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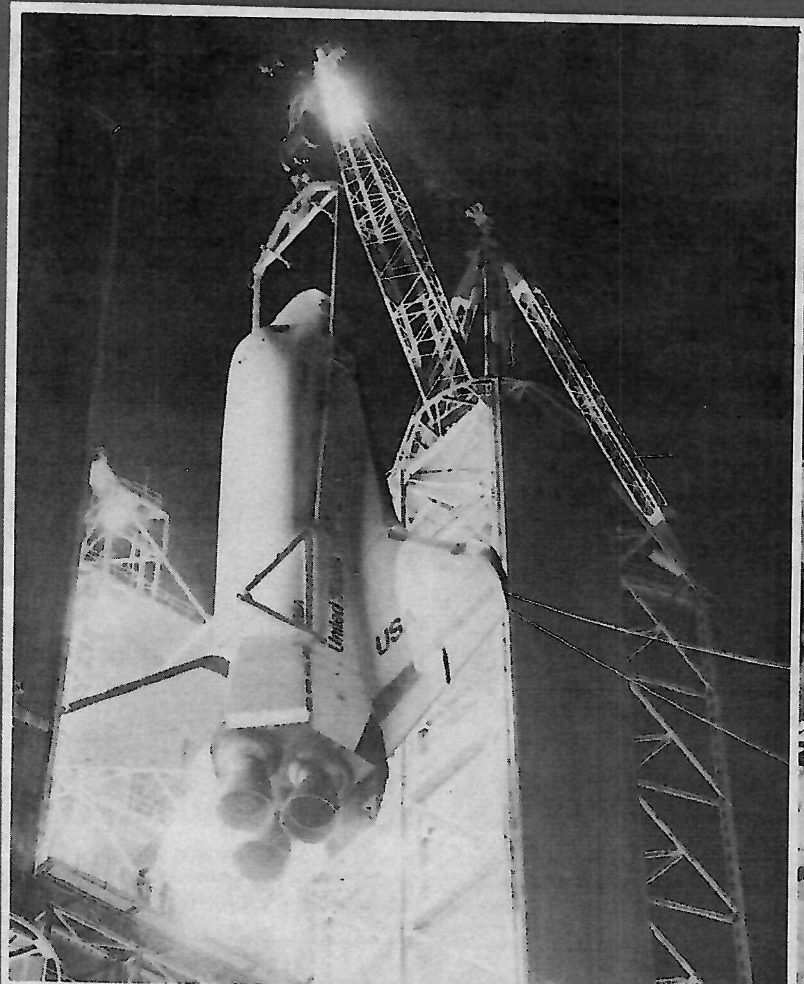

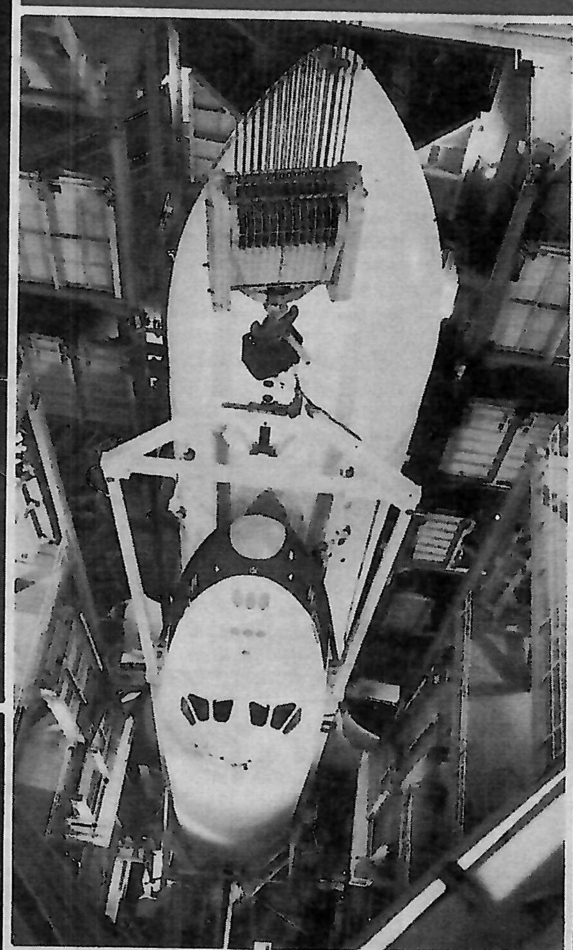

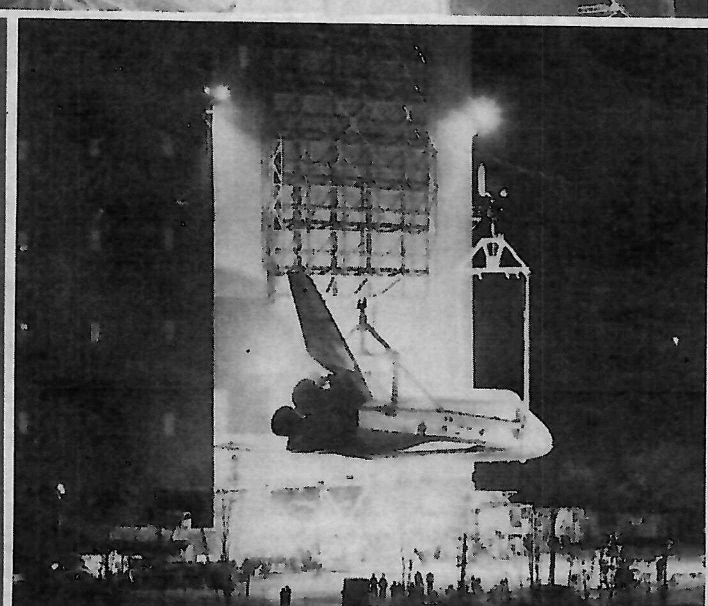

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U.S. RECONNAISSANCE SATELLITE PROGRAMMES

By Anthony Kenden

Introduction

For the last decade and a half the United States and the Soviet Union have been keeping watch on each other from space, using reconnaissance satellites to observe ballistic missile sites, weapons testing and deployment, military exercises, factory and shipyard construction, and a whole host of other "interesting" activities. This may seem like an aggressive and unwarranted intrusion into each other's security, but it is in fact a vital part of the balance of power which has maintained peace and restrained the arms race. The great importance of these reconnaissance satellites and their findings has been implicitly acknowledged by the inclusion in the SALT agreements of clauses specifically prohibiting interference with the other party's "national technical means of verification."

A considerable proportion of the satellites launched by both the United States and the Soviet Union have been related to reconnaissance, but they have received very little publicity. Indeed, it is probably the only topic in the whole space exploration field that accounts of Soviet activities are more readily available to the public than accounts of American ones; for a description of Soviet reconnaissance programmes the reader is referred to [1]. It is the aim of this article to provide an overview of American programmes involved in satellite reconnaissance, and to give an indication of their capabilities.

The Beginnings of Surveillance

At the end of the Second World War several hundred German workers who had been involved with the V-2 project were taken to work in the Soviet Union. By 1952 most of them had been allowed to return to Germany, and they brought back with them stories of Soviet developments in the missile field, stories that sounded ominous to Western military experts. Their real significance was brought home by the explosion of the first Soviet hydrogen bomb on 12 August 1953, only nine months after America's first [2]. To an America steadily cutting back its military strength, the prospect of the Russians having a nuclear armed intercontinental missile was not a pleasant one. It thus became of the greatest importance for the US to find out just how far Russian developments had progressed, and this meant surveillance of Soviet missile tests. A radar station was set up at Samsun in Turkey, which gave ample coverage of the tests conducted from Kapustin Yar, 1,550 km to the north-east [3]. However, it soon became clear that these missiles, with their impacts 1,500 km away in the Kyzyl Kum Desert, were only IRBM's and that the ICBM tests were to be carried out from another launch site, much deeper inside Soviet territory, and out of range of foreign radars. To monitor the ICBM tests the U-2 aircraft was developed, and flights over the Soviet Union began in June 1956. By the spring of 1957 the new cosmodrome at Tyuratam had been discovered, and by the middle of the year a U-2 flying out of Peshawar in Pakistan had brought back photographs of it [4, 5]. As the need for information grew, the flights became longer and longer, until it was decided to make one way trips across the Soviet Union from Peshawar to Bodö in northern Norway. During the first of these, the great disadvantage of the U-2 came to light: on 1 May 1960 Gary Powers was shot down by a ground-to-air missile near Sverdlovsk, and in the uproar that followed all further U-2 flights over the Soviet Union were cancelled.

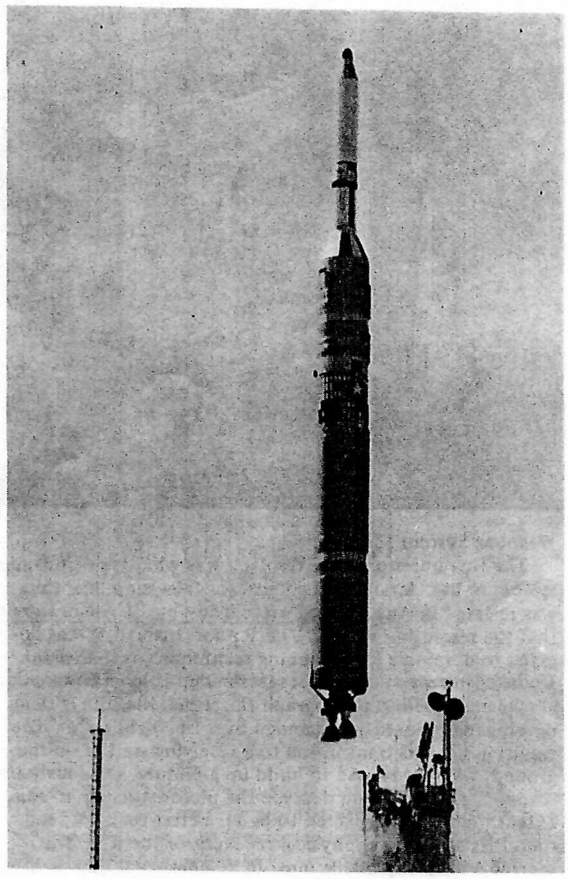

Fig. 1. A Titan 3B blasts off from Vandenberg Air Force Base, California. Rockets of this type have been used extensively to launch close-orbit reconnaissance missions (see Table 3).

United States Air Force

As far as the public was concerned, this seemed to be the end of American surveillance of the Soviet Union, but in fact it was just the beginning. For some time the USAF had been working on a new approach – observation from unmanned satellites. Studies of these started soon after World War II, and as far back as 2 May 1946 Project RAND (soon to become the RAND Corporation) produced a report discussing the technical aspects of a satellite vehicle. In April 1951 they produced a report entitled *Utility of a Satellite Vehicle for Reconnaissance* [6]. On 16 March 1955, four months before the United States was to announce plans to launch a scientific satellite during International Geophysical Year (IGY), the USAF, under the sponsorship of the CIA, issued a formal request for proposals for a "Strategic Satellite System," to be designated WS-117L. On 30 June 1956 the contract was awarded to Lockheed, and the satellite vehicle they developed, the Agena, is still in service today [7].

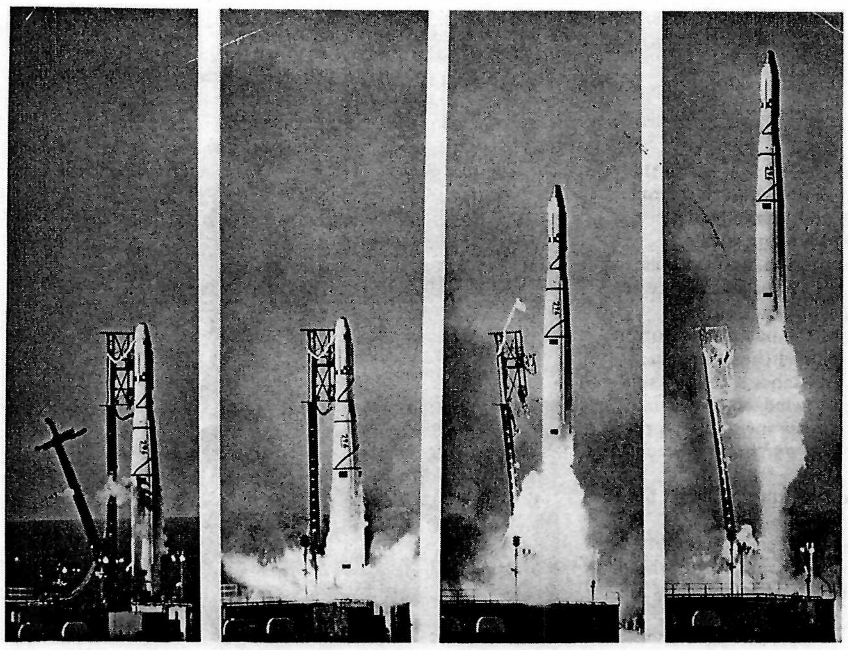

Fig. 2. Launch sequence of a USAF Discoverer polar orbiting satellite at Vandenberg AFB. The Discoverer had a long list of 'firsts' to its credit: the first polar orbiting satellite, the first satellite to be stabilised in space on all three axes, the first to be manoeuvred in space, the first satellite capsule to be recovered from orbit, the first aerial recovery of a space capsule by the air-snatch technique. These qualities established the success of America's first operational reconnaissance satellite system.

United States Air Force

Weapons System 117L

The first question to be resolved was what type of camera system to use. An obvious choice was television, but this was rejected in August 1957 after study by RCA had shown that the resolution would be very poor. Instead, it was decided to develop a film scanning technique (by Eastman Kodak, Philco and CBS Laboratories) in which a conventional camera is used to photograph the scene; the film is then developed on board and scanned by a fine light beam. The resulting signal is transmitted to a receiving station on the ground, where it is used to build up a picture. Obviously the scanning process would degrade the picture quality to some extent, but it was expected to be far better than TV, and the other alternative, physical recovery of the film, still seemed a long way off. It must be remembered that at this time the art of building vehicles which could survive atmospheric re-entry was in its infancy, and the weight penalties for such systems were very high. It was decided, however, to develop a recoverable system as soon as the technology allowed [7].

The launch of Sputnik 1 in October 1957 demonstrated just how advanced Soviet rocketry was, and on 25 November Lockheed's budget for WS-117L was quadrupled [8]. In the meantime, the RAND Corporation had been carrying out further studies on satellite reconnaissance; in a report dated June 1956 entitled *Physical Recovery of Satellite Payloads: A Preliminary Investigation*, it suggested that a modified ICBM nosecone could be used to return camera film to Earth, while the November 1957 report *A Family of Recoverable Reconnaissance Satellites* held out great hopes for a physical recovery system. In January 1958 it was decided that such a system should be developed as soon as possible [7], and General Electric was contracted to produce the recoverable capsule [8]. That November the Department of Defense revealed that WS-117L now consisted of three elements: Discoverer, which would be used as a test bed for developing systems and concepts, Sentry (later to be renamed Samos) which would be the operational reconnaissance system, and Midas, which would be an early warning system to detect missile launches and warn of an attack [9]. The operational systems (Samos and Midas) were each to consist of 8 to 12 satellites in polar orbit, and it was planned that they should be on station by the mid-1960's.

The Agena Vehicle [10]

Lockheed's winning proposal for WS-117L consisted of a second stage to be placed atop an ICBM first stage. The instruments would be placed in the forward section of the vehicle, and on reaching orbit there would be no separation of launch vehicle second stage and payload, as is the usual case. This would allow the orbiting instruments to use the same command, guidance and control equipment as the second stage, giving, it was hoped, a considerable saving in weight and added flexibility. The first Agena was delivered to the USAF towards the end of 1958; it was 1.52 m in diameter and 5.94 m long. Fully fuelled it weighed 3,850 kg, while in orbit it weighed 770 kg. It was cylindrical, with a conical nose at the forward end, and the thrust chamber of the propulsion system protruding from the aft end. The instruments were mounted in the conical section, which carried as its apex the re-entry capsule. This was 84 cm in diameter and 69 cm long, and weighed 135 kg. The stage's rocket engine was the Bell Hustler, producing a thrust of 6,800 kg, and stabilisation was provided by two sets of cold gas reaction jets.

On reaching orbit the vehicle was to rotate through 180° to point backwards along the orbital path. The recovery sequence would be initiated by a command from the ground; first the nose of the craft would be pointed downwards at an angle of 60°, and then the capsule would be separated. It would immediately be spun about its axis to provide stability, and then a retrorocket would be fired to reduce its velocity and start re-entry, which would occur at an altitude of about 110 km. At an altitude of about 15 km the heat shield would be jettisoned, and a parachute deployed. Although the capsule would float, and it could be retrieved from the ocean, the primary method of recovery was to be the mid-air snatch technique. In this aircraft (initially C-119's were used,

Table 1. Discoverer Programme Satellites.

NAME	LAUNCH DATE (GMT)	LAUNCH VEHICLE	LIFE (days)	INCL. (deg)	PERIOD (min)	PERI-APO (km)
Discoverer 1	28 Feb 59	Thor-Agena A		89.7	96	163 - 968
Discoverer 2	13 Apr 59	Thor-Agena A		89.9	90.4	239 - 346
Discoverer 3	3 Jun 59	Thor-Agena A		failed to orbit		
Discoverer 4	25 Jun 59	Thor-Agena A		failed to orbit		
Discoverer 5	13 Aug 59	Thor-Agena A		80.0	94.19	217 - 739
Discoverer 6	19 Aug 59	Thor-Agena A		84.0	95.27	212 - 848
Discoverer 7	7 Nov 59	Thor-Agena A		81.64	94.70	159 - 847
Discoverer 8	20 Nov 59	Thor-Agena A		80.65	103.72	187 - 1679
Discoverer 9	4 Feb 60	Thor-Agena A		failed to orbit		
Discoverer 10	19 Feb 60	Thor-Agena A		failed to orbit		
Discoverer 11	15 Apr 60	Thor-Agena A		80.1	92.16	170 - 589
Discoverer 12	29 Jun 60	Thor-Agena A		failed to orbit		
Discoverer 13	10 Aug 60	Thor-Agena A	1.11	82.85	94.04	258 - 683
Discoverer 14	18 Aug 60	Thor-Agena A	1.12	79.65	94.55	186 - 805
Discoverer 15	13 Sep 60	Thor-Agena A		80.90	94.23	199 - 761
Discoverer 16	26 Oct 60	Thor-Agena B		failed to orbit		
Discoverer 17	12 Nov 60	Thor-Agena B	2.08	81.70	96.45	190 - 984
Discoverer 18	7 Dec 60	Thor-Agena B	3.12	81.50	93.66	243 - 661
Discoverer 19	20 Dec 60	Thor-Agena B		83.40	93.00	209 - 631
Discoverer 20	17 Feb 61	Thor-Agena B		80.91	95.41	288 - 786
Discoverer 21	18 Feb 61	Thor-Agena B		80.74	97.85	240 - 1069
Discoverer 22	30 Mar 61	Thor-Agena B		failed to orbit		
Discoverer 23	8 Apr 61	Thor-Agena B		82.31	94.09	295 - 651
Discoverer 24	8 Jun 61	Thor-Agena B		failed to orbit		
Discoverer 25	16 Jun 61	Thor-Agena B	2.08	82.11	90.87	222 - 409
Discoverer 26	7 Jul 61	Thor-Agena B	2.11	82.94	95.02	228 - 808
Discoverer 27	21 Jul 61	Thor-Agena B		failed to orbit		
Discoverer 28	3 Aug 61	Thor-Agena B		failed to orbit		
Discoverer 29	30 Aug 61	Thor-Agena B	2.10	82.14	91.51	152 - 542
Discoverer 30	12 Sep 61	Thor-Agena B	2.12	82.66	92.40	235 - 546
Discoverer 31	17 Sep 61	Thor-Agena B		82.70	90.86	235 - 396
Discoverer 32	13 Oct 61	Thor-Agena B	1.14	81.69	90.84	234 - 395
Discoverer 33	23 Oct 61	Thor-Agena B		failed to orbit		
Discoverer 34	5 Nov 61	Thor-Agena B		82.52	97.12	227 - 1011
Discoverer 35	15 Nov 61	Thor-Agena B	1.12	81.63	89.7	238 - 278
Discoverer 36	12 Dec 61	Thor-Agena B	4.08	81.21	91.82	241 - 484
Discoverer 37	13 Jan 62	Thor-Agena B		failed to orbit		
Discoverer 38	27 Feb 62	Thor-Agena B	4.06	82.23	90.04	208 - 341

Notes:
1. This table lists all satellites launched in the Discoverer Programme.
2. The lifetimes refer to the recoverable capsules. Lifetimes are quoted for those capsules which were recovered.
3. All launches were made from Vandenberg Air Force Base.

but these were replaced in 1961 by C-130's) trailing large trapeze-like devices would try to snag the capsule as it made its parachute descent. The aircraft would cross the capsule's path just above it, so that the cables of the recovery device, trailing behind and below the aircraft, would ensnare the parachute lines. If all went well the parachute would collapse and fold over, allowing capsule, parachute and recovery device to be hauled into the aircraft.

The Discoverer Programme [8, 11]

All launches in the Discoverer programme (see Table 1) were made from Vandenberg Air Force Base, California, using Thor rockets as their first stages. The plan was to place the satellites in near polar orbits, which would take them over virtually the whole of the Earth's surface. By placing them in orbits with periods of 90 to 95 minutes they could be recovered over the Pacific Ocean after one day on their seventeenth or eighteenth orbits, after two days on their thirty-second or thirty-third orbits, after three days on their forty-eighth or forty-ninth orbits, and so on.

The first launch took place on 28 February 1959 and the Agena went into an orbit with a perigee of 163 km and an apogee of 968 km. It carried no recoverable capsule, but was intended as a test of the Agena and its systems. Unfortunately a fault in the stabilisation system caused the craft to tumble violently in orbit. The second launch, on 13 April, was successful, and all seemed to be going well until a human error caused the re-entry sequence to be initiated too early, and the capsule descended far away from the recovery forces, over northern Norway. Ironically, all the mechanical systems appeared to have worked correctly, and there were reports of sightings of the descending capsule, but a search party was unable to locate it.

After a very promising start the Discoverer programme now entered a period of continuing frustration. The next two launches, on 3 and 25 June, failed to achieve orbit, and when Discoverer 5 actually made it to orbit on 13 August, improper orientation during retrofire sent the capsule into a higher orbit rather than back to Earth. Flight number 6, which was probably the first to carry photographic equipment, seemed to be going very smoothly; a good orbit was achieved on 19 August, and the retrofire and re-entry sequence was carried out according to plan on the seventeenth orbit. During the parachute descent, however, no homing signals were received from the capsule, and it and its cargo were never found. Things then began to get worse; Discoverer 7 could not be stablised in orbit, and a launch vehicle guidance error placed Discoverer 8 in an orbit with an apogee of 1,679 km. It was decided to try and recover the capsule on the fifteenth orbit, but the parachute did not seem to deploy correctly, and the capsule was not recovered.

The next two launches, on 4 and 19 February 1960, did not get into orbit, but on 15 April Discoverer 11 seemed to be working as planned. Re-entry was initiated on the seventeenth orbit, but its descent could not be tracked and it was lost. Discoverer 12 was another launch failure, but with number 13 the programme's luck changed. On 10 August it was placed in a 258 km to 683 km orbit, and

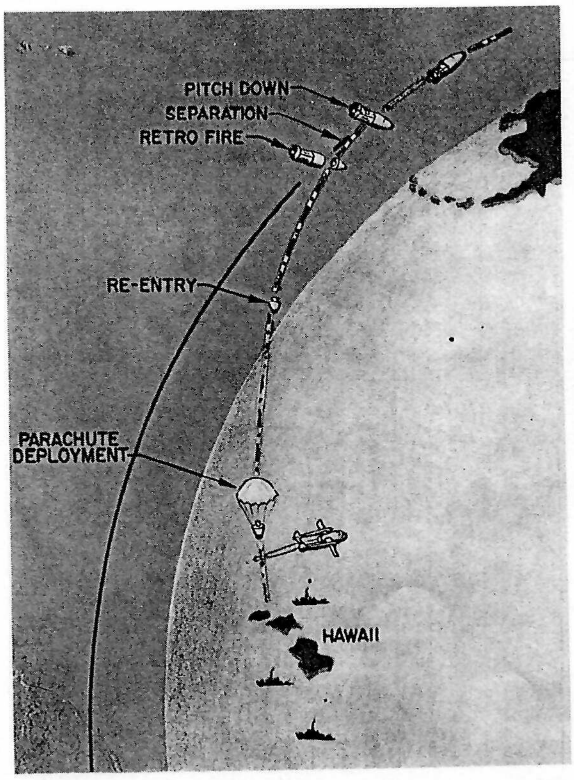

Fig. 3. Agena spacecraft capsule re-entry sequence from polar orbit begins near Alaska.

Kenneth W. Gatland

right on schedule on the seventeenth orbit the capsule was ejected and its retrorocket fired. Radar based in Hawaii, 450 km south west of its path, tracked it on its way down, and although heavy cloud precluded mid-air retrieval, it was soon spotted floating in the ocean, and picked up by Navy frogmen. This was the first object that had ever been recovered from space, a considerable technical achievement.

A week after the recovery, Discoverer 14 was launched. Launch vehicle and spacecraft performed perfectly, achieving a good orbit and ejecting their capsule on the seventeenth pass as planned. As it dropped through the 2,600 m altitude mark it was caught by a C-119 and hauled on board. After 16 months of trying a completely successful mission was accomplished, and whereas the USAF stressed that Discoverer 13 carried "no sensor equipment," no such statement was made for this mission. It seems quite likely that the US was analysing its first photographs of the Soviet Union taken from space by the end of August 1960.

Although a successful mission had been completed, there were still problems to be resolved. Discoverer 15, launched on 13 September, ejected its capsule but it landed outside the recovery area and was lost, while Discoverer 16 failed to reach orbit. This flight marked the introduction of the new Agena B; lengthened to 8.08 m to carry more propellants and with a new restartable engine it could place 950 kg in orbit. The next two missions were both complete successes, returning after two and three days in orbit respectively. Discoverer 19 was orbited on 20 December, but carried no recoverable capsule as it was a test of sensors for the Midas project.

The New Year got off to a bad start when Discoverer 20 could not be stabilised in orbit following launch on 17 February, but the next day all went well for Discoverer 21, another Midas test vehicle. The next three flights did not achieve their objectives, with numbers 22 and 24 failing to reach orbit, and incorrect orientation causing Discoverer 23's retrofire to send its capsule into a higher orbit instead of back to Earth.

The first recoveries of 1961 came with Discoverers 25 and 26, launched on 16 June and 7 July, each returning its capsule after two days, but then the next two flights were launch failures. This uneven record would continue through to the end of the programme in the Spring of 1962, with the next two flights (numbers 29 and 30) leading to capsule recoveries, followed by a flight on which the capsule could not be ejected, and then another success. The year ended with a launch failure, an orbital failure, a mid-air recovery and a retrieval from the sea, the last after four days in space. The final launches of the programme came on 13 January (a launch failure) and 27 February 1962 (a mid-air recovery after four days), bringing the total number of launches to 38. Of these 26 reached orbit, and of the 23 capsules they carried, 8 were recovered in mid-air and four from the sea. This record may not sound very impressive today, but fifteen years ago, when space vehicles were notoriously unreliable, it represented a considerable achievement. Most important of all, the programme had shown that the recovery of photographic film from space was feasible, and the indications were that when the "bugs" had been worked out of the system, it could be carried out on a routine basis.

Operational Reconnaissance System

The development by the Discoverer programme of the film recovery technique did not mean that the radio transmission had been abandoned, for each system had its advantages and disadvantages. The film recovery method gave much better resolution, and showed more detail of what was on the ground, but the weight penalty of carrying a re-entry capsule was high, and meant that only a small quantity of film could be carried. Radio transmission, on the other hand, produced poorer resolution, but many more photographs could be taken on a mission. It also had the advantage that its photographs could be analysed as soon as they had been transmitted to the ground, probably within a couple of hours of them actually being taken, whereas no shots could be studied from a recovery mission until the flight was complete, the capsule had been recovered and the film flown to Washington.

There were three main tasks for reconnaissance satellites in the early 1960's; the first was to get a detailed look at the Soviet ICBM, the SS-6, which was thought to be deployed in large numbers. By studying its ground handling, the number of people required to service it, etc., a good estimate could be made of how quickly an attack could be mounted, and how vulnerable it might be to a first strike. Another important question was how many missiles were deployed, and was the "Missile Gap" really as bad as some people claimed (it was not!). To do this a survey of most of the Soviet Union was required, but as the missiles were so big, a launch site would show up clearly, and good resolution would not be required. The third application was to map the whole of the Soviet Union, to provide targeting data for US missiles (it was discovered when this was complete that the positions of cities shown on Soviet maps were deliberately falsified, with their locations as much as 15 km out [12]). Again, good resolution was not as important as the number of flights necessary to cover the ground.

These factors led to the decision to develop both film recovery and radio transmission satellites as two complementary programmes. Because of their applications, the radio transmission vehicles are usually referred to as area survey satellites, and the film recovery vehicles are referred to as close look satellites.

The Area Survey Satellites

At about the time of the early Discoverer launches, tests were being carried out of the radio transmission system from aircraft. This system was being developed by Eastman Kodak (the camera) and CBS Laboratories (the film scanner), and a close relation, built by the same companies, was to find another application in Moon photography in the Lunar Orbiter series of spacecraft in 1966 and 1967 [11]. The ability to use aircraft as test vehicles, instead of the space vehicles that the recovery system required, meant that these tests could be carried out much more quickly and at far less cost. As a consequence, the first operational area survey satellite was ready for launch only two months after the Discoverer programme had made its first recovery in August 1960. That two-month period saw several milestones in the reconnaissance programme. In early September the programme's name was changed from Sentry to Samos, an acronym for Satellite and Missile Observation System, and soon afterwards it was given a new priority under an Air Force reorganisation. The programme was moved under the direct control of the Secretary of the Air Force, an unprecedented move in the history of USAF developments [13]. Following this, requests for proposals were issued for the close-look satellite, code named E-6 (the area survey satellites were code named E-5), with bids to be in by 13 October. The winning contractor was to deliver a prototype nine months after the start of work, half the normal period for such a complex system [14].

The first area survey satellite, Samos 1, was launched on 11 October 1960, see Table 2. The Atlas-Agena A vehicle's first stage performed as planned, but although the second stage ignited the craft did not reach orbit. At the time the USA was engaged in an all-out bid to close the "Missile Gap," and most of the rockets that came off the Atlas production line were earmarked for deployment as ICBM's, so it was three months until the next Samos launch, but this time a success was recorded. On 31 January 1961 Samos 2 was placed in an orbit with a perigee of 474 km and an apogee of 557 km, giving it a period of very nearly 95 minutes. In orbit it weighed 1,860 kg, of which about 150 kg were instruments, and it operated in space for a month. The success of this flight can be judged from the way US estimates of Soviet ICBM strengths were reduced in the following months, from the original 120 to 60 in June, and then further to only 14 in September [11], and the increased confidence with which they were expressed. The next launch, Samos 3 on 9 September, used the new Agena B upper stage, but failed when the vehicle exploded on the pad.

With the success of the growing US reconnaissance effort, the Soviet Union had been mounting a propaganda campaign against American "militarisation of space," and it was presumably in response to this that the Department of Defense decided to change its policy on the amount of information made public about its launches. It was decided that the programme under which a launch was made should not be identified, and only an announcement of the launch vehicle type and whether orbit had been achieved would be made. However, tables of orbital parameters are issued by the Royal Aircraft Establishment at Farnborough, so even if the USAF does not give these details (as it sometimes doesn't) they are always available to the public. Armed with these, and a knowledge of the sort of orbit required for a given mission and the type of launch vehicle used, it is possible to identify those launches which form part of the reconnaissance programmes with a good degree of certainty. Thus when the first of these unidentified launches was made on 22 November 1961 using an Atlas-Agena B launch vehicle, it was fairly clear that this was a Samos mission. This flight failed to reach orbit, but the next one, launched a month later, was placed in a 244 km to 702 km orbit. Before the advent of satellites it had been expected that the minimum altitude that a

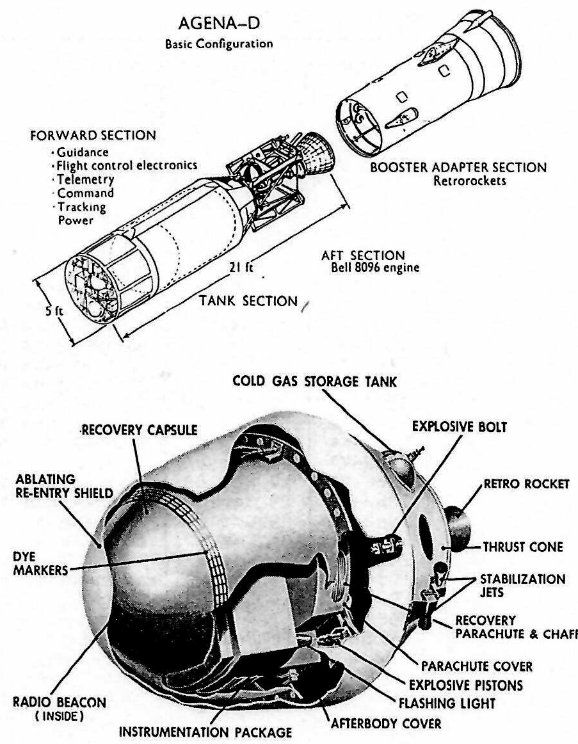

Fig. 4. The orbiting Agena stage upon which the U.S. Air Force built the first family of reconnaissance satellites. Camera equipment and re-entry capsule were in the nose section (not shown here). *Below*, 300 lb. (136 kg) re-entry capsule.

Lockheed Missile and Space Systems/General Electric of USA

satellite could use which would not decay in a matter of hours would be about 450 km, but the early spacecraft had shown that the upper atmosphere was less dense than expected, and altitudes as low as 150 km could be used for flights of a few weeks. This would, of course, benefit the reconnaissance satellites, as reducing their altitudes would increase their ground resolutions and allow their transmission systems to use higher data rates. The launch of 22 December seems to have been the first to test the lower altitudes; as the programme progressed the perigee heights would average about 180 km and the apogees in the 300 km to 400 km range.

By the beginning of 1962 the weight of the photographic system had been reduced enough to allow a change to the Thor-Agena B launch vehicle [15], which could place about 1,000 kg in orbit. The first of these launches was made on 21 February, with the Agena going into a 167 km to 374 km orbit, typical of those that were to follow. All the succeeding launches involved Thor-based vehicles, and the reliability problems that plagued the Discoverer programme seemed to have been cured, for there were to be eighteen more successful launches before the next failure.

As 1962 progressed a transition was made from the Agena B to the Agena D, with the first launch of the new variant on 28 June and the last of the old on 24 November. The new stage had a restartable engine which could be fired from time to time to raise its orbit and prolong its life [15]. The pace of launches built up in 1962, with eighteen successes and no failures marked up by the end of the year, indicating the maturity of the programme and the importance attached to its results.

Table 2. Area Survey Satellites.

NAME	LAUNCH DATE (GMT)	LAUNCH VEHICLE	LIFE (days)	INCL. (deg)	PERIOD (min)	PERI-APO (km)
Samos 1	11 Oct 60	Atlas-Agena A		failed	to orbit	
Samos 2	31 Jan 61	Atlas-Agena A	4646	97.40	94.97	474 - 557
Samos 3	9 Sep 61	Atlas-Agena B		failed	to orbit	
none	22 Nov 61	Atlas-Agena B		failed	to orbit	
1961-αλ	22 Dec 61	Atlas-Agena B	235	89.6	94.1	244 - 702
1962-δ	21 Feb 62	Thor-Agena B	16	81.97	90.0	167 - 374
1962-λ	18 Apr 62	Thor-Agena B	40	73.48	90.9	200 - 441
1962-ρ	28 Apr 62	Thor-Agena B	28	73.11	91.1	180 - 475
1962-φ	30 May 62	Thor-Agena B	12	74.10	89.7	199 - 319
1962-χ	2 Jun 62	Thor-Agena B	26.9	74.26	90.5	211 - 385
1962-αβ	23 Jun 62	Thor-Agena B	14.7	75.09	89.58	213 - 293
1962-αγ	28 Jun 62	Thor-Agena D	78	76.04	93.6	211 - 689
1962-αη	21 Jul 62	Thor-Agena B	24	70.29	90.42	208 - 381
1962-αθ	28 Jul 62	Thor-Agena B	27	71.09	90.64	225 - 386
1962-ακ	2 Aug 62	Thor-Agena D	24	82.25	90.77	204 - 418
1962-ασ	29 Aug 62	Thor-Agena D	12	65.21	90.38	187 - 400
1962-αχ	17 Sep 62	Thor-Agena B	62.2	81.84	93.33	204 - 668
1962-ββ	29 Sep 62	Thor-Agena D	14	65.40	90.30	203 - 376
1962-βε	9 Oct 62	Thor-Agena B	37.3	81.96	90.96	213 - 427
1962-βο	5 Nov 62	Thor-Agena B	27	74.98	90.71	208 - 409
1962-βρ	24 Nov 62	Thor-Agena B	18	65.14	89.92	204 - 337
1962-βσ	4 Dec 62	Thor-Agena D	3	65.1	89.16	194 - 273
1962-βφ	14 Dec 62	Thor-Agena D	25.0	70.97	90.46	199 - 392
1963-02	7 Jan 63	Thor-Agena D	16.3	82.23	90.54	205 - 399
none	28 Feb 63	TAT-Agena D		failed	to orbit	
none	18 Mar 63	TAT-Agena D		failed	to orbit	
1963-07	1 Apr 63	Thor-Agena D	25.0	75.40	90.66	201 - 408
none	26 Apr 63	Thor-Agena D		failed	to orbit	
1963-16	18 May 63	TAT-Agena D	8	74.54	91.12	153 - 497
1963-19	13 Jun 63	TAT-Agena D	29.1	81.87	90.67	192 - 419
1963-25	27 Jun 63	TAT-Agena D	29.7	81.6	90.5	196 - 396
1963-29	19 Jul 63	Thor-Agena D	25.8	82.86	90.44	194 - 387
1963-32	31 Jul 63	TAT-Agena D	12.0	74.95	90.4	157 - 411
1963-34	25 Aug 63	TAT-Agena D	18.6	75.01	89.4	161 - 320
*1963-35	29 Aug 63	Thor-Agena D	69.7	81.89	90.80	292 - 324
1963-37	23 Sep 63	TAT-Agena D	18.2	74.90	90.63	161 - 441
*1963-42	29 Oct 63	TAT-Agena D	83.51	89.90	90.84	279 - 345
none	9 Nov 63	Thor-Agena D		failed	to orbit	
1963-48	27 Nov 63	Thor-Agena D	17.3	69.99	90.2	175 - 386
*1963-55	21 Dec 63	TAT-Agena D	18.0	64.94	89.96	176 - 355
1964-08	15 Feb 64	TAT-Agena D	23.0	74.95	90.86	179 - 444
none	24 Mar 64	TAT-Agena D		failed	to orbit	
1964-22	27 Apr 64	TAT-Agena D	28.19	79.93	90.77	178 - 446
1964-27	4 Jun 64	TAT-Agena D	13.94	79.96	90.27	149 - 429
1964-32	19 Jun 64	TAT-Agena D	26.81	85.0	90.95	176 - 462
1964-37	10 Jul 64	TAT-Agena D	26.52	84.98	91.00	180 - 461
1964-43	5 Aug 64	TAT-Agena D	26.0	79.96	90.71	182 - 436
1964-56	14 Sep 64	TAT-Agena D	21.7	84.96	90.88	172 - 466
1964-61	5 Oct 64	TAT-Agena D	20.50	79.97	90.75	182 - 440
1964-67	17 Oct 64	TAT-Agena D	17.27	74.99	90.59	189 - 416
1964-71	2 Nov 64	TAT-Agena D	25.33	79.95	90.70	180 - 448
1964-75	18 Nov 64	TAT-Agena D	17.45	70.02	89.71	180 - 339
1964-85	19 Dec 64	TAT-Agena D	26.06	74.97	90.46	183 - 410
1964-87	21 Dec 64	TAT-Agena D	21.64	70.08	89.5	238 - 264

Early in the next year a second generation of area survey satellites was introduced, with the first launch on 28 February. By placing three solid propellant boosters on the Thor first stage the payload could be increased to 1,500 kg, which would allow the satellite to carry more film and consumables for longer stays in orbit. The first launch of the new vehicle, known as the TAT-Agena D (standing for Thrust Augmented Thor-Agena D) failed, as did the second, but the third attempt, on 18 May, was a success. Following this flight the use of the older generation was phased out, with its last launch on 27 November. The other development of 1963 was the introduction of subsatellites for electronic intelligence ("ferret") missions. These small craft, weighing about 60 kg, are carried into orbit attached to their main payloads, but once in orbit they are separated and placed in their own higher orbits (they will be described in more detail in a later section). Three launches in 1963 carried these subsatellites, but then they were assigned to the close look vehicles for the next three years. In all, seventeen launches were made during the year, of which thirteen reached orbit.

By now operations had become routine, with both 1964 and 1965 showing a record of thirteen successes and one failure, but 1966 saw the introduction of a third generation launch vehicle and spacecraft. The new spacecraft carried infra-red scanners in addition to its cameras, which allowed photographs to be taken on night passes, and they were equipped with the new Space-Ground Link System [16], which used a 1.5 m unfurlable antenna and enabled pictures to be transmitted to the ground at a much higher rate [17]. To boost this satellite a new launch vehicle was introduced, the LTTAT-Agena D (for Long Tank Thrust Augmented Thor-Agena D). The propellant tanks of the Thor were lengthened, and instead of tapering towards the nose a constant diameter was maintained, giving it a payload capability

Table 2. Area Survey Satellites/contd.

NAME	LAUNCH DATE (GMT)	LAUNCH VEHICLE	LIFE (days)	INCL. (deg)	PERIOD (min)	PERI-APO (km)
1965-02	15 Jan 65	TAT-Agena D	25.0	74.95	90.52	180 - 420
1965-13	25 Feb 65	TAT-Agena D	20.92	75.08	90.07	177 - 377
1965-26	25 Mar 65	TAT-Agena D	10.1	96.08	89.06	186 - 265
1965-33	29 Apr 65	TAT-Agena D	26.5	85.04	91.05	178 - 473
1965-37	18 May 65	TAT-Agena D	28.24	75.01	89.71	198 - 331
1965-45	9 Jun 65	TAT-Agena D	12.58	75.07	89.84	176 - 362
1965-57	19 Jul 65	TAT-Agena D	29.25	85.05	91.01	182 - 464
1965-67	17 Aug 65	TAT-Agena D	54.40	70.04	90.37	180 - 407
none	2 Sep 65	TAT-Agena D		failed	to orbit	
1965-74	22 Sep 65	TAT-Agena D	18	80.01	90.04	191 - 364
1965-79	5 Oct 65	TAT-Agena D	24.01	75.05	89.75	203 - 323
1965-86	28 Oct 65	TAT-Agena D	19.81	74.97	90.54	176 - 430
1965-102	9 Dec 65	TAT-Agena D	16.78	80.04	90.72	183 - 437
1965-110	24 Dec 65	TAT-Agena D	26.59	80.01	90.83	178 - 446
1966-07	2 Feb 66	TAT-Agena D	24.67	75.05	90.64	185 - 425
1966-18	9 Mar 66	TAT-Agena D	19.83	75.03	90.59	178 - 432
1966-29	7 Apr 66	TAT-Agena D	18.43	75.06	89.56	193 - 312
none	3 May 66	TAT-Agena D		failed	to orbit	
1966-42	24 May 66	TAT-Agena D	16	66.04	89.00	179 - 271
1966-55	21 Jun 66	TAT-Agena D	22	80.10	90.15	194 - 367
1966-72	9 Aug 66	LTTAT-Agena D	32.20	100.12	89.35	194 - 287
1966-85	20 Sep 66	TAT-Agena D	21.90	85.13	90.87	188 - 442
1966-102	8 Nov 66	TAT-Agena D	20.6	100.09	89.42	172 - 318
1967-02	14 Jan 67	TAT-Agena D	18.7	80.07	90.13	180 - 380
1967-15	22 Feb 67	TAT-Agena D	17.02	80.03	90.12	180 - 380
1967-29	30 Mar 67	TAT-Agena D	17.65	85.03	89.45	167 - 326
*1967-43	9 May 67	LTTAT-Agena D	64.62	85.10	94.36	200 - 777
*1967-62	16 Jun 67	LTTAT-Agena D	33.16	80.02	89.97	181 - 367
1967-76	7 Aug 67	LTTAT-Agena D	24.85	79.94	89.72	174 - 346
1967-87	15 Sep 67	LTTAT-Agena D	18.69	80.07	89.95	150 - 389
*1967-109	2 Nov 67	LTTAT-Agena D	29.83	81.53	90.47	183 - 410
1967-122	9 Dec 67	LTTAT-Agena D	15	81.65	88.45	158 - 237
*1968-08	24 Jan 68	LTTAT-Agena D	33.54	81.48	90.55	176 - 430
*1968-20	14 Mar 68	LTTAT-Agena D	26.22	83.01	90.20	178 - 391
1968-39	1 May 68	LTTAT-Agena D	14	83.05	88.58	164 - 243
*1968-52	20 Jun 68	LTTAT-Agena D	25	84.99	89.75	193 - 326
1968-65	7 Aug 68	LTTAT-Agena D	19.45	82.11	88.60	152 - 257
*1968-78	18 Sep 68	LTTAT-Agena D	19.25	83.02	90.12	167 - 393
1968-98	3 Nov 68	LTTAT-Agena D	19.99	82.15	88.90	150 - 288
*1968-112	12 Dec 68	LTTAT-Agena D	15.65	81.02	88.67	169 - 248
*1969-10	5 Feb 69	LTTAT-Agena D	18.86	81.54	88.70	178 - 239
*1969-26	19 Mar 69	LTTAT-Agena D	4.35	83.04	88.73	179 - 241
*1969-41	2 May 69	LTTAT-Agena D	21.35	64.97	89.54	179 - 326
1969-63	24 Jul 69	LTTAT-Agena D	30.44	74.98	88.49	178 - 220
*1969-79	22 Sep 69	LTTAT-Agena D	19.74	85.03	88.83	178 - 253
1969-105	4 Dec 69	LTTAT-Agena D	36.26	81.48	88.61	159 - 251
*1970-16	4 Mar 70	LTTAT-Agena D	21.98	88.02	88.76	167 - 257
*1970-40	20 May 70	LTTAT-Agena D	27.53	83.00	88.62	162 - 247
1970-54	23 Jul 70	LTTAT-Agena D	26.99	60.00	90.04	158 - 398
*1970-98	18 Nov 70	LTTAT-Agena D	22.78	82.99	88.70	185 - 232
none	17 Feb 71	LTTAT-Agena D		failed	to orbit	
1971-22	24 Mar 71	LTTAT-Agena D	18.81	81.52	88.56	157 - 246
*1971-76	10 Sep 71	LTTAT-Agena D	25.02	74.95	88.48	156 - 244
1972-32	19 Apr 72	LTTAT-Agena D	22.77	81.48	88.85	155 - 277
1972-39	25 May 72	LTTAT-Agena D	10.20	96.34	89.17	158 - 305

Notes:
1. This table lists all satellites with the characteristics of area survey missions.
2. Launches by Thor-Agena D, TAT-Agena D and LTTAT-Agena D which failed to reach orbit may be ferret missions. It is not possible to discriminate between area survey and ferret missions when only the launch vehicle, and not the intended orbit, is known.
3. Those launches marked with an asterisk carried ferret subsatellites which were ejected into separate orbits.
4. All launches were made from Vandenberg Air Force Base.

of 2,000 kg. The first launch of the new combination was made on 9 August, and the satellite operated for 32 days before decaying, but it appears that some problems may have ocurred, since nine months were to pass before the next launch of this type. In the meantime the area survey function was carried out by the second generation craft, and by the end of the year a total of nine launches had been made, all but one succeeding. This downward trend in the number of launches made each year was to continue, and there appear to be two main reasons for this. Firstly, the improved sensors on board the spacecraft gave better coverage, so less flights were required to observe a given area. Secondly, by now one assumes that a complete survey of the Soviet Union (and other interesting countries) had been made, and a detailed inventory of Russian weapon deployments had been compiled. In this case area survey flights would only be required periodically, to check on changes to the scene.

The first launches of 1967 used the second generation vehicle, but from 9 May onwards all launches used the new LTTAT-Agena D. With the new vehicle came the re-introduction of ferret subsatellites to the area survey programme, a function that was to continue until the end of the programme. A total of nine launches were made during the year, and eight the next, the last of which carried a new type of subsatellite into orbit on 12 December. The first launch of 1969, on 5 February, also carried one, and they both went into high circular orbits, but their possible applications will be discussed later. In 1969 the launch total dropped to six, and the next year to four. The year of 1971 was noteworthy for two reasons – the programme had its first launch failure for nearly five years (and its last), and the appearance of Big Bird. The latter was an entirely new generation of reconnaissance satellite, combining the area survey and close-look functions in a single craft, and within a year of its first launch in June 1971 the area survey programme had ended. In thirteen years 109 launches had been made, and of these 98 succeeded in placing their payloads in orbit, giving a launch reliability of 90%.

Close-Look Satellites

The recovery of Discoverer 13's capsule in August 1960 was the signal for the USAF to press ahead with the development of the operational close-look system. Within three months proposals from industry had been requested, received and evaluated, with the result that contracts were awarded to General Electric for the recoverable capsule and to Eastman Kodak for the camera system [18]. This vehicle would use the Atlas-Agena B combination and weigh around 2,000 kg in orbit, twice the weight of the later Discoverers.

It was reported in February 1962 that the first two satellites had been delivered to the USAF, one for checkout of booster compatibility and ground handling, and one for launch [19]. It was placed in orbit on 7 March (see Table 3), but in the absence of official announcements it is hard to judge the degree of success that this flight achieved. Its orbit, from 251 km to 676 km, was higher than subsequent missions: this could have been intentional, if the first mission was designed to perform extensive checks of the satellite's systems, with photographic resolution sacrificed in favour of longer life, or it could simply have been a launch vehicle guidance error. The main spacecraft stayed in orbit for fifteen months, but it is not clear from the public record if a capsule was ejected or not. The Agena B vehicles followed the design of the Discoverers, with the retro-rocket attached to the capsule, so that its firing, which occurred after separation of the capsule from the main spacecraft, would not alter the orbit of the main vehicle, which would remain in space until it decayed due to atmospheric drag.

The next two launches were made on 26 April and 17 June, but very few details of their orbits have ever been made public. Their orbital lifetimes were two days and one day respectively, which line up with those of later flights, so whatever the reasons for the 7 March flight's high orbit, it was not repeated. Three more launches were made in the year (for which full orbital details are available), but then there was a break of eight months until 12 July 1963, when the first of the second generation close-look vehicles was launched. These used the Agena D stage, and the main change from the older type was in the means of retrofire. The engine of the Agena D is restartable and was used to carry out retrofire [15], which gave a significant weight saving over the earlier configuration. It also meant that when the engine was fired to initiate re-entry, the main spacecraft was also decelerated and so the orbital lifetime quoted is also that of the recoverable capsule.

Four close-look satellites were placed in orbit in the six month period to the end of 1963, and this launch rate was maintained through 1964 (nine successes out of ten attempts) and 1965 (eight successes out of nine attempts). All these flights had similar characteristics – a perigee of about 150 km, an apogee of about 300 km, an inclination between 90° and 110°, and a lifetime of about three to five days. In addition, some of these satellites ejected ferret subsatellites (two in 1964 and three in 1965), a function that had previously been performed by the area survey programme.

In 1966 a third generation of close-look satellites was introduced, using the new Titan 3B- Agena D launcher. They weighed about 3,000 kg in orbit, and the extra capacity was used to carry more film and consumables, and a new multi-spectral camera built by the Itek Corporation [16]. As will be described later, the new camera was designed to photograph the same scene in several wavebands simultaneously and by comparing the different images it was hoped that objects hidden by camouflage could be indentified. The last Atlas-Agena D satellite was launched on 4 June 1967, and with the retirement of the old type of spacecraft the job of carrying ferret subsatellites was transferred back to the area survey programme.

The orbit used by the third generation satellites is slightly different from that of the older type, with a perigee close to 135 km and an apogee in the region of 400 km. Atmospheric drag at altitudes like 135 km is quite marked and the satellites must use their Agena engines often to stay in orbit. Despite this, their lifetimes have increased over the years, as can be seen from Fig. 5 and as a consequence the number of launches per year has dropped. In each of the years 1967 to 1972 there were close-look satellites in orbit for approximately ninety days but the number of launches needed to achieve this dropped from nine in 1967 to three in 1972.

Unlike the area survey programme the launching of close-look satellites did not end when the Big Bird system became operational in mid-1972. Figure 6 shows the flight histories of close-look and Big Bird satellites for 1971 through 1976, and it can be seen that most of the launches came in pairs; the first is a Big Bird, and near the end of its life or soon after it decays a close-look vehicle is launched. From this it would appear that most of the close-look craft are used to fill in the gaps in coverage of Big Birds. One notable exception to this came in 1974. On 5 June a Titan 3B-Agena D was launched, just about halfway through the life of a Big Bird that had been launched on 10 April. The launch failed, but another was made the next day, and this was a success. Obviously the Air Force was very keen to observe something that June; possibly it was the results of the explosion of India's first nuclear device on 18 May [20]. The Big Bird decayed on 28 July, and it was followed in the normal way by a close-look satellite on 14 August. In contrast to this the two launch failures of 20 May 1972 and 26 June 1973 were not followed up by new attempts; it is probable that rather than make new Titan 3B-Agena D launches it was decided to wait for the next Big Birds.

One other application that involved the Titan 3B-Agena D type of satellite was in connection with the US Navy's ocean surveillance programme. In testimony before the Senate in 1973 it was revealed that the Navy had been using surveillance data supplied by the USAF since 1971 [21]. The specific satellites were not identified, but it was implied that they were modified versions of the third-generation close-look vehicles. The orbits used by the satellites launched during this period all conformed very closely to the norm, so just which ones were involved in this project remains unresolved.

At the time of writing the close-look programme is still in progress. By the end of 1976, 93 launches had been made, of which 92% were successful, placing 86 satellites in orbit.

The 'Big Bird' Programme

During the late 1960's, while the third generation area survey and close-look satellites were in regular service, a new, fourth generation reconnaissance vehicle was under development that would perform both their functions. Like its predecessors, it is built by Lockheed and based on the Agena, but in a considerably modified and enlarged form. Measuring 15 m long and 3 m in diameter, and weighing 13,000 kg in orbit [17], it has been given the unofficial (but widely used) name 'Big Bird.'

Table 3. Close-Look Satellites.

NAME	LAUNCH DATE (GMT)	LAUNCH VEHICLE	LIFE (days)	INCL. (deg)	PERIOD (min)	PERI-APO (km)
1962-η	7 Mar 62	Atlas-Agena B	457.1	90.89	93.9	251 - 676
1962-π	26 Apr 62	Atlas-Agena B	2	74.1 ?	90 ?	?
1962-ψ	17 Jun 62	Atlas-Agena B	1	?	?	?
1962-αζ	18 Jul 62	Atlas-Agena B	9	96.12	88.73	184 - 236
1962-αλ	5 Aug 62	Atlas-Agena B	1	96.30	88.62	205 - 205
1962-βπ	11 Nov 62	Atlas-Agena B	1	96.00	88.65	206 - 206
1963-28	12 Jul 63	Atlas-Agena D	5.2	95.37	87.80	164 - 164
1963-36	6 Sep 63	Atlas-Agena D	7.05	94.37	89.06	168 - 263
1963-41	25 Oct 63	Atlas-Agena D	4.0	99.05	88.99	144 - 332
1963-51	18 Dec 63	Atlas-Agena D	1.28	97.89	88.48	122 - 266
1964-09	25 Feb 64	Atlas-Agena D	4	95.66	88.24	173 - 190
1964-12	11 Mar 64	Atlas-Agena D	4.3	95.73	88.2	163 - 203
1964-20	23 Apr 64	Atlas-Agena D	5.2	103.56	89.40	150 - 336
1964-24	19 May 64	Atlas-Agena D	2.9	101.12	89.69	141 - 380
*1964-36	6 Jul 64	Atlas-Agena D	2.0	92.89	89.20	121 - 346
1964-45	14 Aug 64	Atlas-Agena D	8.8	95.52	89.0	149 - 307
1964-58	23 Sep 64	Atlas-Agena D	4.78	92.91	89.00	145 - 303
none	8 Oct 64	Atlas-Agena D		failed to orbit		
*1964-68	23 Oct 64	Atlas-Agena D	5.06	95.55	88.6	139 - 271
1964-79	4 Dec 64	Atlas-Agena D	1.2	97.02	89.69	158 - 357
1965-05	23 Jan 65	Atlas-Agena D	5.2	102.5	88.85	146 - 291
1965-19	12 Mar 65	Atlas-Agena D	4.98	107.69	88.51	155 - 247
*1965-31	28 Apr 65	Atlas-Agena D	5.14	95.60	88.95	180 - 259
1965-41	27 May 65	Atlas-Agena D	5.11	95.78	88.67	149 - 267
*1965-50	25 Jun 65	Atlas-Agena D	4.9	107.64	88.78	151 - 283
none	12 Jul 65	Atlas-Agena D		failed to orbit		
*1965-62	3 Aug 65	Atlas-Agena D	4.11	107.47	89.06	149 - 307
1965-76	30 Sep 65	Atlas-Agena D	4.70	95.60	88.77	158 - 264
1965-90	8 Nov 65	Atlas-Agena D	2.92	93.88	88.74	145 - 277
1966-02	19 Jan 66	Atlas-Agena D	3.88	93.89	88.51	154 - 246
1966-12	15 Feb 66	Atlas-Agena D	7.44	96.54	89.00	148 - 293
1966-22	18 Mar 66	Atlas-Agena D	4.92	101.01	88.87	152 - 284
1966-32	19 Apr 66	Atlas-Agena D	6	116.95	89.94	145 - 398
*1966-39	14 May 66	Atlas-Agena D	6	110.55	89.40	133 - 358
1966-48	3 Jun 66	Atlas-Agena D	6.17	87.01	88.87	143 - 288
1966-62	12 Jul 66	Atlas-Agena D	7	95.52	88.25	137 - 236
1966-69	29 Jul 66	Titan 3B-Agena D	7	94.12	88.58	158 - 250
*1966-74	16 Aug 66	Atlas-Agena D	7.5	93.24	89.58	146 - 358
*1966-83	16 Sep 66	Atlas-Agena D	6	93.98	89.37	148 - 333
1966-86	28 Sep 66	Titan 3B-Agena D	9.06	93.98	89.01	151 - 296
1966-90	12 Oct 66	Atlas-Agena D	8.46	90.88	88.99	181 - 258
1966-98	2 Nov 66	Atlas-Agena D	7.2	90.96	89.20	159 - 305
1966-109	5 Dec 66	Atlas-Agena D	8.2	104.63	89.77	137 - 388
1966-113	14 Dec 66	Titan 3B-Agena D	9	109.56	89.58	138 - 368
1967-07	2 Feb 67	Atlas-Agena D	9	102.96	89.47	136 - 357
1967-16	24 Feb 67	Titan 3B-Agena D	10.15	106.98	90.02	135 - 414
none	26 Apr 67	Titan 3B-Agena D		failed to orbit		
1967-50	22 May 67	Atlas-Agena D	8.18	91.49	88.82	135 - 293
1967-55	4 Jun 67	Atlas-Agena D	8.17	104.88	90.57	149 - 456
1967-64	20 Jun 67	Titan 3B-Agena D	10.22	111.40	89.01	127 - 325
1967-79	16 Aug 67	Titan 3B-Agena D	13	111.88	90.43	142 - 449

The first hint of the existence of Big Bird, or Program 467 as it is officially known, came in June 1969 with the cancellation of the USAF's Manned Orbital Laboratory (MOL) project. The main aim of this programme had been to provide an orbital platform from which men could direct reconnaissance activities in real-time. It was thought that a man in a space station could use his discriminatory powers to great advantage when carrying out an area survey type of role, and when he spotted something of interest he could direct the high resolution camera on board to photograph the scene in detail. In this way, more comprehensive coverage than the current unmanned satellites gave could be achieved, and there would be an added advantage. Once a region requiring detailed photography has been identified from an area survey flight, there is a delay before a close-look mission can be set up and launched, but if both the area survey and close-look missions are performed by the same vehicle (as in MOL), the high resolution photography can be made very soon after a target has been chosen. Plans called for crews to make month-long stays on MOL, returning the exposed films to Earth in capsules when necessary. The Russians have a direct analogue of this in their Salyut station, but while it was pushed through to operational (if somewhat limited) use, MOL's growing cost and the financial pressure of the Vietnam war caused its cancellation. Considering the great importance placed on strategic reconnaissance, the USAF must only have been willing to abandon MOL if they had had an unmanned replacement well under way. When the first Big Bird was launched two years later, it was obvious that this was it.

Big Bird satellites are the largest military spacecraft developed by the United States, and their size dictates the use of the Titan 3D launcher. They carry two imaging systems, one a giant high resolution camera developed by Perkin-Elmer Corporation for close-look photography, and the other a development of Eastman Kodak's area survey camera with a new film scanner [22]. It has also been suggested that they may carry side-looking radar [16], which produces far better resolution than conventional radar but uses the same frequencies and thus has the same cloud penetrating capabilities. Six recoverable capsules are carried, and at regular intervals they are loaded with exposed film and returned to Earth [23], while the radio transmissions are handled by a 6 m unfurlable antenna [24].

The first launch was planned for the end of 1970, but problems with the camera system delayed it until 15 June 1971 [16]. It was placed in an orbit with a perigee of 184 km and an apogee 300 km (see Table 4), which is typical of area survey type missions. Its orbital inclination (96°) was chosen so that it covered the same areas each day at the

NAME	LAUNCH DATE (GMT)	LAUNCH VEHICLE	LIFE (days)	INCL. (deg)	PERIOD (min)	PERI-APO (km)
1967-90	19 Sep 67	Titan 3B-Agena D	10.23	106.10	89.75	122 - 401
1967-103	25 Oct 67	Titan 3B-Agena D	9	111.57	90.15	136 - 429
1967-121	5 Dec 67	Titan 3B-Agena D	11.18	109.55	90.16	137 - 430
1968-05	18 Jan 68	Titan 3B-Agena D	17.13	111.52	89.91	138 - 404
1968-18	13 Mar 68	Titan 3B-Agena D	11	99.87	89.87	128 - 407
1968-31	17 Apr 68	Titan 3B-Agena D	12	111.51	90.10	134 - 427
1968-47	5 Jun 68	Titan 3B-Agena D	12.2	110.52	90.31	123 - 456
1968-64	6 Aug 68	Titan 3B-Agena D	9	110.00	89.85	142 - 395
1968-74	10 Sep 68	Titan 3B-Agena D	15	106.06	89.82	125 - 404
1968-99	6 Nov 68	Titan 3B-Agena D	14	106.0	89.73	130 - 390
1968-108	4 Dec 68	Titan 3B-Agena D	8	106.24	93.30	136 - 736
1969-07	22 Jan 69	Titan 3B-Agena D	12	106.15	97.04	142 - 1090
1969-19	4 Mar 69	Titan 3B-Agena D	14	92.00	90.50	134 - 461
1969-39	15 Apr 69	Titan 3B-Agena D	15	108.76	89.96	135 - 410
1969-50	3 Jun 69	Titan 3B-Agena D	11.2	110.00	90.04	137 - 414
1969-74	22 Aug 69	Titan 3B-Agena D	16	108.00	89.51	133 - 366
1969-95	24 Oct 69	Titan 3B-Agena D	15	108.04	93.39	136 - 740
1970-02	14 Jan 70	Titan 3B-Agena D	18	109.96	89.69	134 - 383
1970-31	15 Apr 70	Titan 3B-Agena D	21	110.97	89.70	130 - 388
1970-48	25 Jun 70	Titan 3B-Agena D	11	108.87	89.70	129 - 389
1970-61	18 Aug 70	Titan 3B-Agena D	16	110.95	89.67	151 - 365
1970-90	23 Oct 70	Titan 3B-Agena D	19	111.06	89.83	135 - 396
1971-05	21 Jan 71	Titan 3B-Agena D	19	110.86	90.09	139 - 418
1971-33	22 Apr 71	Titan 3B-Agena D	21	110.93	89.85	132 - 401
1971-70	12 Aug 71	Titan 3B-Agena D	22	111.00	90.13	137 - 424
1971-92	23 Oct 71	Titan 3B-Agena D	25	110.94	90.02	134 - 416
none	16 Feb 72	Titan 3B-Agena D		failed to orbit		
1972-16	17 Mar 72	Titan 3B-Agena D	25	110.98	89.91	131 - 409
none	20 May 72	Titan 3B-Agena D		failed to orbit		
1972-68	1 Sep 72	Titan 3B-Agena D	29	110.50	89.71	140 - 380
1972-103	21 Dec 72	Titan 3B-Agena D	33	110.45	89.68	139 - 378
1973-28	16 May 73	Titan 3B-Agena D	28	110.49	89.39	136 - 352
none	26 Jun 73	Titan 3B-Agena D		failed to orbit		
1973-68	27 Sep 73	Titan 3B-Agena D	32	110.48	89.67	131 - 385
1974-07	13 Feb 74	Titan 3B-Agena D	32	110.44	89.78	134 - 393
none	5 Jun 74	Titan 3B-Agena D		failed to orbit		
1974-42	6 Jun 74	Titan 3B-Agena D	47	110.49	89.81	136 - 394
1974-65	14 Aug 74	Titan 3B-Agena D	46	110.51	89.89	135 - 402
1975-32	18 Apr 75	Titan 3B-Agena D	48	110.54	89.26	134 - 401
1975-98	9 Oct 75	Titan 3B-Agena D	52	96.41	89.34	125 - 356
1976-27	22 Mar 76	Titan 3B-Agena D	57	96.40	89.25	125 - 347
1976-94	15 Sep 76	Titan 3B-Agena D	51	96.39	89.18	135 - 330

Table 3. Close-Look Satellites/contd.

Notes: 1. This table lists all satellites with the characteristics of close-look missions, to 31 December 1976.
2. Those launches marked with an asterisk carried ferret subsatellites which were ejected into separate orbits.
3. All launches were made from Vandenberg Air Force Base.

same local time, i.e., its precession was synchronised with the apparent yearly motion of the Sun. This meant that lighting conditions at the target areas would be the same each time the satellite passed overhead, which would make picking out changes to the scene much easier.

On the second flight the perigee was lowered by nearly 30 km to a height more typical of a close-look mission (the lower the altitude, the better the resolution), but the apogee was raised by a similar amount, so the period remained the same. Full operational status was attained with the third launch on 7 July 1972, and from this point onwards (with one exception, to be noted later) the flights all had perigees near 160 km and apogees near 265 km, but still retaining the Sun-synchronous inclination. Their orbital lifetimes quickly grew from two to four and then five months, with a steady average of two flights a year.

Big Bird launches have carried many subsatellites into orbit, starting with the second flight. Initially these were for ferret missions, following the end of the area survey programme in 1972, but two payloads for the Space Test Program have been orbited recently, along with several unidentified craft. In the future it is planned that UHF communications subsatellites will be carried to provide direct links from ground stations to SAC aircraft operating in polar regions [23].

For some years there have been reports of a fifth generation reconnaissance satellite to be built by TRW and known as Program 1010, which was to enter service in 1976 or 1977 [25]. It will be a further advancement in the state of the reconnaissance art by providing images in real-time. To accomplish this it is to carry television cameras, whose technology has advanced a long way since their rejection from WS-117L in 1957, and use data relay satellites. These are to be placed in synchronous orbit, and the reconnaissance vehicle's transmissions, instead of being sent to ground stations around the world, will go *via* the data relay satellites direct to the National Photographic Interpretation Center in Washington, D.C. [16]. A Big Bird was launched on 19 December 1976 into an unusually high orbit, from 247 km to 533 km. Four days later this was raised to 341 km to 535 km, more than double the altitude of the normal Big Bird orbit, and then three months later the satellite was again manoeuvred, resulting in a 264 km to 530 km orbit. This new type of orbit may indicate that it was the first test of a Program 1010 vehicle.

The Early Warning Satellites

In the late 1950's American projections of Soviet ICBM

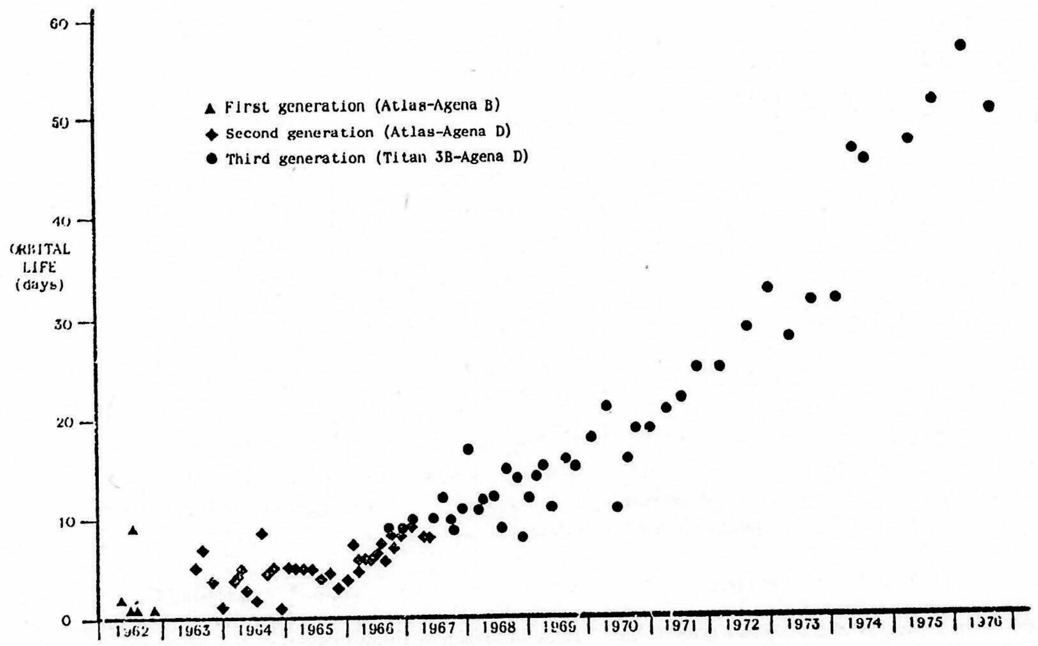

Fig. 5. Orbital lives of the 'close- look' satellite.

deployments indicated that by the early 1960's the USSR would have a substantial advantage over the USA, the so-called "Missile Gap." To counter this a crash programme of ICBM development was started, but it appeared that it would be some years before the balance could be tipped in favour of the United States. In the meantime, the main defence would be provided by manned bombers, which were far superior to their Russian counterparts. This policy had one drawback – it took some time to get the bomber force scrambled and in the air, and while they were still on the ground they were very vulnerable to attack. To make them into a credible defence force, a system had to be provided which would warn of a missile attack in enough time to get the bombers airborne. The Ballistic Missile Early Warning System (BMEWS), composed of three radar stations pointings towards the Soviet Union, was an attempt to provide this, but because they were line-of-sight radars they could only detect missiles after they rose above the horizon, several minutes after launch. In all, they were expected to give 15 minutes' warning, enough to get a fair proportion of aircraft in the air, but not long enough to get them all. The advent of Earth satellites brought a new possibility – if the ICBM launches could be detected from space in the first few seconds of flight, as much as 25 or 30 minutes' warning could be given, enough to get all of SAC's aircraft in the air. The Midas (for Missile Defence Alarm System) segment of WS-117L was set up to do just this.

The principle behind Midas was simple; when a rocket engine fires it produces an exhaust plume of very hot gases. Infra-red sensors on board satellites could detect these against the background of the Earth, and so signal a launch in its early stages. A series of satellites in polar orbits with precisely controlled spacing could, it was hoped, provide a reliable warning system. Unfortunately, although the principle was straightforward, in practice there were many difficulties, and it was to be several years before the system could be considered operational [26].

The infra-red sensor for Midas, built by IT & T, had to be cooled to a low temperature in orbit, and designing such a system to work unattended in space posed many problems. Its weight, plus the weight of the complex orbit-spacing control system, pushed the total for the early models past the 2,000 kg mark, too much for the Atlas-Agena A to place in the planned orbit. As they were to test the concepts and hardware rather than be part of the operational network, it was decided to aim for low near-equatorial orbits, which were within the launcher's capabilities.

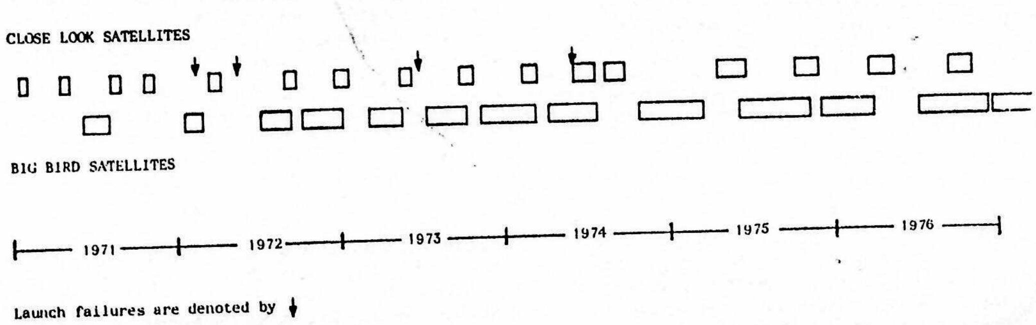

Fig. 6. Orbital histories of the 'close-look' and 'Big Bird' satellites,1971-76.

Table 4. Big Bird Satellites.

NAME	LAUNCH DATE (GMT)	LAUNCH VEHICLE	LIFE (days)	INCL. (deg)	PERIOD (min)	PERIGEE-APOGEE (kilometres)
1971-56	15 Jun 71	Titan 3D	52	96.41	89.38	184 - 300
*1972-02	20 Jan 72	Titan 3D	40	97.00	89.41	157 - 331
*1972-52	7 Jul 72	Titan 3D	68	96.88	88.77	174 - 251
*1972-79	10 Oct 72	Titan 3D	90	96.47	88.93	160 - 281
1973-14	9 Mar 73	Titan 3D	71	95.70	88.76	152 - 270
1973-46	13 Jul 73	Titan 3D	91	96.21	88.77	156 - 269
*1973-88	10 Nov 73	Titan 3D	123	96.93	88.85	159 - 275
*1974-20	10 Apr 74	Titan 3D	109	94.52	88.91	153 - 285
*1974-85	29 Oct 74	Titan 3D	141	96.69	88.86	162 - 271
*1975-51	8 Jun 75	Titan 3D	150	96.38	88.77	154 - 269
1975-114	4 Dec 75	Titan 3D	119	96.27	88.44	157 - 234
1976-65	8 Jul 76	Titan 3D	158	97.00	88.54	159 - 242
1976-125	19 Dec 76	Titan 3D		96.95	92.37	247 - 533

Notes:
1. This table lists all satellites with the characteristics of Big Bird missions, to 31 December 1976.
2. Those launches marked with an asterisk carried ferret subsatellites which were ejected into separate orbits.
3. All launches were made from Vandenberg Air Force Base.

Midas 1 was launched on 25 February 1960 (see Table 5), but the vehicle exploded during second stage separation [27]. Three months later Midas 2 successfully entered a good orbit, with a perigee of 484 km and an apogee of 511 km, giving it a period of 94.4 minutes. All seemed to be going well until the transmitter failed on the sixteenth orbit [28]. By this time the Discoverer programme had been experiencing many failures in its Agena stage, so the next Midas launch was postponed until they had been cured. When Discoverer flights were resumed later in the year two missions were dedicated to tests of sensors for the Midas programme. In the meantime, a change from batteries to solar panels [29] and a general weight reduction effort had cut the Midas payload to 1,600 kg. This, coupled with the use of the new Agena B stage, meant that flights in the operational type of orbit could now be attempted. Since these were to be near-polar, the launches were moved to Vandenberg Air Force Base, as range safety considerations precluded them from Cape Canaveral.

On 12 July 1961 Midas 3 achieved an orbit close to the planned one, almost circular (from 3,358 km to 3,534 km) with a period of 162 minutes. Midas 4 followed on 21 October, but although it was reported to have detected a Titan launch 90 seconds after liftoff on 26 October [30], it was soon clear that the performance of the sensors was not living up to expectations. The main problem was that they could not distinguish between rocket plumes and the reflection of the Sun off the tops of clouds, and signalled many false alarms. Meanwhile, the area survey satellites had shown that the "Missile Gap" did not exist, so the urgency of Midas was reduced [26]. These two factors led to the programme being cut back in mid-1962 to a research and development effort, renamed Program 461.

The Air Force had been investigating the radiation signatures of rocket exhausts during launches from Cape Canaveral since March 1960 using two U-2 aircraft [31], and this effort was stepped up in a search for sensors suitable for the early warning role. From these studies two programmes emerged; the first one was to use simplified spacecraft in random orbits, and was hoped to provide an interim capability. This was to be followed by a series of sophisticated spacecraft observing the Earth from synchronous orbit, built on the technology developed in the earlier programme. An idea of how badly astray the Midas programme had gone can be gained from testimony before Congress by Dr. Harold Brown, Director of Defense Research and Engineering, released on 16 June 1963. He said that of the $423 million spent on Midas up to that time, half had been wasted [32].

The first signs of success in the early warning programme came in President Johnson's report to Congress on aerospace activities in the year 1963. He stated that "two flights were conducted on which a number of in-space detections were made of both liquid-fuelled and solid-fuelled ICBM launches" [33], and he was obviously referring to the satellites launched on 9 May and 19 July, both of which were placed in polar orbits with periods of about 165 minutes, similar to Midas craft. No more launches were made for three years, and then two came in a space of seven weeks. It seems probable that they were to test a new technique that was then under development involving television cameras on board the satellites working in conjunction with the infra-red detectors. The idea was that when the infra-red detector signalled an alarm, the television camera, fitted with a telephoto lens, would focus on the region of interest, and its picture would be transmitted to Earth, where a person watching the scene could decide if this was a missile in flight or not [26].

Very little information about the success or otherwise of the interim programme has been made public, but the fact that development of the synchronous orbit system went ahead suggests that it achieved its goal. Early in 1966 requests for proposals were issued to industry under the code name of Program 266. At the end of the year, by which time it had been renamed Program 949, contracts were awarded to TRW (system contractor), Aerojet-General (for the infra-red sensors) and RCA (for the television system) [26]. The initial contracts were to develop and test sensor techniques, using spacecraft launched by Atlas-Agena D vehicles. If this was a success the go-ahead would be given for the operational programme.

The first synchronous orbit early warning satellite was launched from Cape Canaveral on 6 August 1968. Its orbit was inclined to the equator at an angle of 10°, so that it traced out a figure-eight pattern over the Earth. The aim of this was to improve coverage of the Soviet Union, whose main landmass lies well away from the equator. The orbit was not quite circular, with its apogee in the northern hemisphere, so the satellite dwelled over this region. It was stationed over western Russia, and eight months later it was joined by a second satellite. By arranging their orbits so that one was at its perigee when the other was at its apogee, there would always be one satellite over the northern hemisphere, in the best position to observe the Soviet Union. A third spacecraft was launched on 19 June 1970, but a booster failure left it stranded in its transfer orbit, so a back-up was launched in the following September, and was stationed

Table 5. Early Warning Satellites.

NAME	LAUNCH DATE (GMT)	LAUNCH VEHICLE	INCLINATION (degrees)	PERIOD (min)	PERIGEE-APOGEE (kilometres)
Midas 1	26 Feb 60	Atlas-Agena A	failed to orbit		
Midas 2	24 May 60	Atlas-Agena A	33.0	94.4	484 - 511
Midas 3	12 Jul 61	Atlas-Agena B	91.2	161.5	3358 - 3534
Midas 4	21 Oct 61	Atlas-Agena B	95.89	166.0	3496 - 3756
1962-K	9 Apr 62	Atlas-Agena B	86.68	153.0	2814 - 3382
none	17 Dec 62	Atlas-Agena B	failed to orbit		
1963-14	9 May 63	Atlas-Agena B	87.42	106.5	3604 - 3680
none	12 Jun 63	Atlas-Agena B	failed to orbit		
1963-30	19 Jul 63	Atlas-Agena B	88.41	168.0	3670 - 3727
1966-77	19 Aug 66	Atlas-Agena D	90.07	167.6	3680 - 3700
1966-89	5 Oct 66	Atlas-Agena D	90.20	167.6	3682 - 3702
1968-63	6 Aug 68	Atlas-Agena D	9.9	1436	31,680 - 39,860
1969-36	13 Apr 69	Atlas-Agena D	9.9	1445	32,670 - 39,270
1970-46	19 Jun 70	Atlas-Agena D	28.21	588.9	178 - 33,685
1970-69	1 Sep 70	Atlas-Agena D	10.3	1441.9	31,947 - 39,855
1970-93	6 Nov 70	Titan 3C	7.8	1197.1	26,050 - 35,886
1971-39	5 May 71	Titan 3C	0.87	1434.0	35,651 - 35,840
none	4 Dec 71	Atlas-Agena D	failed to orbit		
1972-10	1 Mar 72	Titan 3C	0.2	1429.9	35,416 - 35,962
1972-101	20 Dec 72	Atlas-Agena D	9.7	1440.4	31,012 - 40,728
1973-13	6 Mar 73	Atlas-Agena D	0.2	1435.1	35,679 - 35,855
1973-40	12 Jun 73	Titan 3C	0.3	1435.9	35,777 - 35,786
1975-55	18 Jun 75	Titan 3C	9.0	1422	30,200 - 40,800
1975-118	14 Dec 75	Titan 3C	3.0	1436	35,671 - 35,785
1976-59	26 Jun 76	Titan 3C	0.5	1433.3	35,620 - 35,860

Notes: 1. This table lists all satellites with the characteristics of early warning missions, to 31 December 1976.
2. All launches into near-equatorial orbits were made from Cape Canaveral, and all launches into near-polar orbits were made from Vandenberg Air Force Base.

over Singapore [34]. This appears to be the satellite that was involved in the "laser blinding" controversy in 1975 [35].

The contractors for the operational system, known as Program 647, were the same as for the Atlas-Agena system, but the spacecraft itself was much bigger and required the Titan 3C to place it in orbit. The programme was divided into two phases; four Phase 1 spacecraft were to be built, three for flight and one for qualification and tests [36], and if they were successful the more advanced Phase 2 would follow. In addition to the missile early warning role, Program 647 vehicles carried sensors to detect nuclear explosions, and were to replace the Vela nuclear test detection satellites. Because of their dual function they are often referred to as integrated satellites.

The first Phase 1 spacecraft was launched on 6 November 1970, but a failure in the launch vehicle guidance system stopped it being placed in the planned orbit. It was possible, however, to adjust the orbit so that a limited amount of sensor testing could be performed, but as a consequence TRW was contracted to modify the non-flight spacecraft so it could be launched as a replacement should either of the next two flights fail. In fact, it was never needed; the other satellites were launched on 5 May 1971 and 1 March 1972, and performed so well that they were declared operational in 1972, and turned over to the Aerospace Defense Command, for whom the system was being developed. One was positioned over the Indian Ocean to monitor Soviet and Chinese missile tests and warn of attack by land-based missiles, and the other was positioned over Panama to warn of attack by submarine-launched missiles [36], and their circular non-inclined orbits meant that only one satellite was needed at each station. Ten years after the original target date, and in a form very different from what had then been envisaged, the United States now had an operational early warning satellite system.

In December 1971, a year after Program 949 appeared to have ended, an Atlas-Agena D was launched from Cape Canaveral. It had all the signs of an early warning mission, but since it veered off course and was destroyed by the Range Safety Officer [37], we cannot be certain. A year later, nearly ten months after the last Program 647 Phase 1 launch, another Atlas-Agena D left the pad, and placed its payload in synchronous orbit, as did a similar flight three months later. There were reports at the time that the infra-red sensors aboard Program 647 satellites were losing their sensitivity for unknown reasons, which suggests that the Atlas-Agena D flights may have been to test improvements to the system [36].

Deliveries to the USAF of Phase 2 spacecraft started in February 1973, and the first launch was made on 12 June. The satellite was positioned over the Indian Ocean, to supplement the one already there, and since then there have only been launches to replace satellites which showed degraded performance or failed. Thirteen Program 647 spacecraft have been procured [38], and five remain in storage to be launched as required.

Within the past few years, probably as a reflection of the programme's operational status, the veil of secrecy that covered it has been partially lifted. It has been referred to explicitly in budget requests (as the Defense Support Program), and details of the design of the spacecraft have been released. The central section of the satellite, where most of its equipment and instruments are housed, is a short cylinder, aligned in orbit with its axis pointing towards the Earth. The cylinder is 2.78 m in diameter and 2.91 m long, and it is covered with solar cells. The output from these is augmented by four solar panels mounted on the end facing away from the Earth. At the other end, looking down to the Earth, is the device which actually detects the missile launchings, an infra-red Schmidt telescope, 3.63 m long with an aperture of 0.91 m. The satellite's orientation in orbit is maintained by spinning about the cylinder's axis at 5 to 7 rpm; the telescope's axis is offset from this by about 7½°, producing a conical scanning pattern as the vehicle rotates. The infra-red sensor consists of an array 2,000 lead sulphide cells at the telescope's focal

Table 6. Ferret Satellites.

NAME	LAUNCH DATE (GMT)	LAUNCH VEHICLE	INCLINATION (degrees)	PERIOD (min)	PERIGEE-APOGEE (kilometres)
1962-σ	15 May 62	Thor-Agena B	82.33	94.02	305 - 634
1962-ω	18 Jun 62	Thor-Agena B	82.14	92.4	370 - 411
1962-αν	1 Sep 62	Thor-Agena B	82.82	94.42	300 - 669
1963-03	16 Jan 63	Thor-Agena D	81.89	94.66	459 - 533
1963-27	29 Jun 63	TAT-Agena B	82.3	94.84	484 - 536
1964-11	28 Feb 64	TAT-Agena D	82.03	94.74	479 - 520
1964-35	3 Jul 64	TAT-Agena D	82.09	94.94	501 - 529
1964-72	4 Nov 64	TAT-Agena D	82.00	95.05	512 - 526
1965-55	17 Jul 65	TAT-Agena D	70.18	94.46	471 - 512
1966-09	9 Feb 66	TAT-Agena D	82.09	94.83	508 - 512
1966-118	29 Dec 66	TAT-Agena D	75.03	94.41	486 - 496
1967-71	25 Jul 67	TAT-Agena D	75.03	94.30	458 - 513
1968-04	17 Jan 68	TAT-Agena D	75.16	94.53	450 - 546
1968-86	5 Oct 68	LTTAT-Agena D	74.97	94.55	483 - 511
1969-65	31 Jul 69	LTTAT-Agena D	75.02	94.67	462 - 541
1970-66	26 Aug 70	LTTAT-Agena D	74.99	94.51	484 - 504
1971-60	16 Jul 71	LTTAT-Agena D	75.00	94.59	488 - 508

Notes: 1. This table lists all satellites with the characteristics of ferret missions.
2. All launches were made from Vandenberg Air Force Base.

plane, and from synchronous orbit each cell views a region on the Earth less than 3 km across. The complete spacecraft weighs about 1,100 kg in orbit [38].

The Electronic Reconnaissance (Ferret) Satellites

If the area survey and close-look satellites are the "eyes" of reconnaissance, then the ferret satellites are the "ears." More correctly known as electronic reconnaissance vehicles, their mission is to pick up and record radio and radar transmissions while they are over foreign territory, for later replay back to ground stations at home for analysis. In this way it is possible to locate the enemy's aircraft and missile defence radars, and deduce a good deal about their characteristics and performance, to eavesdrop on military and governmental communications, including submarine-to-shore links, and it has even been suggested that telephone conversations can be monitored [39]. This knowledge gives a great insight into the offensive and defensive threats posed by the opposition, and to his strategy and future plans.

The United States started its electronic reconnaissance satellite programme at the beginning of the 1960's, but it has always been regarded by the Department of Defense as a very sensitive subject, and little information has been released about it. Although no ferret satellites have ever been officially identified as such, it is possible to pick them out by the type of orbit they use. For electronic reconnaissance, long life in a stable orbit is more important than the resolution attainable, so that the useful life of the satellite is determined by the reliability of its instruments rather than when it decays. Since the Spring of 1962 there has been a long series of spacecraft which have been placed in just this type of orbit, circular at an altitude of about 500 km, with a period of 94 to 95 minutes, from which they take four or five years to decay. There seem to be little doubt that these are ferret satellites.

Two types of vehicle have been used for ferret missions; the first is a large spacecraft, requiring its own booster, and the second is a small subsatellite, launched "piggy-back" with another, larger satellite. For this second type, once the pair of craft have been placed in orbit, the ferret,is ejected and fired into its own higher orbit. The first ferret launched by Thor-Agena B on 15 May 1962 (see Table 6), was one of the large type, and it was followed a month later by another. From then onwards launches have occurred at increasing intervals, with a change to TAT-Agena D launcher in mid-1963 (presumably to accommodate a second generation spacecraft), and then to LTTAT-Agena D in the autumn of 1968 (presumably for a third generation). In the meantime, small ferret subsatellites were being regularly orbited with area survey and close-look launches, starting on 29 August 1963, see Table 7. It has been suggested that the two types of craft perform complementary roles, with the small ones carrying out search-and-find missions using low sensitivity equipment, and the large ones carrying out detailed examinations of selected targets using high sensitivity equipment [40]. If this is so, then it appears that when subsatellite launches were transferred to the Big Birds in January 1972, a new variant was introduced which combined the two functions in the same way that the Big Birds themselves combined the area survey and close-look functions for photographic reconnaissance. This would explain why the large type ferret launch of 16 July 1971 was the last of its kind, and from then on the job of electronic reconnaissance has been left to the subsatellites.

In December 1968 a subsatellite was ejected from an area survey flight into a new class of orbit, circular like the ferrets, but much higher, at 1,400 km altitude. Two months later this was repeated, but then the subsatellite launches reverted to their normal 500 km orbits. Philip Klass suggested in 1971 that these two flights might have been specifically designed to probe Soviet ABM radars, basing his reasoning on the fact that the Galosh system around Moscow reached operational status in the summer of 1969 [40]. Since he made this suggestion there have been three more flights at 1,400 km, and they can all be related to important periods in Soviet ABM developments, adding weight to his argument. The Strategic Arms Limitation Talks ABM Treaty came into force on 3 October 1972, and a week later a high orbit subsatellite was launched. Six months after this another was orbited, and it is reasonable to conclude that they were intended to police the agreement and check on possible violations. The most recent launch of this type came on 8 June 1975, at just the time when there was a great deal of activity at Sary Shagan, Russia's ABM test centre. Two new radar systems were undergoing tests then [41], and it is likely that the latest flight was planned to monitor them.

The current status of the electronic reconnaissance programme is not at all clear. It was reported in March 1970 that Hughes Aircraft was working on a new generation of heavy ferret vehicle under Program 711, to be launched by Titan 3 into a highly elliptical orbit. It was stated that the first launch was planned for late 1970 or early 1971, but no such flights have taken place, and the old type spacecraft orbited on 16 July 1971 was the last of the heavy ferrets. As has been suggested above, it is possible that their mission was carried out by the subsatellites launched with the Big Birds – indeed, it may be that plans for Program 711 were changed, and this is it – but there have been none of these since October 1974. It is hard to imagine that the electronic reconnaissance programme, which appears to have been successful in the past, should be suspended, but it will be some time before the new generation of ferrets, built under Program 980, come into service [42], so this does seem to be the case.

The US Navy's Ocean Surveillance Programme

In 1968 the US Navy initiated studies to explore the possibility of using surveillance radars in unmanned satellites to monitor the movements of ships at sea [43]. They stemmed from concern over the dramatic build-up in Soviet naval power since Admiral Gorshkov became its Commander in Chief in 1956, during which oceans and seas where the USN had once held undisputed power had become more and more the domain of ships from the Soviet Navy. The years 1967 and 1968 had been particularly impressive ones for the Russians; the following types of new vessel came into service in this period alone: Moskva class helicopter carriers, Kresta class guided missile cruisers, Charlie class submarines carrying the new SS-N-7 cruise missiles, Yankee class submarines carrying the new SS-N-6 ballistic missiles, and Victor class attack submarines [44]. In the past the USN had kept watch on the Soviet fleet with aircraft, but the increasing numbers of Soviet ships, and their vastly improved anti-aircraft armaments, led it to consider other surveillance methods, and satellites seemed an obvious choice.

The studies were to investigate the design and use of radars, both side-looking and forward-looking, and their aim was to develop a system which could measure the speed and direction of travel of ships. During the next five years several more contracts were issued to industrial teams for studies under Program 749, concentrating on the design of the satellite's sensors [45], but in 1973 it was announced that the Navy's programme of spaceborne ocean surveillance had been combined with a programme of very high altitude aircraft surveillance to form a "new and comprehensive aerospace surveillance programme" [46]. In retrospect, it would appear that the Navy's initial plans had not been fulfilled, for five years of study is a long time, especially when it is followed by a re-orientation, and it was to be another three years before the first spacecraft was actually launched. U-2 aircraft, in a modified version known as EP-X, had been flying ocean surveillance sensors since February 1973, and it was confirmed that they were to be the aircraft segment of the new programme, which was given the code name Whitecloud [47, 48]. Later in the year it was also revealed that the Navy had been using imagery from USAF reconnaissance satellites since 1971, as a further aid to its studies [21].

Table 7. Ferret Subsatellites.

NAME	LAUNCH DATE (GMT)	LAUNCH VEHICLE	INCLINATION (degrees)	PERIOD (min)	PERIGEE-APOGEE (kilometres)
1963-35	29 Aug 63	Thor-Agena D	81.89	92.07	310 - 431
1963-42	29 Oct 63	TAT-Agena D	89.99	93.35	285 - 585
1963-55	21 Dec 63	TAT-Agena D	64.52	91.68	321 - 388
1964-36	6 Jul 64	Atlas-Agena D	92.97	91.2	297 - 377
1964-68	23 Oct 64	Atlas-Agena D	95.50	91.14	323 - 336
1965-31	28 Apr 65	Atlas-Agena D	95.26	95.16	490 - 559
1965-50	25 Jun 65	Atlas-Agena D	107.65	94.68	496 - 510
1965-62	3 Aug 65	Atlas-Agena D	107.36	94.78	501 - 515
1966-39	14 May 66	Atlas-Agena D	109.94	95.39	517 - 559
1966-74	16 Aug 66	Atlas-Agena D	93.17	94.99	510 - 524
1966-83	16 Sep 66	Atlas-Agena D	94.06	94.25	460 - 501
1967-43	9 May 67	LTTAT-Agena D	85.10	98.38	555 - 809
1967-62	16 Jun 67	LTTAT-Agena D	80.20	94.81	501 - 517
1967-109	2 Nov 67	LTTAT-Agena D	81.68	94.41	455 - 524
1968-08	24 Jan 68	LTTAT-Agena D	81.65	94.75	473 - 542
1968-20	14 Mar 68	LTTAT-Agena D	83.09	94.66	481 - 522
1968-52	20 Jun 68	LTTAT-Agena D	85.18	94.15	437 - 519
1968-78	18 Sep 68	LTTAT-Agena D	83.22	94.75	500 - 514
1968-112	12 Dec 68	LTTAT-Agena D	80.33	114.45	1391 - 1468
1969-10	5 Feb 69	LTTAT-Agena D	80.41	114.22	1396 - 1441
1969-26	19 Mar 69	LTTAT-Agena D	83.08	94.82	504 - 513
1969-41	2 May 69	LTTAT-Agena D	65.71	93.37	401 - 473
1969-79	22 Sep 69	LTTAT-Agena D	85.16	94.51	490 - 496
1970-16	4 Mar 70	LTTAT-Agena D	88.14	94.16	442 - 514
1970-40	20 May 70	LTTAT-Agena D	83.12	94.59	491 - 503
1970-98	18 Nov 70	LTTAT-Agena D	83.18	94.63	487 - 511
1971-76	10 Sep 71	LTTAT-Agena D	75.07	94.60	492 - 507
1972-02	20 Jan 72	Titan 3D	96.59	94.86	472 - 549
1972-52	7 Jul 72	Titan 3D	96.15	94.66	497 - 504
1972-79	10 Oct 72	Titan 3D	95.62	114.79	1423 - 1469
1973-88	10 Nov 73	Titan 3D	96.33 96.93	94.59 114.64	486 - 508 1419 - 1458
1974-20	10 Apr 74	Titan 3D	94.00	95.01	503 - 531
1974-85	29 Oct 74	Titan 3D	96.06	95.22	520 - 535
1975-51	8 Jun 75	Titan 3D	95.09	113.68	1389 - 1401

Notes:
1. This table lists all subsatellites with the characteristics of ferret missions.
2. These subsatellites result from the launches listed in Tables 2, 3 and 4 which are marked with an asterisk.
3. All launches were made from Vandenberg Air Force Base.

The years of research finally reached fruition on 30 April 1976 with the launch of the first ocean surveillance satellite. It was placed in 1,092 km to 1,128 km orbit, inclined at 63°, by an Atlas rocket. The Naval Research Laboratory had designed and built the spacecraft, with the assistance of Fairchild Industries [49], and with the range of sensors it is reported to have it appears to be a very sophisticated vehicle. It is believed to carry millimetre-wave radar, with the capability of tracking surface ships in all weather conditions, radio-frequency antennae for listening in on shipboard radar and communications, and passive infra-red detectors [50], possibly to plot the courses of submerged nuclear submarines, which leave behind them a wake of water that has been used to cool their reactors and is warmer than the surrounding sea, or to track low-flying missiles. Once in orbit it released three small subsatellites into similar orbits to its own (see Table 8), and each of these is reported to carry its own sensors. Their data is transmitted to the parent satellite, where it undergoes preliminary processing before being re-transmitted to Earth [51].

Table 8. Ocean Surveillance Satellites

Spacecraft	Inclination (degrees)	Period (min)	Perigee-Apogee (kilometres)
Main satellite	63.46	107.47	1092-1128
Subsatellite 1	63.44	107.49	1093-1129
Subsatellite 2	63.43	107.50	1093-1130
Subsatellite 3	63.45	107.49	1083-1139

Notes:
1. This table lists the orbital parameters of the ocean surveillance satellite and of the three subsatellites it released in orbit.
2. All four elements were orbited as a single vehicle on 30 April 1976 by Atlas booster from Vandenberg Air Force Base.

The launch of 30 April 1976 is the only ocean surveillance satellite to date, but the indications are that many more will follow as the Navy increases its reliance on spaceborne sensors to keep watch on the high seas. Although the Navy's first reconnaissance satellite was launched 14 years after the Air Force's first, the level of sophistication and complexity that is claimed for it certainly matches that of its USAF contemporaries.

Sensors – Types and Performance

So far I have considered the types of satellites used for reconnaissance and surveillance, but now I shall turn to the sensors they carry for their missions. Just what these satellites can detect is a well kept secret – no reconnaissance satellite picture has ever been released, and it is unlikely that any will be in the foreseeable future – but it is possible to estimate the performance that the sensors should be able to achieve by examining the physical laws they must obey and the performance of civilian systems with similar levels of technology.

All the information that reaches a satellite from the Earth comes in the form of electromagnetic radiation. Although the atmosphere may seem transparent to us, it is in fact opaque to most wavelengths, with only two "windows" through which radiation can pass freely. One "window" covers wavelengths in the range from 0.3μ up to about 10μ, which includes some near ultra-violet, visible light, near infra-red and some far infra-red, and the other from 3 cm to 3 m, which includes radio and radar in the US military bands A through I. Any satellite that is to observe events on Earth must use sensors which operate at these wavelengths.

Cameras operating in the visible portion of the spectrum were the first type of sensor to be used for reconnaissance, and they are still the most common today. The reasons for this are simple; camera design is a well-developed art, they give the best resolution of any wavelength range, and they are the easiest for humans to interpret and understand. The limiting resolution on the ground that a satellite camera system can achieve can be considered as composed of two components – the limiting resolution of the atmosphere and the limiting resolution of the camera itself. These two interact in a complex way to form the achievable resolution, but a way of combining them has been suggested by Amrom Katz [52]. If all resolutions are expressed in terms of the smallest object discernable on the ground, then the achievable limit is simply the sum of the component limits (it should be stressed here that all the calculations which follow are approximate – to be more accurate would require knowledge of a great many details of the satellite's design, details which are highly classified). This rule has an important consequence; the achievable resolution will always be worse that the worst of the component resolutions, so that however good a satellite's design may be, its resolution will always be at least as bad as that due to the atmosphere. It also means that as the camera's resolution is improved more and more, the law of diminishing returns will cut in – the better the system gets, the less effect will further improvements have.

It is generally considered that the atmosphere's limiting resolution is about 10 cm [53], which is independent of the satellite's altitude. All other things being equal, a camera's resolution is dependent on the ratio of its altitude to its focal length, a parameter known as the scale number. Now many details, including achievable resolution, focal length and altitude, have been published for some civilian satellite camera systems. If we can find details for a system of comparable technology to a given reconnaissance satellite, and we know the reconnaissance satellite's focal length and altitude, it is a simple matter to estimate its achievable resolution. Consider the S190A Multispectral Photographic Camera carried on the Skylab missions; it had a focal length of 15.24 cm, and at an altitude of 436 km its achievable ground resolution was 24 m [54]. This gives a scale number of 2,860,000 and as the atmospheric resolution is so small compared with the achievable resolution, a camera resolution of 24 m. Big Bird has been reported to carry a camera with a focal length of "more than eight feet" [17], so taking a value of 2.5 m and an altitude of 160 km, a typical perigee height, gives a scale number of 64,000, and assuming its level of technology is similar to Skylab's gives a camera resolution of 55 cm, and thus an achievable resolution of about two thirds of a metre.

As was mentioned earlier, the photographic system carried by the Lunar Orbiter spacecraft appears to be very closely related to that carried on the early Samos area survey satellites. Its focal length was 61 cm, and operating at an altitude of 46 km it had a resolution of 1 m [55]. This means a scale number of 75,400 and a camera resolution of 1 m, there being no atmospheric effects on the Moon. The early Samos vehicles were claimed to have cameras with focal lengths "as large as 40 inches" [13], so taking a value of 1 m and an altitude of 180 km, typical of the perigees they used, gives a scale number of 180,000 and thus a camera resolution of 2.4 m, so we can estimate the achievable resolution to be about two and a half metres.

It is interesting to compare these two estimates with some of the claims that have been made for reconnaissance satellite capabilities. Philip Klass stated that early Samos satellites should have been able to resolve objects 20 feet across from 300 miles [11]. This scales to 2.3 m from 180 km, in very good agreement with the figure computed here. One would expect the cameras carried by U-2 aircraft, which

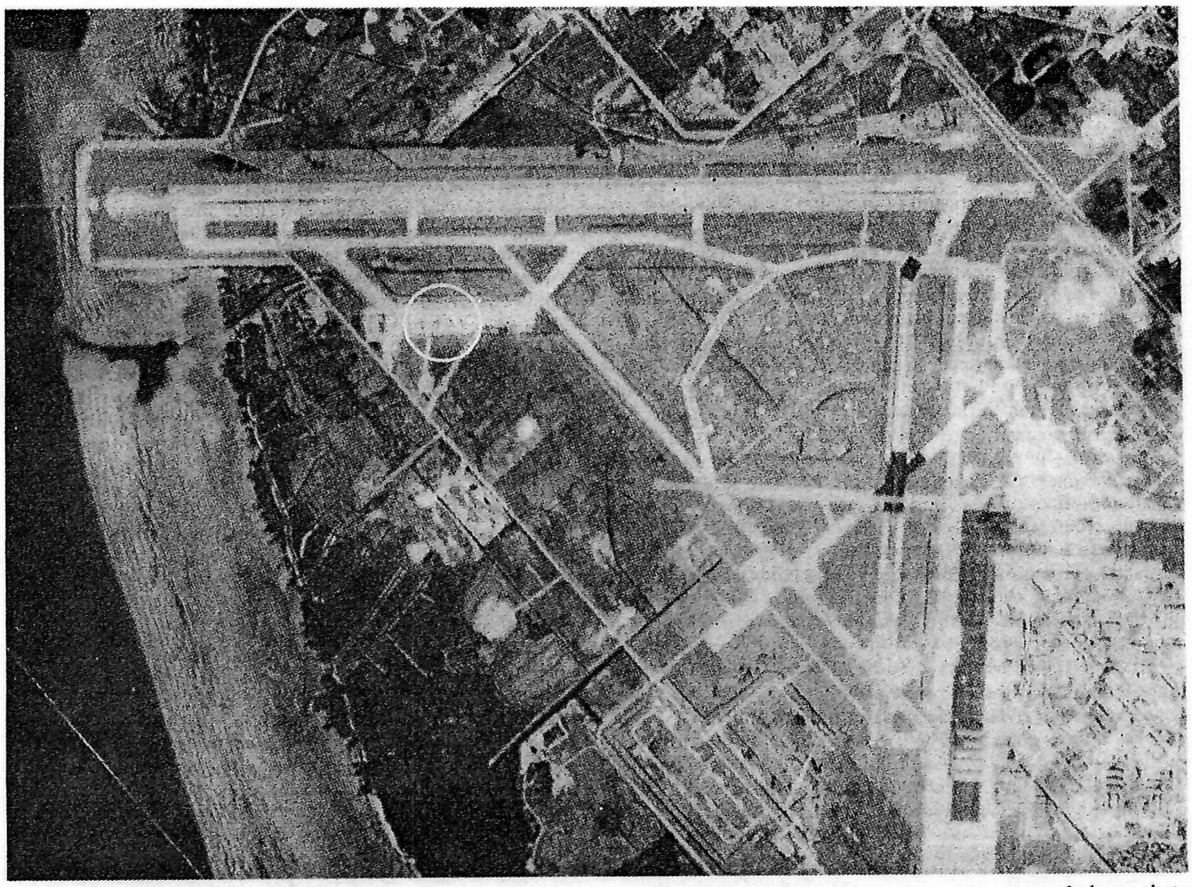

Fig. 7. One of the most revealing space photos of military interest yet released by the United States. Picture is an enlargement of a larger photograph obtained from the Skylab space station showing MacDill Air Force Base. Within the circle can be seen four aircraft parked off the main runway. All photographs obtained by U.S. reconnaissance satellites are classified and this picture gives only a small indication of the resolution that can be obtained [20].

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were contemporaries of the early Samos vehicles, to have similar or slightly better performance (the weight considerations would have been less constraining in an aircraft than a spacecraft). After the Gary Powers incident President Eisenhower showed photos taken from a U-2 flying 21 km over San Diego. They clearly showed the 10 cm wide lines painted on a car park [56]. This would become a resolution of 85 cm from 180 km altitude, somewhat better than our Samos estimate, but considering the degredation due to the area survey satellites' radio transmission system, and that light coloured lines on a dark asphalt background would make an ideal photographic target, the figures are quite compatible.

The dimensions quoted for the smallest objects that can be resolved generally refer to objects whose length and width are of the same sort of order. It is well known, however, that an object which is several orders of magnitude longer than it is wide can be resolved when its width is well below the limiting resolution. There is a good example of this in [52]; a photograph taken from a Viking rocket has a computed resolution of 150 m, and yet it is possible to pick out a railway line, which can be no more than one twentieth of this wide, even including cuttings and embankments. This would imply that it may be possible to pick out extremely elongated objects from Big Birds which are as small as two or three centimetres wide. An example of this would be the high voltage cables of the National Grid, but the claim [57] that individual telephone cables (diameter 3 mm) can be detected does seem to be rather optimistic. Certainly the report [58] that the buttons on a man's shirt can be resolved should be regarded with considerable reservations.

Resolution, however, is not the only consideration when designing a sensor for reconnaissance. The main concern is to maximise the amount of information that can be extracted from the data returned, and one aid to this is infra-red photography. For wavelengths up to about 1μ photographic emulsions have been developed which produce infra-red "pictures" when they are used in conventional cameras. The main advantage that they have over visible light imagery is that surfaces which may be indistinguishable in visible light, like for example a patch of grass and a camouflaged missile silo cover, look quite different in infra-red, because of their different reflection characteristics. This capability to penetrate camouflage was first exploited in aerial reconnaissance during the Second World War, and since then it has become a well established technique. Unfortunately the resolution obtainable with infra-red photography is not nearly as good as visible light photography – Skylab's S190A camera's infra-red resolution was 68 m compared to 24 m in the visible band – so simultaneous photography in both regions of the spectrum came into use, taking advantage of the good features of each while minimising the effects of the bad ones. This in turn led to multi-spectral photography, where images are made in several portions of the visible and infra-red spectrum simultaneously. By careful choice of the film/filter combinations, each image can be made to show a different feature of the target, and comparisons between the images can yield still more to the skilled photo-interpreter.

When the new generation of close-look satellites came into service in 1966 they carried multi-spectral cameras, but it was not until 1969 that a similar instrument was flown on a civilian mission, as experiment SO-65 on Apollo 9. This consisted of four cameras rigidly mounted on a frame and boresighted to view exactly the same area of the Earth. Camera AA used an orange filter in combination with film sensitive to wavelengths between 0.51μ and 0.91μ, giving good differentiation between natural and man-made objects by measuring plant reflectance. Camera BB used a green filter and film sensitive to 0.48μ to 0.62μ, which penetrated shallow water to show the structure of river beds and coastal seabeds. Camera CC used a very dark red filter and film sensitive to 0.7μ to 0.9μ, which showed plant health, disease and insect infestation. Camera DD used a red filter and film sensitive to 0.59μ to 0.72μ, which showed terrestrial structures in a form suitable for mapping and land usage studies [59]. obviously, the ability to obtain images which can show such particular features would be of great use to reconnaissance analysts.

At wavelengths beyond about 1μ it is not possible to use photographic emulsions, and sensors composed of detector elements which give an electrical output dependent on the level of illumination must be used. The output signal can be utilised to build up a photograph-like image, but the resolution attainable is considerably lower than with conventional photography. This type of sensor does have one great advantage though; because the radiation they detect is thermal rather than reflected solar radiation, they operate just as well at nighttime as daytime. A typical example is the line-scanning radiometer carried by the Defense Meteorological Satellite Program (DMSP) vehicles. It has two channels which operate in the 0.4μ to 1.1μ range, using silicon diode sensing elements, and two in the 8μ to 13μ band, using mercury cadmium telluride sensors. From an altitude of 750 km the maximum resolution in the shorter wavelength band 630 m, and maximum in the longer band is 670 m [60]. Infra-red scanners were introduced into satellite reconnaissance with the third generation of area survey satellites in 1966; at the kind of altitude they used, the resolution of the DMSP scanners would be 150 m and 160 m, certainly good enough to be of use in reconnaissance.

Sensors operating at radiation wavelengths produced at the sort of temperatures experienced on Earth, such as DMSP's mercury cadium telluride detectors, do have one major drawback – they require cryogenic cooling, in DMSP's case to 100K. This, of course, increases the spacecraft's complexity considerably and makes the reliability necessary for long life hard to attain. The Program 647 early warning satellites bypass this problem by making use of the fact that as the temperature of the emitter increases, the wavelength of its radiation decreases, and detectors sensitive to the wavelengths emitted by the hot gases of a rocket exhaust have a much higher working temperature. The early warning satellites use lead sulphide cells which have a peak response at 2.7μ and operate at 193K and this comparatively high temperature means that they can use passive cooling [38]. It does mean, however, that they can only detect missiles while their motors are firing, and once burnout is reached and the short wavelength emissions stop the ability to track them is lost.

Sensors which use the long wavelength atmospheric "window" can be divided into two types, passive and active.

Passive sensors do not emit radio or radar signals; they simply listen to whatever they can pick up, record it and then when they are over home territory re-transmit it to a receiving station for processing and analysis on the ground. This type of sensor has been in use on the ferret satellites since 1962, but like all else to do with this programme, their performance is shrouded in secrecy.

Active sensors are those which transmit their own signals and use the reflections to determine the presence of other objects. For reconnaissance and surveillance purposes these are mostly confined to radars operating at the middle of the wavelength range, in what used to be called the L-band but is now referred to as the D-band by United States military agencies (it covers the range of wavelengths from 15 cm to 30 cm, that is frequencies from 1GHz to 2 GHz). Radars such as these have one great advantage – their performance is unaffected by weather conditions. However, they do have one great disadvantage – to give anything like reasonable resolution requires very large antennae. As an example of this, the latest ground-based radar used to detect and track re-entry vehicles and satellites, the USAF's Cobra Dane at Shemya in the Aleutians, also operates in the D-band but its phased array antenna is 29 m in diameter [61]. Obviously, such a size is out of the question for spaceborne applications with present-day technology, and so active radars have found very little application in satellite reconnaissance.

This situation has changed recently with the development of a technique known as synthetic aperture side-looking radar. For this the vehicle transmits radar pulses in a narrow fan at right angles to the direction of flight. As the radar beam sweeps through the fan, the reflected signal is converted into a fine light beam which is scanned across a photographic film. The forward motion of the vehicle, and thus the radar fan, is translated into a motion of the photographic film, so that successive scans build up a picture in much the same way as a television image is built up from a set of lines. The vehicle's forward movement makes the antenna "appear" much larger to objects on the ground, and as the resolution of a radar is proportional to its antenna size, a dramatic improvement in performance over conventional radars can be realised. When NASA's Seasat is launched in May 1978 it will carry a synthetic aperture side-looking radar operating at 1.3 GHz which will have a resolution of 25 m [35]. It has been suggested that the Big Birds carry this type of radar, and although a resolution of 25 m is far poorer than they achieve with their optical devices, the capability to produce images in all weather conditions and at any time of day would be of great value in reconnaissance. The US Navy had also planned to use a side-looking radar in its ocean surveillance satellite, but studies showed that the pitching and rolling movements of a ship at sea would destroy the phase relationships necessary for the technique to work, and so a conventional forward-looking radar is used, although still operating in the D-band [62].

Future Developments

Since the days of the Discoverer programme satellite reconnaissance has evolved from an experimental technique to a reliable, regular, highly sophisticated technology. This is not to say, however, that current capabilities cannot be improved upon, and several programmes are being pursued with this aim.

For some years the main effort in this field has been to expand the missile tracking capabilities of the early warning satellites to include the mid-course coast phase as well as the boost phase. This requires sensors operating in the long wavelength infra-red range (8μ to 14μ), which in turn requires the use of cryogenic cooling. Today's satellites were designed at a time when the most important consideration was to provide a simple and reliable system, so the decision

Table 9. Summary of Launches by Programme and by Year.

Programme	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Discoverer	8	11	17	2															38
Area Survey		1	4	18	17	14	14	9	9	8	6	4	3	2					109
Close-Look				6	4	10	9	15	10	8	6	5	4	5	3	4	2	2	93
Big Bird													1	3	3	2	2	2	13
Early Warning		2	2	2	3			2		1	1	3	2	2	2		2	1	25
Ferret				3	2	3	1	2	1	2	1	1	1						17
Ocean Survey																		1	1
Total	8	14	23	31	26	27	24	28	20	19	14	13	11	12	8	6	6	6	296

was made to use short wavelength sensors, but now the technology of space vehicle design has reached a stage where long wavelength infra-red sensors are becoming a practical proposition for long-term space applications.

As far back as 1969 research was under way in this field [63], and in June 1971 a sensor of this type was flown as Space Test Program payload P70-1 to provide background measurements in support of this work [64, 65]. Following on is the Satellite Infra-Red Experiment (SIRE) which aims to demonstrate the ability of long wavelength sensors to detect space vehicles against the cool space background, culminating in a subsatellite launch in 1980 or 1981. Hughes Aircraft has been contracted to build the sensor and its associated cooling system, and the spacecraft contractor is to be chosen soon [66].

The SIRE payload will be part of a package of DoD experiments in its Space Test Program that mark the first military use of the Space Shuttle. Another payload planned for this mission is from the Teal Ruby programme to investigate the possibility of detecting aircraft from surveillance satellites. Jet engines produce relatively intense infra-red radiation, but discriminating it from the background of the Earth, with all its other radiations, presents considerable difficulties. The key to the solution lies in a new type of sensor called a mosaic focal plane array. A mosaic array is a two-dimensional array of batch-processed detectors mounted integrally with charge coupled devices on a single chip, with as many as several thousand on one chip. By integrating the charge coupled devices, which amplify and process the detector signals, on the same chip as the detectors most of the costly hand-wired interconnections required on an array of the type used by the Program 647 satellites can be replaced by thin film connections, greatly reducing the electrical heating produced during operation, and so allowing smaller cooling units to be used. The high detector densities and anticipated low costs mean that focal plane arrays of hundreds of thousands of channels can be constructed – Teal Ruby's will use a quarter of a million [67] – compared to the 2,000 used in today's satellites. They will be operated in a "staring" mode, with each detector observing the same region continuously and the signal processing logic programmed to respond to changes in illumination levels [68, 69].

Looking further into the future, the Air Force is developing in its High Altitude Large Optics (HALO) programme a multiple threat warning and observation satellite as a replacement for current systems in the 1990's. As it is currently envisaged, a HALO vehicle would be assembled from components orbited in six Space Shuttle flights, and would include adaptive optics using a structure up to 30 m in diameter, mosaic infra-red arrays and high resolution television [70, 71].

Satellite Reconnaissance – The Biggest Payoff of the Space Programme?

Table 9 gives a year-by-year and programme-by-programme breakdown of reconnaissance satellite launches, and it shows that by the end of 1976 there had been 296. Of these 262 succeeded in placing their payloads in orbit, which amounts to 43% of all United States launches to orbit and beyond. This represents a considerable investment in men and resources, and the question naturally arises, has it been worth it? The answer seems to be a very definite "yes," although it is hard to substantiate it in detail because the benefits of satellite reconnaissance are only apparent to the public in indirect ways.

A military organisation must arm itself to counter all the attacks that it percieves an enemy might be able to launch. If it knows in detail just what weapons the enemy has, how they are deployed and what their capabilities are, it can do this with a reasonable level of funding and a good degree of confidence, but if its knowledge is sketchy or incomplete, then it is obliged to develop a whole range of weapons "just in case." This inflates military budgets and, by the interaction of each side trying to match the other, sends the arms race spiralling up. The role of reconnaissance satellites has been to provide this knowledge, and the benefits they have brought are measured in terms of the weapons projects which have not been pursued, but which in the absence of this knowledge would have fallen into the "just in case" category, and would have been pushed through to deployment.

A clue to the scale of these savings was given in a briefing by President Johnson on 16 March 1967. While commenting on the amount of money spent on the space programme, he said "....and if nothing else has come out of it except the knowledge we've gained from space photography, it would be worth tens times what the whole programme cost." [72]. By 30 June 1967 the United States had spent $38.70 billion on its space programme [73, 74], and so the President's figure would imply that the savings were of the order of several hundred billion dollars. Of that $38.70 billion, $10.79 billion had been spent by the DoD, so the cost of the whole reconnaissance satellite effort must have been less than $10 billion, making it not only a very beneficial programme but also a very cost-effective one. There seems no reason to believe that the utility of reconnaissance satellites has been any less since 1967, so extrapolating President Johnson's figure suggests that by now the savings must be in the region of a staggering thousand billion dollars.

Sources of Data Used in Compiling the Tables

The data concerning the successful launches was taken from the RAE's *Table of Earth Satellites* (Volume 1: 1957-

1968, Volume 2: 1969-1973, and Volume 3, Parts 1, 2 & 3: 1974-1976), although in a few cases the identification of the launch vehicle was taken from *TRW Space Log* (published by the Public Relations staff of TRW Systems), the *United Nations Public Registry*, or the references cited below. Data concerning the launch failures was drawn from *TRW Space Log, Table of Earth Satellite and Space Vehicle Failures, 1957-1973* (published privately by J. A. Pilkington, 1974), and NASA's annual compilation *Astronautics and Aeronautics*.

REFERENCES

1. C. S. Sheldon *et al.*, *Soviet Space Programs, 1971-75: Volume 1* (Washington, D.C.: Senate Committee on Aeronautical and Space Sciences, 1976).
2. *World Armaments and Disarmament: SIPRI Yearbook 1974* (Stockholm: Stockholm International Peace Research Institute, 1974).
3. *Aviation Week and Space Technology*, 21 October 1957.
4. P. J. Klass, *Secret Sentries in Space* (New York: Random House, 1971), Chapter 4.
5. V. Marchetti and J. D. Marks, *The CIA and the Cult of Intelligence* (London: Jonathan Cape Limited, 1974).
6. Klass, *op. cit.*, Chapter 6.
7. Klass, *op. cit.*, Chapter 9.
8. Klass, *op. cit.*, Chapter 10.
9. *World Armaments and Disarmament: SIPRI Yearbook 1973* (Stockholm: Stockholm International Peace Research Institute, 1973).
10. K. W. Gatland, *Astronautics in the Sixties* (London: Iliffe Books Ltd., 1962).
11. Klass, *op. cit.*, Chapter 11.
12. H. Gelber, *Nuclear Weapons and Chinese Policy*, Adelphi Paper 99 (London: The International Institute for Strategic Studies, 1973).
13. *Aviation Week and Space Technology*, 12 September 1960.
14. *Aviation Week and Space Technology*, 19 September 1960.
15. Klass, *op. cit.*, Chapter 14.
16. Klass, *op. cit.*, Chapter 17.
17. *Aviation Week and Space Technology*, 30 August 1971.
18. *Aviation Week and Space Technology*, 28 November 1960.
19. *Aviation Week and Space Technology*, 12 February 1962.
20. *World Armaments and Disarmament: SIPRI Yearbook 1975* (Stockholm: Stockholm International Peace Research Institute, 1975).
21. *Aviation Week and Space Technology*, 10 September 1973.
22. *Aviation Week and Space Technology*, 25 September 1972.
23. *Aviation Week and Space Technology*, 16 April 1973.
24. *Aviation Week and Space Technology*, 12 February 1973.
25. *Aviation Week and Space Technology*, 8 May 1972.
26. Klass, *op. cit.*, Chapter 18.
27. *Aviation Week and Space Technology*, 23 January 1961.
28. *Aviation Week and Space Technology*, 6 June 1960.
29. *Missiles and Rockets*, 24 July 1961.
30. *Missiles and Rockets*, 16 July 1962.
31. *Aviation Week and Space Technology*, 18 November 1963.
32. *Aviation Week and Space Technology*, 17 June 1963.
33. *Report to the Congress from the President of the United States: United States Aeronautical and Space Activities, 1963* (Washington D. C., 1964).
34. *Aviation Week and Space Technology*, 7 September 1970.
35. *Aviation Week and Space Technology*, 8 December 1975.
36. *Aviation Week and Space Technology*, 14 May 1973.
37. *Washington Post*, 7 December 1971.
38. *Aviation Week and Space Technology*, 2 December 1974.
39. *US News and World Report*, 9 September 1968.
40. Klass, *op. cit.*, Chapter 19.
41. *Aviation Week and Space Technology*, 7 April 1975.
42. *Aviation Week and Space Technology*, 14 March 1977.
43. *Aviation Week and Space Technology*, 19 February 1968.
44. *Understanding Soviet Naval Developments* (Washington D.C.: Office of the Chief of Naval Operations, 1975).
45. *Aviation Week and Space Technology*, 18 September 1972.
46. *Aviation Week and Space Technology*, 20 August 1973.
47. *Aviation Week and Space Technology*, 19 February 1973.
48. *Aviation Week and Space Technology*, 29 January 1973.
49. *Aviation Week and Space Technology*, 23 June 1975.
50. *Aviation Week and Space Technology*, 24 May 1976.
51. *Aviation Week and Space Technology*, 28 June 1976.
52. A. H. Katz, *Observation Satellites: Problems, Possibilities and Prospects*, RAND Paper P-1707 (Santa Monica, California: The RAND Corporation, 1959).
53. J. C. Ervard, *When to Give Design a Second Look: Philosophy of Reexamination*, in *Astronautics and Aeronautics*, August 1968.
54. *Skylab Experiments, Volume 2: Remote Sensing of Earth Resources*, NASA EP-111 (Washington, D.C.: National Aeronautics and Space Administration,(1973).
55. T. P. Hansen, *Guide to Lunar Orbiter Photographs*, NASA SP-242 (Washington, D. C.: National Aeronautics and Space Administration, 1970).
56. *Washington Post*, 8 December 1963.
57. *New York Times*, 3 April 1966.
58. *Washington Post*, 15 September 1968.
59. *Aviation Week and Space Technology*, 26 May 1969.
60. *Aviation Week and Space Technology*, 3 December 1973.
61. *Aviation Week and Space Technology*, 25 October 1976.
62. *Aviation Week and Space Technology*, 12 February 1973.
63. *Aviation Week and Space Technology*, 8 September 1969.
64. *Aviation Week and Space Technology*, 5 April 1971.
65. R. W. Johnson, C. S. Jund and W. J. Niemann, *Advanced Space Programs: Transition to the Space Shuttle*, in *Astronautics and Aeronautics*, September 1976.
66. *Aviation Week and Space Technology*, 27 June 1977.
67. *Aviation Week and Space Technology*, 18 April 1977.
68. *Aviation Week and Space Technology*, 3 May 1976.
69. *Aviation Week and Space Technology*, 20 June 1977.
70. *Aviation Week and Space Technology*, 23 February 1976.
71. *Aviation Week and Space Technology*, 28 March 1977.
72. *New York Times*, 17 March 1967.
73. J. Van Nimmen, L. C. Bruno amd R. L. Rosholt, *NASA Historical Data Book, 1958-1968: Volume 1, NASA Resources*, NASA SP-4012 (Washington, D.C.: National Aeronautics and Space Administration, 1976).
74. B. W. Augenstein, *Policy Analysis in the National Space Program*, RAND Paper P-4137 (Santa Monica, California: The RAND Corporation, 1969).

SHUTTLE VIBRATION TESTS

Ground vibration tests of the Space Shuttle began last May in a tall test tower at the Marshall Space Flight Center in Huntsville, Alabama. The Orbiter and its Expendable Tank were 'soft-mounted' inside the stand using a system of air bags and cables to suspend the vehicles from a large overhead truss installed like a crossbeam between two test stand walls.

In the tests a computerized Shuttle Model Test and Analysis System (SMTAS) provides required vibrational cycles and force inputs and acquires response data from the vehicle. The term 'vibration' may be misleading. It is not in any way a shake test to find the strength of the vehicle. Engineers simply apply vibrations to its exterior with exciters powered by amplifiers similar to those found on home stereo sets. Sensors record the characteristics of the vibrations as they pass from one area of the vehicle to another.

The information allows engineers to verify the system design and mathematical models that predict how the Shuttle's control system will react to the much more severe vibrations expected during launch and flight into orbit.

Ground vibration tests with the 'Enterprise' prototype will continue for most of the year with pauses only to change the test configuration of the Space Shuttle.

First flight into orbit from Cape Canaveral by vehicle OFT-1 is now scheduled for mid-1979. The test crew will be John W. Young, commander, and Robert L. Crippen, pilot.