296			
				May 29.89	290	330			
				May 30.96	334	358			
Jul 17.17.41	Soyuz-T 12	SL-4	6,950 ?	Jul 17.79	198	225	11.19.14		Cdr - V A Dzhanibekov
				Jul 17.85	196	232			FE - S Y Savitskaya
				Jul 18.04	276	309			RE - I P Volk
				Jul 18.54	271	304			
				Jul 19.23	334	354			
Aug 14.06.28	Progress 23	SL-4	7,015 ?	Aug 14.32	186	250	13.19.00		Unmanned cargo ferry
				Aug 15.01	187	329			
				Aug 15.57	292	361			
				(Aug 15.25)	341	369			Salyut's pre-manoeuvre orbit
Dec 19.03.53	Cosmos 1614	SL-8	1,250 ?		180 ?	220 ?	1.35 ?		Fourth mini-shuttle test-bed mission

This is a full list of all the launches in the manned programme for 1984. Cosmos 1614 was launched from Kapustin Yar at 50.7°, while all the other flights were from Tyuratam at 51.6°. The launch times for the Soyuz-T and Progress missions were announced; that for Cosmos 1614 is estimated and should be accurate to ±3 minutes (as should all subsequent calculated launch times). The durations are launch to landing for manned flights and Cosmos 1614 (estimated duration) and launch to retrofire for Progress (numbers 20, 21 and 22 had no de-orbit time announced). The orbital data refer to manouevres performed before docking with (and, in severe cases, undocking from) Salyut 7. The first orbit docked combination is included in the listings. In the case of Progress 23 there was a manoeuvre of the docked combination almost immediately after docking and therefore the orbit in parentheses is the final one for Salyut before docking. Spacecraft manoeuvres after docking with Salyut are listed in Table 2. The orbital altitudes in this and subsequent Tables are obtained from the Two-Line Orbital Elements, issued by NASA's Goddard Space Flight Center, and assume a spherical Earth with a radius of 6,378 km.

TABLE 2. Manoeuvres Involving Salyut 7.

Pre-Manoeuvre Orbit Epoch	Perigee km	Apogee km	Post-Manoeuvre Orbit Epoch	Perigee km	Apogee km	Manoeuvring Craft	Salyut Port Front	Rear
			Jan 1.15	314	327			
Jan 11.24	312	325	Jan 13.26	298	323	Salyut 7		
Feb 1.27	293	317	Feb 1.83	292	303	Salyut 7		
Feb 25.40	282	283	Feb 25.46	280	309	Progress 19	Soyuz-T 10	Progress 19
Feb 26.28	279	308	Feb 26.53	306	311	Progress 19	Soyuz-T 10	Progress 19
Mar 30.20	291	292	Mar 30.83	289	303	Progress 19	Soyuz-T 10	Progress 19
Apr 18.25	278	290	Apr 18.57	285	326	Progress 20	Soyuz-T 11	Progress 20
May 20.35	272	312	May 23.23	296	347	Progress 21	Soyuz-T 11	Progress 21
May 25.25	295	347	May 25.76	334	359	Progress 21	Soyuz-T 11	Progress 21
Jul 10.17	328	354	Jul 11.00	307	354	Progress 22	Soyuz-T 11	Progress 22
Jul 14.22	307	353	Jul 14.92	334	355	Progress 22	Soyuz-T 11	Progress 22
Jul 28.31	333	353	Jul 28.88	342	372	Soyuz-T 12	Soyuz-T 11	Soyuz-T 12
Aug 15.25	341	369	Aug 17.95	351	375	(Progress 23)	Soyuz-T 11	Progress 23
Aug 25.25	351	376	Aug 25.37	373	375	(Progress 23)	Soyuz-T 11	Progress 23
Sep 25.28	370	374	Sep 27.96	370	375	(Soyuz-T 11)	Soyuz-T 11	
Dec 30.89	365	370						

All the manoeuvres in excess of 1 m/s implied by the Two-Lines are listed. In some cases the Soviets did not announce the manoeuvres and the probable manoeuvring craft is shown in Parentheses.

the rear port on 23 February at 08.21. One of the first tasks of Progress was to boost the complex into a higher orbit, since the Salyut propulsion system had suffered a fuel leak in 1983 while a fuel transfer was being made from Progress 17 and was therefore considered to be unsafe for manoeuvring. It was possible to by-pass the faulty connections to allow Progress to refuel Salyut, allowing the complex to be rotated as experiments require.

The work of Progress 19 was completed after about five weeks, and on 31 March at 08.40 the ferry undocked. Retrofire took place on 1 April at 18.18 over 51.1° N, 22.2° E, and the spacecraft was destroyed over the Pacific Ocean.

2.4 Soyuz T-11: An Indian in Orbit

As part of the programme to fly international crews on Salyut visiting missions, a flight involving an Indian cosmonaut was scheduled for 1984. In 1983 the crews were announced as: Prime crew; Y. V. Malyshev, N. N. Rukavishnikov and R. Sharma. Back-up crew; A. N. Berezovoi, G. M. Grechko and R. Malhotra. However, owing to medical problems, Rukavishnikov was taken off the prime crew and his place taken by G. M. Strekalov, who was being quickly re-cycled after being involved in the T-10-1 launch failure.

Soyuz T-11 with Malyshev, Strekalov and Sharma was launched on 3 April and successfully docked at the rear port on 4 April at 14.31. For the first time, the Soviets had six men on a space station and since the American Shuttle 41C mission was in progress during part of the Soviet-Indian mission, there was a record 11 men in orbit at once.

The T-10 and 11 crews undertook joint work, concentrating on medical tests and the photography of the Indian sub-continent. Some light relief was provided, with Sharma's experiments with yoga.

A further Soyuz T launch was not planned for some months, so a spacecraft switch was completed by the cosmonauts. On 11 April at 07.33 Malyshev, Strekalov and Sharma undocked from Salyut in T-10 and returned to Earth, leaving their newer craft for the resident Salyut crew. Landing came at 10.50, 46 km east of Arkelyk (50.2° N, 66.4° E).

With the recovery, the international component of the manned Soviet programme was closed for the time being; for the first time since 1976 there were no "guest" cosmonauts in training.

2.5 Three Progresses and Five EVAs

Following the return of Soyuz T-10, the Salyut crew once more began to work alone. To allow the continued flights of Progress cargo ferry craft, T-11 had to be switched from the rear port to that at the front. On 13 April the Salyut crew entered the Soyuz T and at 10.27 undocked from Salyut. The station rotated through 180° and the Soyuz redocked. The crew went back aboard to prepare for the next stage in their mission.

On 15 April Progress 20 was launched and docked with Salyut on 17 April at 09.22. In retrospect, it would seem that Progress 20 carried the major supplies for the planned spacewalks.

The first EVA began on 23 April at 04.31, when Kizim and Solovyov ventured into open space, while Atkov remained in the pressurised work compartment during this and all future EVA work. The EVA cosmonauts removed a folded ladder from the transfer module and extended it along the side of Salyut. Containers were also taken outside but no other work was done – this was merely for preparation for future EVAs. The men re-entered Salyut after 4h 15m [2].

Only three days later, Kizim and Solovyov were outside again, the second EVA having begun at 02.40. They moved to the engine bay at the rear and removed a protective cover near a "reserve conduit." A new valve was installed and the conduit was blown through to test its air-tightness. The protective cover was replaced, and the cosmonauts returned after about five hours in open space [3].

The high level of work continued when, on 29 April at 01.35, Kizim and Solovyov again went outside to return to the engine bay. They installed a new conduit, which was tested for air-tightness, and returned inside after 2h 45m [4].

The fourth EVA to repair the engine system began on 3 May at 23.15, when the cosmonauts installed a second new conduit and checked its integrity. Again the EVA time was 2h 45m, but the Soviets announced that at this point the total EVA time was 14h 45m; this allows the duration of the second EVA to be confirmed as exactly 5 hours [5].

After supporting all this work, on 6 May at 17.46, Progress 20 was undocked and de-orbited at an unspecified time the following day.

Progress 21 was launched on 7 May and docked at the rear on 10 May at 00.10. It was possibly on this craft that added solar cell units were carried into orbit, although these could have been aboard Cosmos 1443 in 1983, which had taken the cells into orbit used by the T-9 crew in November.

On 18 May at 17.52, the fifth EVA began for Kizim and Solovyov, this time to add the new solar panels to one of the three "wings" that Salyut carried at launch. The unit upon which the cosmonauts worked has not been announced, but television pictures of the T-12 EVA suggested that they were added to the solar panel on the same side as the EVA hatch. On T-9 the new panels were added to the upright solar cells (Kizim and Solovyov performed the ground simulations of this assembly work for the T-9 crew). The cosmonauts remained outside for 3h 05m, and in this time they attached two new cell units [6] – the T-9 crew assembled only one panel during each of their two EVAs the previous November.

The solar cells carried by Salyut at launch had a total area of 60 m^2, and each of the new sections added 4.6 m^2. When Kizim and Solovyov had assembled the first section and attached it to the main panel, Atkov rotated it to allow the second section to be added.

After all this activity, no more EVAs were planned for the short-term. Progress 21 undocked on 26 May at 09.41 and was de-orbited at an unspecified time the same day.

Progress 22 was launched on 28 May and docked with Salyut at the rear port on 30 May at 15.47. The cargo ferry carried more fuel for Salyut and extra scientific apparatus. After the equipment had been transferred and the suitable amount of rubbish placed aboard Progress, it undocked on 15 July at 13.36 and was de-orbited at an unspecified time the same day. Once Progress was out of the way and in preparation for a new visiting crew, Salyut performed an orbital correction, as if to prove that the repair work completed by Kizim and Solovyov had been successful.

2.6 Soyuz T-12: Savitskaya's Second Flight

It was widely expected that one of the visiting missions to Salyut 7 during 1984 would involve a woman cosmonaut – possibly "Irena," the back-up from T-7 in 1982 – who would perform an EVA. American Shuttle missions in 1984 would call for their first spacewalk by a woman and a woman making her second orbital flight.

After Progress 22 was de-orbited, the path was clear for another spacecraft to be launched to dock at the back of Salyut. For a standard eight-day mission, the nominal landing opportunity opened at the end of July, so a launch could be expected about 22 July. It was therefore a surprise when Soyuz T-12 was launched on 17 July. Moreover, at that time Salyut was in a high orbit suggesting a two-man launch, but the new craft carried three. In command was V. A. Dzhanibekov, the first Soviet to make four orbital flights, and he was joined by S. Y. Savitskaya (who had been the second woman in space) and new cosmonaut I. P. Volk. Volk was an experienced civilian test pilot, having flown the TU-144 supersonic aircraft; he joined the cosmonaut group in 1978. When Savitskaya had taken an examination at test pilot's school, Volk had acted as one of her examiners. Soyuz docked at the back of Salyut on 18 July at 19.17.

Early into the flight, the Soviets made it clear that this was a new visiting crew, rather than a resident crew to whom Salyut would be handed over and that, because of their workload, the mission would last longer than the standard visiting missions. No clues were given for the forthcoming plans.

On 25 July at 14.55 the EVA hatch opened for the sixth time in 1984; Dzhanibekov and Savitskaya were undertaking an EVA, the first involving a woman. Using an electron beam device, Savitskaya completed a series of welding tests, with the result being taken back inside for subsequent return to Earth. The EVA lasted for a total of 3h 35m [7].

Part of the work undertaken by the T-12 crew would not become clear until after the visiting mission ended (see Section 2.7).

A further surprise was in store. Soyuz T-11 had been in orbit for almost four months, equal to its nominal lifetime (although T-9 was in orbit for 149 days and the Soviets indicated that a Soyuz T could fly for up to six months), and therefore it was expected that a further spacecraft switch-around would take place. But when the Dzhanibekov crew returned to Earth they brought back their T-12 craft. Undocking was on 29 July and landing came later that day at 12.55 some 140 km SE of Dzhezkazgan, near 47.0° N, 69.0° E. Possibly the Soviets wished to prove that Soyuz T could survive for at least six months in space.

2.7 A Final EVA and Progress 23

With the return of T-12, it was thought that the T-10 (launched) crew would coast towards an October recovery with a low-key two months in space, possibly with a further Progress supply mission. Such expectations were to be quickly dashed.

As part of their mission, the T-12 crew had to train the resident Salyut cosmonauts to perform a further adjustment to the Salyut propulsion system, and the training would be put to work with a further EVA. On 8 August at 08.46 the hatch opened again and Kizim and Solovov crawled into space. They made their way to the rear and removed part of the protective cover to allow the closing off of a pipe that was part of the fuel system. Before they returned, a section of a solar panel was cut off for return to Earth and analysis. The EVA was said to have lasted about five hours and the crew's total EVA time was now 22h 50m [8].

On 14 August Progress 23 was launched on the final re-supply mission for this crew, docking with the rear port on 16 August at 08.11. This was to be a short mission, with an undocking on 26 August at 16.13 and de-orbit two days later at 01.28 over 33.1° N, 32.2° E (the Soviets were once more announcing the Progress de-orbit times).

2.8 Return of Soyuz T-11

The mission continued with no further spectacular events, and it was expected that the mission would end in the first days of October. On 1 October the Soviets announced that a recovery would be made the following day and that their space tracking fleet would be returning home. On 2 October, Kizim, Solovyov and Atkov finished deactivating Salyut and then entered Soyuz T-11. The craft undocked from Salyut at about 08.40 (the actual time was not announced) and

TABLE 3. Launches in the Non-Cosmos Unmanned Programme.

Launch Date and Time	Launch Site	Launch Vehicle	Payload	Incl °	Period min	Perigee km	Apogee km	Mass kg	Comments
Feb 15.08.46	Tt	SL-12B	Raduga 14	1.2	1,435.9	35,754	35,813	1,940 ?	Statsionar-2 (85°E)
Mar 16.13.59	Tt	SL-12B	Ekran 12	0.1	1,435.9	35,774	35,791	1,970 ?	Statsionar-T (99°E)
Mar 16.23.32	Pl	SL- 6	Molniya-1 60	62.9	734.9	623	40,572	1,550 ?	Replaced Molniya-1 51
			Then	62.9	718.4	621	39,766		
Apr 22.04.19	Tt	SL-12B	Gorizont 9	1.5	1,436.0	35,743	35,827	2,120 ?	Statsionar-5 (53°E)
Jun 22.00.22	Tt	SL-12B	Raduga 15	1.2	1,435.8	35,753	35,809	1,940 ?	Statsionar-15 (130°E)
Jul 5.03.38	Pl	SL-14	Meteor-2 11	82.5	104.1	943	961	1,500 ?	Meteorological
Aug 1.21.36	Tt	SL-12B	Gorizont 10	1.4	1,436.1	35,721	35,851	2,120 ?	Statsionar-13 (80°E)
Aug 10.00.04	Pl	SL- 6	Molniya-1 61	62.9	735.7	418	40,816	1,550 ?	Replaced Molniya-1 53
			Perturbed to	62.8	735.3	496	40,722		
Aug 24.08.27	Pl	SL- 6	Molniya-1 62	62.8	737.3	462	40,850	1,550 ?	Replaced Molniya-1 54
			Then	62.9	717.8	459	39,895		
Aug 24.19.49	Tt	SL-12B	Ekran 13	0.5	1,436.0	35,761	35,807	1,970 ?	Statsionar-T (99°E)
Dec 14.22.12	Pl	SL- 6	Molniya-1 63	62.9	737.0	452	40,847	1,550 ?	Replaced Molniya-1 55
			Then	62.8	717.8	453	39,904		
Dec 15.09.16	Tt	SL-12	VEGA 1		Heliocentric Orbit			5,050 ?	To intercept Venus and Comet Halley
Dec 21.09.14	Tt	SL-12	VEGA 2		Heliocentric Orbit			5,050 ?	To intercept Venus and Comet Halley

All the launch times are estimated. In the cases of the Molniya 1 and 3 satellites the pre- and post-stabilisation orbits are quoted. There is some doubt whether the object currently listed as Molniya 1-61 is actually this satellite. The launch sites are identified as Tt: Tyuratam and Pl: Plesetsk.

landed at 10.57, about 160 km E of Dzhezkazgan (47.8° N, 69.8° E). Their record-breaking mission had lasted for 236d 22h 50m.

While the cosmonauts were recovering, the Soviets were explaining the significance of the mission. At its most simple level it had proved that men could spend eight months in space and safely return to Earth after suitable training in orbit. However, it was still uncertain how long man could remain in orbit and still came back safely. The main problem is the reduction in the body's bone marrow; some authorities suggest that after a year in space the effects cannot be reversed. To explain the duration of the mission, the Soviets said that it was long enough for a flight to Mars. This was taken in some quarters as an indication that the Soviets are planning a manned Mars mission but there is no other evidence.

2.9 Cosmos 1614: A Spaceplane Test

It has been reported that the Soviet Union is planning the introduction of two manned shuttle vehicles during the 1980's [9]. In the next year or two, it is suggested that a mini-shuttle launched on a "throw-away" booster will be introduced, this being used to ferry men and supplies to and from a space station. Later in the decade, a larger heavy lift shuttle can be expected, and this will be at least in the same class as the American series.

In support of the spaceplane programme, three sub-scale shuttles were launched during 1982 and 1983 and recovered at sea. The first two landed in the Indian Ocean (Cosmos 1374 and Cosmos 1445), while the third landed in the Black Sea (Cosmos 1517). The intervals between the launches had been 285 days or so, and it was half-expected that a fourth flight could have come in early October 1984. This failed to materialise, but on 19 December Cosmos 1614 was launched from Kapustin Yar on a mission identical with that of Cosmos 1517. Splashdown in the Black Sea was about 95 minutes after launch, and the launch announcement said that the planned research programme had been completed. A few days after the flight, a Soviet source confirmed that Cosmos 1614 had been a test of a reusable spacecraft, but indicated that the Soviets still had not decided whether to go ahead with a shuttle like the American vehicle [10].

Cosmos 1614 itself was not tracked in orbit, and the orbit quoted in Table 1 is based upon that for the earlier flights. Two-Line Orbital Elements were issued for the rocket body (1984-126B) and two fragments which remained in orbit (1984-126C and D), the data being:

1984-126B, 50.7°, 88.5 min, 176-223 km
1984-126C, 50.7°, 88.3 min, 183-199 km
1984-126D, 50.7°, 88.3 min, 183-200 km

Presumably, Cosmos 1614 was the same vehicle that had flown at least one of the previous three missions, although it is not known for certain how many different re-entry bodies have been used in the programme.

2.10 The "Bios" Experiments

On 21 May, Radio Moscow's science reporter Boris Belitsky described a recent experiment [11]. Two "researchers" named Nikolai Burgeyev and Sergei Alekseyev spent five months in a hermetically-sealed laboratory, cut off from the outside world. The volume of the living and work quarters was 300 m³. All that the researchers received from the outside world were power and television programmes; all the food was grown inside the laboratory. Upon completion, the experiment was hailed as a step towards interplanetary missions.

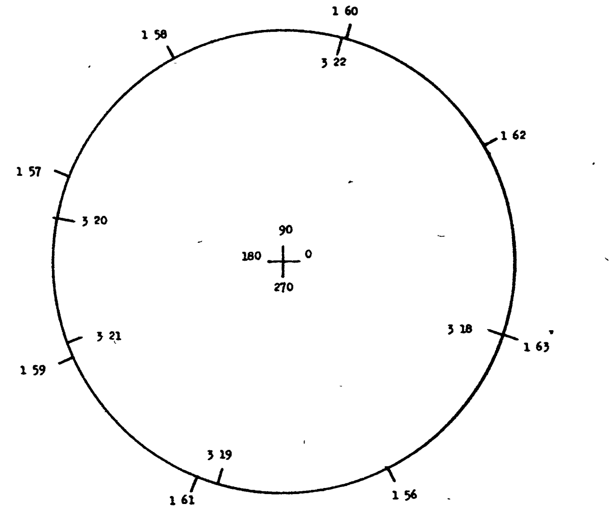

Fig. 2. The right ascensions (RAs) of the ascending nodes (degrees) for the "Orbita" network satellites, Molniya 1 and Molniya 3. Like Figs. 5, 6 and 7, the nodes are calculated to epoch 1985 Jan. 1.0. The latest satellite is shown for each location. For clarity, Molniya 1 flights are shown outside the circle and Molniya 3 flights inside.

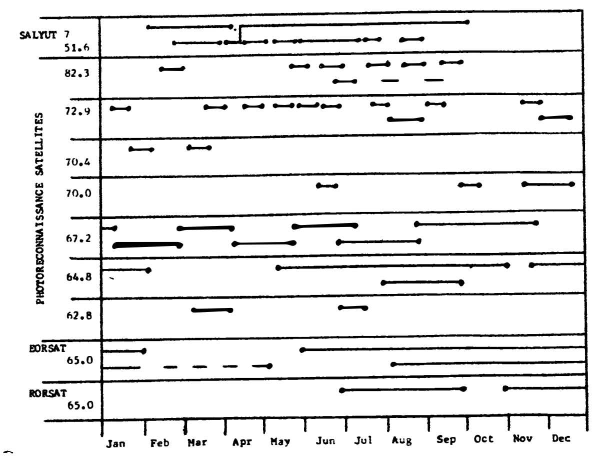

Fig. 4. All the satellites which generally have operating lifetimes of less than a year are shown, although individual satellites cannot be named on this scale. A continuous line shows the period for which the satellite operated in each case. A dotted line is shown for part of the Cosmos 1507 representation, since it is not certain when this Eorsat ended its operating life. For Salyut 7, the upper lines represent occupations of the front docking port and the lower line occupations of the rear docking port.

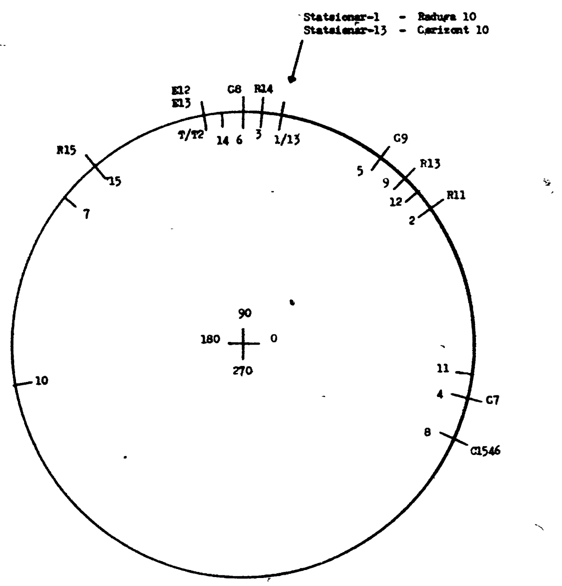

Fig. 3. The Statsionar system. The Statsionar locations are indicated inside the circle over the appropriate longitude, and the latest flight to each location (degrees East) is shown outside the circle. Flights are identified as: "R": Raduga, "E": Ekran, "G": Gorizont and "C": Cosmos. The same position has been registered for Statsionars 1 and 13, and it is assumed that Raduga and Gorizont relate to these respective locations.

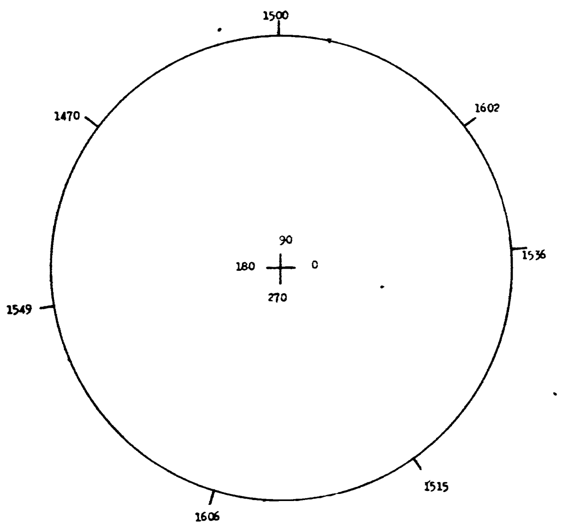

Fig. 5. The RAs of ascending nodes for the presumed larger ferret satellites launched at 82.6°. Cosmos 1500 and 1602 have been returning oceanographic data for civilian use, and it is therefore uncertain whether they should, strictly speaking, be included in this grouping.

3. NON-COSMOS UNMANNED MISSIONS

Of the many unmanned missions launched to Earth orbit or beyond, only 13 were not given a Cosmos name. Ten were communications satellites, one was a meteorological satellite and the remaining two were the Vega interplanetary missions.

3.1 Molniya Communications Satellites

There were four launches in the Molniya programme during 1984, and all were in the Molniya 1 series. The Molniya 3 series had not ended, since those satellites operating at the end of 1983 were still on station at the end of 1984. Presumably, none required replacement. (A new Molniya 3 satellite was launched in January 1985).

Molniya 1-61 seems to have failed to stabilise its orbit initially, but this was attained after some weeks of careful manoeuvring. One piece from Molniya 1-63, 1984-124C, seems to have disintegrated in orbit because extra fragments were tracked in orbits similar to this object.

Figure 2 illustrates the right ascensions of the ascending nodes of the Molniya 1 and Molniya 3 satellites still operating at the end of 1984.

3.2 Statsionar Communications Satellites

Six launches took place in the Statsionar programme in 1984, together with two Cosmos satellites, on related mis-

TABLE 4. Soviet Geostationary Satellite Location.

Name	Location °E	Frequencies GHz	Name	Location °E	Frequencies GHz
GALS 1 (8)	335	7	Statsionar 1	80	4 6
GALS 2 (9)	45	7	Statsionar 2	35	4 6
GALS 3 (3)	85	7	Statsionar 3	85	4 6
GALS 4 (10)	190	7	Statsionar 4	346	4 6
GALS 5 (15)	130	7 8	Statsionar 5	53	4 6
GALS 6 (2)	35	7 8	Statsionar 6	90	4 6
GOMSS	76	1 3	Statsionar 7	140	4 6
Loutch 1 (4)	346	11 14	Statsionar 8	335	4 6
Loutch 2 (5)	53	11 14	Statsionar 9	45	4 6
Loutch 3 (6)	90	11 14	Statsionar 10	190	4 6
Loutch 4 (7)	140	11 14	Statsionar 11	351.5	4 6
Loutch P1 (8)	335	11 14	Statsionar 12	40	4 6
Loutch P2 (9)	45	11 14	Statsionar 13	80	4 6
Loutch P3 (3)	85	11 14	Statsionar 14	95	4 6
Loutch P4 (10)	190	11 14	Statsionar 15	130	4 6
Potok 1 (~4)	345.6	4	Volna 1 (8)	335	1 3
Potok 2 (1, 13)	80	4	Volna 2 (4)	346	3
Potok 3 (~10)	192	4	Volna 3 (9)	45	1 3
SDRN-E	200	11 14 15	Volna 4 (5)	53	3
SDRN-W (~4)	344	11 14 15	Volna 5 (3)	85	1 3
SDRN-B (~14)	95	11 14 15	Volna 6 (7)	140	3
Statsionar-T	99	1 6	Volna 7 (10)	190	1 3
Statsionar-T2	99	1 6	Volna 8 (6)	90	3

A list of all the geostationary locations registered by the Soviet Union, excluding positions registered for the non-geostationary Prognoz missions. In a number of cases, the positions registered for Statsionar missions also relate to other missions. In such other missions, the corresponding Statsionar number is shown in parentheses after the position designator. GOMSS is the Soviet location for a geostationary meteorological satellite.

sions (discussed in Section 6.7).

Raduga 14 replaced or complemented Raduga 12 and Raduga 15 was the first dedicated Statsionar 15 mission. Gorizont 9 probably replaced Gorizont 5, while Gorizont 10 was the first "Gorizont" to be stationed at the Statsionar 113 location, previously used by Raduga satellites. Raduga 10 was the last "Raduga" at that location, although some Cosmos test missions have been located there. Perhaps the Raduga missions were Statsionar 1 and Gorizont is to be Statsionar 13? Ekrans 12 and 13 were Statsionar T missions, although there seems to be no way to distinguish these from Statsionar T2 missions.

Table 4 is a summary of all the geostationary satellite systems registered by the Soviet Union, but this does not imply that separate satellites will be used for each system. For example, the Statsionar 8 location has also been registered for GALS-1, Loutch P1 and Volna 1, and probably a single satellite will carry the transponders for the various systems.

Figure 3 shows the Statsionar locations, together with the latest flight to be stationed at each in use at the end of 1984.

The Soviets have discussed a test-bed antenna that was being used with the Loutch 1 geostationary satellite, deployed over the Atlantic Ocean [12]. This would have been included on the Gorizont 7 satellite, deployed over the Statsionar 4 location in the summer of 1983.

3.3 The Meteor Programme

There was a single launch in the Meteor programme during 1984: Meteor 2-11 in July. Like Meteor 2-8, launched in 1982, the new satellite used the SL-14 booster; most probably the original SL-3 usually used for such launches has now been retired.

When the launch was announced of Meteor 2-11, the Soviets indicated that the satellite carried equipment for obtaining global images of cloud cover and for observing the Earth's surface in the visible and infrared bands. Data could be either transmitted "live" or stored on board for subsequent dumping. The orbital plane of Meteor 2-11 was 50° to the west of that for 2-8.

3.4 The Astron Observatory

In March 1983 the Soviets launched a large astronomical observatory based upon the Venera spacecraft "bus" and named it Astron. The satellite, in an eccentric Earth orbit, continued operating through 1984.

On 26 March more than 200 communications sessions had been held with the vehicle. Before this, the satellite had registered the disappearance of a radiation source in Hercules. Astron had also been used to observe the large discharges of matter from stars of various spectral classes. Results indicated that the star 73 Draconis had hundreds of times more uranium than expected, while Kappa Cancri had hundreds of time more tungsten and lead than anticipated. The observatory had also been used to observe bursts of radiation that appear twice a year, each of 10 seconds duration, resulting from nuclear explosions on the surface of a neutron star. These latter observations were so regular that it had been thought that they may have been from an extraterrestrial civilisation, until the natural explanation was discovered [13, 13, 15].

3.5 The Venera Programme

In October 1980 two Venera radar mappers entered orbit about Venus and although their prime missions were completed at the end of the year, they continued to operate throughout 1984. In addition, at the end of 1984 two more probes were launched to Venus, but these were different from earlier missions in that, following Venus fly-by, the main spacecraft "buses" were to be re-targeted to the first encounter with Comet Halley.

3.5.1 Venera 15 and Venera 16

Veneras 15 and 16 are the orbiters that arrived at Venus in October 1983. At the beginning of 1984 67 communications sessions had been held with the craft, and each day more than one million square km of the Venerian surface had been mapped. According to Soviet scientists, mountain ranges reaching up to 10 km have been mapped, as well as planes of lava and both volcanic and impact craters [16].

Each day strips of the Venerian surface 9,000 km long and 150 km wide were mapped and the data immediately returned to Earth [17]. The results allowed the first maps of the northern polar region to be prepared. The craft observed temperature differences of 100° C on the planet's surface. By mid-January a total of 20 million km² had been mapped from orbit [18].

The resolution of the radar system was about 1.5 km and the images showed circular structures 350 km in diameter thought to be similar to the lunar "seas" [19]. At the end of June a total of 220 communications sessions had been completed and 100 million km² of the planet had been mapped [20].

3.5.2 Vega 1 and Vega 2

In December 1984 the Soviet Union launched its two craft in the Vega programme, which would involve an initial fly-by of Venus – with atmospheric probes being separated – and then an approach to Comet Halley in 1986. The launch of Vega 1 on 15 December was notable in that for the first

TABLE 5. Cosmos Photoreconnaissance Satellites: Third Generation.

Launch Date and Time	Cosmos	Launch Site	Launch Vehicle	Incl °	Orbit 1 km	Orbit 2 km	Orbit 3 km	Orbit 4 km	Final Orbit km	Lifetime Days
1. LOW RESOLUTION SATELLITES.										
Sep 13.10.25	1597 (P)	Pl	SL-14	82.3	211-244				206-234	12.868
2. MEDIUM RESOLUTION SATELLITES.										
Jan 11.12.21	1530	Pl	SL- 4	72.9	194-365		356-415		357-415	13.774
Jan 26.08.51	1533	Tt	SL-14	70.4	224-356		346-415		348-414	13.893
Mar 7.08.01	1542	Tt	SL-14	70.3	226-349		348-414		349-414	13.892
Mar 21.11.06	1545	Pl	SL- 4	72.8	196-370		356-415	236-397	235-397	14.767
Apr 19.11.41	1549	Pl	SL- 4	72.9	197-367		355-414		359-413	13.773
Jun 1.13.51	1568	Pl	SL- 4	72.8	196-368		356-397		357-415	12.815
Jun 11.08.41	1571	Tt	SL- 4	70.0	210-376		349-413		349-414	14.854
Jun 24.12.40	1583	Pl	SL- 4	72.9	197-362	197-367	357-415		358-415	14.802
Aug 6.14.01	1587	Pl	SL- 4	72.9	197-368		356-415		357-415	24.663
Sep 27.08.11	1600	Tt	SL- 4	70.0	204-379	363-418	350-416		349-417	13.899
Nov 14.12.20	1609	Pl	SL- 4	72.9	198-357	196-367	356-415		358-414	13.773
Nov 29.14.01	1613	Pl	SL- 4	72.8	197-356	195-358	356-416		357-415	13.773
3. HIGH RESOLUTION SATELLITES.										
Feb 16.08.15	1537 (P)	Pl	SL-14	82.3	208-288	259-273	259-274		257-272	13.861
May 11.13.00	1551	Pl	SL- 4	72.9	196-279	212-324	212-258	211-263	209-258	11.791
May 22.08.35	1557 (P)	Pl	SL-14	82.3	211-247	210-241			206-234	12.864
Jun 15.08.20	1572 (P)	Pl	SL-14	82.3	215-268	267-273	259-273	261-274	260-273	13.847
Jun 19.10.55	1573	Pl	SL- 4	72.9	197-290	199-299	228-304	229-312		
					231-309	227-261			226-260	8.832
Jun 22.07.40	1575 (P)	Pl	SL-14	82.3	216-267	261-275	257-273	260-281	259-279	14.865
Jun 29.15.00	1580	Pl	SL- 4	62.8	243-346	238-346	227-271		225-266	13.618
Jul 19.08.30	1582 (P)	Pl	SL-14	82.3	213-279	253-279	262-279		262-277	13.867
Jul 27.09.00	1584 (P)	Pl	SL-14	82.3	182-248	181-240	180-365		179-352	13.860
Aug 16.09.50	1590 (P)	Pl	SL-14	82.4	211-266	261-270	262-279		261-277	13.865
Aug 30.10.11	1591 (P)	Pl	SL-14	82.3	209-272	185-343	260-271	267-273	266-272	13.865
Sep 4.10.21	1592	Pl	SL- 4	72.9	196-355	211-386	225-290	226-334	225-355	13.795

All the post-manoeuvre orbits for Third Generation satellites are listed. For the medium resolution satellites, the operational orbit is shown under "Orbit 3," whether or not an "Orbit 2" is listed. If the calculated launch times are correct, the implied lifetimes (to 0.001 days) should be correct to ±2 minutes. No Third Generation satellite was in orbit on 1 January 1984 and they had all been recovered before 31 December 1984.

time a complete picture of the SL-12 Proton booster was released (see Section 8); further pictures were released for the Vega 2 launch on 21 December.

Vega 1 is due to arrive at Venus on 14 June 1985 and then fly-by Halley on 6 March 1986; the corresponding approach dates for Vega 2 are 18 June 1985 and 9 March 1986. At Venus, a lander complex will be separated and within each spherical heat shield will be two vehicles. The surface experiments are carried in a standard Venera lander module, with a total mass of about 700 kg, while special atmospheric experiments will be carried for the first time in an aerostat probe. The aerostat is designed to float in the atmosphere for at least 24 hours returning data. It will be deployed on the night side of Venus, but the atmospheric circulation will carry it towards the morning hemisphere. The mass of the aerostat is 115 kg, while 85 kg of scientific instrumentation is carried on the Vega fly-by probe and 117 kg on the lander [21].

4. THE COSMOS PROGRAMME

The majority of launches in the unmanned programme were under the Cosmos identity: during 1984 Cosmos numbers 1522 to 1615 were launched, made up of two triple payload launches, two octuplets and 72 single payloads.

The Cosmos is covered here under three headings: photoreconnaissance, non-recoverable and the unusual Cosmos 1603. Cosmos 1614, the spaceplane test, was considered in Section 2.9.

Figure 4 presents in graphical form the Cosmos satellites with limited lifetimes, as well as the man-related missions to Salyut 7. The majority of the satellites represented are from the photoreconnaissance programme, but also included are the Rorsats and Eorsats that operated during the year.

5. COSMOS PHOTORECONNAISSANCE SATELLITES

During 1984 there were 36 launches in the photoreconnaissance programme, thus confirming it as the largest single element of the Cosmos series. The launches can be classified as follows:

Third Generation (Low Resolution): 1 launch
Third Generation (Medium Resolution): 12 launches
Third Generation (High Resolution): 12 launches
Fourth Generation (Area Survey): 3 launches
Fourth Generation (Close-Look): 8 launches

This section reviews the satellites by generation and then by type within the generation.

The launch vehicles quoted in the Tables are derived from the analysis presented in the review of 1983 (see notes at the end).

5.1 Third Generation Satellites

The third generation is the oldest type to be operating and consists of three groups: the low resolution satellites perform no orbital manoeuvres, the medium resolution satellites manoeuvre to 360-415 km orbits and the high resolution satellites manoeuvre to a variety of lower orbits. Table 5 is a list of all the third generation satellites launched in 1984; none were in orbit at the beginning of the year and none were operating at the end.

5.1.1 Low Resolution Missions

Flights within the low resolution series are few and are thought to be for general mapping work. The only flight in 1984 was Cosmos 1597 at 82.3°, announced as working within the Priroda Earth resources programme.

5.1.2 Medium Resolution Missions

The medium resolution missions during 1984 can be classified by orbital inclination as:

70.0°: 2 missions
70.4°: 2 missions
72.9°: 8 missions

Previously, the medium resolution satellites were very predictable, the general variation being in the recovery – a day or two earlier or later than normal (which is 14 days). However, in 1984 there were some anomalous missions.

The first was Cosmos 1545. After launch on 21 March, it entered its operational 356-415 km orbit the following day. Normally, the satellite would have remained in this orbit (with only small orbital adjustments by a low-thrust engine) until recovery, but on this mission the orbit was reduced to 236-397 km on 2-3 April, with recovery on 5 April, one day later than usual.

Cosmos 1568 had a lifetime one day less than normal. With Cosmos 1571 and Cosmos 1583, the lifetimes were each one day longer than usual.

Perhaps the most radical change in the medium resolution missions came with Cosmos 1587, with Cosmos 1613 being a repeat mission. Cosmos 1587 was launched on 6 August, but no manoeuvre to the high orbit took place the following day. Natural decay continued until 18 August (195-358 km), when the satellite was manoeuvred to its standard 356-415 km orbit. This was maintained for its standard 13 days, after which recovery was made inside the Soviet Union, giving a lifetime of about 24.7 days. The flights could have been connected with a possible high resolution mission being undertaken on a medium resolution mission. Certainly, the manoeuvres to the operating orbits for Cosmos 1587 and 1613 were carefully chosen to allow the normal landing node to be attained after 13 days in the standard orbit; therefore they cannot be failures.

TABLE 6. Cosmos Photoreconnaissance Satellites: Fourth Generation.

Launch Date and Time	Cosmos	Launch Site	Launch Vehicle	Incl °	Altitudes km	Lifetime Days
1. AREA SURVEY SATELLITES.						
1983						
Dec 27.09.30	1516	Tt	SL-4	64.9	196-276 204-239	44
1984						
Mar 10.17.01	1543	Pl	SL-4	62.8	216-395 216-379	25
May 14.14.00	1552	Tt	SL-4	64.9	182-322 224-311 227-305	173
Nov 14.07.39	1608	Tt	SL-4	70.0	197-250 209-281 210-267	33
2. CLOSE LOOK SATELLITES.						
1983						
Nov 30.13.46	1511	Pl	SL-4	67.1	171-337 165-281	44
1984						
Jan 13.14.41	1532	Pl	SL-4	67.1	169-344 169-265	44
Feb 28.14.01	1539	Pl	SL-4	67.2	168-342 172-304	40
Apr 10.14.00	1548	Pl	SL-4	67.1	167-334 170-298	44
May 25.11.30	1558	Pl	SL-4	67.2	168-294 192-325	44
Jun 26.15.36	1576	Pl	SL-4	67.1	170-351 171-301	59
Jul 31.12.30	1585	Tt	SL-4	64.7	174-302 174-320	59
Sep 25.14.30	1599	Pl	SL-4	67.1	166-249 179-319 170-259	56
Nov 21.10.31	1611	Tt	SL-4	64.8	173-304	In Orbit

A complete list of the Fourth Generation photoreconnaissance satellites that operated during 1984. The initial and final orbits only are generally given because of the many manoeuvres usually performed on these flights. In some cases three orbits are given, the second indicating the operational orbit when it differed from the initial orbit. Lifetimes are to the nearest integer day, since the craft are probably de-orbited rather than being recovered at the end of their missions. Cosmos 1511 and 1516 were in orbit on 1 January 1984, and only Cosmos 1611 operated into 1985 (de-orbited on 11 January 1985, lifetime 51 days).

5.1.3 High Resolution Missions

There were essentially no elements in this programme. The number of flights by orbital inclination in 1984 were:

62.8°: 1
72.9°: 3
82.3°: 8

Perhaps the most interesting aspect occurred with Cosmos 1580, with a return to flights at 62.8°. This inclination was widely used during the 1970's, but has not been used since 1980 (Cosmos 1180). A fourth generation mission also flew at 62.8° in 1984 (Cosmos 1543).

5.2 Fourth Generation Satellites

At the beginning of 1984 there were two fourth generation satellites in orbit: Cosmos 1511 and 1516. The year saw 11 flights, of which one was in orbit at the end (Cosmos 1611).

The classification of the satellites presented here follows that introduced in the review of 1983, but it is not universal. Some call the close-look satellites Fourth Generation, while the area survey missions are classed as Fifth Generation.

TABLE 7. Non-Recoverable Cosmos Satellites.

Launch Site	Launch Vehicle	Launch Date and Time	Cosmos	Incl °	Period min	Perigee km	Apogee km	Notes
ELINT SATELLITES.								
KY	SL-8	Jun 28.13.16	1578	50.7	104.4	295	1,641	-
Pl	SL-8	Jan 26.12.02	1534	65.8	94.5	467	517	-
		Sep 27.09.32	1601	65.8	94.5	474	515	-
		Dec 20.13.02	1615	65.8	94.0	440	500	-
	SL-14	Feb 8.09.24	1536	82.5	97.7	634	666	-
		Mar 15.17.06	1544	82.5	97.7	634	664	-
		Sep 28.06.01	1602	82.5	97.7	633	667	-
		Oct 18.17.47	1606	82.5	97.7	631	665	-
NAVIGATION SATELLITES.								
Tt	SL-12B	May 19.13.42	1554-1556	64.8	681.5	19,162	19,389	C1554
		Sep 6.15.49	1593-1595	64.8	675.7	19,088	19,171	C1593
Pl	SL-8	Jan 11.18.08	1531	82.9	105.0	982	1,010	R C1386
		Feb 2.17.39	1535	83.0	104.8	956	1,017	R C1428
		May 11.06.19	1550	83.0	105.0	975	1,012	R C1535
		May 17.14.44	1553	82.9	104.8	963	1,008	R C1383
		Jun 21.19.41	1574	83.0	104.9	969	1,008	R C1339
		Jun 27.05.00	1577	83.0	104.8	959	1,011	R C1464
		Sep 13.15.56	1598	82.9	105.0	970	1,016	R C1550
		Oct 12.14.44	1605	82.9	104.8	952	1,019	R C1459
		Nov 15.06.40	1610	83.0	104.9	968	1,013	R C1531
RADAR OCEAN SURVEILLANCE SATELLITES.								
Tt	SL-11	Jun 29.00.26	1579	65.0	89.6	250	264	Up to
			Then	65.1	103.9	903	987	27 Sep
		Oct 31.12.27	1607	65.0	89.6	250	264	-
ELINT OCEAN SURVEILLANCE SATELLITES.								
Tt	SL-11	May 30.18.45	1567	65.0	93.3	431	441	-
		Aug 7.22.51	1588	65.0	93.3	427	445	-
EARLY WARNING SATELLITES.								
Pl	SL-6	Mar 6.17.13	1541	62.9	710.4	592	39,397	R C1278
			Then	63.0	717.6	606	39,742	
		Apr 4.01.42	1547	62.9	707.0	583	39,239	R C1382
			Then	62.9	717.6	609	39,738	
		Jun 6.15.35	1569	62.9	710.1	589	39.387	R C1518
			Then	63.0	717.8	606	39,749	
		Jul 3.21.22	1581	63.0	708.3	617	39.267	R C1317
			Then	63.0	717.6	634	39,712	
		Aug 2.08.41	1586	62.9	709.3	602	39,332	R C1456
			Then	63.0	717.6	608	39,737	
		Sep 7.19.15	1596	62.9	707.6	604	39,248	R C1348
			Then	62.9	717.8	631	39,724	
		Oct 4.19.51	1604	62.9	710.6	593	39,409	R C1367
			Then	62.9	717.1	610	39,714	
STORE-DUMP COMMUNICATIONS SATELLITES.								
Pl	SL-8	Feb 21.15.39	1538	74.1	100.7	777	810	R C1420
		Jun 8.11.31	1570	74.1	100.9	790	810	R C1452
OCTUPLE PAYLOAD COMMUNICATIONS SATELLITES.								
Pl	SL-8	Jan 5.20.09	1522-1529	74.0	115.5	1,461	1,494	C1522
		May 28.21.53	1559-1566	74.0	115.8	1,471	1,511	C1559
PROBABLE GEODETIC SATELLITES.								
Pl	SL-14	Aug 8.12.14	1589	82.6	115.9	1,491	1,501	-
		Nov 27.14.27	1612	82.6	98.4	135	1,230	Failure ?
GEOSTATIONARY SATELLITES.								
Tt	SL-12B	Mar 2.03.54	1540	1.4	1,435.7	35,730	35,828	80°E
		Mar 29.05.53	1546	1.2	1,436.8	35,781	35,820	338°E

A list of the non-recoverable Cosmos satellites (excluding Cosmos 1603) launched in 1984. Satellites are classified by mission and then orbital inclination. The "Notes" indicate the satellite for which the orbit is given for multiple payload missions, satellite replacement ("R C....") or for Cosmos 1579 the date to which the satellite operated. The sub-satellite locations at the end of 1984 are given for the two geostationary Cosmos missions. "KY" is the Kapustin Yar launch site.

5.2.1 *Area Survey Missions*

Cosmos 1516, in orbit at the beginning of 1984, was an area survey mission at 64.9°. There were three launches in the group during the year, one at each of the inclinations 62.8°, 64.9° and 70.0°.

Cosmos 1543 was the first photoreconnaissance mission at 62.8° since 1980; the reason for the re-introduction of this inclination is unclear. The classification of Cosmos 1543 as an area survey satellite is open to question, since its flight was somewhat unusual. After launch on 10 March, the initial orbit was 216-395 km. Although apogee decayed to 379 km during the satellite's lifetime, the perigee remained almost at its original altitude, as if small corrections were being made to maintain the altitude. However, no large manoeuvres were made until re-entry.

The satellite is classed as an area survey mission for two reasons:

1. The orbital altitudes are similar to those found on some area survey missions.
2. The lifetime of 25 days is longer than one would expect for a third generation mission (despite Cosmos 1587 and 1613).

Additionally, Cosmos 1543 came mid-way between two other area survey missions (Cosmos 1516 from 1983 and Cosmos 1552).

Cosmos 1552 was unusual in that the initial perigee of 182 km was more akin to a close look satellite, but three days after launch the perigee had been raised to 224 km – typical for an area survey satellite. The most notable feature was the lifetime of 173 days, nearly three times the previous duration record of a Soviet photoreconnaissance satellite.

The final area survey launch of 1984 was Cosmos 1608. After the long life of Cosmos 1552, it was surprising that Cosmos 1608 was recalled after only 33 days. This was the first fourth generation flight at 70.0° (although some flights had been made at 70.4°).

5.2.2 *Close Look Missions*

Cosmos 1511, in orbit at the end of 1983, was a close look satellite, and the only photoreconnaissance satellite in orbit at the end of 1984 was Cosmos 1611, a close look mission at 64.8°. During 1984 there were two launches at 64.8° and six launches at 67.2°.

The flights of Cosmos 1576, 1585 and 1599 were somewhat longer than usual for this type of mission, although by no means in the same class as Cosmos 1552.

It is interesting to note that during 1984 there was a close look photoreconnaissance satellite in orbit for almost every day, the first time that sueh coverage has been obtained.

A record in satellite coverage was set during 22-26 June when six photoreconnaissance were in orbit at once:

Cosmos 1552; 64.9°; 4G-AS
Cosmos 1558; 67.2°; 4G-CL
Cosmos 1571; 70.0°; 3G-MR
Cosmos 1572; 82.3°; 3G-HR
Cosmos 1573; 72.9°; 3G-HR
Cosmos 1575; 82.3°; 3G-HR

6. NON-RECOVERABLE COSMOS SATELLITES

The vast majority of Cosmos satellites within this classification falls into well-established groups, with only a few anomalies appearing. The most anomalous flight was Cosmos 1603, which is considered in Section 7.

6.1 Electronic Intelligence Satellites

There were eight launches during 1984 of the Cosmos satellites considered to be primarily electronic intelligence gatherers, this figure excluding the flights dedicated to ocean surveillance. Cosmos 1578 was a unique mission from

Kapustin Yar, the SL-8 booster never having flown with such a high apogee from that site before. It is possible that scientific experiments may be announced later, but here the flight is assumed to be of the Elint type.

Cosmos 1534 and 1601 were launched into standard orbits at 65.8°, but the orbit for Cosmos 1615 was more eccentric than normal for this inclination. These flights are generally considered to be radar calibration missions.

During 1984 there were no launches of the Elint satellites which had flown at 81.2° into 97-98 minute orbits. Their demise marks the retirement of the original Vostok SL-3 booster after continual use between 1959 and 1983. The replacement missions are probably the Cosmos flights at 82.6°.

There were four flights in the presumed Elint group at 82.6° during 1984. The missions might not be totally military, since some of the Cosmos flights have been identified by the Soviets as oceanographic research satellites, Cosmos 1602 being so identified in 1984. Figure 5 presents the ascending nodes of the satellites in the group launched in recent years. It is uncertain how many orbital planes should be considered for this system: the displayed spacings vary from 33° to 64°, the mean being 51°, which a seven satellite system would require. However, replacement missions are not easy to identify from orbital planes. The original 81.2° system consisted of six satellites separated by 60°.

The Soviets have described the work of Cosmos 1500, launched in 1983 and announced as oceanographic. The satellite uses sideways-looking radar to observe ice coverage in the Arctic and Antarctic and helps to co-ordinate ship movements at sea. The radar operates at a wavelength of 3 cm and obtains a ground resolution of 1.5-2 km. The satellite also carries a multi-channel low-resolution scanner (operating at 4 Hz and resolution is 1.5 km) and a multi-channel microwave radiometer (operating at 0.8, 1.35 and 8.5 cm) [22].

6.2 Navigation Satellites

Launches took place in the two programmes of navigation satellites during 1984: two flights were in the triple-payload Glonass system and nine were in the single-payload SL-8 series.

The Glonass launches were named Cosmos 1554-1556 and 1593-1595, placed in orbit using the Proton SL-12 derived booster. Cosmos 1554-1556 were co-planar with the previous launch, Cosmos 1519-1521, while Cosmos 1593-1595 were co-planar with the triplets Cosmos 1413-1415 and 1490-1492. Since the orbital planes are spaced 120° apart, there is still one potential orbital plane that is empty.

There seem to have been some problems in replacing satellites at 83° in the small navigation satellite programme. Cosmos 1386 was initially replaced by Cosmos 1513, but that seems to have failed quickly to be replaced with Cosmos 1610. Similarly, Cosmos 1428 was replaced initially by Cosmos 1535, but that failed to be replaced by Cosmos 1550. This latter satellite also seems to have failed and the last launch to the orbital plane was Cosmos 1598. Cosmos 1383 (given the Kospas-1 number in the international air-sea rescue system) was replaced by Cosmos 1553, which was not given a Kospas number. Cosmos 1339 was replaced by Cosmos 1574, which was identified as a Kospas satellite, but not given a Kospas number.

6.3 Early Warning Satellites

Seven of the nine early warning satellites were replaced in 1984, and since most appeared to be operating at the end of the year it is the nearest that the Soviets have come to a perfect 40° spacing in orbital planes for the system.

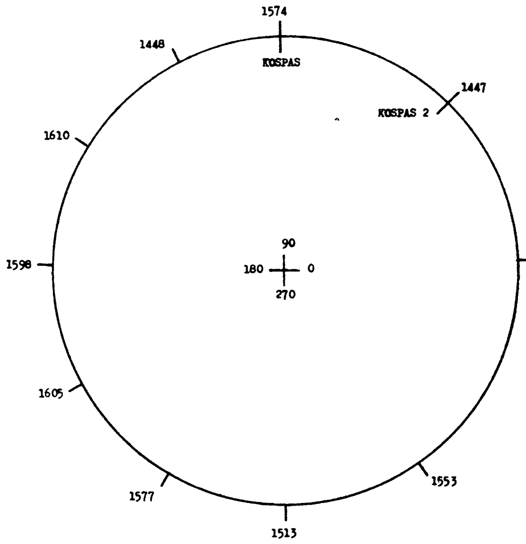

Fig. 6. The RAs of the ascending nodes for the navigation satellites launched into 83°, 105 minute orbit. Cosmos 1383 for which a Kospas number was given was replaced by Cosmos 1553 which had no Kospas number. Cosmos 1574 was said to have been part of the Kospas system, but no number was allocated to it. Not reflected in this figure are the presumed failures launched in 1984: Cosmos 1531 (replaced by Cosmos 1610), 1535 (replaced by 1550) and 1550 (replaced by 1598).

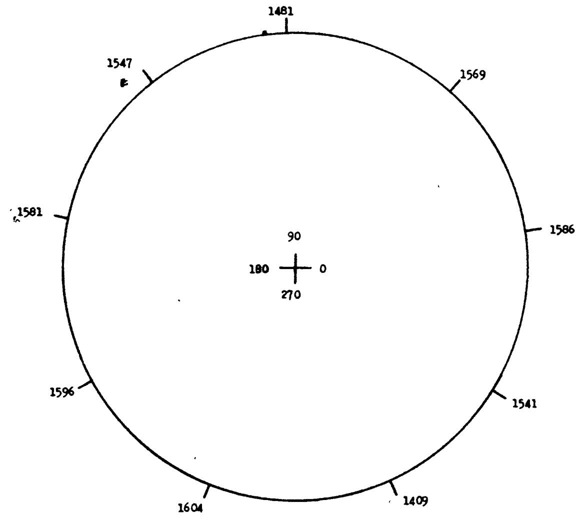

Fig. 7. The RAs of the ascending nodes for the Cosmos early warning satellites. It is uncertain whether the two earliest launches are still returning data.

6.4 Radar Ocean Surveillance Satellites

These are the Rorsats that gained publicity in 1978 and 1983 when Cosmos 954 and 1402 failed to manoeuvre their nuclear power source into high orbits at the end of operations. After the second failure, there was a break of 18 months before another mission was launched.

Cosmos 1579 was launched on 29 June and entered a standard 250-264 km orbit in which it operated for three months. On 27 September, on the orbit beginning at 09.53, the satellite split into three sections and one object manoeuvred to a high 903-987 km orbit, at which time a fourth

object (the uranium power source) separated.

A month after Cosmos 1579 ended operations, Cosmos 1607 was launched into an identical initial orbit. It was still operating at the end of 1984.

6.5 Elint Ocean Surveillance Satellites

At the end of 1983 there were two Eorsats operating in orbit, Cosmos 1461 and 1507. These were phased out of operational use during the first half of 1984, and two new satellites were launched, Cosmos 1567 and 1588.

6.5.1 Cosmos 1461 and 1507

At the beginning of 1984 Cosmos 1461 and 1507 were operating together. Cosmos 1461 would cross the equator 47.2 minutes before Cosmos 1507, and the node would be 5.9° to the east as a result. Cosmos 1507 would repeat any Cosmos 1461 node 24h 8m later. This continued until 30 January, when Cosmos 1461 was manoeuvred from its 324-444 km operational orbit initially to 472-557 km and then to 589-870 km. The satellite ended operations, with slow orbital decay beginning.

It is difficult to assess from the orbital data when Cosmos 1507 ended operations. The operational orbit was generally maintained but perigee was slowly reduced and apogee increased by a few kilometres over the next few months. When Cosmos 1461 was manoeuvred, Cosmos 1507 was in a 429-443 km orbit, but when the next satellite in the series was launched on 30 May the orbit was 423-449 km, and Cosmos 1507 seems to have never operated with the new Cosmos 1567.

The orbital altitude of Cosmos 1507 continued to change slowly, with the maximum altitude being attained about 19 November (orbit 421-458 km). Presumably, the manoeuvres were being performed by the low-thrust engine normally used to maintain the orbital spacings of pairs of these satellites, but it was being burned to depletion. After about 19 November, natural decay seems to have set in and on 30 December the orbit had decayed to 418-454 km.

6.5.2 Cosmos 1567 and 1588

A new Eorsat was launched on 30 May and named Cosmos 1567. There was a delay of more than two months before a second satellite in the series was launched, Cosmos 1588. The orbits were chosen to allow Cosmos 1567 to cross the equator 46.8 minutes ahead of Cosmos 1588, and with its node 11.8° to the east. This spacing meant that any node of Cosmos 1567 would be repeated by Cosmos 1588 1d 22h 27m later. At the end of 1984 this orbital spacing was still being maintained.

6.6 Military Communications Satellites

Two groups of satellites are to be considered here: the singleton launches of store-dump satellites into 101 minute, 74° orbits and the octuple launches into 115 minute, 74° orbits.

Two satellites in the store-dump series were launched, replacing satellites launched in 1982 and 1983. At the end of 1984 the three satellites operating in the system were Cosmos 1503, 1570 and 1538 in order of increasing ascending node longitude.

The octuple launches were Cosmos 1522-1529 and 1559-1566. The first launch continued the recent policy of launches being at six-monthly intervals, but the second was only five months later. The flights continued in the same orbital planes used for all the earlier missions in this series.

6.7 Geostationary Satellites

There is not a proper Cosmos geostationary satellite programme as such, and any flights in this group would normally be classified as either test flights of Statsionar (or another system) improvements or possible failures.

Cosmos 1540 was launched on 2 March and allowed to drift to 80° E, where it remained until the end of the year. The flight was reminiscent of Cosmos 1366 launched in 1982, and it was said to be carrying "experimental equipment for relaying telegraph and telephone communications in the centimetre waveband."

At the end of March a second geostationary Cosmos was launched, number 1546. This time, however, no comment was made about the satellite carrying experimental equipment, and since the satellite was allowed to drift (according to the Two-Line Orbital Elements) for more than a month, it was initially thought to be a failed Statsionar. Towards the end of May the westwards drift stopped, and the satellite was stationed over 338° E. This does not exactly correspond to a registered Soviet geostationary location, but it is close to that registered for GALS 1, Loutch P1, Statsionar 8 and Volna 1. Possibly this was either a test flight or an intended Statsionar 8 which initially was thought to be failing and therefore given the "Cosmos" cover name. At the end of 1984 Cosmos 1546 was situated over 336° E.

6.8 Geodetic Satellites

Cosmos missions assigned to the geodetic category are generally those singleton launches that fly at more than 1,000 km altitude and have no other mission assigned. There was one such mission in 1984, together with another mission that may have been a failure.

Cosmos 1589 was launched into an orbital altitude slot similar to that previously assigned to geodetic missions: Cosmos 1312 (1981) and 1410 (1982) at 82.6° and 1510 (1983) at 73.6°.

The orbit attained by Cosmos 1612 is an anomaly, and the perigee of 135 km was so low that the orbit would not be maintained for many months. However, some clues about the flight may be obtained from the orbit:

1. The perigee of 135 km is akin to that sometimes found when the Two-Lines list the initial ascent orbit of a high circular payload orbit mission.
2. The perigee is in the nothern hemisphere, while most high circular orbit missions have a southern hemisphere perigee, indicating a manoeuvre to circularise the orbit.

It would thus appear that Cosmos 1612 should have entered a circular orbit more than 1,200 km high, but the final booster stage failed to circularise the orbit. The displayed apogee of 1,230 km is lower than for recent geodetic flight circular orbits, but possibly the initial orbital injection was also cut short, thus not allowing the full altitude to be attained.

7. COSMOS 1603: A UNIQUE MISSION

Cosmos 1603 is the most interesting manoeuvrable mission to have been launched by the Soviet Union for many years. The launch was made from Tyuratam on 28 September at

14.00, and a Proton variant was used. The launch announcement gave the orbit as follows: 71.2°; 102.2 min, 852-877 km. However, this hid the manoeuvres that had been made.

7.1 Objects from Cosmos 1603

Six objects were tracked in orbit; the initial orbital data from the Two-Lines are given in Table 8.

The number of objects suggests either a Statsionar or Glonass launch, neglecting the number of payloads carried by the latter:

1. Two-three objects in a low orbit at 51.6°.
2. Two objects in an intermediate transfer orbit (Statsionar: 47°; Glonass: 52°).
3. Payload(s) and apogee motor in final circular orbit.

Radar cross-section measurements of the non-payload objects in the low, intermediate and high orbits for Cosmos 1603 also strongly resembled those found on the Statsionar and Glonass missions in the corresponding orbits. The initial low orbit was more like that of a Statsionar (Ekran 13: 182-192 km) or a Glonass (Cosmos 1593-1595: 183-191 km) mission using the SL-12 derived Proton than a space station mission (Salyut 7: 212-227 km or Cosmos 1443: 193-231 km) using the SL-13 Proton.

7.2 Cosmos 1603 Manoeuvres

According to Refs. 23 and 24, the manoeuvres took place the day after launch. However, more detailed analysis showed this to be incorrect.

The final manoeuvre from 66.56° to 71.01° was the easiest to pin-point, and this was done by searching for the minimum distance between 1984-106A and 1984-106F in their different orbits. Calculations showed that the final manoeuvre had taken place 15h 42m 05s on the day of launch when the satellite was situated over 62.60° N, 40.05° E – almost over the Plesetsk launch site.

Taking the orbits into account, two further manoeuvres must have taken place, and these would have been on the first southbound equator crossing at 14h 32m 51s (51.61°, 188-193 km to 51.61°, 190-844 km) and the first equator crossing northbound at 15h 21m 05s (51.61°, 190-844 km to 66.56°, 835-854 km). The resulting orbital manoeuvres were therefore: Manoeuvre 1 182, Manoeuvre 2 1,918 and Manoeuvre 3 1,913 m/s. These do not directly tie-in with any mission. For Statsionar, two manoeuvres are made, 2,461 and 2.313 m/s (for Ekran 13), while those on the Glonass launches are 1,862 and 1,561 m/s (Cosmos 1593-1595). The significance of the second and third manoeuvres being almost identical is uncertain.

It is difficult to decide which objects made the manoeuvres. There could be a rocket body and fragment in the 66.56° orbit and a separate rocket body and fragment in the 71.01° orbit. If so, the rocket in the 66.56° orbit must be the first restartable rocket stage to be flown on a Proton. Alternatively, a single rocket could have performed all three manoeuvres, with the objects in the intermediate orbit being discarded equipment (possibly strap-on fuel tanks).

One clue may be the rapidity of the three manoeuvres, suggesting that non-storable propellants were being used. A further speculation is that the manoeuvres were performed using high-energy propellants. Possibly liquid oxygen and liquid hydrogen are being introduced to the programme at last.

The actual purpose of Cosmos 1603 is obscure at present,

TABLE 8. Orbital Data for Cosmos 1603.

Object	Epoch 1984	Incl °	Period min	Perigee km	Apogee km
1984-106A	Sep 29.63	71.01	101.98	850	856
1984-106P	Sep 30.20	71.00	101.98	849	855
1984-106C	Sep 30.19	66.56	101.59	814	854
1984-106D	Sep 28.94	51.61	88.30	188	193
1984-106E	Sep 28.94	51.60	88.22	180	193
1984-106F	Sep 29.49	66.56	101.82	835	854

The six objects that resulted from the Cosmos 1603 launch, together with their orbits. These data are the starting point for any analysis of this mysterious mission.

but probably it was the testing of a new restartable high energy propellant upper stage for the Proton. Such a stage is difficult to find an application for within the Proton programme at present, so possibly it is connected with the reported new generation of launch vehicles.

A subsequent report in Ref. 25 suggested that Cosmos 1603 was the first of a new generation of Elint satellite, launched by the SL-12 booster. The theory cannot be confirmed as of early 1985. If the SL-12 was used, then taking a Proton escape stage as 1,900 kg dry and having a specific impulse of 285 seconds, suggests that an initial mass in low parking orbit of 22.5 tonnes would place 10.6 tonnes into the 66.56° orbit. This would imply 4.5-5 tonnes into the 71° operational orbit. These calculations assume that the first two manoeuvres (182+1,918 = 2,100 m/s) were performed by the Proton escape stage – the first time that it would have re-ignited in orbit.

8. THE PROTON BOOSTER REVEALED

Of the five types of launch vehicle (Sapwood, Sandal, Skean, Proton and Scarp) used operationally in the Soviet space programme, the Proton has been the most mysterious. During its 19 years of use only a few glimpses have been given of its upper stages and the complete booster had not been depicted. With the launch of Vega 1 in December 1984 the first full views were released.

Previously, the pictures available of the booster on the pad were:

1. Salyut 1 launch, showing the booster at night. The payload and upper stages were shown and a glimpse of the tips of strap-on boosters [26].
2. Venera 9 and 10 on the pad, showing the upper part of the orbital stage, the escape stage and the payload shroud.

Stills from a film dealing with Venera 9 and 10 showing the upper part of the Proton booster have not been published. Additionally, there were pictures of Luna 17 being mated to its escape stage [27] and Venera 9/10 attached to the escape stages with the shrouds about to be mated (in the film commented upon above).

Figures 8a and 8b are based upon the Venera and Salyut pictures, with the limits of photographic coverage indicated. The pictures of the Vega launch allowed the lower part of the booster to be scaled for the first time from official Soviet data; this is reflected in Fig. 8c.

The launch pictures showed the vehicle initially on the pad, the lift-off and the pitch-over manoeuvre. Six strap-ons were clearly shown, and at pitch-over the central core was still awaiting ignition.

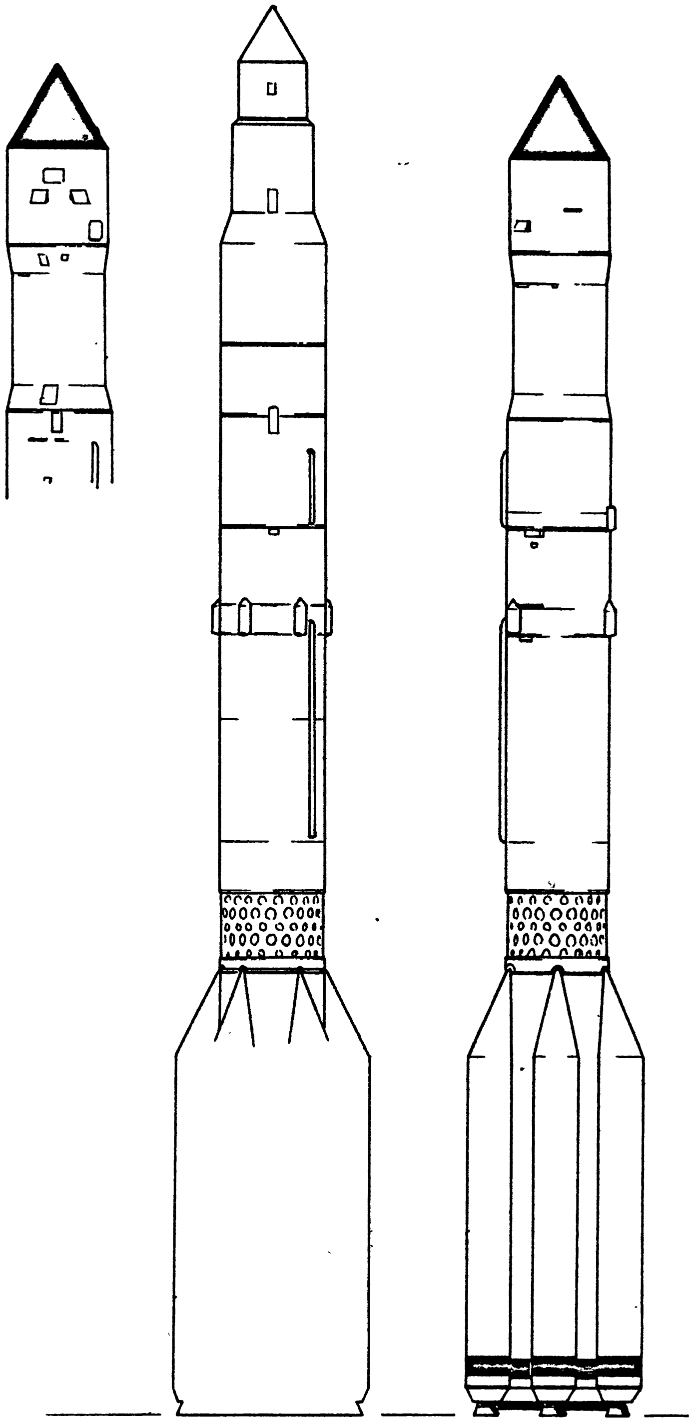

Fig. 8. Three drawings of the Proton booster. At left (a) is the upper part of the booster as shown in a film dealing with Veneras 9 and 10 (1975) and centre (b) shows the upper core, orbital stage and payload for the Salyut 1 booster, with the six strap-ons now extrapolated below the previous limit of vision (indicated by the dotted line). Right (c) shows the Vega 1 booster, with data incorporated from the illustrations at left.

TABLE 9.

Stage Name	SL-12 Venera	SL-13 Salyut 1
First stage strap-ons (6)		
Length (m)	18.5	18.5
Diameter (m)	1.7	1.7
Second stage central core		
Length (m)	31.4*	31.4*
Diameter (m)	4.2	4.2
Third (orbital) stage		
Length (m)	8.3	8.3
Diameter (m)	4.2	4.2
Fourth (escape) stage		
Length (m)	4.4	-
Diameter (m)	3.7	-
Salyut + Payload shroud		
Length (m)	-	16.2
Diameter (m)	-	4.15
Probe shroud		
Length (m)	4.4	-
Diameter (max) (m)	3.9	-
Total length (m)	52.4	55.2

* It is just possible that the core has two stages, in which case this length is for the combined stages.

Approximate dimensions of the Proton booster. Data for the Salyut 1 vehicle combine the launch picture for that mission and the Vega 1 launch pictures. Data for the Venera booster combine the pictures from 1975 with the Salyut 1 orbital stage and the Vega 1 pictures. The dimensions are still estimated, and assume that the core and orbital stage diameters are 4.15 m – the same as the maximum for Salyut.

Using the drawings in Fig. 8, approximate dimensions for the stages can be obtained; those are given in Table 9. Different missions will have different lengths, particularly for the SL-13. The boosters for Salyuts 1 and 4 were of the same length, while a question mark must be left for Salyuts 2, 3 and 5 which were of a different (unrevealed design). The different engine arrangements for Salyuts 6 and 7 would not require as long an engine shroud as Salyut 1. The major SL-12 variant would be for the Zond missions, which used a totally different payload shroud with a shroud tower.

9. THE FUTURE

The manned programme during 1985 will continue to revolve around the Salyut 7/Soyuz T/Progress combination, possibly with an added heavy Cosmos module docked with Salyut. The sub-scale spaceplane has now had four flights, and the time must be ripe for the full-scale vehicle to be flown. A series of new boosters are on the point of being introduced according to some reports [28]. The order of development could be:

1. Test flight of the new Intermediate booster, with a token payload.
2. Test flight of the spaceplane on the Intermediate booster.
3. Test flight of the Heavy Lift booster carrying ballast into orbit.

There are some reports that a manned flight of the spaceplane can be expected during 1985, but it is not known whether this will be preceeded by an unmanned test mission.

If these flights are successful, the Soviet Union will be ready to begin its next major space station project. According to Rukavishnikov, the next space station will be modular and it should be completed by 1990. It is possible that the Heavy Lift booster will be used to orbit a large core station, with further sections being carried into orbit by either the Proton or Intermediate boosters. The core launch could take place in late 1986 or 1987, at which time the spaceplane will replace Soyuz T and Progress at the routine manned

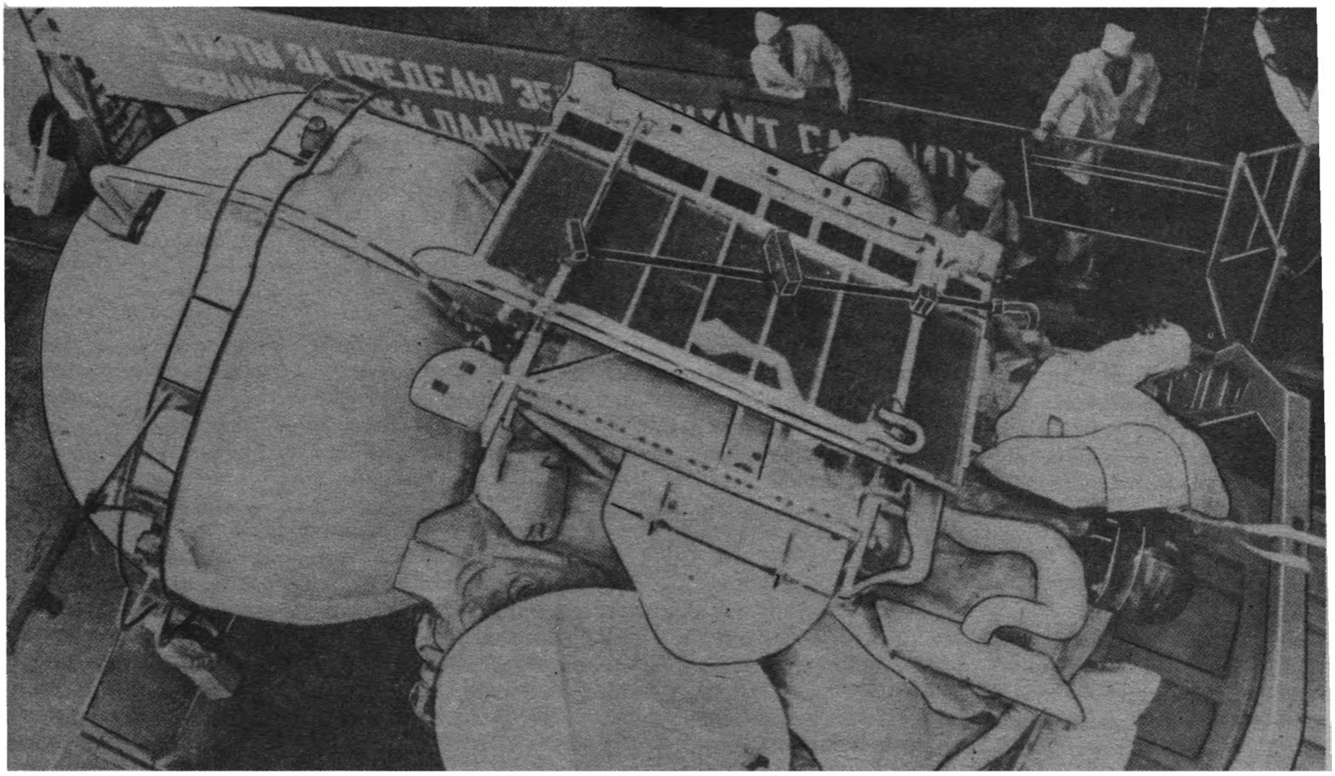

Fig. 9. A Vega probe is prepared for launch. The lander and balloon are housed in the sphere at left.

Novosti

and cargo ferry craft.

Following Vega, planetary interest will switch to Mars, with an orbiter mission being planned for launching during the May 1986 opportunity. This will be placed in an orbit such that Phobos and Deimos can also be investigated. If Mars probes are in transit in the summer of 1986, it remains to be seen whether the Soviets will also launch probes to Venus again when that opportunity next presents itself in August 1986. If they are launched, they will be arriving at Venus during the same time period as the Mars probes will be entering Martian orbit.

10. SUMMARY

The year of 1984 was particularly successful for the Soviets, with no major failures. The most surprising aspect was the non-appearance of the new family of launch vehicles, when flights by the Intermediate booster in summer and the Heavy Lift booster later in the year had been predicted.

One other event during 1984 does not fall within any of the above headings. On 8 December the death of Vladimir Nikolayevich Chelomei took place at the age of 71. Chelomei was a major designer within the Soviet space programme, his interests rivalling those of Korolyov. He is generally credited with being the chief designer of the Proton and Salyut. In his official obituary none of his space work was mentioned, although details might be revealed some months after his death, as happened with Korolyov.

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AN HISTORICAL OVERVIEW OF NASA MANNED SPACECRAFT AND THEIR CREW STATIONS

J. P. LOFTUS
NASA Johnson Space Center, Houston, Texas, USA.

The first generation of manned spacecraft demonstrated all the types of mission activity we plan for the future. Development of these spacecraft and execution of their missions have provided the experience base for the design of current and future spacecraft systems. This paper summarises the crew station characteristics of the Mercury, Gemini, Apollo, Skylab, Apollo-Soyuz and Space Shuttle spacecraft and the design strategies that dictated those characteristics. Also included are some comparisons with current and planned spacecraft and an assessment of the lessons learned as they might be applied in future spacecraft designs.

1. INTRODUCTION

Manned space flight evolved from two lines of technology. One line was developed from experience with high performance and experimental aircraft; the other evolved from experience with rocket-propelled vehicles. The characteristics of manned spacecraft have been derived almost completely from the traditions of aircraft. At the time that rocket technology was progressing at a rate that would make manned space flight feasible, high-performance aircraft were already operating at altitudes functionally equivalent to space flight. Control stability over a wide range of dynamic conditions had been studied, and substantial empirical and experimental data about optimum methods of integrating man into the vehicle, both as a control element and as a system and mission manager, had been developed. Major modifications to crew accommodations in the progression from aircraft to spacecraft were geometric accommodations to the acceleration environments of launch and entry and to the weightless conditions of orbital flight [1-5]. Other modifications were induced by the shiplike characteristics required for long-duration missions, which imposed system servicing requirements and long-term habitability management on the spectrum of crew duties.

The effects of the space environment on man's sensory and motor performance and on higher order mental functioning could not be predicted with certainty. Therefore, man's role at the beginning of manned space flight programmes was that of a semi-passive passenger whose capability had to be demonstrated and who could act as a backup system if a primary system failed. With continued successful task accomplishment, man's role in spacecraft has evolved to that of mission manager where crewmen supervise highly automated systems and manually execute critical operations. In this capacity, the crewman provides the capability to select the system configuration and modes most suitable for characteristics of the particular mission phase and to reconfigure the systems to influence system performance during off-normal conditions.

That optimisation of the crew-to-spacecraft interface is not a specific objective of any manned space flight programme is important to note in any review pertaining to spacecraft design details influenced by the interface between crew and spacecraft. The design objective is to optimise the achievement of programme objectives, not the configuration of the crew compartment, the displays and controls, or the other interfaces through which the crew affects spacecraft activities. In this group of interfaces, as in all other systems, compromises are made to each of the interfacing elements to achieve overall programme effectiveness.

In the sections that follow, the geometric characteristics of the spacecraft that define the work environment for the crew and the equipment management and housekeeping necessary for hygiene, comfort and safety are described. The controls and displays of each spacecraft are described to indicate the degree to which crew functions are integral to functions of the total spacecraft.

The general systems characteristics of each spacecraft are shown in Table 1. As the programmes have defined more ambitious mission objectives, the spacecraft size increases

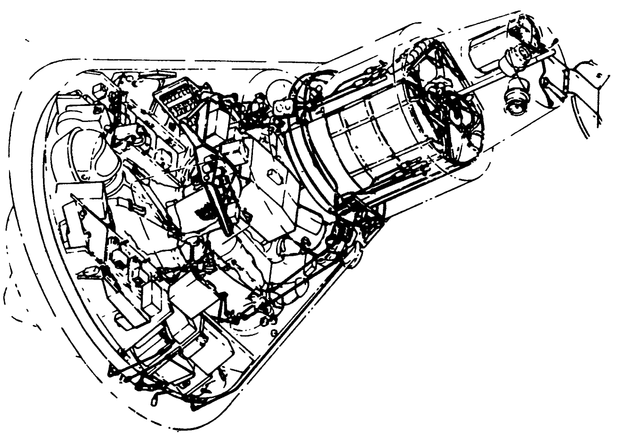

Fig. 1. Mercury spacecraft.

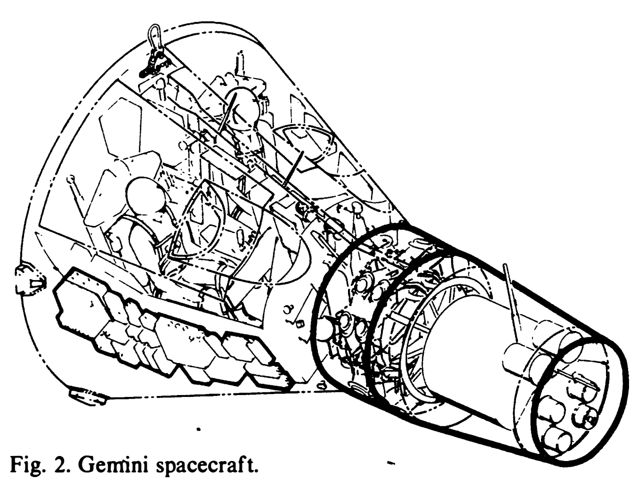

Fig. 2. Gemini spacecraft.

TABLE 1. General Systems Characteristics.

Characteristic	Mercury	Gemini	Apollo		Skylab		Apollo-Soyuz		Shuttle
			Command module	Lunar module	Command module	Orbital workshop	Command module	Docking module	Orbiter
Weight, kg	1208	2165	5668	5178	6088	54 932	5843	5907	90 249
Volume pressurized, m^3	1.43	2.35	7.65	6.65	7.65	351.08	7.65	4.67	71.46
Windows	1	2	3	3	3	3	3	N/A	10
Maximum duration, days	1-1/2	13-3/4	12-1/2	3	8	84	9	9	7-30
Crew size	1	2	3	2	3-5[a]	3	3	6	2-7
Electrical power	Battery 3 primary 9000 Ah 1 standby 1500 Ah 1 pyro 1500 Ah 2 250 V ac 400 Hz 1 150 V ac 4100 Hz	2 fuel cells 25 V NiCd or 6 batteries 400 Ah each Entry 4 batteries 45 Ah each 3 pyro 15 Ah each	3 fuel cells 25 V NiCd 1.5 kW each 5 batteries 200 Ah each 2 pyro batteries 80 Ah 3 115 V ac 400 Hz	Battery 28 V NiCd 4 descent 400 Ah each 2 ascent 400 Ah 2 115 V ac 400 Hz	2 fuel cells 28 V NiCd 1.5 kW each 8 batteries 200 Ah 2 pyro batteries 80 Ah 3 115 V ac 400 Hz	Solar array ATM 11 000 W OAS 11 000 W (5500)[b] 26 batteries 40 Ah each 4 115 V ac 400 Hz	3 fuel cells 280 V NiCd 1.5 kW each 5 batteries 200 Ah 2 pyro batteries 80 Ah 3 115 V ac 400 Hz	N/A	3 fuel cells 28 V NiCd 7 kW each 3 115 V ac 400 Hz
Mission energy	9-11 kWh	30-151 kWh	670 kWh	50 kWh	400 kWh	[c]24 714 kWh	557 kWh		2400 kWh
Number of electrical buses and circuit breakers	4 20	6 107	14 264	5 160	14 256	30 540	14 262	2 5	110 [d]961
Thermal control	Cabin gas cooling Water boiler	Cold plate Water glycol radiator	Cold plate Water glycol radiator	Cold plate Water glycol sublimator	Cold plate Water glycol radiator	Cold plate Water glycol radiator	Cold plate Water glycol radiator	Cabin gas	Cabin gas Cold plate Water glycol radiator Ammonia boiler[e]
Onboard computation	None	1 Computer Rendezvous Navigation	Primary GN&C 50 modes Backup flight control	Primary GN&C 15 modes Abort guidance system	Primary flight control 22 modes Backup flight control	Two computers, For flight and systems control	Primary flight control 22 modes- Backup flight control	N/A	General purpose computers: 5 - 4 primary, 1 backup 140 modes; flight control and system management
G&N and attitude reference	Gyros 3 Horizon scanner	Inertial measurement unit Gyros 3 Horizon scanner	Inertial measurement unit Gyros 3 Sextant VHF ranging	Inertial measurement unit Strapdown IMU Radar Alignment telescope	Inertial measurement unit Gyros 3 Sextant	Rate gyros Sun sensors (x,y) Star tracker (Z)	Inertial measurement unit Gyros 3 Sextant VHF ranging	N/A	Inertial measurement unit: 3 Star tracker Radar TACAN MSBLS
Attitude control, N-s	30 967	Entry 90 478 Orbit maneuvering system 1 077 524	Entry module 256 714 Service module 1 653 828	782 483	329 521 3 517 470	Control moment gyros 3 Cold gas 273 766	329 531 3 517 470		9 236 304
Orbital maneuver ΔV, m/s	98.8	99.1	1951	Descent 2135 Ascent 1850	533.1		271.1		304.8

[a]Rescue mission configuration.
[b]One wing failed due to launch damage.
[c]During 4100 hours of manned occupancy.
[d]421 circuit breakers and 541 remote power controllers with a circuit breaker function.
[e]Ascent and descent.

and the systems become more complex. In Table 1, the growth of spacecraft capability from programme to programme is illustrated in terms of the most significant spacecraft subsystems. The electrical power distribution system reflects system complexity most directly. Since all operating elements must be provided with at least a primary and an alternate source of power, the number of buses and circuit breakers is a good figure of merit of total system capability and complexity.

Parameters of significance to crew life support and extravehicular activity (EVA) are illustrated in Table 2. Tables 1 and 2 provide a general overview of the significant systems characteristics of past spacecraft and the manner in which they relate to the current Space Shuttle Orbiter. The history of US manned space flight missions is summarised in Appendix A.

2. GEOMETRIC CONSIDERATIONS

The most prominent characteristic of manned spacecraft is the orientation of seating so that launch and entry loads are imposed on the crewman transversely; that is, from front to back rather than from head to foot. This orientation maximises physiologic tolerance to acceleration. Orientation of interior work stations is fixed by this consideration in the Mercury, Gemini and Apollo command module (CM) spacecraft. In the Apollo command module, a second array of interior work stations is oriented at 90° to the launch- and reentry-oriented main display console. These stations are used in orbit for operation of the navigation optics, for food preparation and for other functions. The Apollo lunar module (LM) was configured so as to provide maximum visibility with the smallest possible window. Since flight acceleration loads are less than one g and the worst case landing impact loads are small, the crewman can attenuate such loads with his legs and be positioned upright close to the front of the spacecraft with the window oriented so that he can see downward, forward and to each side.

The Skylab configuration is controlled by the need to maintain a central-axis transit passage and by the endeavour to achieve a conventional architectural arrangement normal to the major axis of the spacecraft. By previous standards, the Skylab orbital workshop is a spacious spacecraft. This configuration is attributable in part to its derivation from an existing structure, the Saturn IVB (S-IVB) stage of the Saturn V launch vehicle, and in part to the need for assessing the value of greater volume to the operational effectiveness of longer missions. Volume use rate was low, reflecting the restrictions of the initial launch weight and the limited

TABLE 2. Spacecraft Life Support System Characteristics.

Characteristic	Mercury	Gemini	Apollo CM	Apollo LM	Skylab	Apollo-Soyuz	Shuttle Orbiter
Volume (habitable), m^3 (ft^3)	1.02 (36)	1.56 (55)	5.94 (210)	4.53 (160)	[a]5.94 (210)	[a]5.94 (210)	35 (1300)
Pressurized volume less volume of equipment					[b]344.98 (12 190)	[c]3.1 (109)	[d]74 (2750)
Duration (max.), days	1-1/2	13-3/4	12-1/2	3	84	9	7 to 30
Crew size	1	2	3	2	3/5	3	2 to 7
Cabin atmosphere, mm Hg (psi)	100% O_2 at 258 (5)	100% O_2 at 258 (5)	100% O_2 at 258 (5)	100% O_2 at 258 (5)	[a]100% O_2 at 258 (5) [b]74% O_2/26% N_2 at 258 (5)	[a]100% O_2 at 222 (4.3) to 296 (5.6) [c]60% O_2/40% N_2 222 (4.3) to 520 (10)	21% O_2/79% N_2 at 760 (14.7) or 27% O_2/73% N_2 at 532 (102)
Suit atmosphere mm Hg (psi)	Air cooled 181 (3.7)	Air cooled 181 (3.7)	Liquid cooled 196 (3.8)	Liquid cooled 196 (3.8)	Liquid cooled 196 (3.8)	Liquid cooled 196 (3.8)	Liquid cooled 222 (4.3)
All 100% O_2		EVA umbilical	EVA umbilical	Portable life support system	EVA umbilical		Portable life support system
Suit usage	Cabin backup	Cabin backup Ejection EVA	Cabin backup EVA Crew transfer	Cabin backup Crew transfer Lunar surface excursion	Cabin backup Crew transfer EVA Rescue	Cabin backup Crew transfer Rescue	Cabin backup Crew transfer EVA Rescue ejection (OFT)
EVA's	None	5 (5)[e]	4 (8)[e]	28	18	None	Payload accommodation and contingencies
Time, hr		12.06	8.24	162.13	83.02		

[a]Command module.
[b]Orbital workshop.
[c]Docking module.
[d]With Spacelab module and tunnel installed in the cargo bay.
[e]Parentheses indicate "standup" exposure.

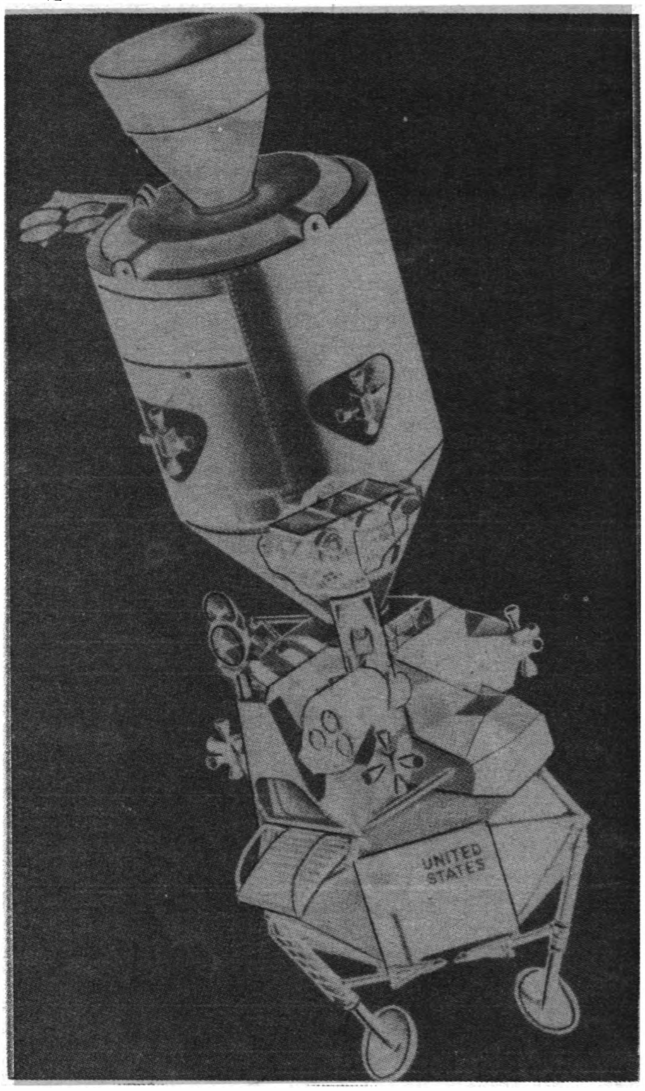

Fig. 3. Apollo spacecraft, docked configuration.

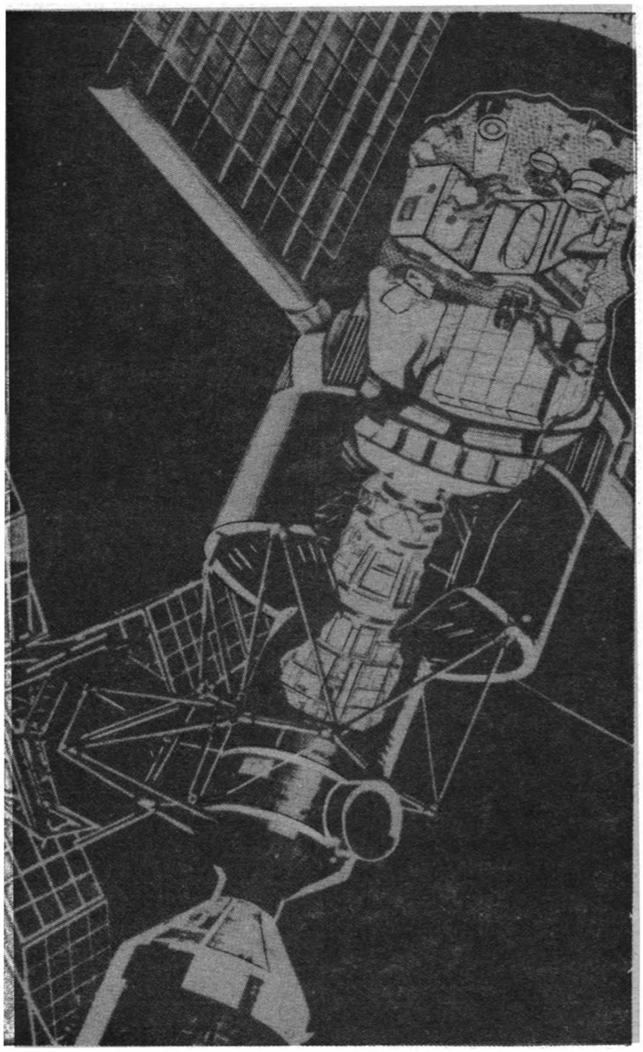

Fig. 4. Skylab Orbital Workshop with Command and Service Module docked.

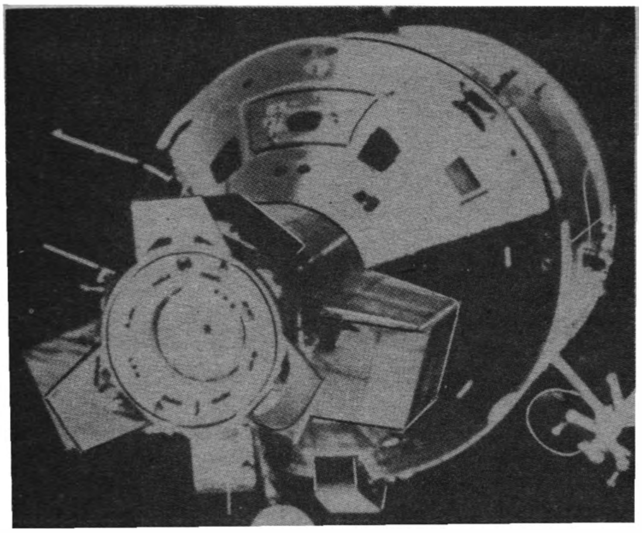

Fig. 5. Apollo spacecraft with Docking Module (configured for Apollo-Soyuz mission).

payload to and from Skylab that can be accommodated by the Apollo command module. Distribution of volume among so many modules and levels has some disadvantages in the loading and transportation of equipment through the assembly.

The general configuration of each American spacecraft is shown in Figs 1 to 6. The relationship of crew size and pressurised volume of each spacecraft is shown in Table 1. The usable volume, defined as volume within the pressure vessel that is not occupied by equipment and that can be used for temporary stowage, for movement by the crewmen or for other functions that enhance habitability, is indicated in Table 2. The volumes increase noticeably from the earliest to the later spacecraft configurations. For the Mercury spacecraft, the Apollo command module and the Shuttle Orbiter, the relationship of the pressurised volume to the effective free volume reflects that most equipment was installed within the pressure vessel. The Gemini spacecraft and the Apollo lunar module had only the crew instrument panels and portions of the environmental control system installed within the pressure vessel. The values in the table are the maximum available and were invariably reduced as equipment was added for each mission. The usable volume is generally two-thirds to one-half the pressurised volume depending upon the quantity of mission-specific equipment that is mounted in areas that are otherwise available to the crew. The historical trend is to increase the amount of such "temporary" stowage and to compromise habitability.

In 1965, Fraser [2] extensively reviewed the literature compiled on the effects of confinement. He indicates that motivated and experienced personnel, occupied with meaningful tasks and informed as to the status and duration of the mission, need a volume of 0.7 to 3.5 m^3/man for missions of seven to ten days and that 4.24 m^3/man appears to be adequate for missions as long as 30 days. The adequacy of current spacecraft by such standards is substantiated by flight experience. However, more general experience indicates that such cramped quarters are not efficient for larger populations or for small crews subjected to high workloads and long flight durations. Stresses placed on the crew by limited volume are lack of movement and exercise that leads to physiological deconditioning, loss of efficiency as two or more crewmen endeavour to pursue their duties without interfering with each other, and sleep disturbances when one crewman's motion disturbs others.

Spacecraft dimensional characteristics become significant as total spacecraft size and volume increase. Movement of crewmen and equipment can disturb the spacecraft and experiments. Such movements also can induce crew hazards from excessively rapid free flight, tumbling and impact on protuberances. Crewmen must also exercise caution in movement to avoid inducing vestibular disturbances. Crew and medical reports indicate that increased volume of the Apollo and Skylab spacecraft and opportunity for movement removed many of the discomforts and debilitating effects of the close confinement characteritics of Mercury and Gemini spacecraft. Larger spacecraft provide the free volume in which vigorous exercise can be performed, and such exercise has proved beneficial for crew health. For future space vehicles with increased performance, more volume for each occupant will enhance both efficiency of operation and habitability.

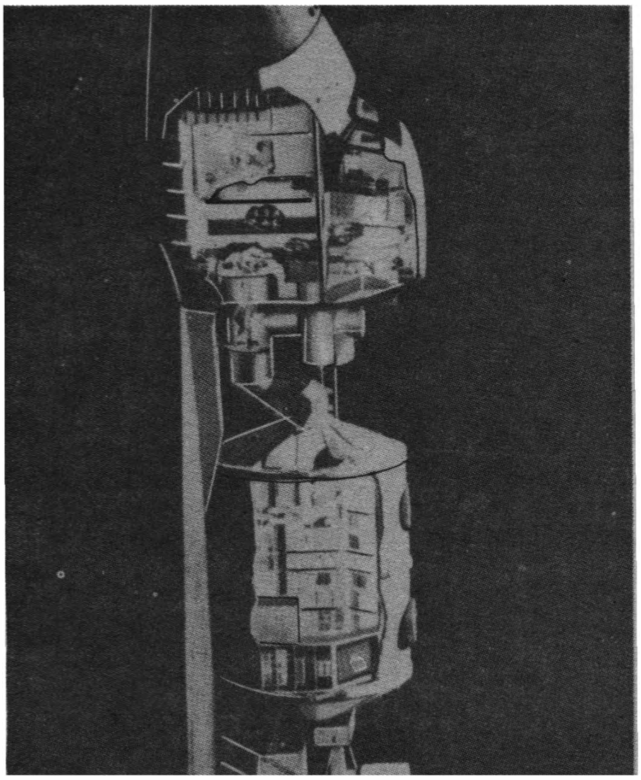

Fig. 6. The Space Shuttle Orbiter with the long module Spacelab in the cargo bay.

3. STOWAGE, HOUSEKEEPING AND EXTRAVEHICULAR ACTIVITIES

The launch and entry accelerations, the weightless environment, confined volume and considerations of safety and efficiency make stowage accommodations and housekeeping procedures a significant part of the crewman's total activity. During extravehicular activity, safety precautions become even more significant. The dynamics of object movement in orbit are such that items not secured to the spacecraft or to the crewman will separate rapidly; consequently, efficient operation requires orderly procedures and careful stowage and handling of all items. Because of the inherent interdependency of extravehicular activities with stowage and housekeeping, these tasks are discussed collectively.

The Mercury spacecraft pilot was restrained by his couch harness assembly and by the spacecraft's interior confines (Fig. 1). The spacecraft was designed as a one-man vehicle, with all items necessary for either vehicle control or personal

use within reach from the crewman's restrained position in the couch. Only one stowage compartment, which was used for flight checklists and other documents, was available. Other equipment items were stowed in bags, in pouches or on specific attachments to the interior structure.

The Gemini Program introduced a spacecraft with a two-place, side-by-side seating configuration (Fig. 2). Quarters were still cramped, and essential cockpit activities again were confined to the approximate reach envelope of the seated crewman. However, increasing activity by the crewman in more complex mission operations is evidenced by the increased number of stowed items compared with that of the Mercury spacecraft (Table 3). The advent of several compartments within the cockpit for stowage of specific items generated the need for disciplined management of loose items to make efficient use of space, to avoid time lost searching for stowage space for items in use, or to recover from stowage items required for anticipated activities.

The increase in the number and the scope of Apollo and Skylab mission objectives is reflected in the growth in the number of stowed items. This growth reflects increase in crew size and in duration of missions and emphasis on scientific objectives as operational maturity evolves. Growth in stowage requirements is caused primarily by time-dependent operational items (e.g., food and film) and by increased emphasis on scientific and applications experiment activities and additional equipment to support them. As the number of items increased, the diversity and complexity of the items also increased. Even when the items attributable to more crewmen and a longer mission are omitted (i.e., food and clothes), increases of 400% are attributable to mission objective equipment. The data for the Space Shuttle Orbiter and our expectation for the Space Station continue the trend.

The Orbiter middeck locker space is used extensively for in-flight experiment installations, as well as stowage. Stowage capacity is always used to the limit as each flight is manifested.

A problem not apparent in the tabulation of this experience is the demand placed on the crew to become familiar with all equipment manipulations. Each unit is simple in its operation and stowage, but the proliferation of such items places great demands on the crew. To contend with these factors, extensive use of decals and placards with appropriate instructions is required. These devices help to minimise training requirements and save time during mission operations.

TABLE 3. Spacecraft Stowage.

Spacecraft	Compartments	Volume, m^3	Items stowed
Mercury	--	--	48
Gemini	13	0.42	196
Apollo	25	2.12	1 727
Skylab	241	19.36	10 160
ASTP	32	2.65	1 965
Shuttle Orbiter	55	4.44	2 600
Space station	300	80.0	20 000

4. EVA CONSIDERATIONS

Preparation for EVA is one of the most demanding activities for space crews. The cabin to be depressurised must be properly organised, the equipment donned and its operation tested. In the limited volume of the spacecraft, this preparation requires well-planned procedures, teamwork and extensive training. The need for such careful simulation and training was established during some of the early Gemini extravehicular activities, when astronauts were not able to complete planned tasks. The simulation of weightlessness by water immersion has been an effective method for developing procedures and training astronauts. The water-immersion simulation is augmented by short periods of zero g produced in aircraft.

Both astronauts and cosmonauts report that EVA is pleasant, with no difficulties in orientation [3]. The crewman appears to use his body or the spacecraft as a frame of reference and is not disturbed by his relative location to the Earth and spacecraft. Since vision is the only sense stimulated and because it provides adequate reference, there are apparently none of the illusions customary when sensory cues conflict. Certain visual illusions are present to a greater degree than when the crewman is inside the spacecraft; bright stars seem closer, dim stars seem farther away and the curvature of the Earth appears more prominent. These illusions appear to some degree in all orbital flights and in many high-altitude aircraft flights.

The 1/6 g environment of the lunar surface proved to be both a help and a hindrance to crewmen during EVA. Loads heavy and cumbersome in 1 g become quite manageable in 1/6 g. However, lightweight items reacting readily to normal gravity tend to respond quite slowly in reduced gravity and become critical in the development of a proper time line. Lightweight items such as thermal blankets have inherent stiffness and must be placed in specific location desired in the 1/6 g environment; in a 1 g environment, the mass overcomes the stiffness and items fall into place.

To develop the lunar surface time line properly for a given mission, the crew begins to exercise without suits to gain familiarity with all items and progresses through a set of activities wherein each step approximates more closely the actual lunar surface activity in terms of procedural details and time planned. Final practice runs are made in pressurised suits using working models of actual hardware and adhering strictly to time allocations and procedural details. Adaptation to the 1/6 g environment has proved reasonably rapid. Movement across the surface averages 0.38 m/s during the first excursion and increases to an average of 0.61 m/s for later excursions.

Despite the extensive training, the activities take almost 30% longer during flight than during training. This additional time is caused in part by the extra time required for each movement when moments of inertia are high and control capability dependent upon reduced gravity forces is low, and in part by the time required to assess characteristics of the real-time situation. An increasing demand has been placed on lunar mission crews in terms of time allocated to actual surface EVA excursions. As greater confidence was gained in hardware performance, and as crew capability was better understood, there was a larger commitment to surface EVA as a proportion of total surface stay time. The initial Apollo mission committed only 10% of surface stay time to EVA, whereas later missions committed as much as 30% of the stay time to EVA. Most of this additional exploration capability was a function of systematically maturing hardware and procedures.

Orbital EVA proved more predictable as soon as proper techniques were designed. In Skylab, there were provisions for EVA to recover the film canisters from the Apollo telescope mount. The techniques for this operation included the use of handrails, tethers, and support similar to those used on the Gemini 12 mission and on the Apollo spacecraft for extravehicular transfer and for film recovery from the

TABLE 4. Crew Displays and Controls.

Spacecraft	Work station	Panels	Control-display elements	Computers number/modes
Mercury	1	3	143	0
Gemini	2	7	354	1/1
Apollo	7	40	1374	[a]4/50
Skylab	20	189	2980	[b]4/2
Shuttle Orbiter	9	88	2312	5/140
Space station[c]	40	200	3000	8/200

[a]Primary, backup in CM and LM.
[b]CM primary and backup, telescope, workshop.
[c]Assumes real-time control onboard, data base management from the ground.

TABLE 5. Crew Control and Display Characteristics.

Device characteristic	Mercury	Gemini	Apollo: Command module	Apollo: Lunar module	Skylab: Command module	Skylab: Orbital assembly module: Multiple docking adapter	Skylab: Orbital assembly module: Airlock	Skylab: Orbital assembly module: Orbital workshop	Shuttle Orbiter
Panels	3	7	28	12	26	31	58	74	88
Work stations	1	2	5	2	5	3	4	8	9
Control elements (total)[a]	98	286	721	378	760	350	694	363	1666
Circuit breakers	[b]20	107	264	160	256	19	307	214	[c]421/541
Toggle switches	56	123	326	144	372	239	326	88	856
Pushbutton switches	8	20	13	7	15	12	0	0	219
Multiposition rotary switches	6	19	21	16	19	50	22	32	124
Continuous rotary switches	3	0	35	21	36	17	3	9	40
Mechanical devices[e]	3	13	57	26	57	7	35	18	6
Unique devices[d]	2	4	5	4	5	6	1	2	6
Display elements (total)[a]	45	68	131	144	152	222	323	116	646
Circular meters	16	7	24	6	23	1	0	2	4
Linear meters	0	25	33	25	33	14	64	42	59
Digital readouts	3	14	18	13	19	20	1	18	12
Event indicators	19	16	47	96	68	182	258	50	559
Unique displays[e]	7	6	9	4	9	5	0	4	12
In-flight measurement points[a]	100	225	475	473	521	[f]918	[f]521	[f]281	3720
Telemetered	85	202	336	279	365	918	521	230	2707
Display onboard	53	75	280	214	289	167	129	30	[g]840/815
Caution and warning	9	10	64	145	61	97	91	8	127

[a]Numbers for each program vary, depending on partiular spacecraft.
[b]Fuses, not circuit breakers, used in Mercury.
[c]Crew compartment circuit breakers; there are an additional 541 remote power controllers with circuit breaker functions.
[d]Three-axis hand controllers, computer keyboards, etc.
[e]Flight director attitude indicator, computer displays, entry monitor, crosspoints.
[f]Of the 1720 measurements in Skylab, 1481 are science data and only 239 spacecraft operation.
[g]Eight hundred forty displayed on meter, indicators, etc.; 815 displayed on display electronics unit (CRT).

Apollo scientific instrument module.

Structural failure of the meteoroid shield during launch and subsequent failure during the mission of other equipment led to a great number of excursions and tasks not considered in the original Skylab plans. The crew successfully executed repairs and adjustments for which no preflight design provisions had been made.

The success of these endeavours confirms the adequacy of the basic design provisions and the training regimen. Orbital EVA offers no significant difficulty if the crewman has adequate cooling in his life-support system and mounting provisions which allow him to react to forces appropriately. Appendix B summarises EVA experience in past programmes.

The docking module for the Apollo-Soyuz Test Program (ASTP) was a unique system. Its primary function was to be an adaptor to reconcile the design differences between US and USSR spacecraft in the mechanical docking mechanisms and the cabin gas mixtures and pressures. In flight, it also added to the habitable volume available to the joint crews. Half the pressurised volume was available for crew movement. The remainder was occupied by an ultraviolet spectrometer for atmospheric composition observations.

Since the nominal cabin atmosphere for the Shuttle is a sea level air mixture, EVA requires crewman denitrogenation. Two procedures are available for use. A 4-hour 100% O_2 prebreathing period in the extravehicular mobility unit prior to reducing pressure to a 222 mm Hg for the EVA is one alternative. For long EVA exercises this has the drawback that the crewman is in the EMU for as much as 11 hours with limited food and fluid available. An alternative procedure reduces the cabin to a 532 mm Hg (10.2 psi) pressure with the oxygen level enriched to 27 per cent. After 12 hours or more at this condition, the prebreathing required is 45 minutes, which is the nominal timeline for EMU checkout prior to airlock depressurisation. This procedure reduces some of the stress on the EVA crew. It does constrain some types of equipment operation in the cabin because the reduced density of the cabin atmosphere provides less cooling capacity to air-cooled equipment.

Increased duration and complexity of missions; increased number, duration and complexity of extravehicular activities; and forces during launch, spacecraft manoeuvre and entry all demand orderly progression of equipment from stowed positions to use positions and to disposition locations. Many hours are spent by crews during preflight training to become thoroughly familiar with stowage provisions for each item and with the sequence in which each item is stowed, used and restowed or jettisoned. The precision with which these actions are performed has significant influence on the time allotments provided within the operational time line. Realistic values must be determined during preflight training for the times to be allocated to these activities in the mission flight plan. All astronauts and cosmonauts, during and after their missions, have remarked on the importance of order and discipline in these activities to efficient conduct of the mission. The consistency with which this aspect of each mission is discussed by astronauts and cosmonauts indicates that this aspect of accommodating to the weightless environment is a source of significant stress, where new design approaches might be beneficial. It is noteworthy that only in these housekeeping activities and in the related extravehicular activities does flight performance require significantly longer amounts of time than performance of the same tasks in training simulators.

5. CONTROLS AND DISPLAYS

The technology of display and control components grew substantially more sophisticated from Project Mercury to the Gemini Program, and this new technology was further refined for the Apollo and Skylab Programs. Increased complexity of the displays and controls emphasises the importance of crew functions to the success of the mission; the emphasis is on finding the most efficient means to convey information to the crew. The relationship of work stations and panel control-display elements in each spacecraft is illustrated in Table 4. The larger the work volume, the greater the number of work stations. Software program structures constrain the growth of discrete controls and displays by making complex displays available on cathode-ray tubes or other variable image displays.

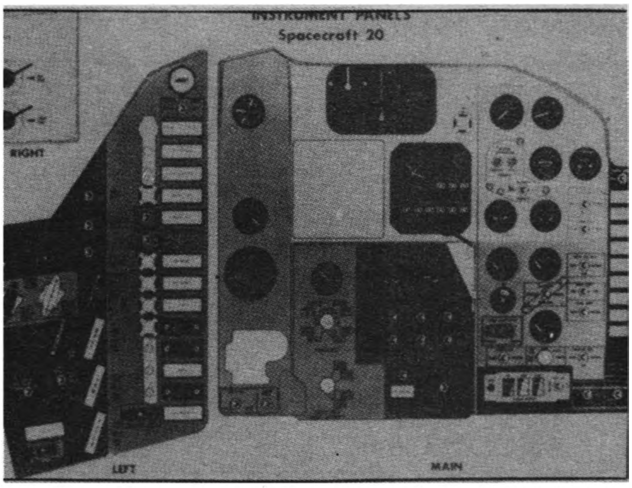

Fig. 7. Mercury control panel, MA-9 configuration.

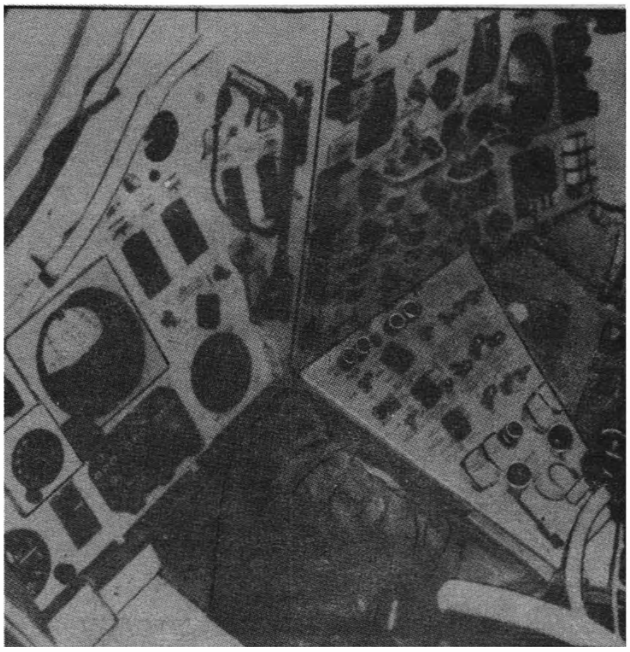

Fig. 8. Gemini controls and displays.

Table 5 provides a detailed tabulation of the control-display devices and indentifies the number of items sensed and either displayed prior to launch and in flight to the crew or telemetered to the Mission Control Center. The table is significant because of the trends illustrated. The growth in data sensed is significantly related to the size of the spacecraft, the size of the crew, the complexity of the mission and the degree to which the spacecraft can operate without support from the ground. The Skylab data are different from

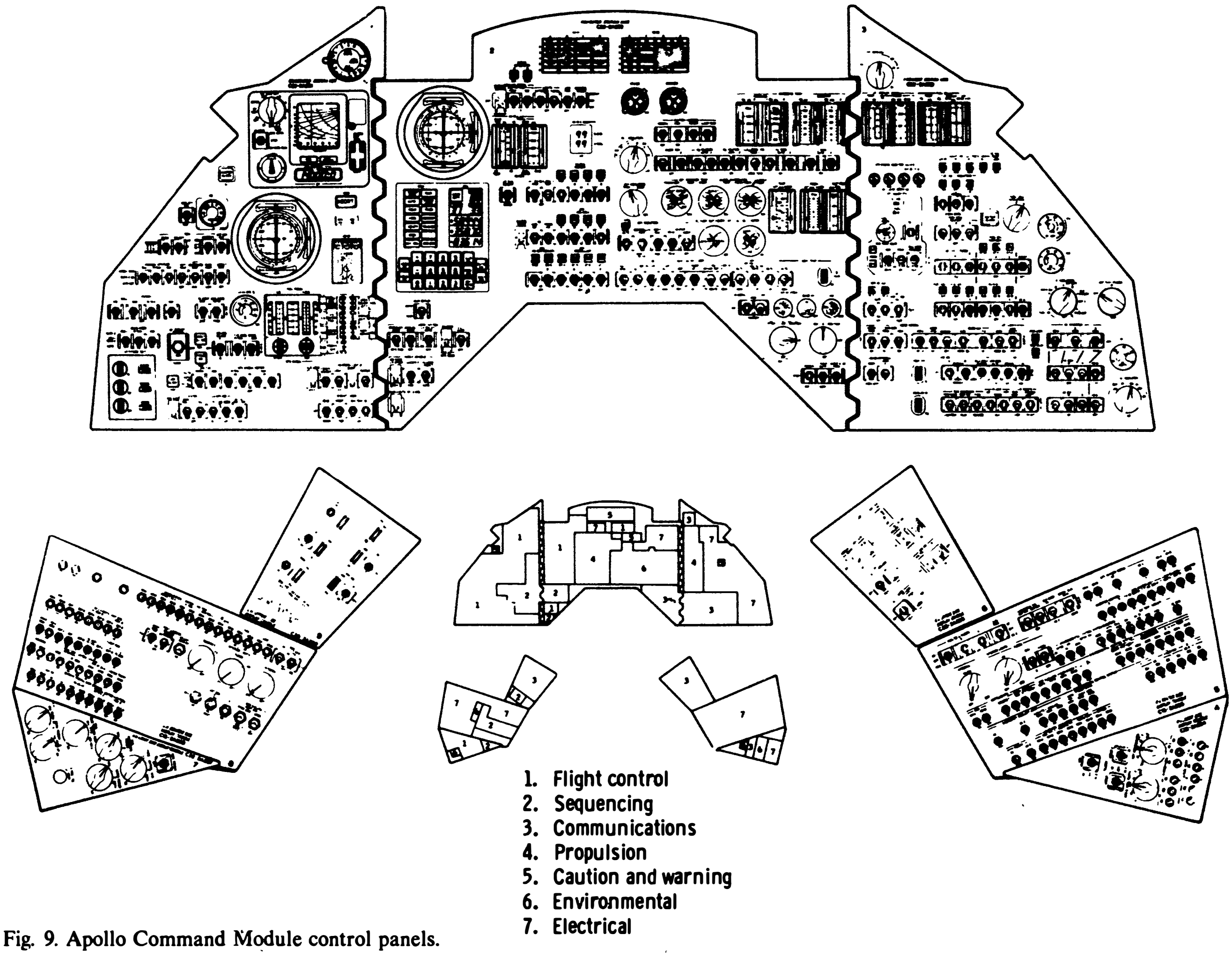

Fig. 9. Apollo Command Module control panels.

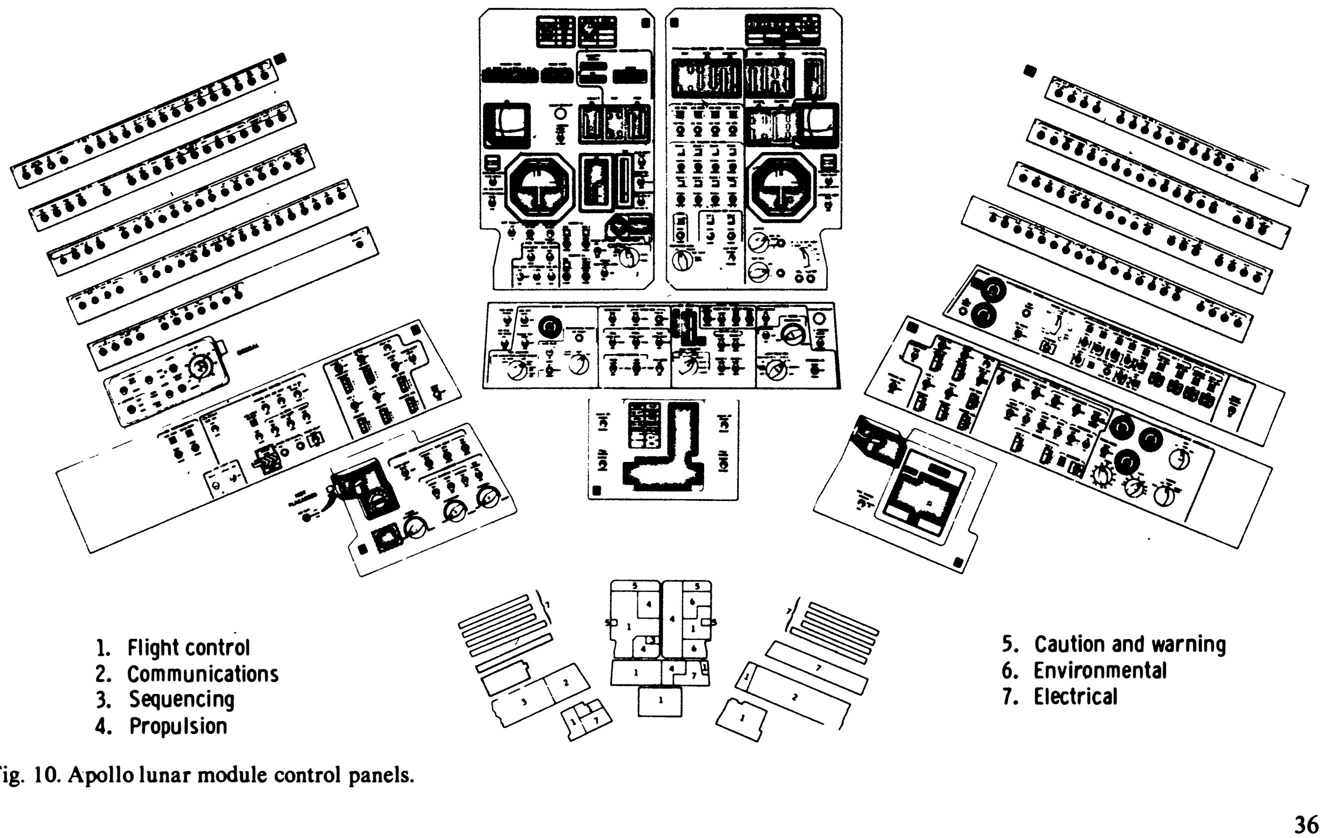

Fig. 10. Apollo lunar module control panels.

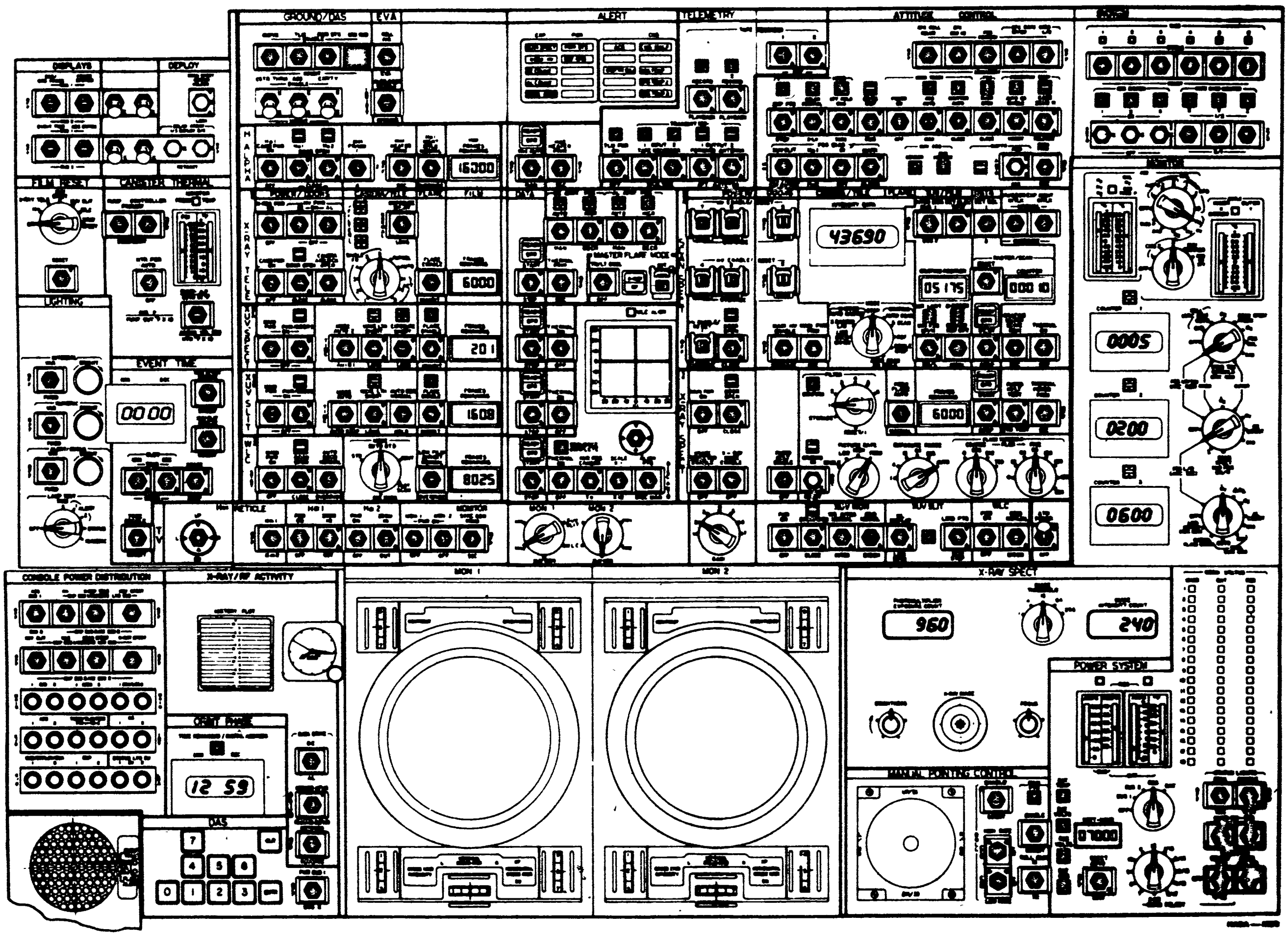

Fig. 11. Skylab Apollo Telescope Mount control panel.

those of other spacecraft because they include all of the scientific experiment as well as the operational spacecraft systems. Of the 1720 values sensed in the orbital assembly module, only 239 relate to operation of the spacecraft; the other 1481 values are the science data.

Primary control-display panels for each of the US spacecraft are shown in Figs. 7 to 12. The Mercury display and control panel is noteworthy for the relative simplicity of the displays, the large number of sequential backup controls and the prominence of sequence and time displays. The instrument panel illustrated in Fig. 7 for the last flight (Mercury-Atlas 9) reflects the most complex configuration of the series. The major factors in the derivation of this configuration were:

1. the principle that there would be redundant means available to accomplish all critical functions,
2. the need to have available both onboard and ground data concerning the status of consumables, and
3. the need, with intermittent communications, to maintain a common time reference with the ground control system to control mission sequences and the retrofire manoeuvre, which initiates ballistic entry.

To save weight and power, attitude was displayed on a meter with three movements: a horizontal needle moving in the vertical plane for pitch and two vertical needles (one at the top and one at the bottom) moving horizontally to display yaw and roll. Attitude rates were displayed on separate movements arranged around the attitude indicator. With ground command, the automatic stabilisation and control system could perform all the critical flight manoeuvre sequences; in fact, the system had been used for unmanned flights. On manned flights, as a rule, the crewmen used a rate-command mode to conserve propellants. The simplicity of the system reflects the simplicity of the mission but placed significant workload on the crewman to integrate discrete data.

The Gemini panel (Fig. 8) was notably more complex than that of Mercury. The Gemini panel introduced the computer keyboard and digital readout; the integrated display of attitude, attitude error and rates on the flight director attitude indicator; the comparative display of redundant system conditions; vertical-scale meters; and the extensive use of circuit breakers, not only to protect circuits but also to disarm selected systems during certain mission phases. The panel arrangement was similar to that of an aircraft, in that flight-control displays were furnished for each crewman (command pilot and pilot), supporting systems were centrally located and shared, propulsion systems were primarily accessible to the command pilot and navigational systems were accessible primarily to the pilot.

Increased complexity of the spacecraft and mission objectives resulted in additional subsystems (e.g., the inertial reference unit, the radar system, and the computer) and in greater complexity and redundancy in other systems (e.g.,

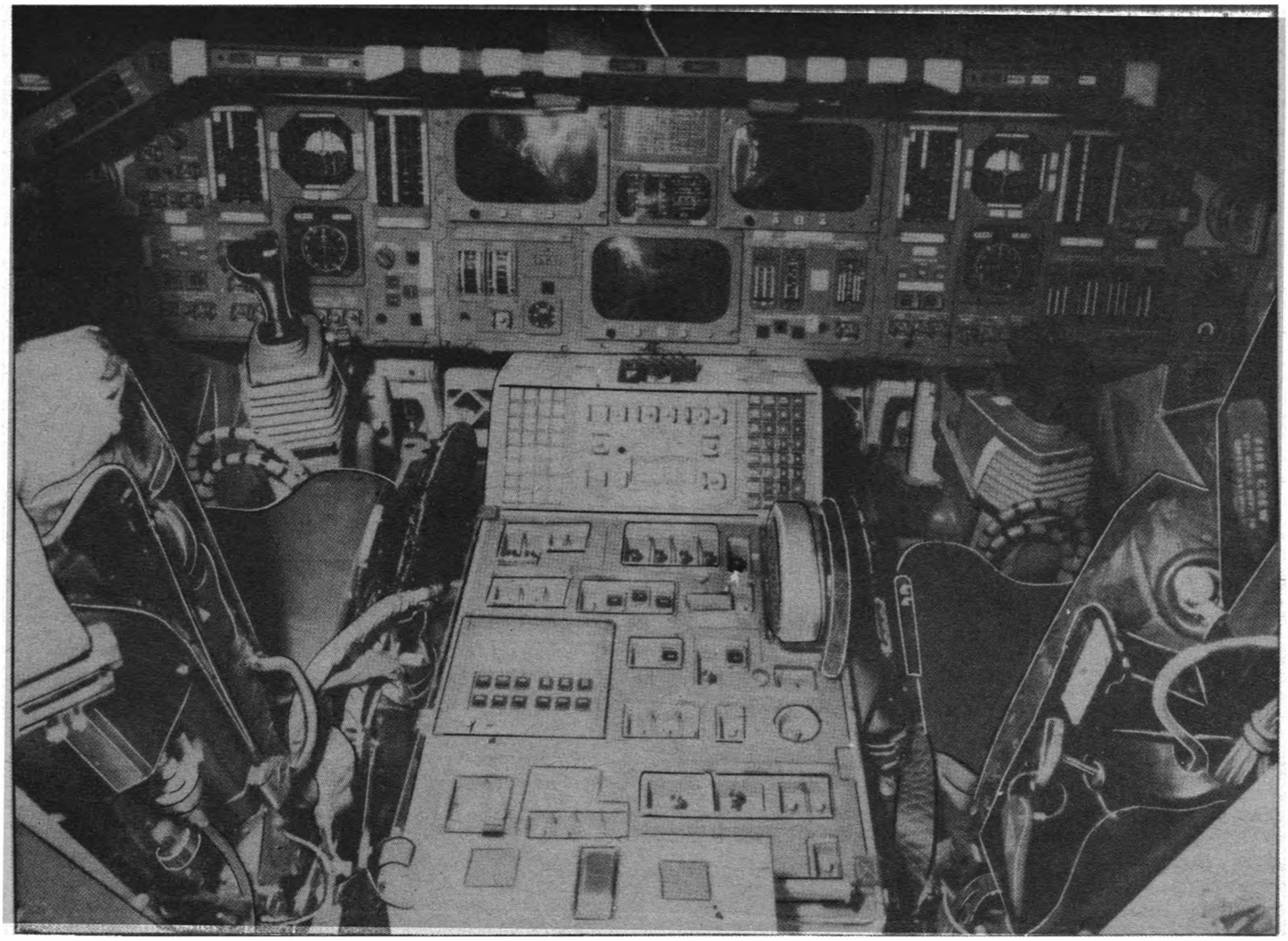

Fig. 12. Shuttle Orbiter flight deck displays and controls.

the attitude manoeuvring system and the electrical power system). These complexities were reflected in the larger number of display and control elements and increased telemetry of data to the ground. To accommodate display requirements, many of the meters were time-shared among several parameters for a subsystem or among redundant systems for a single parameter.

Experience with the display and control system indicated that the integrated display or attitude and rate information on the Gemini flight director attitude indicator was superior to the Mercury display. For most flight modes, a local-vertical reference was useful; for rendezvous, however, manoeuvres were more effectively visualised in a target-centred inertial frame. The use of vertical-scale meters in the Gemini spacecraft conserved panel space and provided a more effective cross-check than had been attainable on the Mercury spacecraft with circular meters that were in line only at the nine and three o'clock positions. Similarity of the cockpit to that of high-performance aircraft illustrates the degree to which the crew had been allocated a similar role. With ground assistance in navigation and flight planning, the mission could be conducted from onboard the spacecraft.

The Apollo command module and lunar module display and control panels (Figs. 9 and 10) are three to four times more complex than the Gemini panel. The increase in complexity results from additional mission phases and the level of system redundancy provided. The left side of the command module main panel (Fig. 9) is arranged for the commander and has the displays and controls for launch, entry, and all propulsive manoeuvres. The centre section provides access to guidance, navigation and propulsion functions; the right centre and right panels contain primary displays and controls for the sustaining systems (environmental control, communications, and electrical power). In addition to the main panel array accessible from the couch, 17 to 20 other panels are located elsewhere in the command module. The most significant are the guidance and navigation station in the lower equipment bay, where the navigational optics are located, and the environmental control system management panel in the lower left equipment bay where a large number of mechanical controls are located. The other panels have controls and displays for special system functions.

In Fig. 9, several trends are evident in the Apollo console arrangement. Circular meters are used in only a few cases and only for parameters with a limited range of excursion; vertical meters are predominant and are time-shared by switching to display a parameter for several redundant systems; prominence in access and visibility is provided for the flight director attitude indicator, the guidance system display and keyboard, and the caution and warning matrix; discrete elements (such as circuit breakers, toggle switches, and event indicators) are used extensively. Discrete controls and displays are used more extensively in diagnostic procedures than in normal system reconfiguration.

The lunar module panel (Fig. 10) indicates many of the same points noted for the command module panels. Circular displays are used only for secondary parameters; unique

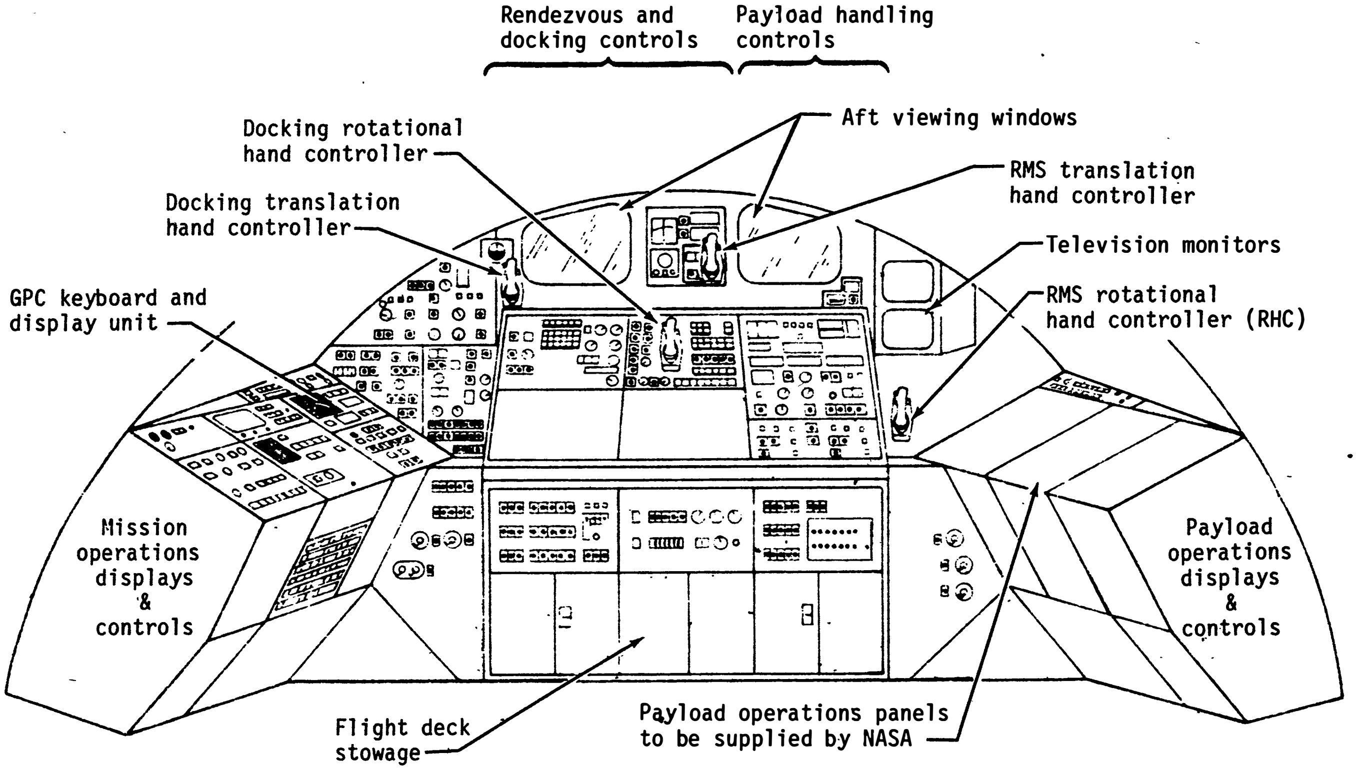

Fig. 13. Aft flight deck crew station.

devices, such as the flight director attitude indicator, the primary guidance system display and keyboard, and the backup guidance data entry and display assembly, are most prominent. The large number of discrete control elements is related to the several configurations of the lunar module after launch; that is, to the parallelism of ascent- and descent-stage subsystems for electrical power, environmental control and propulsion. The panel arrangement is typical for two-man, side-by-side flight vehicles. Each astronaut has the primary flight instruments located in the same visual scan area with a window. The commander on the left has access to the flight-control and propulsion systems; the lunar module pilot on the right has access to the alternate flight-control system, the abort guidance assembly and to the sustaining systems.

One of the most significant aspects of the lunar module displays is the importance of the caution and warning system. This system is substantially more complex than that in any other early spacecraft because the lunar module is either in powered flight (landing, ascent and rendezvous) or in a dormant state (while the crew sleeps or is absent on the lunar surface) during its active life. Since these mission characteristics allow the lunar module crew little time to monitor many subsystem functions, the caution and warning system and the Mission Control Center *via* telemetry act as a third crewmember to perform this status-monitoring function.

The Skylab command module displays represent only minor modifications from the Apollo configuration, but the controls and displays in the remainder of the modules are a significant departure from previous spacecraft. For example, Fig. 11 shows the controls and displays for the Apollo telescope mount. This panel, located in the multiple docking adapter, provides for control of the solar telescopes and instruments located on the mount. Although this panel is of the same order of complexity as the Gemini controls and displays, its purpose is to acquire scientific data, not to conduct flight operations. Notable characteristics of the panel are use of cathode-ray tubes to display telescope views and amplitude-time plots of X-ray activity, extensive use of digital displays, and a relatively low proportion of data displayed to that telemetered. Again, the types of displays reflect advances in spacecraft technology, such as cathode-ray tubes being conditioned to endure launch vibration and acceleration environments. Digital displays are required to provide adequate scale resolution for the parameters of interest.

The fraction of data displayed to ensure proper data acquisition is a small proportion of those data required for eventual analysis. This ratio reflects the programme and flight planning emphasis on using flightcrew time to acquire data, with data reduction and analysis to be performed on the ground. A certain amount of data analysis will be made during the mission to allow evaluation of achievement and to replan further data acquisition. The design logic of this console is the same as that for the flight controls and displays. The objective is to provide a capability for autonomous spacecraft operation, which, in this case, is supplemented by ground-based data analysis and uplink command to enhance effectiveness and reliability.

The bulk of controls and displays in the orbital assembly is used for experiment operation and control. The operational instruments are used primarily for housekeeping; that is, maintenance of thermal and habitable environments and control of consumables such as water, oxygen, nitrogen and electrical power. The magnitude of this trend to increase scientific operations relative to flight systems is evident from the number of work stations and panels in the orbital assembly modules. The large number of panels reflects the number of experiment installations in each of the various modules. Each panel is relatively small and devoted to operational controls for the experiment. Data for experiments other than the Apollo Telescope Mount are returned to the ground primarily by voice link during the mission and

by written forms, film and magnetic tape at the end of each crew visit.

For all spacecraft, the degree to which the flightcrew can be assisted by ground controllers in system monitoring is indicated by comparing the number of available measurements displayed with those telemetered (Table 5). The crew and the ground controllers share a common set of parameters; critical to crew safety and the correct execution of powered flight manoeuvres. The ground controllers also have access to a large number of sensors not displayed to the crew, as well as access to data on a continuous basis that are accessible to the crew only as a discrete event.

The Shuttle crew stations (Fig. 12) make extensive use of cathode ray tube displays. These are the primary displays for management of the systems and flight activity. The meter movements are secondary system displays. The flight director attitude indicator and horizontal situation indicator are functional counterparts of the aircraft instruments.

The flight path data displayed on the display electronics unit can also be displayed on a "heads up" display combining glass so that during the final approach the crew need not look away from the runway in order to keep track of airspeed descent rate or other critical energy management parameters.

Since the Shuttle is a fly-by-wire system, all signals to control systems or sense their state are carried on a data bus. The selection of data or the generation of queries to subsystems to test state or condition is done in the computer software. Prior to lift-off, these queries are done by the launch processing system while the GPCs are configured for ascent. On orbit and prior to entry, these routines are done by one of the GPC systems, using the subsystem management software.

In addition to the launch and entry flight deck, there is a second flight station on the aft flight deck (Fig. 13). This station is used for flight control during the final phases of rendezvous and docking and for stationkeeping during manoeuvres to pick up spacecraft with the remote manipulator system. At this station, there is a GPC entry and display unit and a set of controllers – one for attitude control and another for translation manoeuvres. The second set of controls and displays on the port side is for control of the RMS. In addition to direct views through the aft and overhead windows, the crew can select and display up to four television images on the two monitors on the upper port side. Views can be selected from among seven cameras – four are located at the corners of the cargo bay, one on the floor of the cargo bay, and the other two cameras are located on the RMS – one on the end effector and one just below the elbow. Each of the cameras can be controlled for pan, tile, zoom focus and brightness.

Terminal approach manoeuvres are made along the Z-axis in order to provide maximum visibility to the crew and minimise plume impingement from the Orbiter manoeuvring engines upon the spacecraft being approached.

The ground-based flight control team can maintain continuous time histories of parameters, never needs to time-share parameters on a display, and has independent trajectory and navigation data available from ground-based tracking. Also, ground-based personnel can size their team to the task at hand and assign controllers to particular functions without the need for time-sharing their attention among several functions. Because of these advantages, both analog and discrete data not furnished by the crew are telemetered to the ground, and data that are time-sampled by the crew are monitored continuously. The ground controller has primary responsibility for detecting all gradual degradation failure modes; for example, gyro drift. Sampling rates are selected as a function of the dynamic variability of the parameter and the resolution required for flight-control decisions.

Through the spacecraft and experiment status information conveyed by this telemetry, the Mission Control Center monitors the spacecraft for the crew while they sleep or address themselves to scientific observations and experiments. The telemetry data allow both the flight crew and Mission Control Center personnel to confirm the conditions of all spacecraft systems and assure that proper procedures are being followed. These data are also used to aid the crew in replanning the flight to take advantage of unexpected opportunities or to recover from the failure of a particular instrument or previously planned experiment.

Since the ground system has the capability to determine signal characteristics at all points in the communications network and the crew on-orbit does not, the operating modes of the communication system are normally controlled by ground command from the Mission Control Center.

As indicated in Table 1, there has been increasing reliance on onboard computers to execute the complex functions in navigation and rendezvous. The number of modes is an indicator of the number of alternative program functions available to perform various mission functions. The Apollo primary guidance and navigation system display and keyboard is the most complex and powerful of its crew interface elements (Fig. 14). It displays the status of the computer, the inertial systems and the programs within the computer. With this device, the crew can monitor program status and activity and can sequence and initialise the system as desired.

Communication between crew and system is conducted in terms of a set of program blocks identifying specific functions such as preflight operations (OX), monitoring launch (1X) and lunar module rendezvous (7X). The second digit identifies specific program activities within each major set. Within each program block, a set of two-digit verbs and nouns specifies actions to be performed and the object of the action, including the data to be entered in the calculation or to be displayed during the calculation. The computer can also drive the flight director attitude indicator sphere and error needles to provide analog displays. When the computer program requires a crew management decision about the acceptability of results or the need for new input data, the crewman is queried by flashing the verb and noun displays.

This two-way communication between crew and computer is quite complex; approximately 10,000 key strokes are required to complete all elements of a lunar landing mission. Approximately 40% of all crew training for a lunar landing mission is required to master the primary guidance and navigation system. In this system, as in the others described, much of the complexity derives from providing crew access to a very low level of function. To guard against procedural errors, onboard data are provided to reinitialise erasable memory if an error occurs, and the probability of error is reduced by training each crewman to a high level of proficiency and assigning to each crewman specific mission phase operations.

The Shuttle Orbiter general purpose computer (GPC) keyboard and cathode ray tube displays are the primary crew interface for all the Orbiter systems (Fig. 12). There are five GPCs in the Orbiter; four are operated as a quadredundant set with the primary avionics software system (PASS), and the fifth operates an independent backup flight system software program. During dynamic flight phases in launch and entry when failure reaction times are critical, the quadredundant set vote on the data from sensors, e.g., the three IMUs, and can reject data from one of the units if it is not within a reasonable range of the others. Similarly, they vote on commands or solutions and can reject one GPC from the set if it is at variance with the others.

The number of programs run in the GPC is too large for the immediate memory, so programs are transferred in from a mass memory unit as the mission phases change. For on-orbit operations all but one or two of the GPC systems

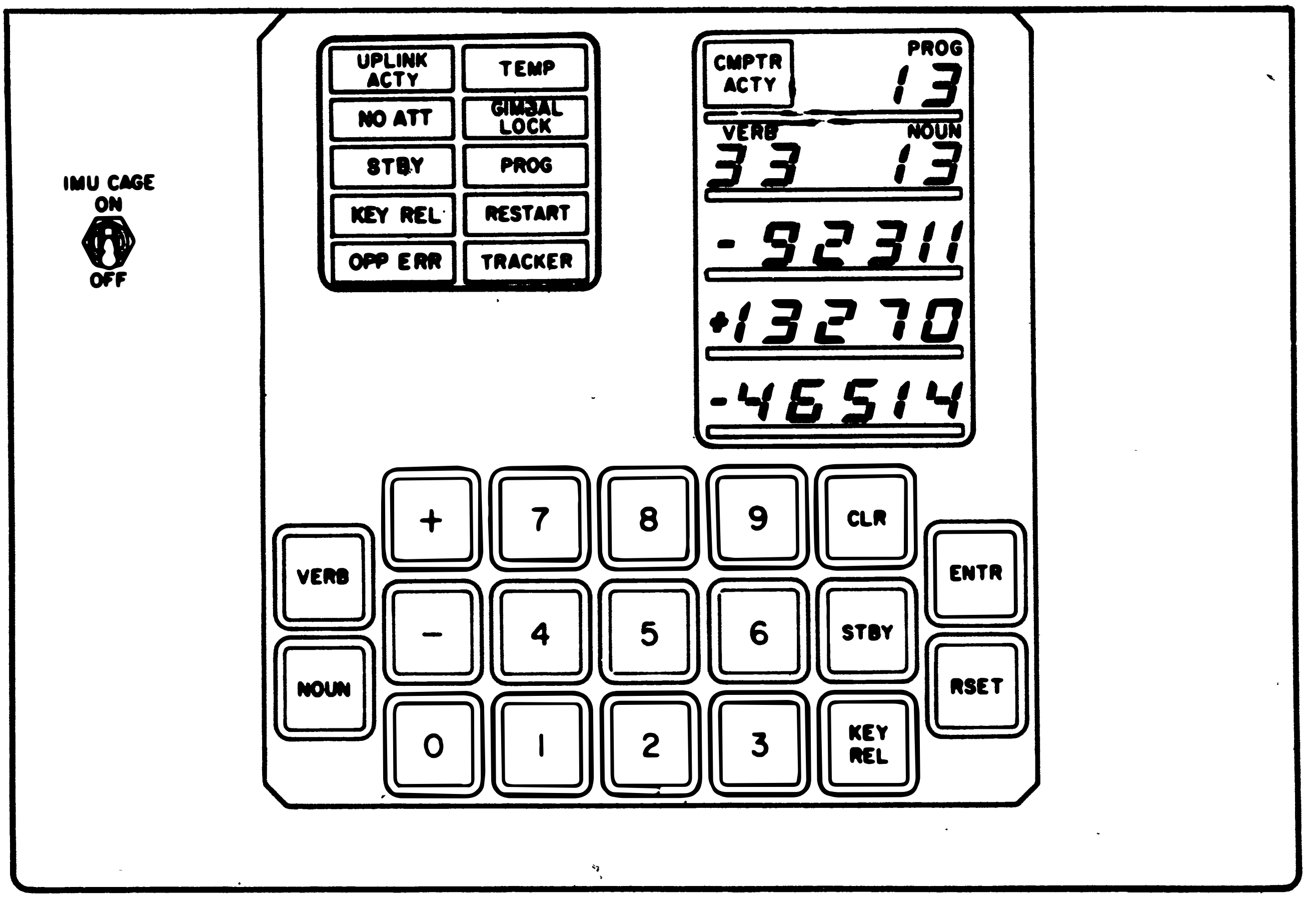

Fig. 14. Apollo primary guidance and navigation system display and keyboard.

are powered down. By crew selection of programs and subroutines, all subsystems can be configured suitably or diagnostic analysis conducted. As in the case of the Apollo G&N display and keyboard, the crew training to master the program capability is significant and the keystroke activity in-flight is quite intense. STS-1 required just under 10,000 keystrokes from crew entry prelaunch to system shutdown after landing rollout.

Another case of crew activity related to control and display is effected by crew observation of exterior objects through either the windows or the optical systems used to align the inertial reference system. In these activities, the crew has the tasks of recognising complex patterns and providing either direct steering commands or input data to the automatic systems. The crew performs such functions in docking, rendezvous targeting, erecting and aligning the inertial platforms, aiming scientific instruments and landing the lunar module.

The view from the lunar module as it approaches the lunar surface and the system used during this manoeuvre are shown in Fig. 15. The display and keyboard of the primary guidance and navigation system displays the elevation and lateral angle of the target point. If the target is not a suitable landing point in the pilot's judgment, he can redirect the system to a more acceptable target by input of the coordinates of the desired site. The computer will then retarget. Alternatively, the crewman can take over and perform the complete manoeuvre manually. In addition to their operational uses, the windows are used for extensive observation by the crewmen just for relaxation.

The remote manipulator system of the Orbiter is a unique device. It is controlled directly by the crew operator since there is no collision avoidance intelligence in the system other than that which the crews direct or television observations provide. Operation of the 15.25 m arm is complex because

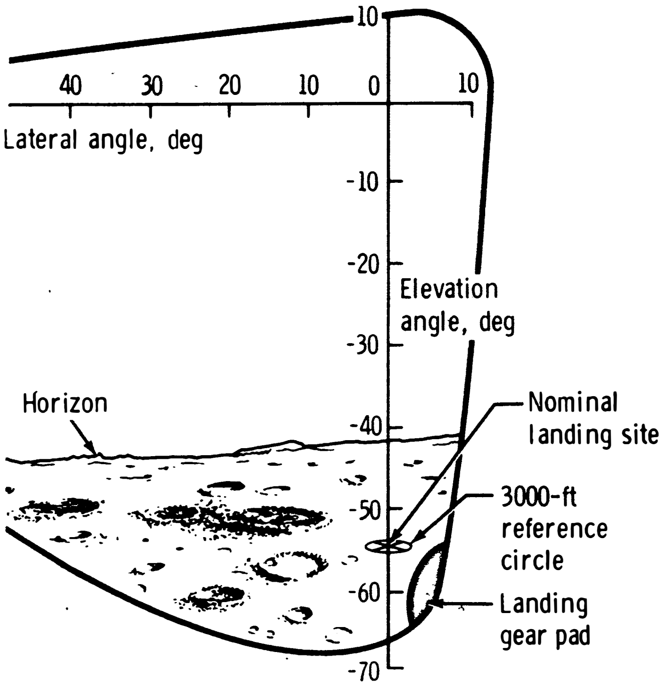

Fig. 15. View through Apollo lunar module window during lunar landing sequence.

of the many varying geometric relationships that can occur. The motion of the arm is controlled by the same type of hand controllers used to fly the Orbiter. Several modes of operation can be selected. Extensive movements are generally done in a resolved motion mode in which the joint motions are coordinated so that the tip follows a linear path. Small motions are generally done a single axis at a time. In addition to motion control of the arm, the operator uses six television cameras for which he has tilt, pan and focus controls and can display four of the six scenes on two monitors adjacent to the port side window to the cargo bay.

Despite the complexity of the operator's functions, high precision and delicate tasks are feasible; 9100 kg payloads have been positioned to tolerance less than 2.5 cm in all three dimensions and less than a degree in all three axes.

6. SUMMARY AND CONCLUSIONS

The first generation of manned spacecraft consisted of expendable vehicles, each of which flew a limited number of missions. Each individual spacecraft was tailored to the general objectives of its programme and to the detailed objectives of a particular flight. The progression from the earliest Mercury flight through Gemini rendezvous procedures development, the Apollo landings on the Moon, and the Earth-orbit research of Skylab and Apollo-Soyuz has demonstrated substantial engineering and science achievement. In each succeeding project and flight, there has been increased reliance on the crew to execute the functions critical to attaining the mission objectives. The Skylab repair is the most dramatic example.

In the perspective of current technology and operational experience, the designs may seem inefficient and often awkward. In the design of an aircraft, we can specify function quite precisely because we have many generations of design experience. In spacecraft, we still have limited experience. The advances in computer capability and in variable imagery offer new options in the development of crew displays. If we can provide the basic sensing and control elements in the subsystems, then the crew displays and controls can evolve in successive generations of software. Such a strategy not only fosters an improved interface between the crew and the vehicle, it improves the ability of the crew to reduce its dependence on ground controllers and enhances the autonomy of the spacecraft. As an example, we have recently added a portable computer to the Orbiter to display spacecraft ground track against an Earth map exactly as we do in the Mission Control Center. The change was made to provide the crew a perspective as to their location relative to the continents and the day-night terminator. We had not anticipated that the large size of the Orbiter cabin could make it so difficult for the crew to keep oriented relative to the groundtrack. The additional display has significantly enhanced crew productivity.

The complexity of large manned spacecraft and the concurrent development of the systems and the crew interface make determination of the best control-display information essentially impossible. If the system is suitably designed, however, second-generation software can provide "expert systems" software and other aids to crew productivity as experience with the system develops insight as to the most effective approach.

Unlike the management of crew information interfaces, which can evolve with experience and learning, the habitability provisions must be enhanced in the original basic design. Past spacecraft and even the Space Shuttle Orbiter have limited amenities. Living arrangements are adequate for limited durations but primitive by any desirable standard for long occupancy by any significant number of crewmembers. Habitability is therefore a major issue in the fundamental architecture of the structural design for a space station if crew productivity is to be sustained for long periods. Space experience has illustrated that high standards of achievement can be attained for short periods with select crews, but ground experience in many other contexts teaches that, for longer duration and more diverse populations, a comfortable accommodation must be provided or productivity will be poor.

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APPENDIX A – Summary of Early American Manned Space Flights

Spacecraft	Launch date	Crew	Flight time hr:min:sec	Comments
		Mercury		
MR-3	05/05/61	Shepard	00:15:22	First suborbital flight
MR-4	07/21/61	Grissom	00:15:37	Second suborbital flight
MA-6	02/20/62	Glenn	04:55:23	First Mercury orbital flight
MA-7	05/24/62	Carpenter	04:56:05	Second Mercury orbital flight
MA-8	10/03/62	Schirra	09:13:11	Extended duration
MA-9	05/15/63	Cooper	34:19:46	Extended duration

contd.

Appendix A/contd.

Spacecraft	Launch date	Crew	Flight time hr:min:sec	Comments
		Gemini		
GT-3	03/23/65	Grissom/Young	04:52:31	First Gemini flight
GT-4	06/03/65	McDivitt/White	97:40:01	20-min EVA, handheld maneuvering unit
GT-5	08/21/65	Cooper/Conrad	190:55:14	Extended duration
GT-7	12/04/65	Borman/Lovell	330:35:01	14-day mission
GT-6A	12/15/65	Schirra/Stafford	25:51:21	Rendezvous with GT-7
GT-8	03/16/66	Armstrong/Scott	10:41:26	Docked with Agena, Gemini reaction control system (RCS) malfunction; mission terminated
GT-9A	06/03/66	Stafford/Cernan	72:20:50	Rendezvous with damaged Agena; 2-hr 7-min EVA
GT-10	07/18/66	Young/Collins	70:46:39	Docked with Agena, 3 EVA periods
GT-11	09/12/66	Conrad/Gordon	71:17:08	Reached record altitude of 1373 km (741.5 nautical miles) using Agena propulsion
GT-12	11/11/66	Lovell/Aldrin	94:34:31	Docked with unusable Agena
		Apollo		
Apollo 7	10/11/68	Schirra/Eisele/Cunningham	260:09:08	First Apollo flight - Earth orbit
Apollo 8	12/21/68	Borman/Lovell/Anders	147:00:42	First manned lunar orbit, no LM
Apollo 9	03/03/69	McDivitt/Scott/Schweickart	241:00:53	First manned LM flight - Earth orbit
Apollo 10	05/18/69	Stafford/Young/Cernan	192:03:23	LM and CSM rendezvous and docking activity in lunar orbit
Apollo 11	07/16/69	Armstrong/Collins/Aldrin	195:18:35	First manned lunar landing, Sea of Tranquility; time on Moon (T.O.M.) 21:36:21
Apollo 12	11/14/69	Conrad/Gordon/Bean	244:36:25	Precise lunar landing near Surveyor, Ocean of Storms; T.O.M. 31:31:12
Apollo 13	04/11/70	Lovell/Swigert/Haise	142:54:41	Lunar flyby during emergency return after service module damaged
Apollo 14	01/31/71	Shepard/Roosa/Mitchell	216:01:58	Third landing - Fra Mauro, "golf cart" first wheels on Moon; T.O.M. 33:30:31
Apollo 15	07/26/71	Scott/Worden/Irwin	295:11:53	Hadley-Apennine region, used Rover - an electric-powered car; T.O.M. 66:54:53
Apollo 16	04/16/72	Young/Mattingly/Duke	265:51:05	Descartes region, traveled 27 km in Rover; T.O.M. 71:02:13
Apollo 17	12/06/72	Cernan/Evans/Schmitt	301:51:59	Taurus-Littrow region, traveled 35 km in Rover; T.O.M. 74:59:38
		Skylab		
Skylab 2	05/25/73	Conrad/Kerwin/Weitz	672:49:49	Repaired damage to Skylab; initial space experiment activity
Skylab 3	07/28/73	Bean/Garriott/Lousma	1427:09:04	Increased duration; continued experiment activity
Skylab 4	11/16/73	Carr/Gibson/Pogue	2017:15:31	Increased duration; completed experiment activity
		Apollo-Soyuz Test Project		
ASTP-Apollo	07/15/75	Stafford/Brand/Slayton	217:28:24	Rendezvous and docking with Soyuz
		Space Shuttle Orbital Flight Statistics		
STS-1 Columbia	04/12/81	John W. Young, Cdr Robert L. Crippen, Plt	54:20:53.1	First flight
STS-2 Columbia	11/12/81	Joe H. Engle, Cdr Richard H. Truly, Plt	54:13:12	First operation of remote manipulator arm

Appendix A/contd.

Spacecraft	Launch date	Crew	Flight time hr:min:sec	Comments
STS-3 Columbia	03/22/82	Jack Lousma, Cdr Gordon Fullerton, Plt	192:04:49	
STS-4 Columbia	06/27/82	T. K. Mattingly, Cdr Henry Hartsfield, Plt	169:11:11	Final orbital test flight
STS-5 Columbia	11/11/82	Vance Brand, Cdr Robert Overmyer, Plt Joseph Allen, MS William Lenoir, MS	122:14:27	First operational flight First revenue payload
STS-6 Challenger	04/04/83	Paul J. Weitz, Cdr Karol J. Bobko, Plt Donald H. Peterson, MS Story F. Musgrave, MS	120:23:42	First flight of Challenger
STS-7 Challenger	06/18/83	Robert L. Crippen, Cdr Frederick H. Hauck, Plt Sally K. Ride, MS John M. Fabian, MS Norman E. Thagard, MS	146:23:59	First U.S. female astronaut
STS-8 Challenger	08/30/83	Richard H. Truly, Cdr Daniel C. Brandenstein, Plt Dale A. Gardner, MS Guion S. Bluford, MS William E. Thornton, MS	145:08:40	First Shuttle night launch and landing
STS-9 Columbia	11/28/83	John W. Young, Cdr Brewster H. Shaw, Jr.,Plt Owen K. Garriott, MS Robert A. Parker, MS Byron Lichtenberg, PS Ulf Merbold, PS	223:47:24	First flight of ESA-developed Spacelab and first non-U.S. crewman
STS-11 41-B Challenger	02/03/84	Vance D. Brand, Cdr Robert L. Gibson, Plt Burce McCandless II, MS Robert L. Stewart, MS Ronald E. McNair, MS	191:15:55	First free flight EVA
STS-13 41-C Challenger	04/06/84	Robert L. Crippen, Cdr Francis R. Scobee, Plt George D. Nelson, MS James D. van Hoften, MS Terry J. Hart, MS	191:40:05	Recovery, repair, and redeployment of SMM
41-D Discovery	08/30/84	Henry W. Hartsfield, Cdr Michael L. Coats, Plt Judith A. Resnik, MS Steven A. Hawley, MS Richard M. Mullane, MS Charles D. Walker, PS	144:56:04	First commercial payload specialist
41-G Challenger	10/05/84	Robert L. Crippen, Cdr Jon A. McBride, Plt Kathryn D. Sullivan, MS Sally K. Ride, MS David D. Leestma, MS Marc Garneau, PS Paul D. Scully-Power, PS	197:23:37	First Canadian; orbital refueling demonstration
51-A Discovery	11/08/84	Frederick Hauck, Cdr David M. Walker, Plt Anna L. Fisher, MS Dale A. Gardner, MS Joseph P. Allen, MS	191:42*	First recovery and return to Earth of a spacecraft

*Projected

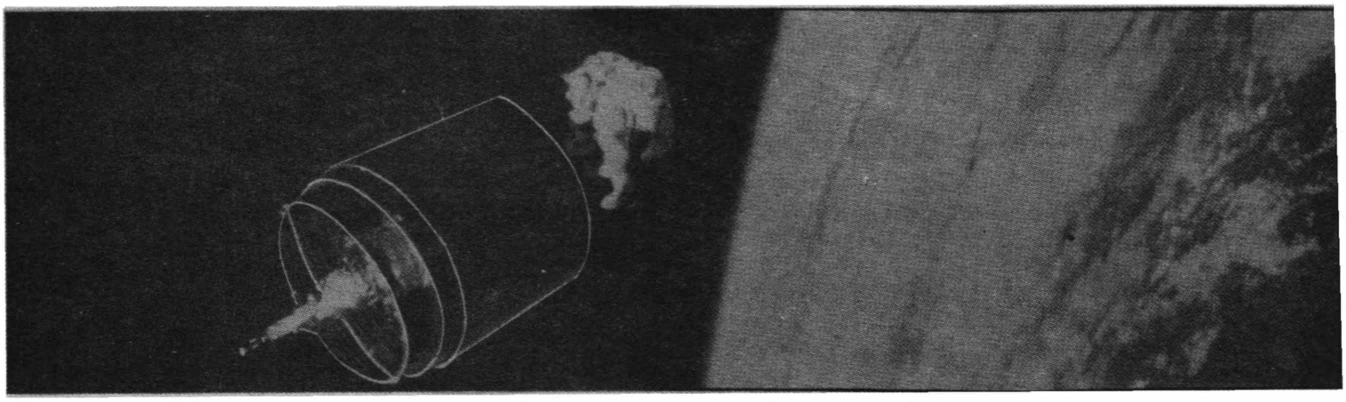

Fig. 16. Allen and Gardner recovered the Palapa and Westar satellites during Shuttle 51A in November 1984.

NASA

APPENDIX B – Extravehicular Activity Record.

U.S. mission	Launch date	In flight		Lunar exploration		Lunar stay time	
		Astronaut	hr:min	Astronaut	hr:min	hr:min:sec	Site
Gemini IV	06/03/65	White	00:36				
Gemini IXA	06/03/66	Cernan	02:07				
Gemini X	07/18/66	Collins	01:27				
Gemini XI	09/12/66	Gordon	02:41				
Gemini XII	11/11/66	Aldrin	05:30				
Apollo 9	03/03/69	Schweickart	01:07				
Apollo 9	03/03/69	Scott	01:01				
Apollo 11	07/16/69			1. Armstrong	02:48	21:36:21	Sea of Tranquility
				2. Aldrin	02:48		
Apollo 12	11/14/69			3. Conrad	07:46	31:31:12	Ocean of Storms
				4. Bean	07:46		
Apollo 14	01/31/71			5. Shepard	09:23	33:30:31	Fra Mauro
				6. Mitchell	09:23		
Apollo 15	07/26/71	Worden	00:38	7. Scott	19:08	66:54:53	Hadley-Apennine
		Irwin	00:38	8. Irwin	18:35		
Apollo 16	04/16/72	Mattingly	01:24	9. Young	20:14	71:02:13	Descartes
		Duke	01:24	10. Duke	20:14		
Apollo 17	12/07/72	Evans	01:06	11. Cernan	22:04	74:59:40	Taurus-Littrow
		Schmitt	01:06	12. Schmitt	22:04		
Skylab SL-2 1st manned visit	05/25/73	Conrad	04:59				
		Kerwin	03:23				
		Weitz	02:11				
Skylab SL-3 2nd manned visit	07/28/73	Bean	02:41				
		Garriott	13:42				
		Lousma	11:01				
Skylab SL-4 3rd manned visit	11/16/73	Carr	15:51				
		Gibson	15:22				
		Pogue	13:37				
Space Shuttle							
STS-6	04/04/83	Peterson	4:42				
		Musgrave					
STS-11	02/03/84	McCandless	6:05				First free flight with manned maneuvering unit
		Stewart	6:17				
STS-13	04/06/84	Nelson	3:05				First repair of a spacecraft on-orbit
		Van Hoften	6:30				
41-G	10/05/84	Sullivan	3:27				First U.S. woman to go EVA
		Leestma	3:27				
51-A	11/07/84	Allen	6:00*				First retrieval of spacecraft to return to Earth
		Gardner	6:00*				
TOTAL[a]			145:38	TOTAL[a]	162:13	299:34:50	Six sites

[a]TOTAL 268:23 man-hours EVA.

*Projected

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AUSSAT: AUSTRALIA'S FIRST NATIONAL COMMUNICATIONS SATELLITE SYSTEM

P. REA
Grimsby, South Humberside, England.

In 1982 Aussat Proprietary Limited selected Hughes Aircraft Company to build three HS376-type communications satellites to provide Australia with its first national communications satellite programme. The Aussat programme is reviewed, and a description given of the Hughes HS376 craft. A description is included of the communications payload and the unique antenna configuration which distinguishes Aussat from all other HS376 series satellites.

1. THE AUSSAT PROGRAMME

Australia has a population of 15.5 million and covers 7,680,000 km^2. With many communities separated by hundreds of kilometres from the nearest major centres of population, communications is an enormous problem.

Applications satellites such as ATS 6 have proved the feasibility of beaming TV pictures into remote areas of the world for educational broadcasting, especially to Third World countries.

The list of countries in the communications satellite market is growing rapidly. One such country is Australia, which established its first national satellite company, Aussat Propietary Limited, in November 1981.

In May 1982 Aussat Proprietary Limited selected Hughes Communications International, a wholly owned subsidiary of Hughes Aircraft Company, to build three HS376-series satellites and two Telemetry, Tracking, Command and Monitoring stations, to be situated at Belrose, near Sydney and Lockridge, near Perth. The contract also provided for launch and operational services.

In the same year the US Shuttle was chosen as launch vehicle, although the satellites are compatible with either the US Delta or European Ariane launchers.

The Aussat programme will provide a wide range of services not only to the mainland but also to offshore islands and Papua New Guinea. It will provide advanced telephone services, TV relays between major cities and high speed data transmission for domestic and business use (allowing teleconferencing). Other areas to benefit will be voice/data communication for the oil and mining industries and for emergency medical communications. Improved air-ground-air links will greatly improve the Australian Air Traffic Control system.

An important part of Aussat's work will be the Homestead and Community Broadcast Satellite Service (HACBSS) which will transmit TV and radio programmes to outback communities currently on the edge of, or outside, present transmission zones. Using receive-only stations with 1.2 to 1.8 m dish antennae on the ground, viewers will point their dishes at the satellite and tune into their appropriate frequency. As many as 300,000 people could benefit from such a service.

In addition, a network of eight Major City Earth Stations (MCES) will be established using 18 m dishes. Earth stations will be built in each of the state capital cities, plus Darwin and Canberra. Each will have dual antennae to access two satellites simultaneously. Distribution to the user would then be by existing means or by dedicated links, e.g. microwave.

2. SUMMARY OF POTENTIAL USERS

- *The Australian Broadcasting Corporation*

For the relay of programmes:

(a) between studios;
(b) to TV transmitters;
(c) The HACBSS;
(d) distribution of Radio Australia Programmes.

- *Commercial Television and Radio*

For the distribution of news etc., between studios and to improve relay facilities to regional stations.

- *Outback Communities*

For the reception of TV and radio from high power transponders onboard the satellite in the HACBSS.

- *Department of Aviation*

A network of more than 100 Earth stations to link Air Traffic Control with aircraft.

- *Department of Defence*

For internal communications.

- *Telecom Australia*

Fully automated telephone services to remote homesteads are planned. Improvements to existing routes could bring telex, facsimile and data transmission facilities to these areas.

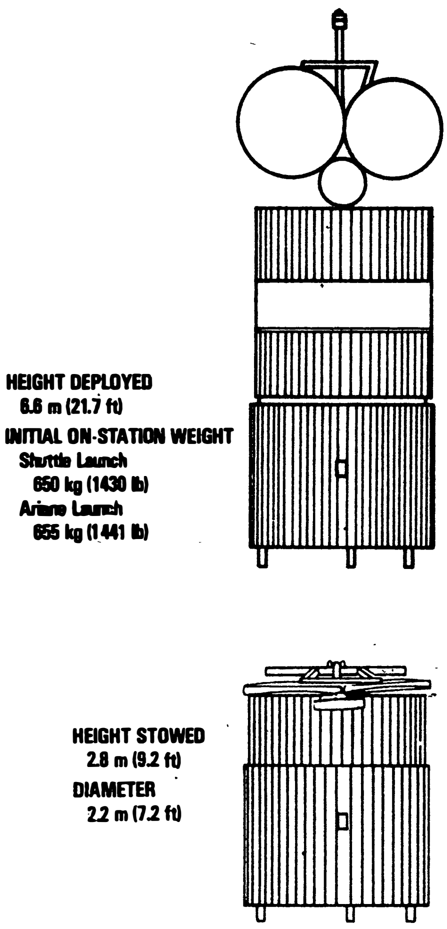
- *The Business Community*

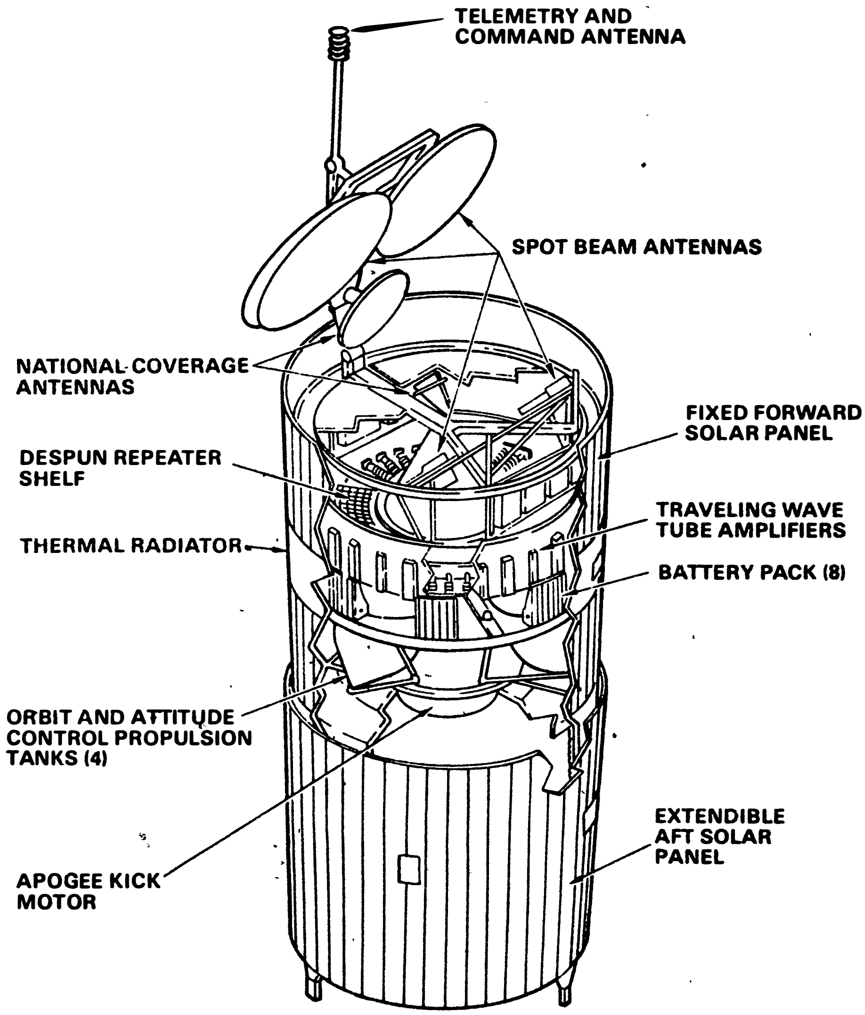
Banks could use the system for the electronic transfer of funds. Mining companies can relay voice, video and data from remote mining areas into Head Offices. Large stores could quickly transfer data between branches in major cities.

- *The Public Sector*

Educational broadcasting into remote areas.

More users could emerge as experience with the system is gained. Aussat has been designed to ensure a system that is flexible enough to cater for all these projected users. Special onboard switches enable most transponders to be





General features of the Aussat satellite.

switched between national and spot beams in line with customers requirements. This makes Aussat one of the most flexible satellite systems currently projected.

The first satellite is due for launch in July 1985 with the second in the following October. A third will initially be held as a ground spare but could be ready for a launch in 1988 or earlier if it is needed.

3. THE HS376 SERIES SATELLITE

Hughes Aircraft Company Space & Communication Group have a tradition of satellite building that goes back almost as far as the space age itself. 1963 saw the launch of the first synchronous communications satellite and 1965 brought the first Intelsat (International Telecommunications Satellite Consortium) satellite, followed by the first Intelsat 2 series in 1966. Out of the five series of Intelsat satellites currently flown, Hughes have built three, losing out to TRW for the Intelsat 3s and Ford Aerospace for the Intelsat 5s. All Intelsat satellites were spin stabilised except the Intelsat 5s, which use three-axis stabilisation. Hughes, however, won the coveted Intelsat 6 contract in 1982 (the biggest contract so far for commercial communications satellites) for a first launch in 1986. These satellites are again spinners, on which Hughes has gathered so much experience.

Hughes used the basic design of their Intelsat 4 series to provide Canada with its Anik A series. Indonesia with its Palapa As and Western Union with their Westars. Known by Hughes as the HS333, this was the forerunner of a much more capable satellite which was destined to become the most widely purchased communications satellite. This was the HS376 (see Table 1).

TABLE 1. HS376 Series Satellites Ordered (as of March 1984).

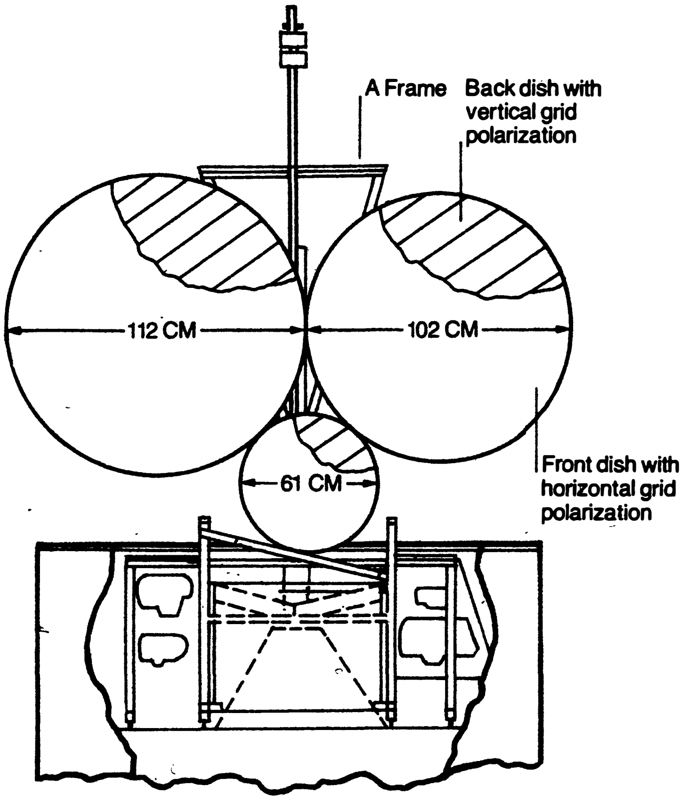
SBS 1	Palapa B1
SBS 2	Palapa B2
SBS 3	Galaxy 1
SBS 4	Galaxy 2
SBS 5	Galaxy 3
SBS 6	Telstar 3A
Westar 4	Telstar 3B
Westar 5	Telstar 3C
Westar 6	Aussat K1
Westar 7	Aussat K2
Anik C1	Aussat K3
Anik C2	SBTS 1
Anik C3	SBTS 2
Anik D1	Morelos A (Mexsat)
Anik D2	Morelos B (Mexsat)

The basic HS376 is a common bus to which the communications payload specified by the customer is installed. This can be C, Ku or Ka band frequencies or a combination of these. They are 2.16 m in diameter with a stowed height of

approximately 2.80 m. When fully deployed in space the height increases to 6.06 m. Weights vary with each satellite but average 590 kg at the beginning of life (BOL), i.e. at geostationary altitude and orbital position. Aussat will be among the heaviest at a projected BOL mass of 655 kg.

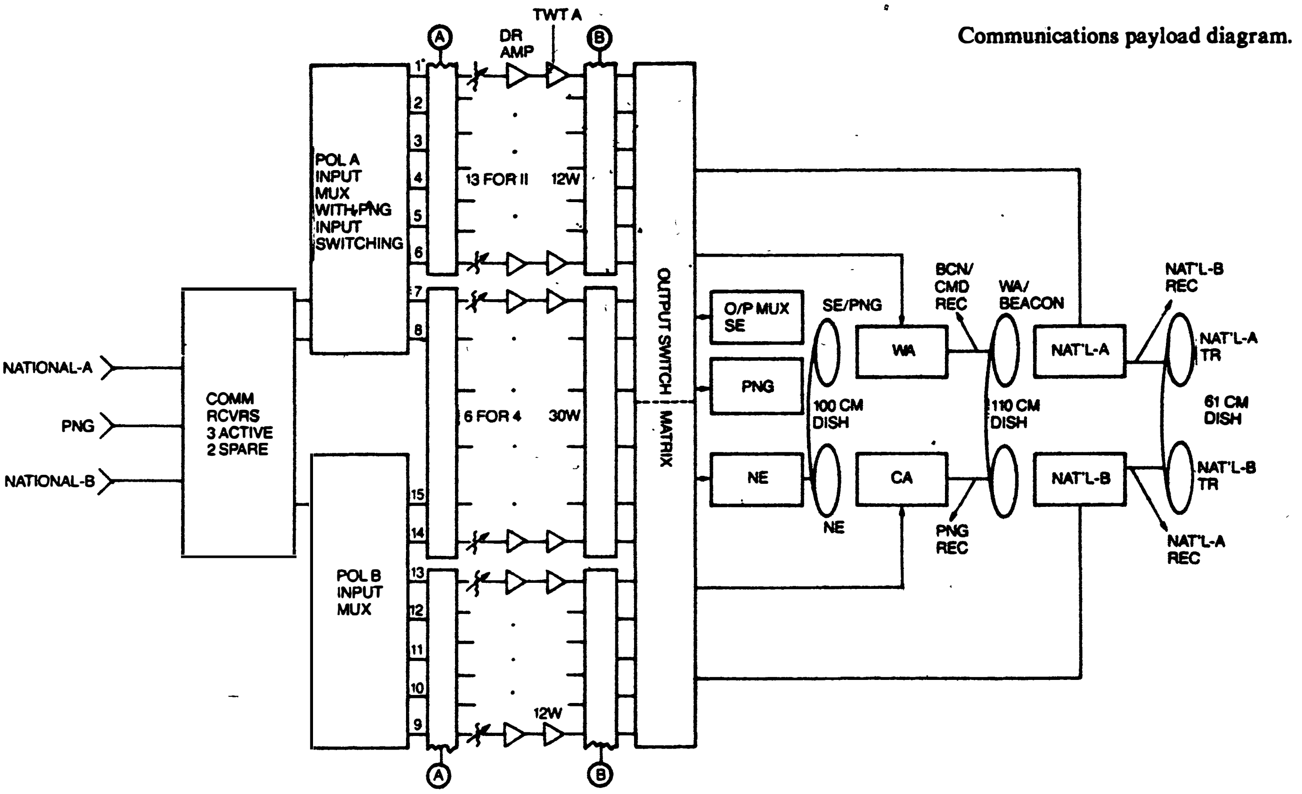
HS376 satellites are the only ones launched so far to use telescoping solar panels. During launch the lower outer panel fits over the upper inner panel; as the satellite nears its orbital position the antenna erects and the outer solar panel telescopes down, exposing the inner panel. This is a compact arrangement – important when considering that Shuttle launch costs are partly based on the fraction of the payload bay length taken up by the satellite and its perigee kick motor. The HS376 configuration came about as a requirement to obtain the greatest area of solar cells within the tight volume restraints of a Delta launch payload shroud and the top-to-bottom dimensions of the Shuttle. The two panels are divided into eight sections of approximately equal power output using Spectrolab K7 solar cells generating 1,046 watts at beginning of life and June Solstice. Two Nickel Cadmium batteries will provide full power during periods when the satellite passes into Earth shadow.

Whereas previous HS376 satellites have used a single antenna, Aussat will use three, with apertures of 61 cm, 100 cm and 110 cm. This represents the most advanced antenna configuration ever specified for an HS376 customer. The dish antennae are in two parts: The rear transmits the beam in the vertically polarised plane while the front uses horizontal polarisation. This allows the re-use of frequencies with little interference. The system will provide seven transmit and three receive beams, the latter for national coverage (two) and Papua New Guinea. Five of the transmit beams are spots serving the Homestead & Community Broadcasting Satellite Service: North Eastern, South Eastern, Central and West Australia plus Papua New Guinea. The other two are National beams giving continental coverage for Fixed Satellite Services, i.e. Point to Point. The antennae have been designed so that the footprint can be narrowed and concentrated on to relatively small areas within the satellite's field of view.



Antennae arrangement.

Aussat has 15 channels, each capable of carrying one TV programme or up to 1,000 two-way telephone circuits. Eight channels are on one polarisation and seven on the other;



Communications payload diagram.

TABLE 2. List of Frequencies.

Channel		Frequency Uplink (GHz)	Frequency Downlink (GHz)
1		14.025	12.277
	9	14.057	12.309
2		14.089	12.341
	10	14.121	12.373
3		14.153	12.405
	11	14.185	12.437
4		14.217	12.469
	12	14.249	12.501
5		14.281	12.533
	13	14.313	12.565
6		14.345	12.597
	14	14.377	12.629
7		14.409	12.661
	15	14.441	12.693
8		14.473	12.725

TABLE 3. Aussat Transmit Performance.

* Nominal primary beam edge eirp (12 Watt channels)	– 36 dBW (national beams) – 41 dBW (PNG beams) – 43 dBW (spot beams)
* Nominal primary beam edge eirp (30 Watt channels)	– 40 dBW (national beams) – 45 dBW (PNG beam) – 47 dBW (spot beams)
* Xpol discrimination of transmit antennae	– 32 dB (minimum)

Each RF channel is provided with a commandable gain step adjustment covering a 10 dB range, with a high gain mode for use with multi-carrier applications and the low gain for use mainly in single carrier per transponder applications.

each channel has a minimum 45 MHz bandwidth spaced 64 MHz apart. The channel centre frequencies are listed in Table 2.

Eleven channels will use 12 W travelling wave tube amplifiers (TWTA) and the remaining four will use high power 30 W TWTAs. These will yield effective isotropic radiated powers as shown in Table 3. Operational flexibility is achieved by using channel connectivity to allow for a TWTA failure. An example of this channel switching is shown in Table 4.

4. REACTION CONTROL SYSTEM

In keeping with all other HS376 satellites, Aussat will use four of the well-proven HE-54 thrusters delivering 22 N from the catalytic decomposition of hydrazine. This type of thruster has seen many years of trouble-free operation, having been qualified on the Intelsat 4 As.

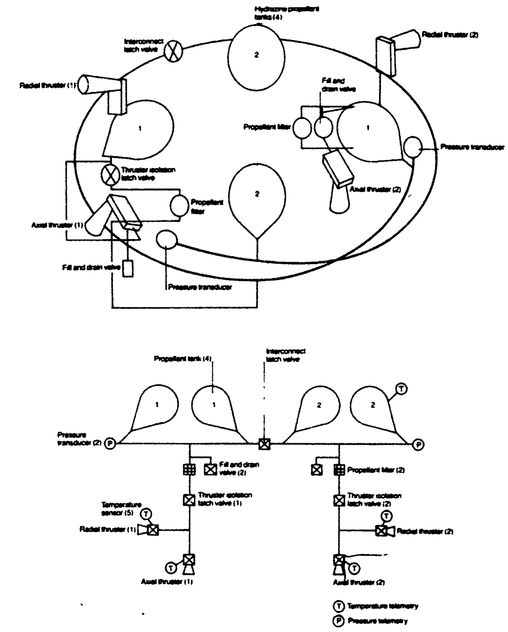
The four titanium alloy fuel tanks are placed 90° apart around the spacecraft structure, each with an internal volume of 6,370 cm³. One advantage of a spinning satellite is that the centrifugal force can be used to force propellants out of their tanks; the 50 rpm of Aussat will produce 3 g's at the tank outlets.

For redundancy, the Reaction Control System is divided into two systems, each with two tanks, two thrusters (one axial, one radial), two isolation valves, two fuel filters, one pressure transducer, one fill and drain valve and all associated electrical wiring. An interconnect valve can be opened

TABLE 4. Channel Connectivity.

BEAM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
National (A)	L		L	L		L	H								
National (B)									L	L		L	F	H	H
PNG				L		L		H							
NE									L		F			H	H
SE	L		L		F		H	H							
CA										L		L		H	H
WA		F		L			H	H							

L: Power Power connection
H: High Power connection
F: Fixed connection
WA: Western Australian
NE: North Eastern
SE: South Eastern
CA: Central Australian



Propellant subsystem schematic.

to allow all the fuel to service the remaining thrusters should any fuel valve not respond to a command to open. A latch valve in the fuel feed line to each system would be closed to isolate that system should a thruster valve remain open or a leak occur. This latch valve can be re-opened to allow near-normal thruster firings, if necessary, but would be closed again after the sequence.

During normal operations the radial thrusters operate individually to provide active nutation control for the spacecraft/PAM configuration, station acquisition and east/west station keeping once in geostationary orbit. The axial thrusters are used more frequently and would provide ANC after spacecraft/PAM separation, station acquisition, injection error corrections, altitude trim and north/south station keeping. The thrusters are operated in the pulse mode although the axial thrusters can be used continuously. Heater circuits will keep the hydrazine at the correct operating temperature.

Intensive ground testing of the RCS and multiple seals on all fuel valves, plus X-ray inspection and proof testing to 1.5 times working pressure in the fuel tanks gives high confidence that Aussat and all HS376 series satellites will not have their seven year lifetimes shortened by RCS failures.

TABLE 5. Aussat Leading Data.

Satellite Bus Design	Hughes HS376
Launch Vehicle Compatible	Shuttle or Ariane
Launch Dates	K1 July 1985 K2 Oct. 1985
K3 July 1988 Probable	
Satellite Life: Basic Design Fuel Budget	 10 years 8 years
Orbital Locations	K1 156°E K2 164°E K3 160°E
NS and EW Station Keeping	± 0.05° Max.
Eclipse Capacity	100%
Frequency Band	14/12 GHz Ku Band
Number of Channels	15 (11 x 12 W; 4 x 30 W)
R.F. Uplink Frequencies	14.025 to 14.473 GHz
R. P. Downlink Frequencies	12.277 to 12.725 GHz
Channel Min. Bandwidth	45 MHz
Channel Spacing	64 MHz
Height Stowed	2.8 m
Height Deployed	6.6 m
Diameter	2.2. m
Initial On-Station Weight	654.7 kg

5. LAUNCH

Though compatible with the European Ariane launcher, Aussat K1 and K2 will begin their lives with boosts into orbit by the Shuttle. As of May 1984, K1 was booked on Shuttle Flight 51I to be flown by Orbiter *Columbia* and K2 booked on Flight 61B, *Challenger*, though operational factors could alter these.

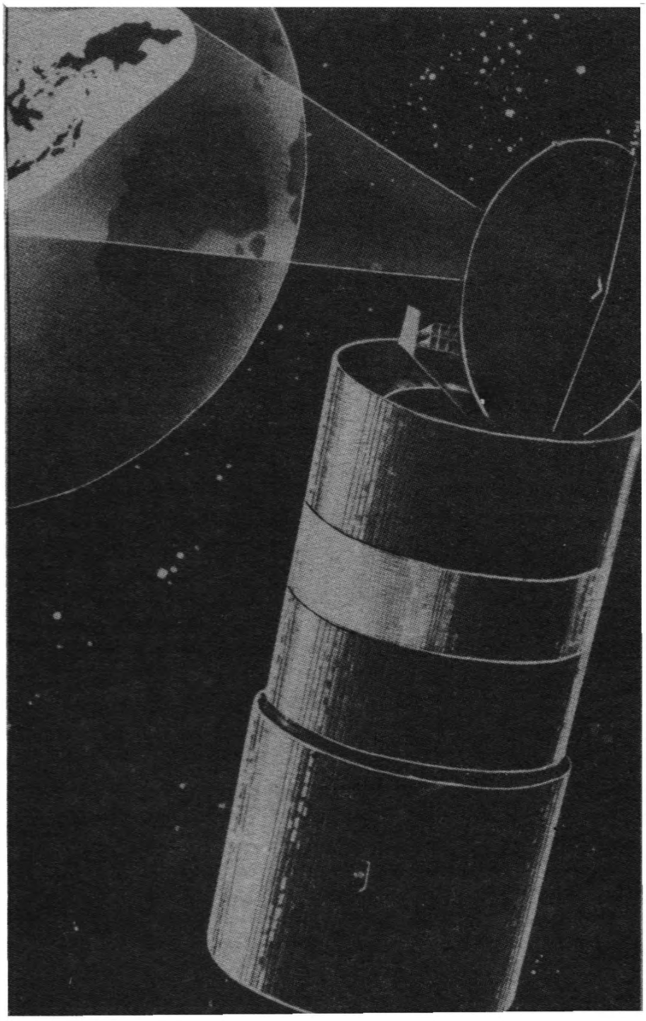
Between November 1982 and February 1984, NASA have made six Shuttle HS376 satellite launches, two each on STS-5, STS-7 and 41B. These last two were not placed into geostationary orbit due to nozzles failures on the PAM perigee kick motors. No PAM is required for an Ariane launch as the third stage places the satellite directly into a geostationary orbit transfer ellipse.

It is also interesting to note that with an Ariane launch telemetry can be received from the vehicle throughout the boost phase. During a Shuttle deployment, telemetry transmitters are activated and the omni antenna is deployed by a PAM timer about 125 seconds after ejection from the Shuttle cargo bay. Ariane was due to carry Brazil's SBTS-1 in January or March 1985, its first HS376.

During a nominal Shuttle launch Aussat needs to be boosted from a low parking orbit to geostationary altitude 36,000 km by a McDonnell Douglas Payload Assist Module-Delta equivalent or PAM-D (previously called SSUS or Spinning Solid Upper Stage). This consists of a Thiokol Star-48 solid propellant rocket motor delivering a maximum thrust of 6,800 kgf for 85 seconds. The motor is 1.2 m in diameter and 1.83 m long.

The satellite is supported in the Shuttle cargo bay by a standard PAM cradle assembly. Inside this sits the spin table with the combined Aussat/PAM. Associated with this is the PAM Airborne Support Equipment (ASE) consisting of all the reusable elements needed to control and monitor the PAM and satellite from lift-off to deployment. A folding Sun shield with Mylar insulation protects the satellite from thermal damage.

Before deployment, the crew can check the satellite's systems electrically. The spin table imparts a rotation of 50 rpm for stability to the satellite. Explosive bolt cutters release a clamp band and four separation springs, each pre-loaded to 90 kgf, release the satellite with a velocity of 0.6 m/s. At the moment of release a timer on the PAM starts and after 45 minutes the PAM motor is ignited.



An artist's impression of an HS376 satellite in orbit. This is the Indonesian Palapa satellite; Aussat will carry two main dish antenna.

Hughes

At the start of the burn the satellite will be travelling at 27,600 kph at an inclination to the equator of 28.5°. After the burn the satellite will be in an 11 hour orbit with apogee near geostationary altitude and an inclination of 27°.

The PAM will then separate. The satellite's own built-in Star-30 solid propellant apogee kick motor will fire on the third apogee to circularise the orbit at 35,860 km and reduce the remaining inclination to zero. The satellite will now be in a 24 hour orbit.

A controlled drift along the orbit will, after two to three weeks, bring the satellite over the desired longitude where drift will be stopped and operations can begin.

Significant Aussat data are summarised in Table 5.

ACKNOWLEDGEMENTS

The author wishes to thank Hughes Aircraft Company, Dr. D. Baker of Space Services International and Roger Laishley for their help.

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MARECS: EXPERIMENTAL (1972) TO OPERATIONAL (1984)

J. M. BAYLEY
Manager, ECS Development, British Aerospace.

The Maritime European Communication Satellite (Marecs), now in commercial service, started life early in the 1970's. There were many false starts and changes of direction during its evolution but, with the launch of Marecs A in December 1981, and its subsequent successful commercial operation, the far-sightedness of those early decisions have been vindicated.

1. BACKGROUND

The origin of Marecs is buried back in 1972, when MOD (PE), on behalf of the Department of Trade and Industry, let a contract for the Definition Phase of the Geostationary Technology Satellite (GTS). British Aerospace,then HSD, was the Prime contractor for the programme, and the objects were "designed to promote UK Space Technology."

Among the many novel features of the spacecraft there were two in the Communications Payload which were to have a major influence on future developments: the L Band antenna and the L Band TPA (Transistor Power Amplifier).

On 31 July 1973, the European Space Research Organisation (now the European Space Agency) announced at the European Space Conference being held in Brussels that they would undertake the development of a maritime satellite to be known as Marots. As a result of this decision, the British Government decided to cancel its own national GTS programme and give its support to the European programme for Marots. In fact, the UK contributed more than half towards the total cost of £31.M.

Marots was to be a maritime version of the Orbital Test Satellite (OTS), then under development by BAe (HSD). In fact, the service module was the same. The utilisation of the OTS service module allowed the use of already developed equipment in support of the Maritime Communications Payload. Bus concepts notoriously (at that time) looked good in theory, but in practice worked out as expensive re-designs. In this case, however, a very high degree of commonality was achieved, the only major changes being the inclusion of an additional battery to provide increased eclipse capability, an increase in the solar array yoke size to reduce the shadowing effect of the large L Band dish antenna and the elimination of the North/South station keeping capability.

During 1978 it was decided to uprate the service module by taking advantage of the experience gained from OTS and to base it on the new generation of the European Communication Satellite (ECS), already in the design stage at British Aerospace.

Finally, and most importantly, the emphasis was changed away from "Experimental" to "Operational" with the decision of Inmarsat to utilise the spacecraft in an operational, commercial role.

Thus the "Maritime European Communication Satellite" (Marecs) was born.

2. MARECS SCHEDULE

The Marecs-A satellite was successfully launched on 19 December 1981 at 23.29.03 local time from the Centre Spatial Guyanais at Kourou, French Guiana.

After some 36 hours in a spin-stabilised mode during the Transfer Orbit (TO), the Apogee Boost Motor was successfully fired at Apogee 4, bringing the satellite into a Near Synchronous Orbit (NSO), with a drift of 0.74°/day. It reached its required position of 26° West on 5 January 1982, whereupon the on-station phase started. Once on-station, the satellite went through a series of tests constituting the Commissioning Phase, which was followed by an Acceptance Test Phase.

On 1 May 1982 the Marecs-A satellite became the prime satellite for maritime communications over the Atlantic Ocean Region (AOR) of the Inmarsat space segment and has been ever since.

Marecs-A is the first of a series of two maritime communications satellites to be leased by ESA to Inmarsat, the International Maritime Satellite organisation. The second of the series, Marecs-B, was launched on 10 September 1982 but, owing to a launcher failure, did not achieve orbital velocity. Immediately following the loss of Marecs-B, negotiations started with Inmarsat and Industry for another satellite, to replace Marecs-B. This resulted in the Marecs-B2 satellite being approved and subsequently built. It successfully passed its Flight Model Acceptance Review (FMAR), on 12 December 1983 and was successfully launched on V 11, the 11th launch of Ariane, in November 1984. It is now operating satisfactorily.

3. THE MARITIME COMMUNICATIONS SYSTEM DESCRIPTION

3.1 General

The Marecs Satellite System is used in a global communications system that is configured to provide high-quality full-duplex, reliable real-time voice, data and teleprinter services between ship Earth stations and coast Earth stations, which are directly connected to the terrestrial network.

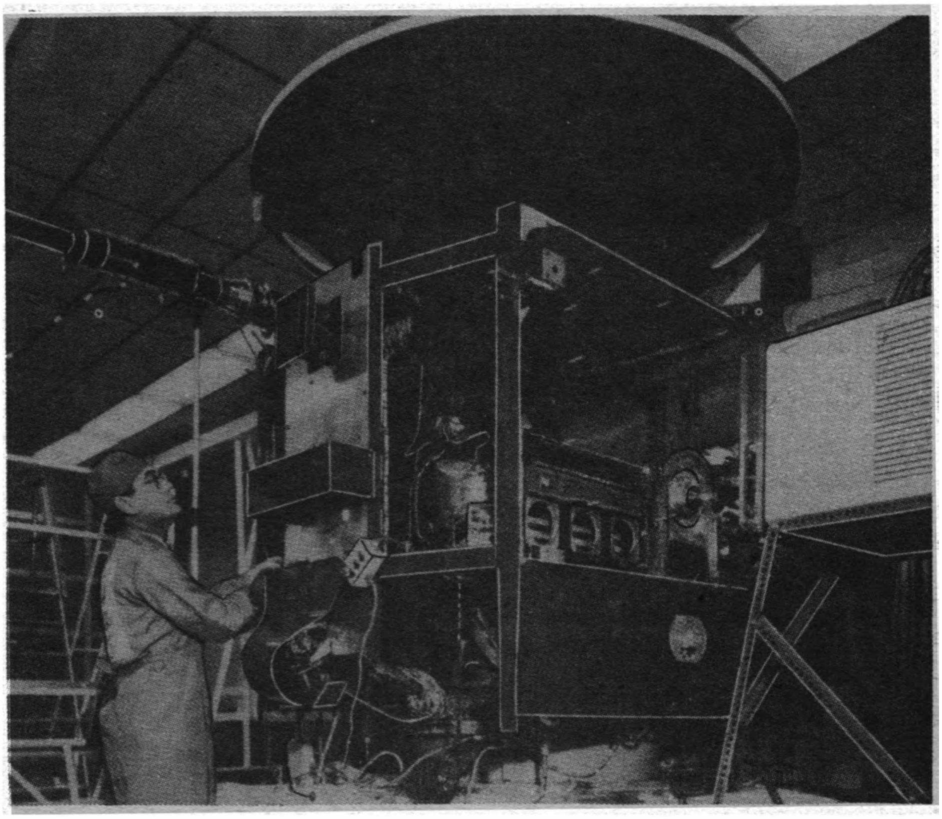
3.1.1 System Elements

The Maritime Communications System is made up of:

1. The Marecs satellite
2. The ground network required for on-station TTC
   a. The Operations Control Center (OCC) in Darmstadt (Germany)
   b. A C-band Earth station in Villafranca (Spain)

A Marecs satellite in preparation.

BAe



c. A VHF station at Redu (Belgium), as back-up to Villafranca

d. A communications network, connecting these facilities to the OCC

e. The ground equipment required for testing and routine monitoring of the payload, also located in Villafranca

f. Coast Earth stations, through which the traffic between ship Earth stations and the terrestrial network is routed.

g. Ship Earth stations

h. The Inmarsat Operations Control Center in London (UK), which coordinates and monitors the Inmarsat global communications network.

3.1.2 Communications Service

The services which are provided presently by the system are:

1. A telephone service with access to the international public telephone network and which is capable of supporting facsimile and data transmission.
2. A telex service with access to the international public telex network.
3. A provision for handling priority messages for the maritime distress and safety services.
4. A provision for relaying low bit-rate distress messages.
5. A provision for the broadcast of messages such as weather forecasts and regional distress alerts to groups of ships.

3.2 Communication Links

Two-way communication links are accommodated between the system elements as described below.

3.2.1 Shore-to-Shore Link

The link from coast Earth stations to ship Earth stations through the satellite is referred to as the "Forward Link." It is established at C-band for the up-path (6420.25-6425 MHz) within the frequency allocation of the Fixed Satellite Service, and at L-band for the down-path (1537.75 to 1542.5 MHz) within the frequency allocation of the Maritime Mobile Satellite Service.

3.2.2 Ship-to-Shore Link

The link from ship Earth stations to coast Earth stations through the satellite is referred to as the "Return link." It is established at L band for the up-path (1638.6-1644.5 MHz) within the frequency allocation of the Maritime Mobile Satellite Service and at C band for the down-path (4194.6 to 4200.5 MHz) within the frequency allocation of the Fixed Satellite Service.

3.3. Communication Channels

3.3.1 Voice Channels

Voice channels are accommodated both in the forward and return links to provide full duplex telephone service between ship Earth stations and coast Earth stations.

The modulation scheme used for both directions is SCPC (Single Channel per Carrier) where each carrier is narrow-

band FM modulated by the audio signal. The satellite has an in-orbit measured capacity equivalent to between 52 and 60 voice channels of Inmarsat specified quality, depending on the TPA redundancy configuration.

3.3.2 Teleprinter Channels

Teleprinter channels are also accommodated both in the forward and return links to provide full duplex telex service between coast Earth stations and ship Earth stations. The signalling used is TDM (Time Division Multiplexing) in the forward link and TDMA (Time Division Multiple Access) in the return link. Telex channels are accommodated in blocks of 20, each block using approximately the equivalent capacity of a single voice channel.

3.3.3 Distress Channel

In the return link, the 1644 to 1644.5 MHz band in the up-path, which corresponds to the 4200 to 4200.5 MHz band in the down-path, is reserved for the relaying of low bit-rate distress messages transmitted by EPIRBs (Emergency Position Indicating Radio Beacons).

Due to EPIRBs EIRP limitations, the level of the distress signals must be additionally amplified in the satellite transponder with respect to the other communication signals before transmission to the coast Earth stations.

3.4 System Coordination and Control

Various coordination and control functions have to be implemented to ensure smooth operation of the communications system. They are briefly reviewed below.

3.4.1 Accessing

The ship Earth stations can access the communications system by means of a random access call channel. A request message is transmitted by the ship Earth station on this channel to the coast Earth station in charge of network coordination (NCS). This NCS will respond with a channel assignment message on the TDM call channel in the forward link.

3.4.2 Channel Assignment

For both telephoney and telex services, channels are assigned by coast Earth stations. The control of channel assignment will be executed by one Network Control Station for each ocean region.

3.4.3 Frequency Control

In order to limit the effects of frequency inaccuracy due to various sources, (doppler effect, local oscillator drift, etc.), pilot tones are used in both forward and return links to set the frequency references at L-band.

3.4.4 Power Control

Power control may be implemented on the forward link through monitoring at L band of a reference pilot in order to optimise the sharing of the satellite L band power between the carriers present in the transponder.

4. SATELLITE USAGE AND OTHER RELATED INFORMATION

4.1 Introduction

This section summarises Inmarsat's operations *via* the Marecs-A spacecraft to date. The information provided covers the following items.

4.2 Marecs-A

Marecs-A is being used by Inmarsat as the operational spacecraft in the Atlantic Ocean Region.

1. Communications performance has been nominal with no outages or degradation to service.
2. At the request of Inmarsat the forward link EIRP was increased by reconfiguring the L band TPA from a (2+2) to a (3+3) configuration. The operation was performed successfully as scheduled on 18 November 1983. The forward link was disabled at 00.01.00 GMT and was re-enabled at 00.08.35 GMT.

4.3 Coast Earth Stations

On 1 January 1983, only two coast Earth stations, Southbury in USA and Eik in Norway, were operating through Marecs-A. On the 28 January, Goonhilly in UK commenced operation in the Atlantic Ocean Region, while Eik transferred operation on 14 February to the Indian Ocean Region.

On the 30 June, Umm-Al-Aish in Kuwait joined the Inmarsat system, commencing operation in the Atlantic Ocean Region. Thus, by the end of 1983, there were three coast Earth stations operating through Marecs-A.

Coast Earth stations which commenced operation in 1984 are:

1. Pleumeur Bodou in France started operation on 18 January 1984.
2. Tangua in Brazil started restricted traffic operation on 25 January and full operation by the end of February.
3. Odessa in USSR in early 1984.
4. Fucino in Italy started operation in Spring 1984.

4.4 Ship Earth Stations

On 1 January 1983, 1550 ship Earth stations were operating through the Inmarsat system. The growth continued during 1983 at a steady pace and the total number of installations on the 31 December 1983 stood at 2187.

By the end of 1983 Ship Earth Stations models were available from 13 manufacturers. Ten had already obtained type approval of Inmarsat for a total of 20 ship Earth station models, fully satisfying the Inmarsat technical requirements. The new models include three classes:

1. Duplex telephone and duplex telex;
2. Duplex telephoney and receive-only telex;
3. Duplex telex.

4.5 Voice Channels

Thirty voice channels were assigned by Inmarsat for Marecs-A operation during 1983. The total available coast Earth station capacity during this period was 37 voice channels.

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PHOTOMETRY: A METHOD FOR EXTRASOLAR PLANET DETECTION

W. L. COMBRINCK
Cape Town, South Africa.

A selection of photometric methods for the detection of extrasolar planets is described, elucidating their potentials and limitations.

1. INTRODUCTION

As a result of improvements in instrumentation, notably due to the neoteric developments in solid state electronics, the search for extrasolar planets has intensified during the past decade. Numerous methods have been used, proposed and developed. Categorically, methods for the observation of non-solar planetary systems can be divided into two main sections: direct and indirect. Direct methods include the observation of decametric emission, thermal emission, reflected starlight and line emission characteristics of a planetary atmosphere. Indirect methods are mostly used at present, especially astrometry, although other indirect methods, such as the determination of radial velocities, have received attention.

To date, there exists no unequivocal evidence for the existence of extrasolar planets. However, the likelihood of such existence is great. Since scientists are constantly improving methods of data-acquisition and reduction, it appears inevitable that sooner or later, probably within the next decade, we shall learn that our Solar System is not unique. In consequence, we shall possibly be much closer to developing a realistic theory on the formation of planetary systems.

Photometry can be used in both direct or indirect methods, and it has a potential as a method for extrasolar planet detection. Its limitations are due mostly to atmospherical instability; ground-based observations thus have an inherent difficulty. This makes observations from beyond the atmosphere, e.g. orbiting space platforms, lunar-based telescopes, etc., essential.

Compared with the number of papers on astrometry as an extrasolar planet-detection method, relatively few have been published on photometry. Paradoxically, it appears that a combination of astrometric and photometric methods, as developed by George Gatewood, could very well be successful.

2. SUGGESTED METHODS

During its transit across the solar disk, a planet the size of Jupiter would cause a decrease in the observed brightness of the Sun. This diminuition, as seen by a distant observer in the ecliptic plane, would amount to approximately 0.01 magnitudes. Since an accuracy of 0.01 magnitude is readily obtained in conventional photometry, one should, in principle, be able to detect extrasolar planets using this method.

Unfortunately, even though technologically feasible, a rather long search time restricts the use of this method at present. The eclipse would last about one day, necessitating a search of 10^4-10^5 stars before probable success [1]. To enable this type of search to be fruitful, a battery of automated telescopes could be used. The observed dip in the light curve could be due to instrumental instability or other factors. In order to lessen the possibility of ambiguity, Rosenblatt [2] describes a two-colour photometric method for extrasolar planet detection. Unlike the antecedent method, which depends on the absolute change in luminosity during an eclipse, this method relies on a characteristic colourimetric "signature," measured as a change in colour ratio. A planet in transit crossing the limb of a star produces a slight shift in frequency towards the blue. As the planet approaches the centre region of the star an abnormal reddening follows, finally shifting towards blue again as the planet nears the distant limb.

Rosenblatt describes possible instrumentation and methods for the analysis of this signature, as well as the probability of detecting such eclipses. For an in-depth account, see Ref. 2. Three main sources of noise are identified:

(1) Stellar noise, which is mostly a result of intrinsic variation in light flux from the observed or comparison stars.

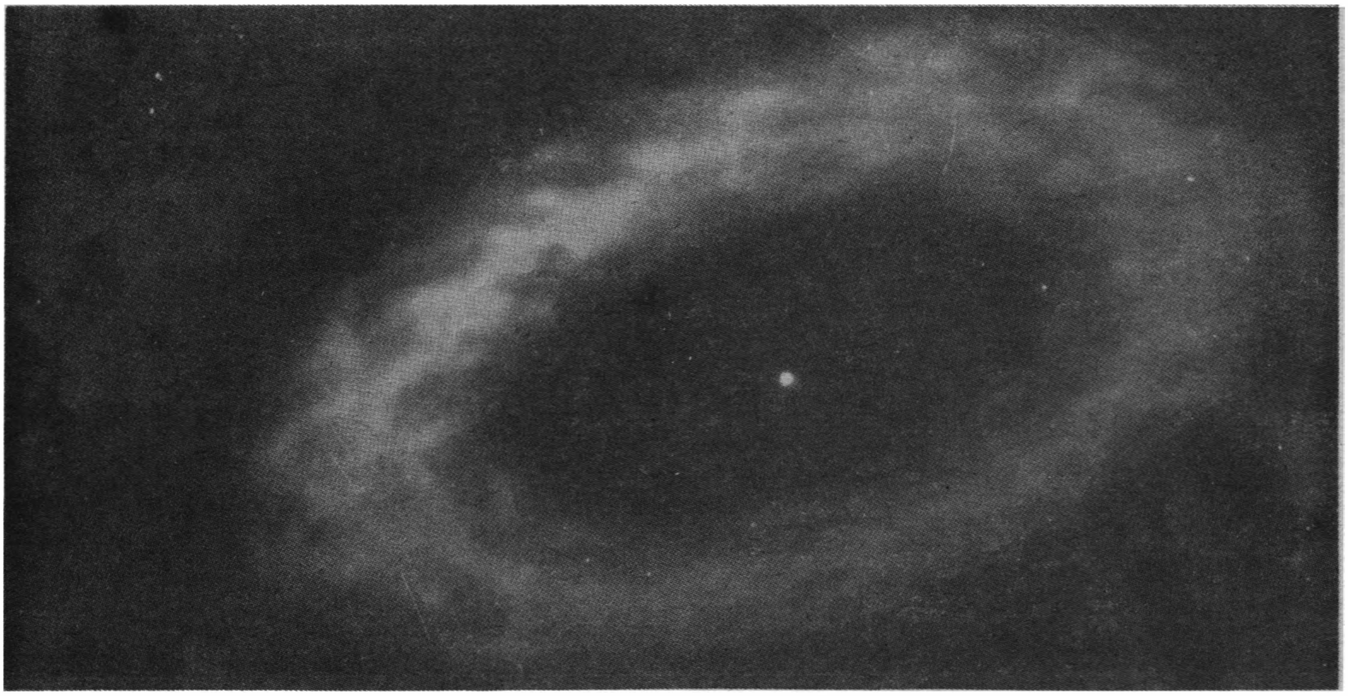
(2) Atmospheric noise, a result of instability and inhomogeneity in the atmosphere, resulting in variations in transparency.

(3) Instrumental noise, such as instability in photodetectors, electronic circuits, etc.

It is evident that the first type of noise will be very difficult to reduce, if at all. Rosenblatt proposes techniques that should produce a reduction in the other two sources. As an example, he suggests that variations in photocathode sensitivity might be reduced by maintaining a high degree of instrumental stability. The effects of these variations are generally colour specific, adding a noise component unique for the particular tube employed. One should therefore determine the noise component for the tube in use, so as to avoid generalising and introducing systematic errors. Furthermore, to enable the observer to proceed with realistic confidence, one should make sure that an observation is not a result of such a variation in sensitivity, by using a multiple coincidence technique and utilising a number of telescopes. Constant observation over an extensive period will prevent the observer from assuming the presence of a planetary body while merely observing a sunspot or a dark spot caused by other phenomena [3].

The system proposed mainly consists of three wide angle telescopes controlled by a central computer, each telescope being equipped with a two-colour photometer utilising an image dissector for tracking and rapid switching between programme stars.

A more futuristic approach, which might be realised within a decade or two, is the proposal by Matloff [4],



Large amounts of material were observed by the Infrared Astronomical Satellite orbiting several stars, among them Vega. The IRAS resolution was not high enough to detect planets.

suggesting the use of wideband photometry in the search of extrasolar planets. In the event of large orbital or lunar-based telescopes being built, extrasolar Jovian and Earthlike planets could be observed.

As a result of the large difference in brightness between a star and a smaller planetary companion, the use of high resolution spectroscopy might not be feasible, even when one has access to orbiting or lunar-based telescopes composed of mirror arrays. Matloff suggests the use of a UBV system, such as the digitised multi-colour photometer by Johnson and Mitchell [5].

The definitions of apparent magnitude, colour index and spectral irradiance, can be used to obtain approximate expressions for the (U-B) and (B-V) colour indices of extrasolar planets.

$$(U\text{-}B)_{P.S.} = (U\text{-}B)_S + 2.5 \log_{10} \left(\frac{{}^R P_B}{{}^R P_U}\right)$$

$$(B\text{-}V)_{P.S.} = (B\text{-}V)_S + 2.5 \log_{10} \left(\frac{{}^R P_V}{{}^R P_B}\right)$$

Extrasolar planet colours are denoted by $(U\text{-}B)_{P.S.}$ and $(B\text{-}V)_{P.S.}$, while the planet's primary star colours are indicated by $(U\text{-}B)_S$ and $(B\text{-}V)_S$. Planet reflectivity at the centre of the U, B and V detection systems are represented by ${}^R P_U$, ${}^R P_B$ and ${}^R P_V$ respectively. Matloff used observational values of ${}^R P_U$, ${}^R P_B$ and ${}^R P_V$ obtained from Mars, Venus and Jupiter, as well as theoretical values of reflectance for Earth-like planets with a wavelength-independent surface reflectivity of 25% for his calculations. The result was that Earth-like planets will appear bluer than their primary stars, while planets similar to Mars, Jupiter or Venus will be redder.

Since many unknown planet types probably exist, categorising planets as a result of wideband photometry also requires data on planet orbit and primary star radiation characteristics before one could conclude that a "blue" planet is Earth-like.

3. RECENT DEVLOPMENTS

Recent developments at the Allegheny Observatory of the University of Pittsburgh include the construction of a prototype of a Multichannel Astrometric Photometer (MAP). Perturbations in the position of a star due to the gravitational influence of a companion will be determined electronically, instead of photographically. Expected accuracy is 2-3 milliarcseconds per hour of observations. To equal this accuracy, more than a year of observations in conventional photometry is needed. During 1984 George Gatewood and his group planned to undertake an intensive search for Jovian planets by observing 100-200 nearby stars. Observations were due to begin after the Thaw refractor had been fitted with a new 75 cm objective. If these measurements were to be made with the Hubble Space Telescope, an improvement to about 1 microarcsecond (a factor of a thousand) in accuracy would ensue [6].

4. CONCLUSIONS

Photometry as a method for the detection of extrasolar planets does have application, although Earth-bound observations place a limit on the accuracy that can be achieved.

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6. M. D. Papagiannis, *JBIS*, **36**, 305-307 (1983).

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REFUELLING SALYUT SPACE STATIONS BY PROGRESS TANKERS

P. MILLS
Kings Lynn, Norfolk, England

1. INTRODUCTION

When the Soviet Union launched the world's first tanker spacecraft, Progress 1, on 20 January 1978, it was the first attempt at refuelling in space. Although the new Progress spacecraft had been tested in orbit before (under the Cosmos label) and unmanned spacecraft had docked before, no refuelling or transfer of gas from one spacecraft to another had taken place. The success of the Progress 1 flight was important to the long term goals of the Soviet space programme. If the refuelling had failed a complete re-design would have been necessary, thus delaying the Salyut programme.

Progress 1 was also a departure from the normal Soviet practice of testing every aspect of a new spacecraft and its systems before a manned application. Sending it on a first-time attempt at refueling was an operational requirement, essential for the long life of Salyut 6. The refuelling operation had to succeed on its first operational flight.

The operation was a complete success and refuelling of Salyuts in orbit by Progress tankers is now routine. This paper briefly describes the Progress craft and the Salyut ODU and shows how refuelling takes place.

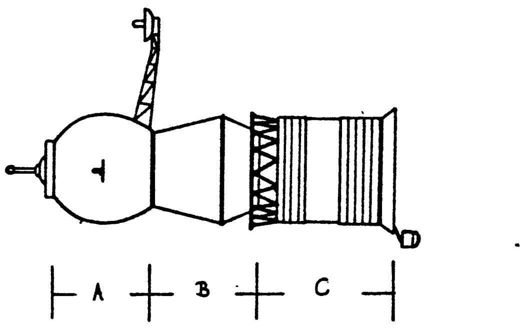


Fig. 1. Progress spacecraft configuration. A: Cargo Compartment, B: Fuel and Oxidizer Comapartment, C: Instrument and Assembly Module.

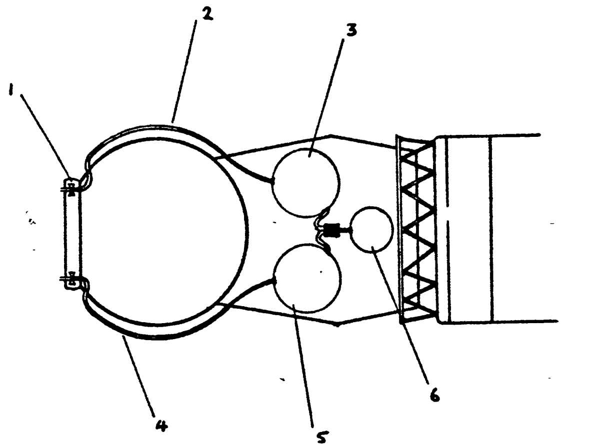


Fig. 2. Fuel and Oxidizer Compartment. 1: Valve, 2: Fuel pipe line, 3: Fuel, 4: Oxidizer pipe line, 5: Oxidizer, 6: High pressure nitrogen bottle. Only one tank of each is shown, for clarity.

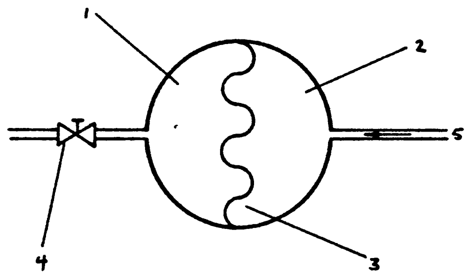


Fig. 3. Simplified diagram of Progress, Salyut ODU fuel/oxidizer tank. 1: Fuel or oxidizer, 2: High pressure nitrogen, 3: Flexible internal partition, 4: Valve, 5: Nitrogen supply.

2. PROGRESS SPACECRAFT CONFIGURATION

The Progress spacecraft is developed from the Soyuz ferry [1] used on earlier joint flights with Salyut stations. There appear to be two versions of Progress: a tanker and a pure cargo spacecraft. The spacecraft consists of three compartments: the cargo compartment, fuel and oxidizer compartment and the instrument/assembly module (Fig. 1).

The pure cargo ferry carries no fuel or oxidizer, only heavy supplies housed in the forward cargo compartment. Later Progress cargo ferries possibly carried water supplies in the fuel and oxidizer compartment.

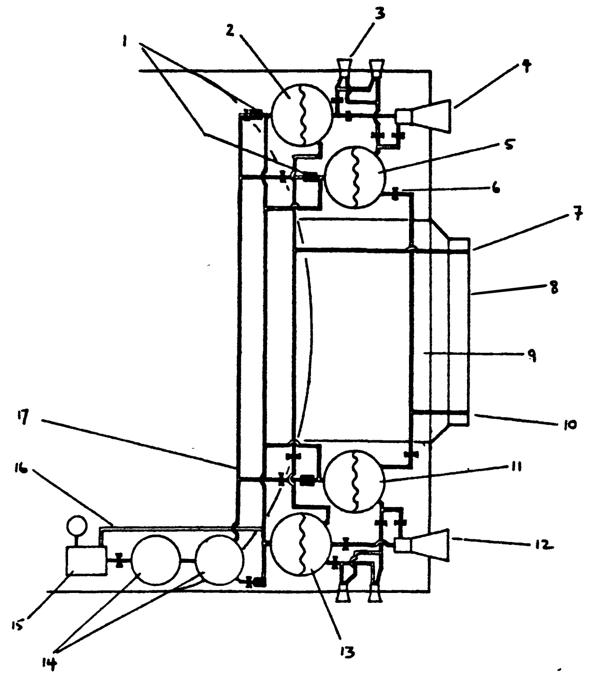
3. PROGRESS FUEL AND OXIDIZER COMPARTMENT

The fuel and oxidizer compartment houses two tanks for the fuel, which is unsymmetrical dimethylhydrazine (UDMH) and two tanks for the oxidizer, nitrogen tetroxide. In addition, a bottle of high pressure nitrogen gas is stored there [1].

The pipelines for the fuel and oxidizer run along the outside of the cargo module and are protected by a thermal blanket covering the craft. The fuel and oxidizer compartment is unpressurised and cannot be entered by the Salyut crew (Fig. 2).

4. PROGRESS AND SALYUT FUEL AND OXIDIZER TANKS

The fuel and oxidizer tanks are the same both for the Salyut ODU and Progress. They are pressure-fed by high pressure nitrogen gas acting on a flexible partition inside the tanks. The pressure squeezes the liquid either into the Salyut ODU (for the Progress pressure system) or into the relevant Salyut



Left: Fig. 4. Salyut propulsion system (only two fuel and two oxidizer tanks shown).

1. Nitrogen pumps.
2. Fuel tank.
3. Attitude Control engines.
4. Main engine.
5. Oxidizer tank.
6. Valve.
7. Fuel supply pipe.
8. Rear docking port of Salyut.
9. Rear transfer compartment of Salyut.
10. Oxidizer supply pipe.
11. Oxidizer tank.
12. Main engine.
13. Fuel tank.
14. H.P. Nitrogen storage bottles.
15. Compressor.
16. Nitrogen return pipe line.
17. Nitrogen feed pipe line.

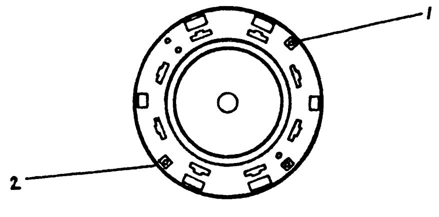


Fig. 5. Salyut Rear Docking Unit. 1: Fuel connection, 2: Oxidizer connection.

engine (for the Salyut pressure system). The principle is shown in Fig. 3.

5. SALYUT PROPULSION AND ATTITUDE CONTROL SYSTEM (ODU)

The Salyut station itself has been described adequately elsewhere [2] and therefore this section will review only the ODU on Salyut.

The refillable Salyut propulsion and attitude control system was first used on Salyut 6· Salyut 7 uses a similar system. The earlier Salyuts used a non-replenishable propulsion system, virtually identical with the Soyuz ferry propulsion system then in use [3].

The propulsion and attitude control system known as the ODU consists of three fuel and three oxidizer tanks, a high pressure nitrogen supply at 3,234 psi, two main propulsion and numerous attitude control engines and a 1 kW electrically driven compressor, along with the necessary pipes, valves and pumps (Fig. 4) [A]. The connections for the transfer of fuel and oxidizer between Progress and the Salyut are located in the docking ring of the rear Salyut docking unit (Fig. 5).

6. THE REFUELLING OPERATION

The refuelling operation can be carried out either by the Salyut crew or by ground control if the station is unmanned or if the cosmonauts have other work to complete. After Progress has docked, the fuel and oxidizer connections are checked for integrity. The nitrogen pressure in the Salyut fuel and oxidizer tanks must then be lowered, this is done with the compressor. Because of the large drain on the Salyut electrical system, the compressor operation is spread over several days. Fig. 6 illustrates the state of the systems

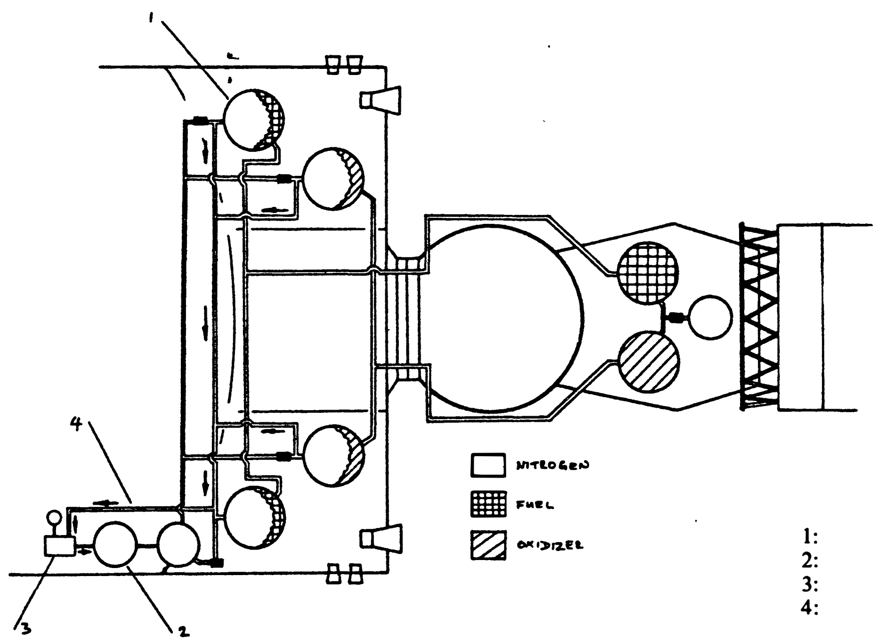


Fig. 6. Reducing tank pressure.

1: Pressure in tanks being reduced.
2: Pressure in storage bottles being increased.
3: Compressor.
4: Nitrogen return pipe line.

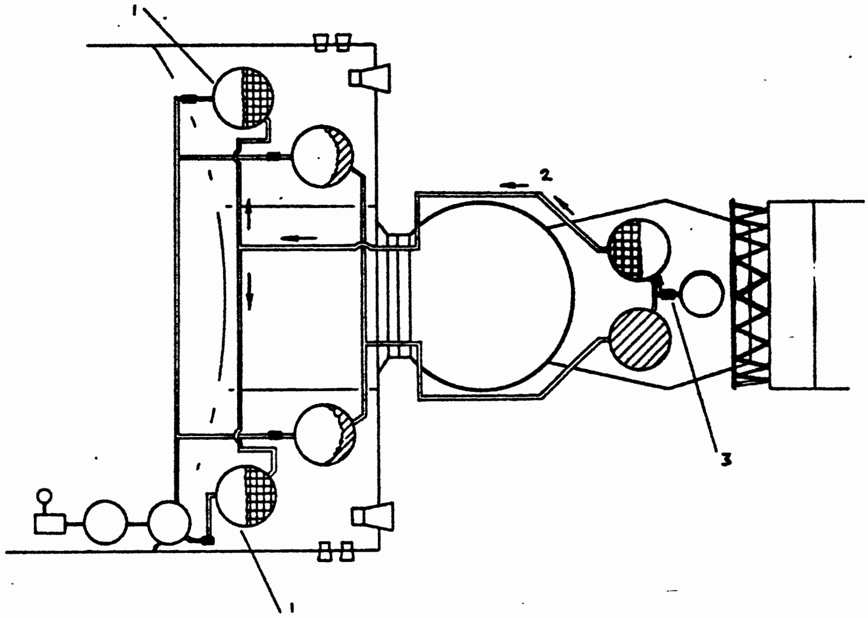


Fig. 7. Refueling takes place:

1: Salyut tanks being filled.
2: Nitrogen pressure forcing fuel out of Progress fuel tank.
3: Nitrogen pump.

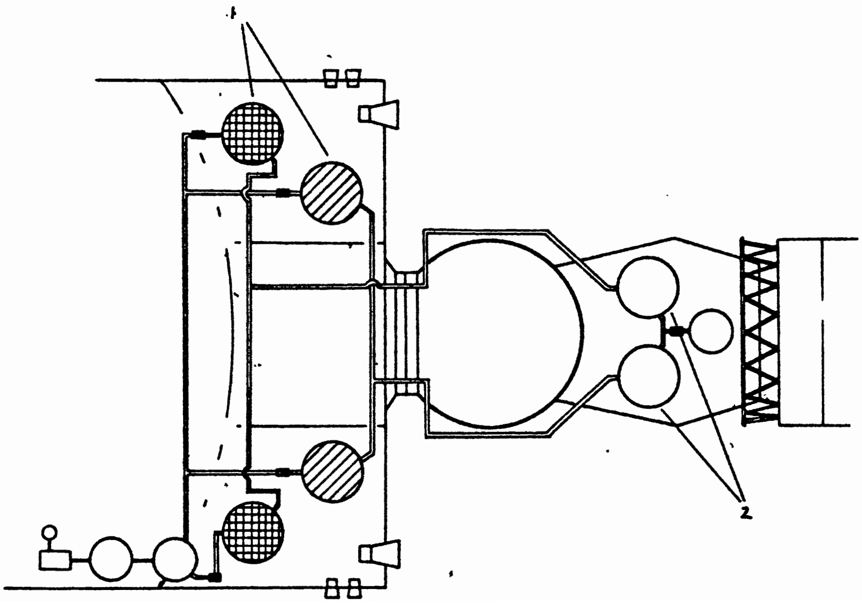


Fig. 8. Fuel and oxidizer transfer completed.

1: Salyut fuel and oxidizer tanks full.
2: Progress fuel and oxidizer tanks empty.

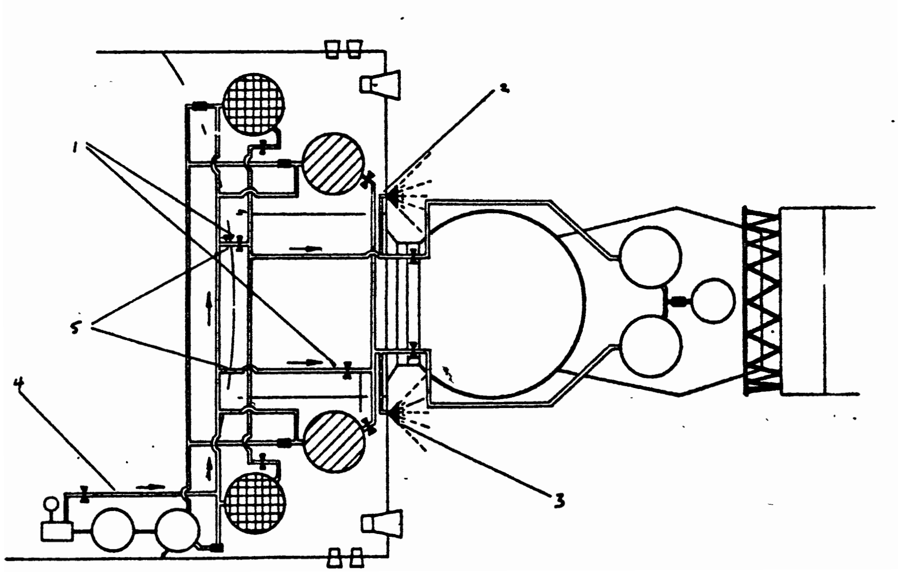


Fig 9. Purging the pipelines.

1: Non-return valves.
2. Vent line.
3. Vent valve.
4. Nitrogen return pipe line.
5. Blow-off lines.

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NOTICES OF MEETINGS

Lecture
Theme: **METEORITES: SURVIVORS OF THE EARLY SOLAR SYSTEM**
by Dr. A. L. Graham
Dept. of Mineralogy, British Museum

To be held in the Society's Conference Room, 27/29 South Lambeth Road, London, SW8 1SZ, England, on **18 September 1985,** 7.00-9.00 p.m.

Admission is by ticket only. Members should apply in good time enclosing a stamped addressed envelope.

Symposium
Theme: **SPACE STATION APPLICATIONS**

A one-day Symposium on the above theme will be held in the Society's Conference Room on **25 September 1985,** 10.00 a.m. to 5.00 p.m.

The Society has long advocated permanent space stations so this Symposium is an important event in the space calendar. A panel of international speakers will present a series of papers to update present thinking on one of today's major space topics.

40th ANNUAL GENERAL MEETING

The 40th Annual General Meeting of the Society will be held in the Gallery Lounge, Grosvenor Hotel, Buckingham Palace Road, London, SW1W OSJ on Saturday **28 September 1985,** at 3.00 p.m. precisely.

AGENDA

1. To receive the Report of the Society's affairs for the year to 31 December 1984.
2. To receive the Society's Balance Sheet and Accounts for the year ended 31 December 1984 and the Auditor's Report thereon.
3. To appoint auditors and determine the method of fixing their remuneration. The present auditors have expressed their interest in continuing in Office.
4. To elect four Members of the Council of the Society. In Accordance with Article 15 the following Members of the Council will retire at the meeting:

   G. W. Childs — L. R. Shepherd
   T. J. Grant — G. M. Webb

   If the number of nominations exceed the number of vacancies, election will be by postal ballot in accordance with Article 44. The final date for the receipt of ballot papers will be 31 January 1986.
5. General discussion
6. Closing remarks by President.

By Order of the Council

L. J. Carter
Executive Secretary

EXTRAORDINARY GENERAL MEETING

NOTICE IS HEREBY GIVEN that an EXTRAORDINARY ANNUAL GENERAL MEETING of the BRITISH INTERPLANETARY SOCIETY Limited will be held in the Gallery Lounge, Grosvenor Hotel, Buckingham Palace Road, London, SW1W 0ST on Saturday **28 September 1985** at 4.00 p.m. for the purposes of considering and if thought fit passing the following Resolutions which will be proposed as Special Resolutions:

RESOLUTION

1. That the Company's Memorandum of Association be modified be deleting the existing clause 3(iv) and substituting the following therefor:

(iv) To purchase or otherwise acquire and undertake all or any part of the property, assets, liabilities and engagements of any association, society or corporation whose objects shall be charitable PROVIDED that the Society shall not possess or subscribe to any association, society or corporation which shall not prohibit the distribution of its income and property among its members to an extent at least as great as is imposed on the Society by virtue of Clause 4 hereof"

2. That the Regulations contained in the printed document submitted to the Meeting and for the purpose of identification signed by the Chairman be approved and is hereby adopted as the Articles of Association of the Company in substitution for and to the exclusion of all the existing Articles of Association of the Company.

BY ORDER OF THE COUNCIL
L. J. CARTER
Executive Secretary

A member who cannot be personally present at the meeting may appoint by proxy some other person, who must be a member of the Society, to attend and vote on his behalf, subject, however, to the proviso that a proxy cannot vote except on a poll.

Members receiving *JBIS* only may obtain a copy of the full Report and Accounts for the year to 31 December 1984 on request to the Executive Secretary. Please include a stamped addressed envelope.

One-day Symposium
Theme: **BRITISH LIQUID PROPELLANT ROCKETS**

A one-day Symposium on the above theme will be held in the Society's Conference Room on **2 October 1985,** 10.00 a.m. to 5.00 p.m.

Full details are given overpage.

Lecture
Theme: **ANTIPROTON ANNIHILATION PROPULSION**
by Dr. R. L. Forward

To be held in the Society's Conference Room, 27/29 South Lambeth Road, London, SW8 1SZ on **2 October 1985,** 7.00-9.00 p.m.

Admission is by ticket only. Members should apply in good time enclosing a stamped addressed envelope.

LIBRARY

The Library will be open to members from 5.30-7.00 p.m. on the following dates:
18 Sep 30 Oct 20 Nov

Membership cards *must* be available for inspection before admittance.

While every effort will be made to adhere to the published programme, the Society cannot be held responsible for any changes made necessary for reasons outside its control.