ESSEX

FINAL REPORT

DEVELOPMENT OF CONCEPTS FOR SATELLITE RETRIEVAL DEVICES

(NASA-CR-161178) DEVELOPMENT OF CONCEPTS FOR SATELLITE RETRIEVAL DEVICES Final Report (Essex Corp., Huntsville, Ala.) 78 p HC A05/MF A01 CSCL 22A
N79-20158
Unclas
G3/12 16669

CONTRACT NAS 8-33373

MARCH 9, 1979

ESSEX REPORT NO: H-79-04

HUNTSVILLE FACILITY 3322 Memorial Parkway South, Huntsville, Alabama 35801

ESSEX

FINAL REPORT

Contract NAS8-33073

DEVELOPMENT OF CONCEPTS FOR SATELLITE RETRIEVAL DEVICES

Prepared For:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Prepared By:

Edwin C. Pruett
Kem B. Robertson, III
Tomas E. Loughead

ESSEX CORPORATION
3322 South Memorial Parkway
Huntsville, Alabama 35801

February 8, 1979

Essex Report No. H-79-04

FOREWORD

This report describes the tasks performed and the end products developed by Essex Corporation during an eight month study to develop concepts for satellite retrieval devices for use with NASA's Teleoperator. The work was performed under the technical direction of Dr. Richard A. Campbell, EC25, during the initial part of the contract and Mr. John L. Burch, EC25, during the latter part. The guidance and technical contributions provided by both gentlemen are gratefully acknowledged.

ESSEX

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 BACKGROUND

The Teleoperator is being developed by NASA to augment the Space Transportation System (STS) for satellite placement, retrieval, or servicing at altitudes or obrital planes where it would be impractical to use the Shuttle. The Teleoperator will be primarily a general purpose propulsion stage that can be fitted with manipulator arms, automated servicers and satellite retrieval devices for particular missions.

One proposed use of the Teleoperator is for retrieval of orbiting spacecraft for several purposes, including on-site servicing, or return to the Shuttle for servicing inflight or for later repair on earth. To provide the Teleoperator with this retrieval capability, a device will be required that can be remotely controlled by the Shuttle crew to dock the Teleoperator to the satellite. Although docking devices were developed for the Gemini, Apollo and Apollo/Soyuz programs, none of these devices is particularly suited for satellite retrieval by a remotely operated vehicle.

The retrieval device required by the Teleoperator will differ from the docking devices used in these previous programs in several major design areas: (1) the Teleoperator retrieval device may have to capture a non-prepared, dynamic target; (2) the device need not be a peripheral type docking mechanism since crew transfer through the docking interface is not required; and (3) the target spacecraft may be lightweight and highly susceptible to thruster impingement and nonreacted docking loads.

A fourth major design consideration that will affect the retrieval device is that it will be operated remotely by a Shuttle crewman. All previous docking tasks (at least by NASA) have utilized a crewman in the docking vehicle to control the vehicle attitude and position and to operate the docking device. The Teleoperator docking task will be different--the crewman will remotely control the Teleoperator and the docking mechanism from the Shuttle or, possibly, from a ground station. This will require that special consideration be given to the visual information the crew needs to use the retrieval device and other limitations imposed by the remote operations such as reduced motion cues. These four primary factors as well as a large variety of lesser design considerations will necessitate the design of a new type of satellite retrieval device for use by the Teleoperator.

1.2 SCOPE

The purpose of this contract effort was to develop concepts for satellite retrieval devices that would satisfy the unique design requirements imposed by: (1) the target satellite, (2) the Teleoperator, and (3) remote control by the Shuttle crew.

Section 2.0 describes the tasks Essex performed to accomplish this objective and the results of each task. Section 3.0 describes the two primary retrieval device concepts developed during this study. These are:

(1) a general purpose retrieval device for docking with a satellite to which a grappling fixture has been attached, and

(2) a retrieval device for docking with the Solar Maximum Mission (SMM) spacecraft.

In addition to a description of the mechanical aspects of these two devices, Section 3.0 also contains an explanation of the crew operations involved and how the two design concepts handle the problems created by the requirement for remote control.

Section 4.0 presents a summary of contract activities, end products, and recommendations for further study. Drawings for the two retrieval device concepts are included as Appendices B and C.

2.0 TECHNICAL APPROACH

This effort was conducted in two phases:

Phase 1 - Requirements and Constraints Definition
Phase 2 - Concept Development.

Each phase was divided into three tasks, making six tasks altogether. These are illustrated in Figure 2-1.

Tasks 1 through 3 were performed to define the design goals and constraints for the satellite retrieval device. These tasks formed a base for the later tasks. Task 4, in which the major part of the contract time and effort was concentrated, resulted in the development of two new retrieval device concepts. Tasks 5 and 6 involved evaluating these concepts and preparing detailed engineering drawings illustrating them. All six tasks and their specific outputs are discussed below.

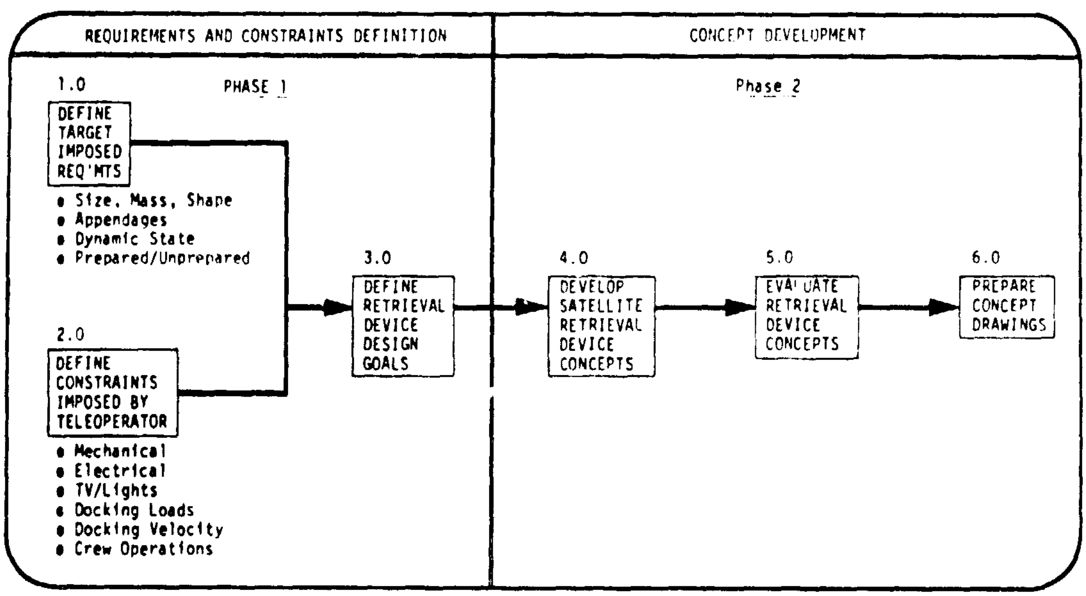


Figure 2-1: Contract Task Flow Diagram

2.1 TASK 1 - DEFINE TARGET-IMPOSED REQUIREMENTS

Essex originally proposed to use several spacecraft to serve as design drivers for the concept development effort. These spacecraft were to be representative of all the targets that the Teleoperator might be called upon to retrieve. The satellite design features that could affect the configuration of the retrieval device included: (1) the satellite's size, mass and shape: (2) appendages such as antennas, booms, or solar panels that could affect the Teleoperator's approach path or that could be susceptible to thruster impingement; (3) probable dynamic state; and (4) whether or not the target satellite was prepared for capture (i.e., whether it was equipped with a grappling fixture, docking ring, or other such docking aid).

At the contract kickoff meeting, two spacecraft were chosen as design drivers. These were: (1) the San Marco D/L (Figure 2-2), which is a small, lightweight target with no appendages or docking aids, and (2) the Solar Maximum Mission (SMM) spacecraft (Figure 2-3), which is a large, massive, stable target with several appendages including solar panels and a high gain antenna. The SMM is the first of a series of Multimission Modular Spacecraft (MMS) that will utilize common support equipment but will employ a wide range of scientific experiment instruments.

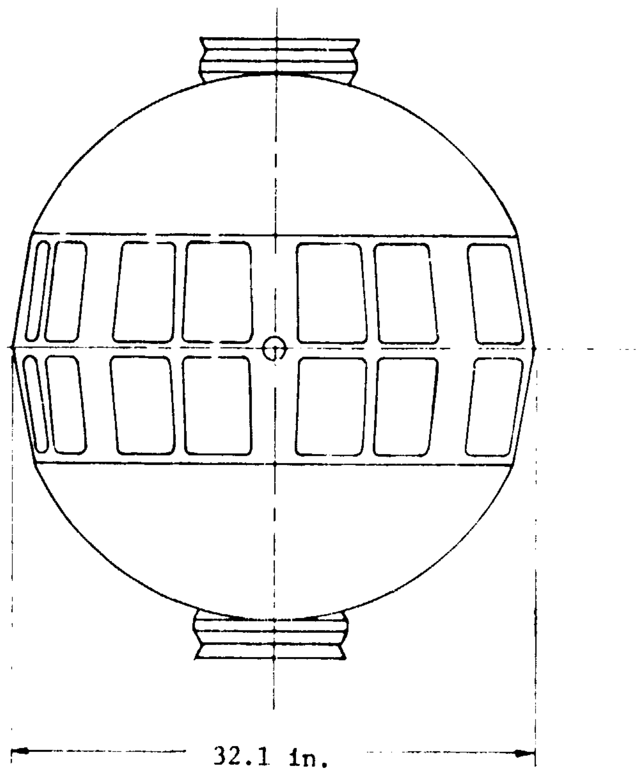


Figure 2-2: San Marco D/L Spacecraft

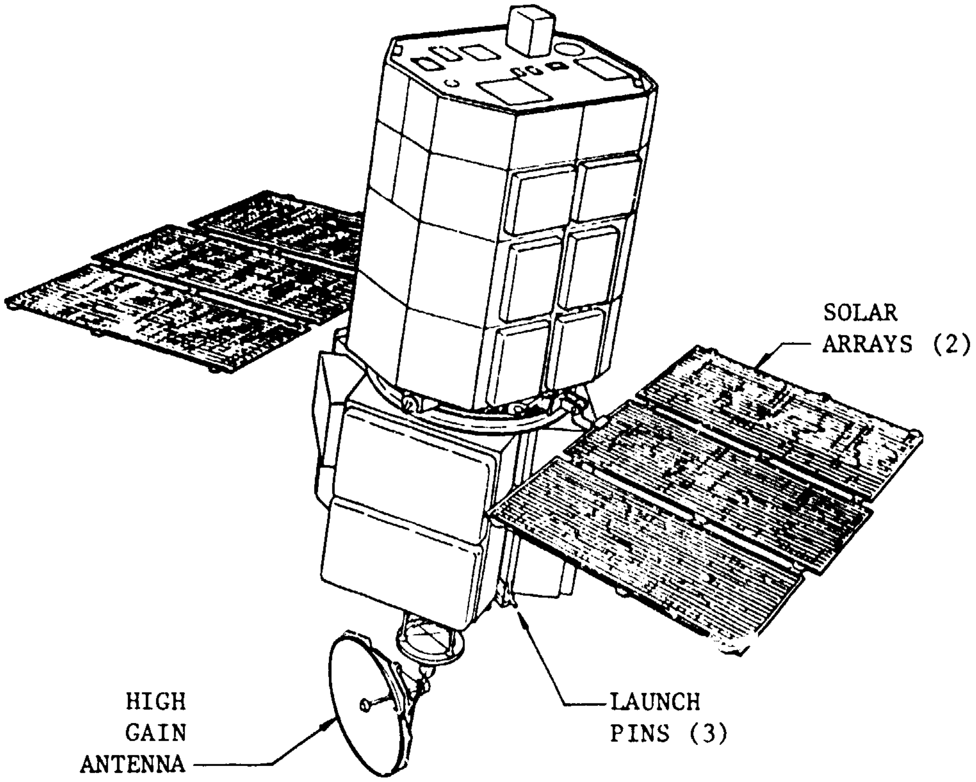


Figure 2-3: Solar Maximum Mission Spacecraft

Later in the study, the San Marco D/L spacecraft was deleted from consideration so more emphasis could be placed on development of a retrieval device for two versions of the SMM spacecraft. Initially, it was thought that the SMM high gain antenna could be jettisoned prior to retrieval by the Teleoperator and that a grappling fixture could be mounted on the SMM aft end beneath the antenna. Later, it was determined that the antenna could not be jettisoned and that an entirely different retrieval device would probably be required.

In either case, the SMM represents a large (7.2 ft. wide by 14.0 ft. long), massive (4714 lbs.) spacecraft that will probably be three-axis stabilized during docking. Two nonfurlable solar arrays will prevent access to the side of the SMM and could cause thruster impingement problems. Specific SMM design characteristics that will affect the design and operation of the retrieval device are discussed below. The discussion is divided into two parts--one addressing the SMM spacecraft with the high gain antenna and the other addressing the same spacecraft without the antenna.

2.1.1 SMM Spacecraft With the High Gain Antenna

A detailed view of the SMM spacecraft aft end with the antenna in place is presented in Appendix A. As a result of discussions with Goddard Space Flight Center (GSFC) personnel, a major design goal for the retrieval device was established. It was determined that the only possible change to the SMM to support the retrieval task would be the extension of the three launch pins from 3.0 in. to approximately 11.0 in. Ideally, GSFC would prefer that no other changes be made to the spacecraft since the addition of docking targets, grappling fixtures, etc., would add weight and could severely impact physical integration of the vehicle, which was scheduled to begin in October 1978.

Since the three launch pins support the SMM in the Delta during launch and carry all ground handling and launch loads, they are well suited to withstand any loads imposed by docking. However, using the three pins as grapple points for Teleoperator-mounted latches would present two major problems:

(1) The retrieval device jaws must be aligned with all three pins prior to docking.

(2) The high gain antenna and the side-mounted equipment modules must be avoided during docking.

At this point the major design problem appeared to be simultaneously aligning some type of grapple device with the three launch pins while avoiding the surrounding SMM equipment.

Another option considered was the use of the side-mounted Shuttle Remote Manipulator System (SRMS) grapple fixture by a retrieval device mounted on the Teleoperator. The use of this existing fixture would have two advantages: (1) no changes would be required for the SMM spacecraft, and (2) an existing retrieval device could be mounted to the Teleoperator with little, if any, change. There were, however, three problems associated with this plan. These problems are discussed below.

1. Serial Operation - If the Teleoperator retrieved the SMM spacecraft using the SRMS grapple fixture, the SMM attitude control system would be deactivated immediately after docking. The two vehicles' attitudes would then be controlled solely by the Teleoperator. After transporting the SMM to the Shuttle, the Teleoperator would release the SMM so the SRMS could have access to the grapple fixture for retrieving the SMM and storing it in the cargo bay. Once released by the Teleoperator, the SMM attitude control system would have to be reactivated to provide stability prior to capture by the SRMS. This system restart was regarded as undesirable by GSFC personnel because of the chance that an attitude control system failure could result in loss of the SMM spacecraft.

2. Access to the Grapple Fixture - The Teleoperator, fitted with strap-on hydrazine fuel tanks, could contact the SMM nonfurlable solar panels before reaching the grapple fixture. Relocation of the grapple fixture was considered undesirable for SRMS operations.

3. Offset from Center of Mass - The SRMS grapple fixture is approximately 4.0 ft. from the SMM spacecraft center of mass. If the Teleoperator were to

dock with and impact translation loads directly through the grapple fixture, the Teleoperator attitude control system would have to resolve the thrust moments about the center of mass, resulting in unnecessary fuel expenditure.

For these three reasons, the use of the SRMS grapple fixture by the Teleoperator-mounted retrieval mechanism was dismissed from further consideration.

2.1.2 SMM Spacecraft Without the High Gain Antenna

Without the antenna in place, the entire aft end of the SMM would be available for mounting docking targets, grappling fixtures, drogue rings and other retrieval gear. Although this flexibility does not appear to be realistic for the SMM spacecraft, it may be possible to have access to the spacecraft aft end on other Multimission Modular Spacecraft vehicles.

If the Teleoperator retrieves the SMM spacecraft using a grapple fixture or drogue at the SMM aft end, no significant satellite-imposed impact on retrieval device design is expected. Docking and translation loads can be handled through the longitudinal axis of the SMM so no vehicle control problems are expected. Since the SMM is expected to be three-axis stabilized at the time of retrieval, no vehicle alignment problems should occur. Also, no interference is expected from SMM appendages since the aft end, without the antenna, would be relatively clear.

However, since the SMM spacecraft will be pointed toward the sun at the time of docking, the Teleoperator cameras will be looking directly into the sun. This will likely be a problem for the cameras and for the crewman, since the SMM part of the retrieval system will be in shadow. This problem does not affect the design of the retrieval mechanism itself but may impact crew operations, mission timelines, alignment markings, camera and filter selection, etc.

2.2 TASK 2 - DEFINE CONSTRAINTS IMPOSED BY THE TELEOPERATOR

During Task 2, Essex examined the Teleoperator being developed by MSFC to identify any restrictions or constraints on the design of the retrieval device imposed by the Teleoperator. Since the Teleoperator for satellite retrieval has not been designed, no firm restrictions could be identified. Rather, it was felt that any reasonable requirement placed on the Teleoperator by the capture device could be satisfied. The five types of design constraints that were considered are presented below.

1. Mechanical Interfaces - The retrieval device should be a bolt-on mechanism that transmits docking and target handling loads to the Teleoperator's major structural members.

2. Electrical Power Limitations - Electrical power to operate latch actuators, lights, etc., should be low power, direct current (e.g., 28 Vdc). No firm power limitations were identified.

3. TV System and Lights - The current Teleoperator concept has two TV cameras and two floodlights. As a design goal, the retrieval device concepts

developed in this study should not have additional camera or light requirements, although placement of this equipment on the Teleoperator or retrieval device is optional.

4. Docking Loads/Velocity - Maximum docking loads and closing velocity could not be determined. However, a soft dock followed by a positive hard dock is most desirable from a crew control standpoint.

5. Operations - Special restrictions on flight trajectories, mission events, or crew operations may be required for such activities as precapture checkout of target and Teleoperator systems. Such restrictions should not adversely affect normal Teleoperator functions.

These design and operational restrictions are discussed in Section 3.0 for the two retrieval device concepts developed during this study.

2.3 TASK 3 - DEFINE RETRIEVAL DEVICE DESIGN GOALS

A set of design goals for the capture device(s) was established, based on the anticipated capabilities and limitations of the Teleoperator and the physical configuration of the SMM, both with and without the aft-mounted high gain antenna. Not all of the design goals were a direct result of the Teleoperator and SMM requirements and constraints; some were derived from Essex' experience with remote manned docking tasks using MSFC's five degrees-of-freedom (DOF) simulator. Design goals, such as maximum approach attitude error and maximum roll error, reflect what the crewman can be expected to achieve using current control and display equipment (STS cameras, monitors and hand controllers). These design goals, which are summarized in Table 2-1, were used to evaluate the two capture device concepts developed in Task 4.

Table 2-1: Satellite Retrieval Device Design Goals

Lateral Offset	± 10 in.
Roll Misalignment	± 10° initial roll alignment to ± 1° after hard dock
Approach Attitude	± 15°
Axial Velocity	0 to 4 in./sec.
Lateral Velocity	0 to 2 in./sec.
Self-Aligning Capability	Yes
Unlatch Capability	Yes
Maximum Docking Loads	0 to .1 G desired
Capture Device Size	Depends on Target
Capture Device Mass	Depends on Target

2.4 TASK 4 - DEVELOP SATELLITE RETRIEVAL DEVICE CONCEPTS

Several retrieval device concepts were developed for the two types of target satellites--the Solar Maximum Mission spacecraft with and without the aft-mounted high gain antenna. Several types of retrieval device concepts were considered that utilized mechanical jaws, cable snares, inflatible probes and various other mechanisms to provide an initial soft dock followed by alignment and hard dock. Although many of these concepts appeared to be feasible, only one of the concepts was determined to be suitable for the SMM retrieval task with the high gain antenna in place. This concept and one concept for SMM retrieval without the antenna are described briefly in the paragraphs below. A more thorough description of these devices is presented in Section 3.0.

2.4.1 Orthogonal Retrieval Device (ORD)

The retrieval device concept developed for the SMM spacecraft without the high gain antenna is shown in Figure 2-4. This device consists of a box structure open on the front, top and bottom and having two sets of parallel capture bars orthogonal to each other with the rear set of bars retractable to the rear of the box.

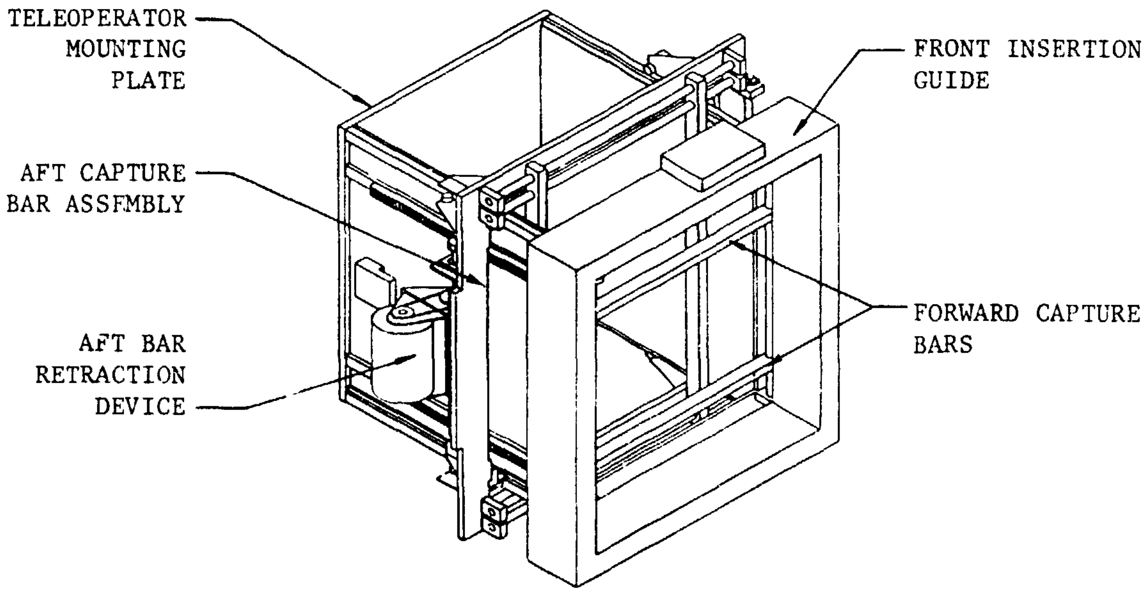


Figure 2-4: Orthogonal Satellite Retrieval Device

With the twin bars, the device captures a 24.75 in. long by 1.0 in. square cross section grapple fixture mounted on the target spacecraft. Roll, pitch, yaw and vehicle offset errors are corrected as the orthogonal bars grip the square cross section grapple fixture shaft and the aft bars pull the grapple fixture to the rear of the retrieval device (see Figures 2-5 and 2-6). Although this device was developed for retrieval of the SMM, it could easily be used on any spacecraft to which the grappling fixture could be attached. A complete description of this retrieval device is presented in Section 3.0, including its components, electromechanical operation, and crew tasks required.

2.4.2 Solar Maximum Mission Spacecraft Retrieval Device

The retrieval device concept developed for the SMM with the high gain antenna in place is shown in Figure 2-7. This device consists of three rotary, solenoid-operated latches mounted on three box beam arms. The configuration of the arms allows the latches and their associated funnel-shaped guides to secure the SMM launch pins without contacting the high gain antenna or side-mounted equipment modules.

This concept satisfies the GSFC design goal of minimum impact on the SMM design, but it may be difficult for the crew to use because of the stringent requirements for aligning the two vehicles prior to capture. This potential problem is discussed in Section 3.0 along with a thorough description of the design and the crew operations associated with the retrieval task.

2.5 TASK 5 - EVALUATE SATELLITE RETRIEVAL DEVICE CONCEPTS

As each of the retrieval device concepts was developed, it was evaluated in terms of the anticipated hardware and operational complexity, weight, electrical power requirements, need for new technology, allowable alignment and position errors and impact on target spacecraft design. This initial evaluation led to the selection of the two retrieval devices described in Task 4. Section 3.0 describes these two retrieval device concepts and presents detailed evaluation data.

2.6 TASK 6 - PREPARE CONCEPT DRAWINGS

Detailed concept drawings of the two satellite retrieval devices were then developed. Reduced copies of these drawings are attached as Appendices B and C. A complete set of full size drawings was presented to the COR under separate cover.

The drawings indicate how the devices would work and present some details for individual components. Descriptive information is presented for off-the-shelf hardware such as gears, sprockets, pillar blocks, bearings, and solenoids. Although a complete stress analysis and component sizing exercise was not performed, the equipment shown should be more than adequate to evaluate the concepts.

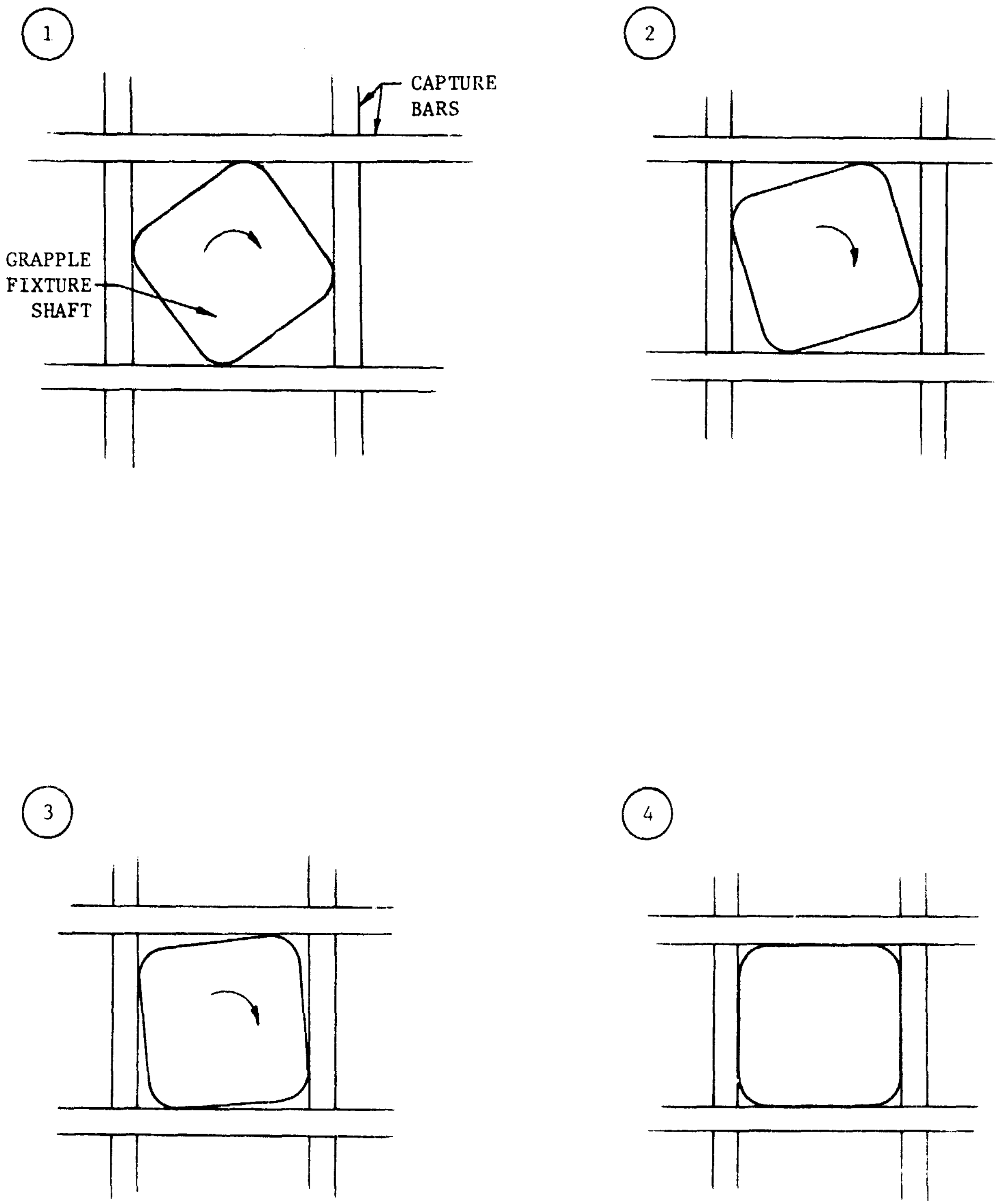


Figure 2-5: Capture Bar Roll Correction Sequence

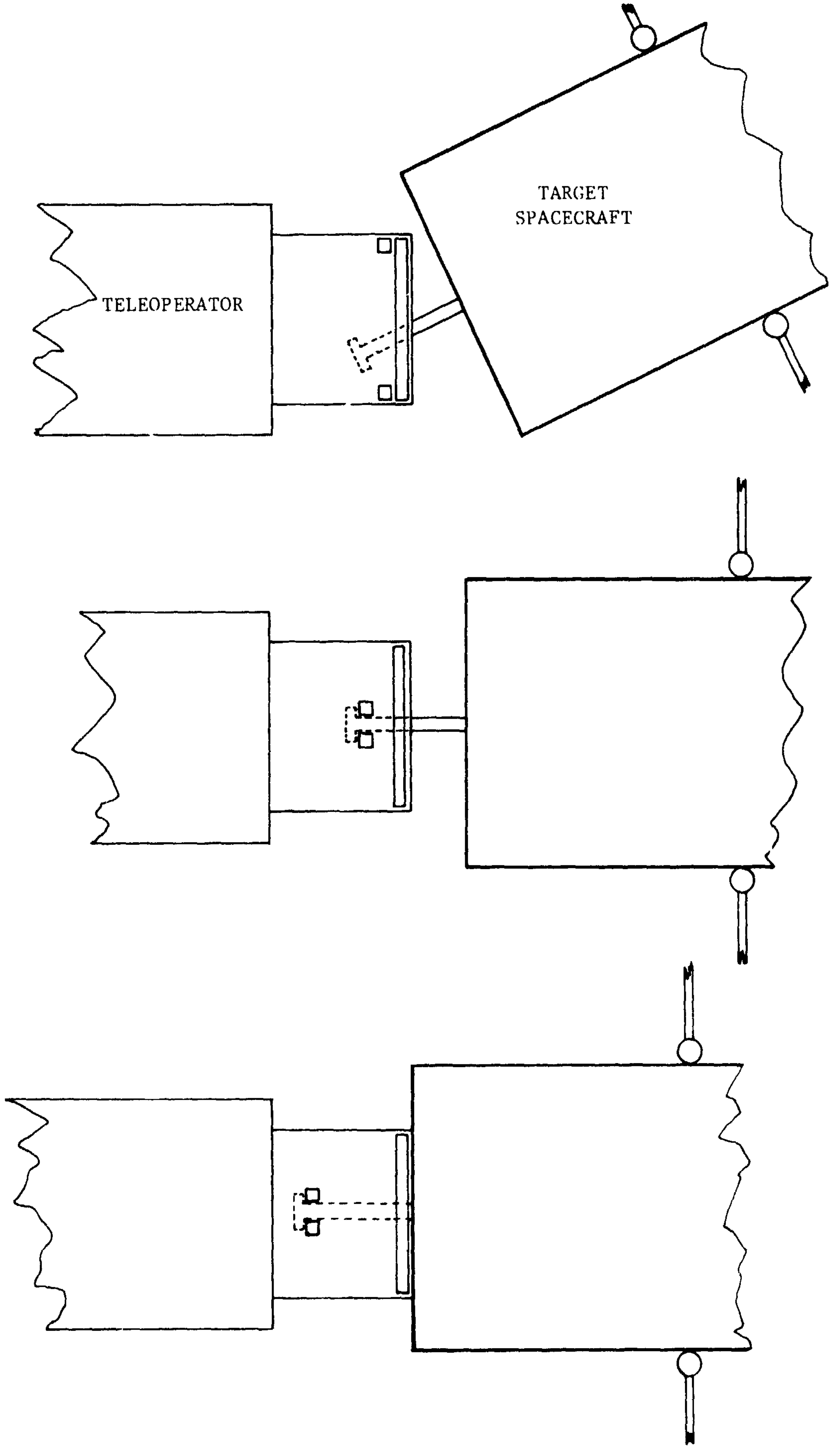


Figure 2-6: Retraction Device Pitch and Yaw Correction Sequence

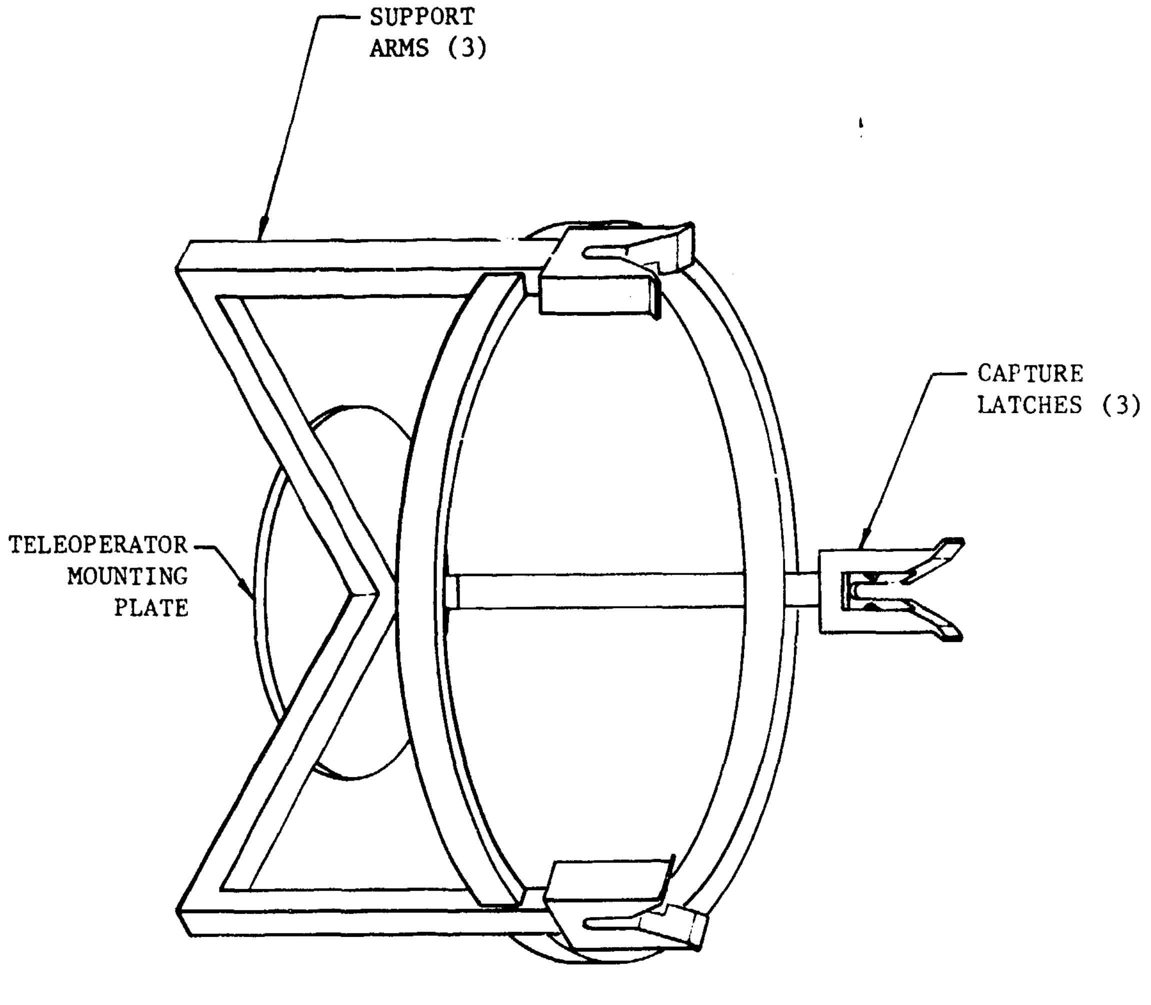


Figure 2-7: SMM Retrieval Device Concept

3.0 DESCRIPTION OF SATELLITE RETRIEVAL DEVICE CONCEPTS

This section describes the design of the two retrieval devices developed during this study and delineates the crew operations required to perform the retrieval tasks.

3.1 ORTHOGONAL RETRIEVAL DEVICE

The first retrieval device developed is roughly box-shaped and open on the front (see Figure 3-1). This device, called the Orthogonal Retrieval Device (ORD), captures a grapple fixture (Figure 3-2) mounted on a target satellite. Two orthogonal sets of parallel bars located near the front of the box trap the grapple fixture in the center of the box once the box has been flown over the grapple fixture. The rear set of parallel bars is then pulled to the rear of the box, forcing the Teleoperator and satellite into pitch, yaw and position alignment. Roll error is eliminated by the parallel bars gripping the square cross-section grapple-fixture shaft. Latches mounted on the perimeter framework on the front of the box will then complete the hard dock.

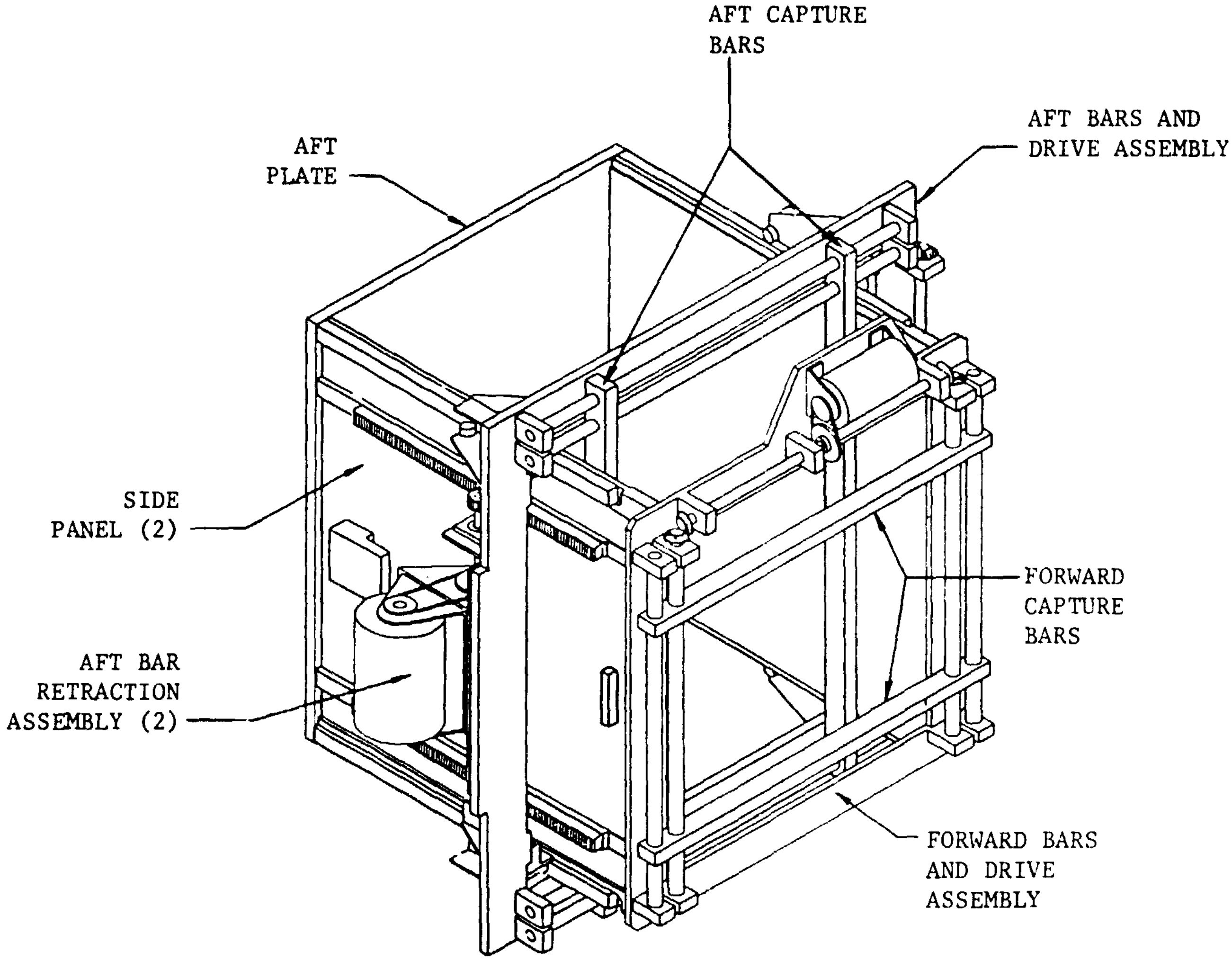
The paragraphs below present more detailed information on the following:

- Physical description
- Mechanical operation
- Acceptable alignment errors
- Crew operations
- Concept evaluation
- Areas for additional study
- Summary.

Drawings and sketches are provided throughout the section to illustrate the concept. More detailed drawings are included in Appendix B.

3.1.1 Physical Description

Figure 3-1 shows the Orthogonal Retrieval Device configured for satellite capture. The major parts of the retrieval device are the front insertion guide, forward bars and drive assembly, aft bars and drive assembly, aft bar retraction assemblies (2), side panels (2), and aft plate. The device also includes latches on the front insertion guide for completing a hard dock once the Teleoperator and satellite are aligned and pulled together. These are not shown in Figure 3-1 since these may be different for each target satellite. Each of these major system elements, as well as the target-mounted grapple fixture, is discussed below.



(FRONT INSERTION GUIDE NOT SHOWN)

Figure 3-1: Orthogonal Retrieval Device

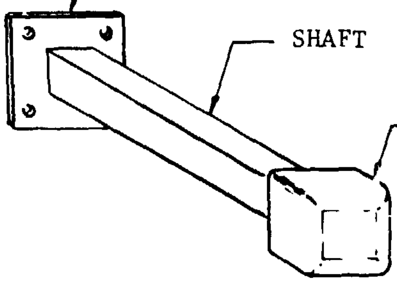


Figure 3-2: Target Mounted Grapple Fixture

a. Front Insertion Guide - This funnel-shaped device, shown in Figure 3-3, is a metal guard used primarily to protect the parallel bar drive screws, the bend gears, the drive shaft, and the guide shafts. It is also used to guide the grappling fixture into the box if the fixture is offset more than ± 10.0 in. The front insertion guide is attached to the front plate so movement of the capture bars is not restricted.

b. Forward Bars and Drive Assembly - As shown in Figure 3-4, this assembly consists of the front plate, drive motor, sprockets and chain, drive shaft, two sets of bevel gears, two drive screws, two guide shafts, two parallel capture bars, and various pillar blocks and bearings. The assembly also includes three limit switches mounted to the front plate so the capture bars can be stopped automatically in a full open position, a full closed position with the bars 1.0 in. apart, and in a "capture" position with the bars 1.5 in. apart. The logic behind the use of these limit switches is discussed along with mechanical and crew operations in Paragraphs 3.1.2 and 3.1.4.

As the reversible motor turns in one direction, the drive system elements (i.e., sprockets, chain, drive shaft and bevel gears) work together to turn the two drive screws. The screw threads and associated internal threads on the capture bars are selected so the two bars both move in the opposite direction as the motor turns (see Figure 3-5).

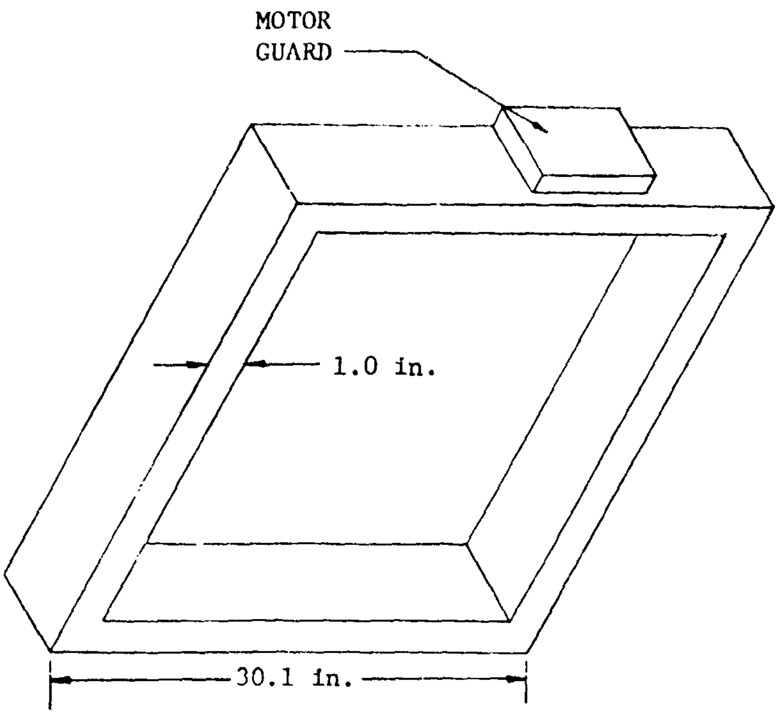


Figure 3-3: Front Insertion Guide

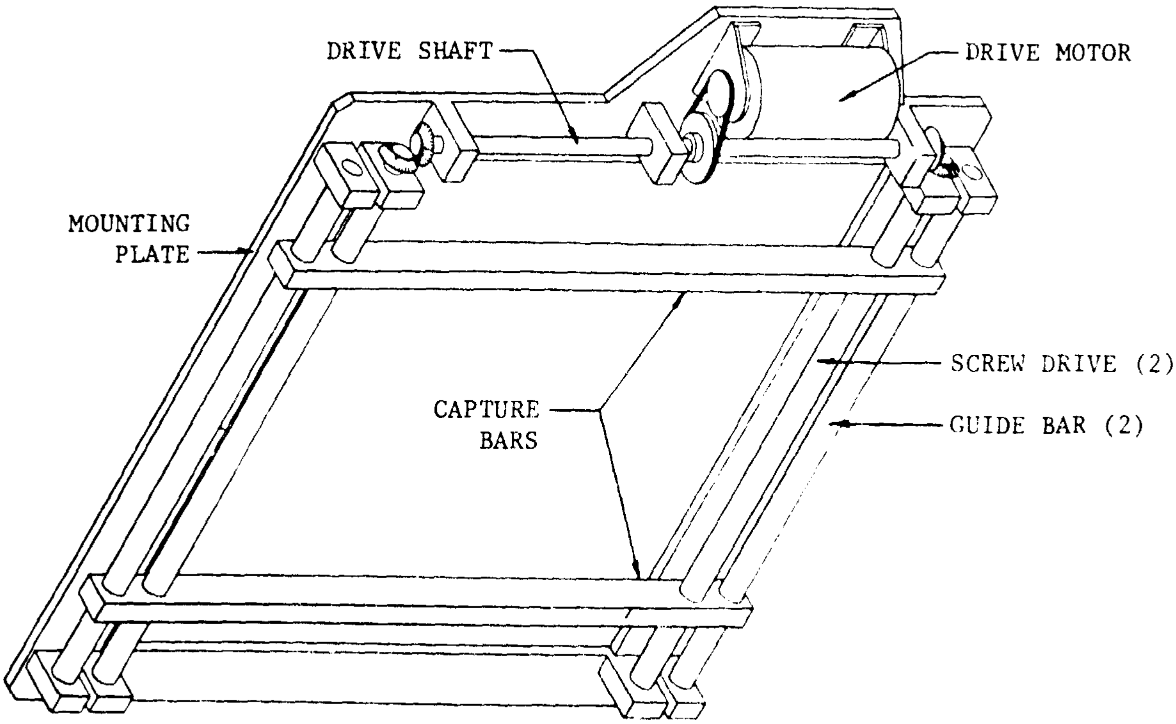


Figure 3-4: Forward Bar and Drive Assembly
(Ref. Appendix B, Dwg. No. H-78-06)

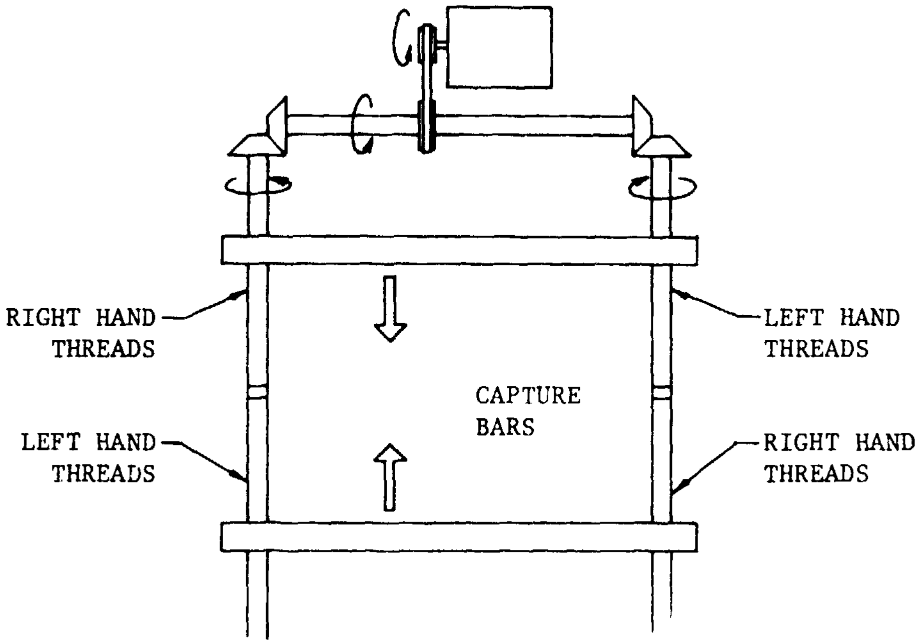


Figure 3-5: Forward Bar Screw Thread Logic

The front plate serves as a mounting platform for (1) the motor, (2) the limit switches and (3) the pillow blocks for the guide shafts, drive screws, and drive shaft. It also interfaces with the side panels via 10 machine screws. The front plate is constructed with 0.50 in. aluminum and is 29.3 in. tall and 28.0 in. wide. An additional 4.25 in. tall plate at the top is used as a motor mount location. A 24.0 in. tall by 22.0 in. wide opening in the front plate allows the grapple fixture to enter the retrieval device.

Although a complete engineering analysis was not performed, the drawings presented in Appendix B identify commercially available bevel gears, bearings, sprockets, chain, and component hangers that should be adequate to test the retrieval device concept. This statement holds true for the gears, bearings, etc., for the other elements of the retrieval device as well.

c. Aft Bars and Drive Assembly - This assembly is similar in operation and mechanical design to the forward bar and drive assembly but the parallel bars are orthogonal to the bars on the forward assembly (see Figure 3-6). The assembly consists of a 39.6 in. by 37.0 in. by 0.5 in. plate with a 31.0 in. by 28.8 in. opening along with drive system and capture bar elements similar to those described for the forward bar and drive assembly. Since the aft bar assembly is retractable, an additional set of components is required. These are eight McGill Camrol bearing rollers that interface with roll surfaces on the side panel assembly. These rollers are mounted to brackets which are attached to the aft bar plate.

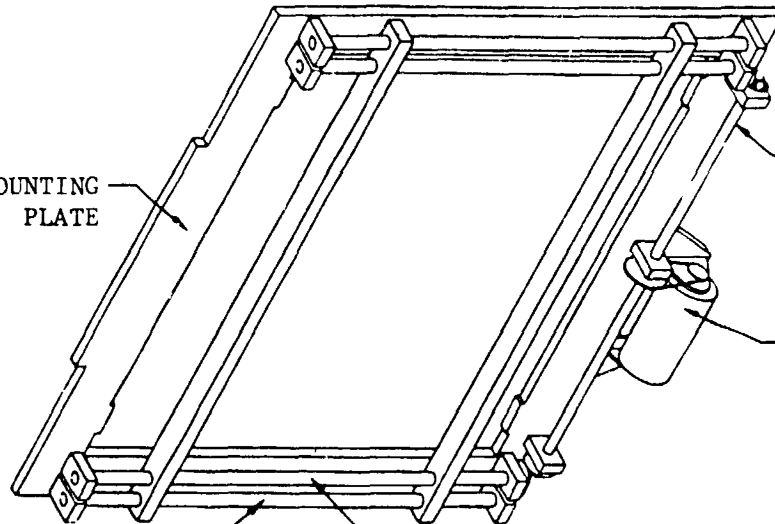


Figure 3-6: Aft Bars and Drive Assembly
(Ref: Appendix A, Dwg. No. H-78-06)

Two limit switches are also located on the aft bar and drive assembly plate to stop the drive motor when the capture bars are in the full open and full capture (1.0 in. apart) positions. These switches will be used to stop the drive motor in an automated mode after the crewman has issued the "open" or "close" command and the bars have reached their proper location.

d. Aft Bar Retraction Assemblies (2) - A retraction device is provided on two sides of the aft bar and drive assembly to pull it to the rear of the device after the parallel bars have secured the grapple fixture. Each of the two assemblies, as shown in Figure 3-7, contain a motor and chain drive, bearings, a drive shaft, and drive gears (2) attached to a mounting bracket (which is attached to the aft bar plate). As the reversible motor turns, the drive components turn the gears at each end of the drive shaft. The gears interface with racks on the side panel assemblies and pull the aft bar and drive assembly to the rear of the box. Conversely, when the motor turns in the opposite direction, the retraction mechanism pushes the aft bar and drive assembly to the front of the box. The two assemblies are driven simultaneously to ensure alignment, although small misalignments can be tolerated without binding.

e. Side Panels (2) - Two side panels are required and are attached to the forward bar and drive assembly plate and the aft plate. Each panel is 26.0 in. long, 29.0 in. tall and 0.50 in. thick (Figure 3-8). Two gear tracks are mounted to each panel to interface with the gears on the aft bar

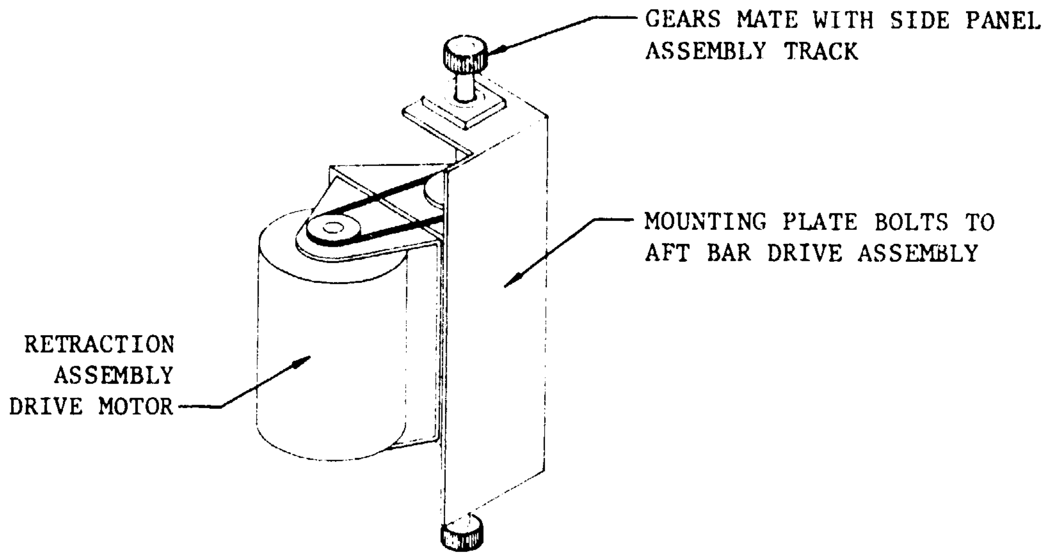


Figure 3-7: Aft Bar Retraction Assembly (2 Required)
(Ref: Appendix B, Drawing No. H-78-06)

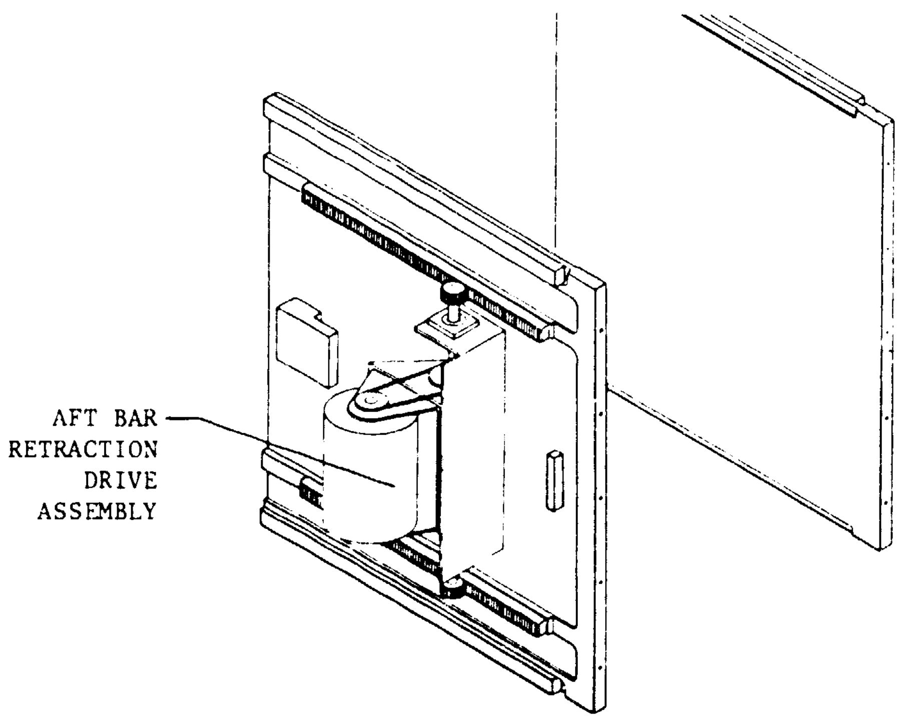


Figure 3-8: Side Panel Assembly (2 Required)
(Ref: Appendix B, Drawing No. H-78-06)

retraction mechanisms.

Additionally, two limit switches are located on one of the side panels to stop the aft bar retraction assembly motors when the assembly has reached the limits of travel in the retract and extend directions. Stop blocks are also located at each end of the side panels to stop the retraction assembly in a fixed position. Crew controlled latches could also be added if needed to secure the retraction assembly once it is in place.

F. Aft Plate - A 24.0 in. wide by 29.0 in. tall by 0.75 in. thick end plate (Figure 3-9) is required to ensure structural integrity and to provide a mounting surface for attachment to the Teleoperator. The aft plate will also be used for mounting an internal television camera, which will provide a view of the target spacecraft and grapple fixture through the box.

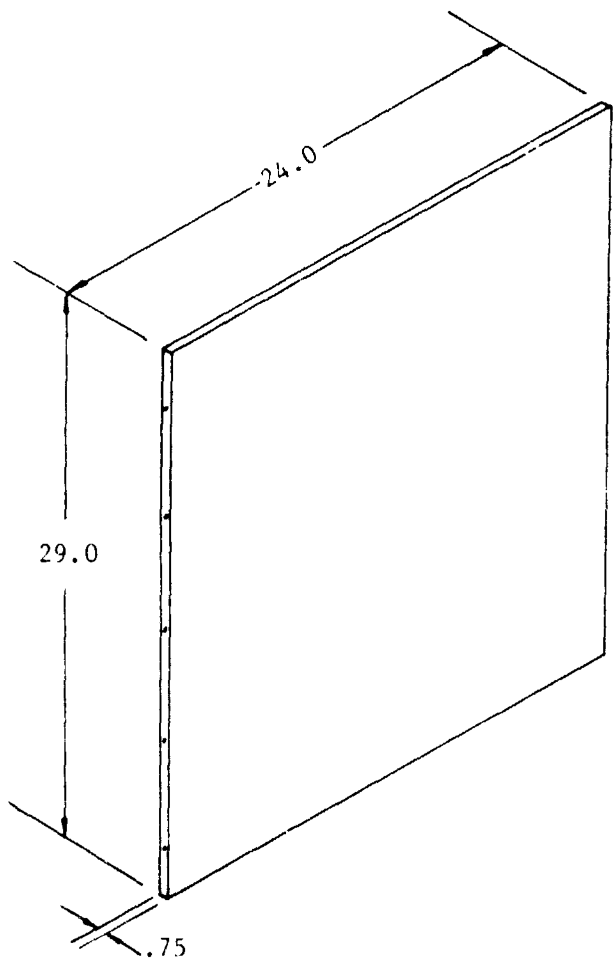


Figure 3-9: Aft Plate Assembly
(Ref: Appendix B, Drawing No. H-78-06)

g. Grapple Fixture - The target mounted grapple fixture consists of a 24.75 in. long, 1.0 in. square cross section shaft with a 2.0 in. by 2.0 in. plate welded to one end and a suitable mounting plate welded to the other end (Figure 3-10). The shaft has radiused corners (0.2 in.) to prevent galling of the capture bars if roll error is as much as 45°. The 2.0 in. square plate at the gripping end of the shaft prevents the aft bars from slipping off the shaft when the grapple device is being pulled into the box.

This grapple fixture minimizes the impact on spacecraft design and only requires that four mounting holes be provided and that the spacecraft mounting surface be capable of withstanding the anticipated docking loads.

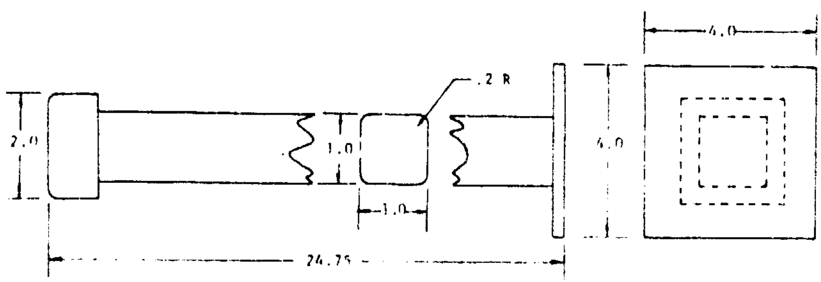


Figure 3-10: Grapple Fixture
(Ref: Appendix B, Drawing No. H-78-06)

3.1.2 Mechanical Operation

Although the Orthogonal Retrieval Device appears to be mechanically complex with a large number of components, the mechanical operation is straightforward, and each component is relatively simple (both in design and application) and should be highly reliable in practice. The operations of the device during satellite retrieval and satellite release are described below in Paragraph 3.1.2.1. The number and location of limit switches to accomplish these tasks are discussed in Paragraph 3.1.2.2.

3.1.2.1 Satellite Retrieval and Release Operations

a. Satellite Retrieval - Four primary operations are performed to retrieve a satellite. These are:

(1) Close the forward capture bars to a capture position
(2) Close the rear bars to a closed position
(3) Retract the rear bar assembly
(4) Effect the hard dock with latches on the aft bar retraction mechanism or the front insertion guide.

Steps (1) and (2) are performed simultaneously when the crewman has determined that the retrieval device is in position over the grapple fixture.

In the first step, the forward capture bars are initially in an open position, 0.5 in. from the limits of travel on the two drive screws. When commanded by the crewman, the motor turns the various drive components and the capture bars are moved along the drive screws to a position 1.5 in. apart. This forces the grapple fixture shaft to the vertical center of the box. When these bars are 1.5 in. apart, a limit switch activated by one of the bars stops the drive motor, and the 1.0 in. cross section grapple fixture shaft is loosely confined by the capture bars.

Simultaneously with Step (1), the aft bars (which are positioned at the front of the box in an open position) are driven to a "closed" position 1.0 in. apart. This traps the grapple fixture horizontally. By application of force on al four sides of the grapple fixture shaft, the two vehicles are forced into roll alignment. Also, the two vehicles are forced into near perfect alignment in pitch and yaw. By forcing the grapple fixture to the center of the box, any horizontal and vertical errors are also eliminated.

In Step (3), the aft bar retraction assembly motors, activated by a command from the crewman, pull the aft bar assembly to the rear of the box. When the aft bar retraction assembly has reached the rear of the box, a limit switch on one side panel stops the retraction drive motors. The limit switch can also send a signal to the forward bar drive motor to drive the forward bars to a closed position 1.0 in. apart, or this can be manually commanded by the crewman.

In Step (4), crew-operated latches (mounted on the retrieval device front insertion guide) engage passive fixtures on the target satellite. The design and location of these latches will depend on the particular satellite being retrieved.

b. Satellite Release - A captured satellite can also be released in much the same manner with the above steps basically reversed. To release the satellite, the crewman would:

- Release the hard dock latches
- Release the forward bars to a "capture" position
- Extend the aft bar drive mechanism to the forward position
- Open both the forward and aft capture bars simultaneously.

3.1.2.2 Description of Limit Switches to Support Semiautomated Operations

Seven limit switches will be used to provide some automated capability for the retrieval device in addition to a fully manual mode (see Paragraph 3.1.4). These limit switches and supporting electronics will stop the fore and aft capture bars and the aft bar retrieval mechanism at desired points after a command has been issued by the crewman at the retrieval device control panel. For example, when the forward bars are commanded to a capture position (from an open position), the motor will drive the twin screws and the parallel bars until a limit switch mounted on the box front face is activated (at a point when the bars are 1.5 in. apart and the target grapple fixture shaft is loosely trapped). The limit switch will stop the motor and signal to the crewman via a mechanical flag or status light that the forward bars are in a capture position.

Table 3-1 defines the limit switches required, their purpose, signal outputs and locations.

Table 3-1: Limit Switch Function Descriptions

SWITCH NUMBER	PURPOSE	QTY	SIGNAL OUTPUTS	LOCATION
1	• Forward bar open position indication	1	a) Stop forward bar drive motor. b) Command forward bar mechanical flag to OPN.	• Front plate, 0.5 in. from end of bar travel in open position near end of bar.
2	• Forward bar capture position indication	1	a) Stop forward bar drive motor. b) Command forward bar mechanical flag to CAP.	• Front plate near end of bar where bars are 1.5 in. apart.
3	• Forward bar closed position indication	1	a) Stop forward bar drive motor. b) Command forward bar mechanical flag to CL.	• Front plate near end of bar where bars are 1.0 in. apart.
4	• Aft bar open position indication	1	a) Stop aft bar drive motor. b) Command aft bar mechanical flag No. 1 to OPN.	• Aft bar plate, 0.5 in. from end of bar travel in open position near end of bar.
5	• Aft bar close position indication	1	a) Stop aft bar drive motor. b) Command aft bar mechanical flag No. 1 to CL. c) Command forward bar drive motor to close forward capture bars.	• Aft bar plate near end of bar where bars are 1.0 in. apart.
6	• Aft bar extend position indication	1	a) Stop aft bar retract motors. b) Command aft bar mechanical flag No. 2 to EXTD.	• Side plate at forward end.
7	• Aft bar retract position indication	1	a) Stop aft bar retract motors. b) Command aft bar mechanical flag No. 2 to RET.	• Side plate at aft end.

3.1.3 Acceptable Alignment Errors

The success of the satellite retrieval task will depend primarily on: (1) the ability of the crewman to fly the ORD over the target mounted grapple fixture, and (2) the ability of the retrieval device to complete the capture task.

The crewman's ability to position the ORD over the grapple fixture will depend on the maximum errors that can be tolerated for all six degrees of freedom (roll, pitch, yaw, left/right, up/down and fore/aft). Obviously, the larger the allowable error, the easier it will be to dock and the higher the probability of retrieval. Also, if large errors are acceptable, fuel consumption and time to dock will be lower.

The Orthogonal Retrieval Device can tolerate quite large initial errors in roll, pitch and yaw and still align the Teleoperator and spacecraft for a hard dock. Acceptable horizontal, vertical and fore/aft errors are not as large but are more easily detected and controlled by the crew prior to activation of the retrieval device. Table 3-2 summarizes the acceptable position and alignment errors the ORD can tolerate. The paragraphs below describe how these figures were obtained.

Table 3-2: Acceptable Position and Alignment Errors for the ORD

Error Source	Maximum Acceptable Error
Roll	± 40°
Pitch	± 50°
Yaw	± 50°
Horizontal	± 10.5 in.
Vertical	± 10.5 in.
Fore/Aft	± 9.0 in.

a. Roll Error - As the twin parallel bars grip the square cross section grapple fixture shaft, any roll error less than ± 45° could be reduced to zero since the forces exerted by the four bars on the shaft will tend to rotate the shaft into alignment (Figure 3-11). However, near a ± 45° roll offset, galling may occur between the bars and corners of the grapple device shaft. To minimize the chance of this happening, the corners of the shaft were radiused (0.2 in.). This will tend to reduce galling and allow a roll error of ± 31° without galling, although a ± 40° error would be acceptable, depending on the hardness of the material selected for the bars and grapple fixture. Figure 3-12 shows three steps in the retrieval sequence as roll error is reduced to zero.

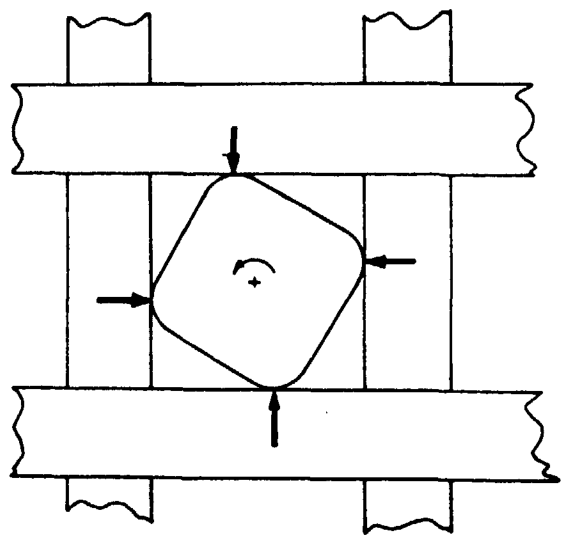


Figure 3-11: Forces Acting on Grapple Fixture Shaft

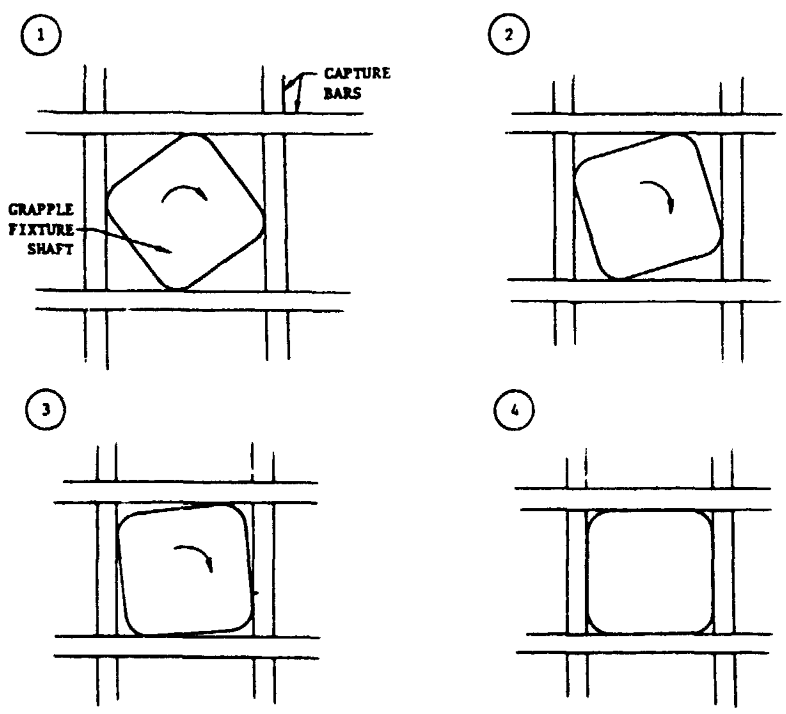


Figure 3-12: Roll Error Correction Sequence

b. <u>Pitch and Yaw Errors</u> - The maximum pitch or yaw error depends on: (1) the size of the retrieval device opening, and (2) the length of the grapple fixture. With an opening of 22.0 in. and a grapple fixture length of 18.0 in., the ORD can tolerate a ± 50° error in either pitch or yaw, although any error over ± 35° could result in contact between the Teleoperator and the satellite being retrieved. Figure 3-13 illustrates retrieval of the SMM spacecraft (without antenna) at a 35° pitch error. As the figure illustrates, the maximum pitch and yaw errors are determined more by the Teleoperator and satellite configurations than by the retrieval device.

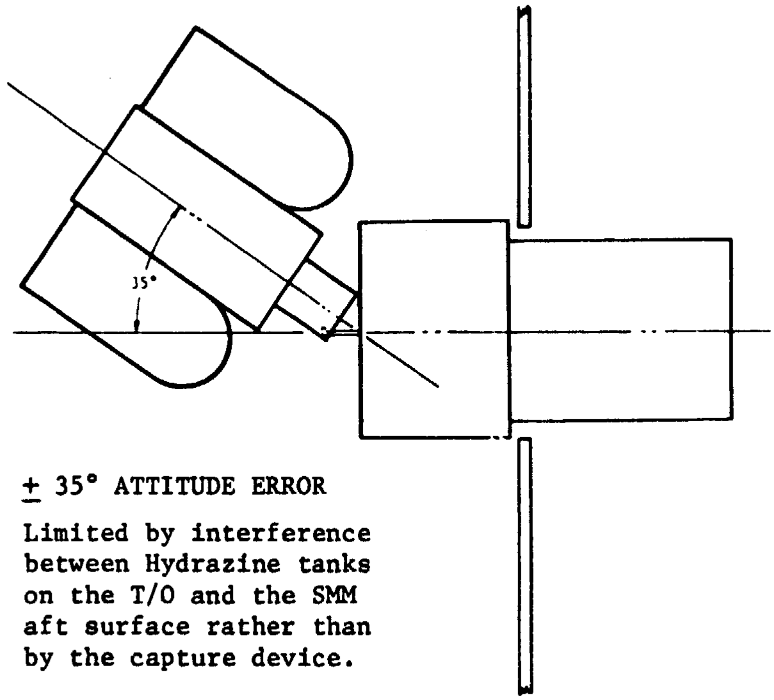


Figure 3-13: Maximum Pitch or Yaw Error

c. Horizontal and Vertical Offset Errors - Since the retrieval device opening is 22.0 in. square and the grapple fixture end plate is 2.0 in. square, the maximum horizontal or vertical offset can be ± 10.0 in. However, the front insertion guide would help direct the grapple fixture into the box if the errors were greater.

Figure 3-14 shows the four steps in capturing the SMM spacecraft with an initial lateral offset of 10.0 in. In Step 1, the Teleoperator has been guided over the SMM grappling fixture and is offset 10.0 in. In Step 2, the two sets of parallel capture bars have been actuated, forcing the grappling fixture to a position near the center of the capture device front section. Here we assume that, while some lateral movement of the two vehicles will occur, most of the movement will be angular displacement with the two vehicles rotating about their own centers of gravity. Assuming no initial lateral movement, both vehicles will rotate about the respective centers of gravity, causing a maximum initial angular difference of 6° between the Teleoperator and the SMM centerlines. Of course, this could be greater if the two vehicles were not perfectly aligned before actuating the capture bars. In Step 3, as the twin parallel bars apply more force to the grappling fixture shaft, the two vehicles will be forced into approximate alignment (probably 0° ± 1°, depending on the loads generated by the electric motors). In Step 4, the aft capture bars have been pulled to the rear, forcing the two vehicles into final alignment.

d. Fore/Aft Error - Once the retrieval device has been flown over the grapple fixture, the bars can be actuated to capture the grapple fixture. However, the fore/aft position of the grapple fixture is not particularly critical, as capture will occur regardless of the fixture's position in the retrieval device. Since the aft bars retract a maximum of 18.0 in., a ± 9 in., fore/aft tolerance can be established as an acceptable error.

As an aid to the crewman, an overlay can be mounted to the Shuttle aft cabin TV monitor to indicate the size of the grapple fixture as it enters the retrieval device. When the end plate appears as large or larger than in the overlay on the monitor, the crewman can command the capture bars to the closed position to start the capture sequence. Figure 3-15 shows this screen overlay as it would appear to the crewman. Use of the overlay in this manner assumes the use of a camera mounted inside looking through the retrieval device with a field of view such that the left and right screw drives for the forward bar and drive assembly are barely visible at the edges of the screen.

3.1.4 Crew Operations

The Orthogonal Retrieval Device can be controlled from the Shuttle aft cabin using one TV monitor (though two are preferred) and a small dedicated control and display panel. Two cameras are required on the Teleoperator--one external camera with a narrow field-of-view lens for target location and a second camera with a wide angle lens located inside the retrieval device at the aft end. The crewman uses the video feedback received from the external camera to approach the target and to perform initial alignment. The crewman then switches to the internal camera for final alignment and closing. He

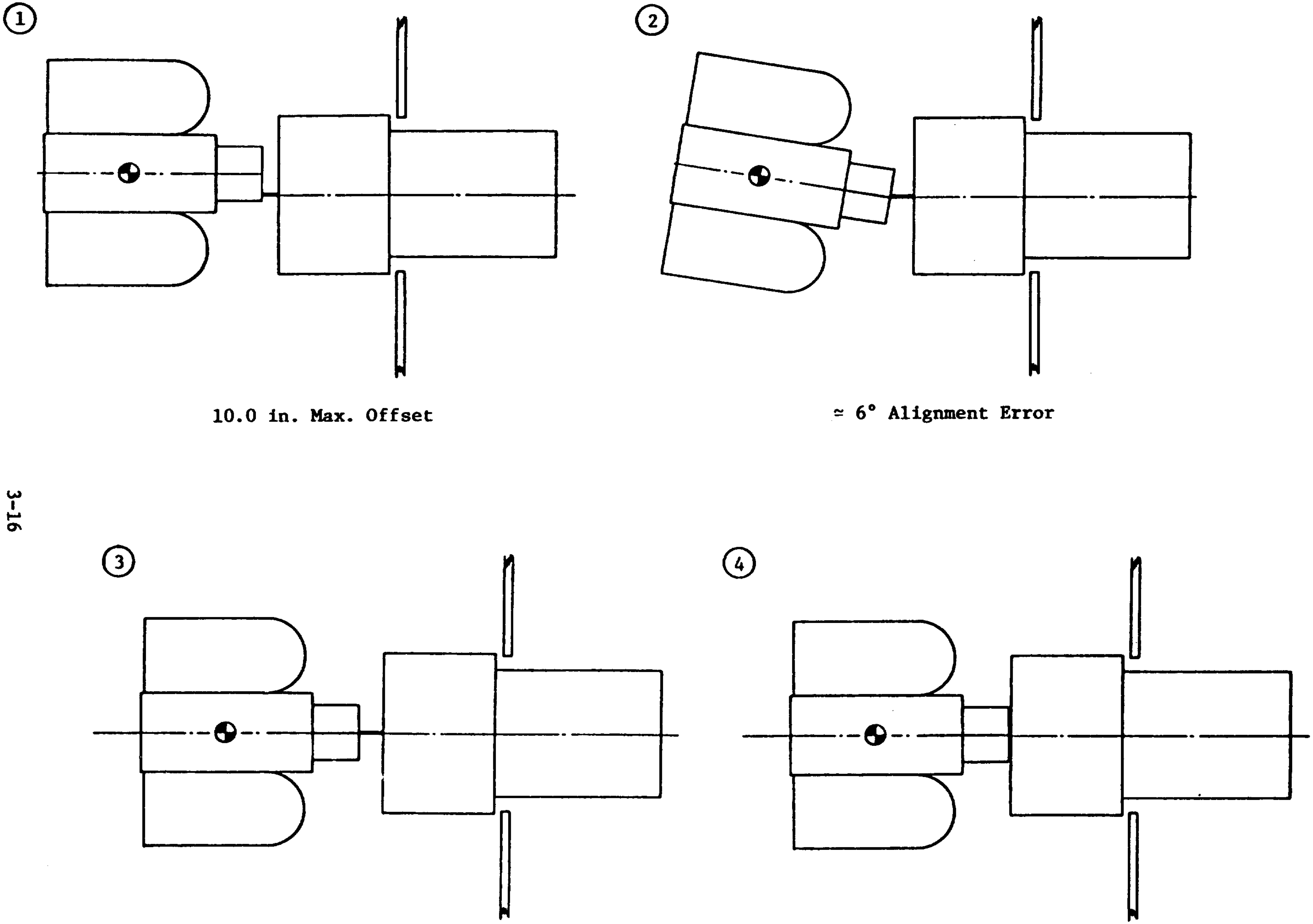


Figure 3-14: Satellite Retrieval with Initial Lateral Offset

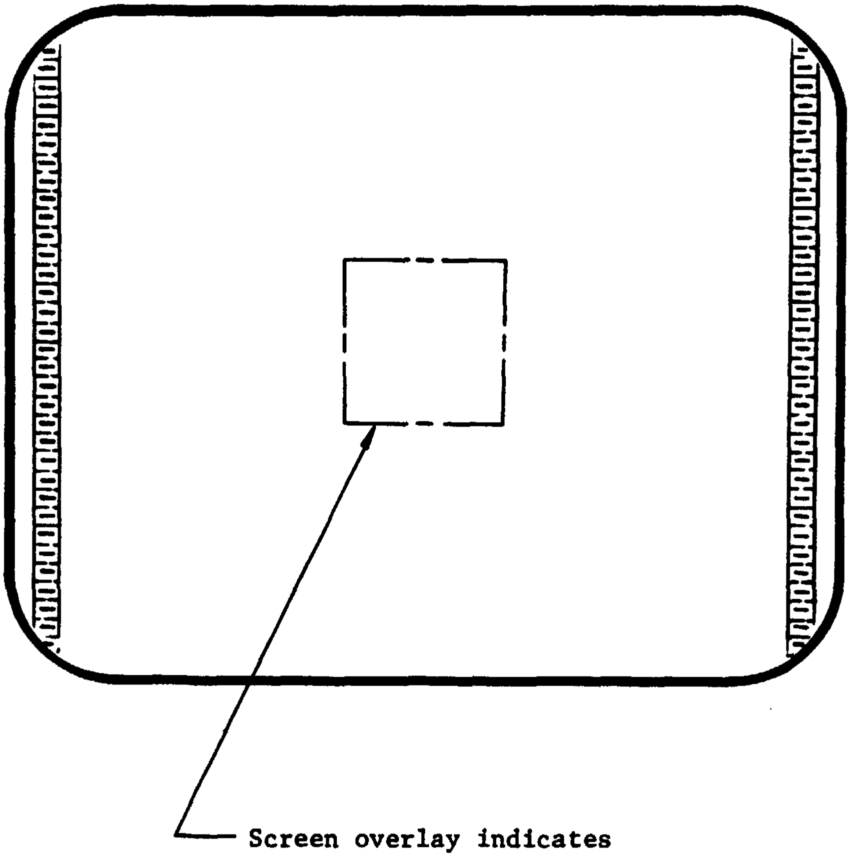


Figure 3-15: Aft Cabin Monitor Screen Overlay

flys the camera to the end plate on the grapple fixture, correcting attitude and position errors along the way. When the grapple fixture tip is inside the retrieval device, the capture bars are closed and the aft bars are retracted.

Detailed crew operations are described in the task analysis forms (Table 3-3) on the following pages.

To support these crew operations, controls and displays will be required for such functions as power on/off, camera selection, capture bar control, and latch operation. Figure 3-16 illustrates a control panel that includes all controls and displays required to support these satellite retrieval tasks. This 8.75 in. by 4.25 in. panel contains three two-position latching toggle switches, four three-position momentary toggle switches, and four mechanical flags. The functions of these controls and displays are defined in Table 3-4.

The BARS AUTO/MAN switch allows the crewman to have supervisory control or full manual control over the capture bar drive motors by using the aft and forward bar capture toggle switches. In the manual (MAN) mode, the bars move in a close or open direction as long as the toggle switches are activated. In the automatic (AUTO) mode, the crewman initiates the open or close motion with the toggle switch; the drive motors are disabled when the appropriate limit switch has been activated.

3.1.5 Areas for Additional Study

The purpose of this study was to develop concepts for satellite retrieval devices and not to perform detailed engineering analyses for specific concepts. Because of this limitation on the scope of the effort, several investigations remain undone. The key issues that should be further studied are discussed below.

a. Latches for Hard Docking - The design, number and location of latches to be mounted on the front insertion guide or aft bar retraction mechanism should be determined for a candidate target spacecraft.

b. Capture Bar Latches - When the motors drive the parallel capture bars to a closed position, a latch may be required to hold the bars securely on the grapple device shaft, or a brake device may be needed on the drive shaft to prevent the capture bars from losing the grip on the grapple fixture.

c. Retraction Mechanism Latch - A latch or brake device will be required to hold the aft bar retraction mechanism in the retracted position.

d. Strength Analysis - The anticipated satellite docking and handling loads should be determined and the individual ORD components analyzed to determine if these loads can be handled with the proposed design.

e. Motor and Gear Sizing - The power required from the four motors should be determined as well as the screw thread characteristics.

HUMAN ENGINEERING TASK ANALYSIS

TASK TITLE Satellite Retrieval

Date 12-11-78
Revision No. Original
Prepared By E. Pruett

Sub Task No.	Subtask Description	Criticality	Frequency	Equipment Description: a - Equipment, b - Tools, c - Job Aids	Time (Sec) Duration	Time (Sec) Cumulative	Work Station	Personnel Number	Personnel Skills and Knowledge	Comments
Initial Conditions - Teleoperator has been deployed from the Shuttle cargo bay and flown by the Shuttle crewman to the vicinity of the target spacecraft.										
1.0	Configure Retrieval Device									
1.1	Verify PWR switch set to ON			Power on/off toggle switch			Aft Cabin	1	Teleoperator flight operations training	
1.2	Verify CAM switch set to EXT			Camera select toggle switch						
1.3	Verify BARS switch set to AUTO			Capture bars manual control select switch						
2.0	Approach Target									
2.1	Locate target visually			External camera, Aft cabin monitor						
2.2	Null pitch, yaw and roll errors									
2.3	Null translation errors									
2.4	Translate to stationkeeping position in front of target grappling fixture									Stationkeeping distance TBD
2.5	Null all attitude and translation rates									

Table 3-3: Satellite Retrieval Task Analysis

HUMAN ENGINEERING TASK ANALYSIS

TASK TITLE Satellite Retrieval

Date 12-11-78
Revision No. Original
Prepared By E. Pruett

Sub Task No.	Subtask Description	Criticality	Frequency	Equipment Description (a - Equipment, b - Tools, c - Job Aids)	Time (Sec) Duration	Time (Sec) Cumulative	Work Station	Personnel Number	Personnel Skills and Knowledge	Comments
3.0	Capture Target Satellite									
3.1	Verify all attitude and translation rates nulled. Correct if necessary.									
3.2	Command CAM switch to INT			Camera select toggle switch						
3.3	Verify Teleoperator directly in front of target grappling fixture. Correct if necessary.									
3.4	Approach target at TBD m/sec.			Aft cabin hand controller, monitor						Approach velocity will probably be 0.2 m/sec or less. Crewman should fly directly to grapple fixture, correcting attitude or translation errors all the way.
3.5	When grapple fixture is inside box, command BARS (FWD & AFT) to CAPTURE			Aft cabin monitor Screen overlay Fwd & Aft capture bar toggle switches						Roll error should be +40° by crew estimate or alignment marks on the screen overlay & the target satellite

Table 3-3 (Cont.): Satellite Retrieval Task Analysis

HUMAN ENGINEERING TASK ANALYSIS

TASK TITLE Satellite Retrieval

Date 12-11-78
Revision No. Original
Prepared By E. Pruett

Sub Task No.	Subtask Description	Criticality	Frequency	Equipment Description (a - Equipment, b - Tools, c - Job Aids)	Time (Sec) Duration	Time (Sec) Cumulative	Work Station	Personnel Number	Personnel Skills and Knowledge	Comments
3.6	Verify fwd bars to capture position and aft bars to closed position (FWD mechanical flag to CAP and AFT mechanical flag to CL)			FWD & AFT mechanical flags						
3.7	Verify visually that capture has occurred			Internal camera, monitor						
3.8	Command AFT BAR to RET to retract aft capture bars			AFT BAR toggle switch						
3.9	Verify aft bars to retracted position (AFT mechanical flat to RET)			AFT mechanical flag						At this point, latches on the front of the box could engage a mating fixture on the target satellite. Location and configuration will depend on the specific target.

Table 3-3 (Cont.): Satellite Retrieval Task Analysis

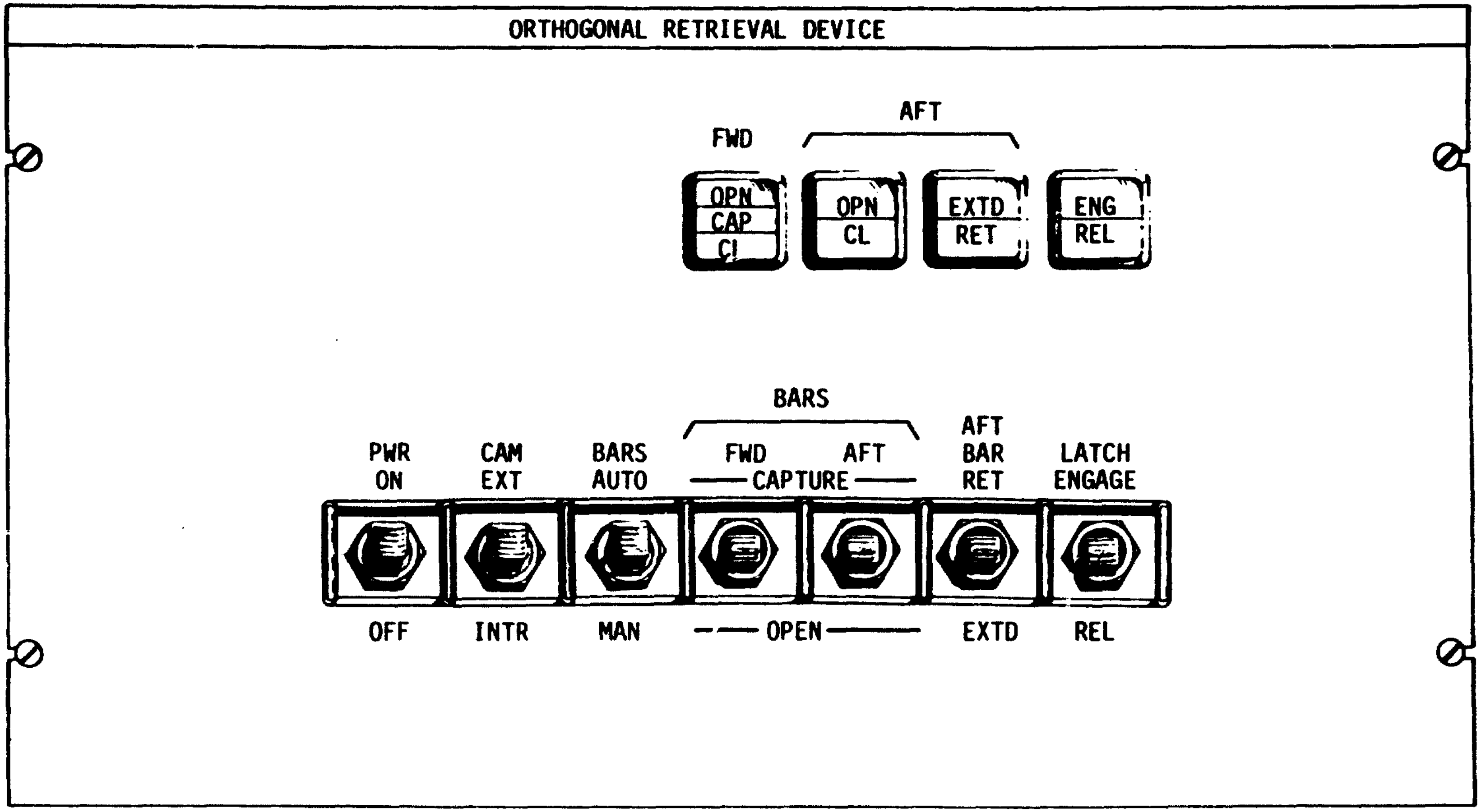


Figure 3-12: Control Panel for the Orthogonal Retrieval Device

Table 3-4: Control Panel Component Functions for the ORD

SWITCH NAME	TYPE	FUNCTION
1. Power On/Off	• Two-position latching toggle	• Provide 28 Vdc to electrical components on panel and retrieval device.
2. Camera External/ Internal	• Two-position latching toggle	• Select internal or external camera for displaying image on aft cabin monitor.
3. Bars Automated Manual	• Two-position latching toggle	• Select mode of controlling fwd and aft bar open/close motors and aft bar retract/ extend motors - Automatic: Motors stopped by limit switches once started by crewman. - Manual: Motors started and stopped by crewman using panel switches.
4. Fwd Bars Capture/Open	• Three-position momentary toggle	• Automatic: Command motors to drive bars either open or closed until stopped by limit switch. • Manual: Command motors to drive bars either open or closed until momentary switch is released.
5. Aft Bars Capture/Open	• Three-position momentary toggle	• Automatic: Command motors to drive bars either open or closed until stopped by limit switch. • Manual: Command motors to drive bars either open or closed until momentary switch is released.
6. Aft Bars Retract/Extend	• Three-position momentary toggle	• Automatic: Command motors to drive aft bar mechanism either forward or backward until stopped by limit switch. • Manual: Command motors to drive aft bar mechanism either forward or backward until momentary switch is released.

Table 3-4 (Cont.): Control Panel Component Functions for the ORD

SWITCH NAME	TYPE	FUNCTION
7. Latch Engage/Release	• Three-position momentary toggle	• Engage and release latch solenoids.
8. Fwd Bars Position (Open/Capture/ Close)	• Three-position mechanical flag	• Indicate position of fwd bars (full open, 1.5 in. apart, full closed).
9. Aft Bars Position (Open/Close)	• Two-position mechanical flag	• Indicate position of aft bars (full extend, full retract).
10. Aft Bars Position (Extend/Retract)	• Two-position mechanical flag	• Indicate position of aft bars (full extend, full retract)
11. Latch (Engage/Release)	• Two-position mechanical flag	• Indicate position of hard dock latches (engaged, released).

ESSEX

3.1.6 Concept Evaluation

Prior to a detailed engineering analysis of the retrieval device, it would be extremely useful to demonstrate the concept using the brassboard design presented in Appendix B. A working, full-size model could be developed to demonstrate the concept and serve as a testbed for component development. This would verify the allowable position and attitude errors claimed in Paragraph 3.1.3, above, and would illustrate needed design changes.

A working demonstration unit of this type could also serve to demonstrate the satellite retrieval capability of the Teleoperator to spacecraft personnel who may have a need for such capability.

3.1.7 Summary

The above paragraphs have described the design and operation of the Orthogonal Retrieval Device. Two of the major objectives of the study were to develop a retrieval device concept that can be easily operated by a remote crewman and that can tolerate large alignment and position errors. The ORD satisfies these objectives more than adequately. Allowable roll, pitch and yaw errors are much greater than they are for any other docking device NASA has used in any previous program. The design is simple and utilizes simple components whose reliability should be satisfactory. The next step in the development of this device is a demonstration of the concept by the use of a full-scale brassboard model and a detailed engineering analysis of the questions described in Paragraph 3.1.5.

3.2 SMM SPACECRAFT RETRIEVAL DEVICE

The SMM retrieval device consists of three latching mechanisms mounted on arms that are positioned to fit around the SMM high gain antenna and align the latches with the three SMM launch pins (Figure 3-17). The device is designed specifically to retrieve the SMM spacecraft without the aid of any SMM-mounted docking aids such as grapple fixtures or docking rings. Although the goal of minimum impact on spacecraft design is satisfied by this design, allowable alignment and position errors are small and may be difficult for the crew to achieve when operating remotely from the Shuttle.

The paragraphs below present more detailed information on the following:

- Physical description
- Mechanical operations
- Crew operations
- Areas for additional study
- Concept evaluation
- Summary.

Drawings and sketches are provided throughout the section to illustrate the concept. More detailed drawings are included in Appendix C.

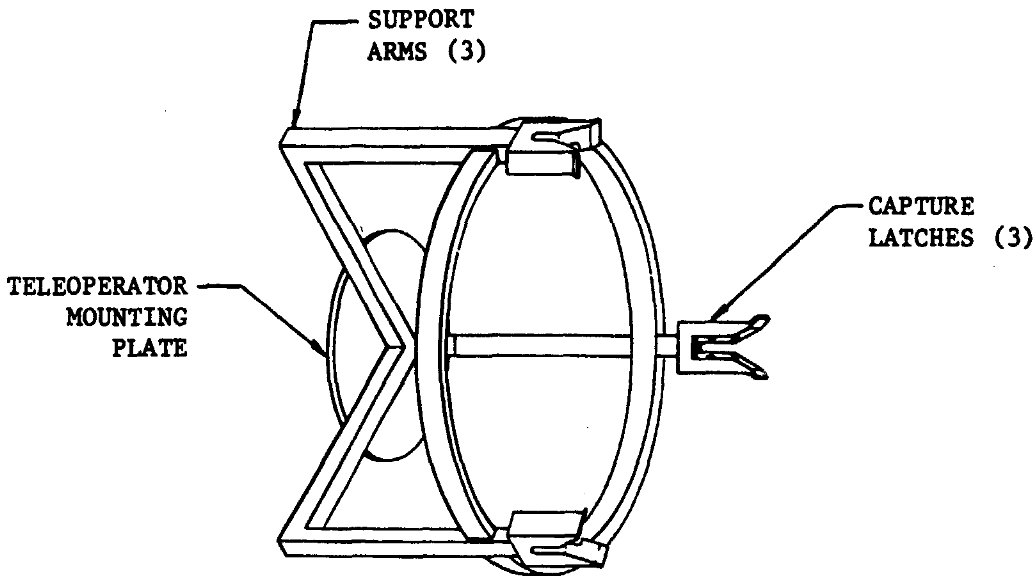


Figure 3-17: SMM Retrieval Device

3.2.1 Physical Description

Figure 3-17, above, shows the retrieval device configured for SMM retrieval. The device consists of three capture latch assemblies, a support assembly, and a mounting plate for attachment to the Teleoperator. Up to three TV cameras will also be required to align the capture latches with each of the three SMM launch pins and verify that the latches are engaged after docking. The major system elements are described below.

a. Capture Latch Assembly (3 Req'd) - As shown in Figure 3-18, the capture latch assembly has a V-shaped body for guiding the SMM launch pin to the rear of the latch mechanism where two spring loaded capture latches trip the pin. The two latches are normally spring loaded when closed but can be opened for pin release by two Ledex rotary solenoids which are attached to the latches with a Globe gear drive. The latches are designed to interface with launch pins extended to 10.0 in. in length.

b. Support Assembly - The support assembly consists of three arms to support the capture latch assemblies in position to mate with the SMM launch pins and fit around the high gain antenna. The support frame is constructed of 3.0 in. box beams and contains the three arms for mounting the capture

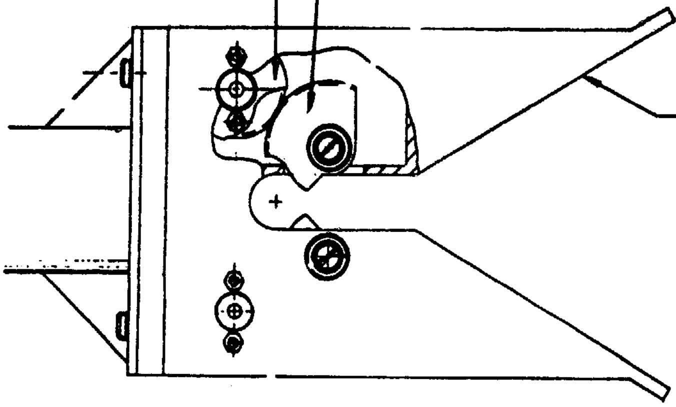


Figure 3-18: Capture Latch Assembly
(Ref: Appendix B, Drawing No. H-78-07)

latches, a circular member to provide support near the ends of the arms, and a three-piece rear structure to support the three arms. Drawing number H-78-07 in Appendix B gives more details on the support assembly.

c. Mounting Plate - A 32.0 in. diameter, 0.5 in. thick plate is attached to the rear of the support assembly for mounting the retrieval device to the Teleoperator.

d. Cameras - Either a single camera for viewing an offset docking target or three cameras mounted to each of the three support arms for viewing the three latch assemblies will be required.

3.2.2 Mechanical Operation

The operation of the SMM retrieval device is very simple because each latch has only four moving parts--the two latches and the two rotary solenoids. As the latch assemblies are guided over the three SMM launch pins, the spring loaded latches (2 per assembly) are depressed and the pin enters the capture position. To release the pin, the solenoids are commanded open and the Teleoperator can then separate from the SMM.

3.2.3 Acceptable Alignment Errors

The success of the SMM retrieval task will depend to a large extent on the crewman's ability to align the capture latches with the three launch pins as he makes the final approach. The V-shaped guides will help reduce any roll error but pitch, yaw and lateral offset errors can be critical since all three pins and latches must be aligned simultaneously while avoiding the high gain antenna and the side mounted MMS modules. The anticipated maximum errors for position and alignment are presented in Table 3-5.

Table 3-5: Acceptable Position and Alignment Errors for the SMM Retrieval Device

Error Source	Maximum Acceptable Error
Roll	$\pm$ 7°
Pitch	$\pm$ 2°
Yaw	$\pm$ 5°
Horizontal	$\pm$ 4.25 in.
Vertical	$\pm$ 1.65 in.
Fore/Aft	Not Applicable

3.2.4 Crew Operations

The crew task will consist of aligning the retrieval device capture latch assemblies with the SMM launch pins and then flying the latch assemblies to the pins, correcting any position alignment errors along the way. To accomplish this, the crewman will need (1) a single camera viewing an offset docking target, or (2) three cameras--boresighted along each of the three capture latch support arms and positioned so the alignment between the latch assembly and the launch pin can be determined. A positive indication of the latch engagement will be required on the operator's control panel.

To verify this potentially difficult crew task, a multiple degrees-of-freedom simulation should be performed to determine whether a crewman using three cameras and three monitors (or one monitor with a select capability) can position the capture device in a position suitable for retrieving the SMM spacecraft.

3.2.5 Areas for Additional Study

As stated earlier, the purpose of this study was to develop concepts for satellite retrieval devices and not to perform detailed engineering analyses. Because of this limitation on the scope of the effort, some additional work needs to be done before the SMM spacecraft retrieval device concept can be completely evaluated. Four of the most critical elements of this additional work are:

(1) Selection of rotary solenoids and appropriate gears and springs
(2) Selection of the configuration of the capture latch guide
(3) Selection of visual alignment aids (i.e., monitor overlays and SMM alignment marks)
(4) Performance of a strength analysis.

3.2.6 Concept Evaluation

The descriptions and discussion presented above and the additional detail provided in Appendix C are more than adequate for evaluating the basic SMM concept for retrieval of the SMM spacecraft. The next logical step in evaluating the concept would be to fabricate a full-scale working model of both this device and the SMM aft end and then test the crewman's ability to perform the docking task. This simulation would serve to evaluate the difficulty of the crew task and would also help identify hardware changes that would simplify the retrieval task.

3.2.7 Summary

The SMM retrieval device has two significant advantages: (1) mechanically, it is very simple, which would enhance its probability for reliable performance and would make it relatively inexpensive to develop, and (2) it has minimum impact on the design of the SMM, namely, three bolt-on launch pins that can be added late in the spacecraft physical integration process. However, because of the rather stringent alignment requirements discussed in Paragraph 3.2.3, use of the SMM device might make the retrieval task troublesome and difficult. This potential problem should be thoroughly investigated through a comprehensive multiple degrees-of-freedom simulation effort.

4.0 PROJECT SUMMARY

During this study, two concepts for satellite retrieval were developed. These two concepts are entirely different in design and crew operation even though they were developed for the same target satellite--the Solar Maximum Mission spacecraft. The two different designs evolved because of a design goal that became an overriding factor near the middle of the concept development effort. This design goal was that the retrieval device should not impact the design of the SMM spacecraft. More specifically, until near the contract midterm presentation, it was assumed that the high gain antenna could be jettisoned prior to docking to allow SMM retrieval using an aft-mounted device such as a docking ring or grapple fixture. At midterm, however, it was determined that the antenna could not be jettisoned and that a new retrieval device concept would have to be developed. Therefore, two entirely different concepts evolved from the case where the antenna could be jettisoned prior to capture and the case where it could not be jettisoned. The design and operation of these two specific concepts are described in detail in Sections 3.1 and 3.2. The paragraphs below summarize the operation of these devices and describe the additional work that should be done to develop the concepts into working demonstration units. The application that these retrieval devices may have for satellites other than the SMM is also described.

4.1 ORTHOGONAL RETRIEVAL DEVICE (ORD)

One of the most critical elements of the docking task is alignment of the two vehicles prior to docking. This part of the docking sequence can be very difficult for the crewman if the allowable alignment tolerances are small. Stringent alignment requirements can also result in high fuel consumption and can cost a large amount of the crewman's time for the docking task. One of the primary advantages of the Orthogonal Retrieval Device is the liberal alignment error that can be tolerated ($\pm$ 40° roll, $\pm$ 35° pitch and $\pm$ 35° yaw) and still result in a hard dock with both vehicles fully aligned. This allowable alignment error, along with the operational and mechanical simplicity of the device, make the ORD a candidate for further development and evaluation. The paragraphs below describe the additional work that should be done with this concept for full evaluation of its potential.

4.1.1 Brassboard Demonstration Model

A full-scale working model of the ORD would be useful to demonstrate the retrieval concept using a multiple degrees-of-freedom simulation technique. The working model could also serve as a testbed for evaluating specific components such as motors, gears, and drive screws. The drawings presented in Appendix B should serve as the basis for construction of this model. These drawings describe most of the materials, finishes, and commercially available components that would be required for a demonstration unit.

4.1.2 Engineering Analysis

An engineering analysis of the retrieval device should be performed to obtain a better definition of the anticipated loads to which the individual components may be subjected; to select components that will handle these loads; to size gears, sprockets, chains and motors; and to determine motor and drive shaft speeds.

4.1.3 Application to Other Spacecraft

The ORD should be a useful retrieval device for any spacecraft that has room for the grapple fixture to be attached. The automated payloads that may be retrieved should be examined to evaluate the need for a retrieval device with the ORD's capabilities.

Also, retrieval of satellites that have not been prepared for capture by the addition of the grapple fixture will be possible if several changes are made to the basic ORD concept. These changes include: (1) enlarging the box opening to allow it to accept an entire satellite or some satellite appendage such as a dipole antenna or solar panel, (2) adding pressure sensors to detect the pressure the capture bars exert on the satellite and to stop the drive motors at some predetermined gripping force, and (3) adding deformable jaws to prevent damaging the satellite. The requirement for this capability should be determined from an examination of the unprepared satellites that may need to be retrieved. If it appears that this capability is justifiable, the basic ORD concept should be modified and the appropriate engineering and simulation studies performed.

4.2 SMM RETRIEVAL DEVICE

The SMM retrieval device described in Section 3.2 satisfies the primary design goal of having no impact on the SMM design other than replacement of the three bolt-on launch pins. However, the strict alignment requirements may make the retrieval task difficult for the remote crewman. As with the ORD, the SMM retrieval device should be further studied to evaluate the difficulty of the docking task and to assess the adequacy of the proposed design. To accomplish these goals, two areas of additional work should be performed as described below.

4.2.1 Brassboard Simulation Model

A working model of the SMM retrieval device should be constructed and used to evaluate the crew operations associated with the docking task. To support this docking simulation, a mockup of the SMM aft end would be required, along with a suitable man-in-the-loop multiple-degrees-of-freedom simulation capability. This full-scale model could be used to evaluate the crewman's ability to perform the necessary vehicle alignment prior to docking.

The brassboard model could also be useful in evaluating specific components such as the rotary solenoids, latch guides and latch jaws.

ESSEX

4.2.2 Engineering Analysis

Although the SMM retrieval device design presented in Appendix C is adequate to demonstrate the concept, a detailed engineering analysis should be performed to define the anticipated docking and handling loads and to select the solenoids, jaws and gears. This study could be performed concurrently with the simulation study so that any proposed configuration or component changes could be evaluated.

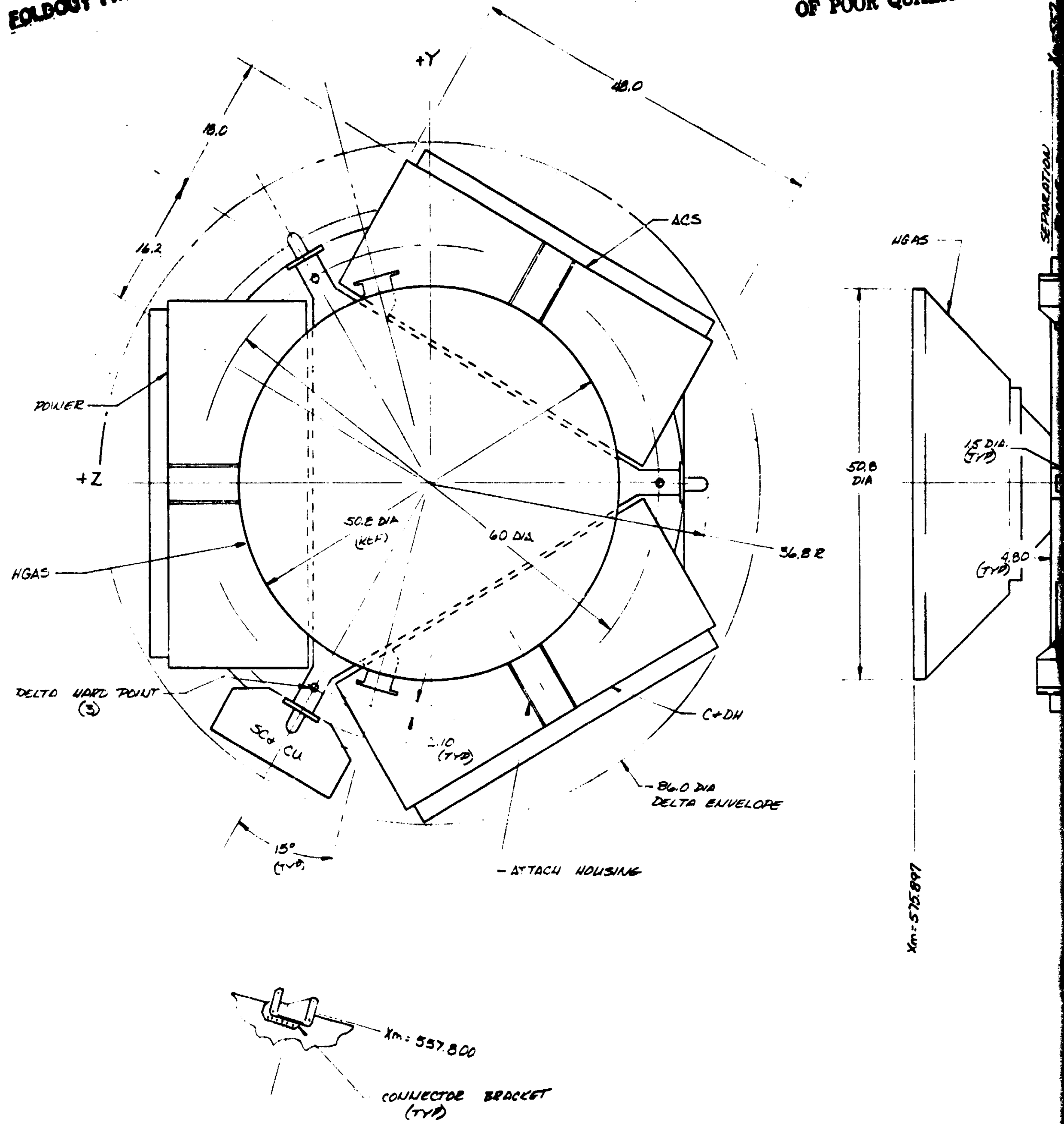
APPENDIX A

SOLAR MAXIMUM MISSION SPACECRAFT DRAWING

(MMS SECTION ONLY)

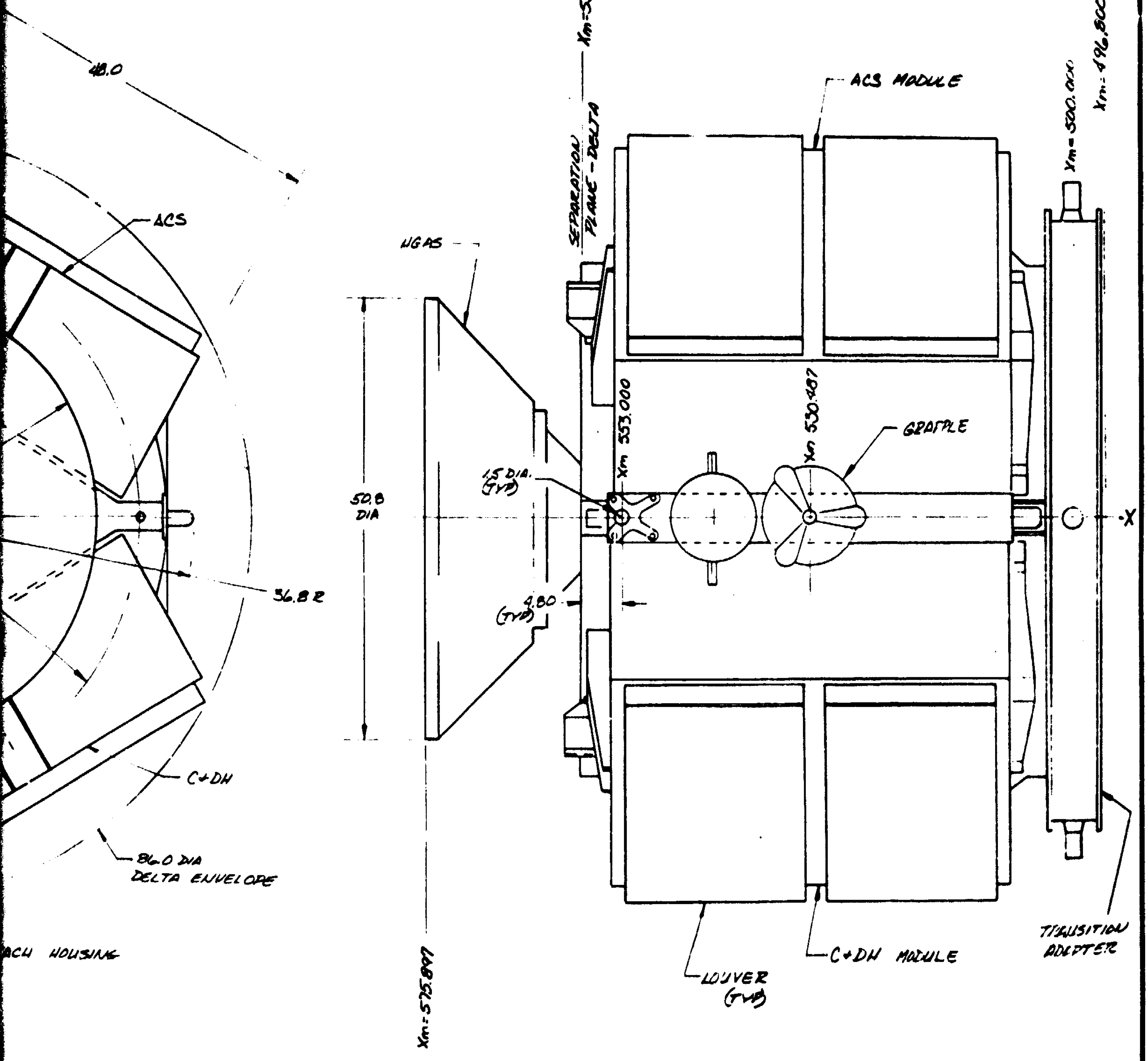
FOLDOUT FRAME

ORIGINAL PAGE IS
OF POOR QUALITY



ORIGINAL PAGE IS
OF POOR QUALITY

2 FOLDOUT FRAME



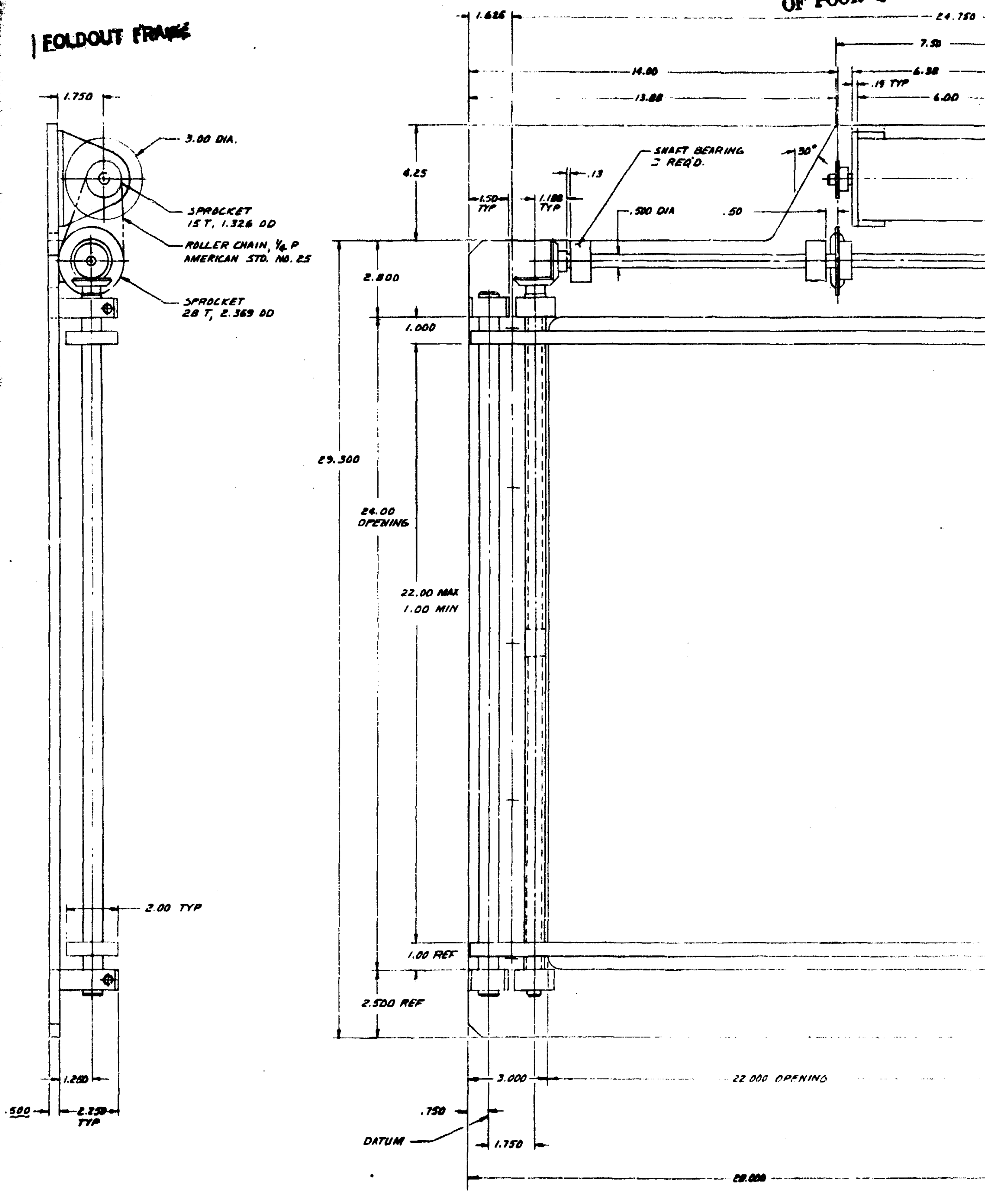
ESSEX		
SCALE:	APPROVED BY:	DRAWN BY
DATE: 1-15-79		CHECKED
MMS/SMM INTERFACE DEFINITION		
		DRAWING NUMBER H8807

PRECEDING PAGE BLANK NOT FILMED

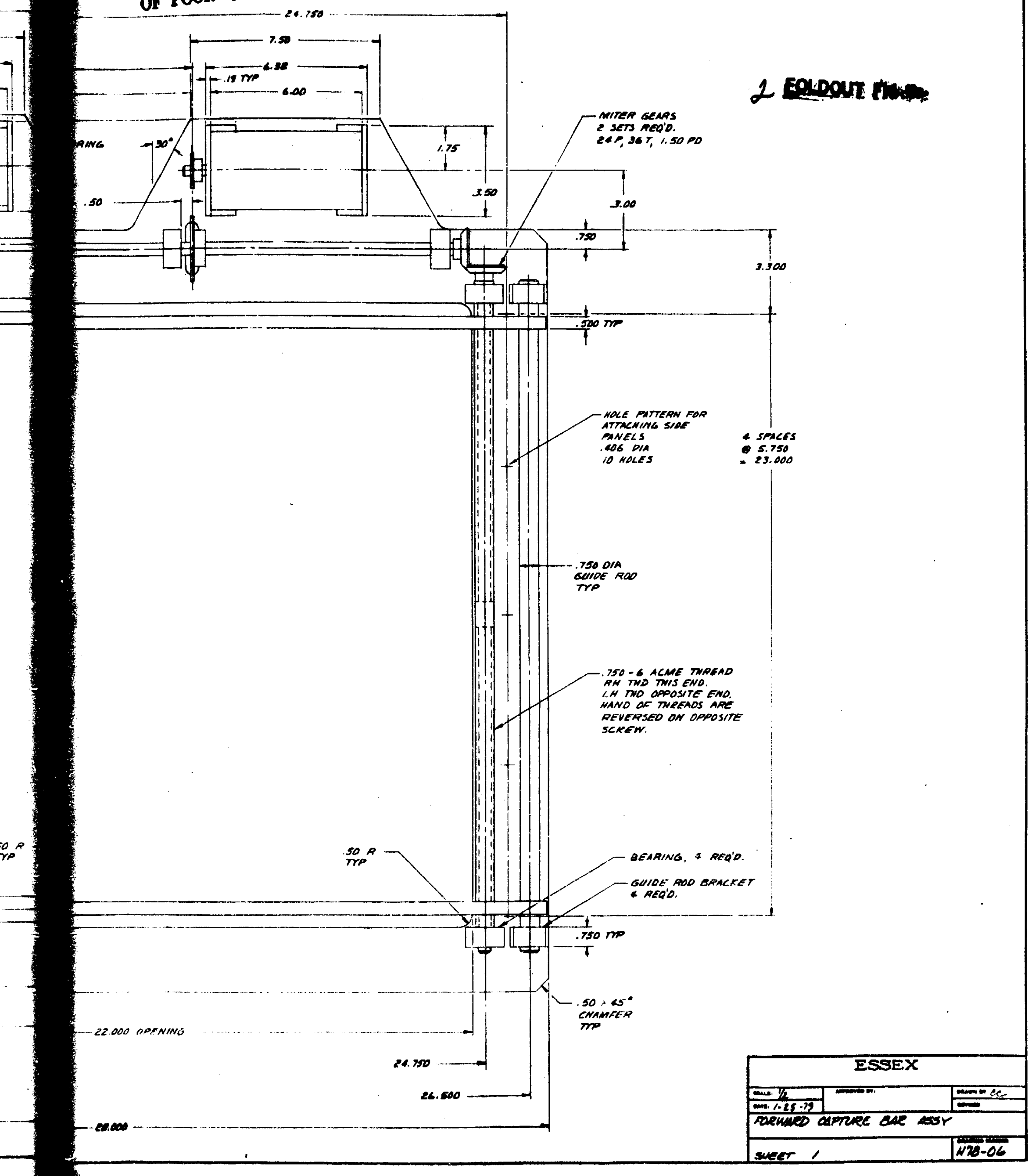
APPENDIX B

ORTHOGONAL RETRIEVAL DEVICE DRAWINGS

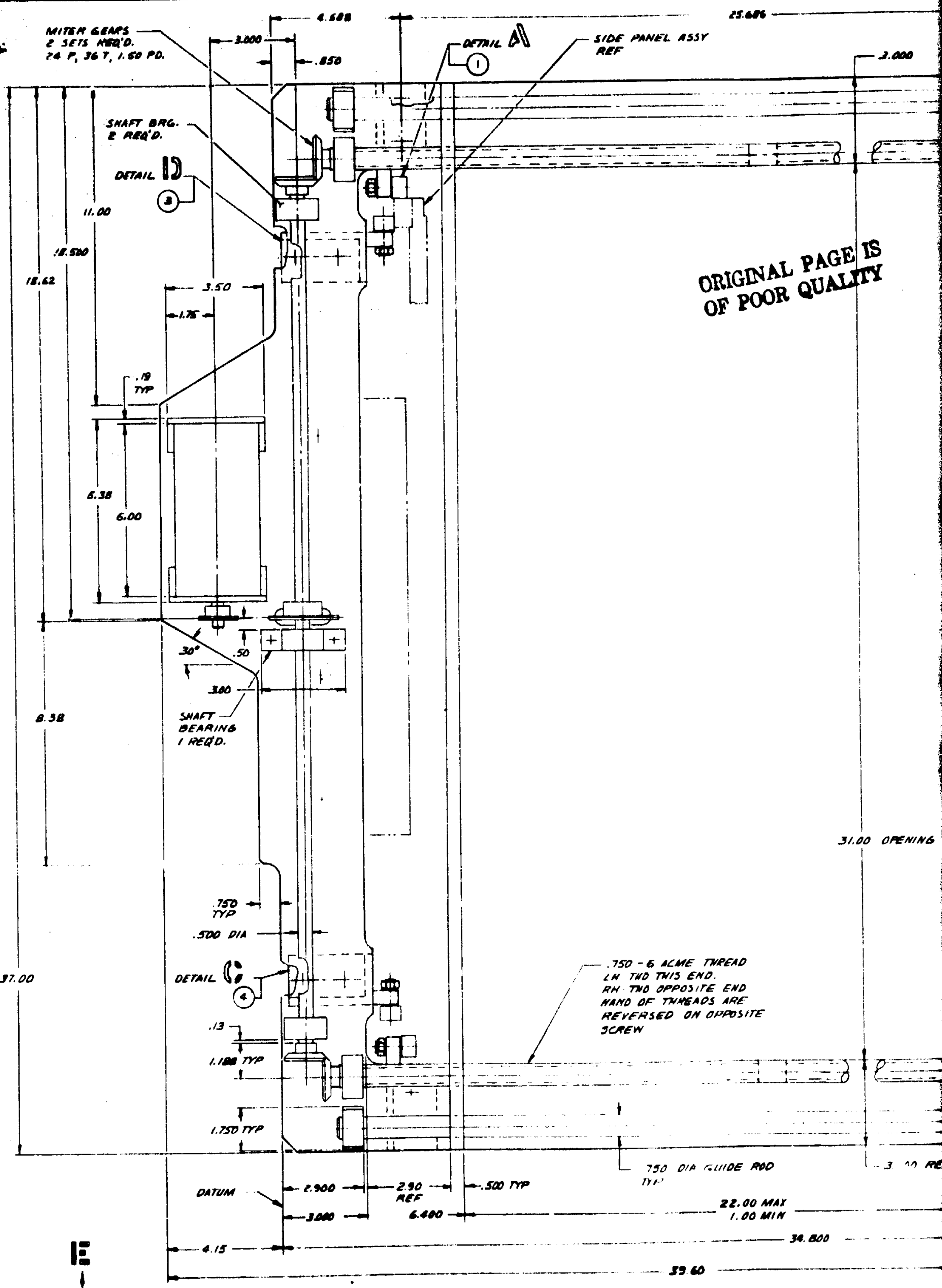
FOLDOUT FRAME

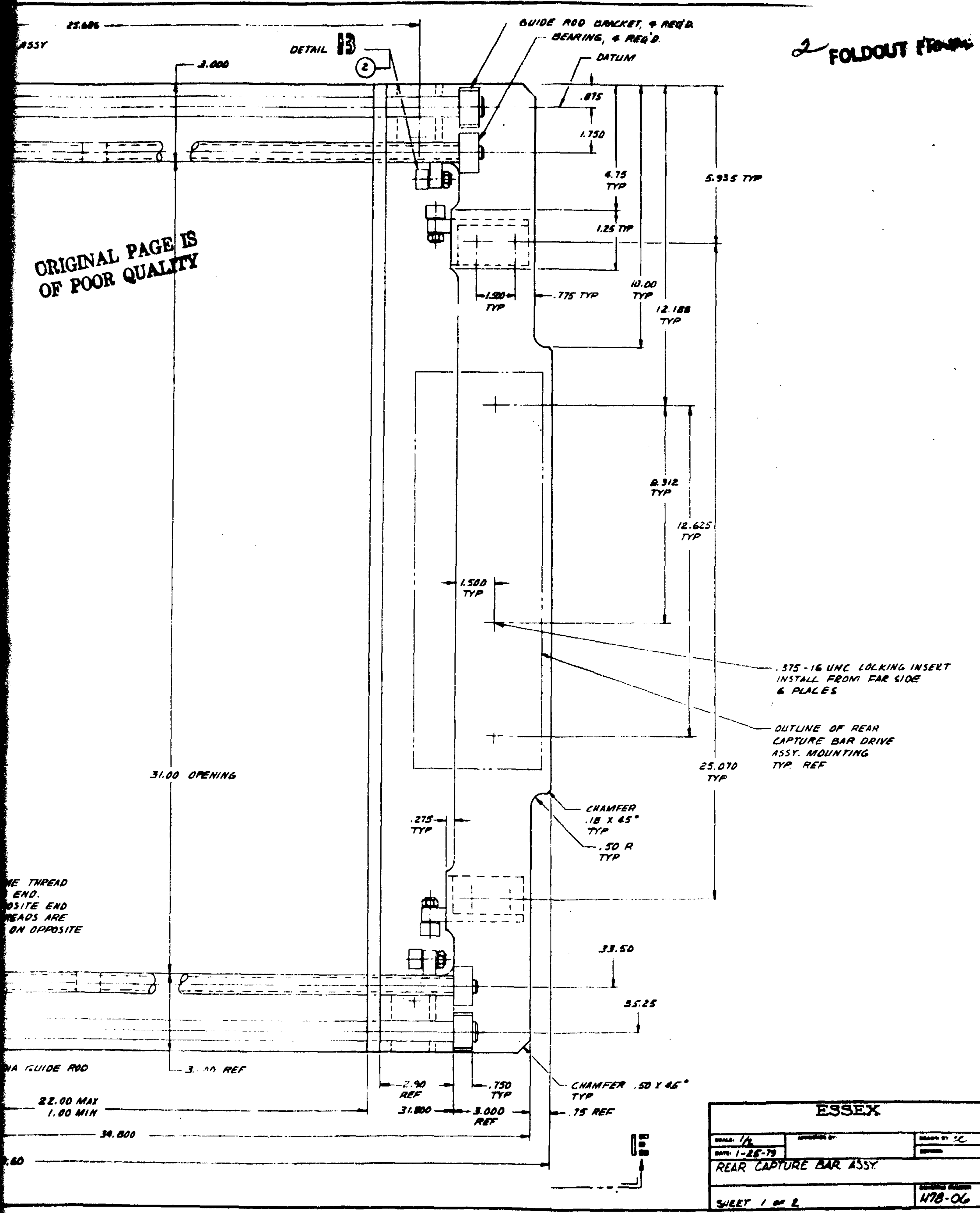


2 FOLDOUT FRAME

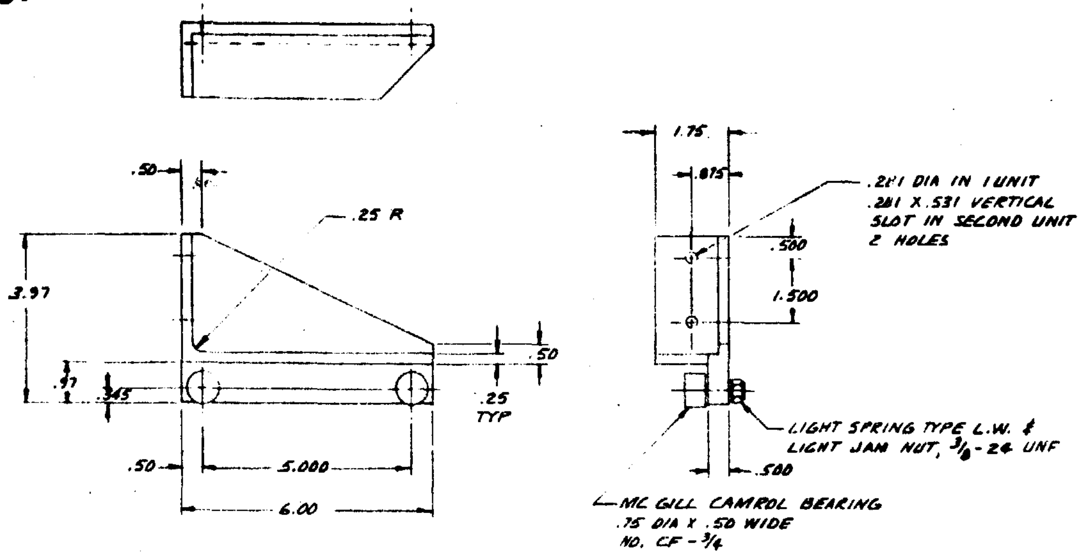


FOLDOUT FRAME

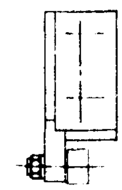




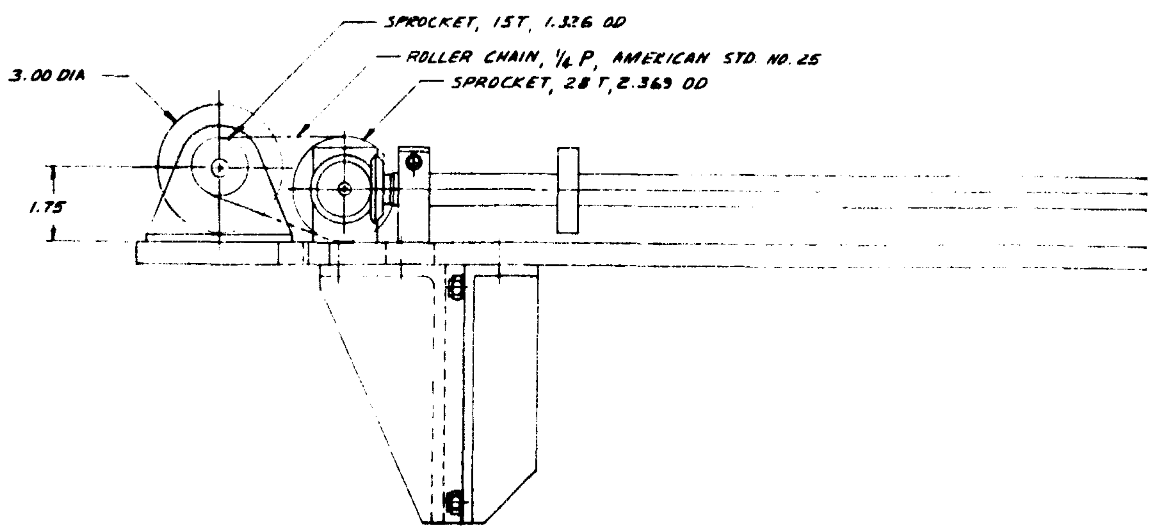
ASSY
25.686
3.000
DETAIL B
2
GUIDE ROD BRACKET, 4 REQ'D.
BEARING, 4 REQ'D.
DATUM
.875
1.750
4.75 TYP
5.935 TYP
1.25 TYP
1.500 TYP
.775 TYP
10.00 TYP
12.188 TYP
8.312 TYP
12.625 TYP
1.500 TYP
.375-16 UNC LOCKING INSERT INSTALL FROM FAR SIDE 6 PLACES
OUTLINE OF REAR CAPTURE BAR DRIVE ASSY. MOUNTING TYP. REF
25.070 TYP
31.00 OPENING
CHAMFER .18 X 45° TYP
.50 R TYP
.275 TYP
THREAD
END.
OSITE END
EADS ARE
ON OPPOSITE
33.50
35.25
DIA GUIDE ROD
3.00 REF
2.90 REF
.750 TYP
CHAMFER .50 X 45° TYP
22.00 MAX
1.00 MIN
31.800
3.000 REF
.75 REF
34.800
B
ESSEX
SCALE: 1/2
DATE: 1-25-79
REAR CAPTURE BAR ASSY
SHEET 1 OF 2
H78-06



DETAIL A
ITEM 1 - 2 REQ'D.



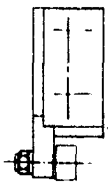
DETAIL B
ITEM 2 - 2 REQ'D.
SAME AS DETAIL A
EXCEPT OPPOSITE HAND



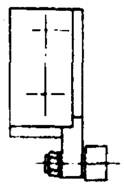
VIEW E-E

FOLDOUT FRAME 2

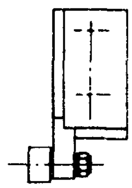
ORIGINAL PAGE IS OF POOR QUALITY



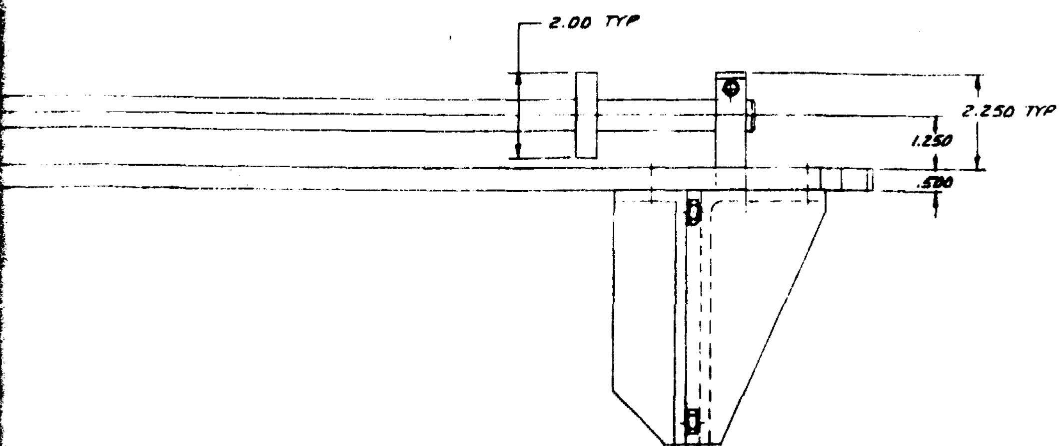
DETAIL B
ITEM 2 - 2 REQ'D.
SAME AS DETAIL A
EXCEPT OPPOSITE HAND



DETAIL C
ITEM 3 - 2 REQ'D.
SAME AS DETAIL A
EXCEPT ROLLER REVERSED



DETAIL D
ITEM 4 - 2 REQ'D.
SAME AS DETAIL B
EXCEPT ROLLER REVERSED



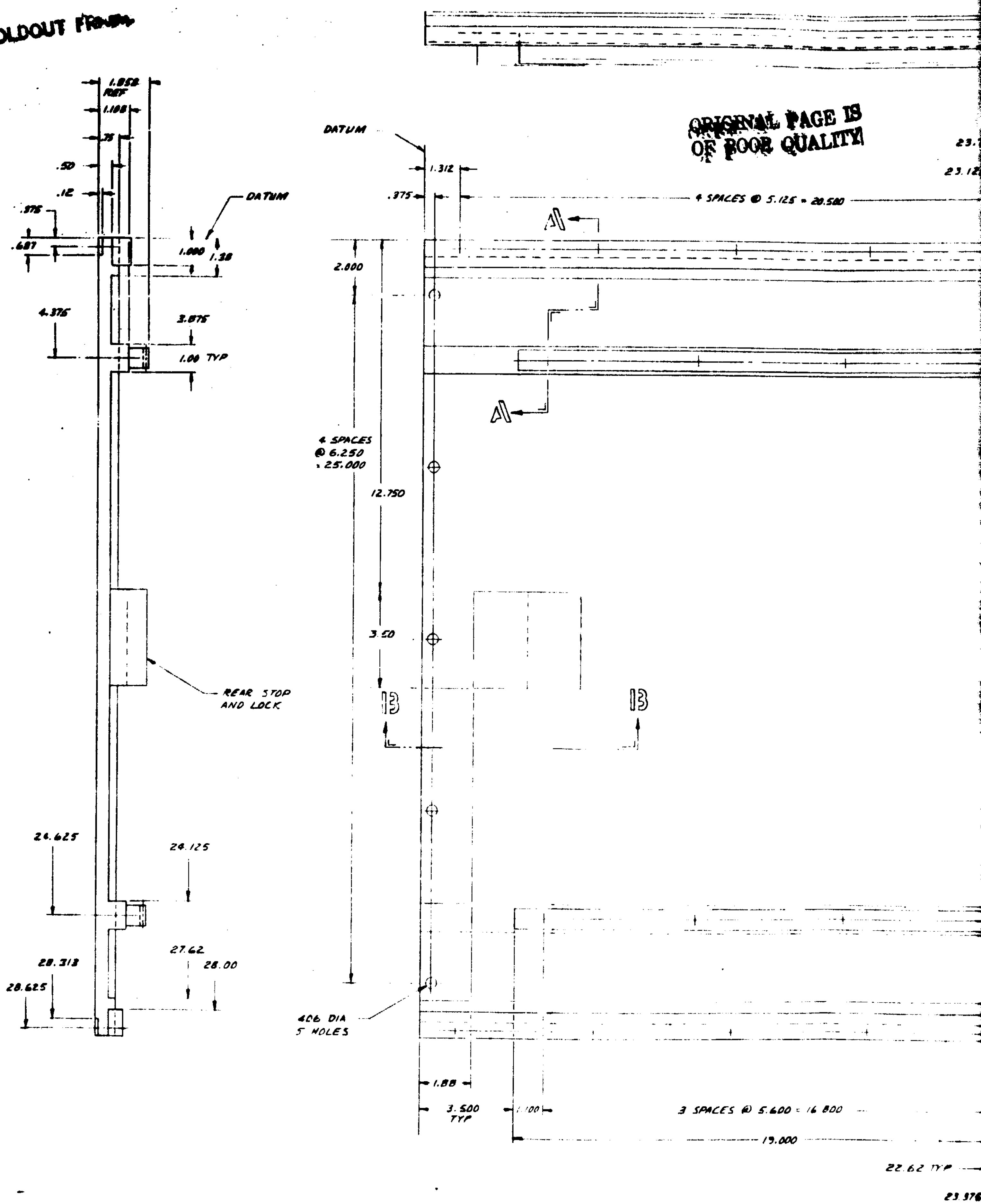
E - E

ESSEX

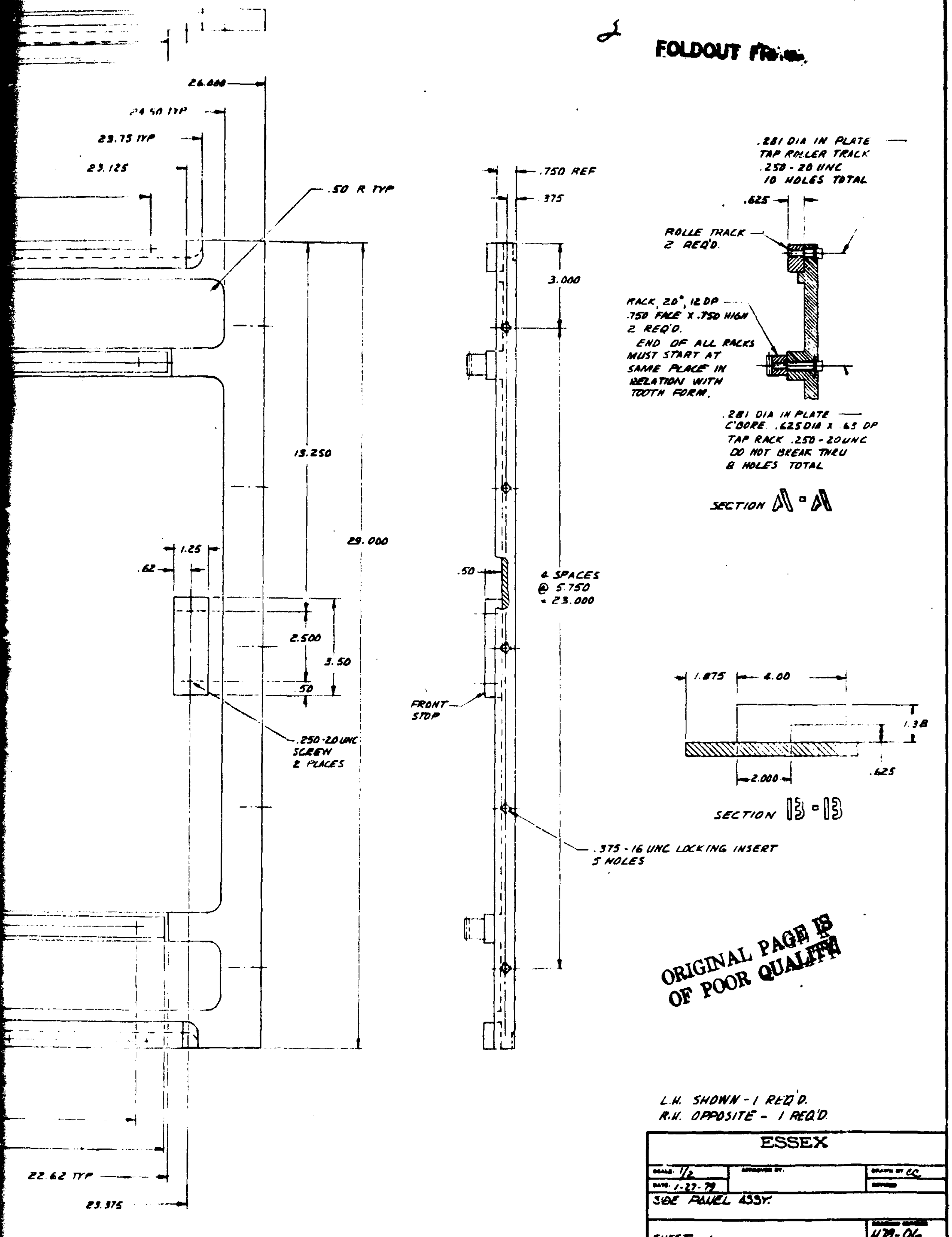
SCALE: 1/2	APPROVED BY	DRAWN BY CC
DATE: 1-25-79		REVISED
REAR CAPTURE BAR ASSY		
SHEET 2 OF 2		N78-06

FOLDOUT FRAME

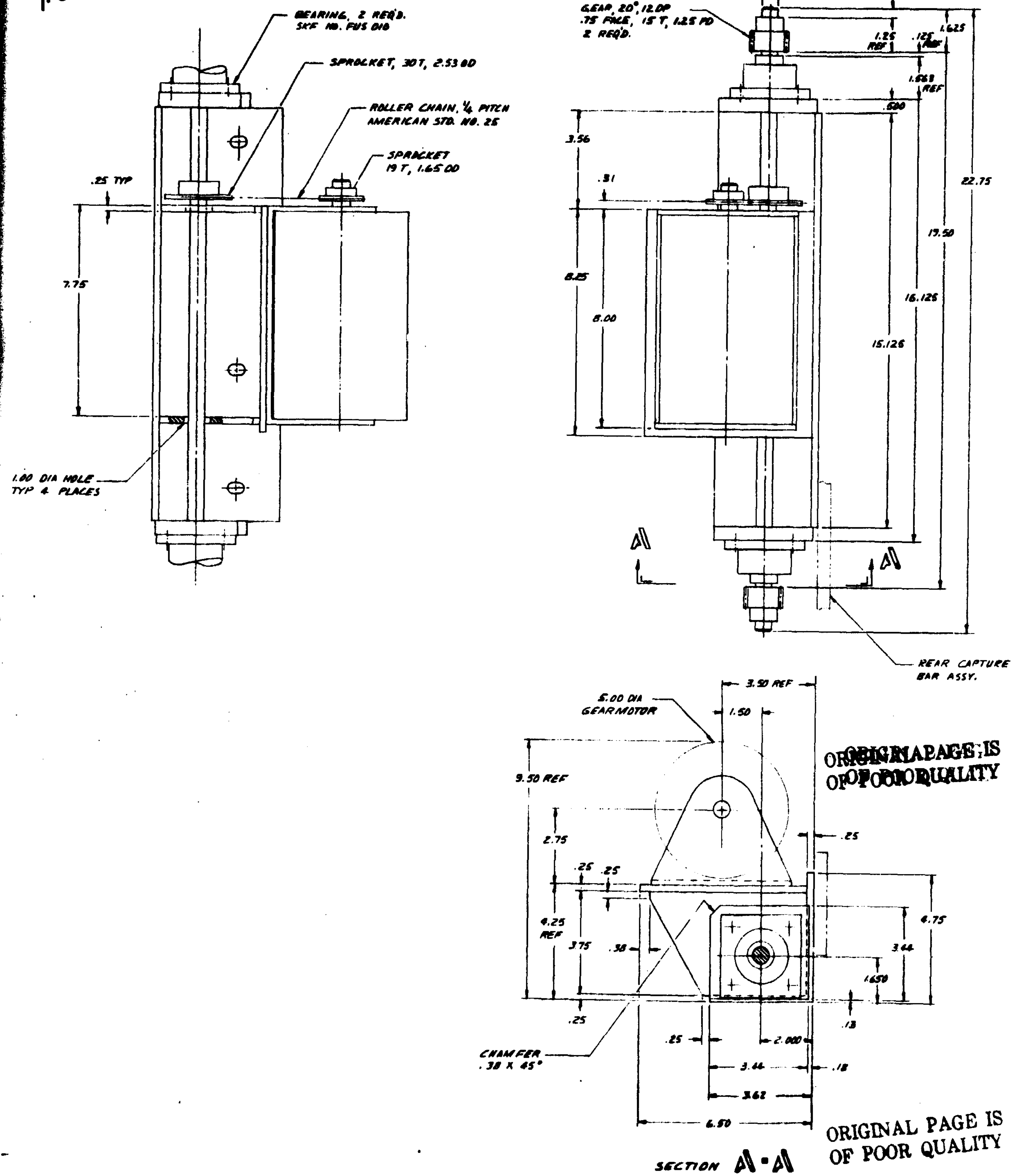
ORIGINAL PAGE IS OF POOR QUALITY



FOLDOUT FRAME

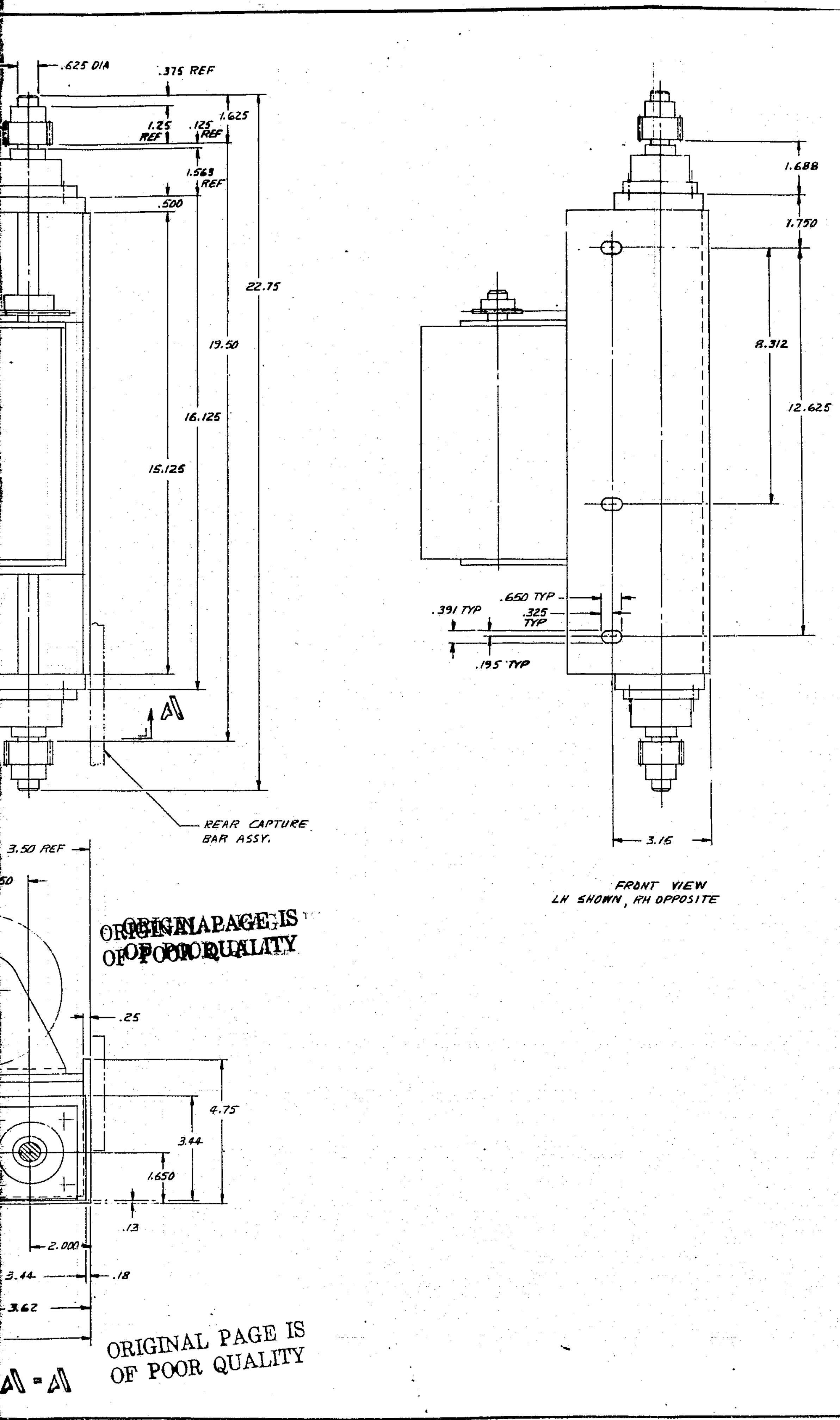


FOLDOUT FRAME



FOLDOUT FRAME

2

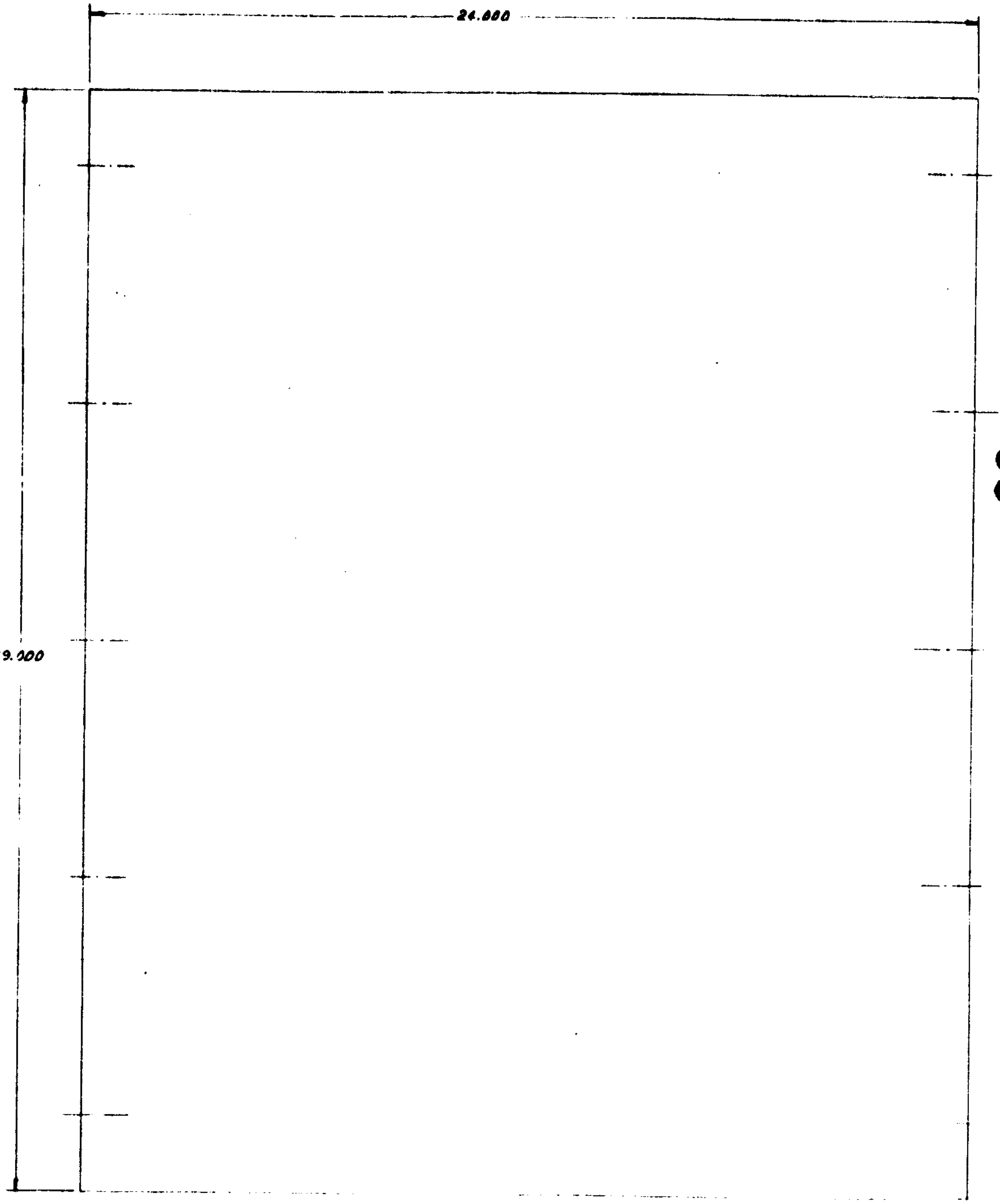


LH SHOWN - 1 REQ'D.
RH OPPOSITE - 1 REQ'D.

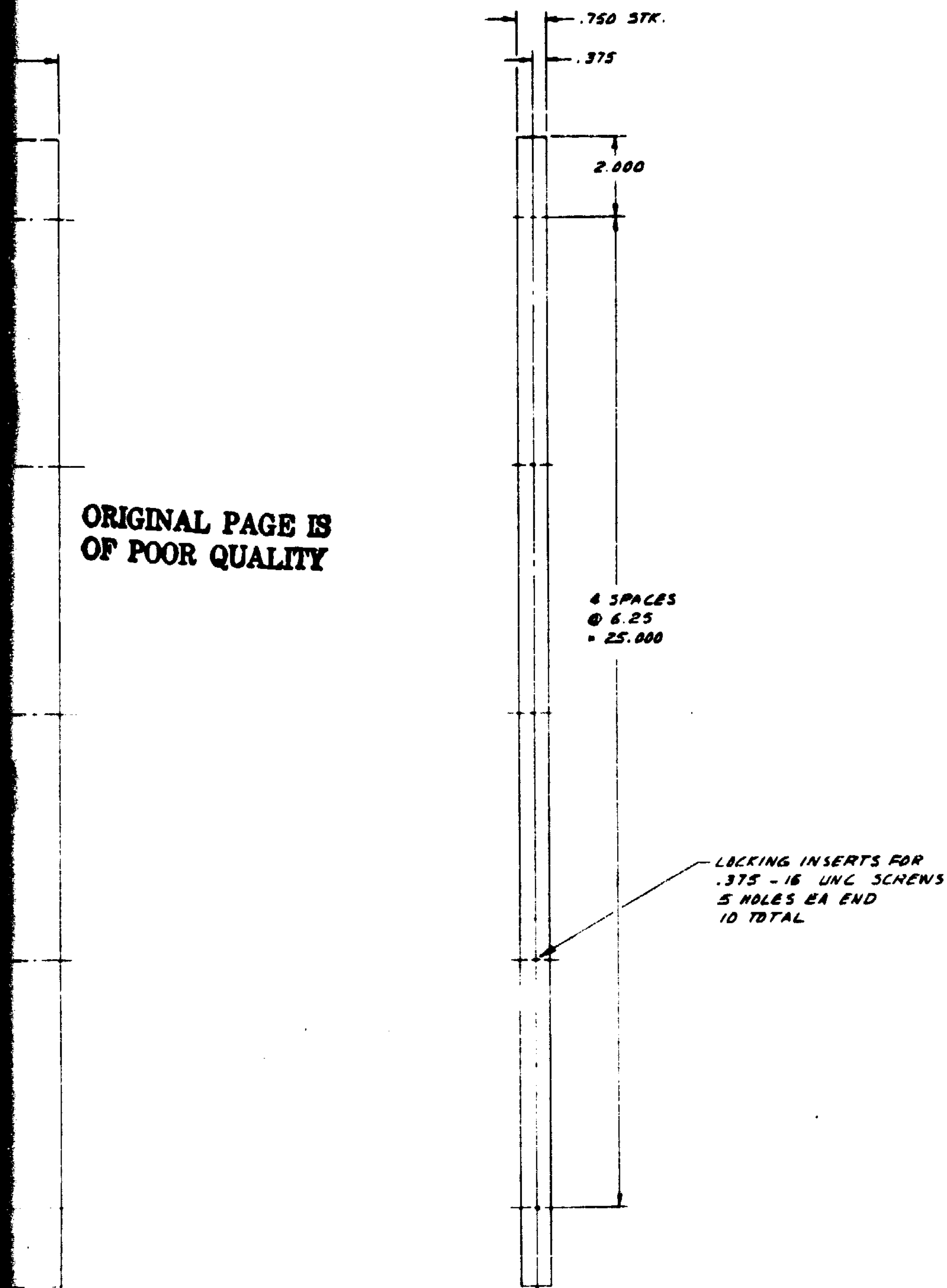
ESSEX

SCALE: 1/2
DATE: 1-28-79
APPROVED BY:
DRAWN BY CC
REVISED
RETRACT MECHANISM ASSY
DRAWING NUMBER H78-06
SHEET 1

FOLDOUT FRAME



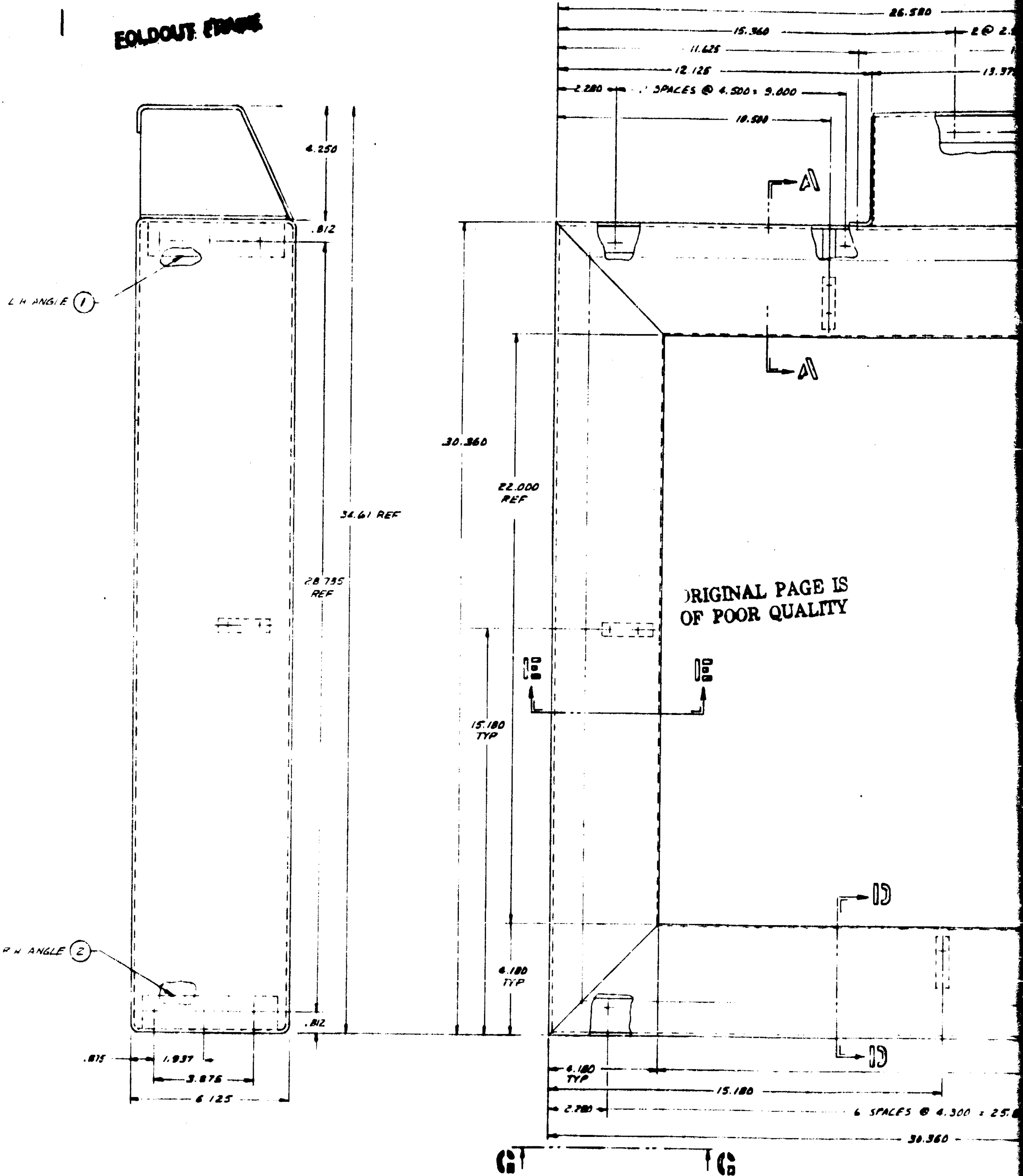
2 FOLDOUT FRAME



ORIGINAL PAGE IS
OF POOR QUALITY

ESSEX		
SCALE: 1/2 / DATE: 1-27-79	APPROVED BY:	DRAWN BY: CC / CHECKED:
REAR MOUNTING PLATE		
SHEET 1		478-06

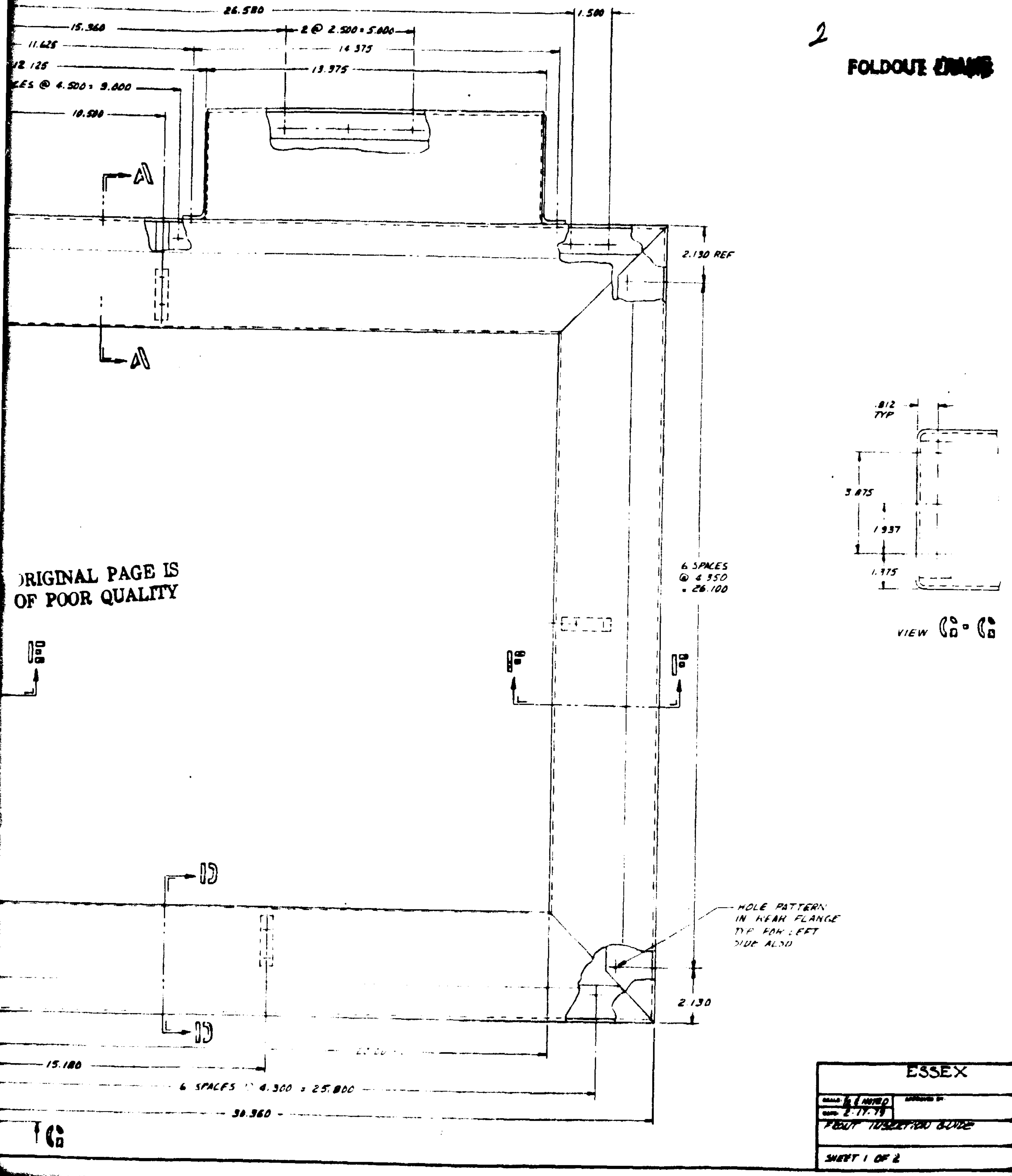
FOLDOUT FRAME



ORIGINAL PAGE IS
OF POOR QUALITY

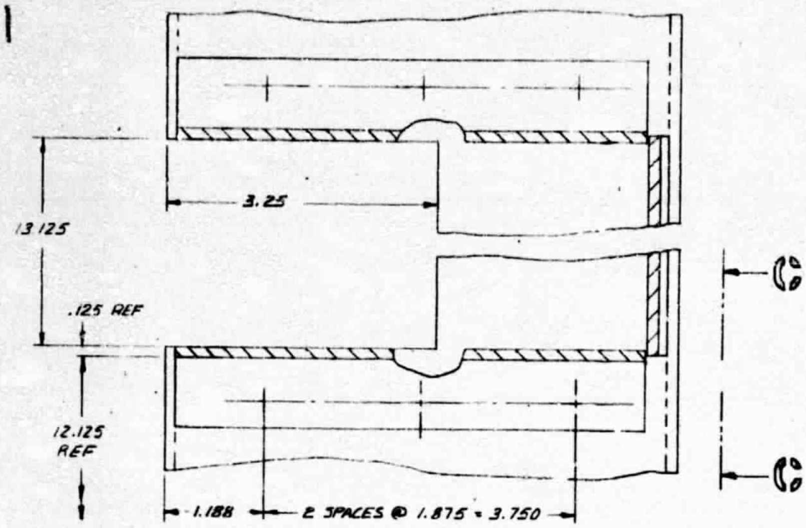
2

FOLDOUT

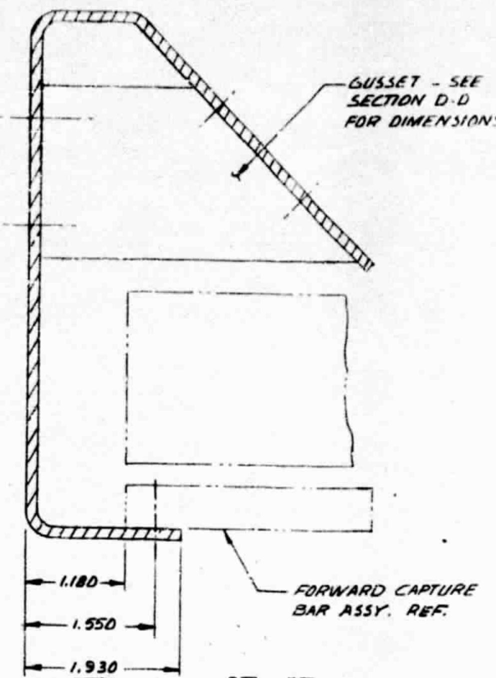


26.580
1.500
15.360
2 @ 2.500 = 5.000
11.625
14.375
12.125
13.375
ES @ 4.500 = 9.000
10.500
A
A
2.130 REF
6 SPACES
@ 4.350
= 26.100
.812
TYP
3.875
1.937
1.375
VIEW
HOLE PATTERN
IN REAR FLANGE
TYP FOR LEFT
SIDE ALSO
2.130
15.180
6 SPACES @ 4.300 = 25.800
30.360
ESSEX
2-17-78
SHEET 1 OF 2

FOLDOUT FRAME

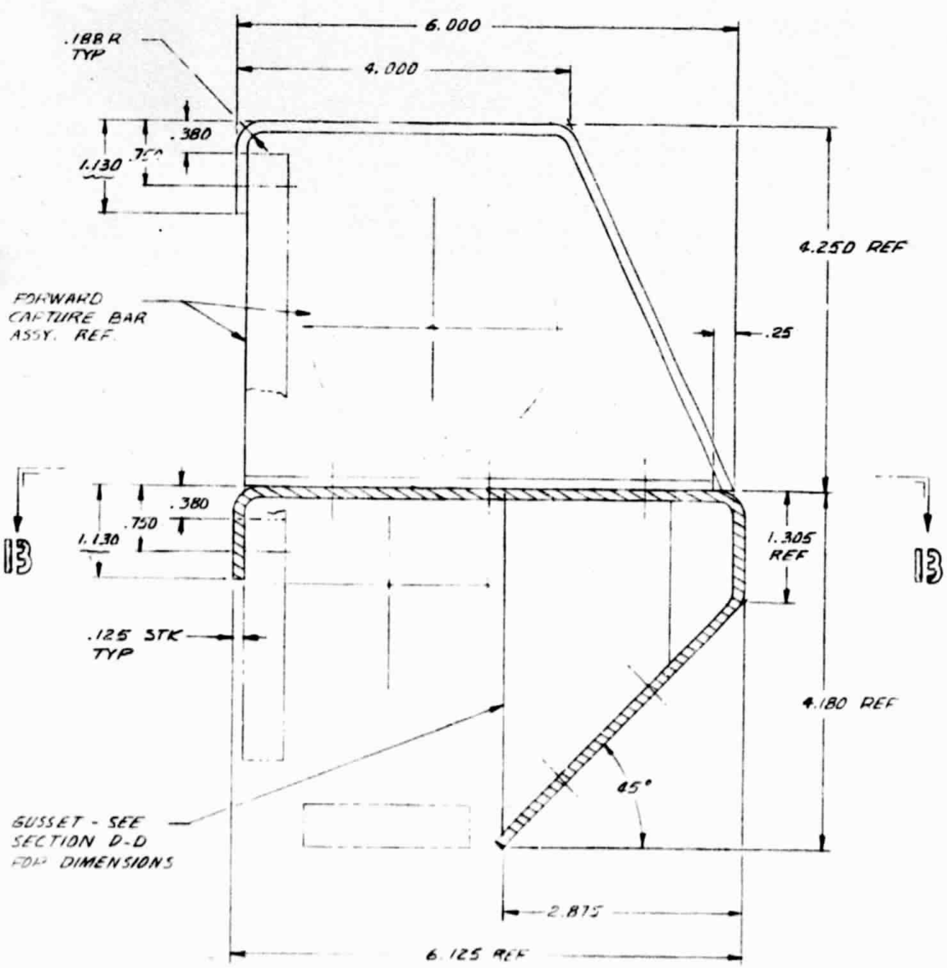


SECTION B - B
SCALE 1/1

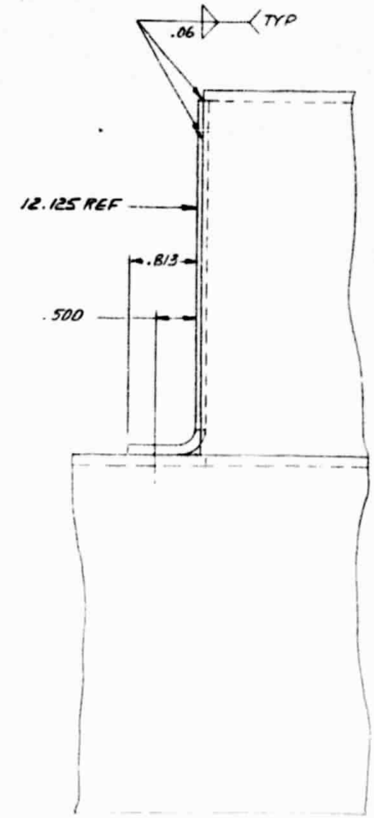


SECTION E - E SHOWN
SECTION F - F OPPOSITE
SCALE 1/1
SEE SECTION A-A FOR
DIMENSIONS NOT SHOWN

ORIGINAL PAGE IS
OF POOR QUALITY



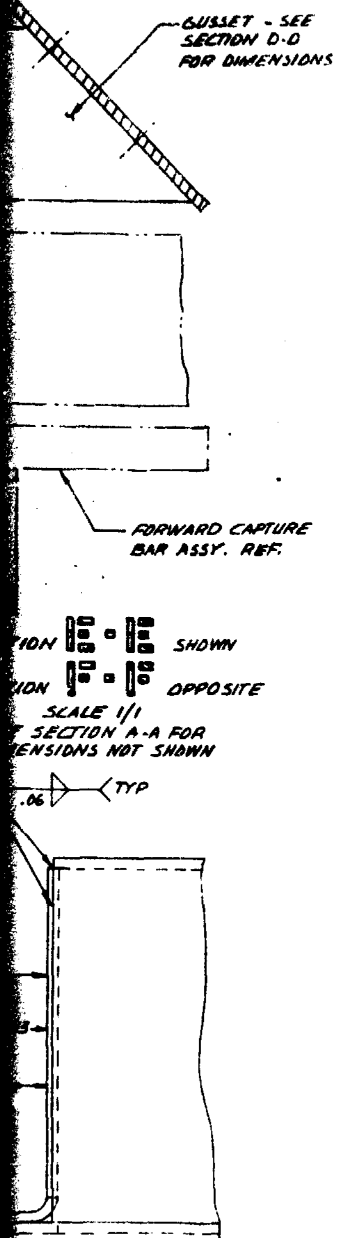
SECTION A - A
SCALE 1/1
ROTATED 90° CCW



VIEW C - C
SCALE 1/1
ROTATED 90° CW

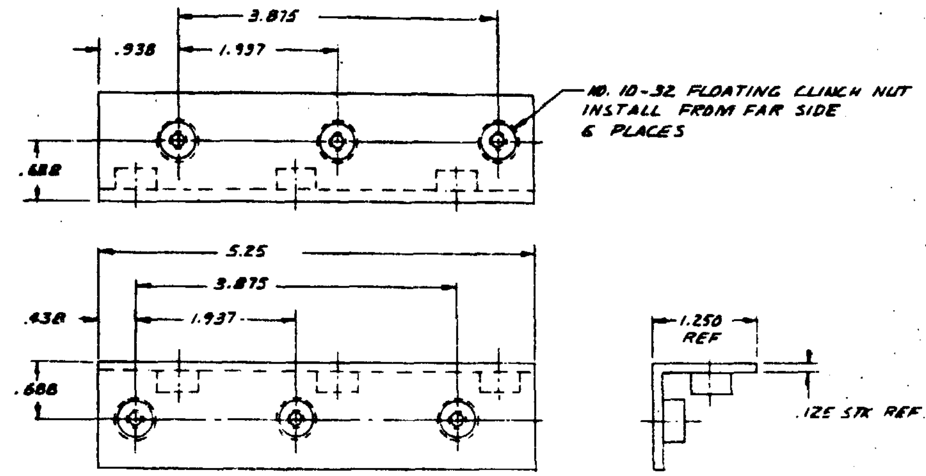
2

FOLDOUT FRAME



C - C

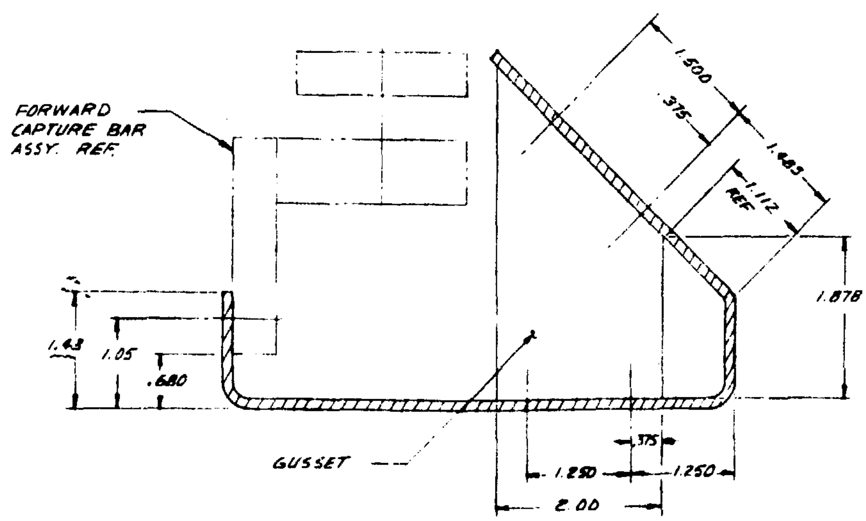
LE 1/1
D 90°CW



ITEM (1) L.H. ANGLE SHOWN - 2 REQD.

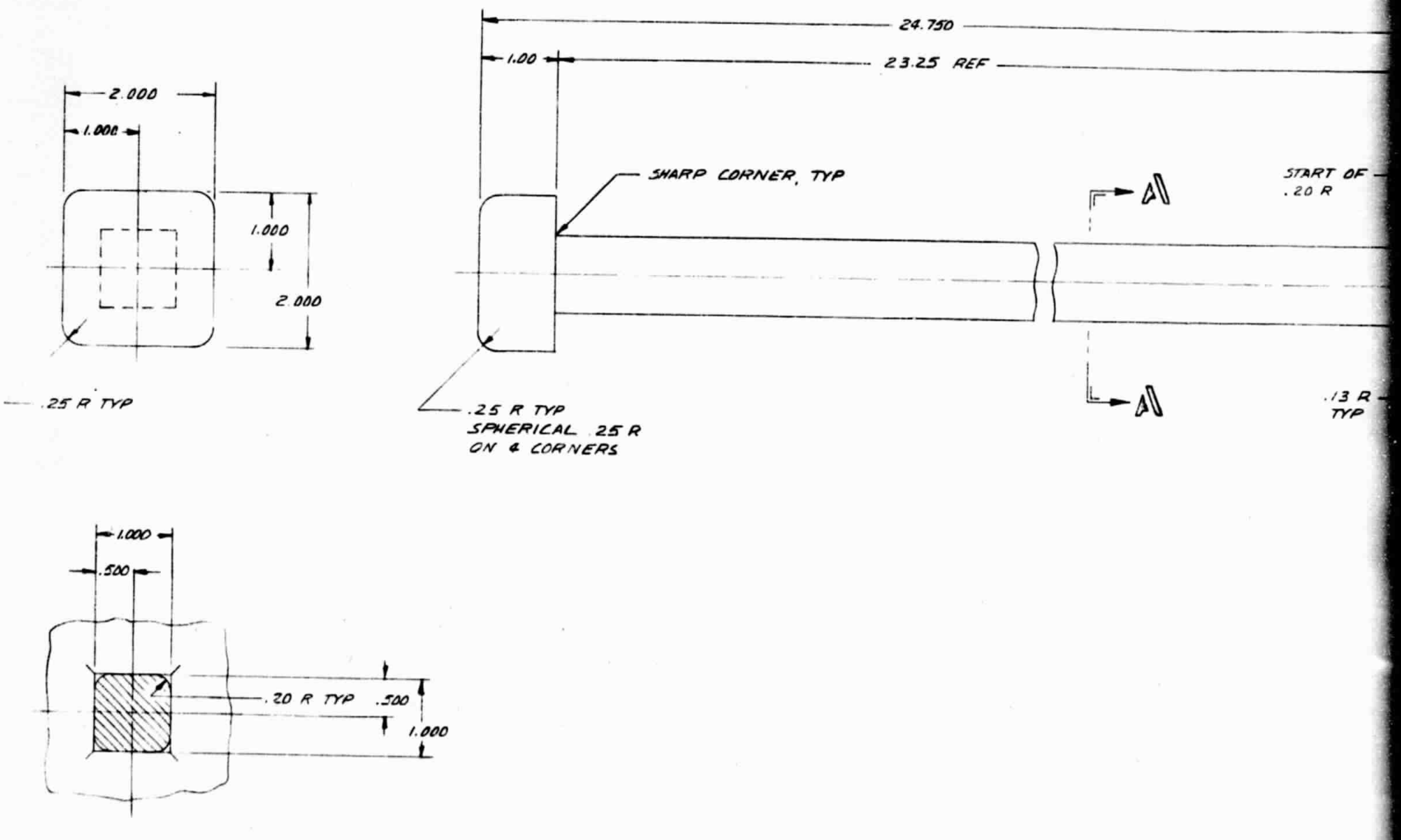
ITEM (2) R.H. ANGLE OPPOSITE - 2 REQD.

MAKE FROM 1.25 x 1.25 x .125 SHARP CORNER ANGLE
SCALE: 1/1



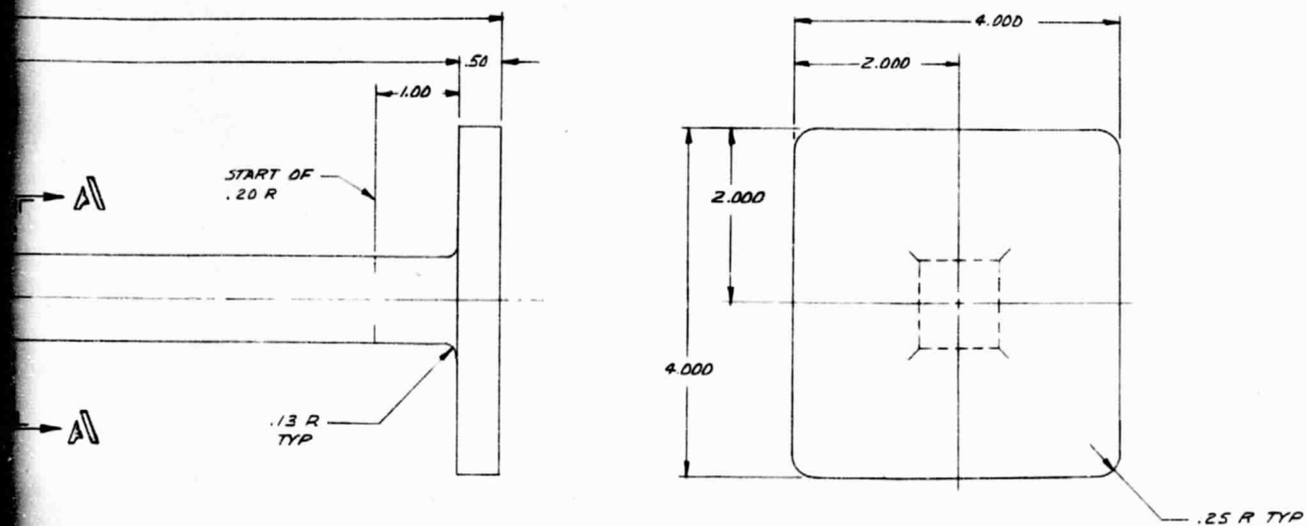
SECTION D - D
SCALE 1/1
SEE SECTION A-A FOR
DIMENSIONS NOT SHOWN

ESSEX		
SCALE 1/1 & NOTED	APPROVED BY:	DRAWN BY: CC
DATE 2-13-79		
FRONT INSERTION GUIDE		
SHEET 2 OF 2		1128-06


2.000
1.000
1.000
2.000
.25 R TYP
24.750
1.00
23.25 REF
SHARP CORNER, TYP
START OF
.20 R
A
A
.25 R TYP
SPHERICAL .25 R
ON 4 CORNERS
.13 R
TYP
1.000
.500
.20 R TYP
.500
1.000

SECTION A - A

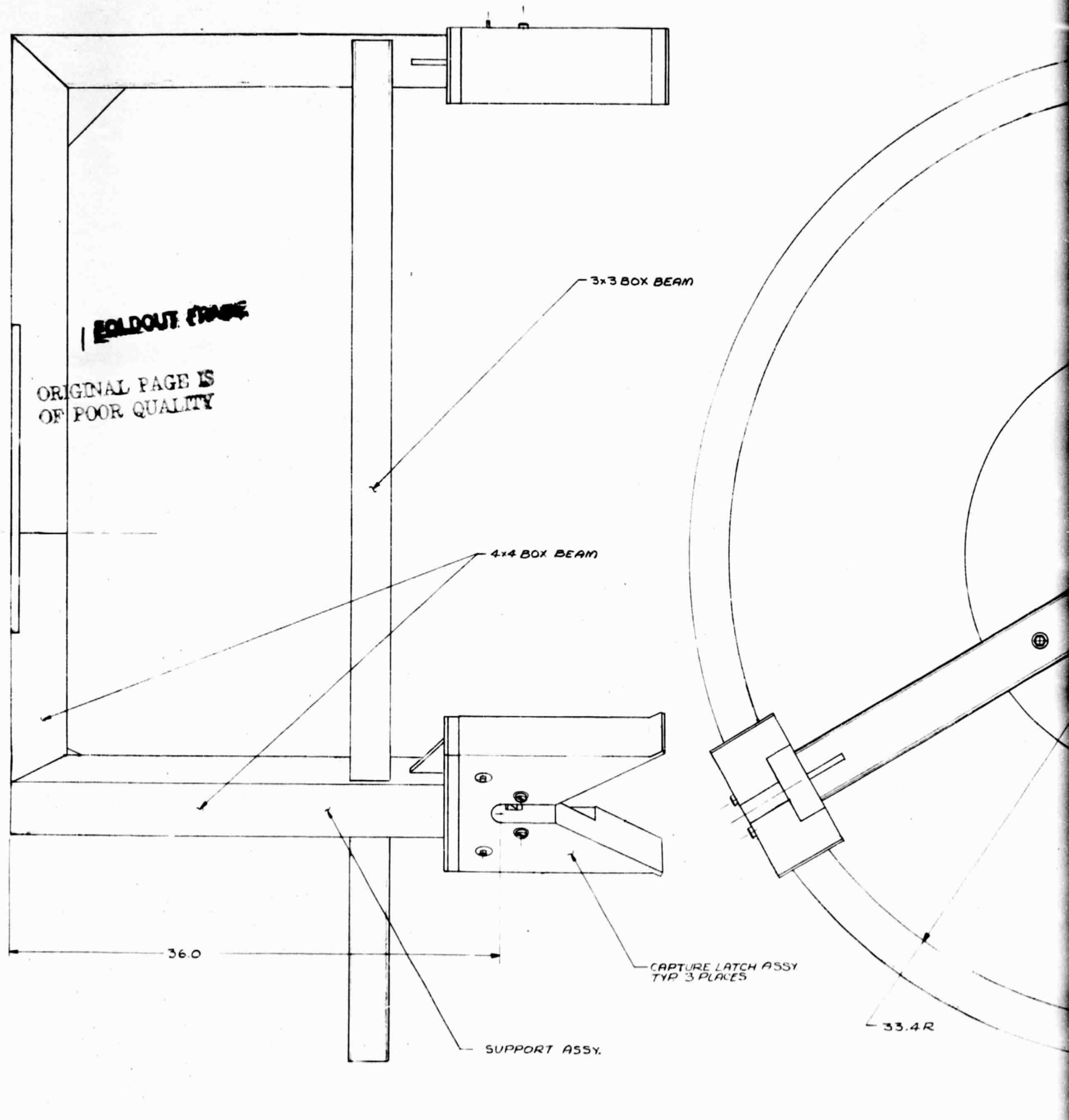
2 FOLDOUT FRAME



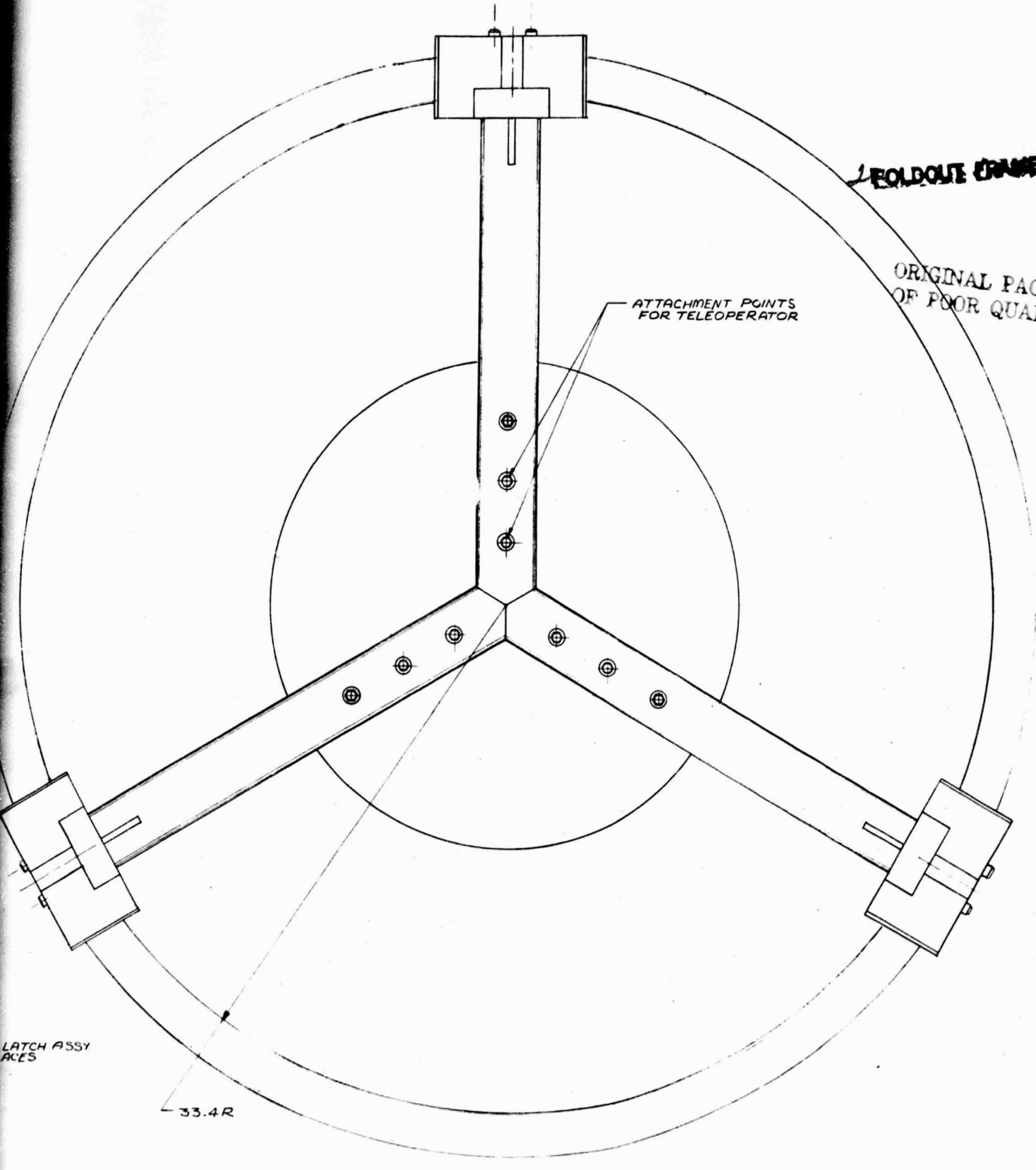
ESSEX		
SCALE: 1/1 DATE: 2-18-79	APPROVED BY:	DRAWN BY BC REVISED
GRAPPLE FIXTURE		
		DRAWING NUMBER H78-06

APPENDIX C

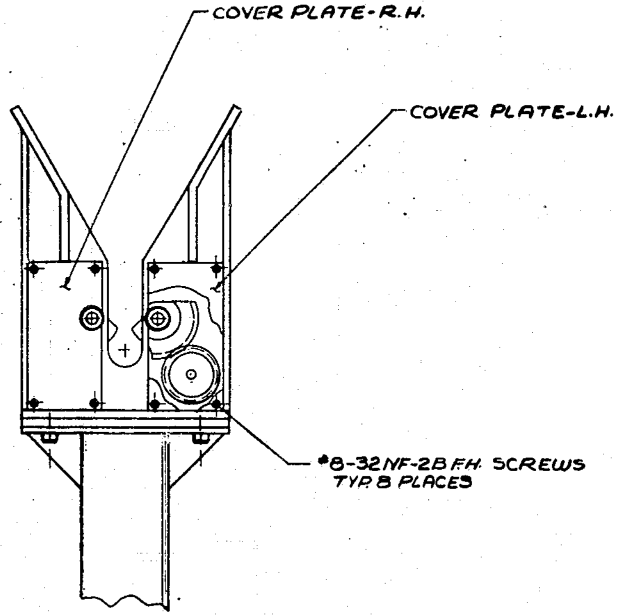
SMM RETRIEVAL DEVICE DRAWINGS


3x3 BOX BEAM
4x4 BOX BEAM
36.0
CAPTURE LATCH ASSY
TYP 3 PLACES
SUPPORT ASSY.
33.4R

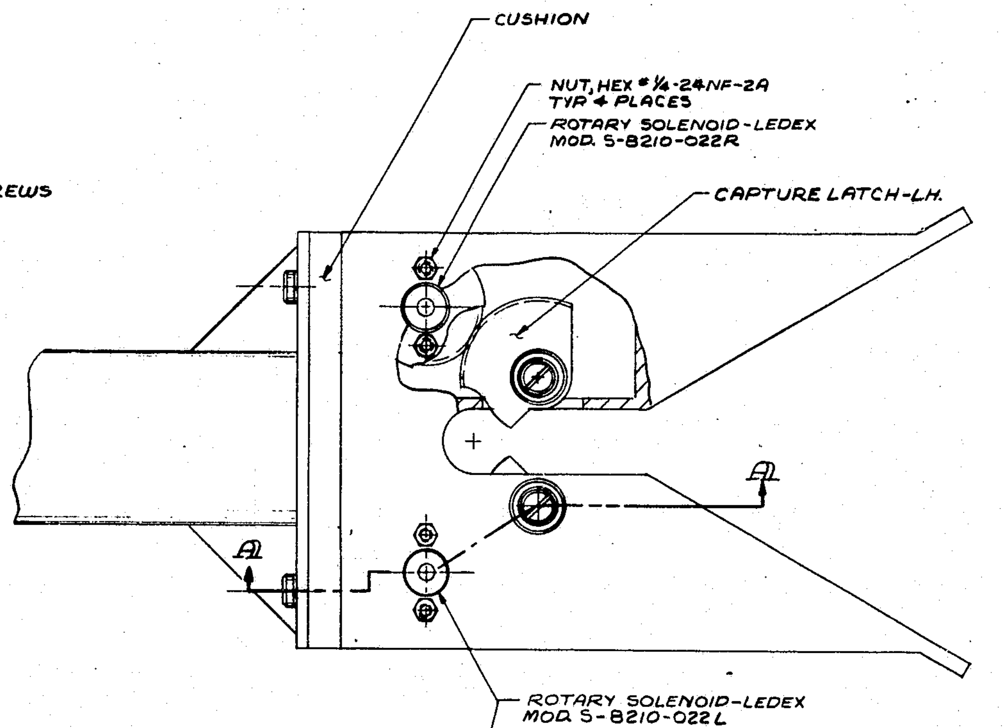
FOLDOUT FRAME

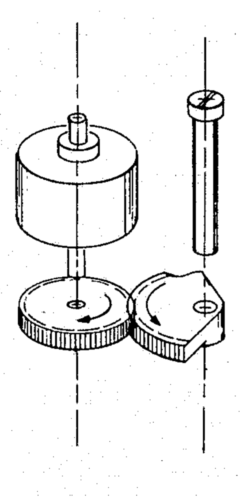


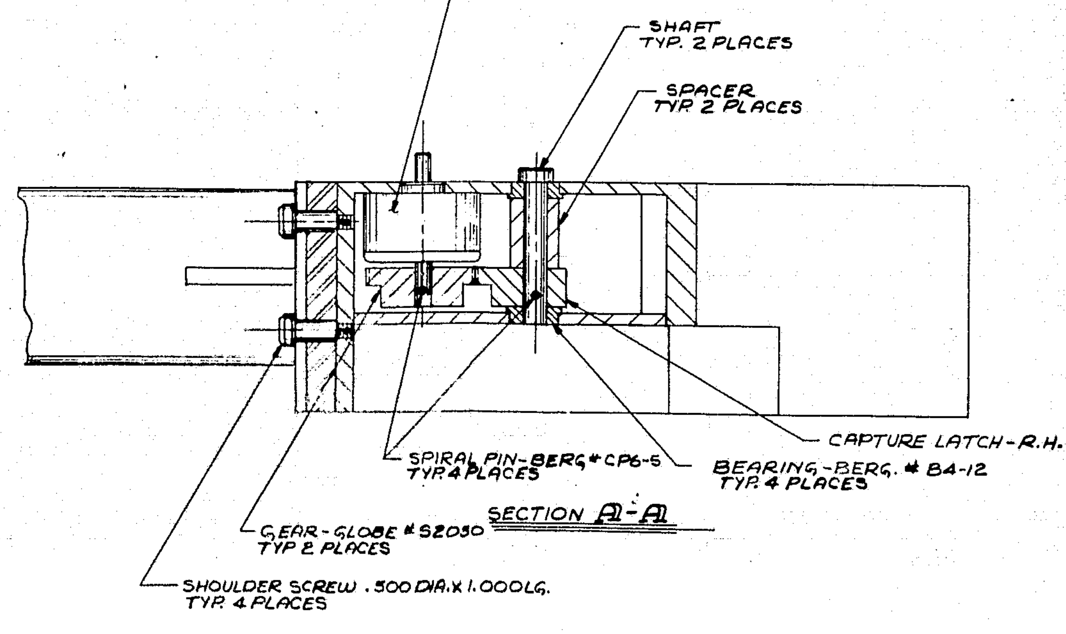
ESSEX CORP		
SCALE: 1/4	APPROVED BY:	DRAWN BY
DATE: 1-24-79		REVISED
SMM CAPTURE DEVICE		
SHEET 1 OF 2		DRAWING NUMBER H78-07



VIEW A-A
1/4 SCALE

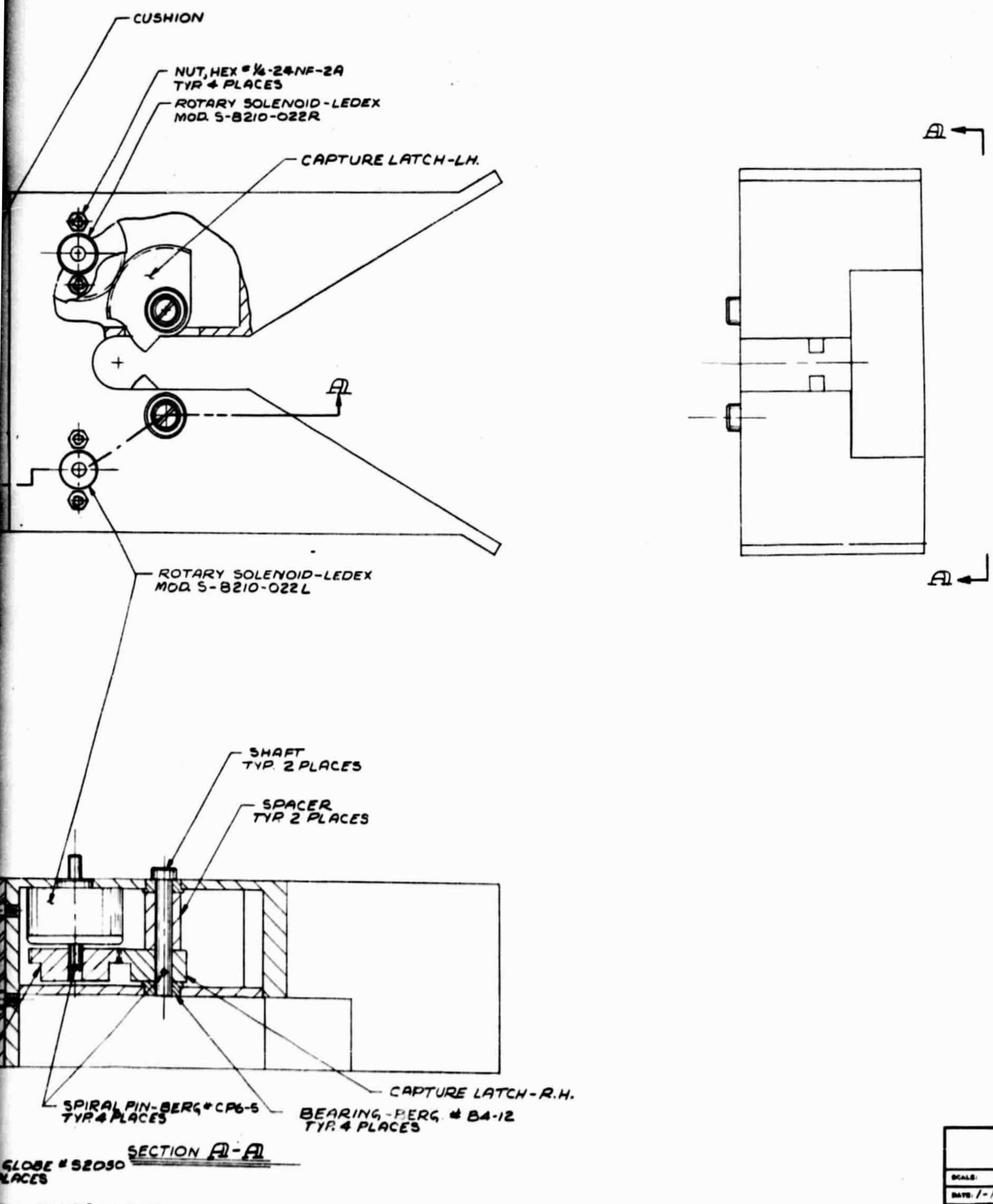






SECTION A-A

2



ESSEX CORP

SCALE: 1/2	APPROVED BY:	DRAWN BY
DATE: 1-15-79		REVISED
CAPTURE LATCH ASSY		
SHEET 2 OF 2		DRAWING NUMBER N78-07