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LUNAR ROVING VEHICLE DEPLOYMENT MECHANISM

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ABSTRACT

The space support equipment that supports the lunar roving vehicle during the flight to the moon and permits the vehicle to be deployed from the lunar module onto the lunar surface with a minimum amount of astronaut participation is discussed in this report. The design and evolution of the equipment are discussed. The success of the overall lunar roving vehicle design, including the space support equipment, was demonstrated on the Apollo 15 and 16 missions.

INTRODUCTION

The lunar roving vehicle (LRV) is designed to provide transportation on the lunar surface for two astronauts and their equipment in support of lunar-exploration missions (fig. 1). The LRV is a manually controlled vehicle equipped with navigation instruments, systems-monitoring instruments, and independent four-wheel drive and suspension system and is powered by two silver zinc batteries. The LRV is transported to the lunar surface in an open quadrant of the lunar module (LM) and secured by space support equipment (SSE). The LRV is manually deployed by the astronauts and loaded with communications and scientific apparatus as required to perform specific missions.

One of the foremost design features of the LRV is the method of stowage in the LM and deployment on the lunar surface. Design specifications required that the LRV be folded to 50 percent of the initial length and 70 percent of the initial width (fig. 2) and to retain deployment capabilities that require a minimum of astronaut effort on the lunar surface.

FOLDING AND STOWAGE

The LRV is stowed in the folded configuration in the LM in a triangularly shaped envelope 1.78 meters wide, 1.65 meters high, and 0.94 meter deep (figs. 2 and 3). The LRV is secured in this bay to three structural hardpoints and positioned by tripods

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mounted to the front of the LRV center chassis (point 10A, fig. 4) and a support tube (item 21, fig. 3) attached from the bay to the rear of the center chassis. The tripods are discarded after deployment.

The LRV is prevented from unfolding by pin-and-clevis type latches between the center-chassis vertical console post and the forward and aft chassis. These latches are released by cables on the saddle fitting during the deployment sequence. The saddle fitting is attached to the forward chassis by a similar latch that is released by the astronaut after deployment. The wheels are held in the folded position by aluminum struts between the wheel drive motors and the corresponding chassis. These struts are released by cable assemblies within the individual chassis when the chassis is within 10° of the fully unfolded position.

Two torsion springs are used to unfold the forward chassis while torsion bars unfold the aft chassis and the wheels. The aft torsion bar is at the neutral position with the chassis folded up approximately 80°. Therefore, it not only unfolds the chassis but decelerates and reduces the dynamic loading before chassis latching in the unfolded position. The chassis are latched in the unfolded position automatically by spring-loaded shear pins, two in each of the four chassis hinges.

DEPLOYMENT REQUIREMENTS

The following are the requirements for deploying the LRV on the lunar surface.

1. The capability must exist to deploy the LRV when the LM is at any attitude within 14.5° of vertical, on a 6° maximum lunar slope, and with the lower LM bay hard points from 0.356 to 1.58 meters from the lunar surface. The worst-case condition occurs if one leg of the LM is in a hole 0.61 meter deep.

2. The capability must exist for LRV deployment between the adjacent LM legs within a specified ground envelope that allows astronaut clearance between the LRV and LM legs for LRV separation.

3. The capability must exist for LRV deployment by the 2-man crew with minimum effort, under full control, within 15 minutes. The following limitations were placed on the motions required of a suited astronaut: arm motion (hand-over-hand pull is preferable to turning a rotating crank or pushing) and gripping capability of a gloved hand. Pull in a free-standing condition on the lunar surface is limited to 120 newtons (27 pounds force).

ALTERNATE DEPLOYMENT CONCEPTS

The initial concept was a system that would deploy the LRV onto the lunar surface automatically with a single pull of a D-shaped handle. Test and analytical results soon indicated that this system would not deploy the LRV repeatedly within the required confidence level. Modifications were then made that added discrete stops to the center. Therefore, current procedures require that this cable be manned by the second astronaut for all deployment activities. This cable is attached to the rear of the aft chassis and over the top of the LRV center chassis and its use is required in certain LM landing attitudes.

3. At 45° of rotation, the cable from the center braked-reel assembly to the telescopic-tube saddle becomes tight (part 4), releasing the forward and aft chassis locks. (It starts with a fixed amount of slack.) The aft chassis and wheels then deploy by spring action (parts 5, 6, and 7). This is the only dynamic motion in the manual SSE deployment. The forward chassis is prevented from deploying at this time by antireverse latches on the telescopic-tube assembly.

4. The LRV center chassis then continues to rotate, still controlled by the right-hand deployment tape, until the rear wheels touch the lunar surface (parts 8 and 9). The center chassis is unlocked from the walking hinge by means of a cam-actuated latch at approximately 70° of chassis rotation but will not move out from the walking hinges as long as tension is on the steel deployment cables (part 9).

5. With the rear LRV wheels on the surface, continued pull on the right-hand deployment tape puts slack in the steel deployment cables and allows the center chassis to move out of the walking hinges and the forward chassis and wheels to deploy by means of spring action (part 11). The steel deployment cables are then released from the center chassis and discarded.

6. The astronaut then pulls on the left-hand deployment tape, which controls the center steel deployment cable and lowers the front of the LRV to the surface (parts 11, 12, and 13). A pull on the saddle-release cable then releases the telescopic-tube saddle from the LRV (part 14), completely freeing the LRV from the LM. Then, the contingency deployment cable, aft wheel-lock tethers, and SSE tripods are removed from the LRV by the action of quick-release pins and are discarded.

DEPLOYMENT TESTING AND ANALYSIS

All LRV components were subjected to static and dynamic analysis and to testing in a vacuum at high and low temperatures as well as under ambient conditions. Some critical components were tested functionally while coated with a layer of simulated lunar dust.

With the exception of short 1/6-weight flights in a KC-135 aircraft, there is no way to simulate a lunar-gravity environment, and the deployment system depends on the force of gravity and inertia to operate. Therefore, the deployment system was analyzed by a computer program that simulated lunar deployment conditions. This program was checked by changing the parameters to a 1/6-weight, 1/3-inertia LRV and by comparing the resulting simulated deployments with actual deployments performed with a special 1/6-weight, 1/3-inertia test LRV.

During this program, the SSE was subjected to developmental, qualification, and acceptance tests. The following areas were included in the tests.

1. Static and dynamic structural load tests.

2. Vibration tests through the complete envelope in the three basic attitudes while the SSE was supporting a full-weight LRV (vibration test vehicle).

3. Deployment from the required deployment angles of the LM with the LM at both maximum and minimum heights and with the deployment surface at the required slant angles. These tests were run with the 1/6-weight test unit for dynamic deployment and with the full-weight qualification-test LRV for clearance and envelope determination.

4. Thermal-vacuum testing and deployment of the 1/6-weight unit under actual lunar conditions of vacuum and temperature after cold soak in space environment and with a one sun thermal environment.

5. Drop test using the qualification vehicle installed in a flight-configuration LM. This test simulated interface integrity during the lunar-landing phase.

During the testing just described, the following requirements were met.

1. Deployment from any LM angle within a 29° conical angle from vertical

2. A 0.356- to 1.58-meter ground clearance below the LM hardpoints

3. A 6° maximum ground slope

4. The LRV center-of-gravity location restraint in the LM bay

5. Thermal: mean temperature LM/LRV attachment points of 200° and 395° K

6. Vacuum: 1.33 by 10^{-7} N/cm^2 (10^{-5} torr)

7. Deployment in a thermal vacuum within 15 minutes

SIGNIFICANT DESIGN FEATURES

Some of the design features that differentiate the SSE design from a normal design for this type of mechanism are as follows.

1. The use of rigid tubing (item 6, fig. 3) rather than cables to pull lock pins, requiring only one lock instead of individual locking pins.

2. The use of very loose clevis joints on the release mechanism to preclude the need for rod-end bearings.

deployment sequence, and additional handle pulls were required after each stop to continue deployment. This semiautomatic system was fully space qualified but was abandoned primarily because of the dynamics and complexity of the required deployment steps. Other drawbacks were the difficulty of deployment demonstration of a full-weight LRV under earth-gravity conditions and the possible difficulty in deploying under certain malfunction conditions. Therefore, a decision was made by the NASA Marshall Space Flight Center (MSFC) to initiate the design of a system called the manual SSE in parallel with the design of a semiautomatic system. The initial concept of a manual system was proposed by the MSFC; however, the design of this system was a joint effort between the MSFC and the LRV contractor.

SEMIAUTOMATIC SYSTEM

The first LM/LRV interface limited the points of contact to three (items 2 and 12, fig. 3). To use these hardpoints, the SSE required a window-frame structure from which the remaining SSE and the LRV were to be supported. Further refinements resulted in discarding this frame and allowing the LRV to be supported by the LM structure with additional low-load LM-to-SSE attachment points.

The original LRV deployment concept was that the folded LRV would pivot out of the LM bay around the two lower hardpoints (item 2, fig. 3) while controlling the movement with cables from the top of the LM bay to each side of the LRV center chassis (points 4A and 4B, fig. 4). These cables were to be controlled by constant-force springs. Next, walking hinges were added (item 4, fig. 3), a mechanism that automatically transfers the point of LRV rotation during deployment from the lower LM hardpoint/LRV tripod interface (point 2A, fig. 4) to the walking-hinge/center-chassis interface (point 4C, fig. 4). In effect, this moves the point of rotation of the entire folded LRV out from the LM approximately 30 centimeters, allowing the forward chassis and wheels to clear the LM bay during deployment. Also required was an assembly of telescoping tubes (item 5, fig. 3 and point 14A, fig. 4) pivoting about attachments between the lower LM hardpoints and terminating at a saddle fitting (item 7, fig. 3) attached by a clevis-pin arrangement to the front of the LRV forward chassis. By adjusting cables and timing the release of various latches, this system then would completely unfold the LRV in midair and lower the entire vehicle to the surface. The constant-force springs were later replaced with velocity-controlled rotary dampers to ensure LRV deployment at a fairly constant velocity. The "rotary dampers" were essentially rotary escapement mechanisms attached to cable drums. Developmental testing soon indicated that it was not practical to deploy the LRV under fully automatic control. Then, the automatic system was converted to semiautomatic status by the addition of a fixed-length center deployment cable and a second D-shaped handle mechanism sequentially released by the center cables. This system was also subject to various dynamic problems, and a decision was made to develop a manually controlled system in parallel with the described semiautomatic SSE.

MANUAL SYSTEM

The manual system was to use as much of the semiautomatic equipment as practical because of the time constraints. The following changes were made to the semiautomatic SSE.

1. The three rotary dampers were replaced with two worm-gear, cable-drum mechanisms (items 13 and 14, fig. 3). These mechanisms use selflocking worm gears attached to the deployment cable drums and are actuated by a reel of nylon tape large enough to be gripped by the gloved astronaut so that this equipment can be operated within the capability of the astronauts for hand-over-hand pull.

2. The center telescope-tube saddle assembly was modified to require only one center deployment cable (item 8, fig. 3), which performs all required unlatching functions as well as stopping the rotation of the vehicle forward chassis at 45° and then lowering the front wheels to the lunar surface.

3. The D-ring mechanism (item 1, fig. 3) was modified to remove D-ring 2 and to require only a single pull of D-ring 1 to unlatch the vehicle. Thus, only one ascent to the LM porch is required in order to initiate deployment.

4. The placement of the deployment cable reels was changed from separate interface points on the LM to the SSE upper diagonal (item 15, fig. 3), and the diagonal was modified by the addition of cantilevered outriggers (item 16, fig. 3) to help absorb deployment-cable shock loads.

5. All this equipment could be operated within the capability of the astronauts for hand-over-hand pull with the deployment tape large enough to be gripped by astronaut gloves.

These changes resulted in the final deployment system used by the Apollo 15 and 16 astronauts on the lunar surface.

DEPLOYMENT SEQUENCE

The following deployment sequence was used. Each step is referenced to parts of figure 4.

1. The protective LM thermal blanket is removed from the bottom of the LRV, and deployment tapes are laid out for easy access (part 1).

2. The astronaut ascends the LM ladder and pulls the D-ring to release the attachment pins (part 1). The pushoff spring then will revolve the LRV out around the lower hardpoints, its velocity controlled by the rate of astronaut pull on the right-hand deployment tape (part 2). At 15° of LRV rotation, the point of rotation will transfer from the lower hardpoints to the walking hinges (part 3). At this point, the necessity may occur for the second astronaut to pull on a deployment cable to help the LRV over

3. The use of controlled friction at the gear faces of the braked-reel assembly to make a self-locking worm drive from a worm drive that could normally be back-driven with full lubrication. This was accomplished by running a clean bronze worm gear with a dry-film, MoS_2-lubricated, hardened-steel worm.

4. The use of graphite-filled nylon bearings with aluminum shafts throughout the gearbox.

CONCLUDING REMARKS

The overall success of this design was demonstrated on the Apollo 15 and 16 missions.

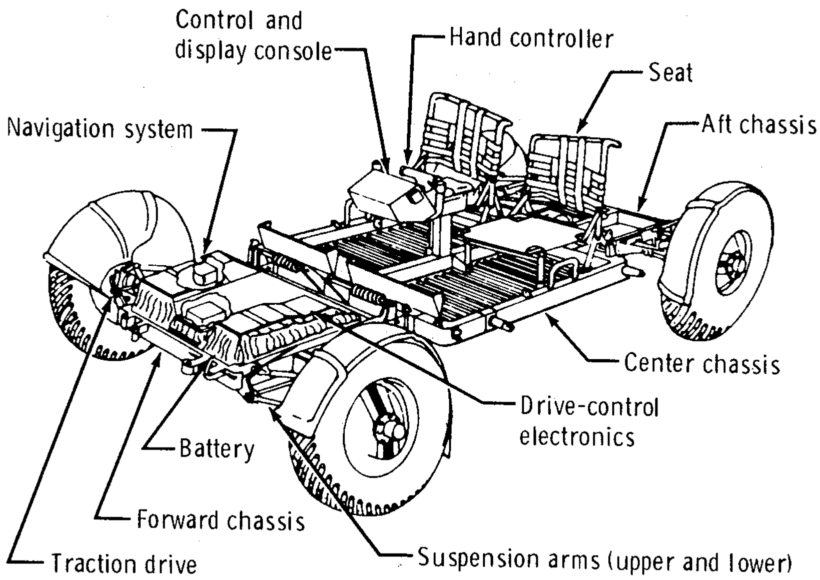


Figure 1. - Lunar roving vehicle, unfolded.

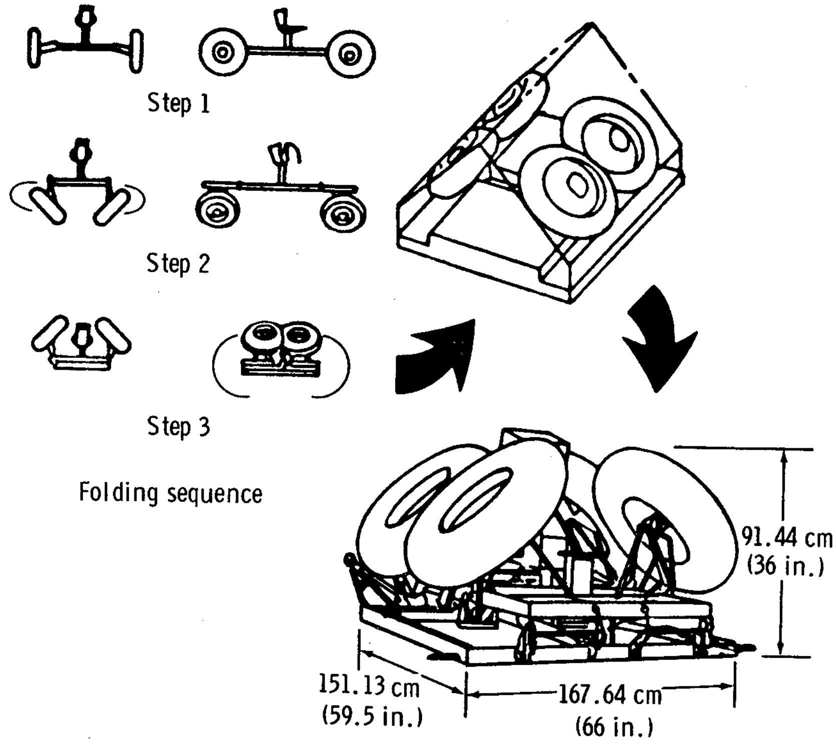
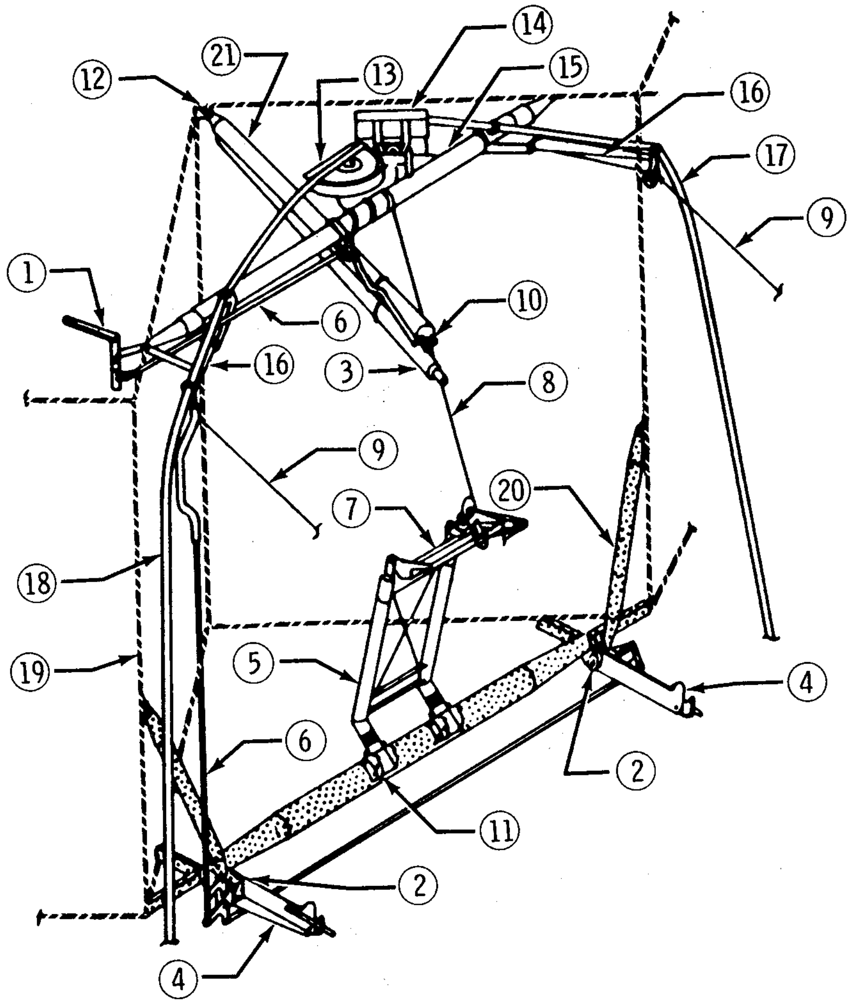


Figure 2. - Lunar roving vehicle, folded.



(1) D-handle mechanism
(2) Lower LM hardpoints
(3) Pushoff spring assembly
(4) Walking hinges
(5) Telescopic tube assembly
(6) Release-system mechanism
(7) Saddle assembly
(8) Center deployment cables
(9) Side deployment cables
(10) Upper release pin
(11) Antireverse latches
(12) Upper LM hardpoint
(13) Center braked-reel assembly
(14) Side double-braked-reel assembly
(15) Upper diagonal
(16) Upper diagonal outriggers
(17) Right-hand deployment tape (for side deployment cables)
(18) Left-hand deployment tape (for center deployment cable)
(19) Outline of LM bay
(20) LM structure
(21) Support tube

Figure 3. - The LM-mounted space support equipment.

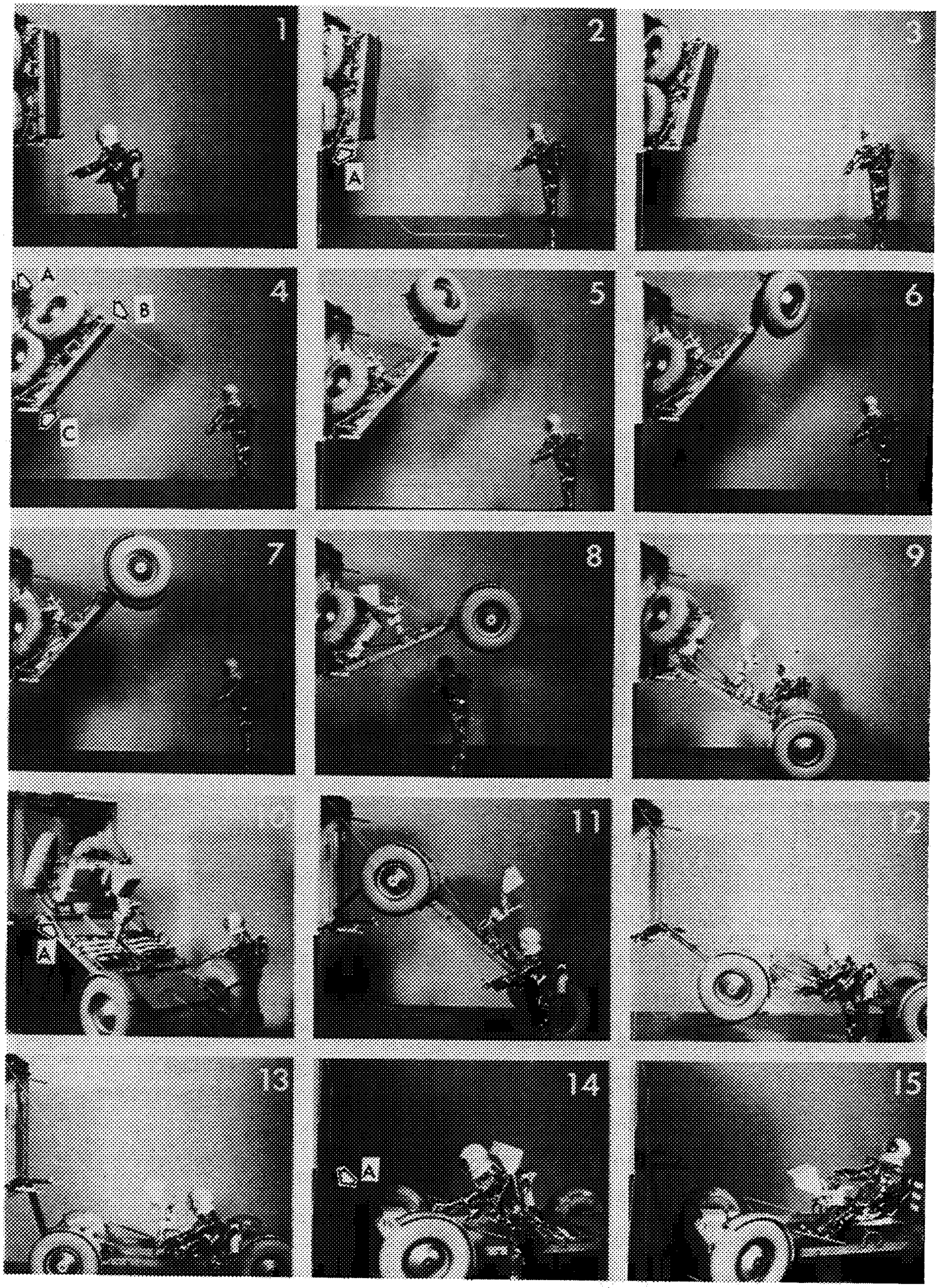


Figure 4. - Lunar roving vehicle, deployment sequence.