"RATIO" AUTOMATED ASSEMBLY TECHNIQUE FOR SPACE STRUCTURES

Paul Slysh, General Dynamics/Convair

1. INTRODUCTION

RATIO* is a technique for implementing the automatic or semiautomatic assembly of large space structures. Work on this technique has received GD/C and NASA** sponsorship.

The technique includes sectionalizing the structure into structural modules capable of being nested, and of configuring mechanisms for the automatic or semiautomatic assembly of the modules. The modules and mechanisms may themselves be rigid or expandable structures.

The technique is applicable to deploying such structures as reflectors for antennas and solar concentrators, booms, extended-area solar panels, as well as cylindrical, linticular and toroidal space stations and re-entry bodies.

The RATIO technique is illustrated in this paper by describing its application to the deployment of a paraboloidal reflector for an antenna.

* This technique is proprietary with the General Dynamics Corporation.

**NAS7-228, Study of RATIO Automatically Assembled Structures, Final Report GDA-DDG64-017, dated 1 July 1964.

2. REFLECTOR CONFIGURATION AND ASSEMBLY SEQUENCE

The chosen reflector has a hexagonal contour and is sectionalized into 24 triangular panels. Using a planar model Fig. 1 shows how the reflector is (a) sectionalized, (b) stacked, and (c) assembled.

It is seen in Fig. 1 that the assembly of the panels takes place according to a systematic sequence of relative motions between successive panels. Panel 1 is assembled to panel 0 by a counterclockwise rotation and linear displacement of panel 1 with respect to panel 0. The same rotation and linear displacement takes place between panel 2 and 1, 3 and 2, 4 and 3, and 5 and 4. Panel 6, however, is assembled to panel 5 by a clockwise rotation of the stack with respect to panel 5. Further examination of Fig. 2 indicates that panels 7, 8, 9, 11, 12, 14, 15, 17, 18, 20, 21, 23, are assembled by counterclockwise rotations and panels 10, 13, 16, 19, 22, are assembled by clockwise rotations. As will be explained, these assembly motions are variations of a single set of assembly motions.

A view of the reflector as part of a space station cassegrain antenna is shown in Fig. 2. In this example, panel 0 is used for pedestal mounting the antenna with respect to the space station and for mounting the subreflector with respect to the reflector.

The subreflector support may be a RATIO, stretch formed wire mesh or other expandable structure. In this case, the support and subreflector are stored between panels 0 and 1 and are deployed after panel 1 is assembled to panel 0. The pedestal remains fixed to panel 0 at all times (i.e. when the antenna is in both the stowed and deployed states).

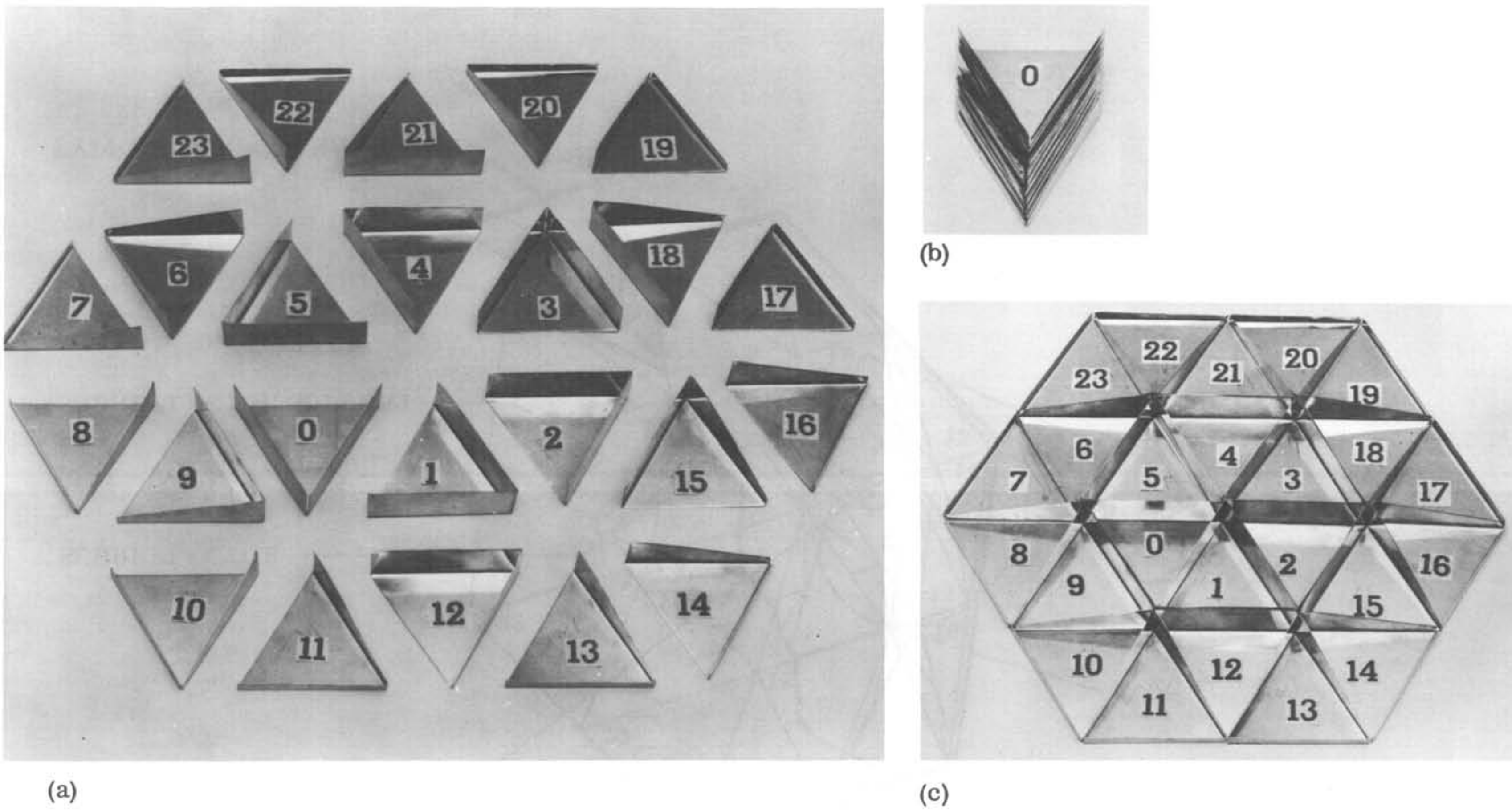


Figure 1. Reflector Structure - Planar Model

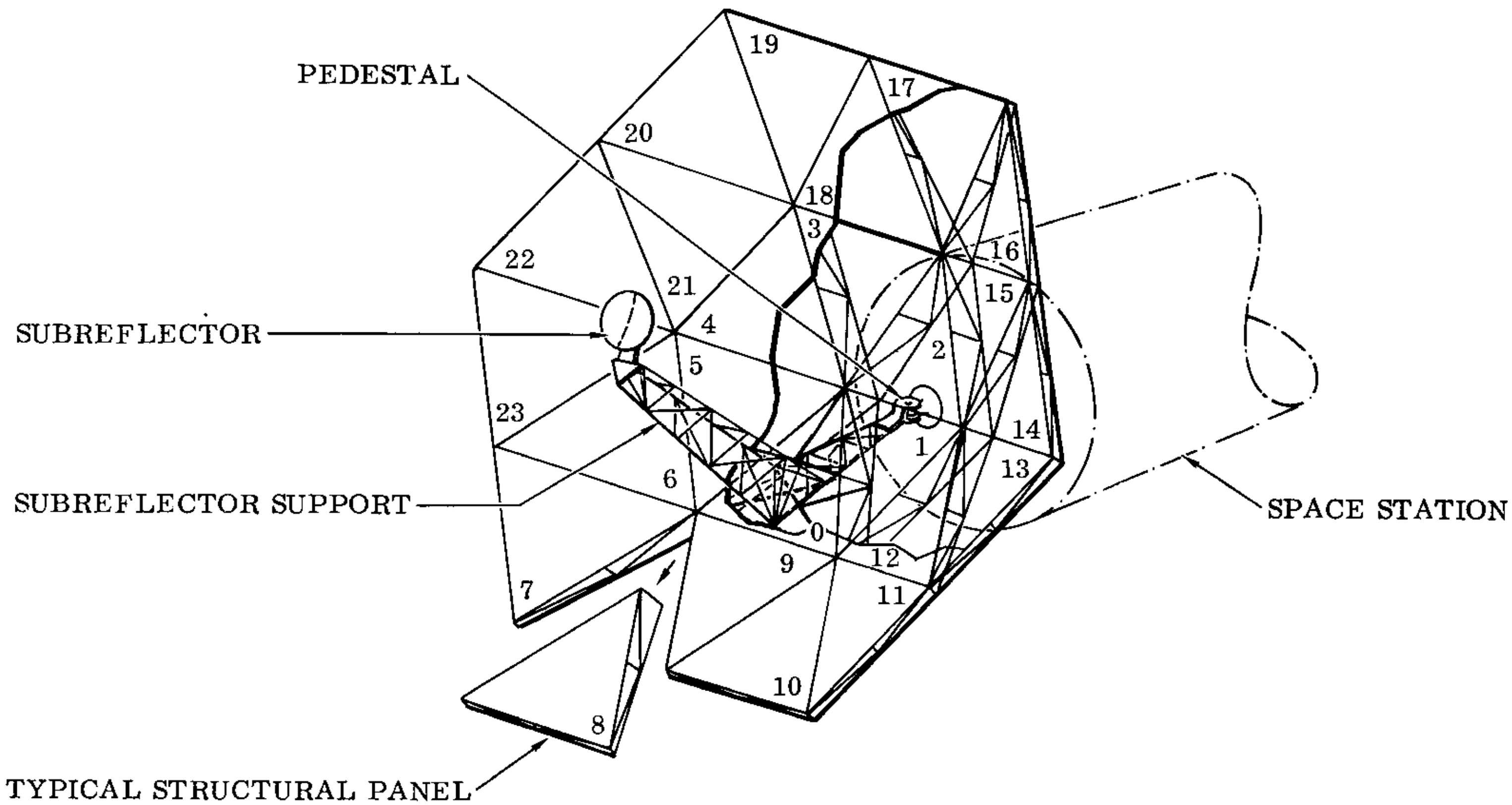


Figure 2. Assembled Antenna

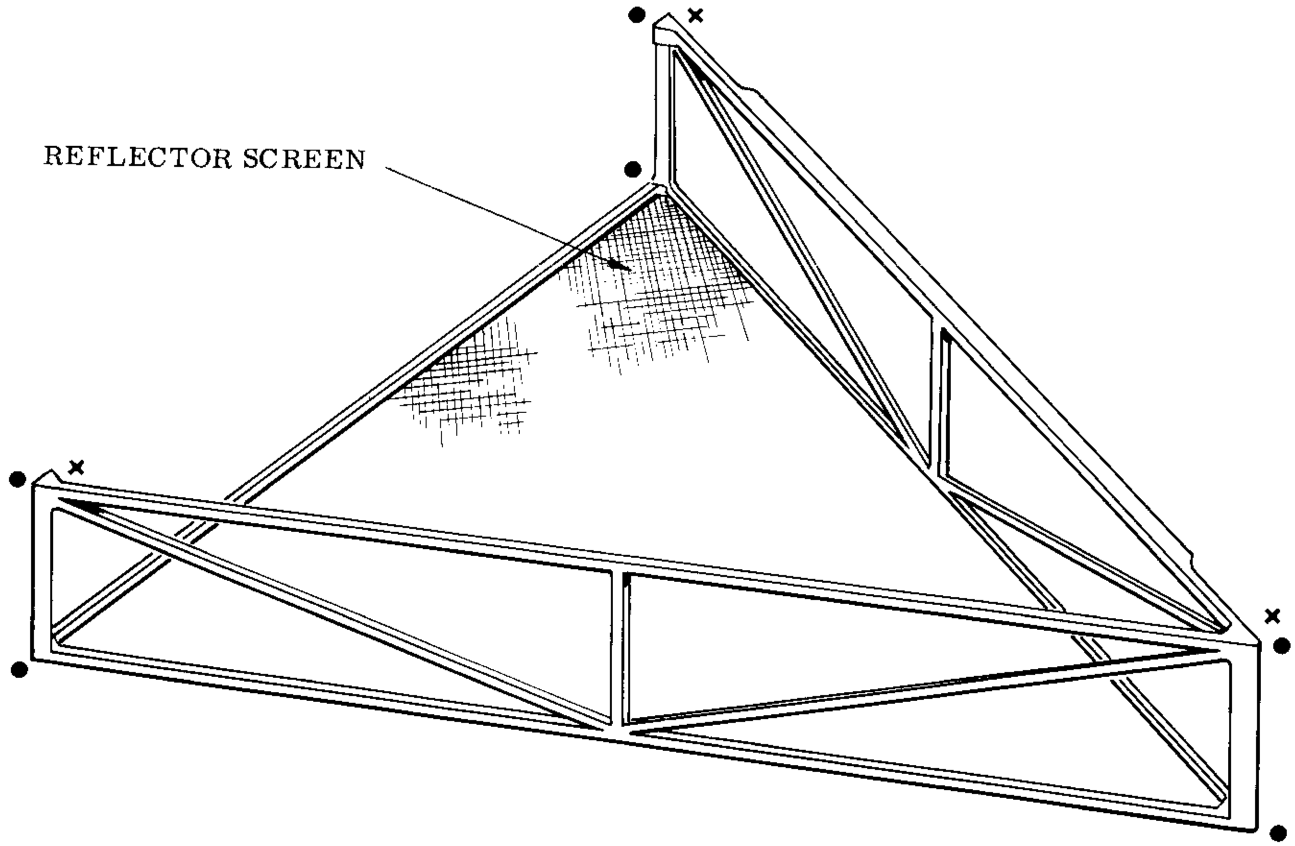
3. PANEL CONSTRUCTION AND FASTENERS

A chosen thin-wall, tubular, truss-frame panel is shown in Fig. 3 together with the corner locations of the panel-to-panel structural fasteners. The corner locations for the assembled-state fasteners provide structural continuity. A typical structural corner and the assembled-state fasteners are illustrated in Fig. 4. The stowed-state fasteners (explained later) are actuated latches located along the edges of the back rib structure.

In the chosen model the ribs along the reflector periphery are only fastened to each other in the assembled-state by fasteners in the structure directly behind the reflector surface.

The width of one of the truss members on the panel rib edge (see Fig. 3) is shown having a width (2T) in the plane of the reflective surface which is twice the width of the other members. This increased width is used to equalize the effective length-to-radius-of-gyration ratios of the rib-edges members in the planes parallel and normal to the reflective surface.

The need for tight machining tolerances is minimized and stress free mating between the assembled panels is enhanced by fabricating the panels by a join-at-assembly method. Typically this method consists of: (1) fastening (screwing) together all the mating structural corners, (2) fixturing the fastened-together corners in their proper space relation to each other, (3) fitting the precut and preformed truss members to the structural corners, and (4) pinning or riveting the truss members to the structural corners at assembly. Fabricated in this way, with precautions for avoiding built-in stresses, the panels may be separated and reassembled within the reassembly tolerances of the (screw) fasteners.



● LOCATIONS OF FASTENERS FOR FASTENING PANELS TO EACH OTHER IN ASSEMBLED STATE

× LOCATIONS OF FASTENERS FOR FASTENING PANELS TO EACH OTHER IN STOWED STATE

Figure 3. Typical Reflector Panel

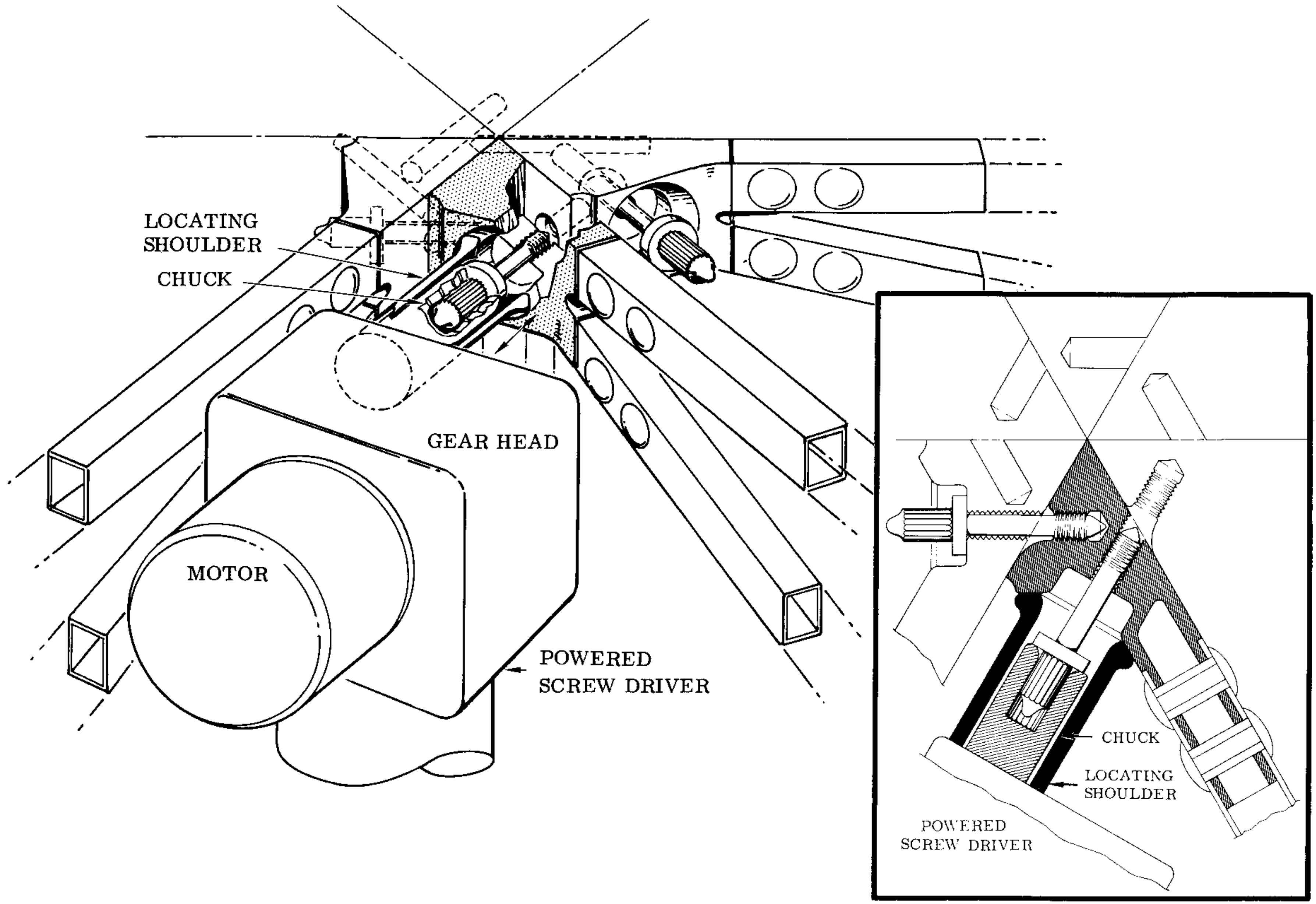


Figure 4. Typical Structural Junction and Fasteners

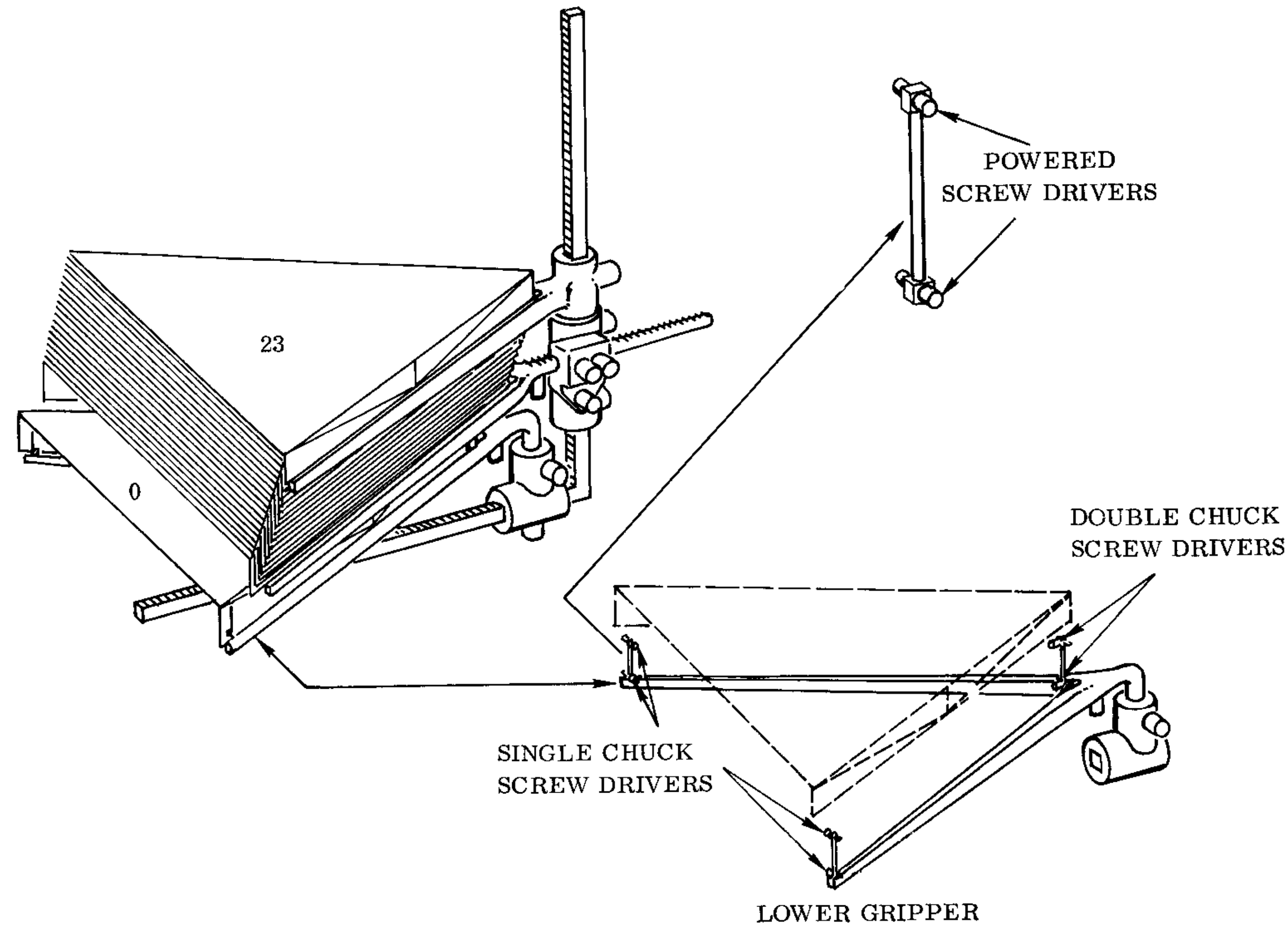
The reflective surface, in the form of a screen wire mesh, is added after the frame structure fabrication is complete.

4. ASSEMBLY EQUIPMENT

A powered screw driver for actuating the screw fasteners is depicted in Fig. 4. Four single chuck and two double (tandem) chuck powered screw drivers are carried on a V-shaped (lower) gripper frame, as shown in Fig. 5a. The two double chuck drivers are at the apex of the V, and the four single chuck drivers are at the other corners. The relative positions of the drivers on the frame are compatible with the relative positions of the screws on the panels.

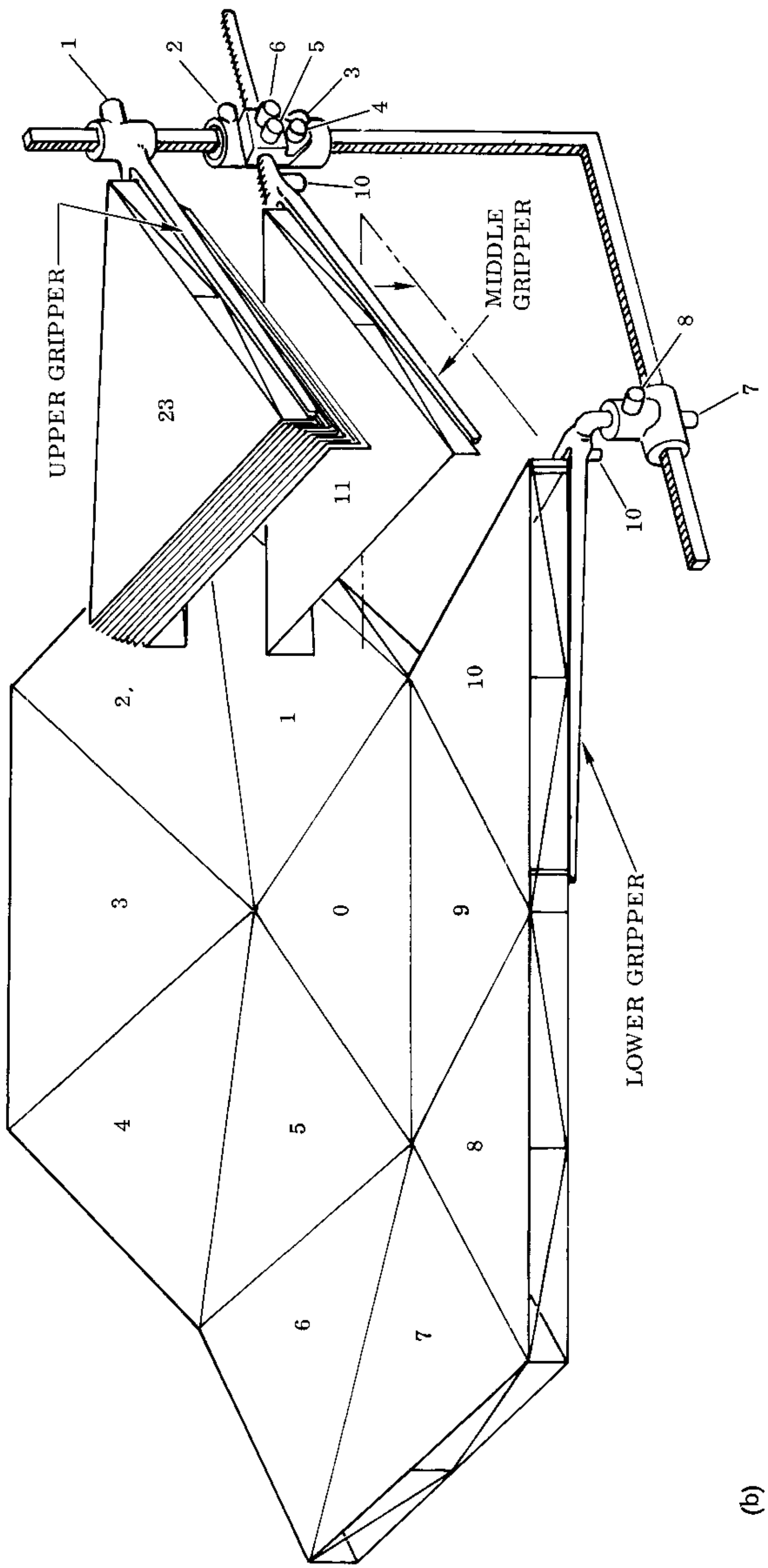
The screws held captive in the structural corners, as in Fig. 4, are engaged by the telescoping shoulders and chucks. The lead-in sections on the screws, shoulders and chucks cooperate to align the drivers and structural corners. In this way the entire panel is aligned with the lower gripper. Then, through the action (to be described) of the assembly equipment a set of mating structural corners are brought into alignment (within the available panel-to-panel screw lead-in tolerances). The chuck-engaged screws are driven to achieve the final alignment and lock-in between the corners. The telescoping shoulder and chuck are finally withdrawn into the gear head disengaging the driver from the panel.

Figs. 5a,b,c, picture the automatic assembly equipment with respect to stowed and deployed reflector. It is seen in these pictures that the panels are manipulated by three V-shaped grippers. The upper gripper acts as a dummy panel to which the unassembled stack of panels are attached. The middle gripper is shown engaged, in Fig. 5b, to the

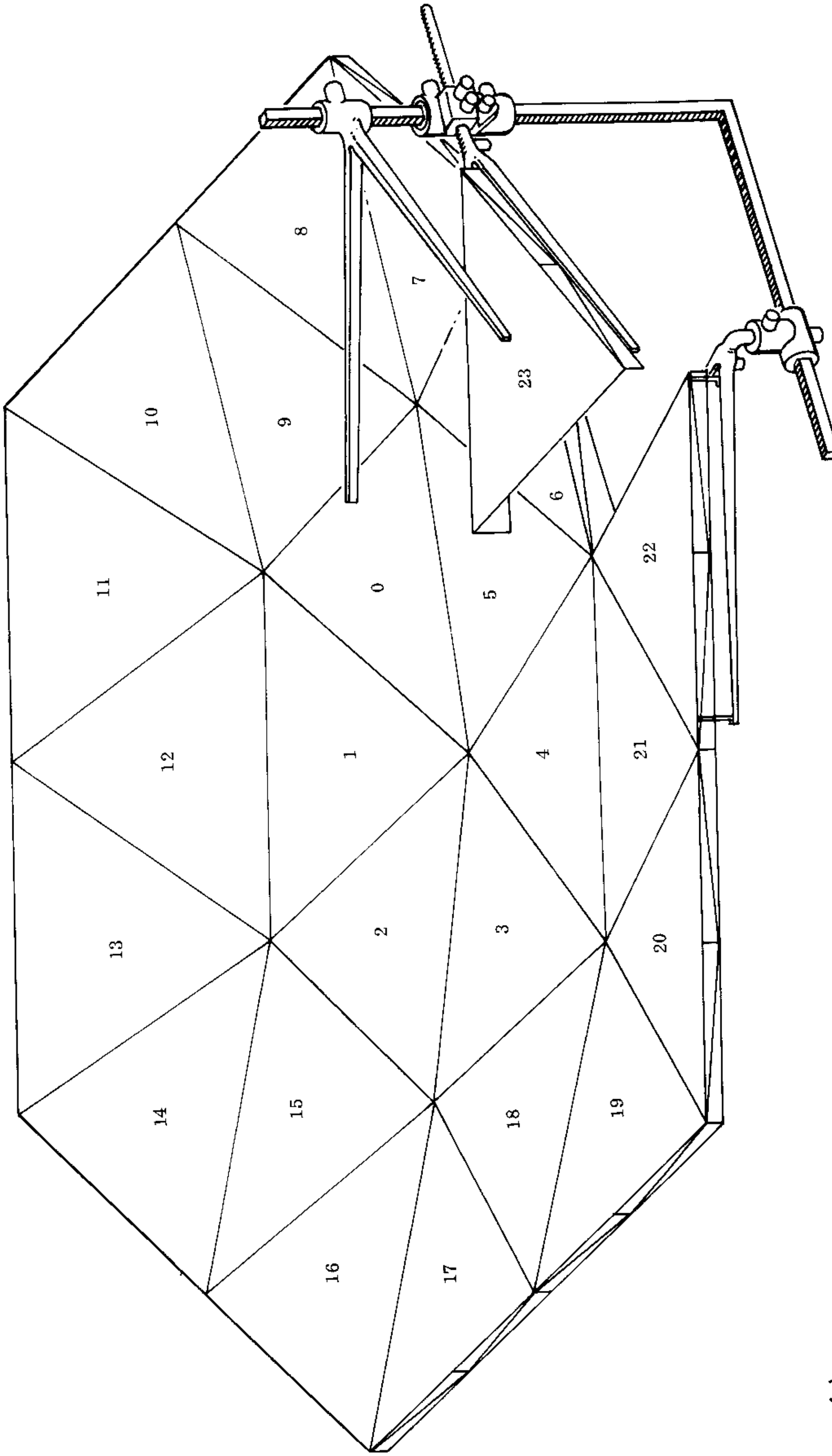


(a)

Figure 5. Assembly Equipment


UPPER GRIPPER
MIDDLE GRIPPER
LOWER GRIPPER
1
2
3
4
5
6
7
8
10
10
23
11
2,
1
10
3
0
9
4
5
8
6
7

(b)



(c)

bottom (rib side) of a panel which has been removed from the bottom of the stack and is in transport to an assembly position. The lower gripper is attached to the last assembled panel (panel 10 in Fig. 5b) which acts as an anchor between the assembled and unassembled panels.

The middle gripper fork, which has a cross-sectional width equal to the width of the panel ribs, engages and grips the panel along the lower edge of its rib. This gripper can also grip a panel along the upper (reflector-face) edge of the ribs.

5. DRIVE FUNCTIONS

Fig. 6 is a schematic showing the drive functions of the assembly equipment. The drive functions called out in Fig. 6 correspond to the numbered drives in Fig. 5b.

Drive functions 1, 2, and 7, are linear translations of the upper, middle, and lower grippers respectively, in the indicated directions along the floating rack frame. Drive function 5 linearly translates the middle gripper parallel to the plane of the middle gripper. The drive functions 3, 4, 6, and 8, are angular displacements of the middle and lower grippers.

Functions 9a,b,c,d, by using separate two-directional drives, produce linear displacements and rotations in the powered screw drivers. One direction of rotation of these drives for a controlled time period produces the forward displacement of the shoulders and chucks. Continuation of this rotation produces rotation of the chucks. Reversing the drives withdraws the shoulders and chucks without rotating the chucks. Drive functions 9a,b,c,d, therefore have three states.

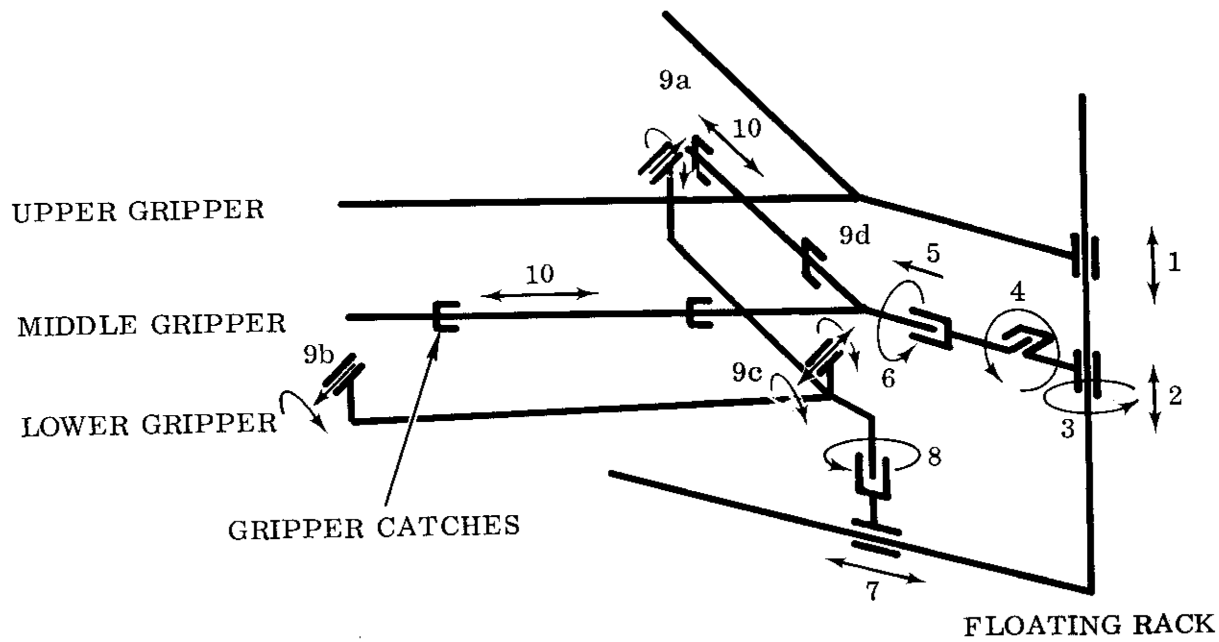


Figure 6. Assembly Equipment Mechanism Functions - Schematic

Drive function 10 is a single linear actuation for simultaneously operating the latches on the middle gripper. Fig. 7 shows a schematic of the middle gripper and panel latches. When the gripper and panel are aligned, operation of actuator 10 produces gripper-panel engagement and the unfastening of the structural stow-state latches. The panel, attached to the gripper and detached from the stack, is now free to be transported by the gripper.

A set of latches integral with the latches on the top side of the middle gripper protrude from the bottom side of the gripper. When the gripper is positioned on top of a panel the latches engage the panel.

The actuators 1 to 8 may typically be powered by step motors, actuators 9 and 10 by continuous running motors, or actuator 10 by a solenoid.

6. MECHANISM FUNCTIONS

The mechanism functions for the assembly of panel 1 to panel 0 are outlined in Fig. 8. The operations cycle diagram in Fig. 9 indicates the drive function actions according to the sequence of events 1 to 15 required for the assembly of panel 1 to panel 0. The corresponding events depicted in Fig. 8 are also called out in Fig. 9. The events to achieve the assembly of panel 1 are summarized with reference to events 1 to 15 in Fig. 9:

1. The stack of panels, fastened to each other, are initially held by all three grippers. The lower and middle grippers are attached to panel 0, and the upper gripper is attached to panel 23 (at the top of the stack in Fig. 5) - Release panel 0 from the stack and raise the stack

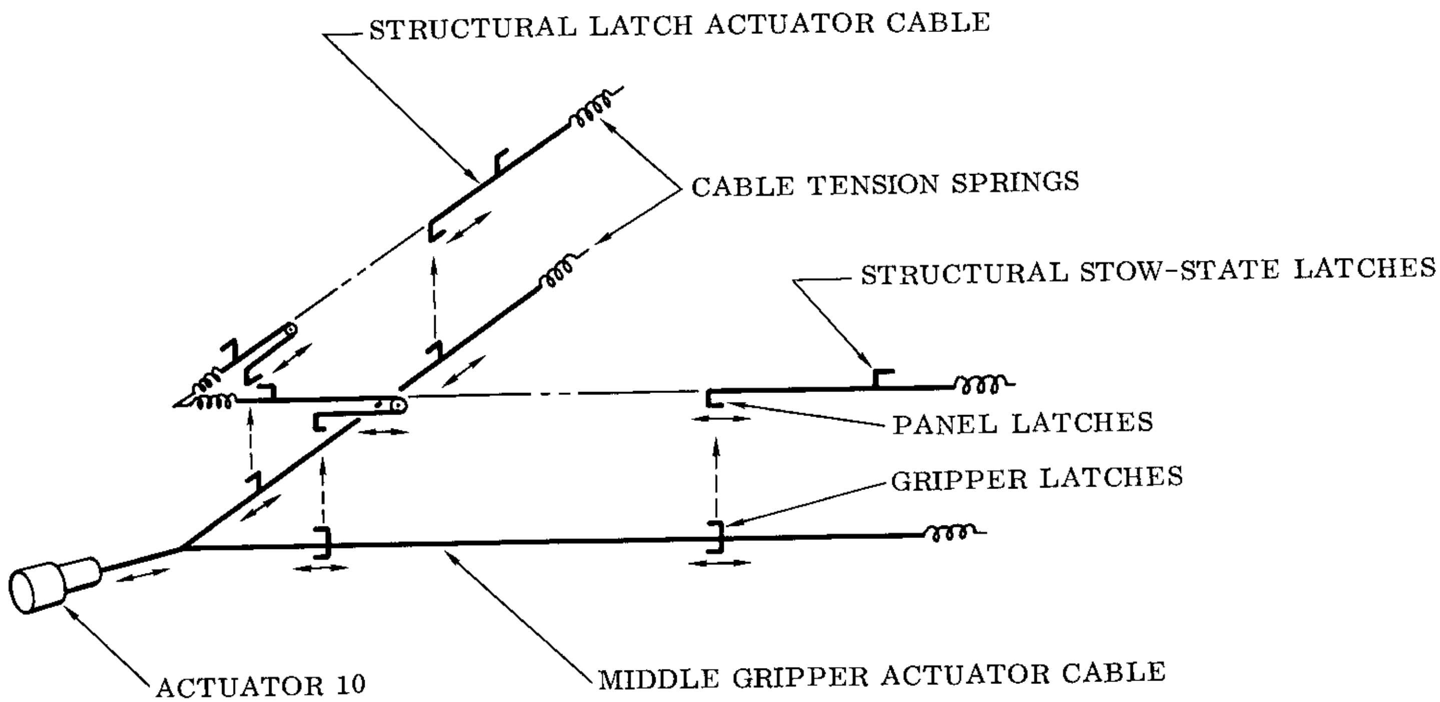


Figure 7. Latch Actuators - Schematic

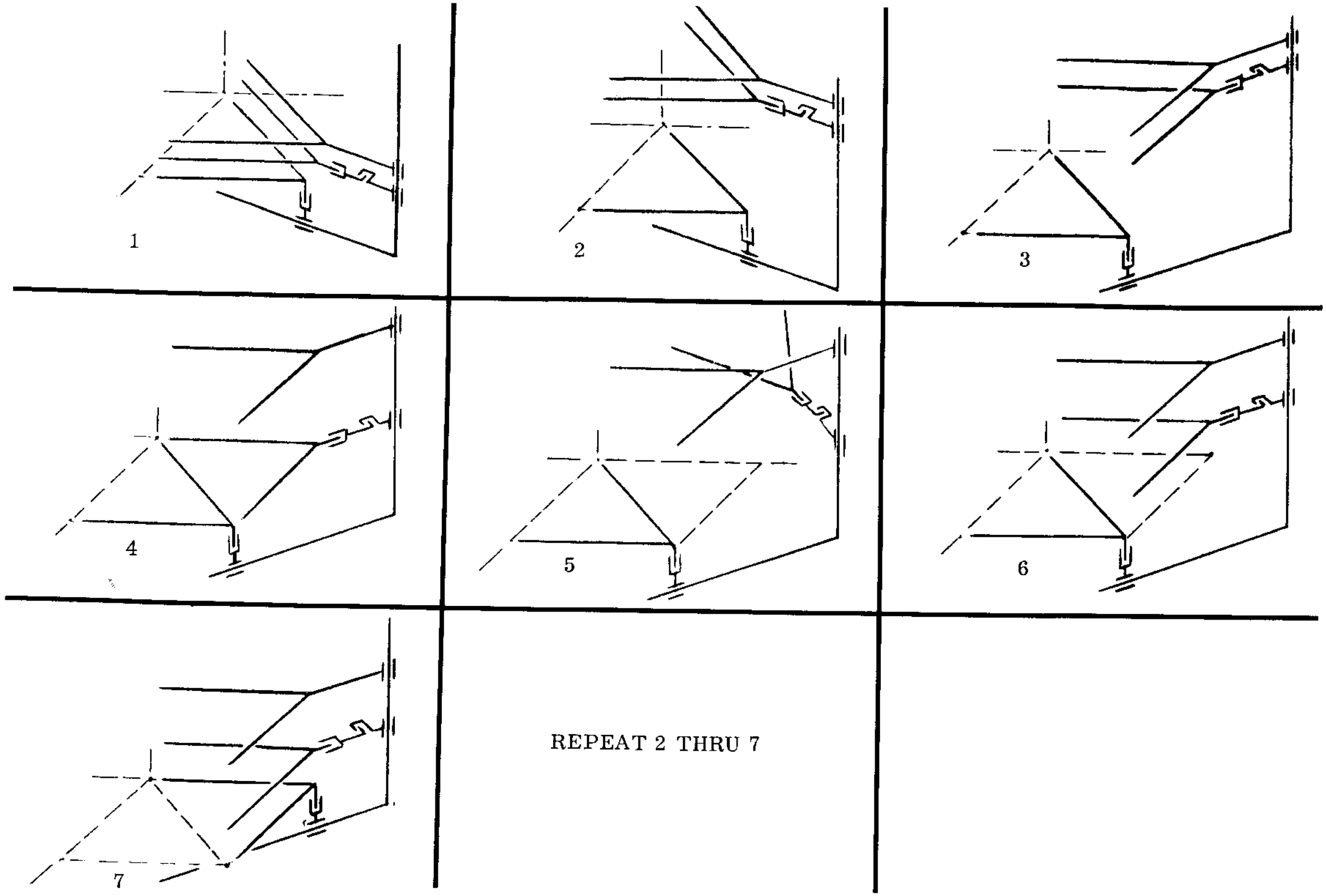


Figure 8. Mechanism Functions for the Assembly of Panel 1 - Schematic

		DRIVE FUNCTIONS											
		10	9	8	7	6	5	4	3	2	1	EVENTS	EVENTS (FIG. 8)
ASSEMBLY OF PANEL 1	RELEASE PANEL O, RAISE STACK	●									●	1	(2)
	ENGAGE PANEL 1 WITH MIDDLE GRIPPER	●					●			●		2	(2)
	GRIP PANEL 1 RELEASING IT FROM STACK	●										3	(2)
	MOVE STACK AND PANEL 1, LOCATE PANEL 1 FOR ASSEMBLY			●	●	●		●	●	●		4	(3)
	FASTEN PANEL 1 TO PANEL O, RELEASE MIDDLE GRIPPER	●	●									5	(4)
MOVE MIDDLE GRIPPER FROM BOTTOM TO TOP OF PANEL 1	DISENGAGE MIDDLE GRIPPER									●		6	(4)
	CLEAR MIDDLE GRIPPER FROM PANEL 1			●	●				●			7	(5)
	RAISE MIDDLE GRIPPER					●	●	●		●		8	(5)
	LOCATE MIDDLE GRIPPER ON TOP OF PANEL 1			●	●	●	●	●	●	●		9	(6)
	GRIP PANEL 1 WITH MIDDLE GRIPPER	●										10	(6)
MOVE LOWER GRIPPER FROM BOTTOM PANEL O TO PANEL 1	RELEASE LOWER GRIPPER FROM PANEL O		●									11	(6)
	DISENGAGE LOWER GRIPPER									●		12	(6)
	MOVE LOWER GRIPPER FROM PANEL O TO PANEL 1			●	●	●	●	●	●			13	(7)
	ENGAGE PANEL 1 WITH LOWER GRIPPER									●		14	(7)
	GRIP PANEL 1 WITH LOWER GRIPPER		●									15	(7)

Figure 9. Operations Cycle Diagram

from panel 0 - These events are brought about by exercising function 10 to unfasten panel 0 from the stack, and function 1 to raise the upper gripper. The dots along the event-1 row in Fig. 9 indicate that the drive functions 1 and 10 are exercised as described.

2. Release middle gripper from panel 0 and mofe to a position of engagement with panel 1 - Exercise of function 10 releases panel 0. Exercise of functions 2 and 5 transports the middle gripper to the engagement position.

3. Operate function 10 to grip panel 1 and release it from the bottom of the stack.

4. Translate panel 1 to its assembly position with respect to panel 0. To accomplish this, functions 2, 4, 6, 7, 8, and 3, are used. Because the upper gripper rides on the same leg of the floating rack frame as does the middle rack carrying panel 1, the stack is also moved by the use of the 7,8 functions; the stack follows along above panel 1.

5. Fasten panel 1 to panel 0 and release the middle gripper from panel 1, by exercising functions 9 and 10.

6. When panel 1 is fastened to panel 0 the assembly mechanism is repositioned on the structure to approximately the same gripper-panel relation which existed at the start of panel 1 assembly. This is started by event 6 in which the middle gripper is disengaged (lowered) from the bottom of panel 1.

7. Here the middle gripper is swung parallel to its face to clear the bottom of panel 1.

8,9,10. Now the middle gripper is located on and fastened to the top of panel 1 leaving the bottom of panel free for the attachment of the lower gripper.

11 to 15. The lower gripper is released from panel 0 and transported for attachment to the bottom of panel 1.

With the completion of event 15 the assembly equipment, except for the middle gripper, is in the same position relative to panel 1 as it was relative to panel 0 at the completion of event 1. It is therefore necessary, with some small modifications, to repeat events 2 through 7 to achieve the assembly of panel 2 to panel 1 as well as 3 to 2 and all subsequent panels.

The modifications in the panel-2-to-panel-1 and all subsequent assembly motions are due to: (1) the decreasing height of the stack as the assembly progresses and panels are removed from the stack, and (2) changes in relative positions or assembly angles between different panels depending on their location on the reflector.

The decrease in stack height (1) is systematic requiring a systematic biasing in the 1 and 5 drive functions with the progress of the assembly.

The changes in relative panel assembly positions (2) take place only three times: the assembly positions are the same for panels 1 to 5, for panels 6, 9, 12, 15, 18, 21, and for panels 10, 11, 13, 14, 16, 17, 19, 20, 22, 23. These changes in assembly position are achieved by modifications in the 4 and 6 drive functions as required.

It follows from the above that one basic motion, or sequence of events, together with the indicated systematic variations in drive functions

1, 5, 4, and 6, are necessary to achieve the overall reflector assembly.

The control logic needed to control the assembly equipment is rather simple by most computer standards. In this example the estimate control logic would weigh under three pounds.

7. FEATURES OF THE RATIO TECHNIQUE

1. It is generally possible to design space structures such that they can be sectionalized into panels which nest in each other to minimize storage volume and susceptibility to damage by boost loads. The panel shapes can be chosen to satisfy available storage volume requirements. In the deployed state the structures are ribbed, and have structural continuity.

2. The assembly equipment can be manually or automatically controlled.

3. For deployment of a structure such as an antenna from a space station it is possible to choose panel assembly sequences in which:

(1) The first panel in the stack of panels is attached to the station and the assembly equipment carrying the stack moves away from the station as it assembles the rest of the structure. (This is the assembly sequence described in this paper.)

(2) The assembly equipment and stack of panels are attached to the station and the structure as it is assembled moves with respect to the station. In this case the last panel of the assembled structure is attached to the station. This assembly sequence facilitates access to the assembly equipment for control, repair, or maintenance by the station personnel, and reduces the instrumentation compexity

for checking the alignment of each assembled panel. This sequence also introduces the possibility of having the assembly equipment available, attached to the last assembled panel, to serve as the antenna altitude control pedestal.

A variation of (1) above is to attach the station to any of the panels to be assembled. As in (1), at the completion of assembly, the assembly equipment is on the last assembled panel. If the chosen panel to which the station is attached is the last panel, then the conditions in (2) exist.

4. Typical preliminary design estimates indicate that for 30 to 200 foot reflector structures having structural weights on the order of 0.05 lbs. per square foot the automatic assembly equipment weight ranges from 50-to-100% of the structural weight for the smaller structures to 10-to-20% for the larger structures. Actual structural and assembly equipment weights depend upon such parameters as: the number of panels into which the structure is sectionalized, structural tolerances, structural rigidity, assembly time, storage volume, etc.

5. The size of the structures that can be assembled is mainly limited by the number and sizes of panels which can be orbited. The same assembly equipment having assembled one stack of panels can be shifted to a new stack to continue the assembly operations.

6. The fasteners used to hold the panels together in the assembled state may be of the reversible or irreversible screw, latch, explosive rivet, magnetic, chemical, or metal forming types. In the stowed state the panels may be held together by similar, reversible fasteners, or by a separate mechanism or manual device which releases one panel at a time from the stack. The fasteners may be

actuated through the action of the transport mechanism or by a separate fastener actuating mechanism. The fastener systems generally perform panel-to-panel lead-in, alignment, and lock-in functions.

7. The slow deployment speeds of the structure make it possible to test and evaluate flight-weight hardware in a gravity compensated (underwater) environment.

8. The assembly equipment is generally significantly more rigid than the structure it is assembling. This makes it possible for the equipment to pull the structure into alignment in the event of small misalignments as caused by reassembly tolerances (thermal gradients, etc.). The fastening action is therefore limited to between panels held by gripper frames. (Referring to Fig. 1, panel 5 is fastened to panel 4 when the middle gripper is holding panel 4. Then the possible misalignments between panels 0 and 5, which may result from the sequential assembly of panels 1 to 5, are pulled out by the assembly equipment. If for some reason the misalignments are excessive, the assembly process may be reversed to look for or eliminate the cause of the misalignment.)

9. It is generally possible to sectionalize the structure such that the effective relative positions of the structural fasteners are the same for each panel while (as in the case of a parabolidal reflector) the surfaces or geometry of the panels are not the same. Variable extensions in the panel gripper functions can be used to extend the allowable variation in the relative positions of the fasteners.

10. Assembly equipments consisting of two or any number of gripper or manipulator arms are theoretically possible. The equipments may (1) be extended to handle separate structural corners for implementing panel-to-panel fastening, (2) providing articulation at the joints for adjusting panel-to-panel alignment, and (3) for serving other station material handling functions when the structural assembly is complete.

11. The assembly equipment can carry a panel-to-panel position register system. This system may use optical or mechanical devices for sensing the alignment or successful completion of a panel assembly.

12. Fixed or variably adjusted dummy panels (depending on the structure) may be substituted for damaged panels. The assembly equipment may be used for separate handling of these panels.