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Produced by the NASA Center for Aerospace Information (CASI)
DEVELOPMENT OF ROBOTICS FACILITY
DOCKING TEST HARDWARE

Contract NAS8-34656

(NASA-CR-171153) DEVELOPMENT OF ROBOTICS
FACILITY DOCKING TEST HARDWARE Final Report
(Essex Corp.) 106 p HC A06/MF A01 CSCL 14B

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August 31, 1984
Essex Report Number H-84-05
This final report represents the results of a 12-month effort by Essex Corporation to design and fabricate test hardware for NASA's George C. Marshall Space Flight Center (MSFC) under contract NAS8-34656. A docking device conceptually developed by Essex for MSFC under contract NAS8-33073 was fabricated. Also, two docking targets providing high and low mass docking loads were required and were represented by an aft 61.0 cm section of a Hubble Space Telescope (ST) mockup and an upgrading of an existing Multimission Modular Spacecraft (MMS) mockup respectively. In addition, a test plan was developed for testing the above-mentioned hardware.

The support and guidance provided by Ed Guerin (EB14), the contract COR, and Richard Cloyd (EP36) were especially helpful in the performance of the hardware design, and the assistance of Frank Vinz (EB44) in interfacing with the 6 DOF equipment in MSFC's Building 4663 was both timely and appreciated.

The assistance of John Haslam, David Henderson, Keith Savas, and Nicholas Shields in fabricating and integrating the mockups in the Teleoperator and Robotics Evaluation Facility is gratefully acknowledged. Appreciation is also extended for their preparation of the Test Requirements section of this report.
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1.0 INTRODUCTION

1.1 BACKGROUND

Prior to the successful retrieval, repair, and release of the Solar Maximum Mission (SMM) satellite during Shuttle Mission 41-C, all spacecraft docking has been performed on a manual vehicular level with one or more onboard crew members piloting the chase vehicle and operating the docking hardware. The use of the Remote Manipulator System (RMS) for retrieval of the SMM demonstrated the feasibility of remote docking. This technique had certain elements in common with both the manned chase vehicle/target capture and totally remote docking systems in that the Orbiter had to be positioned within capture distance of the target satellite and the crewmember was required to remotely "pilot" the end effector of the RMS into a capture position in order to secure the target.

These docking techniques have proven feasible in prior missions and will, in all probability, continue to be used in the future when appropriate. However, there are situations in which neither method of docking will suffice. These include: 1) the capture of a satellite which is beyond the operating range of the Orbiter/RMS reach envelope, 2) the capture of satellites which may be sensitive to concentrations of contaminants found near an actively maneuvering Orbiter, and 3) satellites which may present a hazard to the Orbiter or crew through malfunction or design. Thus, the development of truly remote docking hardware and techniques will allow a wide range of docking scenarios to be enacted.

The development of prototypical docking hardware, as well as realistic docking targets (i.e., ST and MMS) which have well defined berthing pins, was therefore necessary to expand the development of remote crew station configurations, training procedures, lighting and video constraints and parameters which has been an on-going activity at MSFC since 1972.

The Teleoperator and Robotics Evaluation Facility (TOREF, MSFC Bldg. 4619), and the six degree of freedom (6DOF) simulator (MSFC Bldg. 4663) provide facilities for a wide range of evaluation and development techniques concerning remote docking.

1.2 SCOPE

The purposes of this contract were to: 1) provide a full-size mockup of the ST aft end to represent a large, massive docking target, 2) upgrade the existing MMS to represent a smaller, less massive docking target, 3) fabricate the three-element docking device designed under a previous Essex/MSFC contract to mate with both spacecraft docking targets, and 4) identify the docking test requirements.
2.0 TASK DESCRIPTIONS

Four contract tasks were performed as described below.

2.1 TASK 1 - DEVELOPMENT OF SPACE TELESCOPE MOCKUP

A full size mockup of the ST aft end (Figure 2.1 and Appendix A) was constructed using drawings obtained from Lockheed Missile and Space Company as well as Interface Control Documents (ICDs) obtained from MSFC engineering personnel. The ICDs were used in the design of the three berthing pins as no machine drawings were available.

The frame of the main cylinder of the ST mockup was constructed primarily of 3.2 mm thick aluminum architectural angle formed and welded into three wedge-shaped sections 61.0 cm thick (see Appendix A). Internal bracing provided a rigid, lightweight structure (<100 kg) on which the berthing pins, vents, connector tower, docking target, and handrails were mounted. Mounting to the gimbal system for roll, pitch, and yaw was accomplished through the use of a central support tube which also added rigidity and served as an attach point for the diagonal and radial support members. All external surfaces of the mockup were covered with corrugated fiberboard, which served as a base for attachment of the simulated insulation blanket as well as a mounting surface for some of the lighter visual features. The corrugated fiberboard was attached to the frame with large head pop rivets.

The insulation blanket which covers the ST was simulated by 6.4 mm thick bubble-type plastic packaging material covered with .05 mm adhesive-backed metalized mylar film. The result was a bright silver specular finish which closely approximated samples of the actual insulation blanket obtained from MSFC engineering personnel.

The berthing pins (Dwg. No. 47t'01, Appendix A) were constructed of stainless steel pipe which was machined on the outside surface to provide the proper 3.81 cm outside diameter and resulted in a wall thickness of 4.6 mm. The supporting brackets were machined from single billets of 6061-T6 aluminum alloy.

A review of design requirements for mounting the berthing pins above the 6 DOF simulator revealed the desirability of constructing an additional structure for this purpose rather than utilizing a dual purpose berthing pin mount as originally proposed. The benefits gained from this approach included: 1) more structural integrity of the flat floor ST mockup, and 2) ease of transfer of the ST mockup from one facility to the other without disassembly. This structure was fabricated at no additional expense to MSFC.

The support stand for the ST mockup underwent several design modifications due to changes in its location on the perimeter of the epoxy flat floor. Early in the design phase it was decided that the
Figure 2.1: SI Mockup installed on Perimeter of Air Bearing Flat Floor
addition of yaw in the support structure was advisable in order to compensate for torsional stresses anticipated during testing with the Teleoperator Motion Base (TOM-B). Likewise, a bearing system was provided to allow the mockup to be lifted vertically (Z axis) as much as 45.7 cm. This feature was provided as a precaution to avoid damage in the event that a + Z command was given the TOM-B after docking had been accomplished.

The stand was mounted to the concrete floor adjacent to the epoxy floor using 3/8-inch lead anchors. Additional tie downs were provided at the rear of the base to assure that the structure did not tip over.

2.2 TASK 2 - MODIFICATION AND INSTALLATION OF MMS MOCKUP

The original contract required the upgrading of the existing wood and foam core mockup of the aft end of the MMS. An on-site inspection of this structure revealed that the mockup had sustained considerable damage over the years due to testing and frequent moves. The decision was therefore made by Essex to build a new mockup at no additional expense to MSFC.

The new mockup was constructed (Figure 2.2 and Appendix B) of a light-weight aluminum frame covered with the same materials used on the ST mockup, resulting in a realistic approximation of the flight laminated insulation blanket. New berthing pins were constructed using drawings of flight equipment as a guide. As a weight-saving measure, these devices were made of aluminum instead of stainless steel. One additional change from the old mockup was to make the new one 30.5 cm long, instead of 61.0 cm, to reduce loading of the Target Motion Simulator mounting base.

2.3 TASK 3 - FABRICATION AND INSTALLATION OF DOCKING DEVICE

2.3.1 Development of Docking Device Design

The original design specified under MSFC contract NAS8-33073 utilized a passive latch/active unlatch design driven by a pair of rotary solenoids. While the design was feasible, it was not deemed optimal and lacked several highly desirable characteristics, including active latching and a method of determining whether or not a target pin was indeed captured. During the initial design phase, a concept was developed which utilized sliding passive latches and motor-driven cams which were of such a geometry as to grasp and retract the berthing pin if it fell within the capture range (Figure 2.3). Back driving of the latch mechanism was avoided through the use of a worm-wheel drive train.

An informal Preliminary Design Review (PDR) was conducted on October 4, 1983 with Frank Vinz, Gobe Vic, Ed Guerin, and Essex.
Figure 2.3: Interim Design of Docking Device
Corporation staff. The result of the PDR was approval of the general design concept with the following provisions:

a. Switches and motor selected for use on the latch would be actual flight models or physically and functionally interchangeable with flight models.

b. Hard latch indication will be via motor output, which requires the motor to survive repeated stalls.

c. Trunnion position plunger should use a small spring for capture indication and a belleville spring for latch indication and preload.

d. Change the soft capture plungers (sliding configuration) to a pivoting cam arrangement in order to reduce overall required capture force.

e. Use bearing bushings made from Kel-F, Vespel, or similar material instead of bronze.

f. The configuration of the latch should accommodate expected thermal deformation of the aft bulkhead of the Space Telescope.

The following actions were taken on the above recommendations.

a. Switches were selected which had the same footprint as those used in flight equipment but were not hermetically sealed. Essex and MSFC engineering personnel agreed that no tangible benefit would be realized from the use of flight qualifiable switches. The drive motor was changed to one which is flight qualifiable switches. The drive motor was changed to one which is flight qualifiable and is a high grade aircraft-type gear motor manufactured by TRW-Globe.

b. The use of motor output to indicate a hard latch condition was included in the new design. It can be monitored either through current drain by the motor or through a switch closure when a preset docking load is reached (see c below). The above motor and gear train configuration was selected so as not to exceed the manufacturers' recommended loads.

c. The trunnion position plunger assembly was redesigned to allow a capture indication with a depressive force of 0.45 kg hard capture. Position plunger completely depressed requires a force of 22.7 kg (Figure 2.4 and dwg. no. 478001-Spring Plunger Assembly, Appendix C).
d. The soft capture plungers were changed to a pivoting cam arrangement as was recommended. This change resulted in a major impact on the geometry of the latch design and necessitated a reconfiguration of the drive train, gear geometry, trunnion position plunger, and location of indicator switches.

e. The recommended use of Kel-F or Vespel bearing material was not followed after consultation with the COR when it was decided that these materials provide little benefit for non-flight mechanisms when compared with more cost-effective materials.

f. The latch configuration was modified slightly to accommodate the expected 2.3 mm thermal deformation of the ST aft end. This value was obtained from MSFC engineering personnel.

2.3.2 Description of Fabricated Docking Device

The mechanical and electrical systems are detailed here to assist in analysis during integration tests and evaluations.

2.3.2.1 Mechanical Description

The final configuration of the docking device (Figure 2.4) utilizes a symmetrical pair of gear-driven cams which rotate through an arc of 60° to fully retract to a position inside the latch housing. The geometry of the latches is such that once a soft capture is made, the berthing pin is within grasp of the concave surface of the pair of cams. The total linear excursion is approximately 1.6 cm. The rotational force of the cams is obtained through a gear train which includes a worm/wheel combination. A separate gear train drives each cam; however, power is provided from a common D.C. gear motor. The reduction ratio of the gearing system (excluding that internal to the motor) is 108.89:1 for each side which, when coupled with the output of the TRW Globe model 5A2313-21 gear motor, gives a theoretical nominal output torque for each cam of 490 Ncm and a theoretical stall torque of 3006 Ncm. With both cams assumed to have equal contact with a berthing pin, this would result in a nominal total docking force of 257.2 N and a limit of 1577.9 N. Because of the trunnion position plunger's opposing force of approximately 222.4 N, this would result in a total theoretical docked force of 1355.5 N. Figure 2.5 illustrates the docking sequence using a berthing pin from the MMS mockup.

An interim design utilized a differential gear assembly which was meant to equalize the rotational force between the two docking cams and also served to slow the rotational velocity of the cams. This design worked; however, positional synchronization of the two cams proved difficult and it was decided that a straight gear drive would be utilized.
2.5a Approach of Berthing Pin

2.5b Berthing Pin Captured

Figure 2.5: Docking Device Capture and Docking Sequence
2.5c Berthing Pin Fully Docked

Figure 2.5c: Docking Device Capture and Docking Surface (cont'd)
2.3.2.2 Electrical Description

The electric drive motor (TRW Globe model 5A2313-21) was designed for use with a 12 VDC power source. Reversal of polarity of the DC voltage results in a reversal of motor direction. Nominal current required (no load condition) is .50 amperes. Rated load (docking) is 1.2 amperes, and fully loaded (stall) is 5.1 amperes. These values were furnished by the manufacturer and may vary as a function of brush drop, field distortion, power supply, wiring, mechanical friction, etc., and should be used as guidelines in the design of control circuitry.

Each docking device is equipped with five micro switches (Figure 2.5 above) which may be wired in one of several control and/or indicator function modes. Provisions are made for the addition of three more switches for redundancy purposes. Two of the switches (S1 and S4) are used for indication purposes while the other three (S2, S3, and S5) serve as limit switches. The switch circuitry and the motor drive circuitry are electrically separated to allow the drive motor to be controlled either through a process control system or through direct limiting by utilizing the switches and diodes in a series configuration.

2.3.3 Proposed Modifications to the Docking Device

Bench testing of the three docking devices resulted in satisfactory performance of the units. No formal stress analysis was performed. It is anticipated that docking loads observed during testing may reveal deficiencies in the strength of certain mechanical components. The design itself can easily be adapted to accept higher loads with minimal impact on the geometry of the mechanism.

Prior to completion of assembly, informal docking simulations were performed using the exterior portions of the docking devices equipped with position plungers mounted on the TOM-B. These tests confirmed the effectiveness of the geometry of the docking devices and mounting structure and served as a partial proof test of the resistance of the assembly to simulated docking loads.

2.4 TASK 4 - IDENTIFICATION OF TEST REQUIREMENTS FOR THE THREE CLAW DOCKING DEVICE

The experimental and laboratory criteria for successful testing of rendezvous and docking using the three claw docking device are outlined below.

2.4.1 Test Requirements Objectives

In order to demonstrate remote docking capabilities with targets like the Multimission Modular Spacecraft and the Hubble Space Telescope, operators will be required to position and orient the Teleoperator Mobility Base with respect to the target and maintain orientation while translating to the target. The docking operation will need to be
carried out under various lighting conditions, video system configurations, closure rates and geometries, and docking hardware concepts. The identification of the types of parameters and the levels of parameters, along with the appropriate dependent measures to be collected, are the objectives of this test requirements section.

2.4.2 Operator Requirements

The test requirements concerning the remote system operators center on the representative nature of the operator pool. The operators should reflect the male and female operator population, have appropriate technical background and experience, be free of psychomotor and visual anomalies, and be adequately rehearsed on remote systems tasks to eliminate effects of learning from research findings. Other requirements include:

- Even mix of male and female subjects,
- Representative anthropometry,
- Visual acuity and stereopsis tested through the Orthorator exam, color vision tested through the Pseudo Isochromatic Plate Tests,
- Psychomotor coordination and skills tested through the Purdue Pegboard Test,
- Translation and rotation hand controller remote system experience which measures baseline variation of less than 5% on fixed performance criteria,
- Familiarity with operations from the Reconfigurable Work Station,
- Familiarity with activation and deactivation of the docking mechanism,
- Prepared operating instructions for all operators,
- Fixed operating periods for task performance for all subjects.

2.4.3 TOM-B Requirements

The test requirements for the motion base are concerned primarily with preparation and calibration of the TOM-B prior to operations to ensure that all of the control variables are fixed and that the unit operates consistent with the design criteria. The test requirements to be met are:

- Preload thruster and air pad air tanks to 3000 psi or another prespecified level below 3000 psi, if required,
Verify activation of each thruster,

Verify and record the on-board electrical power status,

Verify bi-directional motor drives for each motor driven axis,

Verify CTU operations and transmitter/receiver operations,

Verify operation of on-board experimental equipment such as lights, cameras, pan/tilt units, docking devices, etc.,

Verify correct software model and correct physical configuration of plena which reflect the software model.

2.4.4 Target Requirements

The disposition of the targets used during experiments will be test specific in terms of geometry, lighting, docking targets, etc., but the general requirements for every target used will include the following:

- For fixed targets, verify that the target is secured to the target mount and that all bolts, nuts and break away structures are in place. Verify that the target mount is securely attached to the floor or other pedestal.

- For moveable targets, verify that the target is securely mated to the standard mounting plate and that the appropriate counter weights are securely installed. Verify the bi-directional motor drives for each axis requiring motion. For targets mounted on the target motion system, verify that the low pressure air umbilical is properly connected and that the air flow regulator is correctly set.

- Verify that experiment peculiar subsystems are correctly mounted and set. These would include docking targets, docking probes, target geometries and positions, antennas and solar arrays.

- Verify and calibrate any on-board data recording devices.

2.4.5 Environmental Requirements

The condition of the laboratory environment in which experiments are conducted is critical to the validity and reliability of the experimental data. Those variables which require conditioning and recording are:

- Air Flow - all air handling equipment should be turned off to prevent air currents from confounding the experimental findings.
Ambient Lighting - all lighting systems not required as part of the experimental design should be turned off.

Airbearing Epoxy Floor - this should be cleaned with isopropyl alcohol and a clean mop prior to each test run.

Access - the laboratory spaces should be secured and signs posted stating that testing is being conducted and that entry is not permitted. Access to the operator's control room must also be restricted.

Communications - verify the communications network, including experimenters' communications and isolation of the operator's communication during tests.

2.4.6 Data Requirements

For each of the experiments run in the laboratory, the data requirements are the most significant factor to consider. The independent, dependent and control measures must be carefully identified prior to actually running any experiments. The use of these data, in the form of a multivariate statistical analysis, must also be defined prior to data collection. This will assure that the type of data being collected and the analyses are appropriate to one another and will yield useful design or engineering data at the conclusion of the experimental run. The minimal dependent data requirements will be of the form:

- Performance time - time to complete whole and specific part tasks.
- Performance error - deviations from prespecified performance criteria.
- Resources expenditure - the amount of expendable resources used during a particular task.

There are variations on each of these measures such as direction and amplitude of errors, temporal and spatial distributions, etc., which would be appropriate to specific evaluations.
3.0 CONCLUSIONS AND RECOMMENDATIONS

All contract tasks were performed as planned and the contract end items, including three claw docking device, ST mockup and MMS mockup, were delivered and installed in MSFC Building 4619.

This hardware provides the Teleoperator and Robotics Evaluation Facility with the capability to simulate docking with observatory class spacecraft (i.e. ST) and MMS class spacecraft. These two classes of freeflyers represent the majority of spacecraft anticipated in the 1985-2000 timeframe and will likely be the object of the majority of docking studies.

However, neither the ST or MMS mockups have the capability to simulate continuous, controlled 360° roll which the spin stabilized spacecraft will require. To more accurately duplicate the docking tasks for these spacecraft, this roll capability should be developed as preliminary docking studies are performed on the current mockups.
APPENDIX A: Drawings of Space Telescope Mockup
1. Cally

2. OR-2i

3. POOR

4. " ( -2 )

5. OQIL L 7A4oeU

6. D/A.P.

7. Z6

8. AOP

9. TVJ P -

10. & PL.

11. Cj,)

12. ( course)

13. 0/,Q.

14. CSR.

15. Ty,-

16. ALL FILLET'S

17. 2.090 Tyl

18. 7.30 0 I K

19. 4.250 DIA. STK

20. 1.300 DIA.

21. .25 R TIP

22. ALL FILLETS

23. TIP

24. 25
NOTE:
1. REMOVE ALL BURRS & BREAK ALL SHARP EDGES.
2. MAKE FROM CRS PIPE 1.660 O.D. 
   1.238 I.D. (1/4" O.D., 1/8" I.D. SCH 80)
3. MATERIAL: ALUM. ALLOY 6061-T650
4. PRINT ALL EXTERIOR ALUM SURFACES LIMITE.
ORIGINAL DRAWING
OF POOR QUALITY

120° TYP
2.00 TYP
1.00 TYP
2.50 TYP
2.50 TYP

TYP BOTH ENDS

.250 STK TYP
36.00

.38 (.231 DIA.) DRILL THRU
12 NO. 65

FOLDOUT FRAME
ORIGI

CRILL/TH, QU

H.00 Q/G. 5.

3 .001 H. 3 TK

1/23 5TK.

^P^PLDCU'i ^6^ CENTER

S. T) NK vP

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47ri/0Z/` 	 i

SUPPORT

~ S.T. MOCK UP

2 FOLDOUT FRAME
2 FOLDOUT FRAME

SECTION ASSY ~
S.T. MOCKUP
Holes to be transferred from this frame.

- 30° and thru 10 flanges

-3° angle

2 FOLDOUT FRAME
FOLDOUT FRAME

ORIGINAL PAGE IS OF POOR QUALITY

DIMENSIONS ARE IN TOLERANCE ON FRACTIONS

MATERIAL: ALUM.

FINAL PROTECTIVE FINISH: NONE
FOLDOUT FRAME
5.00 DIA.

120° TYP

H (.266 DIA) DRILL THRU 15 HOLES.

6.00 TYP

3.00

8.00 TYP

6.00 TYP

.75 TYP

MOUNTING PLATE

FOLDOUT FRAME
ORIGINAL DRAWING OF POOR QUALITY

.125 STK TYP

4.000 STK.
SQ.

FOLDOUT FRAME
2 FOLDOUT FRAME

\( \frac{1}{4} \) 20 NC SWAGED THREADED INSERT \\
\( \sqrt{B} \ell G. \ TYP \ B \ PL. \)

DIMENSIONS ARE IN INCHES
TOLERANCES ON

DECIMAL
ANGLES

ALUM. ALLOY

SUPPORT ARM

FINAL PROTECTIVE FINISH

SCALE 1:2

UNLESS OTHERWISE SPECIFIED
OF POOR QUALITY

74.00

FOLDOUT HOME

MATERIAL: ALUM.

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ON FRACTIONS ARE ±.0625.

FINAL PROTECTIVE FINISH:
Huntsville Facility
177 b Memorial Parkway
Huntsville, AL 35801

30° TYP

2.000 TYP

.125 STK TYP

FOLDOUT FRAME

Dimensions are in inches

Angles on fractional

Unless otherwise specified

Material: Alum. Alloy

Brace

Scale: 1/2

Contract: 00478

Drawing Number: 478029

Date: 06.20.84

Approved

Drawn by Loughead
APPENDIX B: Drawings of MMS Mockup
FOLDOUT FRAME
FOLDOUT FRAME
1/4-20 UNC-2A TAP THRU 3 HOLES EQ. SPACED ON 5.500 DIA. B.C.

60°

*H(.2660 DIA.) DRILL EQ. SPACED ON 5 C’SINK 82° X .53 DI

FOLDOUT FRAME
1/4-20 UNC-2A Tap Thru 3 Holes
Eq. Spaced On 3.500 Dia. B.C.

*H (.2660 Dia.) Drill Thru 3 Holes
Eq. Spaced On 5.500 Dia. B.C.
C'Sink 82° x .53 Dia. TyR

6.50 Dia.

1.002" Dia.

.500 Stock

NOTE:
UNLESS OTHERWISE SPECIFIED:
1. REMOVE ALL BURRS. BREAK ALL SHARP EDGES .010 MAX.
2. TOLERANCES: .002 .015
XXX .005
XXX .001
3. MATERIAL: ALUMINUM ALLOY 6061-T6
4. FINAL PROTECTIVE FINISH: ANODIZE, DIE BLACK

ESSEX

SCALE: 1/1
DRAWN BY:
APPROVED BY:
DATE: 3/11/28.81
REVISED

MOCKUP ADAPTER PLATE

T.M.S.

DRAWING NUMBER
B10907
APPENDIX C: Drawings of Docking Device
TYP 3PL

TYP 3PL

\( \frac{1}{2} \) (.312 DIA.) DRILL THRU HOLE ON 13.000 DIA. C.

45º TYP 2 PL.

4.00 TYP

.25 TYP

3.75 R. TYP 3PL

3 R. TYP 3PL

16.00 DIA.

7.00 DIA.

2 FOLDOUT FRAME

CENTER SUPPORT CATCH MOUNT
FOLDOUT FRAME
## Foldout Frame

### Parts List

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<td>4-40 UNC RT HD SCREW</td>
<td>BERG</td>
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<td>CENTER SUPPORT</td>
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<td>HOUSING - SPRING PL.</td>
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<td>8</td>
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<td>4-40 UNC SC, HD CAP SCREW</td>
<td>BERG</td>
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<td>SPRING - COMP - CRES</td>
<td>ASSOC. SPRING</td>
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<td>5</td>
<td>20</td>
<td>8518-19.2-0.45</td>
<td>BELLEVILLE SPRING</td>
<td>BEARING ENGINEERS</td>
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<td>SPRING GUIDE</td>
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<td>PISTON</td>
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<td>1</td>
<td>G1-25</td>
<td>RETAINER RING</td>
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<td>1</td>
<td>478006</td>
<td>PLUNGER</td>
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### Notes
- CENTER 5UP'T
- NO UPW6 - SPRING PL.
- SPRING - COIL - CRES
- BEARING ENGINEERS
- RETAINER RING

### Dimensions
- Dimensions are in inches
- Tolerance on fractions 0.0001
- Tolerance on decimals 0.001
- Tolerance on angles ± 1°

### Material
- See P.L.

### Final Protective Finish
- ~

### Parts

- SPRING PLUNGER ASSY
30 .128 DIA. DRILL THRU 4 HOLES.

.875 DIA.

.450 TYP.

.900 TYP.

1.125 TYP.

1.93

2.00

1.12

1.400

FULL

.8

.2

FOLDOUT FRAME

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES, TOLERANCE ON FRACTIONS IS ±.005, ON WHOLE NUMBERS ±.010. MATERIAL: ALUMINUM ALLOY.

FINAL PROTECTIVE FINISH: HARD ANODIZED 0.5 TO 1.5 MIL THICK.
NOTE:
1- REMOVE ALL BURRS & BREAK ALL SHARP EDGES .01-.02 R.
2- ALL FILLETS .03 R.

FULL R. TYP

.250

.266 DIA.

1.000 DIA.

0.03 X 45° 4 PL

2 FOLDOUT FRAME
NOTE:
1. REMOVE ALL BURRS & BREAK ALL SHARP EDGES .01-.02 R.

<table>
<thead>
<tr>
<th>UNLESS OTHERWISE SPECIFIED</th>
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<tr>
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<tr>
<td>TOLERANCE ON FRACTIONS</td>
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<td>DECIMALS</td>
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<td>ANGLES</td>
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<td>MATERIAL</td>
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<tr>
<td>ALUM. ALLOY 6061-T6</td>
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<td>FINAL PROTECTIVE FINISH</td>
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<tr>
<td>HARD ANODIZE .5 TO 1.5 MIL. THICK</td>
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<tr>
<td>SCALE</td>
<td>1-1</td>
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</table>

HUNTSVILLE FACILITY
2222 S. MEMORIAL PARKWAY
HUNTSVILLE, AL 35801

DRAWN BY
LOU SHEPERD

DATE
JAN. 23, 84

APPROVED

CONTRACT
00478

DRAWING NUMBER
478003

Sheet
"41 (0.96 DIA.) DRILL THRU C' SINK 82° x .19 DIA. 2 PL.

FULL R. TYP.
NOTE:
1. REMOVE ALL BURRS & BREAK ALL SHARP EDGES .01-.02 R

FOLDOUT FRAME
FOR LOCKING THREADED INSERT 3585-04CN-0224 (4-40 NC X 2D) OR EQUIV. TYP 6 PL.

NOTE:
1- REMOVE ALL BURRS & BREAK ALL SHARP EDGES .01-.02 R.

CENTER SUPPORT

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
RANGE ON
SECTIONS DECIMALS ANGLES .015 .005 1/2°
LUM. ALLOY 6061-T6

PROTECTIVE FINISH
RED ANODIZE TO 1.5 MIL THK

SHEET OF
NOTE ~
1. REMOVE ALL BURRS & BREAK ALL SHARP EDGES 0.01 - 0.02 R.
NOTE:
1. REMOVE ALL BURRS & BREAK ALL SHARP EDGES .01-.02 R.

PISTON

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ARE IN DEGREES

PROJECT FINISH
ED ANODIZE
0.5 MIL THK

SCALE
1-1

ESSEX
HUNTSVILLE FACILITY
3330 S. MEMORIAL PARKWAY
HUNTSVILLE, AL 35801

DRAWN BY
LOUGHEAD

DATE
JAN. 23 - '84

APPROVED

CONTRACT
00478

DRAWING NUMBER
478007

SHEET    OF
ORIGINAL PART IS OF POOR QUALITY

30 (.128 DIA.) DRILL THRU 2 HOLES.

.500 STK

11½° R

FOLDOUT FRAME

MATERIAL
ALUM. ALL

FINAL PROTECTIVE FINISH
ALODYNE
Drill & Tap for Locking Threaded Insert - Helicoil No 3578-04CN-0168 (.4-40UNC x .50) or equiv.

Note:
1. Remove all burrs & break all sharp edges .01 - .02 R.
2. All fillets .06 R.

Foldout Frame

Bracket

Unless otherwise specified, all dimensions are in inches.

Alloy 6061-T6

Effective Finish: Dyne

Scale: 1/1
Foldout frame

Material: Alum. Allo

Final protective finish: Alodyne
H (.096 DIA.) DRILL THRU 'SINK 82° X .18 DIA. - 2 PL.

#25 (.149 DIA.) DRILL THRU 12 HOLES.

NOTE —
1. REMOVE ALL BURRS & BREAK ALL SHARP EDGES .01 -.02 R.

NOTE —
2. FOLDOUT FRAME

DRAWN BY
S. MEMORIAL PARKWAY
HUNTSVILLE, AL. 35801

APPROVED

CONTRACT
00478

DRAWING NUMBER
478009

UNLESS OTHERWISE SPECIFIED

ALL DIMENSIONS ARE IN INCHES

ANGLES ON TABLES

DECIMALS

ANGLES

.015

.005

M. ALLOY 6061-T6

PROTECTIVE FINISH

ODYNE

SCALE

1-1

NOTE —

SWITCH MOUNTING PLATE
ORIGINAL PAGE 19 OF POOR QUALITY

.06 BLENDR. TYP BOTH SIDES

.500 DIA. THRU

.499 DIA. THRU

.06 R. TYP. 3 PL.

.160 R.

.110 R.

.550 1.63 R.

.750 DIA. STK.

.04

.04

.50 R.

.50 R.

.75 R.

.250 STK.

.625 STK

105°

80°

22°

102°

.301 .128 DIA.) DRIL THRU 2 HOLES

FOLDOUT FRAME

UNLESS OTW

DIMENSIONS ARE IN INCHES

TOLERANCE ON FRACTIONS .002

MATERIAL 3

FINAL PROTECTIVE FIN
NOTE:
1. REMOVE ALL BURRS & BREAK ALL SHARP EDGES .01 - .02 R.
2. ALL FILLETS .09 R.
3. MAKE FROM BERG GEAR NO. P20S 33-70
4. PN 478011-1 SHOWN 478011-2 OPPOSITE

CAM-LATCH

ESSEX

HUNTSVILLE FACILITY
3332 S. MEMORIAL PARKWAY
HUNTSVILLE, AL 35801

DRAWN BY
LOUGHEAD

DATE
FEB 3-84

APPROVED

CONTRACT
00478

DRAWING NUMBER
478011

UNLESS OTHERWISE SPECIFIED

DIMENSIONS ARE IN INCHES

DECIMALS

ANGLES

.015

.005

1/2°

303 CRESCENT

PROTECTIVE FINISH

SCALE

1-1

FOLDOUT FRAME
DRILL & TAP THRU FOR LOCKING THREADED INSERT - HELICOIL NO. 3585-04CN-0280 (N° 4-40NC X 2.5D) OR EQUIV.

NOTE-
1. REMOVE ALL BURRS & BREAK ALL SHARP EDGES .01-.02 R.

FOLDOUT FRAME
FOLDOUT FRAME

QUALITY

OF POOR QUALITY

2 PL.
<table>
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<tr>
<th>QTY</th>
<th>CAT. NO.</th>
<th>DESCRIPTION</th>
<th>MFG.</th>
<th>NOTE</th>
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<tr>
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<td>CAM-SWITCH</td>
<td>BERG</td>
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<td>2</td>
<td>87-42</td>
<td>BUSHING</td>
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<td>2</td>
<td>Y9-54.AB</td>
<td>SCREW-SCREW CAP</td>
<td>BERG</td>
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<td>1</td>
<td>478011</td>
<td>CAM-LATCH</td>
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**Parts List**

**Dimensions are in inches**

- Tolerances: ±0.005
d- Decimals: 2

**Material**

SEE P.L.

**Final Protective Finish**

- SCALE 1-1

**Original Page is of Poor Quality**

---

- SHOWN
- OPPOSITE

**Foldout Flange**
1. Press fit 1 on 2 (0.0010 to 0.0015 interference).
2. Remove all burrs & break all sharp edges.

<table>
<thead>
<tr>
<th>QTY</th>
<th>CAT #</th>
<th>DESCRIPTION</th>
<th>NOTE</th>
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<tr>
<td>1</td>
<td>W16B35-30</td>
<td>WHEEL (WORM)</td>
<td>BER6</td>
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<tr>
<td>1</td>
<td>P20533-30</td>
<td>GEAR</td>
<td>BER6</td>
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### Parts List

- **ESSEX**
  - **Huntsville Facility**: 3333 S. Memorial Parkway
  - **Huntsville, AL 35801**
  - **Drawn By**: 4/11/84
  - **Approved**: 2-5
  - **Contract**: 05472
  - **Drawing Number**: 478016
  - **Scale**: 1:1

---

**Note:**

- GEAR ASSY
- 2 Foldout Frame
DRILL & TAP THRU FOR LOCKING THREADED INSERT - 32NC (HELICOIL #2)

-1 SHOWN
-2 OPPOSITE

FOLDOUT FRAME
TAP THRU FOR LOCKING THREADED 2-40 NC (HELICOIL N°)

DRILL & TAP THRU FOR LOCKING THREADED INSERT ~ 10-32 NF (HELICOIL N°)

NOTE:
1. REMOVE ALL BURRS & BREAK ALL SHARP EDGES .01-.02E.

ORIGINAL PAGE OF POOR QUALITY

2 FOLDOUT FRAME

DIMENSIONS ARE IN INCHES
TOLERANCES ON FRACTIONS • DECIMALS • ANGLES

- XX2 .015
- XXS .005

MATERIAL: ALUM ALLOY 6061-T6

UNLESS OTHERWISE SPECIFIED

HUNTSVILLE FACILITY
25 S. MEMORIAL PARKWAY
HUNTSVILLE, AL 35801

SLIDER

DRAWN BY
LOUGHEAD

DATE
APRIL 06

APPROVED
2-7-08

CONTRACT
00478

DRAWING NUMBER
478017

SHEET OF
FOLDOUT FRAME

UNLESS OTHERWISE
DIMENSIONS ARE IN INCHES
TOLERANCES ON FRACTIONS DECIMALS

MATERIAL
ALUM A

FINAL PROTECTIVE FINISH
CLEAR ANODIZE

.38 x 45°-2 PL

ORIGINAL PAGE IS OF POOR QUALITY

Nº 30 (.128 DIA.) HOLE

1.069
1.064 DIA.

1.70
1.000

.500
1.000

1.442
1.437
1.442
1.437
1.750
3.50

.376
.375 DIA. T.

.550
.75

.500
2.500
28 DIA.) DRILL THRU

0.069
0.054 DIA. THRU

.250

.12R.

.12

DIAM. THRU 2 PL.

NOTE ~
1- REMOVE ALL BURRS & BREAK ALL SHARP EDGES .01-.02 R.

DRAWN By

DATE

CONTRACT

DRAWING NUMBER

MOTOR MOUNT

ESSEX

HUNTSVILLE FACILITY
3229 S. MEMORIAL PARKWAY
HUNTSVILLE, AL 35801

MATERIAL

ALUM.Alloy 6061-

PROTECTIVE FINISH

LEAD ANODIZE

SHEET OF
ORIGINAL PAGE IS OF POOR QUALITY

DIMENSIONS ARE IN INCHES
TOLERANCE ON FRACTIONS IS ±

MATERIAL
ALUM.
6061-

FINAL PROTECTIVE FINISH
CL. AND
Brackets

25 (.149 Dia.) Drill Thru Holes

- .375 Dia. Thru 2 Pl.

- .12 E.

- .250

Note:
- Remove All Burrs & Break All Sharp Edges .01-.02

Original Page 13

Of Poor Quality
FOLDOUT FRAME

FULL R. TYP.

1.000 STK.

.50

.125

.450

.160

2 PL

2.12

.06 R. MAX.

4 PL.

.500

1.000 STK

.375

1.375

\( \frac{3}{8} (.156 \text{ DIA.}) \) DR 2 HOLES.

ORIGINAL PAGE IS OF POOR QUALITY
NOTE:
1. REMOVE ALL BURRS & BREAK ALL SHARP EDGES. 0.01-.02 R.

DIA.) DRILL THRU.
NOTE:
1. REMOVE ALL BURRS / BREAK ALL SHARP EDGES .01-.02 E.
2. RH 478021-1 SHOWN
   LH 478021-2 OPPOSITE

2 FOLDOUT FRAME
3/32 (.156 Dia.) Drill 7 Holes.

UNLESS OTHERWISE
DIMENSIONS ARE IN INCH
TOLERANCES ON
FRACTIONS 1/64

MATERIAL
ALUM AL

FINAL PROTECTIVE FINISH
CLEAR AN
DRILL THRU

- .55
- .75

.060 STK

2 FOLDOUT FRAME
.3749 DIA.
STK

1.500
STK

FOLDOUT FRAME
NOTE:
1. REMOVE ALL BURRS & BREAK ALL SHARP EDGES .01-.02 R

$ \triangle $ MAKE FROM BERG P/N D21-16.

$ \triangle $ FOLDOUT FRAME

#8-32 NC TAP x .38 DP
NOTE:
1. REMOVE ALL BURRS & BREAK ALL SHARP EDGES.

SHOULDER SCREW (MOD.)
2 (.189 DIA.) DRILL THRU
4-40NC TAP THRU

.12 x 45°

-.06

.490

1.120

.250 STK.

NOTE:
1. REMOVE ALL BURRS & BREAK ALL SHARP EDGES .01-.02 R.

FOLDOUT FRAME