Space TECHNICAL INFORMATION DIGEST

SPACE SYSTEMS INFORMATION BRANCH, GEORGE C. MARSHALL SPACE FLIGHT CENTER

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SCIENTISTS DEMONSTRATE CONTROL OF SOLID ROCKET MOTORS.

Space scientists at Lockheed Propulsion Company have announced the achievement of controlled extinction of a burning solid-propellant rocket motor. This had been done four times at the time of the announcement.

For many years it has been commonly believed by all but a few rocket experts that a solid propellant motor, once ignited, would continue to burn and to consume all the propellant. This belief has limited the vistas of solid fuel adherents because it has been taken for granted that solids cannot be stopped, restarted, or thrust-modulated. But a team of NASA, military, and industry specialists have continued their attempts to solve the problem.

The rocket firm has completed a research program demonstrating the practicality of stopping the burning of a solid rocket motor on command, both at sea level and at high altitude. In the most recent firings, they successfully demonstrated permanent, immediate extinction at a simulated altitude of 46,000 m (150,000 ft) of two 270-kg (600-lb) thrust motors loaded with high-energy Polycarbutene propellant containing a high percentage of aluminum.

Figure 1 illustrates an unfired solid motor (left) and a motor (right) after extinction. The firings were conducted at the Company's Rye Canyon Research Center, in a huge 18 x 7.5 x 5.5 m (60 x 25 x 18 ft) altitude chamber capable of testing a complete fighter aircraft or a transport section. The complex includes altitude chambers that can duplicate the vacuum existing 700 km (435 mi) above the Earth. Its hypervelocity wind tunnels can reproduce speeds up to 44,000 km/hr (27,000 mi/hr).

Four earlier firings were conducted at ambient atmospheric pressure. Two of these tests resulted in permanent extinction; in the other two, the rocket flame was shut down temporarily and then rekindled.

"Flame extinction at both sea level and altitude was accomplished without use of a secondary agent," a company scientist said. "Less than one millisecond elapsed between the command and extinction." He explained that creation of an expansion wave causes a sudden and rapid drop in the motor's chamber pressure that permits quenching of the flame.

For some years propulsion men have been able to terminate thrust of a solid rocket motor with great precision by venting off combustion gases in a forward direction to neutralize the thrust effect. However, the propellant has continued burning until it was fully consumed, and there has been no feasible way to save a portion of it for a second burning period. (Source: Data supplied by Lockheed Propulsion Co., Lockheed Aircraft Corp.)

PENDULUM TESTS APOLLO. A giant four-armed pendulum now helps check out early models of NASA's three-man Apollo spacecraft (Fig. 2). The space-age steel impact test structure, 44.5 m (143 ft) high, is the latest NASA facility placed in operation at North American Aviation's Space and Information Systems Division.

The pendulum, which supports 10 tons in motion while in operation, swings the 3850-kg (8500-lb), full-scale, instrumented Apollo spacecrafts at controlled speeds and angles, dropping them into a water tank or a special land impact

FIG. 1

Fig. 2

area. Apollo is designed to land on ground or water, using three giant parachutes for soft landing.

Numerous Apollo drop tests are scheduled for the pendulum. Some are for the study of how water impact affects the spacecraft's dynamic stability, crew system response, and how well crew couches absorb impact. Information obtained from instruments contained within the spacecraft is relayed and recorded on oscillographs and magnetic tapes for scientific evaluation. The information is being used to confirm and define the design for the crew couches and to determine how other spacecraft equipment will withstand the shock imposed in landing. (Source: Data supplied by North American Aviation, Inc.)

CHARGE DRAG STUDIED ON ORBITING DIPOLE. Six dipoles, fabricated from 430-μ-diam tin wire, were placed in an Earth orbit from a parent satellite in 1962 to determine what effect charge drag would have on the over-all drag of such objects in space. The 34-cm (13-in.) long dipoles, with a diam of 0.043 cm (0.017 in.), were injected in a near-polar, near-circular orbit that averaged 3100 km (1900 mi) in height.

Observations by radar at the Moorestown, N. J., RCA facility over a two-month period indicated that the dipoles, which were continuously in sunlight, experienced a decrease in mean altitude of less than 0.3 km (0.19 mi) per year because of charge drag. As no systematic change in mean altitude is distinct from experimental results, the actual drag resulting from the satellite's net electrical charge interacting with its plasma environmnent may be far less than the experiment shows.

By using an approximate scaling law, scientists found that the corresponding upper bound on the altitude decrease of the dipoles is about 90 km/yr (56 mi/yr). Additional assumptions concerning the plasma led to the establishment of a 0.6-v upper limit for the average electrostatical potential of the dipoles during the experiment. This 0.6-v charge would lead to the 0.3 km/yr (0.19 mi/yr) decrease observed above. (Source: Journal of Geophysical Research, April 1, 1963)

NEW SOLAR TELESCOPE PLANNED. A new solar vacuum telescope to be built at the Air Force Cambridge Research Laboratory, Sacramento Peak Solar Observatory site in Sunspot, New Mexico, is planned by the Laboratories.

Design concepts for the telescope were established by AFCRL scientist, Dr. Richard Dunn. The unique telescope will have a total vertical length of 100 m (328 ft), of which 61 m (200 ft) will be beneath ground level. This basic configuration suggested by Dr. Dunn is subject to modification on the basis of the detailed engineering and design study to be conducted by Charles W. Jones Engineering of Los Angeles. The above-ground segment will rise 39 m (128 ft) above the highest hilltop at AFCRL's existing Sacramento Peak Observatory, which is situated at an altitude of 2800 m (9200 ft) in the Sacramento Mountains in New Mexico. With the completion of the new telescope the Sacramento Peak Observatory, already a major solar research center, will become one of the most complete facilities in the world for the study of solar phenomena.

Plans call for the completion of the new telescope before the next period of maximum sunspot activity. Following a normal 11-year cycle, sunspot activity, presently low, will begin to increase in 1965, and will reach maximum intensity by 1970.

The new facility is closely linked to the nation's space programs. Of prime concern are high-energy proton showers associated with sunspot activities. These showers provide a great potential hazard to man in space and degrade electronic equipment. The study of characteristic features on the surface of the Sun giving rise to these showers will receive special emphasis. From these studies, AFCRL scientists hope to extend the period over which they can predict the onset of proton showers. Prediction at the present time can be made with considerable accuracy over a five-day period.

The exposed, above-ground portion of the telescope will consist of a truncated cone-shaped tower and associated laboratory buildings. Atop the tower will be a rotating turret for tracking the Sun in elevation and azimuth. Light from the Sun will pass through a quartz window having a 76-cm (30-in.) aperture onto flat mirrors mounted in the turret. The mirrors will direct the light down a long 98-m (320-ft) tube to a spherical mirror at the bottom where it will be redirected upward to any one of five observation ports in the associated ground facilities.

Two design features should give the telescope exceptional flexibility and resolution. The first is in the mounting of the optical system. The entire optical system, including the 98-m (320-ft) interior tube and associated instrumentation, will rotate as the Sun is tracked. This system will weigh approximately 150 to 200 tons.

The second feature is that the optical system and associated instruments will be placed in a vacuum. The purpose of the vacuum is to eliminate air turbulence. Turbulence can greatly affect the resolution of the telescope. An added advantage of the vacuum is the elimination of dust from optical surfaces that would degrade resolution and sensitivity.

In addition to research leading to the more precise prediction of dangerous proton showers, the new telescope will be used for research on a range of solar phenomena. Solar activities have a profound effect on the Earth's weather, and on communication and detection systems. AFCRL scientists hope to obtain a clearer picture of solar-terrestrial relationships. (Source: OAR Research Review, May 6, 1963)

NEW TECHNIQUE PROMISES COMPACT, HIGH-SPEED MEMORY DEVICE. A new magnetic memory device that resembles a miniature waffle iron in appearance has been developed at Bell Telephone Laboratories (Fig. 3). It has one of the shortest storage paths for a single bit of any magnetic memory device; the structure is extremely compact, and can operate at high speed on low input power.

The new memory will be particularly useful for large-capacity, economical stores operating at read-write cycles of less than a μ sec. It looks promising for computers and switching systems that now use ferrite cores and thin films.

The basic "waffle-iron" device consists of a base plate made of a high permeability ferrite in which a grid of slots is cut, leaving a regular array of rectangular posts. This gives the surface the appearance of a miniature waffle iron.

Preprinted wiring patterns, a set for the read-write and a set for the digit-sense wires, are placed in the slots. An overlay of square-loop magnetic material (such as a type of permalloy) is laid across the tops of the posts.

Information is stored in the overlay material between the posts in the direction of magnetization of the magnetic flux. The width of a slot is the effective length of the magnetic path in the storage material. The high permeability base and the square-loop material connecting a pair of posts form a closed magnetic flux path. One type of waffle-iron memory has posts 100 mils long and 30 mils wide and a slot width of 30 mils (1 mil = 0.0254 mm or 0.001 in.).

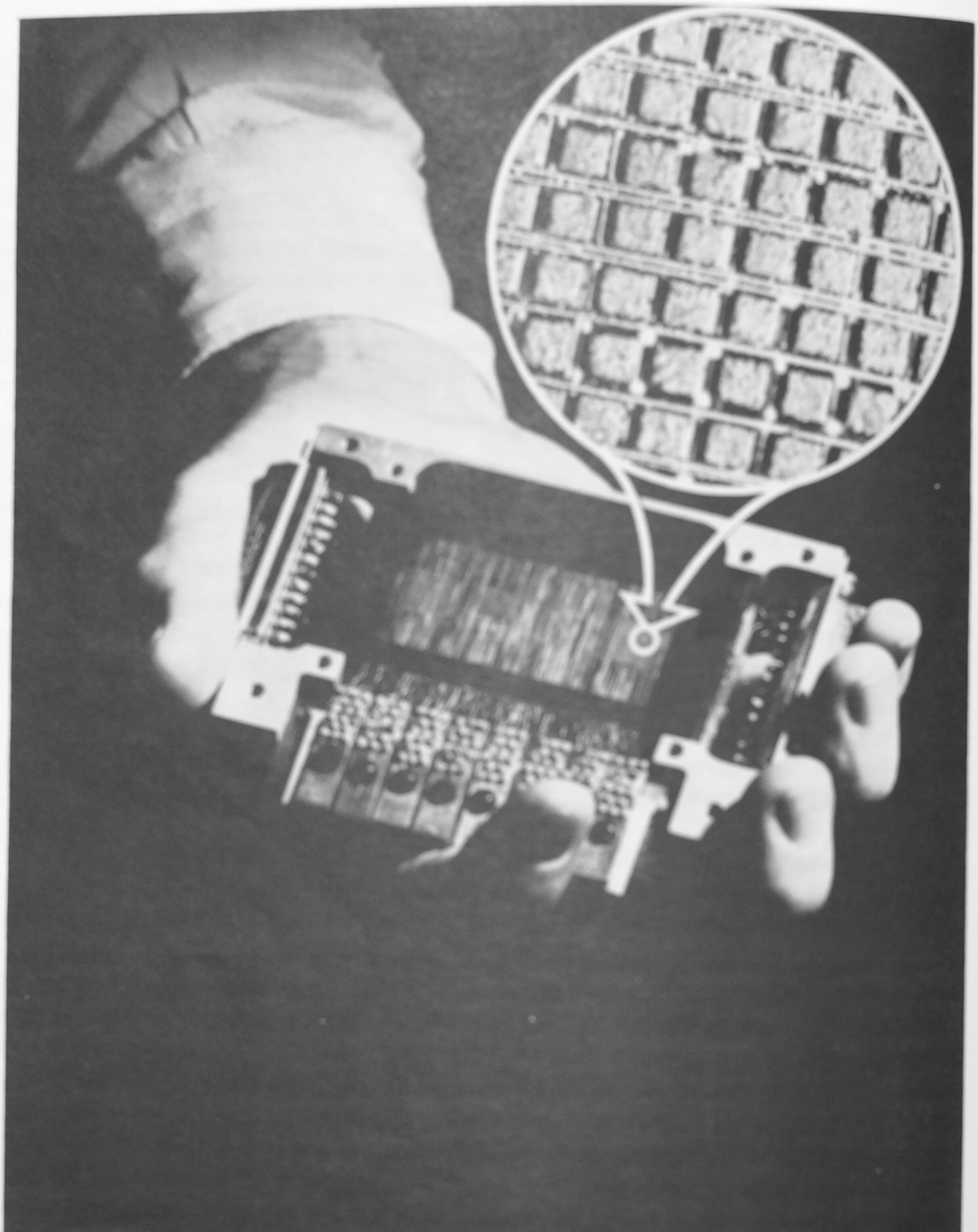

Fig. 3

Both destructive and nondestructive waffle-iron memories have been built. Destructive memories use an overlay of a single magnetic material; non-destructive memories use an overlay of two magnetic materials -- one for storage and the other for sensing. When a nondestructive memory is read, only the sensing material is switched; thus the memory can be interrogated indefinitely without affecting the stored information.

Another form of waffle-iron memory, called the cubic, has been developed in the company's laboratories. The cubic structure allows both the selection and sense wires to follow straight paths instead of weaving around the posts as in the other waffle-iron memory. Also, because these wires cross each other at right angles, a pulse traveling down one wire will not induce appreciable current in the order, thus improving the signal-to-noise ratio. The cubic waffle iron memory has a very fast read-write cycle; it can be made very small and can be assembled simply.

One experimental memory matrix of the cubic type has a capacity of 128 words, allowing 30 bits per word. It has a read-write cycle time as fast as 200 nanosec. The highly polished ferrite base plate used in this design is slotted to form a grid of 5-mil slots, each 10 mils deep, and each spaced 15 mils apart. This matrix has a storage density of 1100 bits/6.45 cm^2 (1100 bits/in^2). The 5-mil slot width, combined with an overlay material that has a high switching threshold, gives fast switching with modest currents. (Source: Data supplied by Bell Telephone Laboratories)

ATLAS MISSILE PERFORMANCE SUMMARIZED. The evolution from the first Atlas ballistic missile that was unsuccessfully fired June 11, 1957, to the Atlas 21-F is the result of research and development in all phases of the missile system. The Atlas test program, reviewed in Aviation Week (February 25, 1963) by George Alexander, enumerates these important advances: (1) 0.032-in. airframe, basically a stainless steel balloon relying on gas pressure for rigidity; (2) contaminant control in liquid oxygen systems; (3) early exploration of problems in staging: timing, hardware clearances, shifting center of gravity, flight control response and adaptability; and (4) handling of liquid oxygen to reduce geysering by using last-moment slug-filling to load the tanks. Of 87 research and development Atlas vehicles, 10 were classified as failures and 18 as partial successes.

The following charts, compiled from information in Mr. Alexander's article, illustrate the differences in each series and the development of the Atlas system.

ATLAS A SERIES

SUCCESSES	12-A, Dec. 17, 1957 10-A, Jan. 10, 1958 11-A, Feb. 20, 1958 16-A, Jun. 3, 1958
FAILURES	4-A, Jun. 11, 1957 6-A, Sep. 25, 1957 13-A, Feb. 7, 1958 15-A, Apr. 5, 1958
ACHIEVEMENTS	Violent maneuvers of 4-A and 6-A in uncontrolled flight before their destruction by range safety officer did not deform the airframe, proving its durability far in excess of design specifications. Aerodynamic heating caused circuits in the vernier engines to fuse and then short; resultant voltage surges rendered the flight control system inoperative, remedied by covering the 1000-lb thrust engine with heat-resistant fairings. Resonant coupling of the missile's autopilot with the bending frequencies of the vibrating airframe was solved by adding a filter to the autopilot. At low pressures of high altitudes, the lubrication oil in the booster turbopump gearbox bubbled off; the reservoir was subsequently pressurized.
BOOSTER ENGINE	MA-1 engines, producing 150,000 lb thrust each, were used. The boosters shared a common pump and lines.
ACCURACY & GUIDANCE SYSTEM	A radio guidance system was flown open-loop (flown and operated aboard the missile though not actually controlling the flight) on the last two Atlas As.
LIQUID OXYGEN HANDLING	Topping method was used: liquid oxygen pumped aboard Atlas at about 30,000 gpm, allowing chill-down of both the ground system and the missile; several hundred pounds of the cryogenic oxidizer added to the tank's normal flight load of 160,000 lb are supercooled below the liquid's nominal -297F, lowering the temperature of the entire liquid oxygen mass and reducing boil-off of the oxidant from its liquid to its gaseous state.

ATLAS B SERIES

SUCCESSES	4-B, Aug. 2, 1958 5-B, Aug. 28, 1958 8-B, Sep. 14, 1958 12-B, Nov. 28, 1958 10-B, Dec. 18, 1958 (Project Score) 11-B, Feb. 4, 1959
PARTIAL SUCCESSES	9-B, Nov. 17, 1958 13-B, Jan. 15, 1959
FAILURES	3-B, July 19, 1958 6-B, Sep. 18, 1958
ACHIEVEMENTS	The discovery that helium pressurizing gas plus the oxygen boil-off maintained sufficient in-flight pressure eliminated the use of supplementary tank pressurization system.
BOOSTER ENGINE	MA-2 engines, producing 155,000 lb thrust each, were used. The booster shared a common pump and lines.
ACCURACY & GUIDANCE SYSTEM	Initial Mod-1 GE-Burroughs guidance system was tested. The radio guidance system consisted of pulse-type tracking radar, rate transmitter and four rate receivers in an X-shaped configuration. The Mod-2 featured some minor improvements. The system was flown partially closed-loop (did not generate steering commands but otherwise operated normally in sequencing engine operations, flight controls, etc.) on the first two Bs and completely closed-loop (system controlled flight completely) on the rest of the Bs.
LIQUID OXYGEN HANDLING	The topping method was used.

ATLAS C SERIES

SUCCESSES	3-C, Dec. 23, 1958 8-C, Jul. 21, 1959 11-C, Aug. 24, 1959
PARTIAL SUCCESSES	4-C, Jan. 21, 1959 7-C, Mar. 18, 1959
FAILURES	5-C, Feb. 20, 1959
ACHIEVEMENTS	C-missiles were the first to be made of 0.020 to 0.040-in. thick stock, at one time the planned design of the weapon's airframe. To accommodate the various density of fuel loads, the common bulkhead, separating the oxidizer and fuel tank volumes, was positioned higher than necessary. When a better quality control of RP-1 kerosene fuel was achieved, the bulkhead was lowered 27 in. and the relative proportions of oxidizer and fuel changed--increasing the former and decreasing the latter. The approximately 4-in. wide baffles were the final configuration, established as a series of 12 rings spaced logarithmically from bottom to top inside the oxygen tank. To prevent vortices and sloshing, the liquid oxygen tank contains a unit in the bottom, and the fuel tank contains a perforated plate in the conical aft end. 11-C carried a 16-mm movie camera in its nose cone and returned the first films taken of Earth from a 700-mi altitude. 8-C flew the first ablative reentry vehicle.
BOOSTER ENGINE	The MA-2 engines, producing 155,000 lb of thrust, shared a common pump and line.
ACCURACY & GUIDANCE SYSTEM	Mod-3 system used only two rate receivers laid out at right angles to each other from the centrally positioned radar and transmitter. Pulse radar, which had a higher pulse repetition frequency than in earlier versions, gave position, range and elevation data on the Atlas. Rate system gave range, range-rate and velocity data through phase shift measurements. The radio guidance system was flown completely closed loop (system controlled flight completely) and proved that the Atlas could be flown close to populated areas with safety.
LIQUID OXYGEN HANDLING	The topping method was used.

ATLAS D SERIES

SUCCESSES	11-D, Jul. 8, 1959 14-D, Aug. 11, 1959 17-D, Sep. 15, 1959 18-D, Oct. 6, 1959 22-D, Oct. 9, 1959 26-D, Oct. 29, 1959 28-D, Nov. 4, 1959 15-D, Nov. 24, 1959 31-D, Dec. 8, 1959 40-D, Dec. 18, 1959 43-D, Jan. 6, 1960 44-D, Jan. 26, 1960 49-D, Feb. 11, 1960 42-D, Mar. 8, 1960 56-D, May 20, 1960 54-D, Jun. 11, 1960 62-D, Jun. 22, 1960 27-D, Jun. 27, 1960 60-D, Jul. 2, 1960 32-D, Aug. 9, 1960 66-D, Aug. 12, 1960 76-D, Sep. 16, 1960 79-D, Sep. 19, 1960 71-D, Oct. 13, 1960 55-D, Oct. 22, 1960 83-D, Nov. 15, 1960 90-D, Jan. 23, 1961
PARTIAL SUCCESSES	7-D, May 18, 1959 5-D, Jun. 6, 1959
FAILURES	3-D, Apr. 14, 1959 51-D, Mar. 10, 1960 48-D, Apr. 7, 1960
ACHIEVEMENTS	The weapon was declared operational after the successful launching and 4500-naut-mi flight into the Pacific of 12-D, conducted by a SAC crew. Weight of the airframe and of all airborne systems was reduced beyond the original design when the A, B, and C series revealed that these improvements could be made safely. This over-all improvement, plus improvements in the Rocketdyne engines, was translated into greater range and heavier warheads. Strategic Air Command crews have launched 29 Atlases in training exercises with 20 successes, 5 partial successes, and 4 failures.
BOOSTER ENGINE	The MA-2 engine, producing 155, 000 lb of thrust was used. The booster shared a common pump and lines.
ACCURACY & GUIDANCE SYSTEM	Seven Atlas Ds (42-D, 28-D, 54-D, 60-D, 66-D, 76-D, & 71-D) flew the Arma all-inertial guidance system for evaluation purposes preparatory to E-series testing. The radio guidance system conducted the first flight open- and the last six closed-loop; D missiles struck within 1 naut mi of targets with a frequency above 80%.
LIQUID OXYGEN HANDLING	The topping method was used.

ATLAS E SERIES

SUCCESSES	9-E, Feb. 24, 1961 12-E, May 12, 1961 18-E, May 26, 1961 22-E, Jul. 6, 1961 21-E, Jul. 31, 1961 25-E, Oct. 2, 1961 30-E, Oct. 5, 1961 35-E, Dec. 1, 1961 36-E, Dec. 19, 1961 40-E, Feb.13, 1962
PARTIAL SUCCESSES	3-E, Oct. 11, 1960 4-E, Nov. 29, 1960 8-E, Jan. 24, 1961 13-E, Mar. 13, 1961 16-E, Mar. 24, 1961 26-E, Sep. 8, 1961
FAILURES	17-E, Jun. 22, 1961 32-E, Nov. 10, 1961
ACHIEVEMENTS	E-series was the first Atlas to carry the square autopilot instead of the round units flown until then. So-called because of the external configuration of their enclosing canisters, the square unit was miniaturized and mostly solid state; the round autopilot included a number of vacuum tubes. Because the hydraulic fluid was leaking from the poppet (rise-off valve) during the booster operation, leaving no hydraulic fluid to drive the sustainer around its gimbal block when BECO occurred, a unidirectional-flow valve was placed upstream of the poppet, and additional insulation was wrapped around hydraulic lines.
BOOSTER ENGINE	First Atlas series powered by Rocketdyne MA-3 propulsion system, producing 165,000 lb of thrust and contained separate and independent turbopump and propellant-feed lines and were designed for greater accessibility and maintainability. The series had no rough combustion cutoff (RCC) device as was used on research and development vehicles.
ACCURACY & GUIDANCE SYSTEM	Guided by American Bosch Arma Corp. all inertial system, the series landed within 1.5 naut mi of Atlantic Missile Range targets about 80% of the time.
LIQUID OXYGEN HANDLING	Slug-filling method was used: rapid transfer of liquid oxygen from storage tanks into the missile by helium under high pressure, waiting until the last practical moment in the countdown. Chill-down times and boil-off are reduced considerably, and geysering is reduced.

ATLAS F SERIES

SUCCESSES	2-F, Aug. 8, 1961 4-F, Nov. 22, 1961 7-F, Aug. 13, 1962	8-F, Sep. 19, 1962 14-F, Oct. 19, 1962 16-F, Nov. 7, 1962 21-F, Dec. 5, 1962
PARTIAL SUCCESSES	5-F, Dec. 8, 1961	6-F, Dec. 20, 1961
FAILURES	11-F, Apr. 9, 1962	
ACHIEVEMENTS	This series was emplaced in a concrete silo and raised to the surface by elevator for launching, which was the only difference between it and the E-series.	
BOOSTER ENGINE	The MA-3, producing 165,000 lb of thrust, was used. Each engine had separate and independent turbopumps and propellant-feed lines.	
ACCURACY & GUIDANCE SYSTEM	The all-inertial system, landing within 1.5 naut mi of Atlantic Missile Range targets about 80% of time, controlled the flight.	
LIQUID OXYGEN HANDLING	Slug-filling method was used.	

HISTORY OF ATLAS TESTING BY SERIES

SERIES	A	B	C	D	E	F
RESULTS	4 successes 4 failures	6 successes 2 partial successes 2 failures	3 successes 2 partial successes 1 failure	27 successes 2 partial successes 3 failures	10 successes 6 partial successes 2 failures	7 successes 2 partial successes 1 failure
OBJECTIVES	Over-all performance & compatibility of the booster engines, auto-pilot system & airframe, including the pneumatic, hydraulic, & electrical systems.	Test performance of 3-engine propulsion system & boosters; Evaluate nose cone separation mechanism; Determine performance of radio command guidance; Evaluate experimental monopropellant accessory power supply package.	Demonstration of both GE guidance system's accuracy & reliability, & the accuracy of range safety procedure & equipment.	*	*	*
RANGE	600 naut mi	6 programed 2400-3100 naut mi 2 programed 5500 naut mi	3800-4300 naut mi	average programed 5500 naut mi		
ACHIEVEMENTS	Pressurization in the oil reservoir; Aerodynamic heating problem solved; Proved airframe could withstand more dynamic forces than specified.	Development of in-flight tank pressurization system.	Proved Atlas could be flown close to populated areas with safety; Anti-slosh baffles in propellants tanks; Lighter gage airframe skin; Readjustment of the oxidizer-fuel proportions.	Weight of airframe & airborne system reduced; Seven Ds flew the Arma all-inertial guidance system; Used to train SAC crews; Weapon declared operational.	First Atlas to carry square autopilot; Solved problem in hydraulic flight control system; First Atlas powered by Rocketdyne MA-3 propulsion system.	Series launched from concrete silos.

*Testing of System as Complete Entity, Including Ground-based Elements.

TECHNICAL REPORTS AVAILABLE. The following listed technical reports can be requested through the NASA library, M-MS-IPL, Bldg. 4481.

NOTE: Those reports with an AD number may be on file in the local DDC branch in Bldg. 4484. Readers can save time by calling 876-6088 and inquiring if such reports are available before ordering them through NASA.

1. A STUDY OF HUMAN PILOTS' ABILITY TO DETECT ANGULAR MOTION WITH APPLICATION TO CONTROL OF SPACE RENDEZVOUS, R. F. Brissenden. NASA N-63 10626
2. HUMAN ENGINEERING CRITERIA FOR MANNED SPACE FLIGHT: MINIMUM MANUAL SYSTEMS, D. K. Bauerschmidt and R. O. Besco. AD 288 513
3. THE INFLUENCE OF PRECESSION OF EARTH RENDEZVOUS ORBITS ON LUNAR MISSION REQUIREMENTS, W. R. Wells. NASA N-63 10329
4. HYDROGEN-OXYGEN PRIMARY EXTRATERRESTRIAL (HOPE) FUEL CELL PROGRAM, A. Frank et al. AD 291 621
5. DIRECT ENERGY CONVERSION AND SYSTEMS FOR NUCLEAR AUXILIARY POWER (SNAP), S. F. Lanier and H. D. Raleigh. TIS 3561
6. COMPARISON OF HIGH ENERGY RATE (DYNAPAK) AND CONVENTIONAL EXTRUSION OF REFRACTORY METALS, D. G. Rabenold. AD 288 019
7. THE EXTRUSION, FORGING, ROLLING, AND EVALUATION OF REFRACTORY ALLOYS, D. R. Carnahan and J. A. Visconti. AD 290 630
8. EXPERIMENTAL PERFORMANCE OF AN ION ROCKET ENGINE USING A RECTANGULAR-SLAB POROUS-TUNGSTEN EMITTER, R. J. Cybulski et al. NASA N-63 10327
9. TRANSITION AND HOVERING FLIGHT CHARACTERISTICS OF A TILT-DUCT VTOL RESEARCH AIRCRAFT, H. L. Kelley. NASA N-63 10200
10. DEPARTMENT OF DEFENSE, REFRACTORY METALS SHEET-ROLLING PROGRAM. AD 288 127
11. FUNDAMENTAL AND APPLIED RESEARCH AND DEVELOPMENT IN METALLURGY. NMI-2107