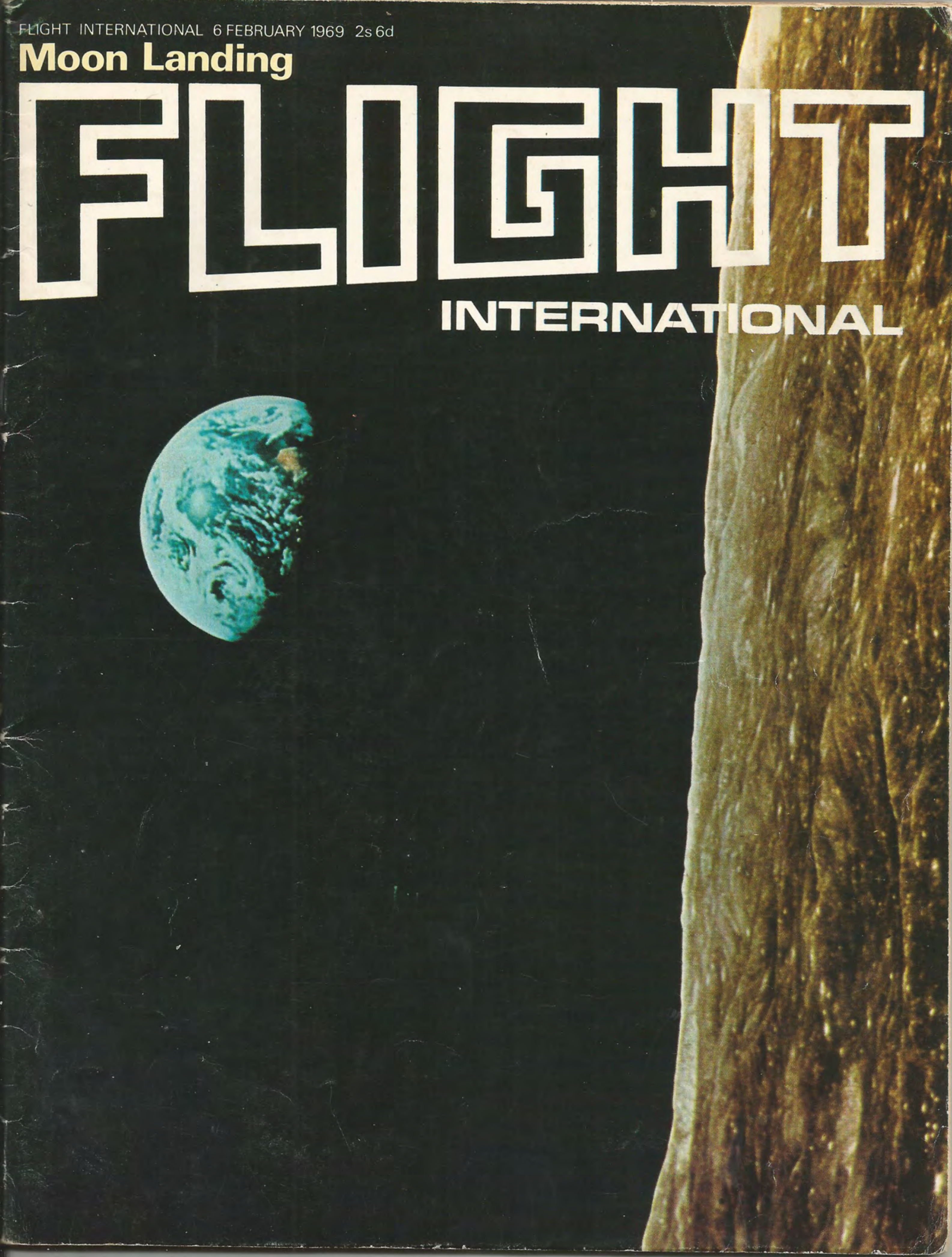
FLIGHT INTERNATIONAL 6 FEBRUARY 1969 2s 6d

Moon Landing

FLIGHT INTERNATIONAL



"FLIGHT" SPACE SPECIAL

Our Space Special this year is entirely devoted to the topic which appears likely to mark 1969 as a historic year in the exploration of space: the American Apollo project to land man on the Moon. This particular special issue is normally published in July, but it has been brought forward to give readers the opportunity of acquainting themselves with this tremendous undertaking well in advance of the landing itself, which may occur as early as July 18. The following article was prepared by the assistant technical editor in collaboration with staff artist Frank Munger, who was responsible for all the cutaway and other drawings. "Spacecraft Scoreboard," normally included in the Space Special each year, will appear in an early issue of "Flight."

By MICHAEL WILSON

MOON LANDING

1—BEGINNINGS

"We have examined where we are strong and where we are not, where we may succeed and where we may not. . . . Now is the time to take longer strides—time for a great new American enterprise—time for this nation to take a clearly leading role in space achievements which, in many ways, may hold the key to our future on Earth. . . . We have never made the national decision or marshalled the national resources required for such leadership. We have never specified goals on an urgent time schedule, or managed our resources and our time so as to ensure their fulfilment. . . . For while we cannot guarantee that we shall one day be first, we can guarantee that any failure to make this effort will make us last. . . . I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to Earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or so expensive to accomplish."

With these words to Congress on May 25, 1961, the newly elected President Kennedy signified his approval for America's most expensive and ambitious civil and military aerospace project. He did not allude to the fact that the world's first astronaut was a Russian (the late Yuri Gagarin had flown into space on April 12, less than six weeks before), or to the Bay of Pigs débâcle in April 1961, both of which were negative contributions to American world prestige. On the positive side, however, was NASA, created on October 20, 1958, full of enthusiasm to get to grips with space but needing a stimulus to weld together industry and government. With these pressures, therefore, the scheme was approved by Congress.

Plans for such a mission had been studied for some years previously and in July 1960 NASA had begun discussions with industry for a project, known as Apollo, to fly three men around the Moon. It is interesting to recall, in this context, that the earliest serious studies were those of the British Interplanetary Society which, in 1939, published a detailed analysis of a rocket to carry three men to the Moon and back. Many aspects of this project are remarkable for their forward thinking and similarities to solutions adopted in the Apollo programme.

Long before the first Sputnik had been launched the need for large rockets had been appreciated and Wernher von Braun in America had initiated launch vehicle studies in April 1957. The aim of these was to create a booster of 1.5lb million by clustering previously developed engines. In August 1958 the Advanced Research Project Agency formally initiated design of what was to become the Saturn project; this large vehicle was so named in February 1959. NASA took the programme over from ARPA (a military organisation) in March 1960 and the first static firing of a Saturn I was conducted on April 29 of that year.

Early in 1960 (with manned Moon flights on the horizon), the Saturn programme was given the highest national priority and a ten-vehicle R&D programme was approved. The first Saturn I was flown on October 27, 1961.

During 1961 and 1962 there existed considerable controversy on the best way of accomplishing the lunar mission. Although the use of a Saturn I for the manned lunar landing was theoretically possible, six vehicles would have been needed to ferry into low-Earth orbit the sub-assemblies from which the spacecraft could be built. No space rendezvous or docking had taken place at that time, and the solution was discarded as being too expensive and advanced.

Two other possibilities existed: the direct method, in which a single vehicle (weighing an estimated 5,000 tons and still using conventional fuels) would make the round trip to the Moon. This rocket, designated Nova, would have been about 40 times as heavy as any vehicle then in use in the United States and this solution was also discarded as being too "far out." The second, the technique finally adopted, known as LOR (lunar orbit rendezvous), called for one rendezvous in orbit around the Moon, and had the attraction of needing a single launch vehicle weighing about 3,000 tons—well below the vehicle size required by the Nova mission. The Saturn V vehicle was therefore sized to this mission, and the decision to proceed with this rocket was made in January 1962.

The Saturn I vehicle had cluster of eight H-1 engines totalling 1,504,000lb thrust in the first stage and six RL-10 lox/liquid hydrogen engines of 90,000lb in the second stage. Seven vehicles were used for R&D flights, the last three of the ten being employed for flying the three Pegasus meteoroid-detection spacecraft.

Realising the need for a vehicle capable of flying Apollo development hardware heavier than that which could be orbited by Saturn I, and before Saturn V could be made available, NASA initiated a programme for an Uprated Saturn I. This vehicle was considerably larger than Saturn I, had a total first-stage thrust of 1.6lb million, and a single J-2 engine of 200,000lb thrust in the second stage. The first of 12 Saturn IBs, as the vehicles came to be called, flew in February 1966. Recurring problems with this rocket delayed its introduction and only four unmanned flights and one manned mission (the outstandingly successful Earth-orbit Apollo 7, launched on October 11 last year) were completed before Saturn V became operational. This vehicle, the largest rocket in the American inventory, has flown two unmanned missions—Apollo 4 on November 9, 1967 (the first flight), and Apollo 6 on April 4 last year. Its first manned mission was Apollo 8, the highly successful ten-Moon-orbit flight of December 21 last year.

In parallel with the development of launch vehicles was the increasing knowledge of how to maintain man in space. On May 5, 1961 (less than three weeks before President Kennedy's statement to Congress) Alan Shepard made America's first manned sub-orbital flight in Mercury 7. The Mercury programme was initiated on December 8, 1958, with the object of developing the minimum manned spacecraft. While Mercury was not, therefore, designed specifically in support of the Apollo programme, almost every aspect of the one-man vehicle was relevant to the lunar mission. Two sub-orbital and four orbital Mercury flights were made.

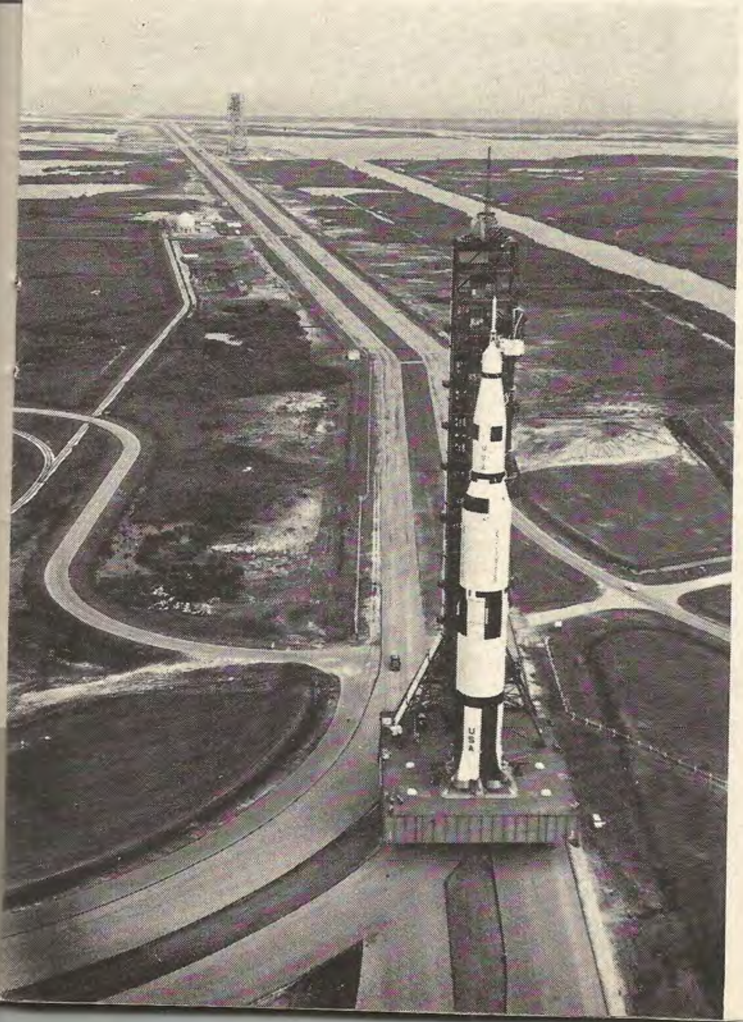
To further develop the techniques necessary for the lunar mission it was announced in December, 1961, that a more advanced programme, known as Gemini, would be implemented. The main purpose of Gemini was to enable more ambitious manned space flights, including rendezvous and docking manœuvres, to be made, and to provide an environment for two astronauts for a period of two weeks. The first flight was made on March 23, 1965. Gemini astronauts made, in all, ten rendezvous manœuvres with other orbiting spacecraft, using seven different modes. Nine dockings were achieved with Agena target vehicles, and over 12hr of extra-vehicular activity were accumulated. Ten Gemini missions were flown, the last (GT-12) on November 11, 1966.

Coming right up to date now, four further Apollo flights are scheduled for this year, one at least of which will be to land astronauts on the Moon. Apollo 9, to be flown this month, will test the lunar module in Earth orbit for the first time in a manned flight. Apollo 10 is scheduled for April/May, and will also be devoted to tests of the lunar module leading to its flight qualification. Apollo 11, tentatively planned for July, is the first of two possible landing flights. If Apollo 11 is unsuccessful, Apollo 12—a contingency flight—could take place about September.

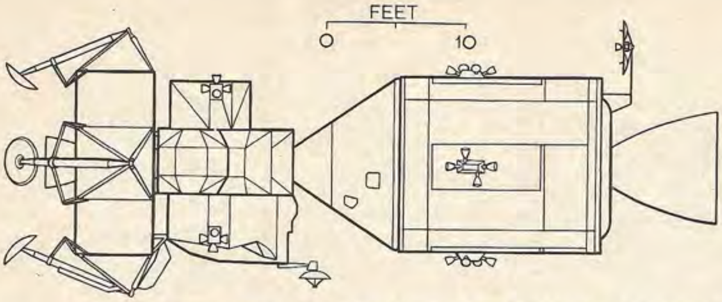
2—THE VEHICLE

The Apollo/Saturn V vehicle in the final, or lunar-landing configuration, consists of eight basic units. These are: S-IC first stage; S-II second stage; S-IVB third stage; instrument unit; the LM (the lunar module, itself consisting of two units: the ascent and descent stages); the SM (service module), the CM (command module, attached to the top of the service module) and the LES (launch escape tower). For the purpose of description under this heading, the vehicle consists of the three launch stages, the instrument unit, and the LES. The spacecraft, for the same purpose, consists of the lunar module, the service module and the command module, and is described under the appropriate heading.

The S-IC first stage is made by Boeing, and consists of a vertical grouping of five cylindrical major components and



Assembly of a vehicle as complex as Saturn V is a lengthy business and would engage a launch pad for several months. To avoid this the rocket is assembled at Cape Kennedy in the VAB (vehicle assembly building, not shown) which can accommodate up to four Saturns. The complete rocket is then transported by means of this tracked crawler vehicle, from the VAB to Launch Complex 39 (a distance of three miles) at a speed of 1.5 m.p.h.



The three elements which constitute the spacecraft—the service module, command module and lunar module—are shown here joined together as they will be during the flight to the Moon. The service module is at the extreme right; the conical command module faces left and is joined to the lunar module at left

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a cluster of five Rocketdyne F-1 engines. Working upwards from the engine is the thrust structure, fuel tank (containing 203,000gal kerosene), inter-tank structure, lox tank (containing 331,000gal liquid oxygen) and forward skirt. The thrust structure takes the entire static and dynamic thrust loads and, weighing 24 tons, is the heaviest first-stage component. Four fairings and the same number of rigid fins are attached to the lower end of the structure. The purpose of the half-conical fairings is to smooth the airflow over the engines, while provision of fins reduces the angular rate of rotation caused by "hard-over" failures, giving the crew more chance to take remedial action or abandon the vehicle.

Four of the five F-1 engines are gimballed for attitude control, the fifth (central) engine being fixed. Each engine is a single-start unit, 19ft long and 12ft 4in in width (the nozzle diameter is 11ft 7in) delivering 1,520,000lb thrust at sea level, with a rated burn time of 150sec and a specific impulse of 260sec. The total mass flow for five engines (lox+kerosene) at launch is 28,415lb/sec.

The S-II second stage, built by North American Rockwell, is the most powerful hydrogen-fuelled launch vehicle at present in production in the western world. It also consists of five stages: inter-stage ring, aft skirt and thrust structure (which supports and houses the five engines), lox tank, liquid hydrogen tank, and forward skirt. As with the first stage, four of the five engines are gimballed, the fifth (axial motor) being fixed. The Rocketdyne J-2 engine is 11ft 1in long, with a nozzle exit diameter of 6ft 5in, and delivers 225,000lb thrust at altitude for a rated duration of 500sec and a specific impulse of 424sec. Five solid-propellant ullage motors, each generating 22,500lb thrust for 4sec, provide "artificial gravity" (after first-stage separation) to ensure that the fuel and oxidiser settle in the tanks so that the fuel system remains primed. The stage has a single relatively thin bulkhead which forms both the top of the lox tank and the bottom of the liquid hydrogen tank, and which has to maintain a temperature difference of 90°C between the two liquids. Although the fuel/oxidant content of the S-II stage is considerably less than that of the first stage, they differ only slightly in size because the liquid hydrogen occupies such a large volume. Four solid-propellant retro-rockets of 37,500lb thrust each push this stage away from the S-IVB at separation after burnout.

The third and final propulsive element of the Saturn V vehicle is the S-IVB stage, designed and built by McDonnell Douglas Astronautics. It consists of a forward skirt, propellant tank, thrust structure, aft skirt, and aft interstage. As with the S-II stage, the fuel and its oxidant—liquid hydrogen and lox—are separated by a common bulkhead. The single J-2 engine is interchangeable with the propulsion units in the second stage, and is gimballed for control purposes. Two solid-propellant ullage motors, each of 3,400lb thrust, accelerate the stage sufficiently to settle the fuel and oxidant after separation from the S-IIC stage.

Attached to the upper end of the S-IVB stage is the instrument unit. This ring structure, 36in high and 260in in diameter, is built by IBM. It is the "nerve centre" of the vehicle and contains the electrical and electronic equipment needed for guidance, tracking, and telemetering of engineering data for the Saturn V. It also contains its own environmental-control system which is also used to condition equipment in the forward end of the S-IVB stage.

The other component used only during the launch is the launch escape tower. This is a lattice structure some 33ft high which is attached to the conical end of the command module. The upper end contains a 147,000lb-thrust rocket engine. In the event of an emergency arising during the period T−30min to T+3min (T=lift-off) the crew can abandon the launch vehicle by operating the escape system. This breaks the connections with the vehicle and energises the rocket motor, causing the tower and command module to separate from the launch vehicle and eject to a safe distance from the launch site. At the top of the trajectory the tower detaches itself and falls away separately, while the recovery parachutes in the command module are deployed.

3—THE COMMAND MODULE

The only part of the vehicle and spacecraft which is recovered intact at the conclusion of the flight, the command module houses the three astronauts during their journey to and from the Moon, and consists of a conical chamber about 12ft in diameter and 10ft high. The configuration of the module, used also for the Mercury and Gemini spacecraft, is due very largely to the work of H. J. Allen (until recently director of NASA's Ames Research Centre) in 1952. A body at a great distance from the Earth, and allowed to fall freely under the influence of the gravitational field of the latter, acquires a characteristic velocity of about 37,000ft/sec. It is convenient to allow atmospheric drag to dissipate the kinetic energy so acquired in the form of heat, and Allen showed that this could be achieved by using a shape having a blunt face towards the direction of flight. By this means about 90 per cent of the heat load could be transferred to the shock-wave formed ahead of the hypersonic body. Much of the residual heat could then be dissipated in raising the temperature of a special coating on the blunt face, which could then disintegrate in a controlled way, so reducing the heat load which was finally transferred to the spacecraft.

During early studies of lifting bodies it was found that uncontrolled entry at a fixed lift/drag ratio was unacceptable for the lunar mission owing to the wide spread of touch-down positions, resulting from unavoidable inaccuracies in re-entry path measurement and injection and uncertainties in atmospheric data. The choice of L/D depends on the cone angle of the spacecraft; for Apollo an L/D value of 0.35 was adopted. This allows a range variation of some 3,000 miles from 400,000ft. Another parameter, the ballistic coefficient W/C_dA (where W and C_d are the weight and drag coefficient of the spacecraft, and A is the effective area of the re-entry face) was chosen to give appropriate characteristics. This quantity may be thought of as a kind of wing loading. The value chosen for Apollo, 50lb/sq ft, provides the appropriate deceleration levels for the design flight path and allows the spacecraft to be manœuvred for landing over a very wide range. Fortunately the Earth's atmosphere is sufficiently dense that quite low values of the coefficient can be achieved with reasonably small effective base areas.

The command module consists of two main structures joined together: an inner pressure shell and an outer heat shield. The first is of aluminium-sandwich construction in which aluminium-honeycomb core is faced both sides with aluminium sheet; the thickness varies from 1.5in at the base to 0.25in at the apex of the spacecraft. The heat shield is made from stainless steel honeycomb brazed between steel alloy facing sheets. It varies between 2.5in and 0.5in thick, and accounts for 25 per cent of the weight of the command module. The principal task of the heat shield that forms the outer cover is to protect the crew and spacecraft systems from the high temperatures—about 2,800°C—experienced during the re-entry stage. The ablative material with which the heat shield is faced is a phenolic epoxy resin, which controls the rate of heat absorption by charring and then melting away.

The pressure-tight cut-outs allow entry to the command module. Access to the spacecraft at the beginning and end of the flight is by way of a 29in×38in hatch in the side of the craft, operated by a rachet handle action on a series of locking cams. Access to the lunar module in flight is through a tunnel hatch at the apex of the craft.

Five transparencies are provided around one side of the spacecraft: two side windows, each 13in square (located at the sides of the left and right astronaut couches), are used for observation and photography; two triangular rendezvous windows face the outside couches and allow a view forwards (over the apex of the craft) and are used for rendezvous manœuvres and docking as well as for general observation; and a hatch window.

The couches can be adjusted to assume a number of convenient positions applicable to a number of functions. They support the crew members during acceleration and deceleration, position them at their work stations, and attenuate landing shocks. For rest, use is made of two sleeping bags slung under the couches (i.e., between the couches at the base of the craft). Only two sleeping bags are used since one crew member is scheduled to be awake at all times.

The clothing worn varies with the stage of flight. There are three basic conditions: unsuited, suited and extravehicular. For the majority of the time the astronaut wears a bio-instrumented harness, a communications soft hat, a porous, constant-wear garment, flight overalls and bootees, and breathes cabin oxygen. At critical stages of the flight a spacesuit and helmet are donned. The full EVA (extravehicular) suit is described in a later section.

Food to provide each astronaut with about 2,800 calories/day is either freeze dried or concentrated and is carried in plastic bags. Each bag has a one-way valve through which water is pumped. The bag is then kneaded for 3min after which it may be cut open and the contents consumed. Sufficient food for 14 days is carried; Apollo is designed to be habitable for this period.

Personal hygiene is still a problem which has not been really satisfactorily solved. Liquid waste is dumped overboard, while solid waste is accumulated in bags which are retained on board.

The majority of the displays and controls which need to be monitored frequently are situated on the main display console which faces the three couches and extends on both sides of them. Other displays and controls are situated throughout the crew compartment and on the couches, while most of the navigation and guidance equipment is in the lower equipment bay at the foot of the centre couch. The main display console has been arranged to suit the responsibilities of the individual crew members. The spacecraft commander sits in the left-hand couch, the lunar module pilot in the centre and the command module pilot on his right. While each crew member has a special responsibility, he must know the spacecraft completely and be able to carry out any functions.

The command module and service module are integrated to a very high degree and it is therefore convenient to describe the latter briefly before discussing the various on-board systems.

4—SERVICE MODULE

The service module is a single cylindrical structure which, as its name implies, carries many of the spacecraft systems and consumable items (oxygen, water, propellant and hydrogen) for almost the entire lunar mission. It is attached to the CM from launch until just before re-entry, when it is jettisoned, to burn up in the atmosphere. The SM also contains the main propulsion engine of the spacecraft, which is used to brake the latter so as to enable it to enter orbit around the Moon, and to provide the subsequent velocity increment to place the spacecraft on an Earth-return path. It also provides major mid-course velocity corrections.

The structure comprises basically two upper and lower circular bulkheads, separated by six chemically milled aluminium beams which transmit the various loads. Much of the space available is occupied by two oxidiser tanks and two fuel tanks, and the other systems fit in the remaining space.

The Aerojet General service propulsion engine and its 9ft 4in nozzle are gimballed and provides 20,500lb of non-

Continued overleaf

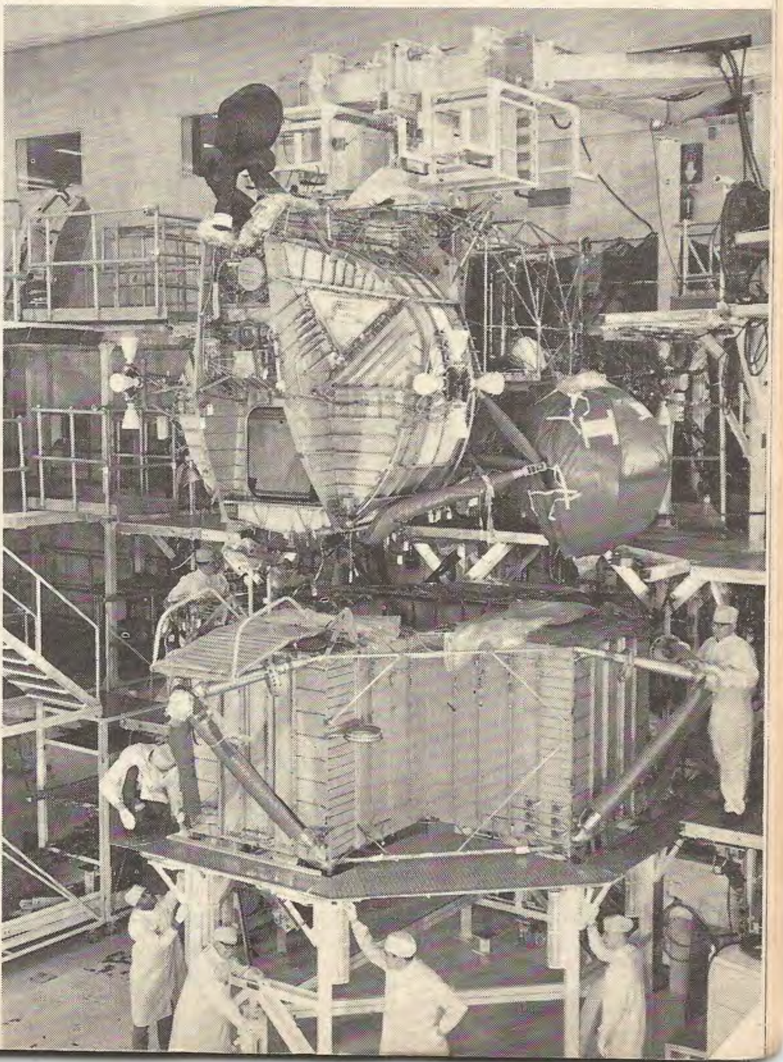
APOLLO/SATURN V DATA

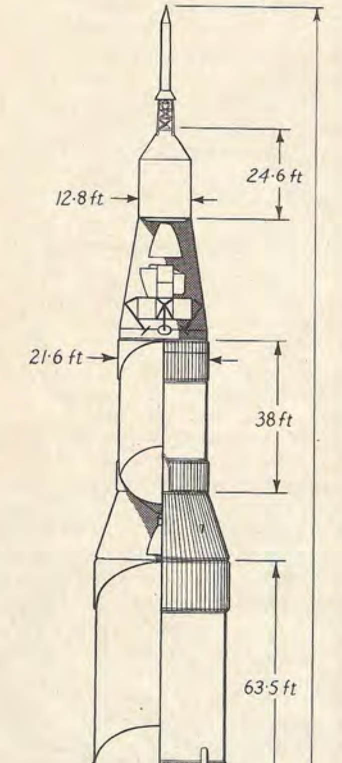
Vehicle/ Spacecraft	Height		Diameter		Gross wt. (lb)	Zero fuel wt. (lb)	Propulsive thrust (lb)
	(ft)	(in)	(ft)	(in)			
LES	33	0	4	0	8,900	—	155,000
CM	10	7	12	10	12,400	12,000	—
SM	22	7	12	10	55,000	12,704	21,500
LM	22	11	29	9	32,500	9,000	see below
SLA	28	0	12 21	10* 8*	4,150	—	—
IU	3	0	21	8	4,500	—	—
S-IVB	58	6	21	8	262,000	34,000	225,000
S-II	81	6	33	0	1,037,000	95,000	1,125,000
S-IC	138	0	33	0	4,792,000	300,000	7,500,000

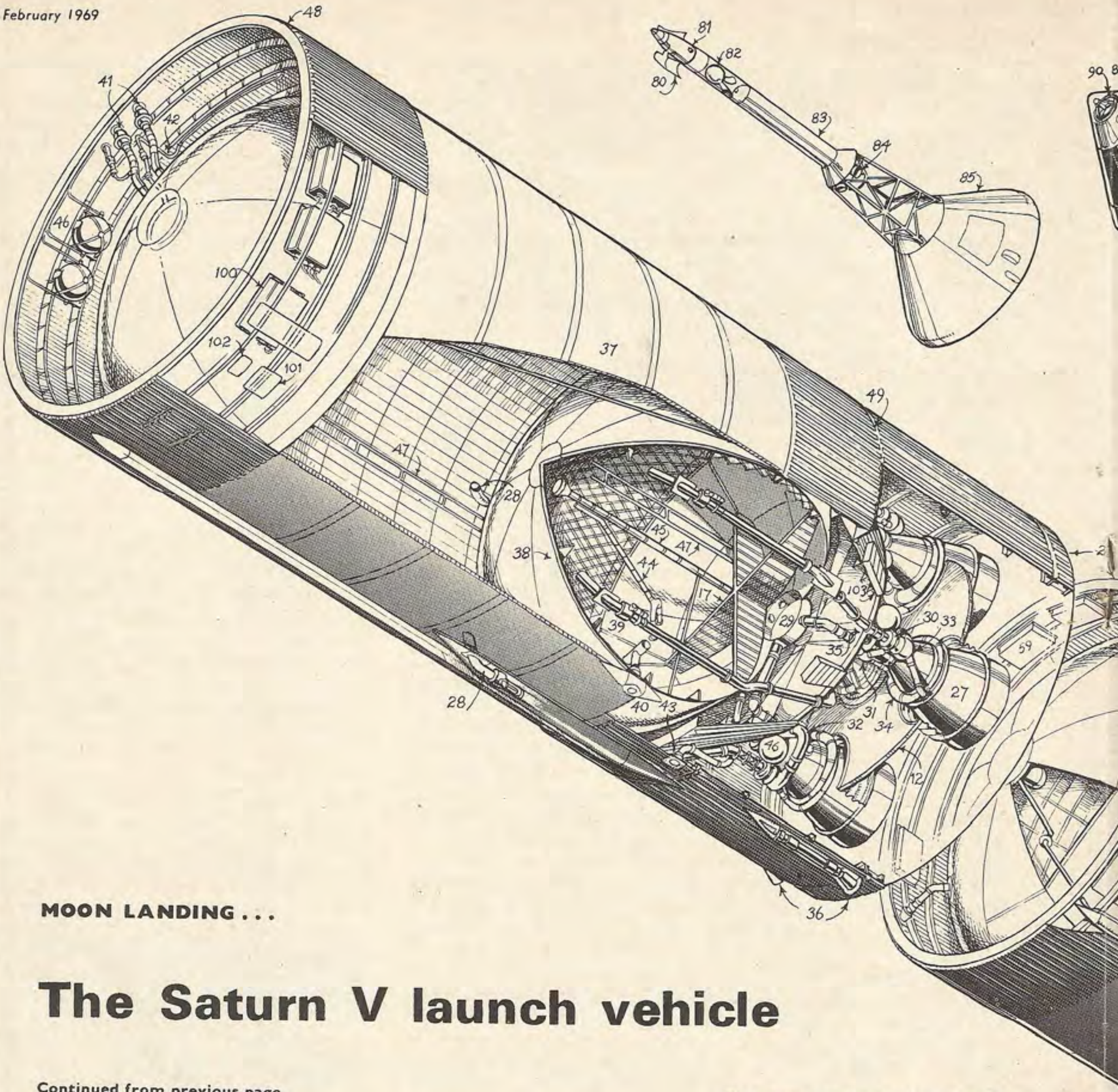
* Top and bottom diameters

SLA is the spacecraft—LM adapter, a truncated cone containing the LM. Total spacecraft weight at launch (CM+SM+LM but not including SLA), 99,900 lb. Gross weight of Apollo/Saturn V at lift-off for the lunar mission, 6,208,450lb. Spacecraft weight as percentage of lift-off weight, 1.5 per cent. The LM consists of descent and ascent stages, and data for these are as follows:—Descent stage: height, 10ft 7in; diameter 14ft 1in; weight (dry), 4,300lb; fuel weight, 17,880 lb. Ascent stage: height, 12ft 4in; diameter 14 ft 1in; weight (dry), 4,850lb; fuel weight, 5,170lb; fuel weight for reaction-control system, 605lb; pressurised volume, 235 cu ft; habitable volume, 160 cu ft. The column labelled propulsive thrust does not include contributions from the attitude-control systems of the CM, SM and LM.

From the photographic aspect the lunar module suffers from one disadvantage: owing to its extremely light construction it has to be supported during manufacture. The main elements are, however, clearly visible and should be compared with the cutaway drawing on page 217







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The Saturn V launch vehicle

Continued from previous page

throttlable thrust. It has a rated life of 750sec, can be re-started 50 times and may be operated for as little as 0.4sec. The fuel is a 50/50 mixture of hydrazine and UDMH (unsymmetrical dimethyl hydrazine), and the oxidiser is nitrogen tetroxide. The combination is hypergolic (the liquids react spontaneously on contact with one another) and consequently no ignition system is needed.

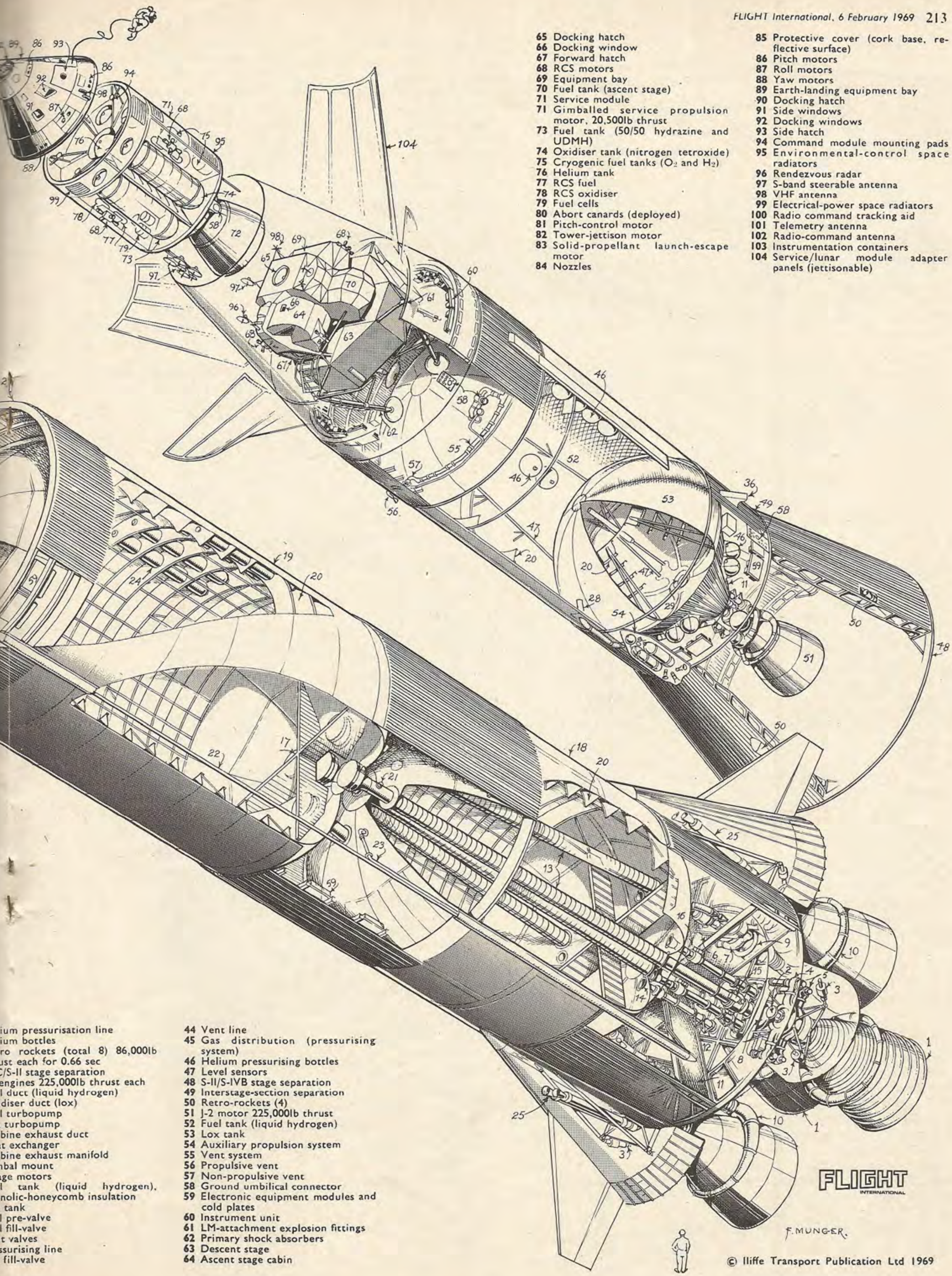
The SM contains three Bacon-type fuel cells by P&W, each 44in high, 22in diameter and weighing 245lb, which supply electrical power to the SM and CM, besides providing some drinking water. The fuel for these cells is cryogenic hydrogen and oxygen (carried in separate tanks in the SM) which is also employed for the environmental control system in the CM. Three silver/zinc storage batteries supply power to the CM after separation of CM and SM before re-entry. A further tank in the SM contains helium gas at 3,600lb/sq in used for pressure feeding the fuel and oxidiser to the engine.

Orientation of the CM and SM is commanded by two reaction-control systems, one on each module. That on the CM is used only after separation from the SM and in certain abort modes, and attitude control in space is normally obtained by operating the subsystem on the SM. The reaction control system on the SM comprises four similar, independent quads located 90° apart around the SM. Each quad consists of a in two directions: for example, one quad provides ± pitch and cluster of four engines (built by Marquardt), providing thrust ± roll while the quad mounted 180° apart provides ∓ pitch and ∓ roll. Each engine provides 100lb of thrust, using hypergolic monomethyl hydrazine and nitrogen tetroxide. Orientation

Continued on page 214

The various elements of the Saturn V launch vehicle and Apollo spacecraft may be identified by reference to the dimensioned general-arrangement drawing at the extreme left. Saturn V is America's largest rocket and, with the addition of nuclear upper stages, has been proposed for advanced planetary missions including manned voyages to mars. The standard Saturn V shown above can place 261,000lb in 100 n.m. orbit, 62,000lb in geo-stationary orbit, or 98,000 in Earth-escape trajectory. A total of 14 Saturn Vs has been ordered

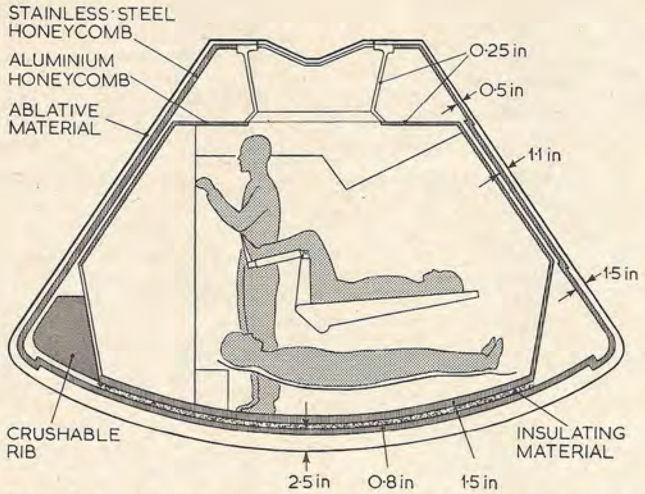
1 Bi-propellant F-1 engine
2 Gimbal mount
3 Gimbal-control actuator
4 Oxidizer valve
5 Fuel valve
6 Oxidizer pump
7 Fuel pump
8 Turbine (55,000 b.h.p.)
9 Heat exchanger
10 Turbine exhaust manifold
11 Thrust structure
12 Heat shield
13 Lox feed
14 Fuel feed
15 Lox pre-valve
16 Fuel pre-valve
17 Anti-vortex baffle
18 Fuel tank (kerosene)
19 Lox tank
20 Slosh baffles
21 Cut-off sensor
22 Gaseous-oxygen tank pressurisation line
23 Helium
24 Helium
25 Retro
thrust
26 S-IC/S-I
27 J-2 engi
28 Fuel duc
29 Oxidiser
30 Fuel tur
31 Lox tur
32 Turbine
33 Heat ex
34 Turbine
35 Gimbal
36 Ullage
37 Fuel
phenolic
38 Lox tan
39 Fuel pre
40 Fuel fill-
41 Vent val
42 Pressuri
43 Lox fill-



65 Docking hatch
66 Docking window
67 Forward hatch
68 RCS motors
69 Equipment bay
70 Fuel tank (ascent stage)
71 Service module
71 Gimballed service propulsion motor, 20,500lb thrust
73 Fuel tank (50/50 hydrazine and UDMH)
74 Oxidiser tank (nitrogen tetroxide)
75 Cryogenic fuel tanks (O_2 and H_2)
76 Helium tank
77 RCS fuel
78 RCS oxidiser
79 Fuel cells
80 Abort canards (deployed)
81 Pitch-control motor
82 Tower-jettison motor
83 Solid-propellant launch-escape motor
84 Nozzles
85 Protective cover (cork base, reflective surface)
86 Pitch motors
87 Roll motors
88 Yaw motors
89 Earth-landing equipment bay
90 Docking hatch
91 Side windows
92 Docking windows
93 Side hatch
94 Command module mounting pads
95 Environmental-control space radiators
96 Rendezvous radar
97 S-band steerable antenna
98 VHF antenna
99 Electrical-power space radiators
100 Radio command tracking aid
101 Telemetry antenna
102 Radio-command antenna
103 Instrumentation containers
104 Service/lunar module adapter panels (jettisonable)

ium pressurisation line
ium bottles
ro rockets (total 8) 86,000lb
ust each for 0.66 sec
C/S-II stage separation
engines 225,000lb thrust each
l duct (liquid hydrogen)
diser duct (lox)
l turbopump
t turbopump
bine exhaust duct
t exchanger
bine exhaust manifold
nbal mount
ge motors
l tank (liquid hydrogen),
nolic-honeycomb insulation
tank
l pre-valve
l fill-valve
t valves
ssurising line
fill-valve

44 Vent line
45 Gas distribution (pressurising system)
46 Helium pressurising bottles
47 Level sensors
48 S-II/S-IVB stage separation
49 Interstage-section separation
50 Retro-rockets (4)
51 J-2 motor 225,000lb thrust
52 Fuel tank (liquid hydrogen)
53 Lox tank
54 Auxiliary propulsion system
55 Vent system
56 Propulsive vent
57 Non-propulsive vent
58 Ground umbilical connector
59 Electronic equipment modules and cold plates
60 Instrument unit
61 LM-attachment explosion fittings
62 Primary shock absorbers
63 Descent stage
64 Ascent stage cabin



This maximum cross-section drawing of the command module illustrates the various positions which may be adopted by the crew. The astronaut standing on the base structure is facing the guidance and navigation station. The upper seat position is used for operation of the main control and display panel while the "flat-out" attitude is employed for sleep

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may be achieved by firing either one of two pairs of engines in a given plane.

The environmental-control system provides a living environment for three astronauts for 14 days. Under normal conditions the command module is pressurised to 5lb/sq in with 100 per cent oxygen atmosphere (during countdown and launch an oxygen/nitrogen atmosphere is employed to lessen the fire risk) and the temperature is stabilised to between 70°F and 75°F. The system provides oxygen and hot and cold water; removes carbon dioxide and odours from the CM; provides for the venting of waste; and dissipates excessive heat from the cabin and equipment. It is automatic in operation to a very large extent.

The spacecraft is guided and controlled by two inter-related systems which provide rotational, line-of-sight and speed/acceleration data to the propulsion and reaction-control systems and the data-display panels. These are the guidance and navigation system, and the stabilisation and navigation system.

Astronaut commands to change the attitude and speed is via two rotation-control handles and a speed-control handle. The rotation controllers enable pitch, roll and yaw commands to be sent to the reaction-control system. At the same time they cause the propulsion motor to gimbal so that, if the latter is operating, a change of flight path is also commanded.

Two indicators on the main display console show the attitude of the spacecraft with reference to star fixes. From them attitude error and rates of change may be ascertained.

5—THE LUNAR MODULE

The lunar module is the very first manned spacecraft to be designed for operation exclusively in space and the reduced gravitational field of another planet. It is strong enough only to withstand the acceleration forces during launch and the stresses of a Moon landing, and the design is not constrained by aerodynamic considerations. It is therefore a unique vehicle.

The function of the LM is to transport two astronauts from the command module (in orbit around the Moon) to the surface and provide a base and facilities for an excursion of about 24hr. At the conclusion of the stay the LM will ferry the two astronauts back to the orbiting CM.

Grumman Aircraft Corporation was selected by NASA in November 1962 to build what was known originally as the LEM (lunar excursion module) now shortened to LM. So far the vehicle has had one unmanned orbital test flight and the purpose of the Apollo 9 flight this month is to fully test the manned vehicle in low-Earth orbit.

The greatest problem in the LM design was weight control. Every pound of weight added to the spacecraft has to be paid for with about 70lb of vehicle and fuel. For this reason great care was taken at all stages to ensure the minimum redundancy both in structure and systems.

The LM consists of two units, the descent and ascent stages. The descent stage operates rather like a launch vehicle in reverse; it is used to fly the ascent stage (containing the crew) to the Moon, soft-landing it on the surface. It later provides the platform from which the ascent stage is launched to regain the command module; its function is then completed and it is left on the surface. The ascent stage contains the astronaut's compartment, the ascent propulsion system and control and guidance equipment for both stages. The LM is designed to operate for a maximum stay of 48hr while separated from the CM, the main constraint being heat absorption in the supercritically cooled bottles of helium used for pressure-feed of the reaction-control system.

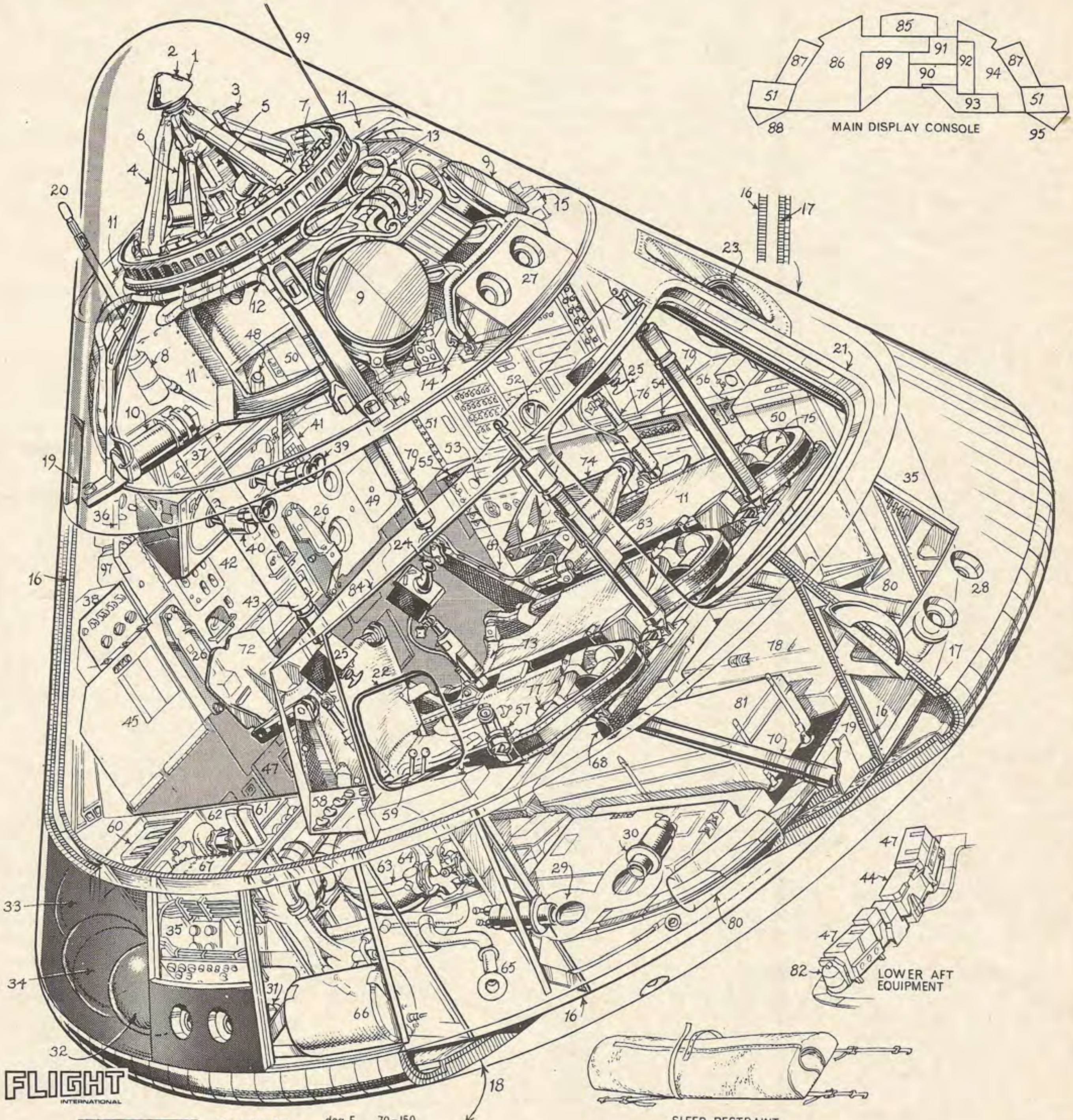
The descent stage is a fairly simple octagon-shaped platform structure containing the four landing legs (which fold together for stowage in the launch vehicle), batteries, scientific equipment which will be used on the Moon, fuel tanks and the descent engine. It is a chemically milled aluminium alloy structure. The function of the engine is to brake the LM from its orbital velocity of 5,480ft/sec and allow a gentle touchdown on the Moon. The engine is unusual in being of the deep-

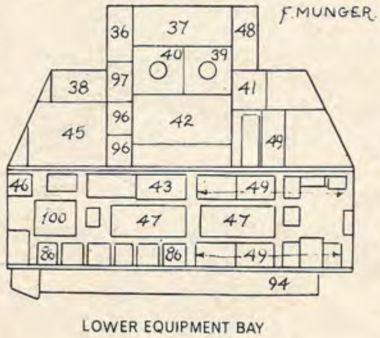
Continued on page 216

KEY TO DRAWING OPPOSITE

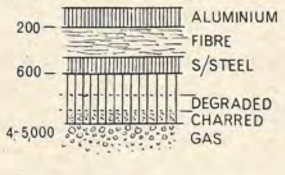
1 Docking probe
2 Capture latches
3 Capture latch release (LM side)
4 Probe shock-attenuator assembly
5 Telescoping cylinder (nitrogen pressure retraction)
6 Fixing strut
7 Docking latches
8 Forward heat-shield ejectors (operate at 25,000ft)
9 Drogue parachute mortar, fires at 23,000ft, 16.5ft conical ribbon parachute slows capsule from 300 m.p.h. to 175 m.p.h.
10 Pilot parachute mortar (3 locations) fires at 10,000ft
11 Main landing parachute stowage (3 locations) uprighting bags stowed under 83.5ft ring-sail parachute slows capsule to 22 m.p.h. on spash down
12 Main parachute riser
13 Sea-recovery cable
14 Dye-marker and swimmer umbilical
15 Launch-escape tower electrical receptacle
16 Pressure shell, bonded aluminium honeycomb 0.25in to 1.5in thick
17 Brazed stainless-steel honeycomb 0.5in to 2.5in thick
18 Aft heat shield, phenolic-filled epoxy ablative material, weight 3,000lb
19 Launch-escape tower frangible nuts
20 Flashing recovery beacon (deployed)
21 Outward-opening hatch 29in x 34in 12-latch, quick release, nitrogen pressure counter-balance system
22 Side windows, 13in x 13in
23 Rendezvous windows, 8in x 13in (inner pane tempered silica 0.25in thick, outer amorphous-fused silica 0.7in thick, reflective and infra-red and ultra violet filters)
24 CM rotation control
25 CM translation (thrust) control
26 Alternative (navigation) positions for control units
27 Negative pitch motor (all motors 93lb thrust)
28 Positive pitch motor
29 Negative roll motor
30 Positive roll motor
31 Negative yaw motor
32 Helium tank No 2 system (titanium)
33 Fuel tank No 1 system (titanium)
34 Fuel tank No 2 system
35 Servicing hatch
36 Auxiliary test panel
37 Optics stowage
38 Lighting control
39 Telescope
40 Sextant
41 Computer display and keyboard
42 Guidance and navigation control panel
43 Computer
44 Tape recorder
45 Food stowage
46 Medical kit
47 CO_2 absorber stowage
48 Radiation-survey meter
49 Communication equipment
50 Flight-data file
51 Circuit breakers
52 Waste stowage
53 Waste-management panel
54 Battery circuit breakers
55 Power circuit breakers
56 Uprighting system panel
57 Docking sight (stowed)
58 Oxygen control
59 Cabin-pressure control
60 CO_2 filters (lithium hydroxide and activated carbon)
61 Oxygen to umbilical supply control
62 Suit compressors (two)
63 Oxygen surge tank
64 Cabin pressure-control valve
65 Steam vent
66 Potable water tank
67 Glycol evaporator
68 Couch-support beam
69 Side stabiliser beam
70 Shock-absorber strut
71 Glassfibre cloth
72 Foot-pan
73 Foot-pan and seat folded down
74 Foot-pan and seat folded up
75 Adjustable head rest
76 Adjustable control support
77 Restraint straps
78 Personal kit and special kit stowage
79 Tool stowage
80 Sleep-restraint stowage
81 Pressure-suit stowage
82 Fire extinguisher, 8lb aqueous foam
83 Internal viewing mirror
84 Main display console
85 Control warning
86 Flight control
87 Audio control
88 SCS (stabilisation control system) power
89 RCS (reacton control system) monitor
90 Environmental control (see also 95)
91 Cryogenics
92 Service propulsion
93 Communications
94 Electrics
95 Environmental control
96 Gyro units
97 Accelerometer electronics
98 VHF scimitar antenna
99 VHF recovery beacon (deployed)
100 Camera stowage

The command module





LOWER EQUIPMENT BAY



Notwithstanding a diameter and height of 12ft and 10ft respectively, space for three astronauts during a seven-day flight is at a premium, although the crew does have more room per man than those of Mercury or Gemini. This view shows the upper surface of the command module, which has five windows. The detailed drawings outside the command module are approximately to scale among themselves, but are reduced by half from the scale of the main drawing. Key on facing page throttling multi-start type, and can be varied from 9,710lb thrust maximum down to 1,050lb. It may be gimballed on its mounting up to 6° from the vertical axis to provide pitch and yaw control during descent (roll control is provided by the reaction-control system on the ascent stage).

Four main propellant tanks (two oxidiser and two fuel) are symmetrically disposed around the engine. Such items as scientific equipment, the aerials to be set up on the Moon's surface, four electrical sub-system batteries, six portable life-support system batteries, and tanks for helium, oxygen and water are located in bays adjacent to the propellant tanks.

The landing gear is of cantilever type and consists of four legs connected to outriggers. Each leg comprises a primary strut and footpad, a drive-out mechanism, two secondary struts, two downlock mechanisms and a truss. Each strut has a shock absorbing insert of crushable aluminium honeycomb to soften the landing impact. The forward-facing landing gear has a boarding ladder on the primary strut to enable the astronauts to climb from the forward hatch to the Moon. The four legs are left retracted until shortly after the astronauts enter the LM during lunar orbit. They are extended by operating a switch in the LM. The footpads, 37in diameter, are made of two layers of spun aluminium bonded to an aluminium honeycomb case.

The ascent stage employs a single, constant-thrust rocket engine developing 3,500lb *in vacuo* which thrusts the ascent stage away from the descent stage at the conclusion of the stay on the Moon, and places it in CM-acquisition orbit. Two tanks are situated one either side of the structure, and provide fuel (a 50/50 mixture of hydrazine and UDMH) and oxidiser (nitrogen tetroxide) for the main propulsion engine and for the reaction-control system.

The reaction control system stabilises the LM during descent and ascent and controls the attitude and lateral movement during landing, rendezvous and docking manœuvres. The system comprises 16 thrust chambers fed by two separate helium-pressurised propellant supplies. The 100lb thrusters can be pulsed or fired continuously.

During flights the astronauts are not seated but stand on the floor of the LM supported and restrained by straps passing around the waist and fixed to the roof and floor of the cabin. The reason for this is that the astronauts have a better view below the spacecraft, and the absence of seats keeps the weight down. With Moon gravity only one-sixth that of Earth, there should be no fatigue or landing-shock problems.

Guidance and navigation is an inertial system monitored by star fixes taken with an alignment telescope. Altitude and velocity are provided by a landing radar which is also used to update inertially derived data. During the descent, stay and rendezvous stages, a rendezvous radar tracks its transponder in the CSM to generate range, range rate and angle measurements to the LM guidance computer.

6—COMMUNICATIONS

Communications is the science of information transmission. The Apollo mission is so complex that a very comprehensive system indeed must be organised to meet the demands placed upon it. The requirements are specifically to provide voice, television, telemetary, tracking and ranging facilities between the spacecraft and Earth, between the orbiting CM and the landed LM and between the LM and Earth the astronauts on local excursions. Most of the telecommunication sub-system on the spacecraft is built by Collins Radio.

A completely new ground network, the Apollo unified S-band system, has been commissioned for America's manned spaceflight programme. The adjective "unified" indicates that the system can be operated simultaneously in both the tracking and communication modes, using a single band of frequencies in the range 1,550 MHz-5,200MHz (Mercury and Gemini used different frequency bands for tracking and communication). Specifically this system enables two-way voice transmission between spacecraft and Earth; two-way telemetry data; ranging, Earth-spacecraft-Earth (for tracking purposes); and TV transmissions, spacecraft-Earth.

S-band equipment is carried in both the CM and LM, and communication with Earth is by means of a network of 14 ground stations around the globe. Eleven of these, each with a 30ft antenna, help to provide continuous horizon-horizon coverage while the spacecraft is in Earth orbit, and are supplemented with tracking ships and aircraft. As the spacecraft moves out towards the Moon, the horizon restrictions disappear and, since the 30ft aerials are not large enough to provide a link at great distances, the task of maintaining contact falls progressively more on the three 85ft stations at Goldstone, California; Madrid, Spain; and Canberra, Australia. Each of these stations is connected with the Manned Spacecraft Centre at Houston, Texas, and the Goddard Space Flight Centre at Greenbelt, Maryland, by landline, ocean cable, microwave or satellite links.

UHF is used for communications between the CM and LM and between the LM and the astronauts during their excursions on the Moon. Astronauts will also be able to talk direct from the surface to Earth via an S-band relay on the LM.

7—KENNEDY SPACE CENTRE

Gateway to the Moon for the Western world is the—it must be admitted—flat and rather dreary area on Florida's East coast, formerly known as Cape Canaveral, and now as Cape Kennedy. Reasonably close to the equator making for convenient orbits, facing east (the direction of the Earth's motion gives 1,000 m.p.h. bonus to launch vehicles) and having virtually uninterrupted emergency splash-down area over a very wide area, Cape Kennedy is very well placed indeed.

Following President Kennedy's 1961 commitment NASA obtained Congressional approval to create a national spaceport on 88,000 acres of land on Merritt Island, adjacent to Cape Kennedy. In August 1961 this location was officially designated as the launch site for the Moon programme, and became launch complex 39. Two launch areas, designated Pads A and B, have been built to handle the Apollo flights.

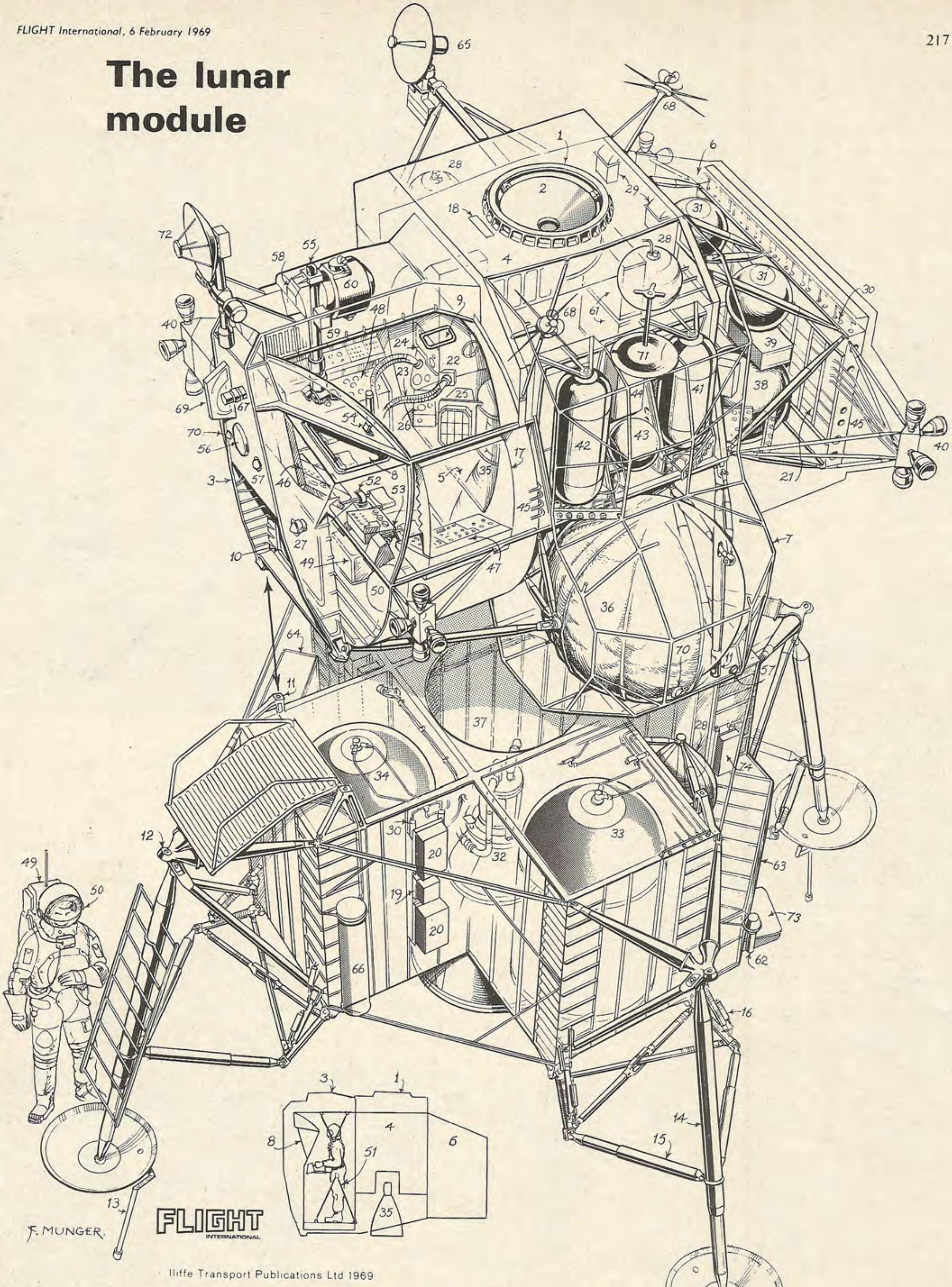
The complexity of Apollo has brought about a radical change in the operation of the launch site. All previous NASA launches have taken place on the "fixed launch" principle. In this the rocket and spacecraft is assembled and integrated at

Continued on page 218

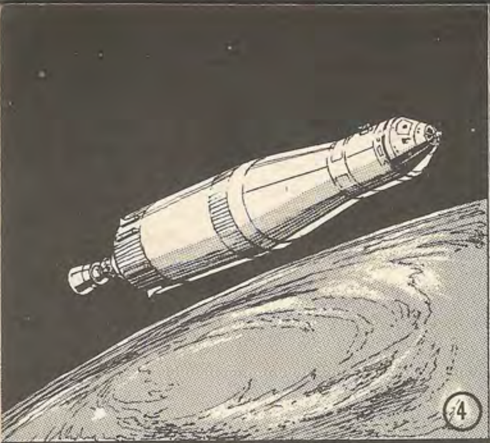
KEY TO DRAWING OPPOSITE

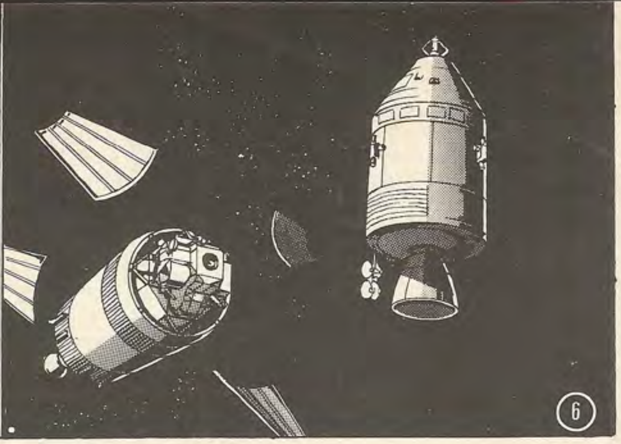
1 Docking hatch LM/CM
2 Docking drogue (removeable for access)
3 Cabin assembly
4 Mid-section equipment bay
5 Engine-bay deck
6 Aft equipment bay
7 Insulation-support frame
8 Forward-vision window
9 Docking window
10 Forward hatch
11 Descent/ascent section explosive attachment bolts
12 LM/third-stage attachment lugs
13 Lunar-surface sensing probe
14 Primary shock-absorber strut
15 Secondary shock-absorber strut
16 Deployment truss and down-lock
17 a.c./d.c. (28V d.c. 115V a.c., 400Hz)
18 CSM/LM electrical umbilical connectors
19 Electrical control assembly
20 Descent batteries (4x12V silver zinc)
21 Electrical control assemblies, ascent batteries (two), abort electronics, attitude and translation control, rendezvous radar electronics, S-band electronics
22 Environmental-control system
23 Umbilical hose
24 Oxygen control
25 Cabin-air recirculation fan
26 Water control and suit temperature control
27 Cabin pressure-relief valve
28 Water tank
29 Primary and secondary water evaporators
30 Cold-plate units
31 Gaseous oxygen
32 Descent engine, 10:1 throttle ratio, 10,000lb maximum thrust
33 Descent fuel tank. Aerozine 50 (50-50 hydrazine and UDMH) port and starboard
34 Descent oxidiser tank (nitrogen tetroxide) fore and aft
35 Ascent engine, 3,500lb thrust in vacuo
36 Ascent fuel tank (Aerozine 50); oxidiser tank to starboard
37 Aperture for ascent-engine skirt
38 Helium tank (two)
39 Helium pressurisation control modules
40 Reaction-control motors, 100lb thrust, pulsed or continuous firing
41 Reaction-control fuel (Aerozine 50) port and starboard
42 Reaction-control oxidiser (nitrogen tetroxide) port and starboard
43 Reaction-control helium
44 Helium pressurisation module
45 Pipe runs to motors
46 Main flight panel
47 Commander's side console
48 Second crew-member's side console
49 Portable life-support equipment
50 Extra-vehicular visor
51 Support and restraint harness
52 Attitude-control stick
53 Translation/thrust control
54 Optical sight
55 Alignment telescope
56 Tracking light
57 Docking light
58 Abort sensor
59 Rate gyro
60 Inertial-measuring unit
61 LM guidance computer
62 Radio-isotope thermal generator
63 Scientific-equipment boxes
64 Specimen return containers
65 S-band steerable antenna
66 S-band erectable antenna (lunar surface)
67 S-band in-flight antenna
68 VHF antenna
69 Scimitar antenna
70 C-band antenna
71 Docking target
72 Rendezvous radar
73 Landing antenna
74 Landing-radar electronics

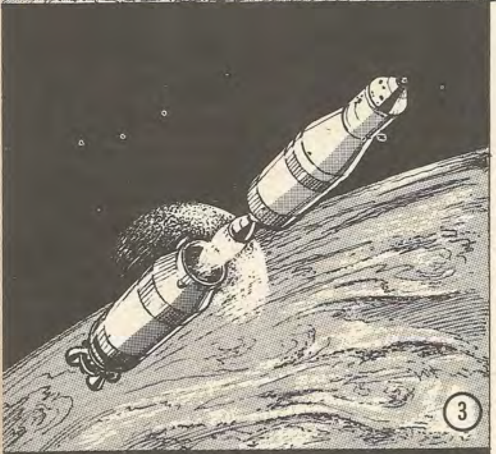
The lunar module

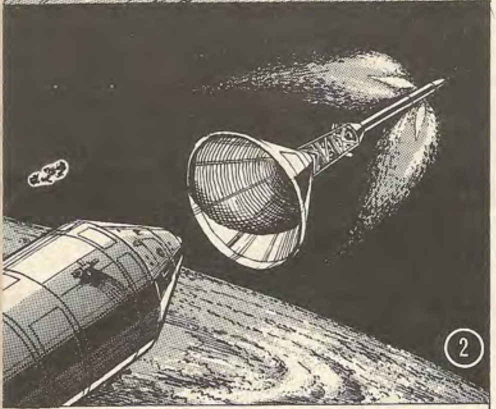


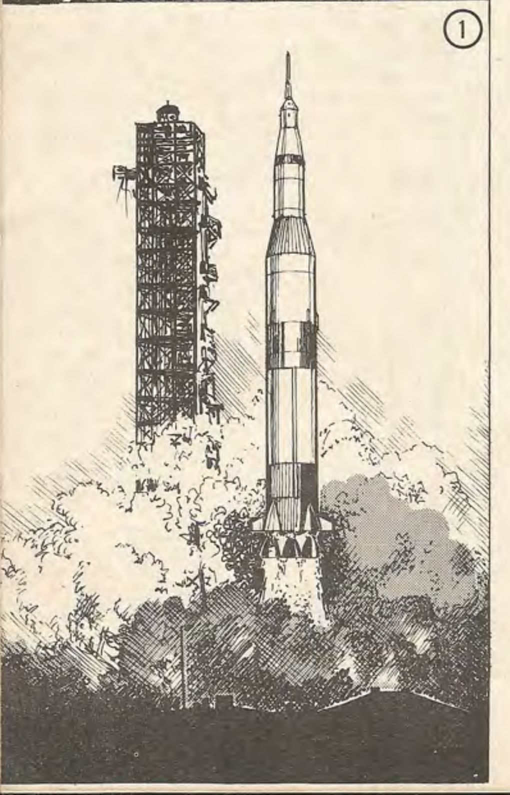
The two elements of the lunar module—the ascent and descent stages—are shown above separated for clarity. Scale is provided by the astronaut standing beside the ladder, and dressed in the full spacesuit which is "de rigeur" for any expedition outside the spacecraft or on the Moon. The descent stage provides a launch platform for the ascent stage. At lift-off, the upper-stage engine exhausts through the central tunnel in the lower stage











MOON LANDING . . .

Continued from page 216

the launch pad. But with Apollo, time between scheduled launches is less than the assembly and integration time. This necessitated a scheme whereby two or more vehicles could be built up simultaneously and transported to the launch site. This originated the mobile launch concept.

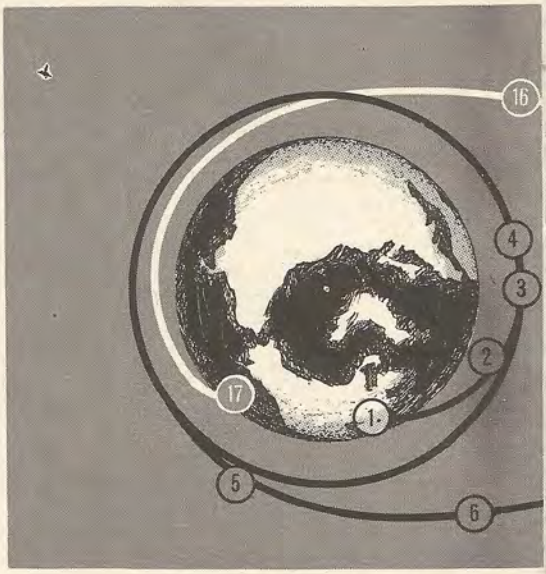
The technique employed with Apollo is to assemble the Saturn V vehicle and spacecraft in a protected environment after which it is transported over a three-mile road to the launch site for final checkout and launch. For this purpose what is claimed to be the world's largest building, the VAB (vehicle assembly building) was erected so that up to four vehicles could be assembled simultaneously. This structure is 525ft high, 716ft long and 518ft wide.

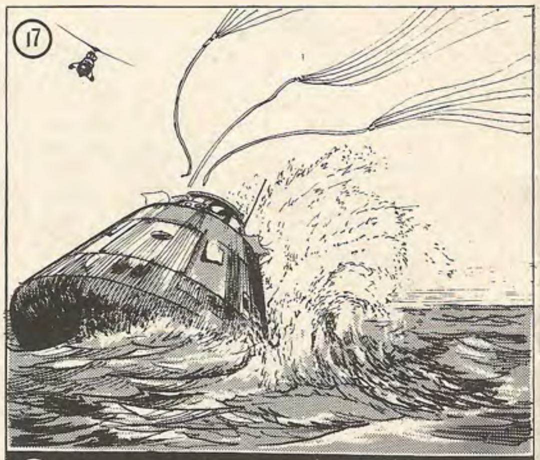
Each vehicle is assembled in the VAB on a mobile launcher, which is then transported by special vehicle to the launch pad. The transporter vehicle is 131ft long and 114ft wide and requires 5,500 h.p. to drive its 5,000 ton load at a speed of about 1.5 m.p.h.

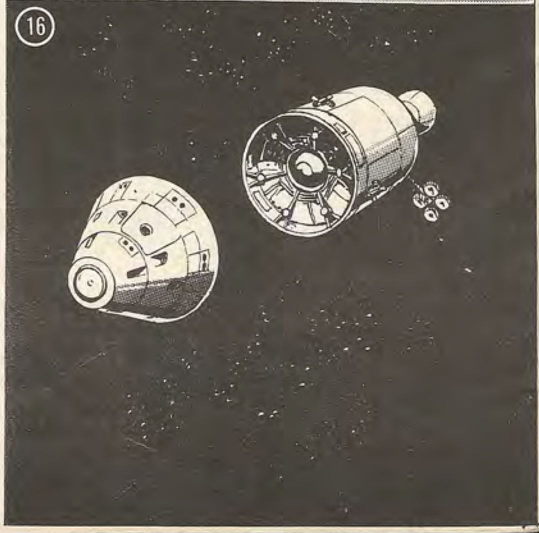
8—THE FLIGHT

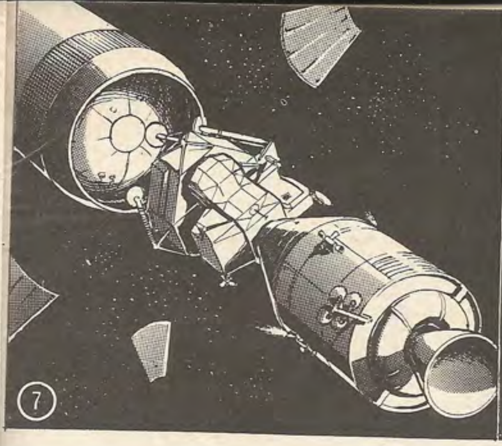
As a result of the flights of the unmanned Ranger, Lunar Orbiter and Surveyor orbiting and landing spacecraft, backed up by the flight of Apollo 8 last December, some five sites suitable for the landing have been chosen along the Moon's equator. These sites are on the always-visible face of the Moon so that communications with Earth are possible without having to use a special relay system. The best lighting conditions for each site occur when the angle made by the Sun with the Moon's horizon lies between 7° and 20°, which allows the best contrast for landmark identification and landing. Lighting considerations therefore determine the date of launch. If the launch has to be postponed so that the Sun angle at that site is outside the limits, then the next site (moving East over the lunar equator) is chosen, and a new launch date geared to that site.

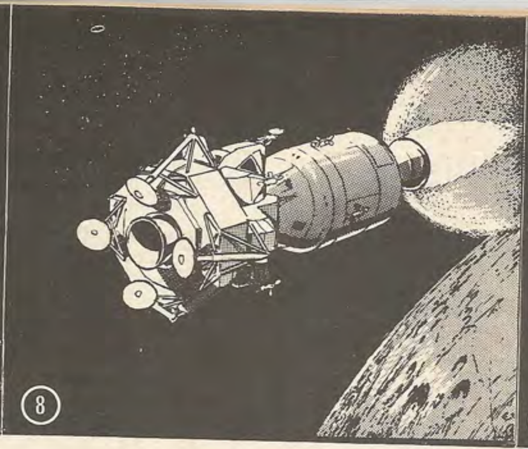
The flight path to and from the Moon will be generally similar to that of

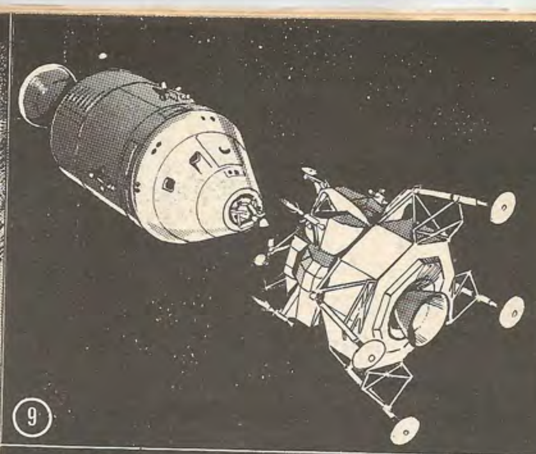


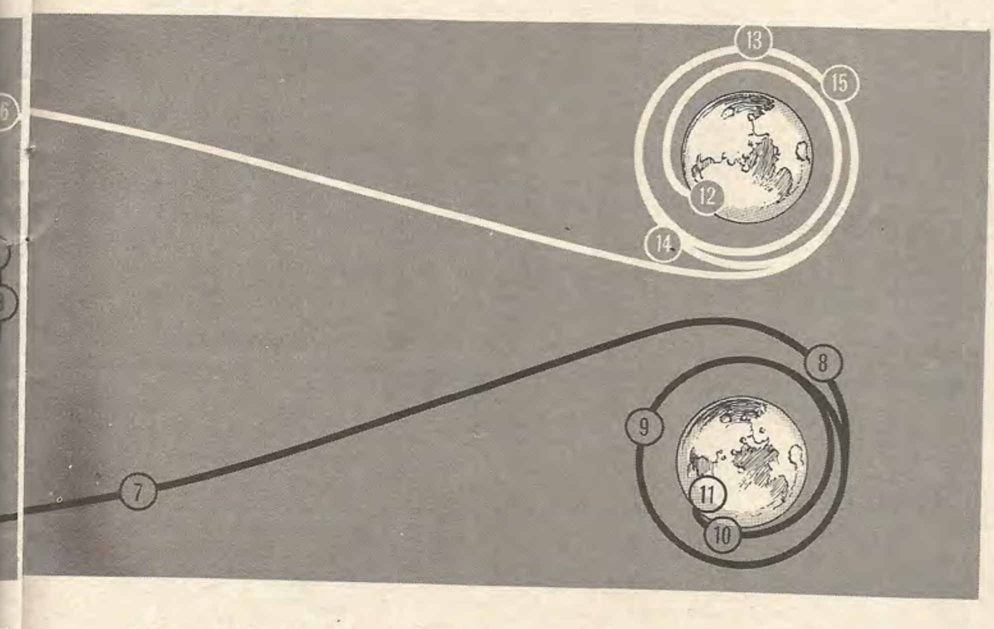


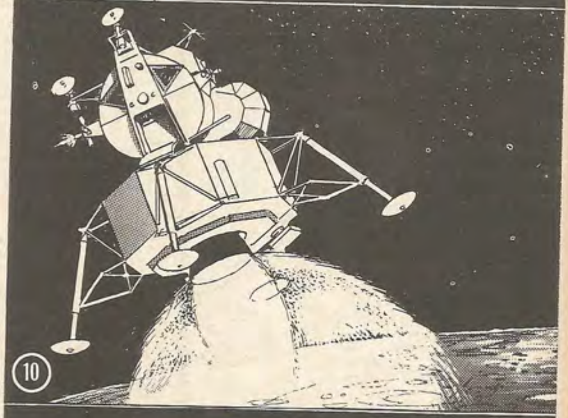


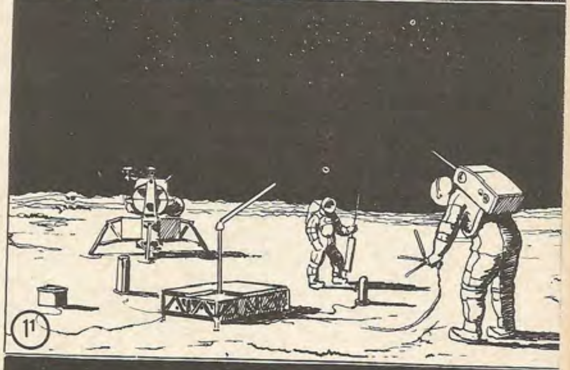












The main events of the flight are illustrated here diagramatically and pictorially. The sequence of events around the sides of these pages may be related to the journey as shown above. 1, Lift off; 2, launch escape system jettison; 3, staging (3rd stage burn); 4, insertion to Earth orbit; 5, translunar insertion; 6, module transposition, CM/LM docking; 7, jettison 3rd stage; 8, Moon orbit insertion, crew transfer to LM; 9, CM/LM separation; 10, LM descent and landing; 11, lunar exploration; 12, LM lift-off; 13, LM/CM docking and crew transfer to CM; 14, LM jettison; 15, trans-Earth insertion; 16, SM jettison and re-entry; 17, splashdown

Apollo 8 last December. The mission will be flown from one of the two Saturn V launch pads at Cape Kennedy. While details of the actual Moon-landing flight will not be finalised for some months, the following schedule represents a nominal mission. The launch window is open for about 8hr per day.

After launch the S-IC stage boosts the vehicle to an altitude of 36 miles at a distance of 54 miles down-range, taking 151sec and cutting-off at a speed of 6,068 m.p.h. At lift-off, incidentally, the weight of the vehicle is just balanced by four F-1 engines, leaving the fifth to provide upward acceleration. The centre engine is

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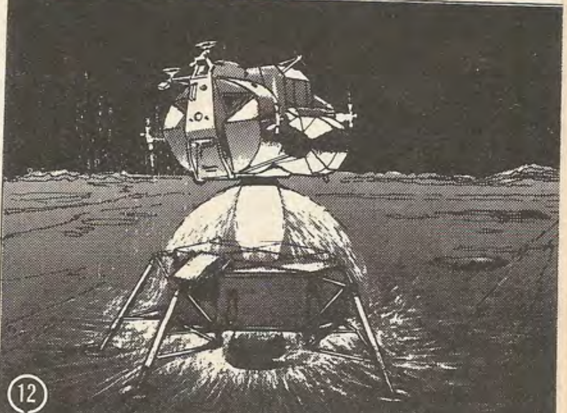
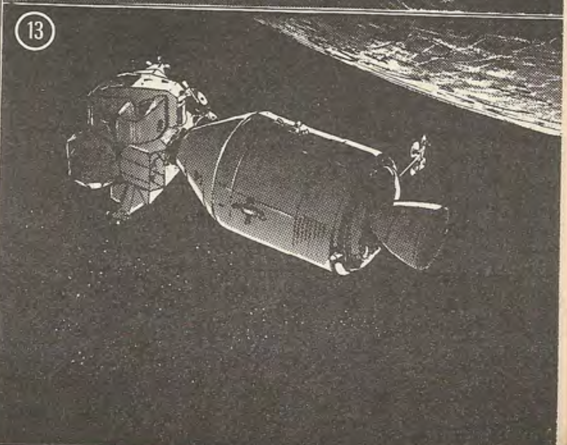
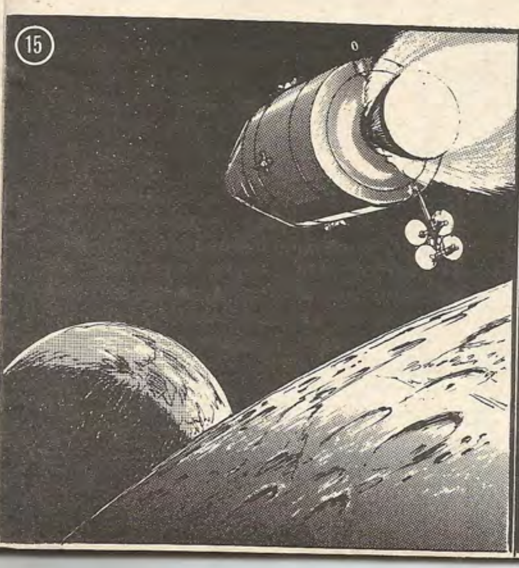
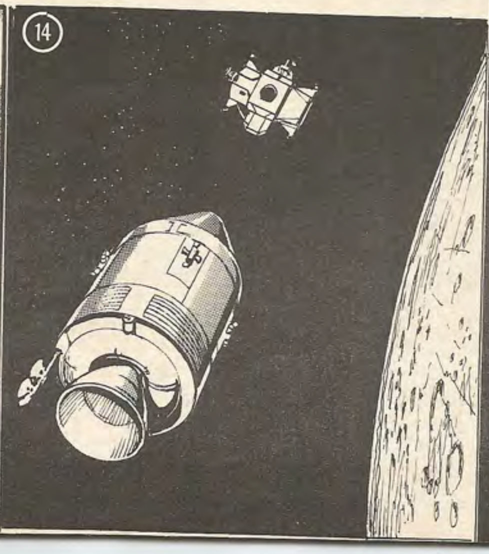
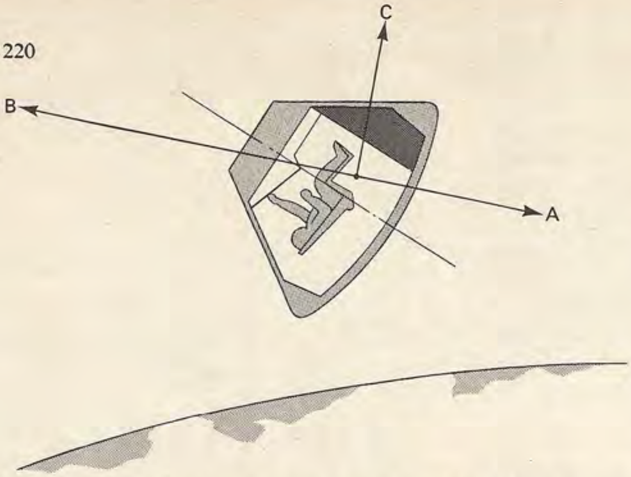










This drawing illustrates the attitude of the CM during re-entry. The astronauts travel "heads down", and they are therefore able to see the Earth. A, B and C represent respectively the flight, drag and lift vectors

MOON LANDING . . .

cut off 126sec after lift-off to prevent the load factor from exceeding 4g. A 2sec delay occurs between first-stage cut-off and second-stage ignition to allow the former to be jettisoned safely, after which the S-II stage takes over and burns for 367sec. At the end of this burn, 520sec from lift-off, the vehicle has attained an altitude of 106 miles and a downrange distance of 927 miles. The velocity at S-II burnout is 15,258 m.p.h. The LES is jettisoned during the S-II burn, 187sec after lift-off and at a height of 54 miles. The first of two S-IVB third-stage burns begins 524sec after lift-off to provide Earth-orbital velocity of 24,700 m.p.h., and is cut-off 157sec later.

At least two Earth-orbits will be flown while the spacecraft systems are checked to ensure serviceability. As a general rule the mission is made on the basis of a step-by-step "commit point" basis; decisions to continue the mission, return to Earth or adopt a different flight plan are made before each manœuvre, based on the serviceability of spacecraft and crew.

TLI (translunar injection) is achieved by a second S-IVB burn of about 5min 12sec (beginning when the spacecraft passes through the antipodal Moon-Earth axis) which confers the velocity increment of about 12,000ft/sec needed for a 65hr transit to the Moon. The next stage is to organise the spacecraft so that the SM engine may be used. This is not possible in the launch configuration since the LM is stowed just before the SM. The CSM (command and service module) is therefore separated from the S-IVB and rotated to face the other direction.

Meanwhile the fairings which cover the LM (the adapter panels) have been jettisoned to expose the LM, and the CSM is manœuvred using the attitude-control engine to dock with the former. This operation is done manually, using a sighting ring on the CM as an aiming mark. With the LM rigidly attached, the CSM then separates from and abandons the S-IVB/IU stage. This early manœuvre allows the service propulsion engine to be used if necessary (e.g. for an emergency abort), and provides the crew with some dress-rehearsal practice and confidence. The S-IVB is then commanded to follow a separate trajectory around the other side of the Moon to put it into heliocentric orbit, out of the way of the spacecraft.

Mid-course path connections are made, using the service propulsion system. All the while the spacecraft has been slowing down (from the moment of cut-off of the second S-IVB burn, in fact) and eventually a minimum velocity of about 2,100 m.p.h. is reached before the gravitational field of the Moon becomes greater than that of the Earth. After this the spacecraft accelerates as it nears the Moon. In an emergency, the spacecraft could return to the Earth with no further expenditure of energy by swinging around the far side of the Moon. The dynamics of the orbit are such that the spacecraft would then enter an Earth-return path.

The decision proceed with the planned mission is followed by a braking operation to allow the spacecraft to enter an elliptical orbit around the Moon. LOI (lunar orbit insertion) into a 69/196 mile orbit is achieved by operating the SPS engine while the spacecraft is behind the Moon, to provide a velocity change of 2,991ft/sec. A second burn then circularises the orbit at 69 miles by means of a 138ft/sec decrement. While present NASA plans call for the lunar mission to be flown from a 69-mile altitude, it is understood that this may be reduced considerably to provide extra safety margins for the lunar-module rendezvous.

The LM will have been checked out by the crew during the flight; access to the vehicle is possible once the CSM is mated with the LM. The two astronauts who will land on the Moon will don their special spacesuits, open the communicating hatch into the LM and, after removing and stowing the triangular docking probe, climb through to the LM.

At least one circular orbit of the Moon will be made to verify spacecraft performance and make a final landmark check. The decision to proceed with the landing is marked by the separation of the CSM and the LM. The LM then rotates so that its engine faces the direction of motion. The initial de-boost of the LM is made behind the Moon, as a result of a small impulse from the descent engine. Following a coast period of about 1hr (covering about 180° of longitude), the spacecraft will have drifted down to about 50,000ft. If for some reason the decision is made not to land, the LM will continue its elliptical orbit to intersect that of the LM so that rendezvous can take place without further expenditure of LM energy. If everyone is still happy the descent engine is again operated to initiate Stage 1, the braking manœuvre. Maximum thrust is employed at a near-horizontal flight path so that efficient reduction of orbital velocity is achieved, and the duration of burn is nearly 8min, during which the LM has travelled about 250 miles while the height has reduced to about 8,600ft.

The final approach, Stage 2, begins at this height, some eight miles from the touchdown point, with a pitch manœuvre which brings the horizon and landing site into the pilot's view for the first time since separation. The purpose of this manœuvre is to allow the crew time (about 90sec) to assess the trajectory and the proposed landing area and enable the pilot to assume manual control of the spacecraft if he so desires. At the end of Stage 2, altitude is about 500ft and the slant range to touchdown is 1,200ft. During all this time the two vehicles are in sight of one another and communications may be maintained.

Stage 3, the landing phase, is under manual control since a detailed assessment of the surface is necessary and some lateral manœuvring will almost certainly be necessary. The last 100ft is covered in a vertical descent and proximity of the spacecraft to the surface is signalled by movement of the sensing rods attached to each landing footpad. The duration of this stage is nominally about 75sec, but may be extended if necessary.

During the descent one astronaut flies the craft while the other assess the surface for final guidance.

The period immediately after landing will be occupied in running a pre-launch checkout on the spacecraft systems.

After verification of the spacecraft and its systems the two astronauts will turn their attention to the scientific aspect of the flight. The immediate tasks will be the survey and photography of the area around the Moon, the collection of soil samples in sterilised containers and the deployment of a package containing three scientific experiments. These will comprise a passive seismometer, a laser-ranging retro-reflector, and a solar-wind analyser.

The seismometer is a self-contained 100lb seismic station with its own Moon-Earth data link, powered by solar cells and containing a radio-isotope heater to enable it to survive the extremely cold night for up to one year. The second experiment is a wholly passive device consisting of an array of precision optical reflectors which will serve as a target for Earth-based lasers. This will enable data on the Earth-Moon distance and the fluctuation of the Earth's rotation rate to be obtained. The solar wind analyser is a 1lb experiment, developed by the Swiss Government, consisting of a sheet of aluminium foil directed across the solar-wind flow to absorb the rare gas constituents: helium, neon, argon, krypton and xenon. It will be retreived before the astronauts leave for the Earth, and returned for analysis.

The experience gained in deploying these experiments will be used when planning the more ambitious ALSEP (Apollo lunar surface experiments package) on the next flight. ALSEP was originally scheduled to be flown on the first flight but was replaced when doubts arose as to the ability of astronauts to manage the deployment task. Experience with EVA (extra-vehicular actively) on Gemini flight has demonstrated that astronauts trained to perform simple operations during space walks were frequently unable to do so, and were quickly tired. During the first landing, therefore, the tasks will be carefully graded in order of increasing difficulty.

The first stay on the Moon will last for about 18hr/24hr and astronauts will take turns in leaving the LM to explore the immediate neighbourhood. The Moon is an inhospitable world; far from there being an atmosphere the pressure at the surface corresponds to a hard vacuum. Pressurisation and oxygen must therefore be supplied. There are no breezes to cool the astronaut in direct sunlight or warm him in shadow, and so an environmental support system is necessary. This will have to cope with a temperature variation of between +100°C and −100°C. In the absence of an atmosphere and a magnetic field, particle and wave radiation bathes the Moon's surface; both are harmful to man. Also, in the absence of atmosphere, meteorites of all shapes and sizes rain down on the Moon at speeds of up to 64,000 m.p.h.—their frequency, fortunately, falling off rapidly with size; some form of protection is clearly necessary. Even the most trained astronauts are human, and urine collection and disposal must be accommodated. Finally, the astronauts must still be allowed to move around with as little restraint as possible.

The outdoors spacesuit (or extra vehicular garment), which satisfied all these requirements, is made by the International Latex Corporation. It is worn during all critical stages of the flight, during periods when the LM is depressurised and during all activities outside the CM and LM, whether in space or on the Moon. The pressure suit comprises a number of components: a torso limb suit, the basic pressure envelope, which encloses the entire body except for the head and hands; a thermal meteoroid suit; a liquid-cooled environmental suit; a pressure helmet with visor; gloves; lunar overshoes; and a portable life-support system, carried as a back-pack.

The complete pressure suit weighs 60lb (10lb on the Moon) and, with the life-support system, allows excursions of up to 3hr before the consumables need to be replaced.

At the end of their stay the astronauts make a final check of the ascent stage and then operate the propulsion engine just as the command module appears over the horizon. Guidance and navigation data from both Earth and the command module will have been fed to the guidance system of the ascent stage to ensure that, after launch, the CM passes over the landing site as the LM is approaching the correct altitude. The LM is flown in line behind and below the CM, the distance and speed differential being gradually reduced, using range and closing rate information from the rendezvous radar, until the LM is about 200ft behind the CM and closing with it at about 10ft/sec. The docking manœuvre will be manually controlled by the LM crew.

Since the CM is following a near-equatorial orbit, the launch window for the LM occurs every 2hr (the orbital period of the CM) and the change of orbital plane is negligibly small. In an emergency, therefore, a return to the CM may be effected at very short notice.

After climbing back into the CM and sealing the hatch, the LM ascent stage is jettisoned in orbit around the Moon, while preparations are made for the return journey. Both Earth-tracking data and on-board navigation fixes are fed to the computer which, as the CM passes behind the Moon, commands the service propulsion engine to fire and provide a velocity increment of about 3,520ft/sec. This places the CM into a Earth-return trajectory.

Several mid-course corrections will be necessary during the 55hr/60hr return flight, but (as on the outward journey) these are expected to be small—of the order of a few feet per second.

The SM is separated and jettisoned from the CM about 15min prior to re-entry, when the speed of the CM will be about 36,200ft/sec. The re-entry is flown at a constant deceleration of about 4g. A drogue parachute is deployed at 24,000ft, the three main parachutes opening at 10,000ft. These parachutes are slung off-centre from the axis of the CM so that it impacts on the water on one side, thus cushioning the shock. A piece of British equipment—Ultra's SARAH (search and rescue and homing) beacon will assist the recovery crew to locate the spacecraft.

9—CONCLUSIONS

It is hardly possible to do justice to the Apollo project in a matter of a dozen pages. One can only pick on the end products—the rocket, its spacecraft, and the voyage to the Moon—and describe these. For Apollo is a mammoth undertaking which has absorbed about 60 per cent of all the money spent by America on civil space programmes up to the present. The cost of the programme is estimated at $25,000 million, or £10,000 million. By contrast, the cost of the Anglo-French Concorde, supersonic transport, Europe's most technologically ambitious project, will be about one-tenth of this figure.

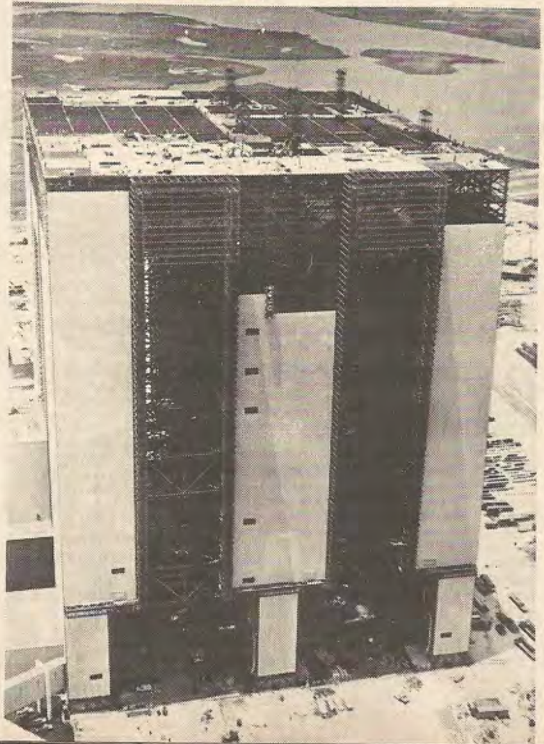
The programme has so far been more successful than anybody (including NASA) had dared hope. The tragic accident in January 1967 during a routine ground check put the programme back 19 months and for a long while it seemed that President Kennedy's dream of an American on the Moon by the end of the decade was not to be fulfilled. But by extraordinary feats of engineering powers and expert management, the project was brought back on to the rails and the first two flights, Apollos 7 and 8, could hardly have been more successful. The Moon landing date has been retrieved from a hazy 1970 to a specific date—July 18, 1969—provided the next two development flights uncover no snags.

Manned spaceflight is, however, expensive in the extreme. Apollo is, in fact, the minimum-possible manned planetary landing mission. Two men will be placed on the Moon for a few hours to make some simple observations and collect some shovelfuls of soil. Yet to accomplish this has required a national effort by the world's richest country, involving an appreciable fraction of her gross national product.

Meanwhile the Apollo Application problem, devised to capitalise on Apollo experience and hardware, begins in 1971. This will enable men to operate for extended periods in near-Earth orbit, opening up the way for advances in medicine, agriculture, technology, meteorology and a host of other commercial and military applications.

Meanwhile Apollo is being readied for the most exciting voyage yet undertaken by man.

The vehicle assembly building allows up to four rockets to be assembled simultaneously



OAO IN OPERATION

THE ORBITING ASTRONOMICAL OBSERVATORY, which was launched from Cape Kennedy on December 7 (see *Flight*, December 19), is now fully operational. Immediately after injection into orbit the 21ft solar-cell array was deployed. A series of engineering tests was then applied to check the serviceability of the spacecraft, and the six star-tracking telescopes were activated on December 9.

The observatory is America's heaviest and most complex unmanned satellite (although at 4,400lb it is still well below the weight of Russia's Protons, at about 25,000lb each).

From its 480-mile orbit inclined at 35° to the equator, OAO-2 will examine the ultra-violet radiation of stars within the galaxy, interstellar dust, and planets in the solar system. In addition certain stars in other nearby galaxies such as M.31 will be observed. The significance of OAO is that, for the first time, it will be possible to secure continuous observations of celestial objects in ultra-violet light. The Earth's atmosphere is effectively opaque to most wavelengths and only two "windows" exist. These cover the spectrum of visible light (3,500-7,000 Angstroms, i.e., 3.5×10^{-5}cm to 7×10^{-5}cm) and the range of wavelengths between 1cm and about 100m which is used by radio astronomers. While optical astronomy has been pursued for 350 years by human eyes working in the first band of wavelengths, and radio astronomy has enabled notable scientific advances to be made at microwave frequencies, it has been realised for a number of years that study of the infra-red and ultra-violet radiation from stars might lead to significant discoveries.

Only by flying sounding rockets above the Earth's atmosphere has it been possible to obtain such observations. It has taken some 15 years and 40 such flights to accumulate three hours of data from 150 stars; by comparison, OAO-2 can collect twice as much data in one day, and that from much fainter stars.

One experiment of particular importance is the study of very young stars; some of these can be observed actually evolving in clouds of gas such as the Orion nebula. They have very high surface temperatures (in the order of 50,000°C) and consequently radiate much more strongly in ultra-violet than in visible light. Some of these stars are estimated to be not more than 20,000 years old.

The specific scientific objectives of OAO-2 are as follows:—

(1) To study stars of mass 100 times that of the Sun. Calculations show that such stars are unstable and should give rise to supernova-type explosions.

(2) To determine the surface temperatures of young stars in order to learn more about their ages.

(3) To study the helium content of stars to determine the nuclear processes which occur.

(4) To examine the red giant stars which (in their later stages) have burned most of their hydrogen.

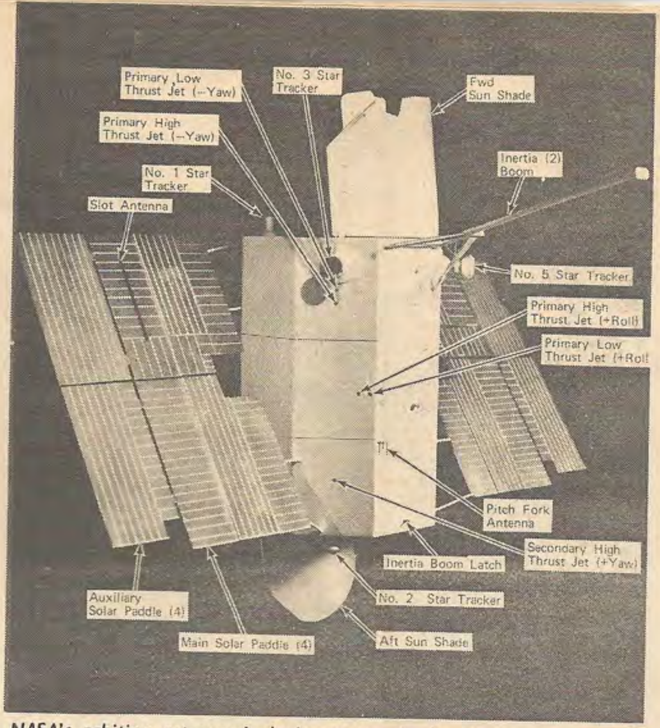
(5) To compare the chemical compositions of various types of stars.

(6) To elucidate the origin, evolution and structure of the recently born stars.

(7) To discover new classes of objects which might be brighter in ultra-violet light than current theories predict.

(8) To study the tenous interstellar matter which permeates space and to ascertain the amount of absorption which occurs so that estimates of its density may be made.

(9) To measure the proton winds (analogous to the solar wind) which, from some stars, have intensities of between a million and a thousand million times that of the Sun.



NASA's orbiting astronomical observatory is America's most complex unmanned spacecraft. The hexagonal-sectioned body contains two main experiments, each looking in directions 180° apart. Two other similar spacecraft are scheduled for launch later this year and in 1970

(10) To study very young stars in other galaxies.

(11) To make observations which will assist in synthesising models of stellar structures.

(1) To study the colour and distribution of unusual stars.

To enable these studies to be made OAO-2 carries two experiments, provided by the Smithsonian Astrophysical Observatory and the University of Wisconsin. The Smithsonian experiment will survey 700 stars each day to enable the first detailed ultra-violet map to be constructed, while the Wisconsin equipment will allow given stars to be studied in great detail over an extended period. The two experiments can complement each other; thus if the Smithsonian equipment should discover an object of particular interest the Wisconsin package will be able to make further and more detailed observations.

The two experiments are carried in the 4ft diameter central cylinder of the observatory and look out of the spacecraft in diametrically opposite directions. Success of the mission depends on the ability of the spacecraft to point its experiments accurately at pre-selected objects, and the attitude-control system is one of the most advanced yet developed.

Two trackers are normally sufficient to define a given direction but six are necessary to ensure tracking under conditions where guide stars can become occulted by the Earth; this number also provides the redundancy necessary for a reasonable lifetime.

The computer system can store 256 commands, a greater capacity than any other American unmanned spacecraft. Particular attention was given to the on-board processing of scientific information to prevent the overloading of ground stations which has occurred with a number of previous spacecraft.

APOLLO WORKSHOP GETS UNDER WAY

The first orders for hardware and equipment for the orbiting laboratory, the main part of the Apollo Applications programme, have recently been placed with contractors. In this programme a modified S-IVB will be flown into Earth orbit by Saturn 1B for the purpose of building up a space laboratory and living accommodation for three astronauts for a month.

LLRV Review Board Reconvened Following the accident to the second Bell LLRV (lunar-landing research vehicle) on December 8, Dr Thomas O. Paine, NASA's Acting Administrator, has asked the review board of the first accident (on May 6 last year) to review its findings.