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General Accounting Office

Weather Satellite Costs Have Increased; Problems Have Occurred In Their Manufacturing Quality Control

The National Oceanic and Atmospheric Administration (NOAA) operates the nation's civilian weather satellite system. The cost of buying these satellites has risen steeply over the years and some of them have failed in orbit earlier than expected. This report discusses the reasons for increased satellite costs and failures and the actions taken by NOAA and its procurement agent, the National Aeronautics and Space Administration (NASA), to improve satellite performance. The report also discusses two problems with the manufacturing quality control of the weather satellites: contractors' installation in the satellites of parts not approved by NASA and a shortage of government quality control inspectors at some contractor plants during fiscal year 1984.

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RESOURCES, COMMUNITY,
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DIVISION

B-216229

The Honorable Jack Brooks
Chairman, Committee on
Government Operations
House of Representatives

The Honorable James H. Scheuer
Chairman, Subcommittee on
Natural Resources, Agriculture
Research, and Environment
Committee on Science and Technology
House of Representatives

Your August 1 and 2, 1984, letters expressed concern over the premature failure of two National Oceanic and Atmospheric Administration (NOAA) weather satellites and asked for a review of the weather satellite program. After discussions with your offices, we concentrated our review on recent satellite cost increases and two issues related to the manufacturing quality control of the satellites: the use by contractors of unapproved parts in the construction of the satellites and staffing of quality control inspectors at contractor plants. In addition, through meetings, we kept your staffs abreast of our review, briefing them on NOAA's procedures for planning and procuring satellites.

NOAA operates two geostationary weather satellites, providing continuous viewing of the United States and adjacent coastal waters, and two polar orbiting satellites, providing global coverage. The National Aeronautics and Space Administration (NASA) acts as the procurement agent for NOAA for the purchase of these satellites. Our review of this satellite program showed that

- --Inflation and the purchase of weather satellites in smaller quantities than had been previously bought contributed to sharply increased weather satellite costs in recent years.
- --Satellite manufacturers did not obtain NASA approval for all parts installed in satellites as they were required to do by contract. However, NASA analyses of the premature failure of satellites do not attribute failures to the use of these unapproved parts.

--NASA believes that too few government inspectors were located at some plants manufacturing weather satellites in fiscal year 1984.

INFLATION AND SMALL SCALE PURCHASES OF SATELLITES HAVE CONTRIBUTED TO INCREASING SATELLITE COSTS

NOAA purchased three geostationary satellites in 1977 for an average cost of $18.6 million per satellite and two more in 1982 for an average cost of $68.1 million. It paid an average of $17.9 million for eight polar orbiting satellites in 1975 and an average of $75.7 million for three more in 1983. Much of these increases is due to inflation in the aerospace industry, according to NOAA and NASA officials. But even after measuring the increases in constant dollars, the price of the satellites more than doubled between the earlier and later purchases. A major reason for this real dollar increase, according to NOAA and NASA officials, is the purchase of smaller numbers of satellites in the second of each of the above procurements. NOAA bought only two geostationary satellites in 1982 because it believed that it could not obtain budget authority for a larger purchase. It bought only three polar orbiting satellites in 1983 because it expected to have to redesign the satellites thereafter.

NOAA plans to take advantage of quantity discounts on its next procurement of geostationary satellites by contracting for three with an option for two more. NOAA's next procurement of polar orbiting satellites will be only a three-satellite purchase because it expects to use NASA's space station for polar orbiting coverage at the end of the operating lives of these satellites.

TWO QUALITY ASSURANCE PROBLEMS

NASA standards for the weather satellite program require that high quality, standard parts be used. As the procurement agent for NOAA, NASA is responsible for monitoring quality assurance at contractor plants and approving parts to be used in satellite components. Two Department of Defense agencies assist NASA in carrying out its responsibilities in these areas: the Air Force Plant Representative Office (AFPRO) and the Defense Contract Administration Service (DCAS).

Despite standards for quality and parts usage, the weather satellite program has experienced problems with quality control. For example, contractors used parts in polar orbiting and geostationary satellites that had not been approved by NASA for spaceflight. Manufacturers are required by contract to install in NOAA's weather satellites only parts from

NASA-approved parts lists. If they wish to use parts not on approved lists, contractors must submit evidence that the parts are suitable for spaceflight and obtain NASA approval. Contractors who built some geostationary and polar orbiting satellites installed unapproved parts without submitting the required evidence of suitability. However, NASA's analyses do not indicate that the use of unapproved parts caused the premature failure of any of the weather satellites.

Furthermore, in fiscal year 1984 AFPRO did not provide as many quality assurance inspectors as NASA believed necessary at the Hughes Aircraft Company and Santa Barbara Research Center manufacturing plants. NASA officials attributed staffing shortages to AFPRO's commitment to Defense projects and high turnover rates among inspectors.

Appendixes I and II provide additional information on these topics.

OBJECTIVES, SCOPE, AND METHODOLOGY

The objective of our review was to examine NOAA's policies and practices for planning and procuring its weather satellites, including quality assurance practices and the reasons for increasing weather satellite costs.

We performed work at NOAA, Department of Commerce, Department of Defense, Office of Management and Budget, and National Aeronautics and Space Administration/Goddard Space Flight Center. NOAA is an agency of the Department of Commerce.

To obtain information about the operational history and characteristics of the weather satellites, we interviewed NOAA's Assistant Administrator for the National Environmental Satellite, Data, and Information Service; the Chief of the Service's Systems Planning and Development Staff; and their staffs. We discussed procurement, quality assurance procedures, and the causes of satellite failures with these officials, the NASA Meteorological Satellite Project Manager and his staff, and other NASA officials responsible for weather satellite procurement, quality assurance, and parts assessment. We also met with representatives of Hughes Aircraft Company, Santa Barbara Research Center (a subsidiary of Hughes), and RCA to discuss quality assurance issues, the use of unapproved, nonstandard parts for building weather satellites, and the reasons for satellite failure. We discussed quality assurance and staffing with AFPRO and DCAS officials. We also reviewed NOAA and NASA reports on the causes of early satellite failure.

To obtain information on cost increases in NOAA's weather satellite program, we met with the Office of Management and

Budget examiner for the weather satellite program; the Chief and staff, Business and Environmental Programs Division, Department of Commerce; and NASA and NOAA budget and program officials. Using NOAA budget documents, we worked with NOAA officials to determine satellite and launch costs for previous and recent procurements. We discussed our results with NOAA budget and program officials and a NASA meteorological satellite deputy project manager to obtain explanations for cost increases. Our work on this assignment was done between September 1984 and April 1985.

Our work was performed in accordance with generally accepted government auditing standards. The views of directly responsible officials were sought during the course of our work and are incorporated in the report where appropriate. In accordance with your wishes, we did not request NOAA, NASA, or satellite manufacturers to review and comment officially on a draft of this report.

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As arranged with your offices, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of the report. At that time we will send copies to the appropriate House and Senate committees, Members of Congress, the heads of departments and agencies, and other interested parties.

J. Dexter Peach
Director

Contents

TABLES

ABBREVIATIONS

AFPRO	Air Force Plant Representative Office
DCAS	Defense Contract Administration Service
DOD	Department of Defense
FEI	Frequency Electronics, Inc.
GAO	General Accounting Office
GOES	geostationary operational environmental satellites

NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NSC	National Security Council
NSPAR	Nonstandard Parts Approval Request
OMB	Office of Management and Budget
RCED	Resources, Community, and Economic Development Division
SBRC	Santa Barbara Research Center

WEATHER SATELLITE COSTS HAVE INCREASED; PROBLEMS HAVE OCCURRED IN THEIR MANUFACTURING QUALITY CONTROL

ORGANIZATION AND HISTORY OF NOAA's WEATHER SATELLITE PROGRAM

Satellites have been used for observing weather since April 1, 1960, when the National Aeronautics and Space Administration (NASA) launched the first meteorological satellite to provide photographs of the earth and clouds. The weather satellites provide information for use in daily weather forecasts, storm warnings, and research. The system evolved to a four-satellite configuration of two geostationary operational environmental satellites (GOES) and two polar orbiting (NOAA) satellites.

Operation, management, and procurement

The National Oceanic and Atmospheric Administration (NOAA) is responsible for operating and managing the weather satellite system. NASA, under a 1973 agreement with NOAA, is responsible for procuring and launching the satellites. NOAA determines program requirements; obtains funding for establishing and operating its satellites; approves procurement plans; monitors system performance; and disseminates and archives data, forecasts, and analyses. NASA designs, engineers, and procures the weather satellites; contracts with the Air Force Plant Representative Office (AFPRO) or Defense Contract Administration Service (DCAS) for quality assurance monitoring at contractor and subcontractor plants; procures launch vehicles; arranges for satellite launches; and monitors the satellites during their initial phases in orbit. NOAA reimburses NASA for its services.

Geostationary satellites

NOAA's goal is to maintain two fully operational GOES for continuous viewing of U.S. weather. These satellites orbit over the equator at the same rate that the earth turns so that they are always above the same spots on the earth's surface. One satellite orbits east of the United States to monitor North and South America and parts of the Atlantic Ocean. The other satellite orbits west of the United States and views North America and parts of the Pacific Ocean basin. The GOES carry imaging instruments[1] that provide day and night pictures of clouds. Other instruments measure the earth's magnetic field and space radiation and relay weather and other environmental data from one ground location to another. Because they provide a continuous view of weather, the satellites are especially valuable for detecting and tracking severe weather, such as hurricanes and local storms. They are also useful in detecting and tracking tropical cyclones, estimating rainfall amounts for flash flood warnings, and monitoring freezing surface temperatures for fruit frost predictions. Images from the GOES are broadcast to a NOAA-operated ground station, usually every 30 minutes. They provide the pictures of weather patterns seen on television weather broadcasts. Japan, India, and the European Space Agency (a consortium of 11 European countries) also operate geostationary weather satellites. According to a NOAA official, the Soviet Union plans to launch this type of satellite in the near future.

NOAA purchased two prototypes and eight GOES under four different contracts: two with Philco-Ford (later changed to Ford Aerospace) and two with Hughes Aircraft Company. Ford built the two prototype satellites, launched in 1974 and 1975, and GOES-1. Ford also built GOES-2 and -3. Hughes built GOES-4, -5, and -6 and is currently building GOES-G and -H, which will be called GOES-7 and -8 after they are successfully launched.[2] All GOES since GOES-1 were designed to last 5 years in orbit.

Operational history of GOES

Technical breakdowns have plagued the GOES. As table I.1 shows, four of the six GOES launched thus far have not reached their 5-year lifetimes. Three of the four failures (GOES-2, -3, and -5) occurred because a tungsten filament bulb essential for producing and encoding weather images burned out prematurely. The bulb performed well on GOES-1, and by the time the problem was apparent on GOES-2, GOES-3 had been launched, and it was not feasible to modify GOES-4, which had been fully assembled. The

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[1]The Visible-Infrared Spin-Scan Radiometer Atmospheric Sounder scans the earth and gathers images in reflected visible light and in infrared thermal radiation. This instrument is built by the Santa Barbara Research Center, a subsidiary of Hughes Aircraft Company.

[2]Geostationary satellites are initially given alphabetical designations. After being launched successfully they are referred to numerically. For example, GOES-E was designated GOES-5 after it was successfully launched.

bulb's operating voltage was lowered on GOES-5 in an attempt to increase its life, but it also burned out early--after 3 years.[3] GOES-6, which was launched April 28, 1983, had major modifications to correct the problem at an estimated cost of $700,000. NOAA and Hughes officials told us that they suspected that the bulbs burned out prematurely because of imperfections in the tungsten used in making filaments for the bulbs and because some bulbs were improperly sealed. The bulbs were made by a small company several steps down the contracting chain from Hughes. NOAA officials told us that larger companies, such as General Electric and Westinghouse, were not interested in producing the bulb in the required small quantities. Hughes has sought to improve the bulbs' reliability on GOES-6 and GOES-G and -H by performing some of the steps involved in the bulbs' manufacture itself and by installing more backup bulbs in these satellites. According to NOAA officials, these changes should prevent future premature failures. GOES to be built after GOES-H will have electronic encoding devices instead of the optical encoders (bulbs) used previously.

An open circuit in a printed wiring board located in the power system of GOES-4's imaging instrument caused the early failure of this satellite. According to NASA and Hughes officials, the board would have had to be destroyed to detect the fault that occurred. Hughes modified the board on later satellites to make faults less likely.

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[3]As a result of the early failures of GOES-4, and -5, according to NOAA officials Hughes did not receive more than $5 million in incentive fees that it would have earned if the satellites had been fully operational for a 7-year period.

Table I.1: Geostationary Satellite Lifetimes

Satellite	Date launched	Date operational[a]	Date failed	Operating life	Cause of failure
GOES-1	10/16/75	1/08/76	b		imaging instrument (bulb)
GOES-2	6/16/77	8/15/77	1/26/79	1 year, 5 months	imaging instrument (bulb)
GOES-3	6/16/78	7/13/78	3/5/81	2 years, 8 months	imaging instrument (bulb)
GOES-4	9/9/80	10/15/80	11/26/82	2 years, 1 month	imaging instrument (printed wiring board)
GOES-5	5/22/81	8/05/81	7/29/84	3 years	imaging instrument (bulb)
GOES-6	4/28/83	6/01/83		still operational	

[a]After the satellites are launched, numerous engineering evaluations must be completed before the first operational data is received from the satellite.

[b]GOES-1 was taken out of service in 1977 when it was replaced by GOES-2. It was reactivated from April 4, 1978, to July 13, 1978, to replace a prototype satellite; from November 29, 1982, to June 1, 1983, to replace GOES-4; and from August 23, 1984, to February 3, 1985, to replace GOES-5. GOES-1 capabilities were partially degraded in March 1979 when it lost its ability to take pictures at night, but the satellite did not fail completely until February 3, 1985, when daytime imaging capability also failed.

Currently, GOES-6 is the only fully operating geostationary weather satellite. GOES-G is expected to be ready for launch in May 1986 and GOES-H in August 1986. NOAA officials believe that the improvements made to these satellites should enable them to reach their 5-year lifetimes. However, they acknowledge possible future gaps in coverage if GOES-6 fails prematurely, if the GOES-G and -H launch vehicles fail, or if GOES-G or -H fails prematurely in orbit.

NOAA is currently negotiating a contract with Ford Aerospace for the manufacture of three redesigned GOES (GOES-I, -J, and -K) with an option to purchase two more (GOES-L and -M). If funding is approved by the Congress for the five-satellite purchase, NOAA plans to keep a backup GOES in orbit to ensure continuous two-satellite coverage. NOAA officials were uncertain whether GOES-K would be launched into orbit as a backup for GOES-I and -J if Congress approved the purchase of only three satellites. The planned launch schedule[4] for this next generation of GOES is as follows:

Table I.2: Launch Schedule for Next Generation of GOES

Satellite	Launch date
GOES-I	1990
GOES-J	1990
GOES-K	1991
GOES-L	1994
GOES-M	1994

Polar orbiting satellites

NOAA's polar orbiting satellites are the latest in a series that began in the early 1960's. Satellites of the current generation, first launched in 1978, include TIROS-N, the prototype, and seven other satellites ordered from RCA

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[4]NOAA's geostationary satellite system consists of two in-orbit satellites. NOAA wanted a third in-orbit backup satellite, but because of the lack of money this was not achieved. Thus, NOAA tries to be ready to launch replacement satellites when a major system, such as the imaging instrument, fails. To fill gaps in coverage, NOAA moves working satellites to provide coverage where it is needed. For example, when GOES-5, which provided coverage of the eastern United States and Atlantic Ocean, failed prematurely in July 1984, NOAA moved GOES-6 east to partially compensate for the loss. Since GOES-1 was still partially operational, it was also used to help cover the gap left by GOES-5 until GOES-1 failed in February 1985. NOAA can move up a launch date if a satellite in orbit starts to malfunction and can delay launch if a satellite continues to work properly beyond its expected lifetime.

Corporation (RCA). Six of the seven satellites[5] have already been built and one is being manufactured. NOAA ordered three more satellites from RCA in 1983, designated NOAA-H, -I, and -J.

Unlike GOES that orbit over the equator providing regional coverage, NOAA's polar orbiting satellites circle the globe passing over the North and South Poles, each covering the earth twice daily. These satellites make measurements of temperature and humidity in the earth's atmosphere, surface temperature, cloud cover, and water-ice boundaries. The satellites can receive, process, and retransmit data from balloons, buoys, and other platforms located anywhere on the earth's surface. Because their sensors yield more detailed data than the GOES, and because of their globe circling orbit, polar satellites are the principal source of environmental data for the 80 percent of the globe that is not covered by conventional data gathering, such as weather balloons. They broadcast weather information to 120 countries worldwide. The Soviet Union is the only other nation which operates polar orbiting weather satellites.

NOAA-8 and NOAA-9 also carry search and rescue equipment capable of relaying distress signals to ground stations from airplanes and ships.

Operational history of polar orbiting satellites

NOAA has successfully launched five of the TIROS-N generation of polar orbiting satellites. As table I.3 indicates, the 2-year lifetime[6] of these satellites has been met or exceeded with the exception of NOAA-8, which stopped operating after 1 year of service but is now partially operational. NOAA procured all TIROS-N satellites from RCA on a

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[5]These satellites, designated NOAA-A to NOAA-G before launch, were to have been numbered NOAA-6 to NOAA-12 after successful launch. However, NOAA-B was not numbered because it never achieved orbit and NOAA-D has not been launched. Therefore, the current generation of satellites actually orbited includes TIROS-N and NOAA-6 to NOAA-9. NOAA-G, the last of the series, is being assembled.

[6]According to a NOAA official, polar orbiting satellites have many more mechanical parts that can fail than geostationary satellites. These parts, which include tape recorders, momentum wheels, and gyroscopes, are expected to wear out after short periods, limiting the lifetimes of polar satellites to only 2 years compared to 5-year lifetimes for geostationary satellites.

sole-source basis because their design is similar to the Air Force's polar orbiting satellites, also developed and built by RCA.[7] NOAA awarded contracts for the TIROS-N/NOAA 6-12 satellites in 1975 and for three follow-on satellites (NOAA-H, -I, and -J) in August 1983.

Service from NOAA-8 was lost in June 1984 when a timing device essential for control of the satellite malfunctioned, for reasons that are not fully known. The satellite contained a backup timing device, which should have taken over the functions of the primary device, but the automatic switch on board the satellite did not fully activate the backup. In July 1985, after several months of effort, engineers from RCA, NOAA, and NASA were able to restore NOAA-8 to partial service. NOAA hopes to avoid a repetition of this problem by redesigning future polar orbiting satellites so that operations can be transferred from the primary to the backup timer by ground command.

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[7]As a result of a 1973 study regarding the feasibility of better coordinating the Air Force and NOAA systems, the Office of Management and Budget (OMB) directed NOAA to base its design of the TIROS-N/NOAA A-G satellites on the design used by the Air Force. In addition, the two agencies were directed to coordinate future efforts for new satellite designs.

Table I.3: Polar Satellite Lifetimes

Satellite	Date launched	Date operational[a]	Date failed	Operating life	Cause of failure
TIROS-N	10/13/78	11/1/78	2/27/81	2 years, 3 months	lost attitude control
NOAA-6 (A)	6/27/79	7/16/79	10/22/83	4 years, 3 months	sounder[b]
NOAA-B	5/29/80				launch vehicle failed, did not achieve orbit
NOAA-7 (C)	6/23/81	8/24/81	2/7/85	3 years, 5 months	sounder[b]
NOAA-D					in storage[c]
NOAA-8 (E)	3/28/83	6/20/83		partially operational	
NOAA-9 (F)	12/12/84	2/25/85		still operational	

[a]After the satellites are launched, numerous engineering evaluations must be completed before the first operational data is received from the satellite.

[b]The sensors on NOAA-6 and NOAA-7 that provide visual images are still operating. The instruments that provide numerical data on atmospheric conditions (referred to as sounders) have failed.

[c]NOAA-D is expected to be launched in November 1988.

RCA is currently building three more polar orbiting satellites (NOAA-H, -I, and -J), and NOAA plans to issue a contract solicitation later this year for NOAA-K, -L, and -M. In addition, NOAA intends to launch NOAA-D in 1988. These seven satellites are expected to provide two-satellite coverage until the end of 1993. Thereafter, NOAA intends to use a portion of the planned manned space station system[8] for its polar orbiting sensors. Continuous two-satellite coverage until the space station is available depends on the satellites achieving their designed lifetimes and on the timely completion of the space station.

The following table shows the planned launch dates of the remaining polar orbiting satellites.[9]

Table I.4: Launch Schedule for NOAA's Polar Orbiting Weather Satellites

Satellite	Launch date
NOAA-G	November 1985
NOAA-H	October 1987
NOAA-D	November 1988
NOAA-I	January 1989
NOAA-J	November 1989
NOAA-K	January 1991
NOAA-L	November 1991
NOAA-M	January 1993

Convergence of NOAA and Air Force satellites

The Air Force also operates two polar orbiting weather satellites. According to NOAA officials, these satellites as currently configured would not be an adequate substitute if NOAA's own polar satellites failed, because their temperature readings are less accurate at lower levels in the atmosphere. Additionally, Air Force and NOAA officials said that the Air Force does not replace its satellites if the instruments that

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[8]In response to President Reagan's January 25, 1984, state of the union address directing NASA to develop a permanently manned space station within a decade, NASA developed a plan for a station to be launched in 1993. One of the planned elements of the station will provide the scientific community with an astronaut-tended vantage point for monitoring the earth's atmosphere, oceans, land masses, and space environment using remote sensing instruments. According to NOAA officials, estimated cost of the space platforms is unavailable.

[9]NOAA's polar orbiting satellite system consists of one satellite with another one in orbit for backup. NOAA launches a replacement when a satellite loses its sounding capabilities --the polar satellites' primary mission.

take soundings (the sensors of primary value to NOAA) fail, because the primary mission of the Air Force satellite is to take pictures of cloud cover. During the 1970's two studies were done to assess the possibility of converging NOAA's and the Air Force's systems.

In 1973 OMB and the National Security Council (NSC) reported the results of a study examining the possible convergence of NOAA's and the Air Force's polar orbiting weather satellites and the impact on national space policies. The study concluded that while potential economies could be gained by integrating the two systems, they should remain separate because of national and international concerns. However, OMB directed NOAA and the Air Force to use common satellites and sensors to the extent possible. As a result NOAA switched from a single, high altitude (1690 kilometers) satellite to a lower altitude (850 kilometers) two-satellite system permitting the use of a common satellite shell. Sensors remained separate because of the different data requirements of NOAA and military users.

In conformance with Presidential Directive NSC-42, dated October 11, 1978, another interagency study was made of options for integrating weather systems into a national system and of the effect this would have on national space policies. Led by the Office of Science and Technology, OMB, and NSC, other participants included NOAA, NASA, the Department of Defense (DOD), the Department of State, and user agencies. Policy decisions resulting from this study (articulated in Presidential Directive 54, dated October 16, 1979) confirmed the decisions reached in the 1973 study that although some savings might be achieved by further integrating NOAA's and the Air Force's polar orbiting systems, the potential savings did not outweigh the resulting technical and service problems and the negative impact on U.S. national and foreign policies. However, OMB directed the two agencies to coordinate future efforts for new satellite design and development.

INFLATION AND SMALL SCALE PURCHASES OF SATELLITES HAVE CONTRIBUTED TO INCREASING SATELLITE COSTS

The costs of procuring satellites have risen sharply in recent years. The average cost of a GOES increased by 266 percent between 1977, when the GOES-4, -5, and -6 contract was signed, and 1982, when GOES-G and -H were contracted. The average cost of a polar orbiting satellite increased 323 percent between 1975, when NOAA contracted for TIROS-N/NOAA 6-12, and 1983, when it awarded a contract for NOAA-H, -I, and -J. Part of this increase can be accounted for by inflation in the aerospace industry (see app. II), but according to NOAA and NASA officials some of it is attributable to the purchase of satellites in smaller quantities.

For example, NOAA's average costs for each of the satellites purchased in the eight-satellite TIROS-N/NOAA 6-12 procurement were $17.9 million. When NOAA ordered three additional satellites (NOAA-H, -I, and -J), cost per satellite was $75.7 million, a 323-percent increase. Even after adjusting the increase to account for inflation, the average cost of a satellite increased 160 percent between the two procurements. One of the main reasons for the 323-percent increase, accounting for between 25 percent to 40 percent of the increase, according to NOAA and NASA officials, was the smaller number of satellites purchased under the second procurement. NOAA officials said that contractors can build large numbers of satellites at lower average cost by ordering satellite parts in larger volumes and by spreading start-up and other fixed costs more efficiently.

NOAA officials told us that they bought only three satellites under the NOAA-H, -I, and -J contract because they believed that future satellites would have to be redesigned for a space shuttle (rather than rocket) launch.[10] As indicated above, NOAA's next purchase of polar orbiting satellites (NOAA-K, -L, and -M) will also be a group of three, because it expects to be able to use the space station for future polar orbiting sensors. According to a NOAA official, NOAA-K, -L, and -M will probably be launched by shuttle.

NOAA purchased five geostationary satellites for service in the 1980's, the first three (GOES-4, -5, and -6) in 1977 and two additional satellites (GOES-G and -H) in 1982. The last two satellites cost about $68.1 million each or about 4 times more per satellite than the first three. According to NOAA officials, there were several reasons for the increased costs, including inflation, the purchase of the last two satellites on a sole-source basis,[11] and the fact that Hughes was unable to completely consolidate the production of GOES-4, -5, and -6 with work on Japanese geostationary weather satellites of similar

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[10]According to NOAA officials, as of August 1985, a decision on whether to launch NOAA-H, -I, and -J by shuttle or rocket had not yet been made.

[11]Because of the premature failure of earlier GOES, NOAA wanted replacements available as soon as possible. NOAA believed that it could not take the extra time for a competitive procurement.

design. But officials also acknowledge that the smaller purchase added to the increase in the average cost of GOES-G and -H (see app. II). Hughes offered to build a third satellite for $49.6 million--$18.5 million below the average cost of GOES-G and -H, but NOAA believed that because of an austere budget climate, it could not obtain budget authorization for the third satellite.[12]

NOAA hopes to achieve economies of scale on its next GOES procurement. It is currently negotiating with Ford Aerospace for the purchase of three GOES, with an option for two more. The cost savings possible from buying large quantities are illustrated by NASA's estimates of what the first three satellites and the two optional satellites should cost. NASA cost estimators calculated that the first three satellites should cost $367 million (about $122 million per satellite) and the additional two $187 million (about $93 million per satellite).

TWO QUALITY CONTROL PROBLEMS: USE OF UNAPPROVED PARTS AND SHORTAGE OF QUALITY CONTROL PERSONNEL

Our review showed that two problems occurred in the quality control of weather satellite manufacturing. First, both polar orbiting and geostationary satellites were built with unapproved parts. Second, during construction of GOES-G and -H in fiscal year 1984, Department of Defense agencies, which inspect the quality of weather satellite manufacturers' work at their plants, did not provide the number of quality control personnel that NASA officials believed were needed to ensure reliable production of GOES. As the procurement agent for NOAA, NASA is responsible for monitoring quality assurance at the contractor's plant and approving parts to be used on weather satellites. Reviews of premature satellite failures made by NOAA, NASA, and contractors have not identified unapproved parts as a cause of failure.

NASA requires contractors to use standard parts

NASA contracts for the manufacture of weather satellites require that the satellites be built with parts that meet DOD or NASA standards. DOD standards, set forth in Military

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[12]The circumstances surrounding this purchase are discussed in our report entitled Reasons for Lack of Replacement for Failed Weather Satellite (GAO/RCED-84-198, Aug. 31, 1984).

Standard-975, classify parts into two levels of quality: grade one are "higher quality" and grade two are "high quality." NASA requires the use of grade one parts in its GOES and polar satellite projects. Grade one parts, and parts listed in the Goddard Space Flight Center Preferred Parts List, which supplements Military Standard-975, are standard. All standard parts are approved parts that can be used for the two projects. Nonstandard parts do not meet project requirements; however, they can be approved for use on GOES and polar weather satellites by qualification.

Nonstandard parts
approval request process

According to a NASA flight assurance manager, contractors are required to spell out specifications for product control requirements in their responses to NASA's requests for proposals. Included in the requirements are procedures for submitting and approving Nonstandard Parts Approval Requests (NSPAR) for nonstandard parts. The manager said that the procedures are negotiable; however, when signed by both parties, they become part of the procurement contract. The contracts for GOES-4, -5, and -6 and GOES-G and -H; TIROS-N/NOAA 6-12; and NOAA-H, -I, and -J required manufacturers to obtain NASA approval of nonstandard parts. According to NASA officials, the contractor pays no penalty for using unapproved, nonstandard parts.

NASA approves nonstandard parts through its NSPAR process. Requirements for approval vary somewhat from contract to contract, but the following procedures, which are contained in the contract for GOES-G and -H, illustrate the process.

The process requires that contractors provide NASA with a request 5 working days prior to adding a nonstandard part to its parts list. After preliminary approval by NASA, the contractor is authorized to buy and use the part unless NASA objects. The contractor's Parts Materials and Process Control Board initiates a NSPAR by authorizing preparation of a new part specification if necessary. The board also reviews new part specifications for completeness of content, including performance, reliability, and quality assurance requirements. A copy of the specification is forwarded to NASA for informal review and comments. The board also reviews and approves the proposed basis for parts qualification (i.e., hours of testing) and test plans. Meanwhile, the contractor must test the nonstandard part to determine whether it meets project standards. Qualification of all parts must be supported by valid test data and experience.

After compiling and reviewing all documentation required for the NSPAR, the board gives its approval. NSPARs for each nonstandard part approved by the board are submitted to NASA for review within 10 working days of final board approval. NASA must complete its review within 30 calendar days of receipt. Once a nonstandard part is tested, approved, and used, it can be used in subsequent satellites without revalidation. Contractors are forced to submit NSPARs when previously approved parts are no longer available.

Contractors do not always obtain required qualification of nonstandard parts

RCA used unapproved, nonstandard parts for NOAA's TIROS-N/NOAA 6-12 polar orbiting satellites. NASA was unaware that these parts were used when it accepted the satellites for launch, because it did not review the parts lists that a subcontractor used for the project.[13] NASA has recently improved parts control by requiring RCA, which is now manufacturing replacement satellites for TIROS-N/NOAA 6-12, to submit subcontractor parts lists for review.

NASA learned that a subcontractor used unapproved parts when it investigated the malfunction of NOAA-8. When NOAA-8 failed prematurely in June 1984, NASA asked RCA to submit the parts lists used in the component that caused the failure. An RCA subcontractor, Frequency Electronics, Inc. (FEI), of New Hyde Park, New York, used parts on the lists for the manufacture of TIROS-N/NOAA 6-12. The lists, dated April 1976, contained about 11 unapproved parts. This discovery caused NASA to examine the parts FEI planned to use in polar orbiting satellites now being manufactured (NOAA-H, -I, and -J). NASA found that unapproved parts were also on the new parts lists. FEI officials believed that since the parts were on the parts lists for TIROS-N/NOAA 6-12, they were approved for NOAA-H, -I, and -J also. At NASA's request RCA is requiring FEI to submit NSPARs for these parts. According to NASA officials, the

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[13] NASA officials are uncertain about why parts lists were not reviewed. They believe that since NOAA was directed by OMB to use the Air Force design for TIROS-N/NOAA 6-12, NASA did not receive the parts lists. An Air Force representative located at RCA told us that he could not determine whether the Air Force had a parts review and test requirement during the period when the first TIROS-N satellites were built. The representative said that records dating back that far were not retained. According to the representative, the Air Force now has standards for parts approval.

component on NOAA-8 that malfunctioned contained unapproved parts. We asked RCA officials why unapproved parts were used but did not receive an explanation.

Hughes used unapproved, nonstandard parts during the manufacture of GOES-4, -5, and -6, but with NASA's knowledge. According to Meteorological Satellite Project officials, although NASA was aware that these parts were on the satellites, it had to accept the unapproved parts or delay satellite launches because Hughes had not submitted NSPARs. For example, in November 1978 NASA's Flight Assurance Manager for GOES pointed out in status reports that NSPARs had not been submitted nor NASA approval given for nearly 100 parts Hughes planned to use on GOES-4, -5, and -6. In February 1980 the manager reported that Hughes did not submit adequately documented parts approval requests, which resulted in some 70 parts being installed in satellite hardware that had not received NASA approval. GOES-4 was launched on September 9, 1980, with unapproved parts on board. A NASA flight assurance manager said that GOES-5 and GOES-6 were launched with unapproved parts also.

NASA officials told us that even before GOES-4 was launched, the agency was working with Hughes to clear up the parts problem. However, the NSPAR problem has continued during the current Hughes contract for GOES-G and -H. In April 1985 51 parts for GOES-G and -H still required NSPARs. In May NASA officials told us that about 80 percent of GOES-G was complete, and it was very likely the 51 parts were already in the satellites. According to the parts engineer, this condition remained the same as late as August. GOES-G is scheduled to be launched in May 1986. The Meteorological Satellite Deputy Project Manager, whose office is responsible for deciding whether to launch the satellites, said that, as was the case with GOES-4, -5, and -6, if the satellite is finished with unapproved parts enclosed, NASA may be faced with the problem of deciding whether to delay the launch, incurring more expense, or to launch with the unapproved parts. NASA officials said that they need to decide whether to stop satellite production until all nonstandard parts are tested and approved or continue production with the unapproved parts. They said that in some cases testing and getting NSPARs approved could take more than a year.

Shortage of quality assurance staff at contractor facilities

NASA assigns quality assurance representatives to some contractor facilities to oversee quality assurance during satellite manufacturing and to advise the flight assurance manager located at the Goddard Space Flight Center. NASA has a representative at the Hughes and RCA facilities. The Hughes representative also monitors activities at the Santa Barbara Research Center (SBRC), a Hughes subsidiary that makes the primary GOES sensor. Since NASA does not have enough representatives to fully monitor quality assurance activities, it has agreements with AFPRO and DCAS to provide monitoring assistance. AFPRO was responsible for quality assurance monitoring at both Hughes and SBRC until August 1984 when DCAS assumed these duties at SBRC. DCAS is also responsible for work at the RCA plant in Hightstown, New Jersey.

According to NASA's inplant representative at Hughes, AFPRO staffed about two persons below its commitment levels during fiscal year 1984 at Hughes and SBRC. For example, during October 1983 staffing was 3.75 persons below a commitment of 5 persons. In July 1984 staffing was 2.70 persons short. In a September 1984 letter to AFPRO, the NASA inplant representative stated that understaffing on the GOES project had been pointed out several times during the previous year and that memorandums, meetings, and telephone conversations had been exchanged; but the situation had not been remedied. AFPRO responded in September that it had provided five people to the GOES program between November 1983 and March 1984. AFPRO said that additional personnel would be used as necessary to fulfill AFPRO responsibilities. When we visited the Hughes plant in February 1985, the NASA representative told us that AFPRO staffing levels were adequate. By that time manufacturing activity on GOES-G was declining, thus requiring less AFPRO support. NASA officials told us that staffing shortages are attributed to AFPRO's commitment to Defense projects and the high turnover rate among inspectors. According to the NASA representative at RCA, DCAS staffing was adequate at the RCA plant when we visited it in January 1985.

INCREASING SATELLITE COSTS

As indicated in appendix I, NOAA bought GOES under four contracts. The third contract was for three satellites (GOES-4, -5, and -6); the fourth for two (GOES-G and -H). On the basis of cost figures provided by NOAA, we analyzed NOAA's actual and expected expenditures for the third and fourth contracts to determine the average price of a satellite under each. We found that even after allowing for inflation, the average cost of a satellite and launch increased 117 percent, from $56.2 million to $122 million (in 1985 dollars adjusted to eliminate the effect of aerospace inflation) (see table II.1).

According to NOAA officials, the increase is due to the fact that Hughes was able to consolidate the production of GOES-4, -5, and -6 (but not GOES-G and -H) with work on Japanese geostationary weather satellites of similar design and to the inefficiencies of buying parts for two satellites instead of three or more. The officials also said that the costs for the GOES-G and -H launches increased primarily because of increased fees NOAA pays for maintenance and readiness of the Delta rocket launch facility at Kennedy Space Flight Center. In the past NOAA had shared these costs with NASA, but since NASA has stopped using the Delta facility, NOAA now has to pay to keep it open. In addition, GOES-G and -H were purchased on a sole-source basis, while GOES-4, -5, and -6 were purchased through a competitive procurement.

We did a similar analysis of cost increases for the 10 polar orbiting satellites NOAA purchased from RCA. These satellites were purchased under two contracts. The first, signed in 1975, was for eight satellites, one of which NASA paid for (TIROS-N) and seven of which NOAA paid for (NOAA 6-12). The second, signed in 1983, was for three satellites (NOAA-H, -I, and -J) all paid for by NOAA. The average cost per satellite for manufacture and launch increased 125 percent from $44.1 million to $99.2 million from the first to the second contract, also in 1985 inflation-adjusted dollars (see table II.1).

One of the main reasons for this increase, according to NOAA and NASA officials, is that the first contract included eight satellites while the second included only three. Because the contractor could not purchase parts in large, economic quantities or set up a production line stretching over a long period, costs increased between 25 percent and 40 percent, according to the officials. The officials also cited costs for new instruments on the second contract. However, NASA figures show NOAA's total cost for the instruments to be added to the satellites is about $8.4 million (in 1985 dollars). In addition, NOAA officials said the cost of some satellite equipment escalated at a faster rate than aerospace inflation. Finally, they said that NOAA will pay additional costs for launch vehicle testing and for user fees associated with maintaining exclusive launch readiness capability.

NOAA and NASA officials could not assign dollar figures to many of the reasons (sole-source procurement, absence of other work at contract plants, etc.) they gave for the increases in satellite costs.

Table II.1
Estimates of NOAA's Average Unit Cost for Weather Satellites[a]
($ millions)

Geostationary satellites	Actual year dollars[b]	1985 adjusted dollars[c]
GOES-4, -5, -6		
Spacecraft	$ 18.6	$ 30.4
Launch	19.1	25.8
Total	$ 37.7	$ 56.2
GOES-G, -H		
Spacecraft	$ 68.1	$ 72.0
Launch	49.7	50.0
Total	$117.8	$122.0
Percent increase from GOES-4, -5, -6 to GOES-G, -H		
Spacecraft	266%	137%
Launch	160%	94%
Combined	212%	117%
Polar satellites		
NOAA 6-12		
Spacecraft	$ 17.9	$ 29.5
Launch	11.8	14.6
Total	$ 29.7	$ 44.1
NOAA-H, -I, -J		
Spacecraft	$ 75.7	$ 76.8
Launch	24.9	22.3
Total	$100.6	$ 99.2[d]

	Actual year dollars[b]	1985 adjusted dollars[c]
Percent increase from NOAA 6-12 to NOAA-H, -I, -J		
Spacecraft	323%	160%
Launch	111%	53%
Combined	239%	125%

[a]Estimates include only costs paid by NOAA and are based on actual spacecraft and launch appropriations from fiscal years 1975 to 1985 and on NOAA budget estimates for future years.

[b]Actual year dollars represent past or expected expenditures without accounting for inflation.

[c]Amounts in this column have been adjusted to eliminate the effect of inflation in the aerospace industry. The adjustment was made using composite federal price deflators for the aerospace industry published by the Bureau of Economic Analysis, Department of Commerce. Deflator rates for 1984-85 are estimates and an inflation rate of 5 percent was assumed for 1986 and beyond.

[d]Total does not add due to rounding.

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