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EVOLUTION OF LAUNCH CONCEPTS AND SPACE FLIGHT OPERATIONS

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New concepts evolve from the inventory of available knowledge and frequently become the building blocks for future concepts. The concepts of rocket launching and space flight operation are not exceptions. The simple concept of one man using a trough or forked stick to launch a hand-made rocket for his own amusement or to awe and injure an enemy has evolved into a highly complex operation emploving the varied skills and capabilities of many people.

Knowledge, originally acquired for other purposes, is applied to the development of new skills and specialized fields of knowledge directly related to the evolution of new concepts. These concepts, in turn, contribute to the evolution of new skills and technologies and the creation of an ever-increasing pool of knowledge.

3.1 History

The first historical rocket was developed by the Chinese in the 13th Century. Known as the "Arrow of Flying Fire," it consisted of a quantity of gunpowder wrapped into paper and tied to an arrow which was ignited and shot from a bow. Two-men teams were used to launch the fire arrows: one man held the arrow on a drawn bow while the other man ignited it. It was soon observed that the arrows were self-propelled after ignition, and the bow was replaced by a variety of simple launchers. The most common of these consisted of one or two forked sticks, wooden or earthen troughs, or hollow tubes (Fig. 3.1). Each of these methods used the simple expedient of adjusting the elevation and azimuth angles of the launcher to achieve the desired rocket trajectories and ranges.

Before World War II, launch and space flight concepts remained relatively unchanged. They could be comprehended and implemented by a single individual. Experimentation and research were emphasized; the more distant goal of manned interplanetary flight spurred the experimenters to achieve the more immediate goal of atmospheric exploration.

Fig. 3.1 Early Chinese rocket launcher.

Military requirements dictated new rocket concepts during World War II and launch operations began to assume an identity of its own. German rocket development paced similar development in other countries, culminating in the A-4 or V-2 rocket. A brief description of the V-2 and its launch complex indicates its generic relationship to present and future launch and rocket concepts.

The V-2 was approximately 46 ft long, 11.5 ft in diameter and, fully fueled, weighed 34,000 lb. It was powered by a single engine that developed 69,100 lb of thrust. It burned liquid oxygen and a mixture of alcohol and water. The range was determined by combustion cutoff, and the direction of flight was controlled by preadjusted steering devices, supplemented in special cases by radio control. The V-2 was transported by rail or truck, erected hydraulically, and launched from quickly prepared sites (Fig. 3.2).

Approximately 30 vehicles and trailers supported the V-2 by supplying the necessary fuel and oxidizer, communications and checkout equipment, and maintenance facilities. Included also were the hydraulic transporter and erector with umbilical connections, and the mobile subswitching and relay centers. The V-2 trucks and trailers were forerunners of the ground support equipment required to service and equip today's intercontinental ballistic missiles. Their principles are employed in many of today's fixed complexes, including the launch service structure, the launch control center, umbilical connections, and fuel and oxidizer storage and supply.

3.2 Current Development

Military requirements provided initial impetus to the development of new launch concepts and space flight operations. Many of the skills and capabilities required to successfully pursue these developments, however, were recruited from outside the military community. The organization of teams of scientists, engineers, and technicians evolved from the need to consolidate and coordinate a variety of talents to achieve a common goal: the successful launching and operation of space flight vehicles.

The evolution of the V-2 vehicular complex produced the highly instrumented and functional Saturn C-1 launch complex designed to achieve maximum efficiency and safety (Fig. 3.3). A brief examination of the Saturn C-1 vehicle and launch complex (LC 34) illustrates the varied technologies that have been brought to bear to achieve the initial Saturn launching.

On the launching pad the Saturn C-1 is approximately 163 ft high. Its liftoff weight is about 1,000,000 lb and with three stages activated, it will orbit more than 20,000 lb. The first stage has eight engines

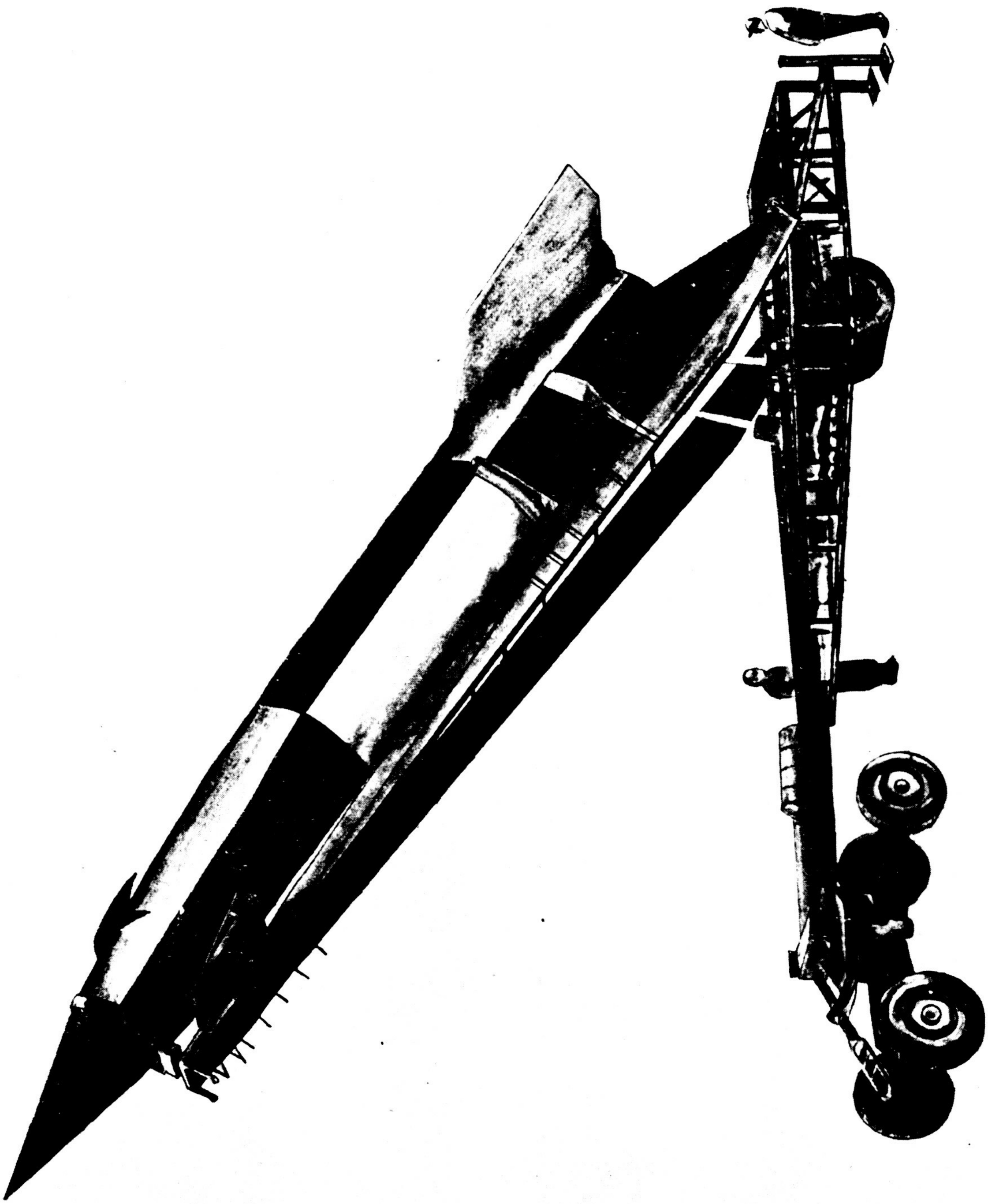

Fig. 3.2 V-2 shown mounted on mobile launcher.

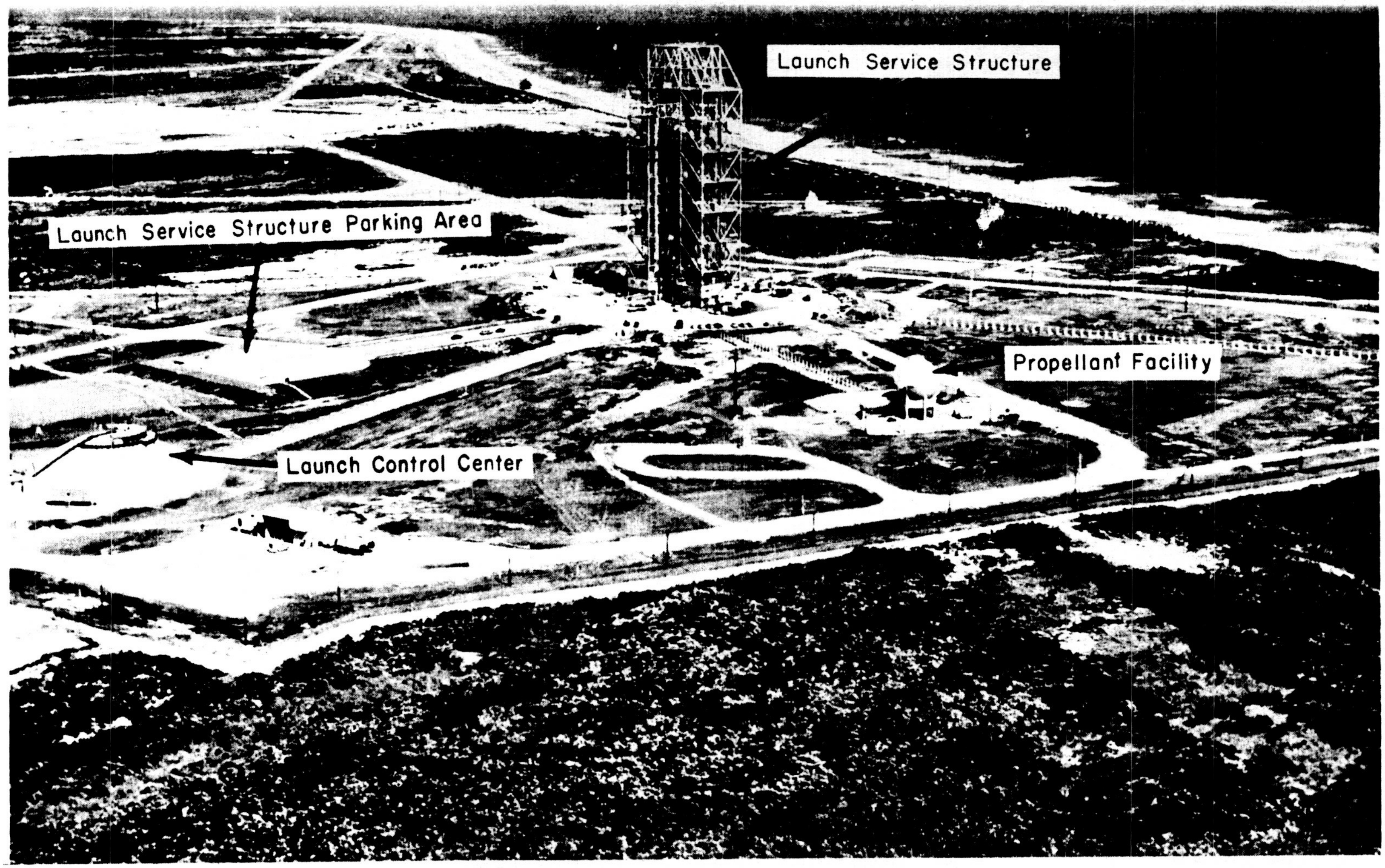

Fig. 3.3 Saturn C-1 launch complex LC 34.

burning RP-1 and LOX with a total thrust of 1,500,000 lb. Four of the engines are gimballed to provide control during first-stage powered flight. The second stage develops 90,000 lb of thrust with six liquid-hydrogen/LOX engines. The third stage has two liquid-hydrogen/LOX engines that develop 30,000 lb thrust. The Saturn uses all-inertial guidance. A high-speed digital computer will ultimately be incorporated to provide a universal guidance system capable of performing a variety of mission requirements to meet differing payload objectives.

Launch complex 34, at Cape Canaveral, Florida, used for the first Saturn launching, is a 45-acre facility expressly built for launching America's first space vehicle developed for the peaceful exploration of space. The main functional elements of the launch complex are the launch control center, launch service structure, launch pad, and propellant and pressurization facilities.

The launch control center is housed in a domed building, 120 ft in diameter (Fig. 3.4). The inner dome is of 5-ft thick reinforced concrete. On top of the inner dome is an earth fill which varies from 7 ft in the center to 14 ft at the edges. The final layer is 4 in. of gunite. The building is designed to withstand a blast pressure of 311,000 psi.

The service structure, used to erect and checkout the vehicle on the launch pedestal, is 310 ft high and weighs 2800 tons. Said to be the world's largest wheeled structure, it is mounted on four carriages powered by four 100-hp motors. It is capable of moving from 1.5 to 40 ft/min. It is anchored to steel piers by large wedges, enabling it and the vehicle it protects to withstand hurricane winds up to 125 mph.

The launch pad, 430 ft in diameter, is constructed of 8 in. thick, reinforced concrete. Located in the center of the pad, the launch pedestal is used to support and retain the vehicle during checkout and launch operations. Bolted to the top of the pedestal are eight steel arms, four to support the vehicle and four others to support and hold it down until proper ignition is attained. The foundation of the pedestal is a 160 ft by 106 ft concrete block set 9.5 feet below the surface of the pad.

The propellant facilities include an RP-1 system, LOX system, and a liquid hydrogen system. Two 30,000-gal cylindrical tanks are used for RP-1 fuel storage. The transfer system and associated plumbing includes two 1000-gal/min pumps, a recirculation pump, a filter-separator unit and miscellaneous valves, pipes, and controls. The main LOX storage tank in a sphere with an outside diameter of 43 ft. A smaller LOX vessel is used for replenishing the oxygen which boils off during the latter stages of launch preparation. The liquid hydrogen facility consists of a vacuum-jacketed, 125,000-gal sphere, pneumatic and electrical consoles, and the necessary plumbing and valves.

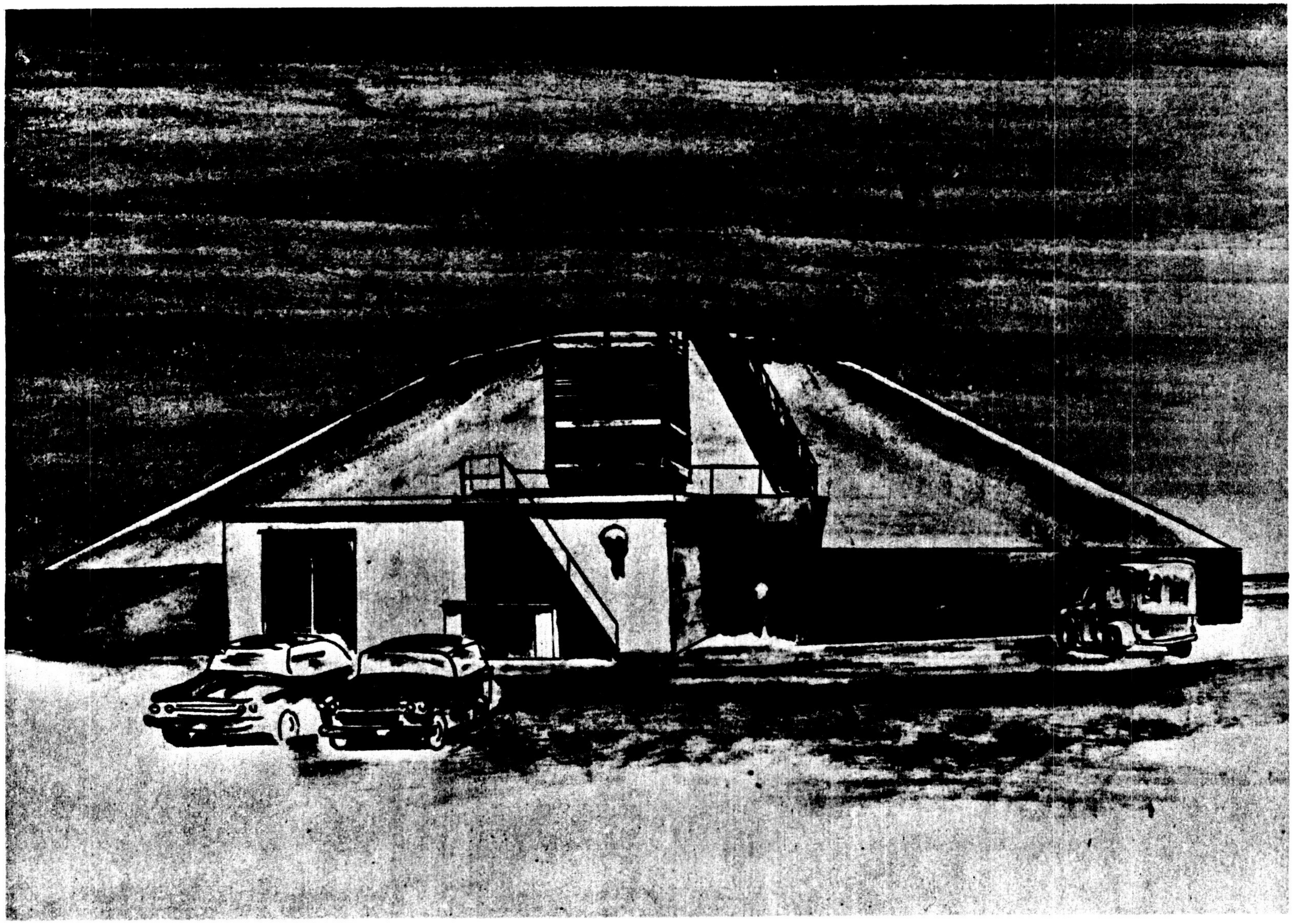

Fig. 3.4 Launch control center of LC 34.

High-pressure helium and nitrogen gases are required for the vehicle. The helium is used for bubbling the LOX tanks in the vehicle to keep the oxidizer from forming strata of different temperatures. The nitrogen is used for purging propellant lines, engine, and instrument compartments; for air bearings; and for pressure-operated components. The high-pressure system receives helium at 3000 psi pressure and boosts it to 6000 psi. The nitrogen is procured in liquid form and converted to gas before it is supplied to the vehicle.

In addition, a complex water system is available for safety and protection purposes. A comprehensive voice communications network and a closed-circuit television loop are used for intercommunication and monitoring the checkout and launching.

3.3 Skill Utilization

Until recently, missiles and space vehicles could be designed without too much consideration being given to the means for launching them. Launch preparations had to conform to vehicle design and were adapted to vehicle configurations and specifications which often prevented efficient launch operations.

This policy of tailoring launch procedures to vehicle design is no longer feasible with the advent of large space vehicles. The complexity of their configurations and the initial expense of their design and fabrication makes it apparent that all phases of a space program require design coordination at all stages of system development to insure success. Two significant trends have gradually emerged with the evolution of launch operations. As launch facilities and procedures became larger and more comprehensive, a need was created for professional, scientific, and technical services and skills that had been developed in other fields. At the same time, the exigencies of launch and space flight developments were reshaping these skills and capabilities into new fields of specialization that, in turn, gave birth to new professions and skills.

The many technologies, skills, and professions required for launch operations include such diversified and apparently unrelated fields as electrical, mechanical, and civil engineering, medicine, meteorology, law, psychology, and mathematics. Engineers design the complicated circuits for computers and checkout equipment, structural elements, and launch pads; space doctors study the preflight and postflight behavior characteristics of animals and men; meteorologists determine flight feasibility in terms of weather; lawyers busy themselves with the legal aspects of land acquisition; physiologists and pyschologists study in-flight effects on human and animal behavior; mathematicians program computers, calculate trajectories, and analyze data transmissions. These are but a few of the technological and professional contributions required to sustain space activities.

Backing up the technical specialists are administrative and service specialists in such fields as public information, protocol, industrial relations, security, and publications. Many trades and professions are called upon to staff these important support functions. Among those contributing their skills and abilities are policemen, photographers, writers, and clerks. Their abilities, however, are shaped by the particular problems they encounter that are peculiar to launch operations.

Industrial relations provide a good example of how a support service can be shaped into a form somewhat different from the classic mold. In private industry, the industrial relations specialist must concern himself primarily with the labor unions that represent the workers of his company. Quite often there is only one man with whom an agreement must be reached. A similar situation does not exist for the industrial relations office of a large government-operated launch facility. Numerous unions and contractors are involved in the design, construction, and maintenance of space vehicles and launch facilities; and the industrial relations office must consider each contractor's relationship to the government and to the unions with whom they have bargaining agreements. It must also consider other government agencies engaged in launch operations and in the construction of launch facilities.

In the process of working with unions, contractors, and government agencies, the industrial relations specialist becomes a launch operations industrial relations specialist. He is in the anomalous position of representing an employer who hires employers. Instead of the classic company-union relationship, it has become a government-company-union triangle.

All the specialized fields and subfunctions necessary to launch a space vehicle into orbit or on a deep space mission cannot be completely envisioned by one person. The interdependent network of information and services is, for all its complexity and self-contained features, dependent upon a continuous incoming flow of materials, services, and information.

In the development of complex space vehicles and associated launching systems, nearly all fields of knowledge are called upon. This utilization, however, is not a unilateral benefit; the application of these fields of knowledge to specialized launch and space flight problems has contributed to their advancement in other applications. For example, the requirement for lightweight, reliable instrumentation for guidance and control and for exploratory scientific experimentation in space accelerated the development and production of subminiature components such as transistors. The application of transistors to communications, computers, and automated equipment has become widespread.

Radar, telemetry, and optical instrumentation supply the major portion of the information on each space vehicle launching and flight. Applications arising from radar and telemetry requirements for space vehicles include improved landing and flight controls for commercial aircraft, astronomical tracking and observation of the Sun and other radio stars, and additional navigation safeguards. Increasingly accurate, long-focal length cameras have also been developed that determine vehicle position in flight as related to a stellar background. These cameras are currently being used in geodetic surveys. In addition, the use of cryogenic propellants such as liquid hydrogen and liquid oxygen, contribute to the development of new equipment and techniques used in manufacturing, handling, storage operations, and have recently found application in the food preservation industry.

3.4 Future Concepts

As indicated by the comprehensive Saturn C-1 launching installations must be designed to provide maximum operating efficiency for a particular type of space vehicle. Several versions of the Saturn vehicle were planned, consecutively designated C-1, C-4. Each succeeding one was to be a more powerful and logical follow-on to its predecessor. However, the success achieved with the first version, C-1, has advanced the Saturn program to the projected C-5 version. The initial concept of the Saturn C-5 is a three-stage vehicle with 7,500,000-lb thrust first stage, a 1,000,000-lb thrust second stage, and a 200,000-lb thrust third stage. The three stages are expected to place 110-ton payloads into an Earth orbit to accomplish in-space rendezvous for manned lunar flights.

The higher launching rates, greater thrust, and increased acoustic disturbance inherent in the advanced Saturn are a few of the factors that are shaping a new concept for launch facilities. The launch complex for the Saturn C-5 now being planned (Fig. 3.5) will incorporate features of this concept; these include a separate vertical assembly building, a transporter/launcher complete with umbilical tower, an arming tower, fueling facilities, and a minimum pad.

The vertical assembly building will provide the space and equipment necessary to assemble and checkout the entire space vehicle. This will eliminate the necessity for long periods of time on the launching pad for checkout and assembly. It will also provide a controlled environment where assembly and checkout operations can be conducted under favorable conditions.

The transporter/launcher (Fig. 3.6) serves as a platform for vertical assembly, checkout, transport and launch. It also contains the umbilical tower so that umbilical connections will remain intact while the vehicle is being transported; this will eliminate repeated checkout procedures at the launch site. In addition to reducing checkout

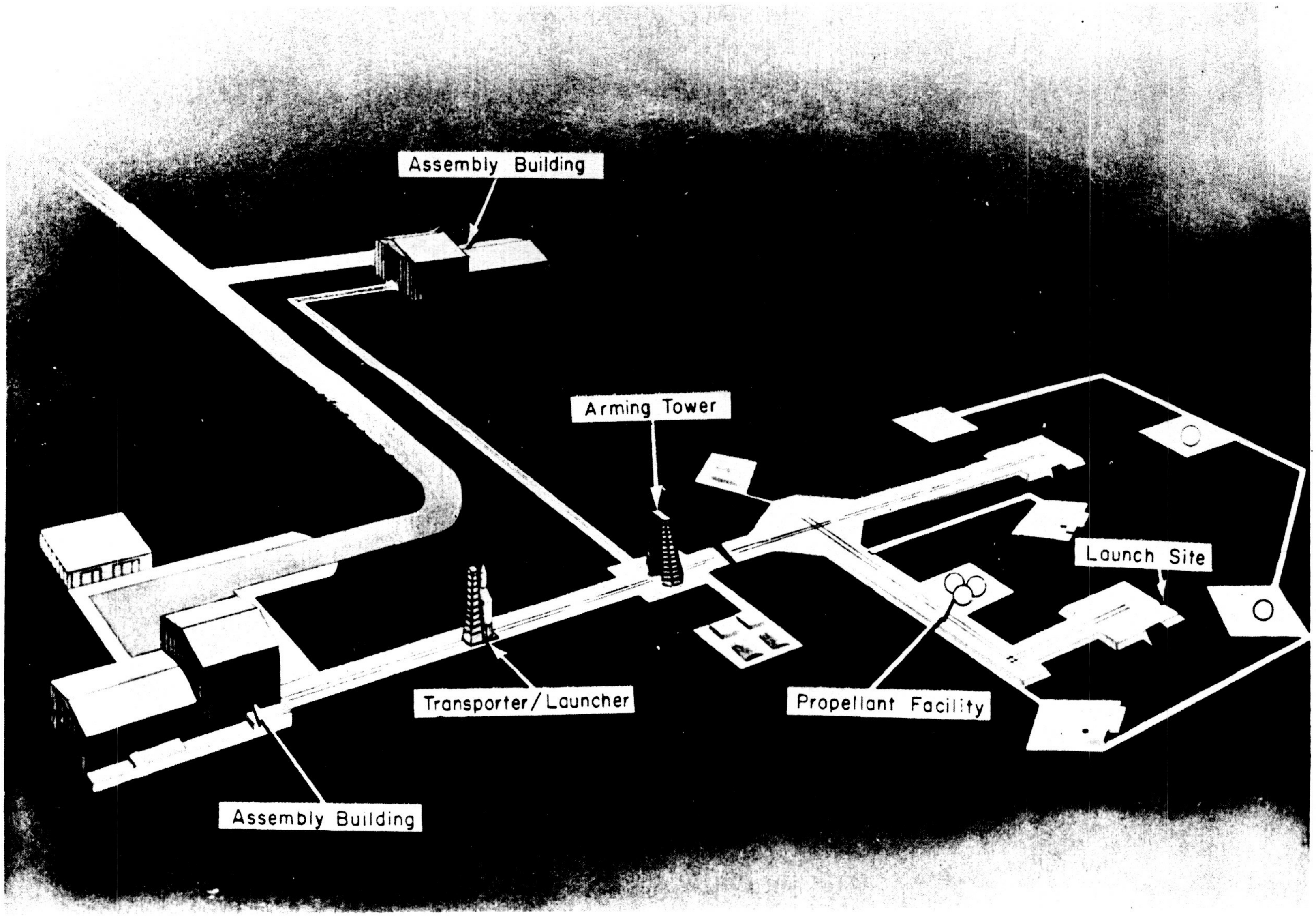

Fig. 3.5 Planned launch complex for Saturn C-5.

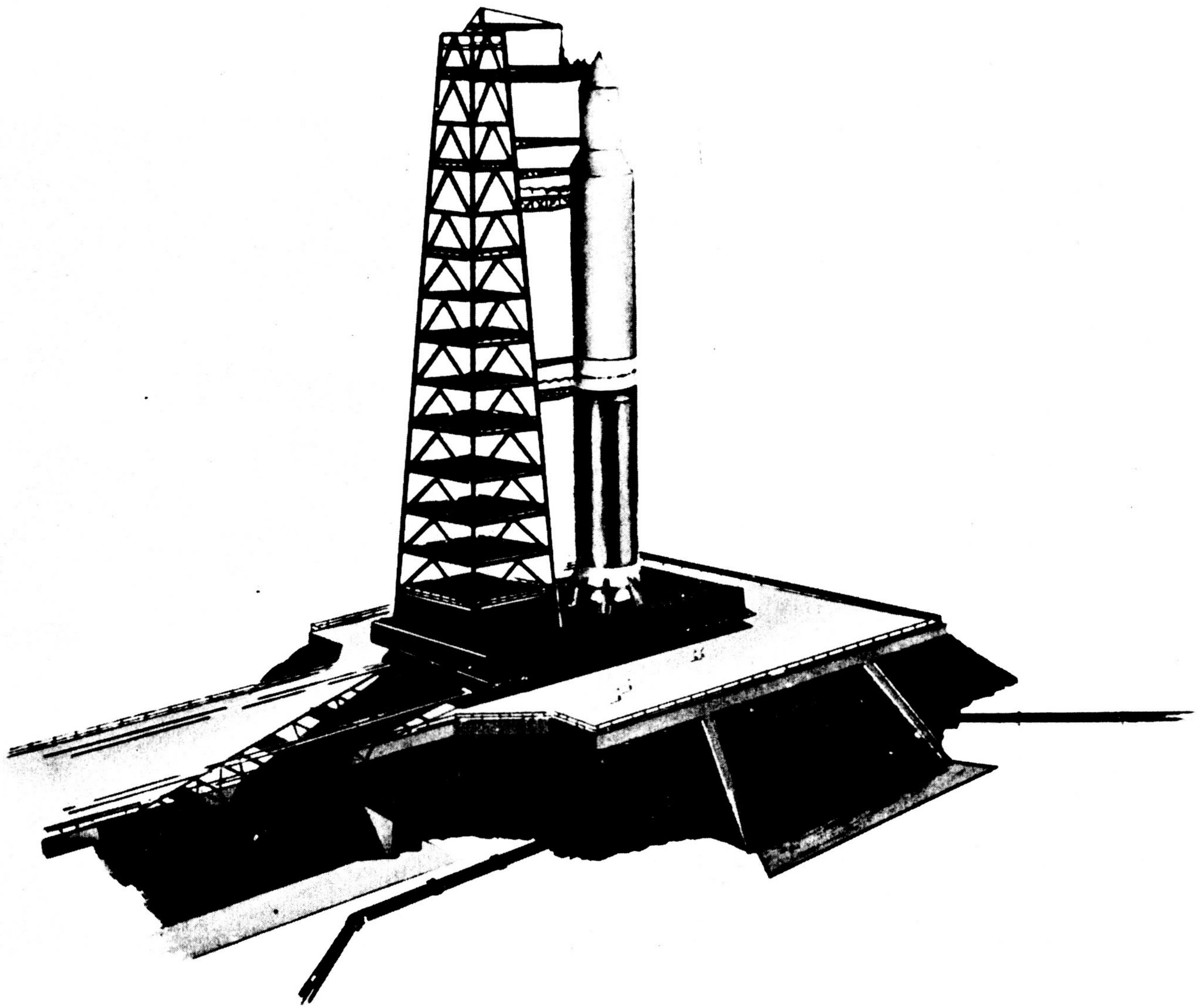

Fig. 3.6 Proposed Saturn C-5 transporter-launcher.

time on the pad, the transporter/launcher may be used to return the vehicle to the assembly building if a hurricane or other threatening weather is imminent. The transporter/launcher and assembly building eliminate the requirement for individual launch service structures. Two approaches to the development of the transporter/launcher are under study. The first is the use of wheeled vehicles operating on rails, and the second is the use of barges for water transport. Precise control of movement, vibration, and stability are essential factors in the development of the transporter/launcher.

The arming tower will provide a facility where explosive items such as retrorockets, squibs, and igniters can be installed while the vehicle is protected from environmental hazards. The arming tower will be so located that vehicles from one or more assembly buildings may be serviced.

The minimum launch pad (Fig. 3.7) will consist essentially of compacted earth covered with concrete. A flame deflector will be positioned under the pad. The complex pad facilities previously required will be eliminated through use of the vertical assembly building, the transporter/launcher, and the arming tower. This new concept is based on a high launch rate and consideration of the complexity of future space vehicle configurations. It is less expensive, operates more efficiently, and is capable of launching space vehicles at a more rapid rate than is now possible. The advantages of this new concept in launch complexes include a higher launching rate and the resultant reduction iniinitial construction costs and amount of real estate required for individual launches.

In addition to the savings in money and real estate, there are several other advantages that will accrue from the application of the new launch concept. One advantage is that umbilical connections will remain intact while the vehicle is being transported to the minimum pad, thereby preserving the validity of tests made in the assembly area. An interconnecting cable, carrying digital information and commands, will be the only connection between the launch control center and the space vehicle on the pad. The disconnection and reconnection of components, the principal reason checkout procedures are now repeated at the launch site, will no longer be necessary. This will result in reduction of operational work time and effectively reduce launch operations costs.

One factor that makes this concept possible is the use of automatic and digital equipment. Much of the present checkout and launch equipment consists of analog computers whose findings are affected by the voltage drops encountered over long transmission circuits. This led to the development of the blockhouse, near the launch pad, to reduce the distance between the information source and the analog computers. With digital computers, which record by impulse, variable voltage is not a factor; therefore, data received from a long distance retains its validity.

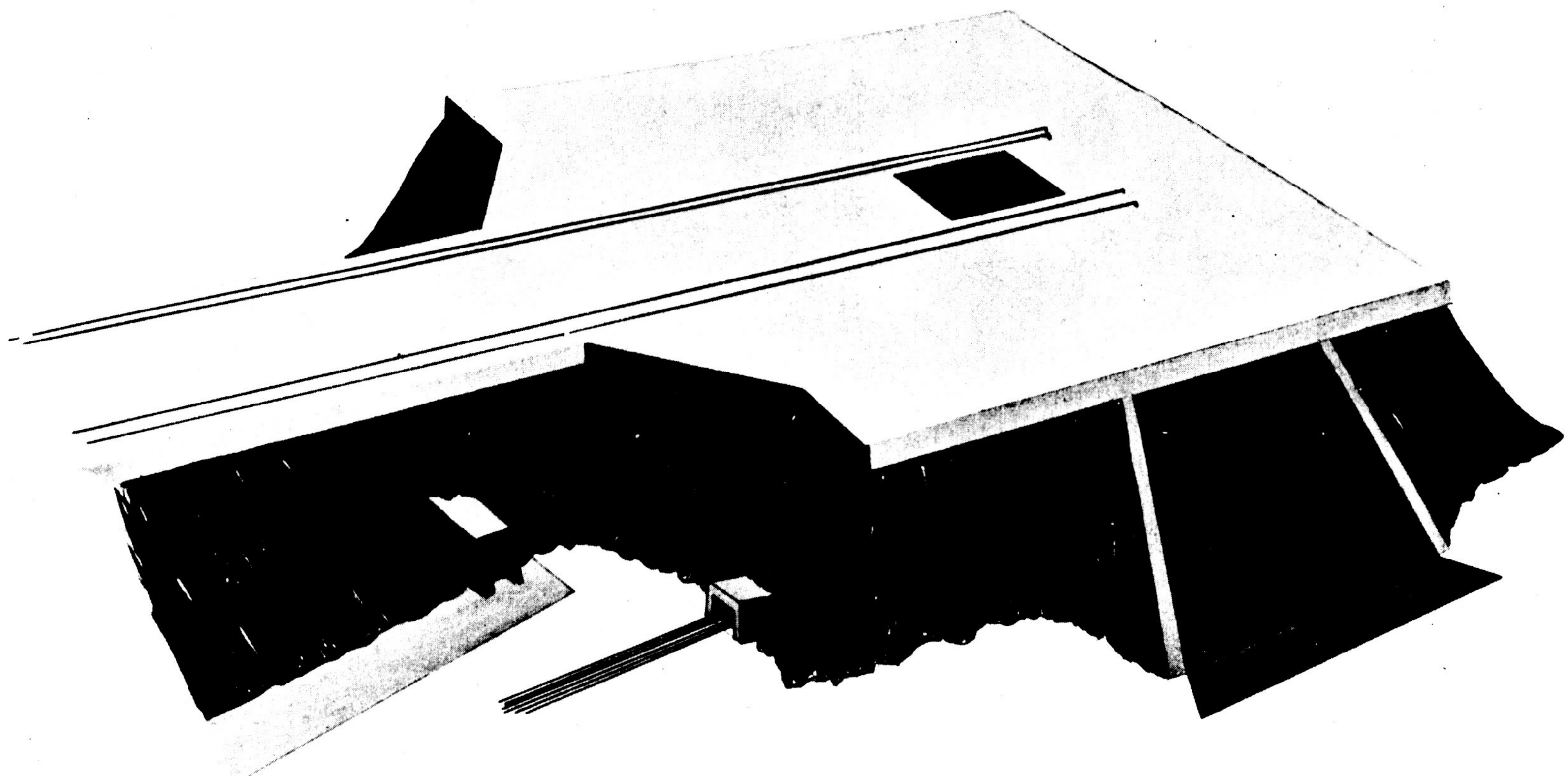

Fig. 3.7 Minimum launch pad.

This situation eliminates the need for a blockhouse and makes it possible to checkout and launch the space vehicle with one set of equipment located in the assembly building.

The need for individual service structures will also be eliminated by this new concept. These structures are now used to assemble the vehicles and to protect them from hurricanes. The vehicles, under the new concept, can be assembled before they reach the pad and can be removed from the pad area before a hurricane strikes. This factor alone will result in great savings in time and money, because the service structures are heavy and impose tremendous loads on their means of transport. The elimination of the service structure and the blockhouse will also result in a reduction of acoustical and explosive hazard areas.

One of the most rewarding aspects of this concept is the short stay time at the launch site. Instead of occupying an expensive launch complex for several weeks, the vehicle will remain at the relatively inexpensive pad area for less than 1 week. This concept will allow the assembly building to operate at full capacity, and thereby increase the launching rate.

The flexibility of this concept is another of the major advantages. Separate assembly buildings for liquid and solid propelled space vehicles can be located on the same complex. By modifying the transporter/launchers and their umbilical towers to fit individual configurations, these buildings become adaptable to various manned and unmanned space vehicles. This flexibility is also demonstrated by the capability of moving vehicles to the pad and back into the assembly building in a few hours, while maintaining their flight readiness even under hurricane conditions; this mobility, in turn, will reduce the hazard of weather-induced corrosion.

The concept also provides increased flexibility in scheduling the launching of vehicles that may or may not be able to meet a precise launch schedule. If a particular space probe, for example, can only be fired within a restricted time frame, the delay of a previously scheduled launch at the same pad area will not interfere with the mission. The earlier scheduled vehicle can be held in the assembly building on its transporter/launcher until after completion of the priority program. This concept also demonstrates how facility configurations, checkout and launch procedures, and vehicle design and development combine to become one synchronized and integrated effort.

Many other concepts vie with the dispersed-fixed concept as embodied in the proposed C-5 complex. Included are the underground silo and the fixed above-ground concepts, as well as several versions of the mobile concept. The underground silo concept is already being employed (Fig. 3.8).

Fig. 3.8 Underground silo shown with ICBM.

Operational Atlas ICBMs are deployed in strategically located underground silos throughout the country. The underground silo launch site has several advantages. It is easily concealed, protected from the elements, relatively invulnerable to air attack, and comparatively easy to maintain after construction. In addition to the Atlas sites, the underground silo concept is planned for Titan and Minuteman ICBMs. Since the Minuteman is a solid fuel missile, its silo will not require contiguous underground fueling facilities.

Future space vehicles may dictate a variation of the fixed-vehicle/fixed-tower concept, wherein vehicles are assembled at the launch site and launched directly from the assembly structure. The nature of their missions eliminates the "shoot and scoot" or "shoot and hide" requirements so necessary for military missiles. Neither will they be required to maintain the high launch rate planned for the Saturn C-5s. The fixed-missile/mobile-tower concept, whereby vehicles are also assembled at the launch site but launched after the assembly structure has been moved, is the basic concept in use today, especially at missile and vehicle test centers.

The mobile concept is actually several concepts, but all of them have in common the idea of launching missiles and space vehicles from a moving site or from a site which can be moved. The main advantage is the relative invulnerability they provide against enemy attack. For this reason, the military has taken the lead in translating these ideas into reality.

Several nuclear submarines capable of launching Polaris missiles while continuously on the move are already on station (Fig. 3.9). This will require tactical, rather than strategic intelligence of their whereabouts by a potential enemy. Nonmilitary applications of the mobile launch concept will be used for other than security reasons. Launches from orbit are already being seriously considered for manned space probes. This concept would have space vehicles outfitted and refueled from orbiting modules.

These are a few of the concepts that have been employed, are being employed, and will be employed to launch missiles and space vehicles. In the meantime, feasibility studies of other concepts will be made as they are conceived.

Intimately associated with launch operations is the burgeoning area of space flight operations. The elaborate measures and precautions that are taken before a flight are not concluded upon the successful liftoff of the space vehicle. The environment of space must be probed and explored to resolve many of the technical and human problems that will be encountered in manned space flight operations. Space navigation, inflight maintenance and checkout, orbital rendezvous, refueling and

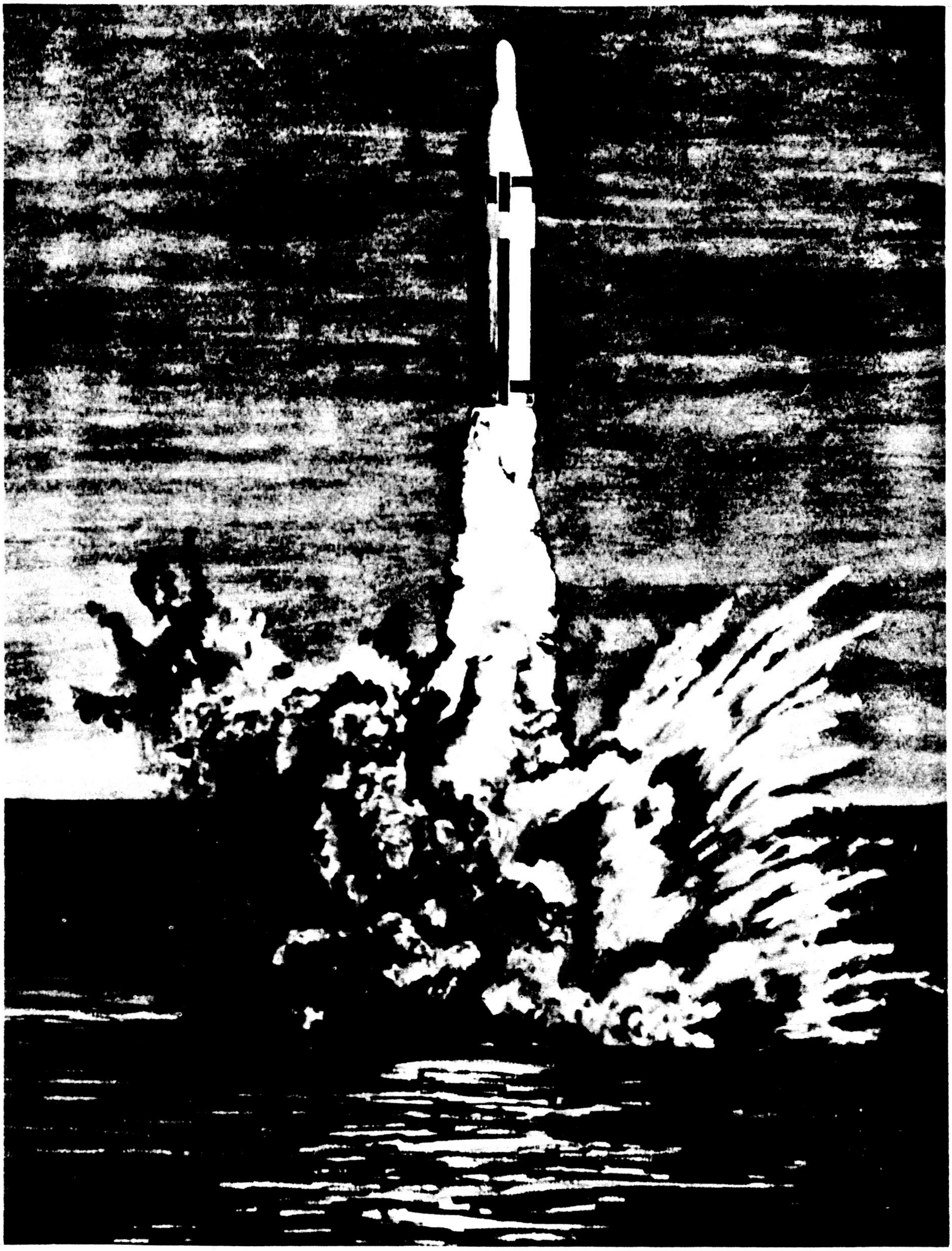

Fig. 3.9 Underwater missile launching.

docking, escape velocities, nutrition, and on-board equipment are a few of the areas where these problems will be encountered.

Manned lunar and planetary space probes will create an interesting paradox. Many facilities, services, supplies, professions and skills are required to launch a space vehicle; yet one man, or a few men at the most, will be expected to duplicate the function of this vast apparatus without having direct access to it. Flight and launch operations, which ordinarily would take weeks or months of advance preparation and planning, may require nearly instantaneous execution simultaneous with, or soon after, the decision to launch has been made.

Several methods are now available to provide an astronaut or flight crew the vast amount of information necessary for quick execution of flight and launch decisions. Other methods will be developed through experience. Television, telemetered information, ground analysis, and automatic identification of trouble can be employed. After automatic sensing devices locate a trouble area, telemetered information can be sent to ground stations for analysis. If necessary, specialists may be consulted for solutions that can be transmitted back to the spacecraft. Television may also be employed to spot trouble or to communicate with ground stations.

Some problems, such as those connected with long periods of weightlessness and inflight nutrition, will require extended space flight experience before they can be satisfactorily resolved. Procedures for emergency repairs on lunar or planetary surfaces will also improve with experience. A continuation of the aggressive pursuit of space exploration will take brains, imagination, rare skills, management, engineering know-how, salesmanship, and the cooperative efforts of many individuals and groups of people. These efforts, if properly applied, will continue the evolution of launch and space flight concepts and will contribute to the development of unexplored fields of knowledge.