FOOT = Follow-On operational Tests (vehicles up to 174F ordered prior to decommissioning)

Here is my Atlas E/F article, an article on recycled Thors and an extra article on an early satellite launcher in case you would be interested

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THE ATLAS E/F LAUNCH VEHICLE - AN UNSUNG WORKHORSE

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For the past 22 years the Atlas E/F rocket has been the unsung workhorse of the US launch vehicle inventory. 39 launches of the converted Atlas E and F (E/F) Intercontinental Ballistic Missiles have taken place up to April 1990, utilising 11 different upper stage combinations. In 1983 a number of Atlas E/F payloads were shifted to the new Atlas H rocket, derived from the SLV-3D version of NASA's Atlas-Centaur launcher.

1. INTRODUCTION

The Atlas rocket has been manufactured almost continuously since 1956 by the Convair Division of General Dynamics Corporation in San Diego, California. After serving with the US strategic nuclear arsenal in the early 1960s, obsolete E and F model Atlas missiles were disarmed and placed into storage with the intention of reusing the boosters for future space and ballistic test programmes.

The 26.0m long missiles were externally identical, differing only in the mode of deployment. Atlas E, which first flew in October 1960, was designed to be launched from a semi-hardened 'coffin' shelter protected by a retractable concrete roof. Atlas F (first flight: August 1961) was operationally deployed in a 53m underground silo, but unlike Titan or Minuteman the missile could only be launched after being elevated to the surface (fig. 1).

2. VANDENBERG ATLAS MODIFICATION PROGRAMME

When the Atlas weapon system was decommissioned by the US Air Force in 1965, 190 Atlas E and F vehicles were consigned to long-term storage at Norton Air Force Base, California to await refurbishment for future launches. After completing refits on the last remaining Atlas D ICBM's, General Dynamics received a $4 million contract on February 14, 1966 to modify an initial batch of 23 Atlas E/F vehicles [1], starting with the newer F models.

After the first 23 conversions were performed at Convair's Kearny Mesa plant in San Diego, subsequent overhauls were relocated to the launch site at Vandenberg Air Force Base, California. The Vandenberg Atlas Modification Programme (VAMP) was initiated when a reduction in the projected launch rate rendered refurbishment work at Kearny Mesa uneconomical.

As work progressed on each airframe at Vandenberg, the Atlas avionics systems were shipped back to San Diego for upgrading and standardising of the range safety, telemetry and electrical systems. The principal change was replacement of the Bosch-Arma inertial guidance system with the General Electric Mod 3G radio command system, originally developed for Atlas SLV-3 (Standard Launch Vehicle) operations at Cape Canaveral. The pre-programmed auto-pilot of the Mod 3G system was augmented by trajectory corrections transmitted in real-time from the G E Range Tracking Station (GERTS), located not far from the launch site.

Refurbishment of the MA-3 propulsion system of Atlas E/F was performed by the manufacturer, the Rocketdyne Division of Rockwell International. Rocketdyne inspected each engine and retrofitted or repaired any component that did not meet specifications. Individual systems were then bench-tested, but

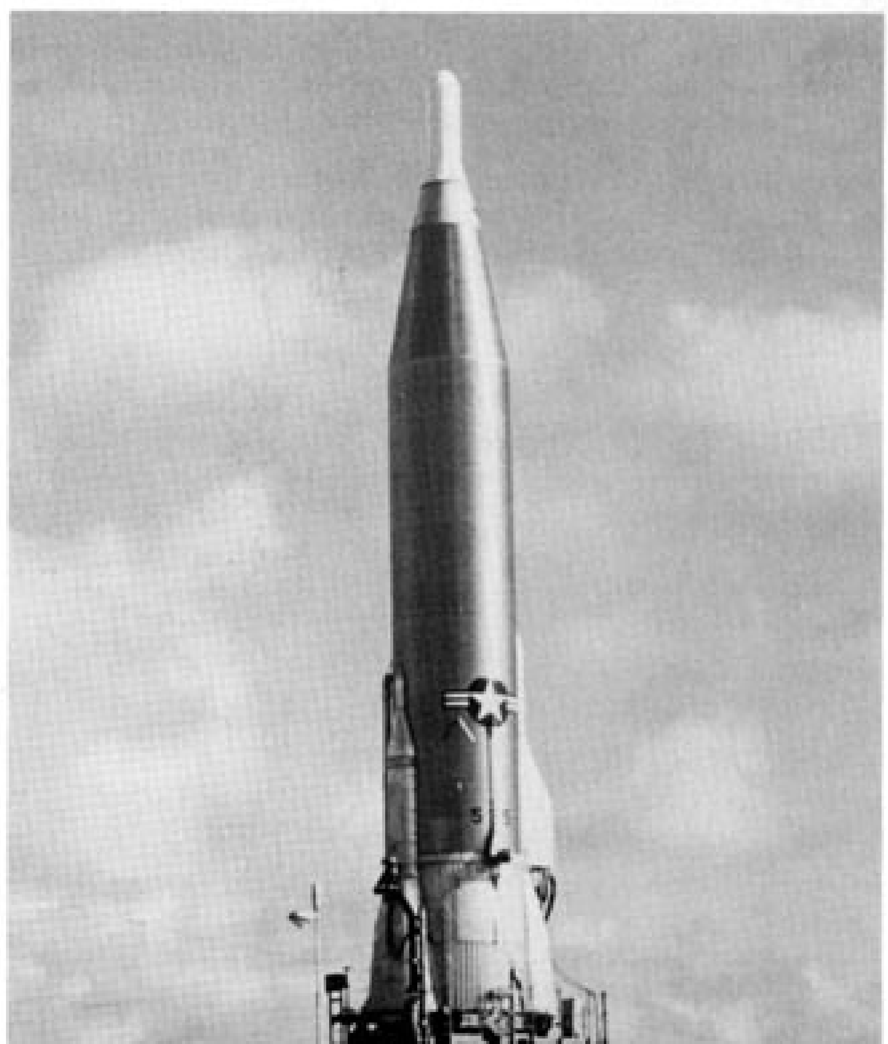

Fig. 1 An Atlas F missile in firing position at the silo test launch facility at Vandenburg AFB in August 1962. *(USAF)*

TABLE 1: *Atlas Facts*

1 Fourteen different versions of the Atlas rocket have been developed by General Dynamics since 1956 with a total production run of 589 vehicles.

2 As of April 1990 the cumulative total of Atlas launches stands at 495, almost evenly divided between orbital flights (245) and suborbital missions (250). Eighty-six rockets were utilised for static ground testing (many of which ended up in museums), and there are currently 5 Atlas E/F's.

3 Atlas is 'stage-and-a-half' launch vehicle. 'Stage 0' comprises the twin-chamber booster engine (mounted in a 4.5 m boat-tail structure that is jettisoned early in the flight), and 'Stage 1' is the centre-mounted sustainer engine that operates throughout the ascent. The engines share a common propellant supply.

4 A separate gas generator unit in the booster section provides power for the turbo machinery and Booster engines. The gas generator combustion products are vented into the main exhaust stream, producing a distinctive ragged flame and dark smoke plume.

5 The Atlas avionics and guidance systems are housed in external equipment pods at the base of the main propellant tank.

6 To save structural weight the Atlas is constructed of extremely thin gauge stainless steel with a thickness of only 0.096 mm to 0.254 mm.

7 The Atlas airframe, with a maximum diameter of 3.05 m, cannot support its own weight and must be pressurised like a balloon to maintain structural integrity.

8 Without the payload fairing the length of the basic Atlas E/F launch vehicle is 20.5 m. The rocket has an empty weight of 6,800 kg and carries about 112,700 kg of liquid propellants at liftoff.

TABLE 2: *The MA-3 Propulsion System of Atlas E/F(Rocketdyne)*

Engine, designation	Thrust kN	Nominal burn time (seconds)
Booster LR89-NA-7	1,468	122
Sustainer LR105-NA-5	254	325
Vernier (X2) LR101-NA-7	4.45	343.5

TABLE 3: *Future NASA launches of Atlas E/F(NASA)*

Provisional date	Rocket	Payload
June 1990	Atlas 50E	NOAA-D
May 1991	Atlas 34E	NOAA-I
September 1992	Atlas 11E	NOAA-J

no static firings were conducted due to the proven in-flight history of the engines. Rocketdyne implemented a specialised refurbishment programme in 1969 designed to extend the storage life of the engines indefinitely.

3. LAUNCH FACILITIES

From 1968 to 1972 Atlas E/F shared launch facilities with the ABRES (Advanced Ballistic Re-entry Systems) programme at the north end of Vandenberg AFB. Due to range safety considerations there was only a narrow range of retrograde polar orbit accessible from the ABRES pads. The rockets had to be launched in a westerly direction, then 'dog-legged' south during ascent to head into polar orbit.

The Air Force decided to convert Space Launch Complex 3 at South Vandenberg for Atlas E/F (the SLC-3 East and West pads were previously used for Atlas SLV-3 and LTTAT Thor-Agena D, respectively) to provide better access to certain high inclination polar orbits. The first Atlas E/F was launched from SLC-3 in July 1974. Launch operations at the Western Space and Missile Centre (Vandenberg AFB) are the responsibility of the 6595th Aerospace Test Group, a unit of the US Air Force.

4. ATLAS E/F LAUNCH VEHICLE

The most conventional aspect of the unorthodox Atlas launch vehicle design (Table 1) is the three-chambered MA-3 propulsion system. The MA-3 engines (Table 2) burn liquid oxygen (LOX) and RP-1 kerosine propellants and develop 1,730 kN of thrust. Liftoff occurs almost simultaneously when the main engines are ignited, without the need for 'hold-down' time to verify thrust buildup. Attitude control during powered flight is provided by two small vernier engines located on the Atlas airframe.

Out of 93 Atlas E/F rockets that General Dynamics refurbished for the Air Force, 48 vehicles were launched on ballistic flights and 45 were allocated for orbital missions. 5 vehicles remain in storage at Vandenberg AFB, three of which will be used by NASA in the near future to launch polar orbiting NOAA weather satellites (Table 3).

The Air Force has plans to launch two additional military weather satellites with Atlas E/F before shifting the DMSP launch role to refurbished Titan II boosters in 1993. The USAF also announced that it intends to sell the remainder of the Atlas E/F's in storage in order to deplete the inventory.

The saving to the US government has been estimated at $20 million each time a refurbished Atlas E/F rocket carries a payload into orbit. Atlas 52E, the rocket used to launch the NOAA-10 weather satellite (Table 4), was more than 25 years old when it finally took its turn on the launch pad in September 1986. After being accepted by the Air Force from General Dynamics in May 1961, the vehicle served as an operational ICBM before being mothballed in 1965. Nearly 20 years elapsed before a payload was assigned to Atlas 52E and the vehicle was pulled out of storage for reconditioning.

5. ORBITING VEHICLE ONE

The satellite launching debut of the refurbished 27.3 m Atlas E/F rocket occurred on April 6, 1968. At 0200 LT Atlas 107F lifted off from the ABRES-A2 complex at Vandenberg carrying two cylindrical 1.39 m Orbiting Vehicle One (OV1) scientific satellites for the Air Force Aerospace Research Support Programme (ARSP) [2].

Each OV1 satellite was launched into orbit by individual FW-4S solid rocket motors manufactured by the Chemical Systems Division of United Technology Corporation (Table 5). The OV1 Propulsion Module stage was equipped with twelve hydrogen peroxide thrusters to perform the separation manoeuvre and to provide attitude stabilisation during the solid rocket burn.

TABLE 4: *Atlas E/F and H launch chronology.*

Date	Payloads	Designation	Launch Pad	Atlas	Upper Stage
April 6, 1968	OV1-13,14	1968-26	ABRES-A2	107F	Propulsion Module(s)
July 11	OV1-15,16	1968-59	ABRES-A2	75F	Propulsion Module(s)
March 17, 1969	OV1-17,17A,18,19	1969-25	BMRS-A2	104F	Propulsion Module(s)
August 6, 1971	OV1-20,21	1971-67	BMRS-A2	76F	Propulsion Module(s)
October 2, 1972	P72-1,RADCAT	1972-76	BMRS-A1	102F	Burner II
July 13, 1974	P73-3(NTS-1)	1974-54	SLC-3W	69F	PTS
April 12, 1975	P72-2	LAUNCH FAILURE	SLC-3W	71F	TE-M-521-5
April 30, 1976	NOSS-1	1976-38	SLC-3W	59F	TE-M-364-4(?)
June 23, 1977	P76-4(NTS-2)	1977-53	SLC-3W	65F	SVS
December 8	NOSS-2	1977-112	SLC-3W	50F	TE-M-364-4(?)
February 22, 1978	NDS-1	1978-20	SLC-3E	64F	SVS
May 13	NDS-2	1978-47	SLC-3E	49F	SVS
June 26	Seasat	1978-64	SLC-3W	23F	Agena D
October 6	NDS-3	1978-93	SLC-3E	47F	SVS
October 13	Tiros-N	1978-96	SLC-3W	29F	ISS
December 10	NDS-4	1978-112	SLC-3E	39F	SVS
February 24, 1979	P78-1	1979-17	SLC-3W	27F	OIS
June 27	NOAA-6	1979-57	SLC-3W	25F	ISS
February 9, 1980	NDS-5	1980-11	SLC-3E	35F	SVS
March 3	NOSS-3	1980-19	SLC-3W	67F	TE-M-364-4(?)
April 26	NDS-6	1980-32	SLC-3E	34F	SVS
May 29	NOAA-B*	1980-43	SLC-3W	19F	ISS
December 8	NOSS-4/LIPS-I	LAUNCH FAILURE	SLC-3W	68E	TE-M-364-4(?)
June 23, 1981	NOAA-7	1981-59	SLC-3W	87F	ISS
December 18	NDS-7	LAUNCH FAILURE	SLC-3E	76E	SVS
December 20, 1982	DMSP 5D-2F6	1982-118	SLC-3W	60E	ISS
February 9, 1983	NOSS-5/LIPS-II	1983-08	SLC-3E	6001H	TE-M-364-4(?)
March 28	NOAA-8	1983-22	SLC-3W	73E	ISS
June 9	NOSS-6	1983-56	SLC-3E	6002H	TE-M-364-4(?)
July 14	NDS-8	1983-72	SLC-3W	75E	SGS-II
November 17	DMSP 5D-2F7	1983-113	SLC-3W	58E	ISS
February 5, 1984	NOSS-7	1984-12	SLC-3E	6003H	TE-M-364-4(?)
June 13	NDS-9	1984-59	SLC-3W	42E	SGS-II
September 8	NDS-10	1984-97	SLC-3W	14E	SGS-II
December 12	NOAA-9	1984-123	SLC-3W	39E	ISS
March 12, 1985	Geosat	1985-21	SLC-3W	41E	OIS
October 8	NDS-11	1985-93	SLC-3W	55E	SGS-II
February 9, 1986	NOSS-8	1986-14	SLC-3E	6004H	TE-M-364-4(?)
September 17	NOAA-10	1986-73	SLC-3W	52E	ISS
May 15, 1987	NOSS-9/LIPS-III	1987-43	SLC-3E	6005H	TE-M-364-4(?)
June 19	DMSP 5D-2F8	1987-53	SLC-3W	59E	ISS
February 2, 1988	DMSP 5D-2F9	1988-06	SLC-3W	54E	ISS
September 24	NOAA-11	1988-89	SLC-3W	63E	ISS
April 11, 1990	P87-2	1990-30	SLC-3W	28E	Altair 3
December 1,	DMSP			Atlas 61E	

*Booster Malfunction

TABLE 5: *Atlas E/F Solid Upper Stages*

	OVI Propulsion Module	Burner II	PTS	TE-M-521-5	SVS	SGS-II	ISS	OIS
Diameter	72.4cm	1.65m	1.5m	44.2cm	1.5m	1.2m	94cm	1.4m
Length	2.05m	1.73m	1.65m	97.3cm	3.4m	3.96m	1.32m	1.8m
Stage Mass	354kg	807kg	1,270kg	123.9kg	2,497kg	4,540kg	666kg	573.4kg
Motor(s)	FW-4S	TE-M-364-2 (Star 37B)	TE-M-364-4 (Star 37E)	TE-M-521-5 (Star 17A)	TE-M-364-4 (Star 37E)*	TE-M-711-8 (Star 48)*	TE-M-364-15 (Star 37S)	TE-M-616 (Star 27)
Thrust ea.	26.6kN	44.5kN	69.0kN	15.1kN	75.6kN	65.4kN	43.9kN	27.0kN
Burn duration each motor	32 sec	42 sec	44 sec	21 sec	44 sec	90 sec	44 sec	33.5 sec
Utilisation	OVI	P72-1	NTS-1	P72-2	NTS-2 ,Navstar	Navstar	NOAA,DMSP	P78-1,Geosat

* twin motors

NOTE: Navy Ocean Surveillance System (NOSS) is believed to use a Star 37E solid motor integrated with the spacecraft in the same manner as the ISS stage (NOAA/DMSP). The dimensions for TE-M-521-5 and ISS are for the motors only. The most recent launch in April 1990 utilised a 1.5 m Thiokol Altair 3 (Star 20) Upper Stage motor from the Scout launcher.

A 4.94 m aluminium clamshell fairing built by General Dynamics protected the payloads within the sensible atmosphere. Up to three Propulsion Modules could be mounted on the modified 2.78 m adapter section developed originally for the RMP-B re-entry research programme. The spacious 2.13 m diameter fairings later became standard for most Atlas E/F payloads.

6. BURNER II

Boeing's versatile Burner II stage (usually employed with the McDonnell Douglas LV-2D Thor booster) was the second upper-stage combination assigned to Atlas E/F. The Thiokol TE-M-364-2 'Star 37B' solid motor (Star stands for Spherical Thiokol Apogee Rocket and the number represents the diameter of the motor in inches) was nestled in a conical metal framework which mounted the stage's electronic and attitude control subsystems [3]. Burner II was stabilised by a hydrogen peroxide thruster system derived from the Scout launcher, with supplementary N_2 gas jets for roll-axis control.

On October 2, 1972 Atlas 102F combined with Burner II (fig. 2) to orbit a 208 kg passive radar calibration target and a 726 kg radiation research payload for the US Air Force Space Test Programme (STP). Boeing was the prime contractor for the P72-1 'Radsat' spacecraft carrying four experiments, and the US Army Ballistic Missile Defense Agency provided the cylindrical 12.2 m 'Radcat' target to calibrate ABM radars. Both payloads entered near-circular 700 km polar orbits inclined 99.7°.

The Air Force ordered an elongated version of the 1.65 m diameter Burner II fairing to enclose the satellites, which extended the length of the launch vehicle to 28.9 m. The only other launch of an Atlas-Burner II (with the SLV-3 Atlas configuration) failed to orbit a multi-satellite payload in August 1968.

7. PAYLOAD TRANSFER SYSTEM

The third solid upper-stage to fly on Atlas E/F was the Payload Transfer System (PTS), a prototype of the Stage Vehicle System that was later to orbit the first seven Navigation Development System (NDS) satellites for the Air Force Navstar programme. The TE-M-364-4 solid motor employed by PTS is one of a series of upper-stage propulsion units derived from the Surveyor lunar

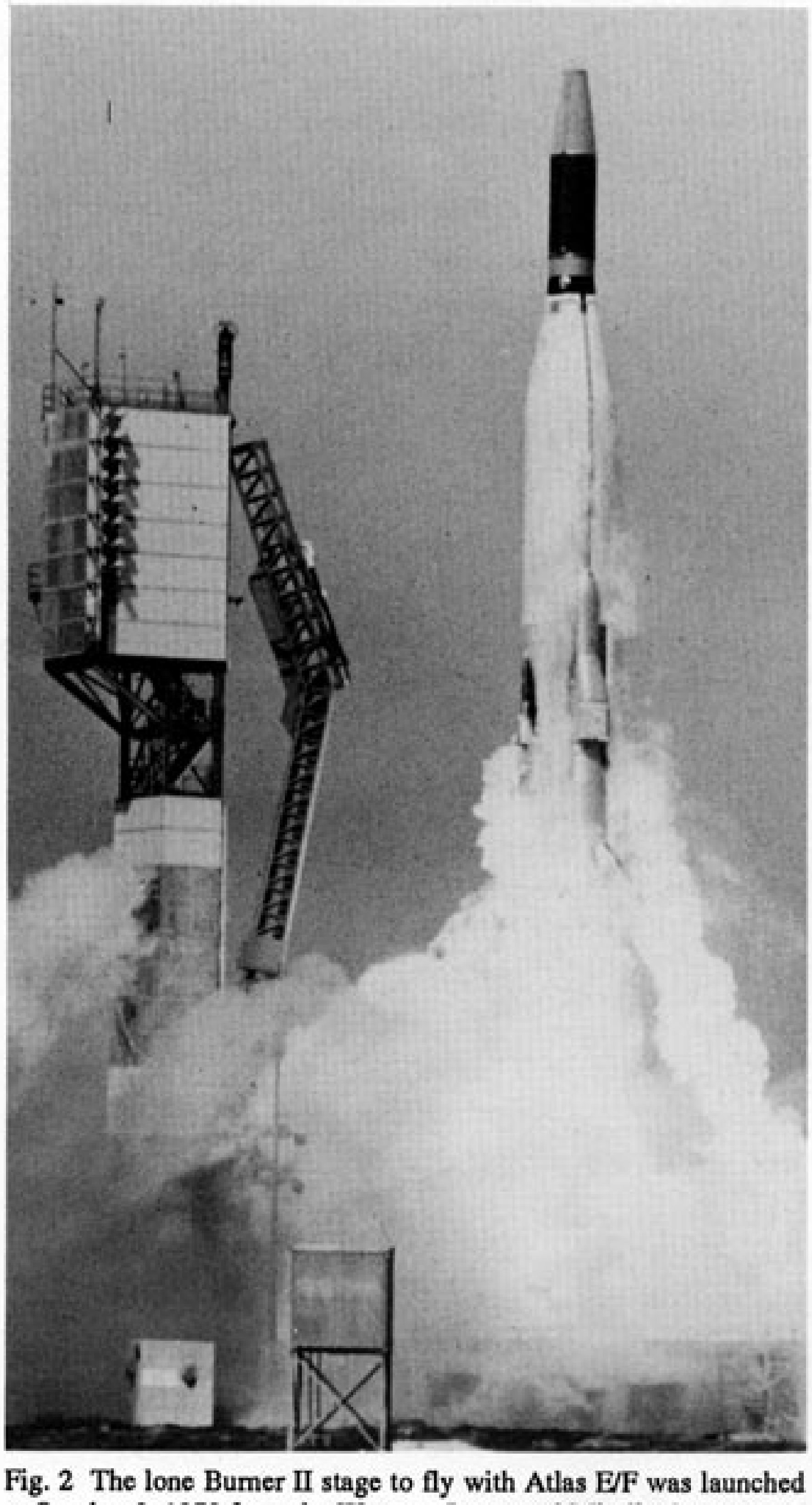

Fig. 2 The lone Burner II stage to fly with Atlas E/F was launched onOctober 2, 1972 from the Western Space and Missile Centre. *(USAF, courtesy A. Wilson)*

landing retro-rocket.

PTS and SVS outwardly resembled the Orbit Insertion System (fig. 3), smallest of three solid upper-stages manufactured for Atlas E/F by the Fairchild Space Company. Four dual-nozzle hot gas generator bottles (six on SVS) were discharged 0.3 seconds after the PTS stage separated, initiating spin stabilisation of the payload.

Protected by a 7.4 m fairing, the 295 kg Navigation Technology satellite (NTS-1) was designed to demonstrate the Navstar time-ranging navigation concept utilising space-borne atomic clocks. The 1.22 m diameter spacecraft tested the first atomic clocks in space, two light-weight rubidium vapour instruments developed by a West German firm [4].

Ignition of the TE-M-364-4 motor occurred 20 seconds after booster separation. The Delta Vee (Δv) of the injection burn was 2,600 m/s, placing NTS-1 into a 193 km x 13,900 km transfer orbit inclined 125°. The Air Force elected to deploy NTS-2 and Navstar at 63° inclinations rather than in the unusual retrograde orbit employed by NTS-1 . The PTS stage was discarded 256 seconds after burnout [5].

The orbit of NTS-1 was circularised with a TE-M-604 (Star 24) apogee kick motor (AKM) producing 20 kN of thrust. The final parameters of the orbit were 13,445 km x 13,767 km with a period of eight hours. The burned out Star 24 motor was later jettisoned (AKM casings were retained aboard the Navstars).

8. SVS AND NAVSTAR

The 440 kg NTS-2 spacecraft was the first of eight payloads to be placed into orbit by the new Stage Vehicle System (SVS) built by Fairchild. The 3.4 m stage (also designated SGS - Block 1) utilised a pair of TE-M-364-4 solid motors to insert the payload into a temporary transfer orbit with a perigee of 154 km and an apogee of 20,000 km. NTS-2 and the Rockwell-built Navstars each employed 2.13 m diameter fairings, and the launch vehicle was the same height as the PTS version, 29.2 m. The in-orbit mass of Navstar is about 455 kg.

The 'stage 1' motor was ignited 17 seconds after separation from the booster and imparted a Δv of 1,100 m/s to the spacecraft. The expended motor was jettisoned after a coast period of 38 seconds and 'stage 2' was ignited some 17 seconds later. The Δv of the second burn was 2,140 m/s. Stage 2 was separated from the payload after coasting for 255.6 seconds [6].

The payload remained in the transfer orbit for about 50 hours before the apogee kick motor was fired. The resulting orbit was roughly circular with an altitude of about 20,000 km and a period of twelve hours. The AKM employed by NTS-2 and the Block 1 Navstar spacecraft was a TE-M-616 (Star 27) motor that developed 27 kN of thrust. The Star 27 later formed the basis of the aforementioned Orbit Insertion System (Section 14).

TABLE 6: *Summary of a Typical Atlas E/F Countdown (NOAA-10)(NASA)*

Time (hr:min:sec)	Event
T-2:10:00	Service Structure rolled back; begin RP-1 propellant loading
T-1:00:00	Begin loading cryogenic LOX propellant
T-0:05:00	Propellant loading completed
T-0:02:15	Launch vehicle on internal power
T-0:01:00	Vehicle pressurisation completed and LOX vent valve closed
T-0:00:00	Ignition and liftoff

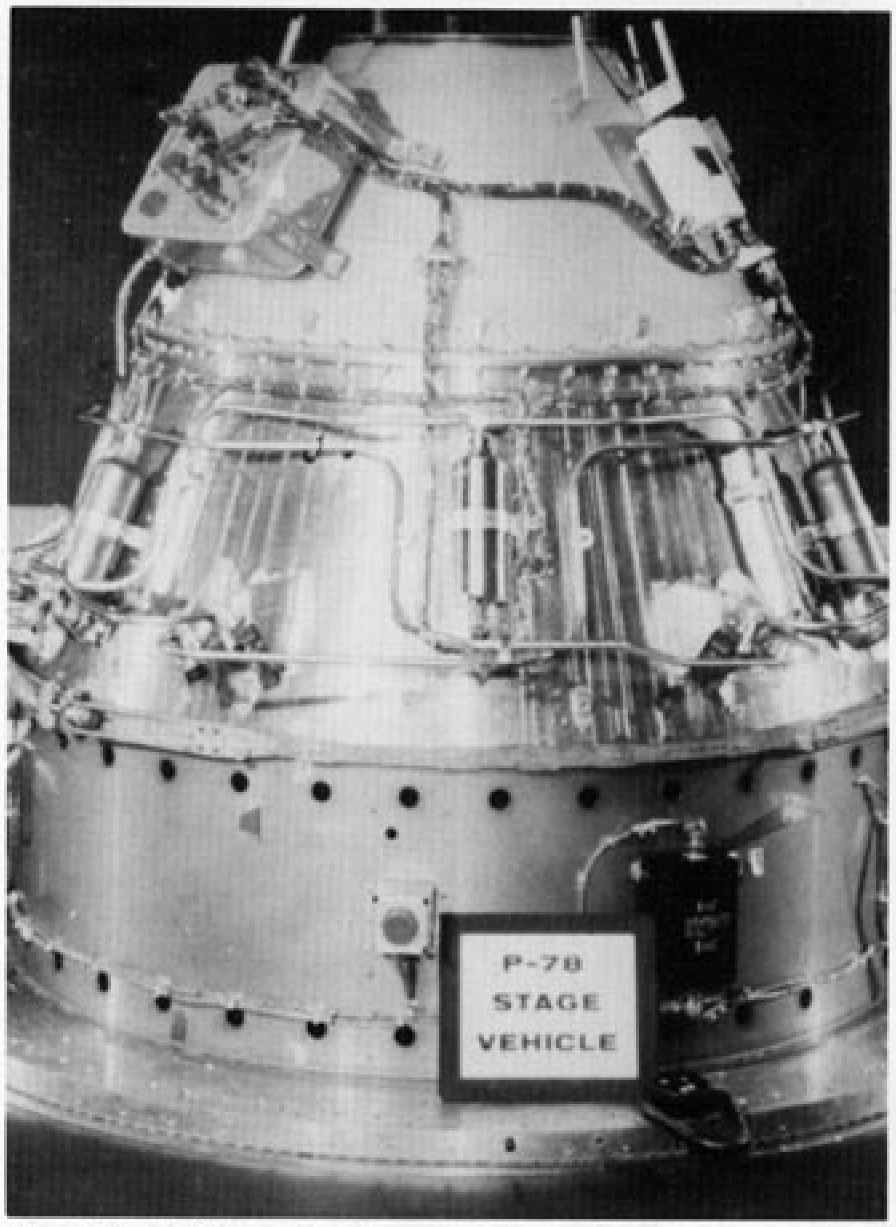

Fig. 3 The Orbit Insertion System (OIS) upper stage.
(Fairchild Space Company, courtesy Ed Hengeveld)

A 27.3 kg package of instruments designed to detect nuclear explosions from space was tested aboard the NDS-6 spacecraft (1980-32A). The present nuclear detection system is deployed aboard Defense Support Programme (DSP) early warning satellites, and beginning in 1989 operational versions of the new sensors will be launched on the advanced Block II versions of Navstar.

On December 18, 1981 the only Navstar that failed to reach orbit (NDS-7) was lost in a spectacular accident at the launch site. Less than 10 seconds after lift-off Atlas 76E unexpectedly pitched over and veered off course at an altitude of only 60 m. The vehicle plunged to earth and erupted into a giant fireball less than 150 m from the launch pad.

9. SGS-II

The final four pre-operational (Block I) Navstar satellites were injected into orbit by a new twin-motor upper-stage designated SGS-II. Built by McDonnell Douglas Astronautics Company, SGS-II utilised the same solid motors as the Payload Assist Module (PAM) stage that has seen service on both Delta and the Space Shuttle since 1980.

The tandem-mounted TE-M-711-8 (Star 48) motors produced 65.4 kN of thrust during relatively long burns of 90 seconds each. The SGS stage and payload were spun up to 95 rpm as the Atlas separated, and 20 seconds later the first Star 48 was ignited. After burnout of the second stage motor Navstar was travelling in a 63° transfer orbit with parameters of 550 km x 21,000 km. Two days later the Star 27 AKM was fired to circularise the orbit.

Due to the untimely loss of two PAM stages during the satellite deployments on shuttle mission 41-B, the scheduled April 1984 launch of NDS-9 was delayed until the cause of the Star 48 motor failures was identified. The flawed carbon-carbon composite nozzles were determined to have come from a different manufacturing batch than nozzles from previous missions, and flights were cleared to resume using the original hardware. NDS-9 was launched only four days after the successful June 9, 1984 altitude chamber firing of a Star 48 at the USAF Arnold Engineering Development Centre.

10. WHITECLOUD

The launch vehicle for the first four Navy Ocean Surveillance System (Project Whitecloud) spacecraft was the 27.3 m Atlas E/F rocket (fig .4), while five follow-on launches were conducted with the new Atlas H booster (Section 15). Future NOSS/Whitecloud vehicles are scheduled to be orbited by refurbished Titan II ICBM's from SLC-4W at Vandenberg AFB [8].

The function of the Navy Ocean Surveillance System (NOSS) is to search for the presence of Soviet naval vessels from space. Three identical subsatellites are deployed from each NOSS spacecraft to intercept radio and radar emissions from the targets. The location of each warship is determined through interferometric analysis of the captured signals, and the course and speed of the targets is derived from the change in position between observations.

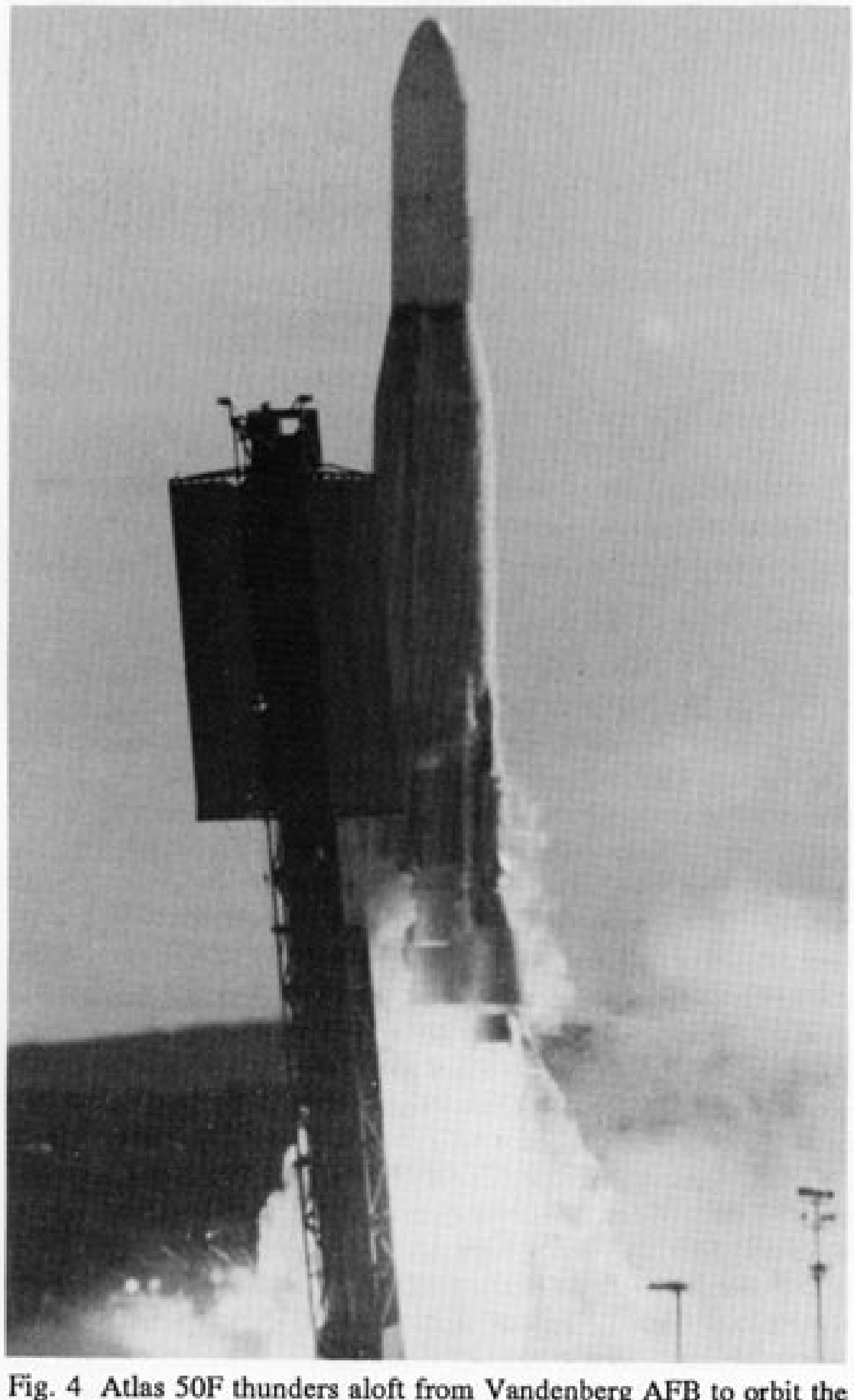

Fig. 4 Atlas 50F thunders aloft from Vandenberg AFB to orbit the Whitecloud 2 spacecraft in December 1977.
(DOD Still Media Depository)

The rectangular-shaped subsatellites measure approximately 90 cm x 244 cm x 40 cm and are deployed at distances of up to 43 km from the central section. The largest facet is covered by solar sells and the radio receivers are mounted on the opposite face. There have been several unsubstantiated reports that the subsatellites are connected to the orbital dispenser by long wires or tethers [9, 10].

Each Project Whitecloud satellite operates in a near circular 1,100 km orbit with an inclination of 63°. The orbiting clusters positioned at 120° intervals around the Earth to ensure regular observations of the targets, and the combined mass of the NOSS spacecraft is estimated at 800 kg.

Martin Marietta Corporation was selected as prime contractor for the NOSS spacecraft after the first two orbiting prototypes were built by the Naval Research Laboratory (NRL) in Washington DC. The upper-stage system is classified, but is believed to consist of a TE-M-364 series motor (Star 37E?) integrated with the spacecraft in the same manner as the ISS stage of the NOAA/DMSP weather satellites (Section 13).

The lone launch failure in the NOSS series came on December 8, 1980, coincidentally the first use of an Atlas E vehicle after 22 consecutive Atlas F space launches. According to the Air Force a malfunction caused a deviation in the trajectory of the launcher about 1,609 km downrange, forcing the Range Safety Officer to destroy Atlas 68E about seven minutes after lift-off.

11. P72-2

The only use of the Thiokol TE-M-521-5 solid motor as an Atlas E/F upper-stage [11] ended in failure on April 12, 1975 when an unspecified malfunction of the launch vehicle prevented the P72-2 spacecraft from attaining orbit. The 123.9 kg Star 17A motor, installed at the base of the cylindrical atmospheric research satellite, was the smallest upper-stage to be used with Atlas E/F. Five experiments were incorporated on the 725 kg Space Test Programme payload built by Rockwell International, which measured 4.27 m long and 1.37 m in diameter [12, 13].

12. SEASAT

In June 1978 NASA's 2,293 kg Seasat-A oceanographic satellite was injected into orbit by the Lockheed Agena D, the only liquid-fuelled upper-stage to be paired with an Atlas E/F vehicle. Lockheed also manufactured the Seasat payload module, which was fully integrated with the 1.5 m diameter Agena (fig. 5). The Seasat project was an outstanding success, but unfortunately a massive short circuit in the power supply on October 9, 1978 brought the mission to an abrupt end after only four months of operation.

The Agena's restartable Bell Aerospace 8096 (YLR81-BA-11) rocket motor burned IRFNA and UDMH propellants and developed 71 kN of thrust. The Agena was ignited for the first of two injection burns 74.5 seconds after booster separation and fired for 3.85 minutes (Table 7). A brief 6.2 second burn was made 45 minutes later to fine-tune the orbit.

During each insertion burn the 12.8 m spacecraft was stabilised by the same hot gas thruster system that would be used to make orbital adjustments. Three-axis stabilisation was maintained throughout the mission by a momentum wheel system.

The Seasat spacecraft was designed by the Jet Propulsion Laboratory (JPL) to study the world ocean with a battery of four microwave scanning instruments and an infrared spectrometer. Operating from a 108° polar orbit of 776 km x 800 km, the

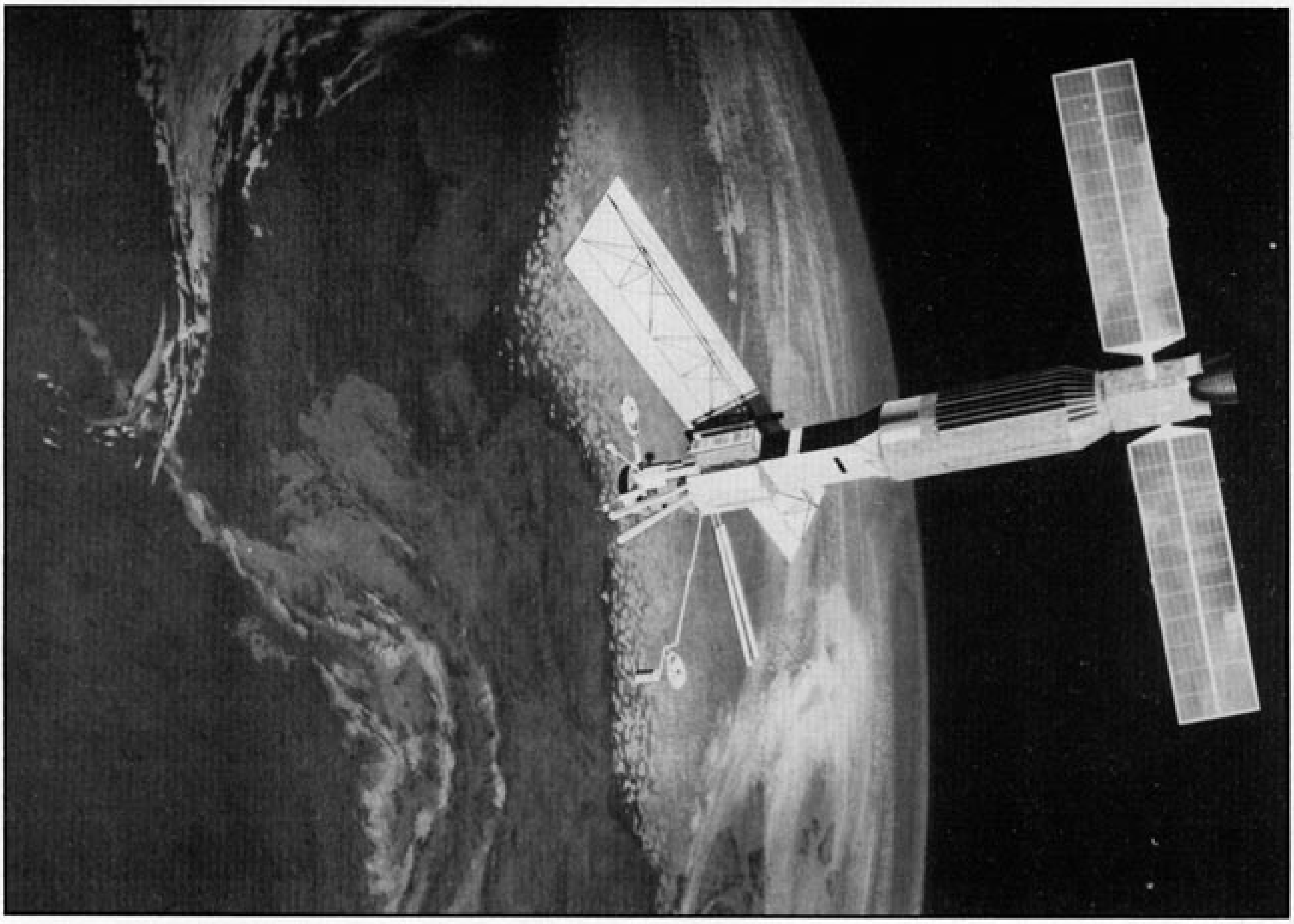

Fig. 5 An artist's concept of the Agena-based Seasat oceanographic satellite in orbit (NASA)

spacecraft generated complementary synthetic aperture radar images and radar altimetry measurements of the ocean surface during each 101 minute orbit. Wind speed, water vapour content and water temperatures were also recorded by the three microwave radiometer instruments [14].

Atlas 23F required a larger than usual number of modifications for the Seasat mission. General Dynamics removed the tapered forward tank section and replaced it with a 3.05 m constant diameter bulkhead like that of the Atlas-Centaur, with an interstage added to attach the Agena. Featuring an oversize payload fairing to improve aerodynamic performance, the 34.6 m Seasat Launch Vehicle System (fig 6) was the tallest Atlas E/F variant.

TABLE 7: *Seasat launch sequence(NASA)*

Event	Time after liftoff (seconds)
Liftoff	0
Booster engine cutoff (BECO)	129.5
Booster engine jettison	132.6
Fairing jettison	207.5
Sustainer engine cutoff (SECO)	284.4
Vernier engine cutoff	303.4
Satellite System (Seasat) separation	308.9
Fire Atlas retrorocket	309.4
Satellite System 90° roll start	318.4
90° roll stop	354.4
Agena first burn ignition	383.4
first burn shutdown	614.5
Agena second burn ignition	3,348.4
second burn shutdown	3,454.6

A Titan IIIB fairing matching the 3.05 m diameter of the Atlas replaced the PTS-type shroud that NASA initially intended to use for Seasat. Lockheed made the hardware available after completing a series of static load qualification tests for the new Titan IIIB 'Ascent Agena' configuration. The 10.2 m fairing was shortened from the original length of 18 m by removal of a structural segment that was damaged during the static testing. Lockheed also replaced the stiffening rings, field joints and separation system before delivering the shroud to NASA.

Use of the former test article saved the space agency about $800,000. Other cost saving efforts included modifying the spare P71-2 (Astex) equipment support structure for Seasat and employing a set of modified Midas (Project 461) solar arrays.

The Seasat launch was delayed three weeks beyond the original May 17, 1978 target date by a number of hardware anomalies. Problems were encountered with the spacecraft radar transmitter and the radio transponder, and extensive modifications were made in the booster section of the Atlas where a suspected hot gas leak in the sustainer engine caused overheating during the first two Navstar launches.

Several openings in the engine compartment were sealed to prevent the unrestricted flow of hot exhaust gasses, and additional temperature sensors were also installed. A number of electrical harnesses, hydraulic lines and vent lines were wrapped with additional insulation, and five aluminium drain lines were replaced with heat-resistant stainless steel tubing. Telemetry confirmed the effectiveness of the modifications, which were incorporated on all future Atlas E/F launches.

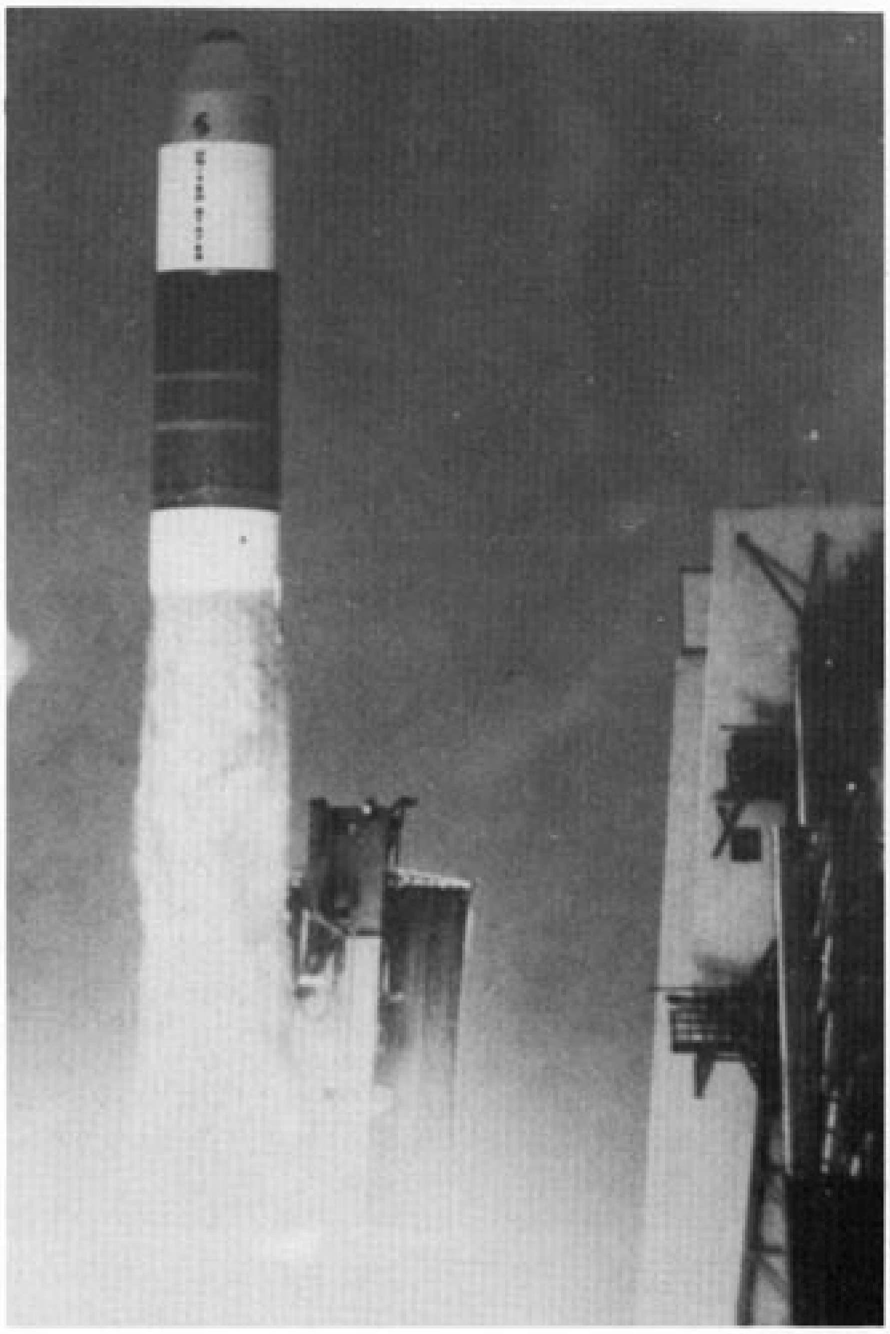

Fig. 6 Dominated by an oversize payload fairing, the 34.6 m Seasat launch vehicle was the tallest Atlas E/F variant. *(NASA)*

13. WEATHER SATELLITES ON ATLAS E/F

NASA procured seven additional Atlas E/F rockets from the Air Force to launch the fourth generation of civilian polar orbiting weather satellites. The first four spacecraft were known as the Tiros-N series and were directly derived from the Block 5D-1 weather satellites developed for the military by RCA Astro-Electronics (Section 13.1)

Each Tiros-N orbiter was 3.71 m long and 1.88 m in diameter with an on-orbit mass of 736 kg. An advanced Tiros-N (ATN) version was introduced by RCA in 1983 that was 45.7 cm longer than Tiros-N and weighed 1,030 kg in orbit. Each ATN platform carries the SARSAT search and rescue hardware in addition to the usual complement of environmental sensors.

The Atlas booster flew a 'direct ascent' trajectory to propel the payload to the planned apogee altitude some five minutes after sustainer cutoff. The orbit was circularised by the integral apogee kick stage, a TE-M-364-15 motor designated in the Integrated Spacecraft System (ISS).

Two separate ascent profiles were flown by the Tiros-N and ATN spacecraft. Sustainer engine cutoff was slightly earlier on ATN launches, and ignition of the ATN insertion motor occurred about three minutes later than with Tiros-N (Table 8). Stabilisation during the injection burn was maintained by onboard reaction control thrusters.

A PTS-type fairing protected Tiros-N and ATN during ascent (fig. 7). To accommodate the larger ATN spacecraft the

TABLE 8: *Tiros-N and ATN ascent profiles(NASA)*

Event	Time after liftoff (seconds)	
	Tiros-N	*ATN*
Liftoff	0	0
Booster engine cutoff (BECO)	121.0	121.5
Booster engine jettison	124.1	124.6
Fairing jettison	144.0	151.5
Sustainer engine cutoff (SECO)	324.5	320.9
Vernier engine cutoff	343.5	339.9
Spacecraft separation	349.5	345.9
Solid motor ignition	626.9	816.4
Solid motor burnout	670.4	860.0
Velocity trim start (onboard thrusters)	675.4	865.0

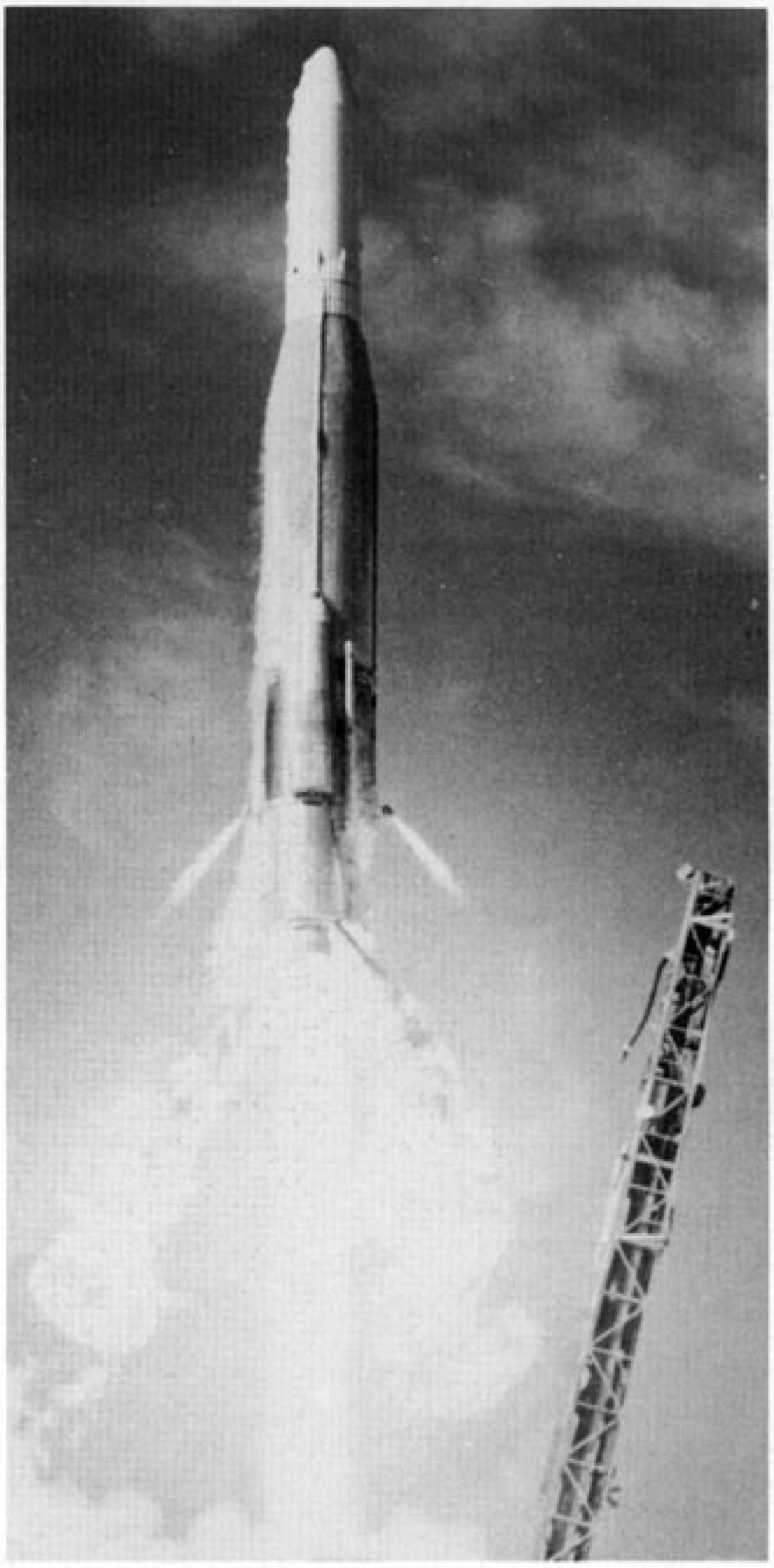

Fig. 7 The first ATN weather satellite ascends from SLC-3W at Vandenberg AFB on March 28, 1983. *(General Dynamics)*

6.9 m Tiros-N shroud was stretched to 7.4 m, increasing the length of the launch vehicle from 28.1 m to 28.65 m. The payload was mounted on a standard 1.29 m conical adapter section (fig. 8). Once in orbit the satellites are formally identified by the NOAA (National Oceanic and Atmospheric Administration) designation.

NOAA and military weather satellites operate in special near-polar 'Sun-synchronous' orbits. The rotation of the orbital plane due to the effect of the equatorial bulge of the Earth is about 1° per day, matching the rate at which the Earth travels around the Sun. This keeps the sun in the same position relative to the plane of the satellite's orbit so that solar illumination along the ground track always remains constant (except for brief periods of eclipse). To achieve this unique orbital geometry the launch vehicle must deliver the spacecraft to the right combination of altitude and orbital inclination. For an average altitude of 833 km the correct inclination of the orbit would be 98.7°.

After three successful launches (including Seasat) NASA suffered their first and only Atlas E/F failure on May 29, 1980. NOAA-B, the third of the Tiros-N series, limped into a useless 264 m x 1,465 km elliptical orbit after one of the booster thrust chambers delivered only 75% of nominal thrust (fig. 9). The deficiency was detected just six seconds after liftoff, and the sustainer engine was automatically commanded to burn an extra 56 seconds to compensate for the energy shortfall.

Unfortunately the extended burn overlapped the pre-programmed separation time, and thrusters aboard the spacecraft tried vainly to effect separation while the booster was still under power. The payload finally separated when the ISS motor ignited, but hydrazine and nitrogen thruster propellant was nearly depleted and the burn was made without attitude control. NOAA-B eventually decayed from orbit on May 3, 1981.

NASA was ready to expedite the launch of a replacement vehicle, but the older orbiters continued to operate and there was no gap in coverage prior to the arrival of NOAA-7 on-orbit in June 1981. In preparation for the transition of military 'metsats' to Atlas E/F (originally scheduled to occur in 1980), NOAA-7 carried a supplementary package of instruments from the USAF to monitor contamination effects during launch and orbital insertion. The NOAA-7 launch also aided a Boston University Observatory investigation into the 'ionospheric holes' phenomenon discovered during the May 1973 launch of the Skylab orbital workshop. Signals monitored from a communications satellite revealed that passage of the Atlas through the ionosphere depleted the local electron content by 60%. Visible manifestations of the event were photographed in the night airglow layer of the atmosphere with ground-based cameras located near Edwards AFB, California [15].

Getting two of the most recent ATN spacecraft into orbit proved to be no easy task for the Atlas launch crews. Due to a succession of minor problems the NOAA-9 spacecraft endured no less than 13 launch scrubs between the initial attempt on November 8, 1984 and liftoff on December 12, 1984.

NOAA-10 became only the second successful American launch attempt after the disastrous string of accidents in early 1986, but not before encountering a record 16 delays. Just prior to the original scheduled departure on June 20, 1986, a potential problem in a booster engine resulted in the Atlas being removed from SLC-3W for replacement of the suspect thrust chamber. Subsequent countdowns were scrubbed due to a combination of technical problems and scheduling difficulties with the Department of Defense.

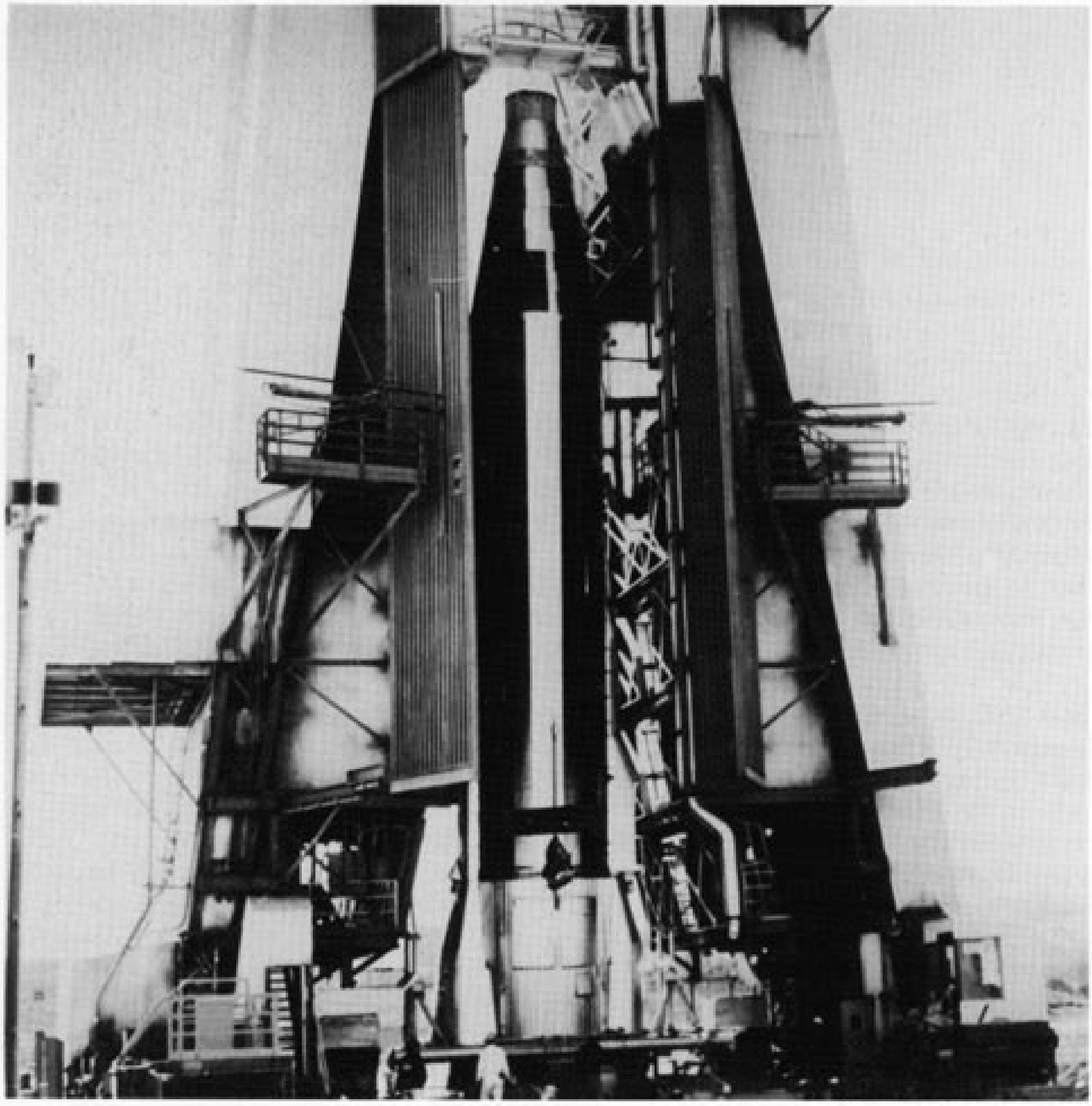

Fig. 8 The Atlas E/F rocket for the NOAA-6 weather satellite is enclosed by the service structure at SLC-3W prior to installation of the payload. (Note the curious and clumsy attempt to cover up what must be the serial number on the centre body of the rocket.) *(NASA)*

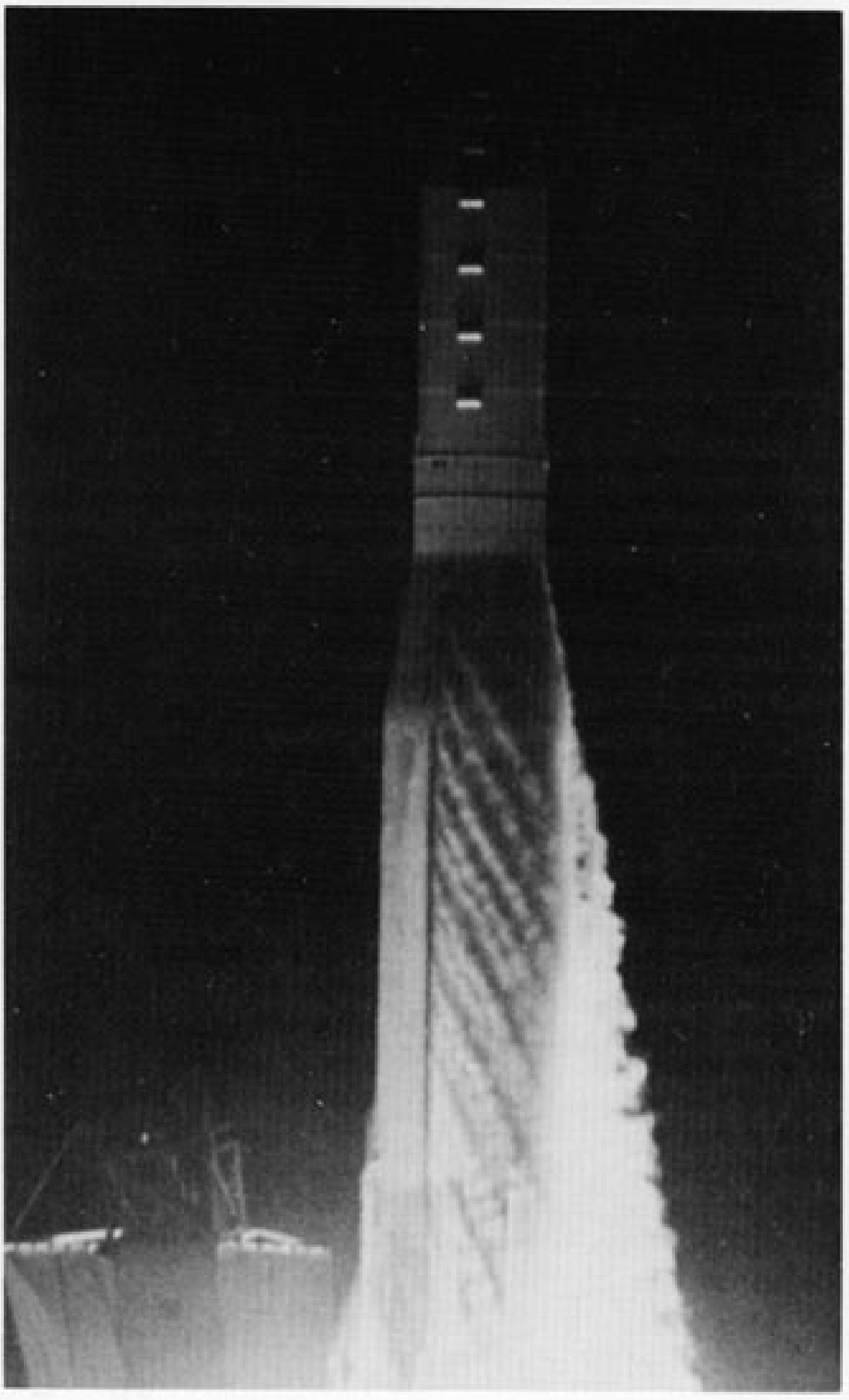

Fig. 9 Ill-fated launch of NOAA-B weather satellite on May 29, 1980. *(NASA)*

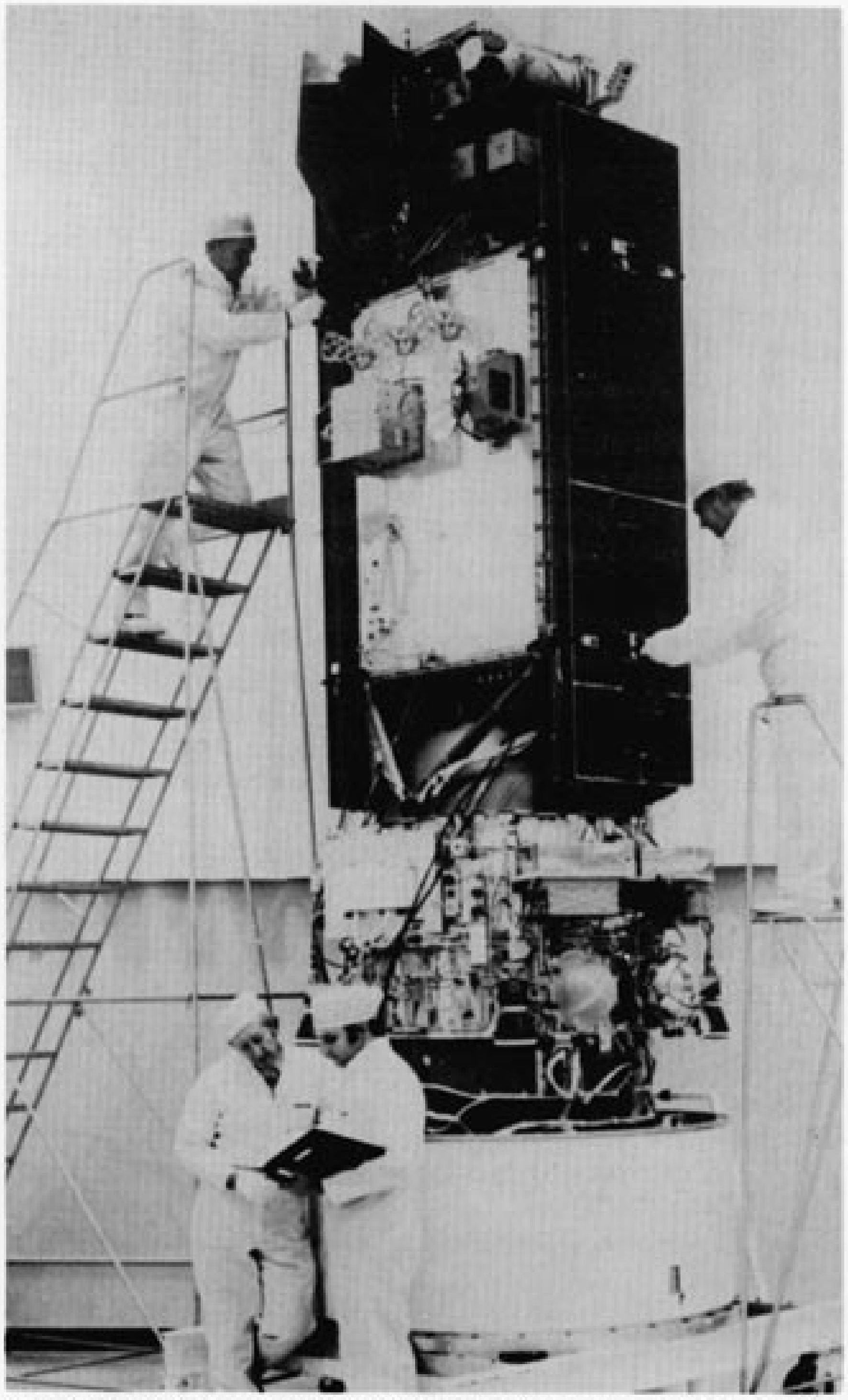

Fig. 10 The solid motor of the ISS upper stage can be glimpsed in the mid-section of this Block 5D-2 DMSP weather satellite. *(RCA Astro-Electronics)*

13.1 DMSP on Atlas E/F

When the Air Force developed an improved version of the Block 5D-1 Defense Meteorological Satellite Programme (DMSP) spacecraft in the late 1970s, the LV-2F Thor launch vehicle was replaced with the same 28.1 m Atlas E/F configuration used to orbit Tiros-N weather satellites. The integrated ISS motor from the NOAA orbiters was also incorporated in the Block 5D-2 design (fig. 10), replacing the two-stage ISS utilised on the Block 5D-1 version. The mass of the Block 5D-2 spacecraft in orbit is 824 kg.

Despite a close physical similarity to the NOAA satellites, DMSP is equipped with an entirely different array of environmental sensors. The primary instrument, the Operational Linescan System (OLS), produces images both in daylight and in darkness, whereas the NOAA Advanced Very High Resolution Radiometer (AVHRR) operates only in daylight conditions.

An experimental microwave sensor built by Hughes Aircraft Company was carried by the third Block 5D-2 vehicle launched in June 1987. Designated the Special Sensor Microwave Imager (SSM/I), the instrument is designed to produce images that reveal wind intensity within tropical storms and to detect the presence of rainfall over continental land masses.

14. ORBIT INSERTION SYSTEM

The Orbit Insertion System (fig. 3) was developed by Fairchild Space Company to carry two Department of Defense research satellites into medium altitude orbits. Incorporating the Star 27 solid rocket that previously served as the Navstar apogee kick motor, OIS stage provided the final push into orbit for the P78-1 satellite of the Space Test Programme and the 635 kg Geosat-A (Geodetic Satellite) payload for the US Navy. The 28.65 m OIS launch vehicle configuration was externally identical to the ATN weather satellites.

Seven astrophysical and space environment experiments were aboard the 868 kg P78-1 spacecraft launched in February 1979 [16]. After booster separation the OIS stage performed a 52° pitch manoeuvre to orient P78-1 for the burn, then spun-up the payload to 55 rpm. OIS imparted a Δv of 787 m/s to the spacecraft, which achieved a nominal 563 km x 604 km orbit angled 97.7° to the equator. P78-1 was destroyed during a controversial test of the air-launched ASAT (anti-satellite) weapon in september 1985.

Geosat-A (fig. 11) was engineered by the Applied Physics Laboratory (APL) at Johns Hopkins University to perform high resolution radar altimetry measurements of the Earth to im-

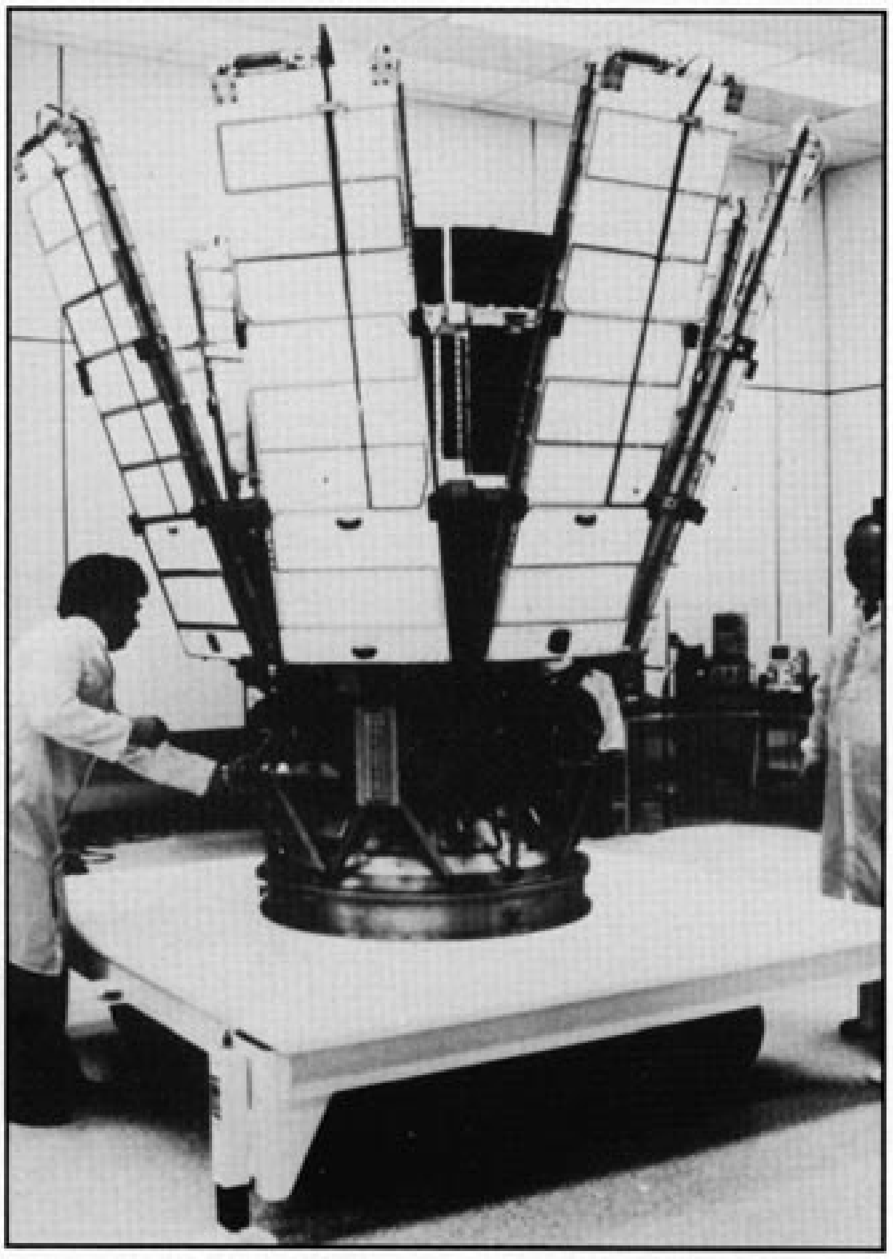

Fig. 11 Geosat-A spacecraft prior to being mated to the OIS upper-stage. *(DOD Still Media Depository)*

prove models of the maritime gravitational field. The 'pulse compression' radar installed aboard Geosat operates at a frequency of 13.5 GHz via a 1 m dish antenna [17]. The radar, otherwise identical to NASA's Seasat and GEOS-3 (1975-27A) systems, was fitted with a 20 W travelling wave tube amplifier to replace the original 2 KW amplifier that had a limited lifetime.

The orbit of Geosat was nearly identical to Seasat's with an equatorial inclination of 108° and a period to 100.7 minutes. The ground track of the orbit repeated once every three days with each equator crossing separated by exactly 18 km.

After completing the initial 18 month geodesy mission for the Navy, Geosat was manoeuvred into a new orbit in October 1986 to begin an unclassified programme of oceanographic research. The orbital track for the Exact Repeat Mission (ERM) was adjusted to repeat once every 17 days utilising Geosat's low impulse Freon-14 thrusters [18].

15. ATLAS H

In February 1983 the air Force quietly introduced a new model of Atlas to orbit the second group of Whitecloud ocean surveillance satellites. Atlas H was a modified version of the 20.1 m SLV-3D first stage of the NASA Atlas-Centaur launcher. Modifications included installation of the radio command guidance system from Atlas E/F and incorporation of a new tapered adapter section to mount the payload (fig. 12). The ISS-type integral upper-stage is believed to have been retained on the uprated Whiteclouds with the switch to Atlas H.

The new Atlas was also equipped with an uprated MA-5 propulsion system from the Atlas G-Centaur that developed 1,953 kN of thrust at liftoff, 31 kN more thrust than SLV-3D (Table 9). MA-5 engines are distinguished from MA-3 versions by the individual turbo-pumps provided for each engine and the single gas generator for the turbo machinery.

Umbilical connections and other vehicle interfaces at SLC-3E were modified for the exclusive use of the 27.4m Atlas H. In contrast to the classified nature of the payloads that were carried, the Atlas H programme was managed by the Atlas-Centaur office at NASA's Lewis Research Centre. Although each rocket performed flawlessly, no further procurement was planned beyond the five Whitecloud launches.

15.1 LIPS-II

An innovative supplementary payload accompanied the NOSS-5 spacecraft on the first Atlas H launch. LIPS-II, the 'Living Plume Shield' (1983-08B), was a $2 million subsatellite created by NRL engineers using the 1.8m x 0.1 m jettisonable shield that protected the spacecraft from the insertion motor exhaust plume [19].

Weighing only 59 kg, the annular-shaped payload carried a 'new type' of communications transponder and a panel of experimental US Air Force gallium arsenide (GaAs) solar cells [20]. A 15.2 m gravity gradient boom was deployed to provide attitude stabilisation. The LIPS-I payload is believed to have been lost in the NOSS-4 launch failure on December 8, 1980.

TABLE 9: MA-5 Propulsion System for Atlas H(NASA)

Engine, designation	Thrust kN	Nominal burn time (seconds)
Booster YLR89-NA-7	1,697	153
Sustainer YLR105-NA-7	267	284
Vernier (X2) YLR100-NA-15	4	284

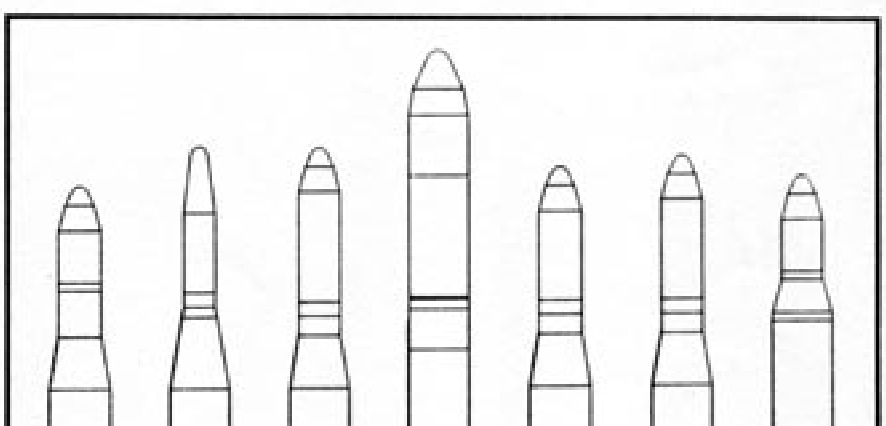

Fig. 12 "The Atlas E/F Pedigree" - Atlas E/F variants from left-to-right (length in parenthesis): OVI and Whitecloud (27.3 m); Burner II (28.9 m); PTS and SVS (29.2 m); Seasat (34.6 m); Tiros-N and DMSP (28.1 m); ATN and Geosat (28.65m); Atlas H (27.4 m).

(G.R. Richards)

16. CONCLUSION

Atlas E/F has achieved a reliability factor of 89% over the past two decades, registering only four failures in 39 launch attempts. Five additional launches with the new Atlas H rocket were also successful. With 5 flight-ready vehicles in storage at Vandenberg AFB, the workhorse Atlas E/F booster is assured of continuing in service well into the 1990s.

17. ACKNOWLEDGEMENTS

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