Ron - Jack is [illegible] hard [illegible] but [illegible] ~~I guess we should evaluate (anticipate) [illegible]~~ controllability ~~and [illegible]~~ (~~[illegible]~~).

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SUMMARY

This note presents a baseline docking technique that could be used to assemble, in earth parking orbit, an interplanetary launch vehicle capable of injecting the heavy payloads needed for manned Mars and Venus missions. The technique would be carried out by two crewman using a docking scope on the spacecraft and alignment targets on the orbiting launch stage (OLS) with which the spacecraft is to dock. Radar will be used to measure range and range rate.

INTRODUCTION

Studies of interplanetary spacecraft designs show that spacecraft weights of 200 000 lb are being considered for the early flyby missions. Injecting payloads of this size for a manned Mars or Venus flyby mission with a Saturn V or uprated Saturn V launch vehicle require multiple launches and the assembly in orbit of several propulsion stages and the spacecraft. The propulsion stages are used to inject the spacecraft from earth orbit onto the interplanetary trajectory. Missions in which the spacecraft orbits Venus or Mars will require injecting even larger weights.

One of the most difficult phases of the interplanetary mission will be the orbital assembly of the propulsion stages. The docking operation, in particular, is critical because it requires the contact of two vehicles, which involves the danger of colliding and damaging one or both of the vehicles.

An indication of the difficulty of the docking task can be obtained from the design impact condition used in preliminary design studies of the docking structure. The maximum errors in contact accuracies required between the two vehicles are 1 fps in velocity, 18 inches in lateral displacement, and 5° in angle. The most difficult of these design impact conditions to satisfy in a docking operation is the 18-inch lateral displacement since the relative lateral positions of the OLS and spacecraft must be known at the docking interface to within 18 inches. Relative position and alignment in Gemini and Apollo missions were obtained primarily by the crew using visual cues. These cues will not be satisfactory in the assembly of the Orbital Launch Vehicle (OLV) since they rely primarily on proximity of the crew to the docking interface. In assembly of the OLV, a stack of two stages and a spacecraft may be 200 ft long for docking with a third OLS, and the docking interface may be as much as 160 ft from the crew station. In addition, the vehicle active in the docking operation will be unmanned and controlled remotely from the spacecraft. Since response times in maneuvering vehicles weighing 300 000 to 400 000 lb are very slow, it is apparent that new procedures are needed to dock and assemble an OLV.

This paper describes a remote docking technique, manually controlled by the crew with the aid of optical alignment equipment, for consideration as the baseline technique for assembly of the OLV.

DOCKING TECHNIQUE

To aid the crew in the docking operation, the spacecraft would be equipped with an optical docking scope that is columnated with the spacecraft centerline and contains a crosshair for use in the alignment. A radar would be used to measure the relative range and range rate between the spacecraft and the OLS with which it is to dock. A digital command link between the spacecraft and the OLS would be required so the crew could control the motions of the OLS. Several alignment targets on each OLS would also be required.

Technique

The docking task is primarily one of aligning the spacecraft and the OLS so that their two axes lie along a straight line. After alignment the crew manually translates the OLS toward the spacecraft to cause it to dock. The crew must also maintain the alignment during the translation phase by maneuvers that restrict perturbation due to orbital mechanics or systems errors in the translation.

A commander and an engineer would be required for the docking operations. The commander aligns the OLS using the docking scope and remote control of the OLS lateral and rotational motions. He commands the docking operation and is assisted by the engineer who controls the forward motion and range of the OLS with the aid of the radar and range rate measurements.

The docking sequence is outlined below:

Commander

1. Maneuver the spacecraft so that the OLS is in the field of view of the docking scope.

2. Roll the OLS (remotely) so that targets are visible and on top of OLS as in figure 1(a).

3. Pitch and/or yaw the spacecraft to bisect targets with the crosshair, as in figure 1(b).

4. Pitch the OLS so that the targets are on the horizontal crosshair; yaw the spacecraft to bisect targets with crosshair, as in figure 1(c).

5. Yaw the OLS to align targets one behind the other on the center of the crosshair as in figure 1(d). At this point, the OLS is in perfect alignment with the stack.

6. Call for forward translation of OLS.

Engineer

7. Start forward high-thrust attitude propulsion system (APS) jets.

8. Stop forward high-thrust APS jets when radar range rate reads 3 fps.

Commander

9. During forward translation use lateral APS jets to prevent any lateral drift of the OLS.

An attitude-hold mode controlled by the attitude control system of the OLS is used to maintain the booster axis alignment during translation. The task of the docking commander is to maintain the front alignment target on the crosshair using later translation commands to the OLS. If the OLS becomes misaligned to the extent of exceeding the docking requirements, the engineer can stop the forward translation. The commander can realign the OLS and continue the docking. A complete OLV composed of the spacecraft and two OLS's is shown in figure 1(d).

Initial Conditions Required By The Docking Technique

The docking technique necessitates that, prior to the docking operation, the OLS is rendezvoused with the spacecraft and brought to zero relative velocity at a range of 500 ft. The direction of the range vector is important. If the displacement is above or below the spacecraft, the OLS will have an orbital period different from the spacecraft and, consequently, will develop a relative velocity and displacement during the alignment procedure which cannot be easily removed by the crew.

The relative position and velocities of the OLS with respect to the spacecraft after the OLS has zero relative velocity is given by the following equations for a circular orbit:

$$\dot{x}(t) = 6wy_o \, (1 - \cos wt) \tag{1}$$

$$\dot{y}(t) = -3y_o w \sin wt \tag{2}$$

$$\dot{z}(t) = -z_o w \sin wt \tag{3}$$

$$x(t) = x_o - 6y_o \sin wt + 6wy_o t \tag{4}$$

$$y(t) = 4y_o - 3y_o \cos wt \tag{5}$$

$$z(t) = z_o \cos wt \tag{6}$$

The x, y, z coordinate system is shown in figure 1(a), (z comes out of the page). $\dot{x}(t)$, $\dot{y}(t)$, and $\dot{z}(t)$ are the time derivatives of $x(t)$, $y(t)$, and $z(t)$. Initial position and velocity vectors are x_o, y_o, z_o and $\dot{x}_o$, $\dot{y}_o$, and $\dot{z}_o$, respectively. w is the circular orbit angular velocity.

It can be seen from these equations that the only stable position for the alignment is a displacement in x either forward or aft of the spacecraft. If y_o and z_o are zero, the above equations reduce to $x(t) = x_o$. An initial displacement in the z direction results in the OLS drifting toward the spacecraft, and the distance between spacecraft closing in one-fourth orbit. This drift is not too serious, however, since it can easily be controlled by the crew using small velocity increments. Station-keeping with initial displacement in y, however, results in an unstable situation where velocity impulses applied to stop the relative motion actually result in increasing the motion (example, Gemini IV).

The condition from which the docking operation is to be initiated is a displacement in x of about 500 ft, either forward or aft, and a zero relative velocity. These conditions become the target for the terminal phase of the rendezvous.

Some Equipment Considerations

Targets.- The proposed docking technique requires that the front target be circular and have a diameter equal to the lateral contact tolerance of the docking structure. Based on one preliminary design of a docking structure, this would be 18 inches. The contact between the docking structures will be within design limits as long as the crosshair of the alignment scope is in the target area. The center of the target must be the same distance from the centerline of the OLS as the alignment scope is from the centerline of the spacecraft. The stem of the targets provides for roll alignment. The front and rear targets should be an equal distance from the center of gravity of the OLS.

Docking in the dark may be possible with florescent targets.

Alignment Scope.- The alignment scope will need to be like a telescopic gun site that can be operated from inside the spacecraft through a periscope arrangement. A simple crosshair reticle, as in a gun site, appears to satisfy the alignment requirements. The field of view should be about 11° since the OLS may subtend an arc of 8° at 500 ft when broadside. A 4-power scope should provide sufficient magnification for accurate alignment at 500 ft.

FUEL REQUIREMENTS

Preliminary estimates of the fuel requirements for the docking operation were made from preliminary estimates of the weight, moments of inertia, and moment arms of the APS jets. The translation fuel requirements were computed using the relation

$$\Delta V = 32.2 \ I_{SP} \ \ln \frac{w_O}{w_B} .$$

Or

$$w_f = w_O \left[1 - \exp\left(- \frac{\Delta V}{32.2 \ I_{SP}}\right)\right]$$

where ΔV = translation velcotiy

I_{SP} = specific impulse of fuel

w_O = initial weight

w_B = burnout weight

w_f = weight of fuel.

A simple relation for the rotation maneuvering fuel was derived as follows:

$$\ddot{\theta} = \frac{\text{Torque}}{I}$$

$$\text{Torque} = \text{thrust} \times r$$

$$\text{Thrust} = I_{SP} \dot{M}$$

$$\ddot{\theta} = \frac{I_{SP} r \dot{M}}{I} .$$

Integrate

$$\dot{\theta} = \frac{I_{SP} r M}{I}$$

$$M = \frac{I \dot{\theta}}{I_{SP} r}$$

where

$\ddot{\theta}$ = rotational acceleration

$\dot{\theta}$ = rotation rate

r = moment arm of thrusters

$\dot{M}$ = fuel flow rate

M = fuel

I = moment of inertia about the maneuver axis.

Note that neither the translational nor the rotational fuel requirements are functions of the size of the thrusters used in these maneuvers.

The moments of inertia for the spacecraft and OLS were estimated on the basis of a homogenous cylinder with mass m. Neither the OLS nor the spacecraft have been designed; therefore data for the moments of inertia are not available. The moment arm of the jets was assumed to be half a diameter in roll and half a length in pitch and yaw.

The moment of inertia for a right circular cylinder of radius r and length l is

$$I_{roll} = m \frac{r^2}{2}$$

$$I_{yaw\ and\ pitch} = m\left(\frac{r^2}{4} + \frac{l^2}{12}\right).$$

In estimating the fuel requirements, it was assumed that the stack would be gravity stablized during the launch and rendezvous phases of the assembly. At the start of the docking operation, the stack would be required to pitch 90°.

The maneuver rates used in the fuel estimates were chosen rather arbitrarily and are supposed to represent a compromise between the fuel requirements and the time required to align and dock, although there is no known restriction on the time available for docking at this preliminary stage of development. Using florescent targets, it would appear that docking operation can be conducted just as well in the dark.

A summary of the docking fuel requirement calculated for two representative OLS's are given in table I.

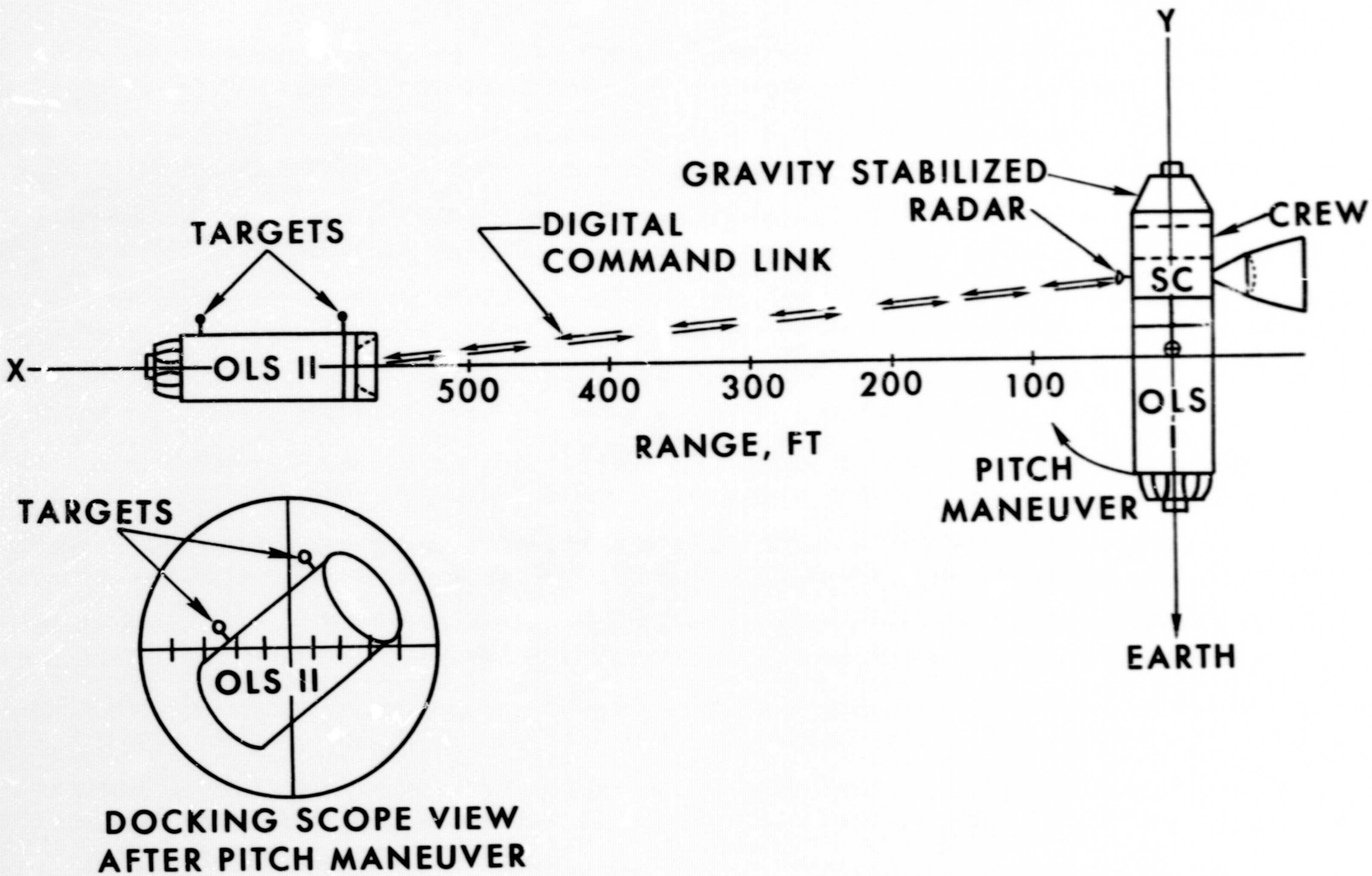
TABLE I.- ESTIMATES OF DOCKING FUEL[a]

Maneuver	Number performed	Maneuver rate	Fuel used for number of maneuvers performed, lb	
			B[b]	C[c]
Target Orientation Maneuvers				
Roll	3	0.05 rad/sec	44.4	61.5
Pitch or yaw	6	0.05 rad/sec	177.6	307.8
Forward and aft translation	5	3.0 fps	401.4	555.9
Lateral translation	6	0.5 fps	80.6	111.6
Total	-	-	971.6	1407.6
Stack Pitch Maneuvers				
1st docking	1	0.05 rad/sec	29.2	51.3
2nd docking	1	0.05 rad/sec	110.3	196.3
3rd docking	1	0.05 rad/sec	596.3	874.9

[a]The specific impulse (I_{SP}) of the fuel for these calculations was 300 sec.

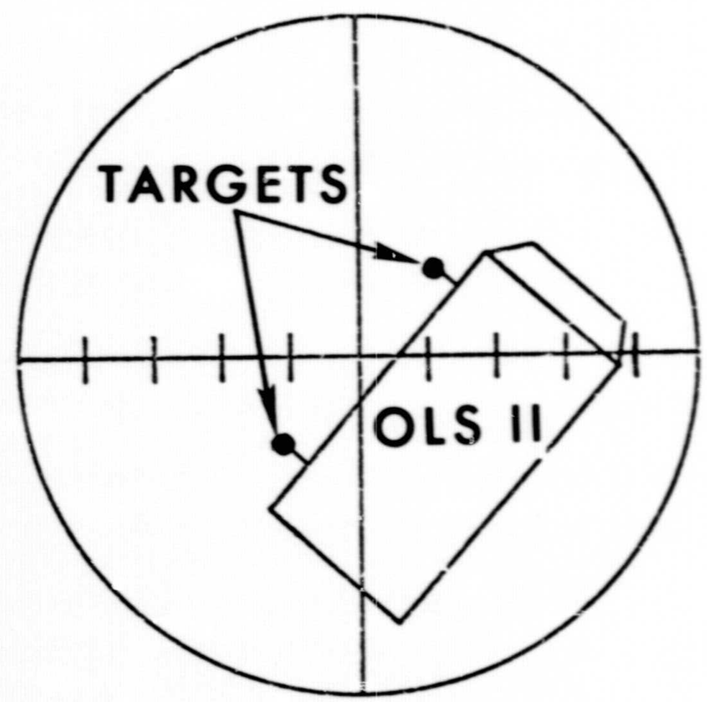
[b]B weight = 260 000 lb; length = 60 ft; diameter = 22 ft.

[c]C weight = 360 000 lb; length = 18 ft; diameter = 22 ft.



(a) Configuration at start of docking sequence.

Figure 1.- Docking technique for orbital assembly of an interplanetary launch vehicle.

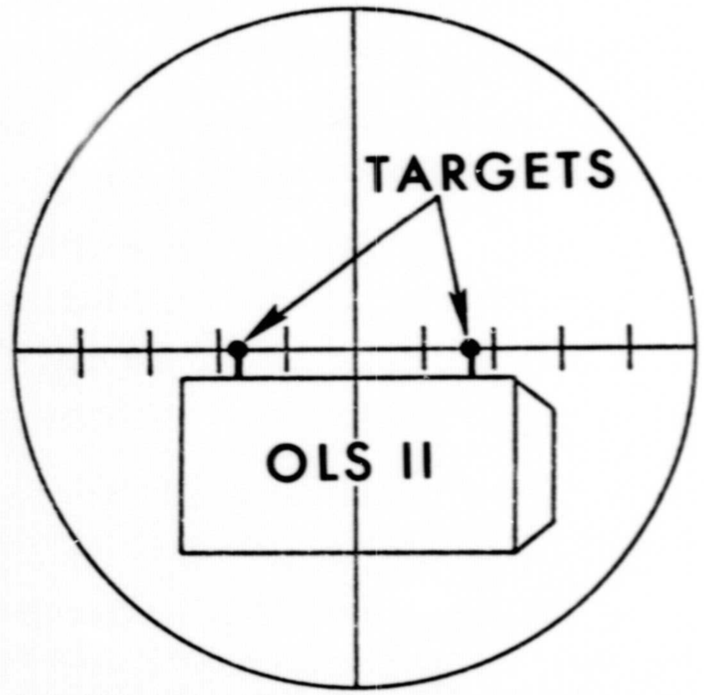


DOCKING SCOPE VIEW

- MANEUVER SPACECRAFT TO PLACE TARGETS EQUIDISTANCE FROM HORIZONTAL LINE IN DOCKING SCOPE

(b) First alinement maneuver.

Figure 1.- Continued.



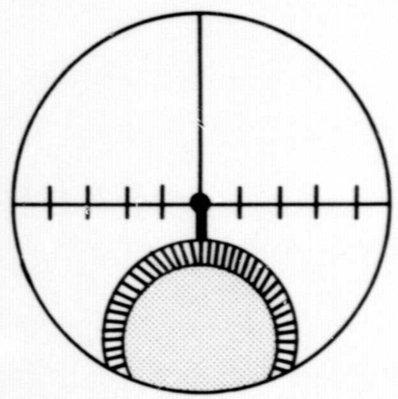
DOCKING SCOPE VIEW

- PITCH BOOSTER TO PLACE BOTH TARGETS ON HORIZONTAL LINE IN DOCKING SCOPE
- YAW SPACECRAFT TO MOVE TARGETS EQUI-DISTANCE FROM CENTER OF DOCKING SCOPE

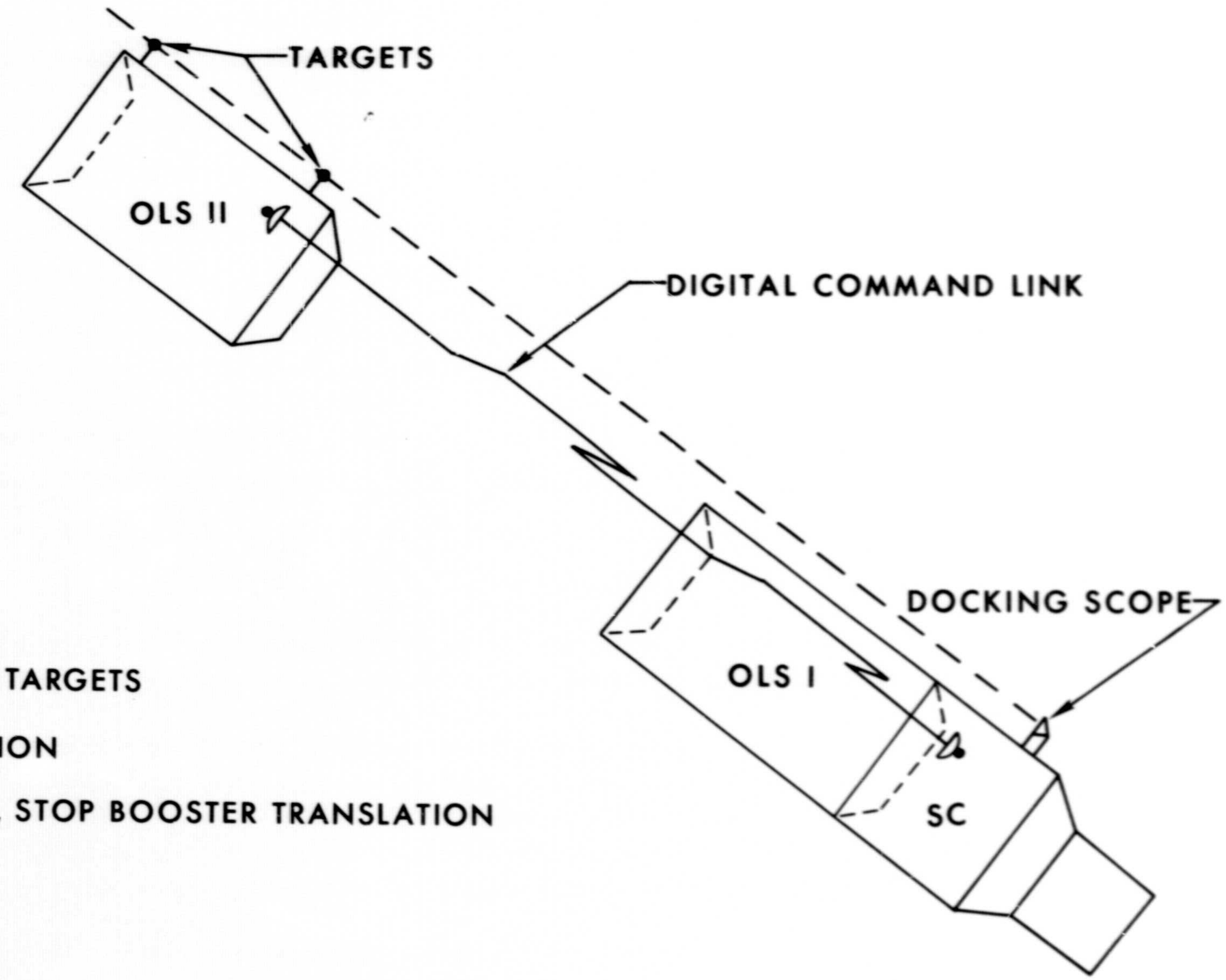
(c) Second alinement maneuver.

Figure 1.- Continued.

E



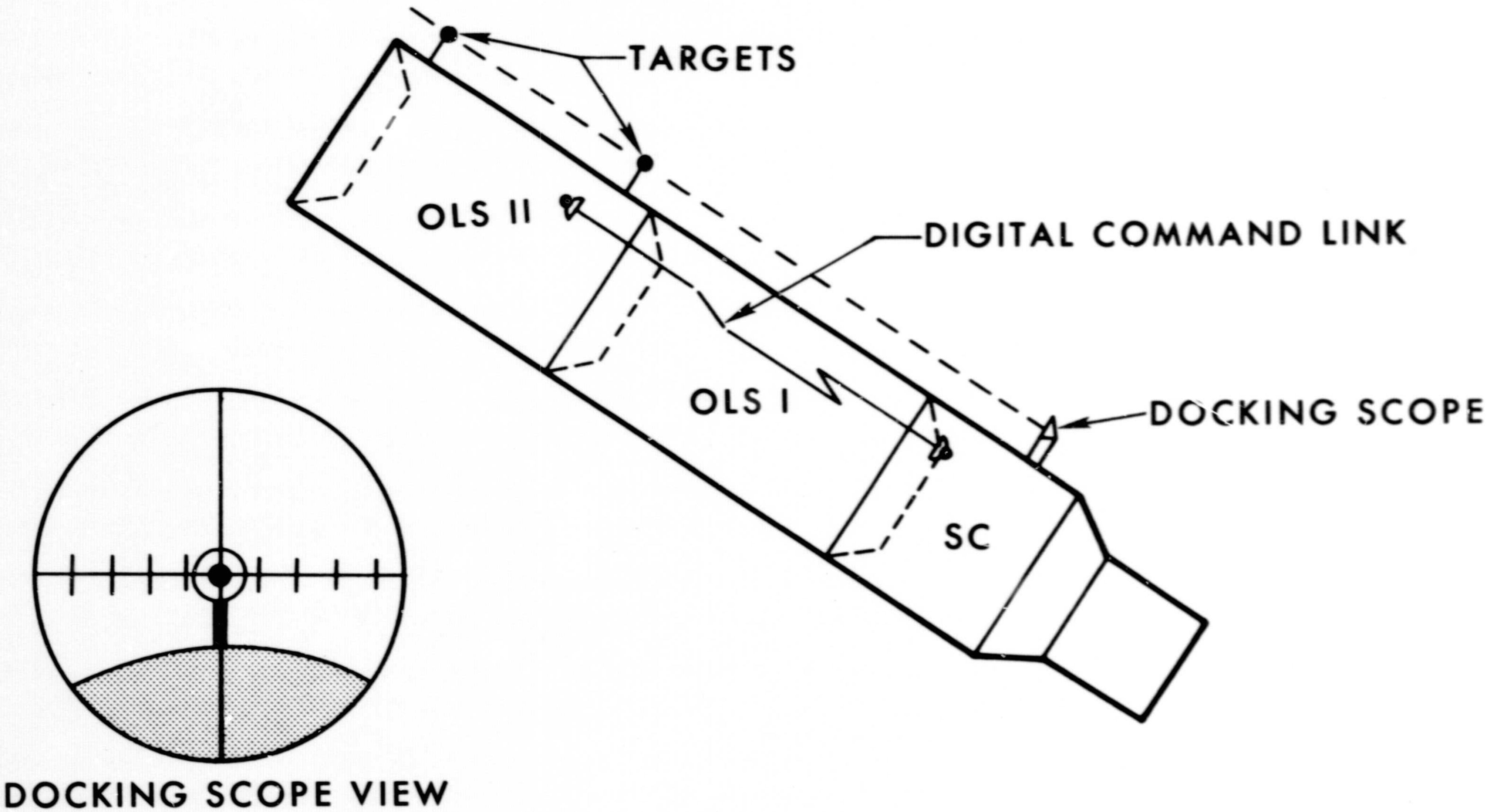
DOCKING SCOPE VIEW



- YAW BOOSTER TO CENTER TARGETS
- BEGIN BOOSTER TRANSLATION
- IF MISALINEMENT OCCURS, STOP BOOSTER TRANSLATION AND REPEAT ABOVE

(d) Third alinement maneuver.

Figure 4. - Continued.



- TARGETS ARE JETTISONED TO PREPARE FOR RENDEZVOUS AND DOCKING WITH NEXT BOOSTER

(e) Docked.

Figure 1.- Concluded.