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APOLLO-SOYUZ TEST PROJECT DOCKING SYSTEM

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ABSTRACT

The United States and Soviet Union in July 1975 successfully completed a joint space mission utilizing each country's spacecraft and the compatible docking system designed and fabricated by each country.

This paper describes the compatible docking system and defines the extensive research, development, and testing leading up to the successful mission. It also describes the formulation and implementation of methods for breaking the language barrier, bridging the extensive distances for communication and travel, and adjusting to each country's different culture during the three-year development program.

INTRODUCTION

In the latter part of 1971, the United States and Soviet Union agreed to a joint space mission utilizing each country's spacecraft and a compatible docking system. This mission, called the Apollo-Soyuz Test Project (ASTP), was successfully conducted as planned in July 1975. The mission profile is shown in Figure 1. Hardware used in the mission is shown in Figure 2.

Docking system design, development, and test were governed not only by the Apollo philosophy but also the interface requirements generated jointly by the United States and the Soviet Union.

OBJECTIVES

The docking system for this mission provided for all facets of the mechanical docking between Apollo and Soyuz. Specific objectives were:

- Attenuate the forces caused by impact in docking the vehicles.
- Make the primary mechanical linkup (capture).
- Limit vehicle rotational excursions.
- Control vehicle misalignments before retraction.
- Draw the docking structural rings together (retraction).
- Structurally connect and seal the docking interface.
- Provide a clear passageway for intervehicular transfer without removing any part of the docking system.
- Abort and separate the vehicles at any stage of the docking operation.
- Provide capability for immediate emergency undocking and release.
- Provide repeated docking and undocking capability.
- Perform docking and undocking functions without the active aid of the other space vehicle.

DEVELOPMENT AND TEST

Basic philosophy for development and test of the system was joint testing for any facet affecting the interface (i.e., docking dynamics) and individual country testing for noninterface

aspects of the program (e.g., launch environments). This philosophy generated the joint test program outlined below.

Two-Fifths-Scale Model

In addition to full-scale hardware for test and flight, a two-fifths scale model was fabricated to demonstrate the general concept of the docking system and to conduct joint dynamic tests and verification of interface compatibility with a similar scale model fabricated by the Soviet Union. This joint series of tests was conducted in Moscow.

Interface Seal

Interface seal testing initiated the joint full-scale hardware test series and established working methods and procedures for personnel, procedures for handling test hardware, and procedures for test conduct and documentation. This series evaluated several seal configurations and various shore hardness values. It considered seal capability at maximum misalignments, temperature extremes, and pressure variations. It further considered a gap between the metal interfaces. This test series was conducted at Rockwell International's Space Division headquarters in Downey, California.

Dynamic Testing

Six-degree-of-freedom dynamic tests were conducted with both development and qualification hardware to demonstrate satisfactory performance during docking operations. This testing utilized a dynamic simulator, which combined a computer and a relative-motion simulator, and exercised the docking system in specified dynamic modes to simulate actual space docking. High- and low-temperature docking system environments were provided during test. This test series was conducted at NASA's Johnson Space Center (JSC), Houston, Texas, on the Dynamic Docking Test System (DDTS). Verification of final hard docking dynamics (i.e., that phase from alignment pin/socket engagement through structural latch closure) was conducted on a simulator at the Space Division.

Mate Tests

Mate tests were conducted on the systems to demonstrate and verify final structural integrity and interface compatibility between the docking interfaces and provide capability for emergency undocking and release. This test series, involving both development and qualification hardware, was conducted at NASA JSC. A typical test setup is shown by Figure 3.

Preflight Mate Check

Preflight mate check tests were conducted to demonstrate satisfactory operation and interface compatibility of the two mating systems that were to dock in space. For this, the prime flight unit from each country was tested in conjunction with the prime flight unit and backup unit from the other country. For this test, both docking and undocking sequences were simulated. This test series was conducted in Moscow.

Test programs conducted by the U.S. on U.S. hardware for purposes of qualification were as follows (system-level tests only):

- Development environmental
- Development dynamic
- Qualification dynamic
- Qualification environmental

As may be expected, precedents were necessary because joint test programs had not been required in the aerospace industry prior to this time. The basic test philosophy used in the Apollo program was to be maintained; likewise, Soviet Union philosophy was not to be breached. This

naturally required mutual test conduct agreements which were defined during various working group meetings.

INTERFACE REQUIREMENTS

Soviet Union and United States personnel early in the program defined a clear method for control of all interfaces through documents entitled Interacting Equipment Documents (IED's). In essence, U.S. and USSR working-level groups met on a regular basis to develop, review, and concur on technical aspects of the project. Specific agreements and hardware interfaces were defined on the IED's which were prepared in both languages and in the metric system. Although interface configuration was jointly established, each country independently developed and designed hardware to satisfy these interface requirements. This naturally evolved to two distinctly different sets of hardware, as shown by Figures 4 and 5.

Joint interfaces were relatively straightforward on dimensional and load aspects but required additional coordination on technical terms not common to each country (e.g., dry lubricant and surface finish). An example of an IED prepared to define the structural latches is shown by Figure 6. Note that representatives from both countries verified both technical content and translation.

The English/Russian language differences did not produce any significant problem, although problems had originally been anticipated. The language difference did force each country to be totally objective in requirements, totally prepared prior to any technical discussions, and provided extreme incentive for making certain language was not a barrier in conduct of business. Although U.S. and USSR personnel attended classes in Russian and English, respectively, there was no attempt to rely on this training in conduct of technical meetings/reviews. For this, a technical interpreter was present and meeting minutes, as well as presented technical material, were in both languages.

SYSTEM DESCRIPTION AND OPERATION

The U.S. docking system for the ASTP is a self-contained unit mechanically attached to the docking module, which, in turn, is attached to the command and service modules. This is as shown by Figures 2 and 4. The Soviets attach their docking system to the orbital module at the end opposite the descent vehicle, as shown by Figures 2 and 5.

The docking system chosen for this mission was an androgynous system (i.e., any unit may be mated with any other unit of same or compatible design). Basic system design also dictated that each country's docking system have the capability of assuming active operational control.

The docking system is best described by the nomenclature of Figure 4 and the following sequence of docking operations (each component or subsystem is defined in greater detail later):

1. Guide ring is extended on the active docking system (as shown by Figure 4 and the upper system of the Figure 3 photograph) to provide impact attenuation upon initial contact with the passive vehicle. At this time, the passive docking system guide ring is in the retracted position (as shown by the lower system of the Figure 3 photograph).
2. Upon guide ring contact, the three capture latches (mounted on the active system guide ring) engage the passive system body-mounted latches. (This is defined as soft dock.) Impact energy is dissipated by the six hydraulic attenuators.
3. Following capture, the guide ring assembly of the active docking system is retracted until the structural mating surfaces of both docking systems meet.

4. The eight structural latch active hooks of the active docking system are then engaged with the passive hooks of the passive system. (This is defined as hard dock.)
5. During final phase of guide ring retraction, alignment is provided by engagement of alignment pins and sockets mounted on each structural ring.
6. The mating surfaces of each spacecraft's structural ring have two concentric seals which, compressed on each other during final retraction and structural latch engagement, are to provide a pressure seal to the tunnel area when it is pressurized.
7. The indicating system provides a continual status of the operation during actual usage. It defines position of guide ring, guide ring contact, structural ring contact, and gearbox readouts.

The undocking sequence normally is provided by the active docking system releasing the eight structural latch active hooks and then releasing the three capture latches. Spring thrusters mounted in the structure provide force to assure undocking with a positive separation force.

In an emergency, undocking may also be accomplished by either the active system disengaging by a redundant system or the passive system disengaging its passive structural latch hooks and its body latch hooks.

COMPONENT DESCRIPTION

The U.S. docking system consists of subsystems performing all sequences of docking and undocking as described below.

Base Structure

The docking system utilizes a basic structure on which all components are mounted. This structure, in turn, attaches to the docking module by an annular series of fasteners. To obtain maximum strength properties using conventional materials, a roll forging of 7075 aluminum alloy was utilized to produce a circular grain flow pattern. The machined forging size is approximately 1530 mm (60 inches) outer diameter, 760 mm (30 inches) inner diameter, and 510 mm (20 inches) wide. Initial temper is T411; final temper immediately prior to final machining is T73 with intermediate heat treatments to preclude warpage and maintain critical surface flatness requirements at sealing surfaces. All components attach to this structure by Slimsert inserts.

Guide Rings

This structure provides three equally spaced guides designed for aligning the mating systems in lateral and angular direction. These guides are set at a 45-degree angle slightly tapered at the tip. Construction is of an aluminum ring, machined from a roll forging, with mechanically attached guides.

Capture Latch

Each of the three capture latches (Figure 7) is mounted flush with the guide surface with two protruding hooks (with roller surfaces) for engagement with the mating body latches. Each capture latch has redundant mechanisms and redundant electrical linear solenoid release actuators. A unique feature is vector sensitivity to allow automatic release of a single latch in the event all three latches in the system are not engaged. Release of a capture latch is provided by two independently operated linear solenoids mechanically linked so that either of the two solenoids releases both hooks. Load

capability for each latch (single hook) is 600 kilograms (1320 pounds) in the vertical direction. To prevent engagement of all six capture latch/body latch combinations at any docking, the guide ring assembly (hence the capture latches) on the passive system is drawn down beyond the engagement reach of the body latches.

Structural Latches

Structural latches, providing final latching between the two systems, are shown in Figure 8. Each latch, in turn, has an active hook, mating and locking with the passive hook of the passive system, and a passive hook, remaining inactive (hence not locking) on the active system. All latches are interconnected by a corrosion-resistant steel, impregnated with solid dry film lubricant, cable system. Structural latch power to lock and provide interface preload as well as to unlock latches for separation is provided by an electric motor drive (described later). An emergency release system is provided to release the eight passive hooks. These structural hooks are also interconnected by an independent cable system powered by the electric motor drive.

Retract and Attenuation Systems

Early design and development trade-off studies indicated that the most feasible method for design of both attenuation and retraction was to handle each in separate systems rather than as one mechanism for both purposes. This evolved to a concept of: (1) six independent hydraulic attenuators for guide ring extension and to attenuate the impact of the spacecraft during initial contact; (2) a steel cable for retraction of the guide ring, as shown in Figure 9; and (3) guide ring extension via internal springs within each attenuator. Six attenuators are mounted in pairs beneath each guide.

Cables, similar to those used on the structural latches, attach at the guide ring via load bungees configured to compensate for different cable lengths and to a base-mounted actuator drum. This system is driven by an electric motor drive.

Body-Mounted Latches

Each of the three body-mounted latches (Figure 7) mounted on the base structure consists of a single hook operated by redundant rotary solenoid release actuators. Body-mounted latches are normally static devices unlatched only in the event of backup release. Maximum load capability is 600 kilograms (1320 pounds) in the vertical direction.

Electrical Indication Systems

These systems provide the necessary power and control for actuators, solenoids, and operation of the indication/sensing systems. System power is from redundant 28-volt dc; indicator power is from redundant 5-volt dc systems hardwired from the command module. The indication system's 32 status switches provide talk-back for all operations for continued crew and system monitoring.

A unique electrical load sensing cell was used to indicate interface preload during structural latch engagement. These cells, approximately 25 mm (1 inch) by 76 mm (3 inches) by 6 mm (1/4 inch) thick, are sandwiched between each latch and structure and hardwired back to the command module.

Actuators

The three electrical motor drive actuators provide power for structural latches and guide ring retract. Each has redundant electric motors and a gear train reduction assembly, including integral brake and full differential, so that with one motor inoperative, the actuator output is the same and operation time is doubled. In addition, each actuator has drive capability in both directions. Output requirements are:

1. Guide ring retract: 1950 kilograms (4300 pounds)
2. Structural latch active drive hook: 1361 kilograms (3000 pounds)
3. Structural latch backup drive: 234 kilograms (515 pounds)

Interface Seals

Two concentric interface seals mating with two seals on the mating system provide pressure integrity within the transfer tunnel region. These seals of silicon material are shown in Figure 10.

Thermal Control System

Considerable analyses were required for a thermal control system that would be totally passive. These analyses resulted in special surface exterior finishes and coatings as well as bagged-beta insulation on the tunnel interior for adequate crew interface temperature. Exterior coatings are:

- Attenuators
 - 260-degree segment facing outward to space
 - Electroless nickel, $\alpha_g/\epsilon = 0.37/0.15 = 2.5$
 - 100-degree segment facing base assembly
 - Gray polyurethane, $\alpha_g/\epsilon = 0.84/0.92 = 0.9$
- Guides (backsides)
 - Two guides facing cold side
 - Finch paint $\alpha_g/\epsilon = 0.35/0.35 = 1.0$
 - Guide toward CM
 - Black polyurethane to preclude glare (not thermal requirement)
- Capture latch sides
 - Finch paint $\alpha_g/\epsilon = 0.35/0.35 = 1.0$
- All remaining component surfaces: no special coatings required

CONCLUSIONS

Actual flight performance of the docking system on each spacecraft was normal. During the flight, two dockings and two undockings were conducted—first with the Apollo operating as the active system and second with the Soyuz as the active system. The docking systems of Apollo and Soyuz performed perfectly during all phases of docking and undocking operations.

Joint documentation developed during the preflight period proved adequate for resolving all problems in preparing and conducting the mission. In addition, working group disciplines adapted for joint operations proved successful.

With proper management, documentation, and program control, docking hardware may be fabricated individually by two foreign nations for a joint space venture.

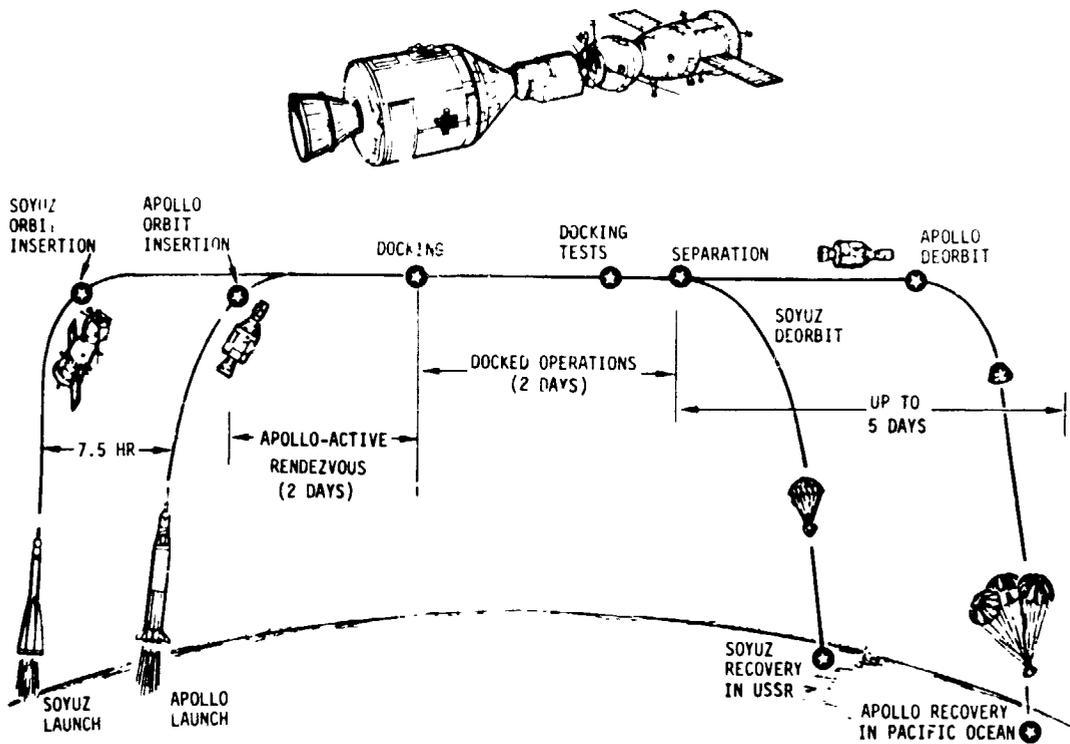


Figure 1. Basic Mission Profile

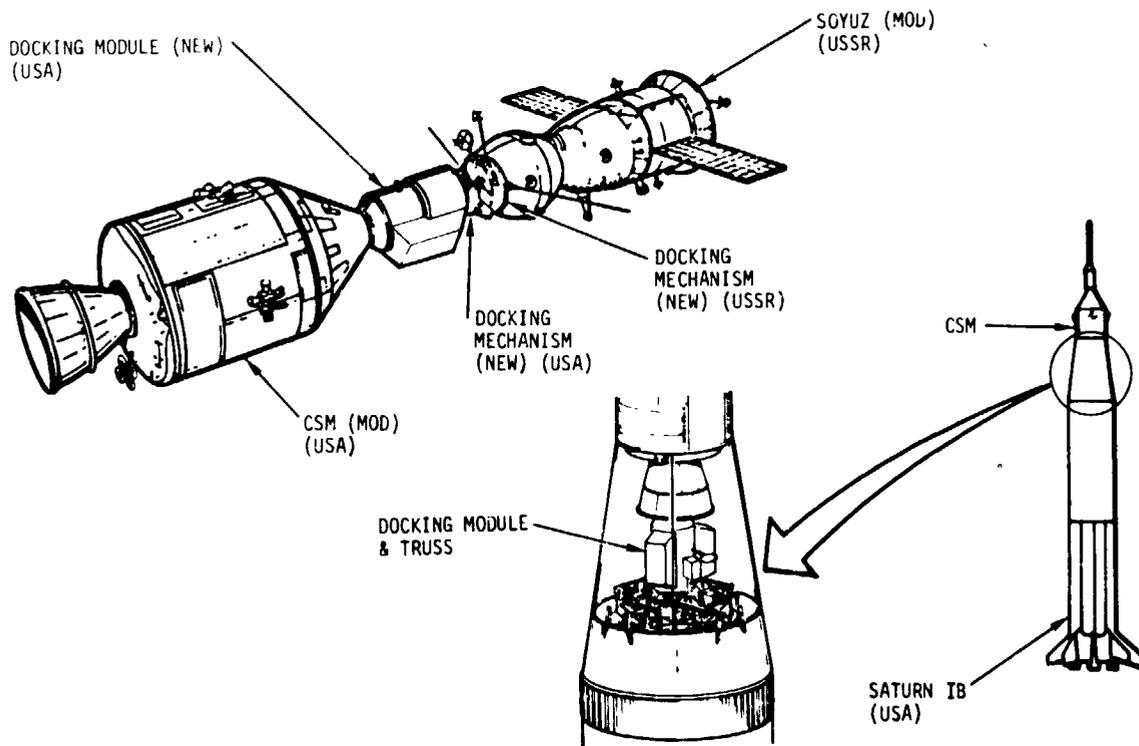


Figure 2. ASTP Major Hardware

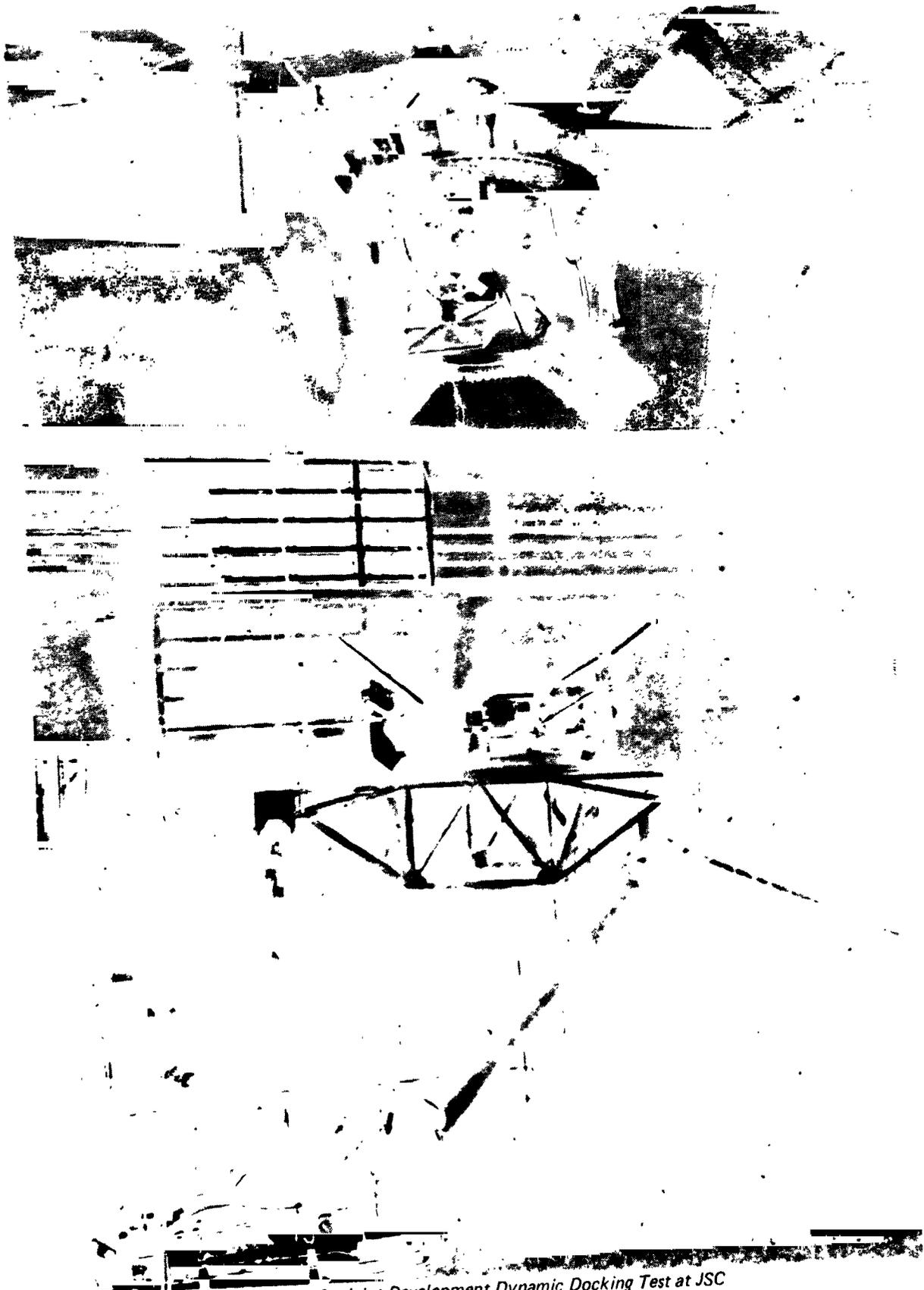


Figure 3. Joint Development Dynamic Docking Test at JSC

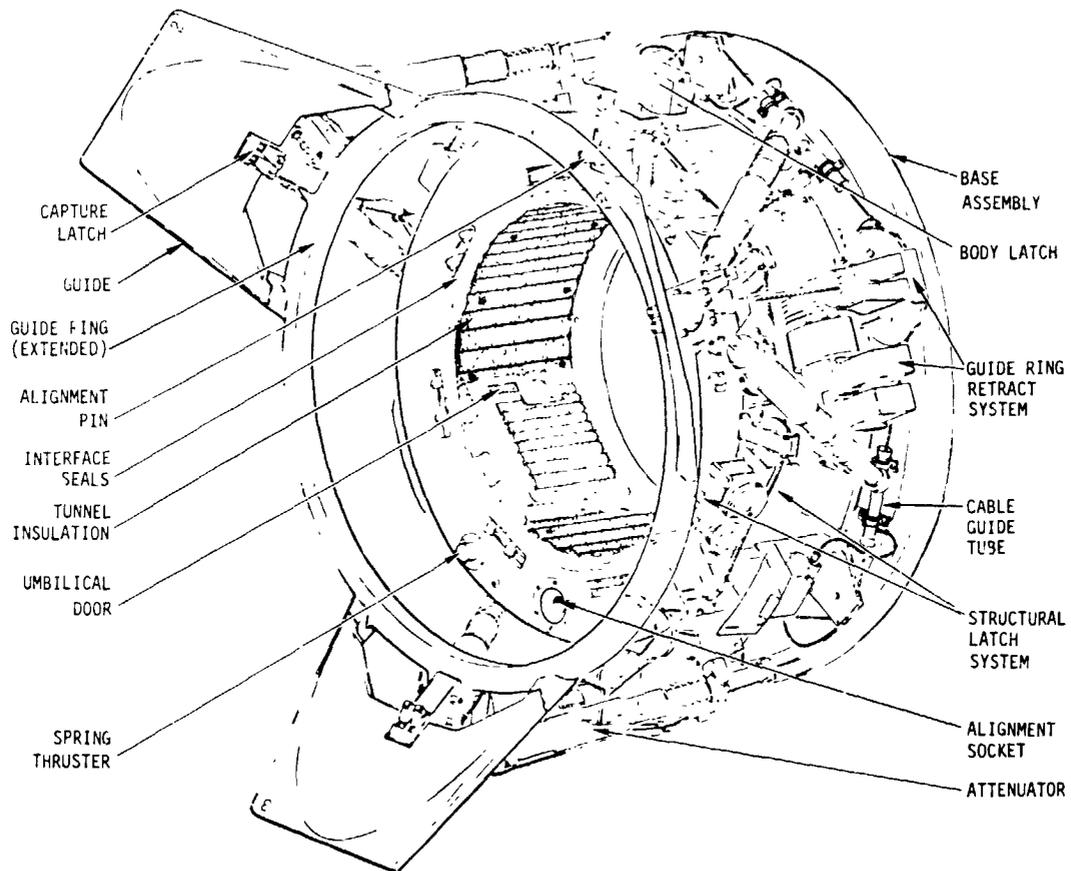


Figure 4. U.S.A. Docking System

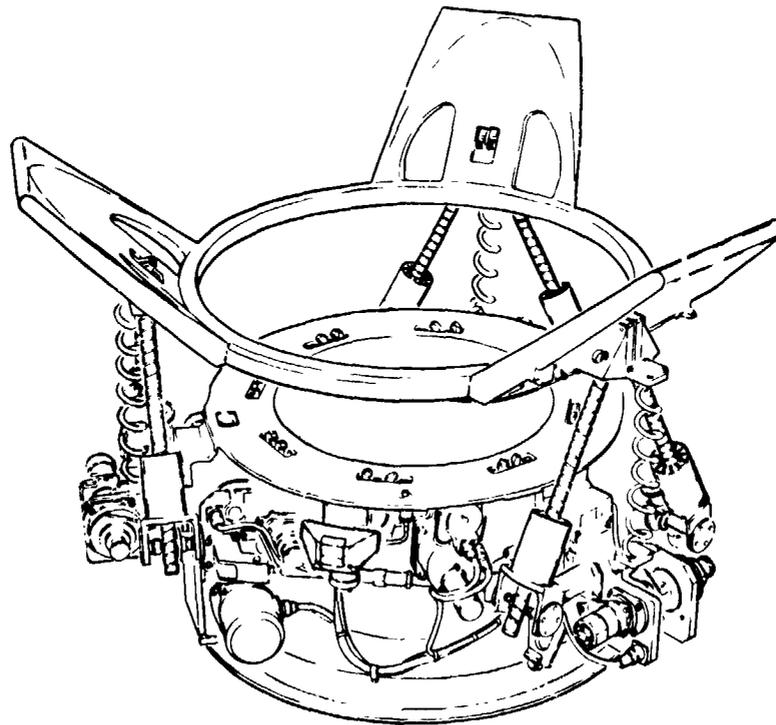
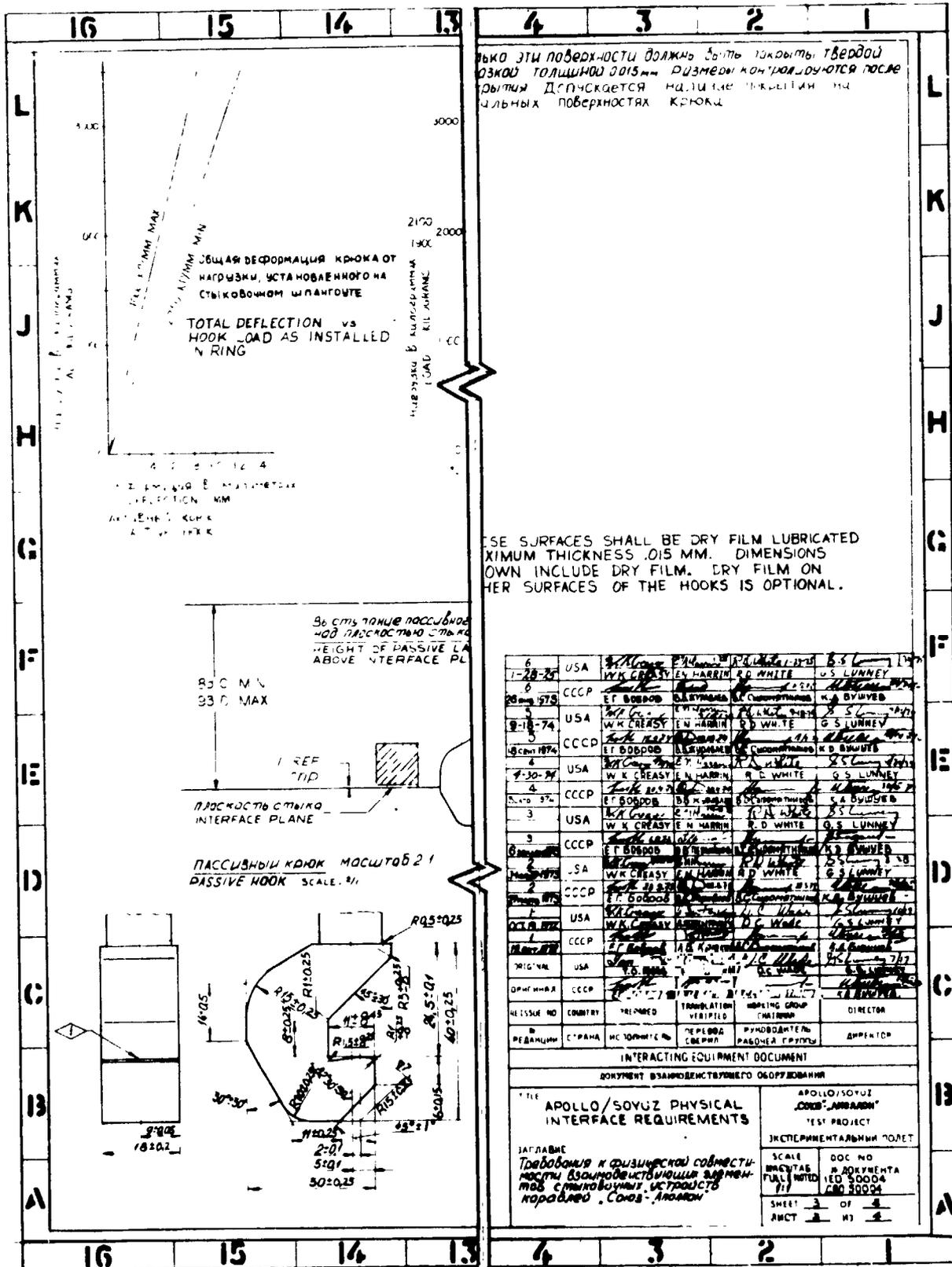
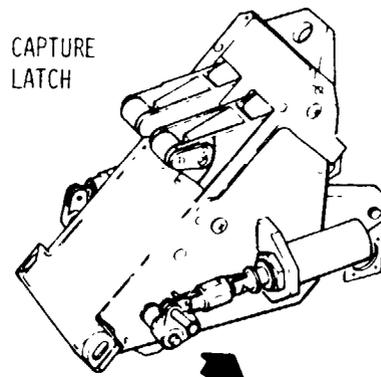


Figure 5. USSR Docking System



- CAPTURE LATCH
 - TWO HOOKS, TWO SOLENOID RELEASE ACTUATORS
 - MAX LOAD 1320 LB



- BODY-MOUNTED LATCH
 - SINGLE HOOK, TWO SOLENOID RELEASE ACTUATORS
 - USED FOR BACKUP RELEASE
 - MAX LOAD 1320 LB

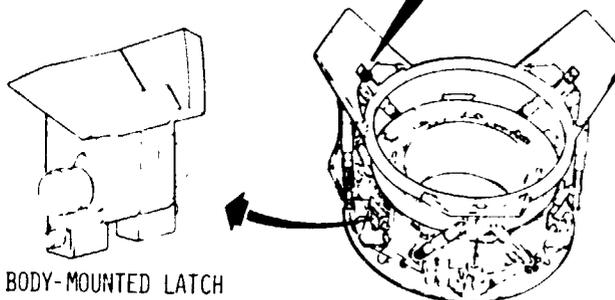


Figure 7. Docking System Capture/Body Latches

- EIGHT LATCH ASSEMBLIES EACH INCLUDES PASSIVE & ACTIVE HOOKS
- ACTIVE HOOK OF ACTIVE SYSTEM MATES WITH PASSIVE HOOK OF PASSIVE SYSTEM
- INTERFACE LOAD/HOOK COMBINATION = 4370 LB MIN, 7374 LB MAX
- OVER-CENTER LATCHING

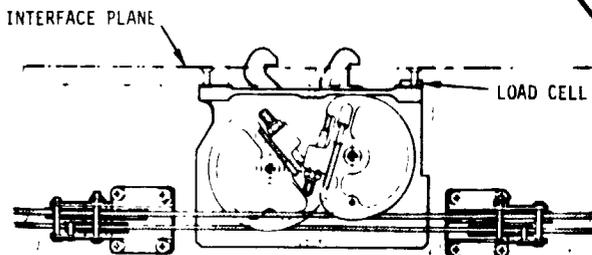
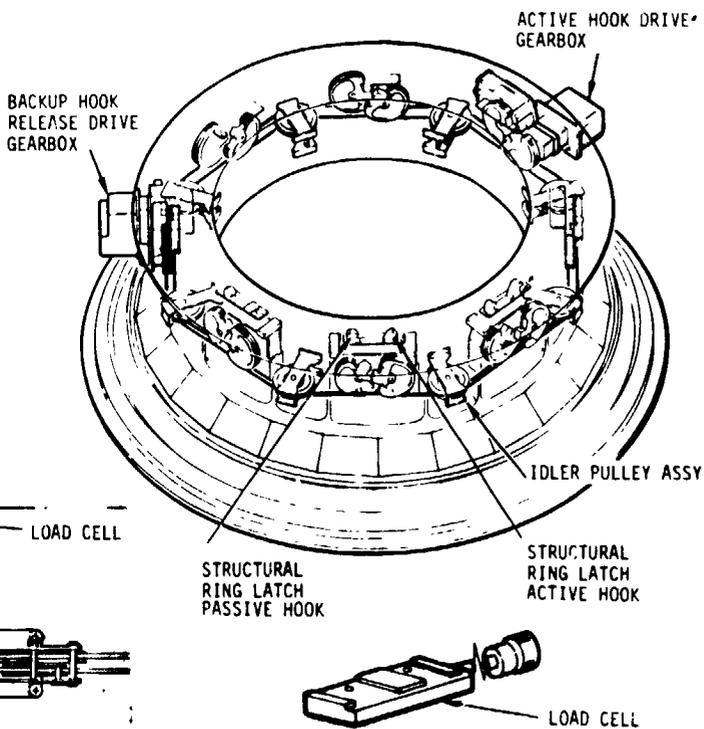


Figure 8. Docking System Structural Ring Latch

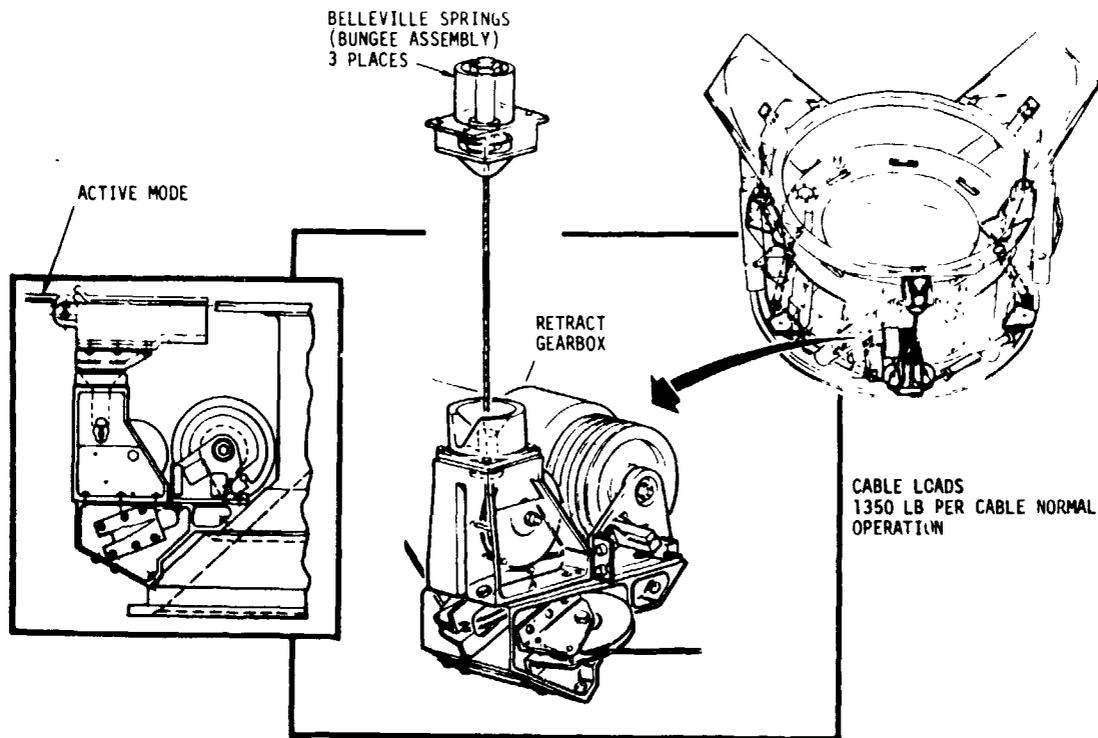


Figure 9. Docking System Guide Ring Retract System

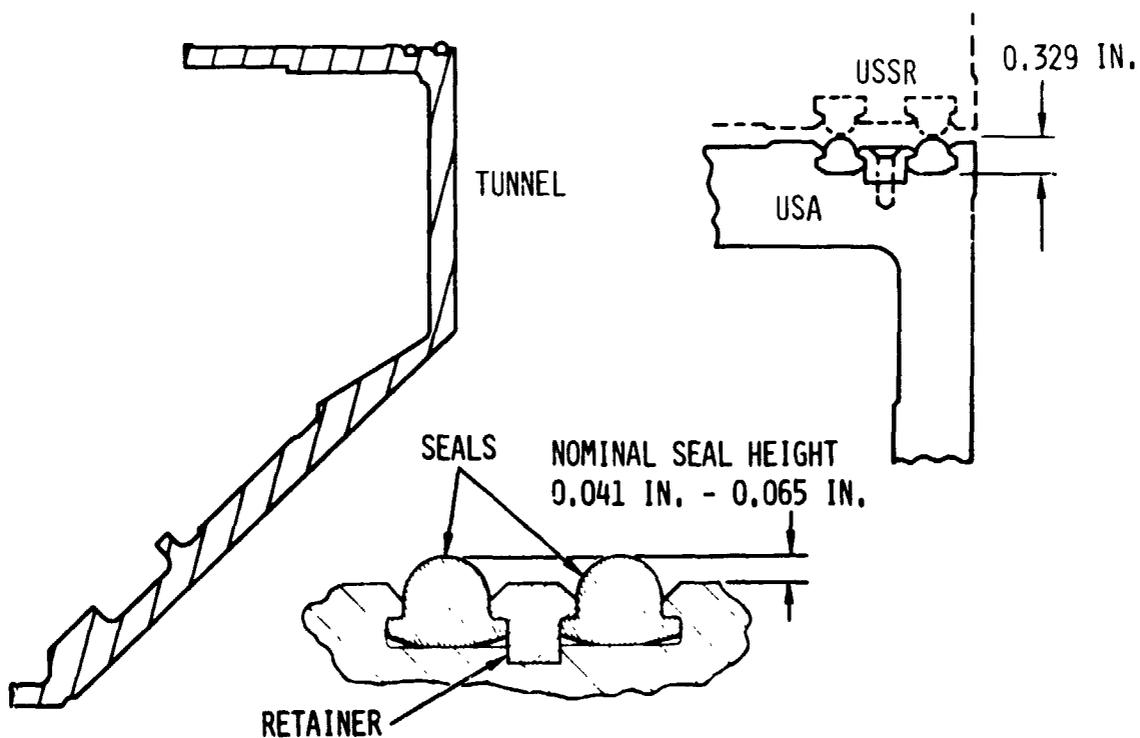


Figure 10. Diagram of Docking System Interface Seals