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Orbital Docking System Centerline Color Television Camera System Test

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Summary

In June of 1995, during STS-71, the Space Shuttle will dock with the Russian Space Station Mir. At the Preliminary Design Review (PDR) for the Shuttle external airlock and docking adapter, the question was raised of whether or not the view of the Mir docking target through the centerline camera would be adequate for the crew to perform the docking. Concerns were expressed specifically on the resolution of the hatch window, the camera system, and the overall lighting levels.

A test was conducted in June 1993 to verify that the proposed design was adequate. The test used the Full Fuselage Trainer (FFT) at JSC to simulate the Orbiter. The FFT was outfitted with a volumetric mockup of the external airlock and docking adapter. A Mir mockup was also built which consisted of a Mir hatch, docking mechanism, and docking target.

Thirty tests were run simulating various lighting conditions. Each test run consisted of lowering the Mir from a distance of about 20 feet above the Orbiter docking adapter to near contact with the Orbiter adapter. After each test run, questionnaires were completed by test subjects who had experience in rendezvous and proximity operations.

The results of the tests indicate that the proposed design will provide adequate visibility through the centerline camera to perform a successful docking. Included in this report are the details of the configuration, the test conditions, test methods, and the conclusions and recommendations.

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Section 1
Introduction

As a result of the Orbiter Docking System (ODS) Preliminary Design Review (PDR), a test was requested by the Johnson Space Center (JSC) Orbiter and GFE Projects Office to verify that the design of the centerline Color Television Camera (CTVC) system is adequate optically for the STS-71 docking mission with the Mir Space Station. A series of verification tests was run, giving primary consideration to anything which affected the view through the camera, including lighting, hatch window, camera alignment crosshairs, cameras and monitors, items mounted in the field of view, and docking target. The tests were intended to verify only that the design is optically acceptable; no attempts were made to verify the design of the camera mounting system or the centerline camera concept. Because of the STS-71 unique camera and lighting configuration, any extrapolation of the data presented here to other docking missions, or to future variations of the design for this mission, may not be valid.

Specific test objectives were to

a. Verify that the resolution of the docking target and visual alignment system are adequate as displayed on the monitor

b. Verify that the field of view through the 4-inch hatch window is adequate

c. Verify that placement of the lights is adequate with respect to overall lighting levels, shadowing, or blooming effects

d. Assess failed light conditions to determine their impacts on docking

e. Demonstrate that docking adapter lighting is required

f. Demonstrate that the view of the camera alignment system is adequate

The JSC Flight Crew Support Division (code SP) was responsible for planning, conducting, and reporting the results of the test as directed by the Manager of the Orbiter and GFE Projects Office at the ODS PDR. Participating organizations, test support personnel, and test subjects are listed in Appendix A.

Section 2
Test Equipment

2.1 Full Fuselage Trainer (FFT) Configuration

The FFT was configured as shown in figure 1. The fidelity of the components is reasonable, particularly in volume and color. The window in the overhead hatch of the external airlock was an actual flight window, RI P/N VO75-332652. The spacelab was not installed; however, its nosecone was simulated by using the endcone from a Space Station Freedom node.

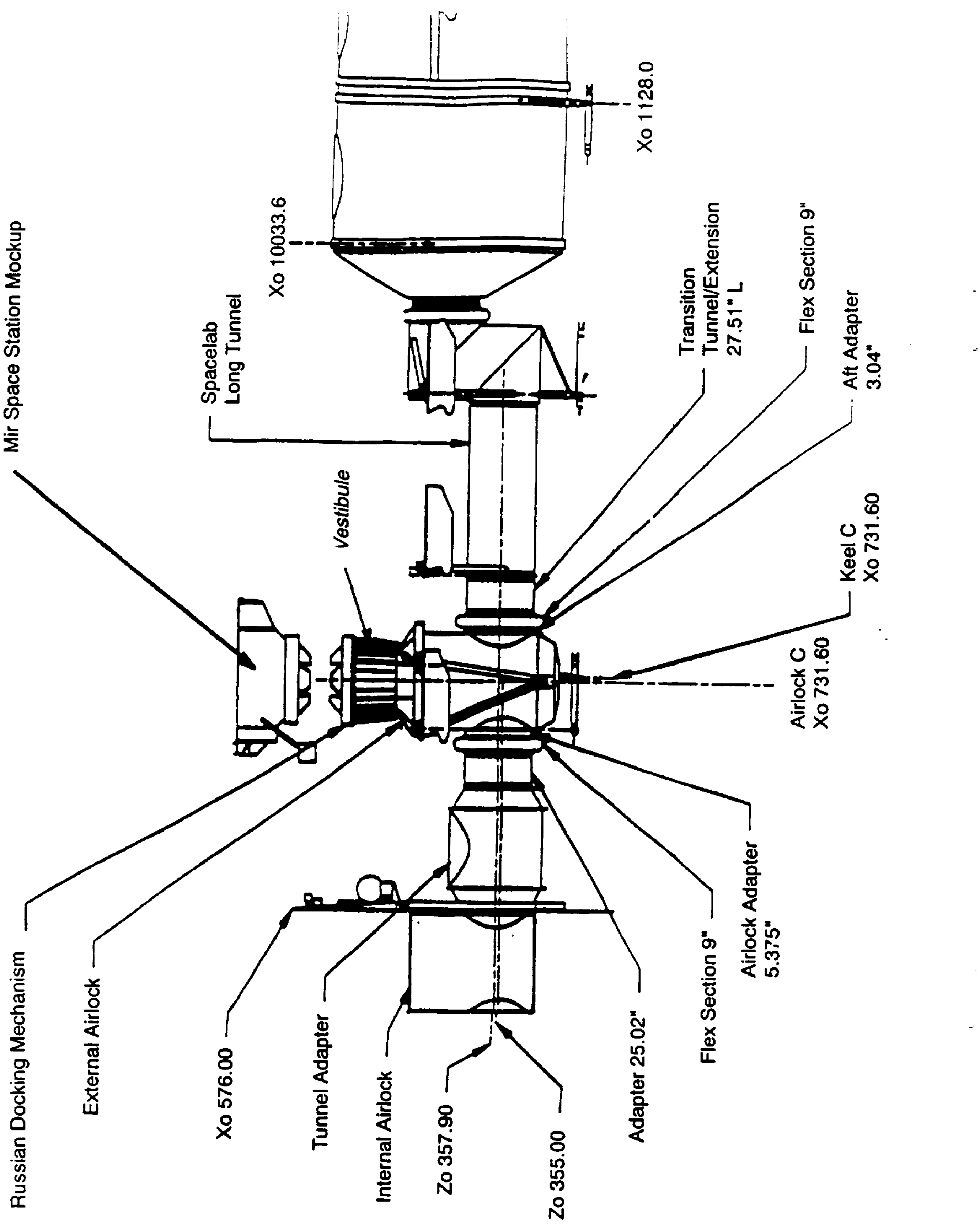

Figure 1. Full Fuselage Trainer configuration.

2.2 Shuttle Docking Adapter

The docking base and mechanism were flight-like, with high fidelity internal dimensions and color. The internal handholds and external avionics boxes were mounted to the docking base. The docking mechanism could be manually extended and retracted through its full range. These tests were all run with the Orbiter side of the docking mechanism extended 1 foot from the docking adapter base. The camera alignment crosshair was mounted in the movable portion of the docking adapter, as shown in figure 2. The crosshair was the latest known configuration, consisting of a ring held by three wires mounted approximately 6 inches below the tip of the docking petals.

2.3 Mir Configuration

The Mir mockup consisted of the hatch and docking adapter portions only, as shown in figure 1. The entire Mir was not modeled for this test. The petal spacing was high fidelity, but did not have the capability of being extended. The colors were based on the video of the Soyuz/Mir docking and photographs obtained from Russia. The docking target mounted to the Mir was a flight-like unit. The bolts which attach the docking target to the Mir were unpainted stainless steel to give the reflection they would give if their paint were scraped off. The Mir was suspended from a crane directly over the Orbiter docking adapter, and could be raised to a height of approximately 30 feet.

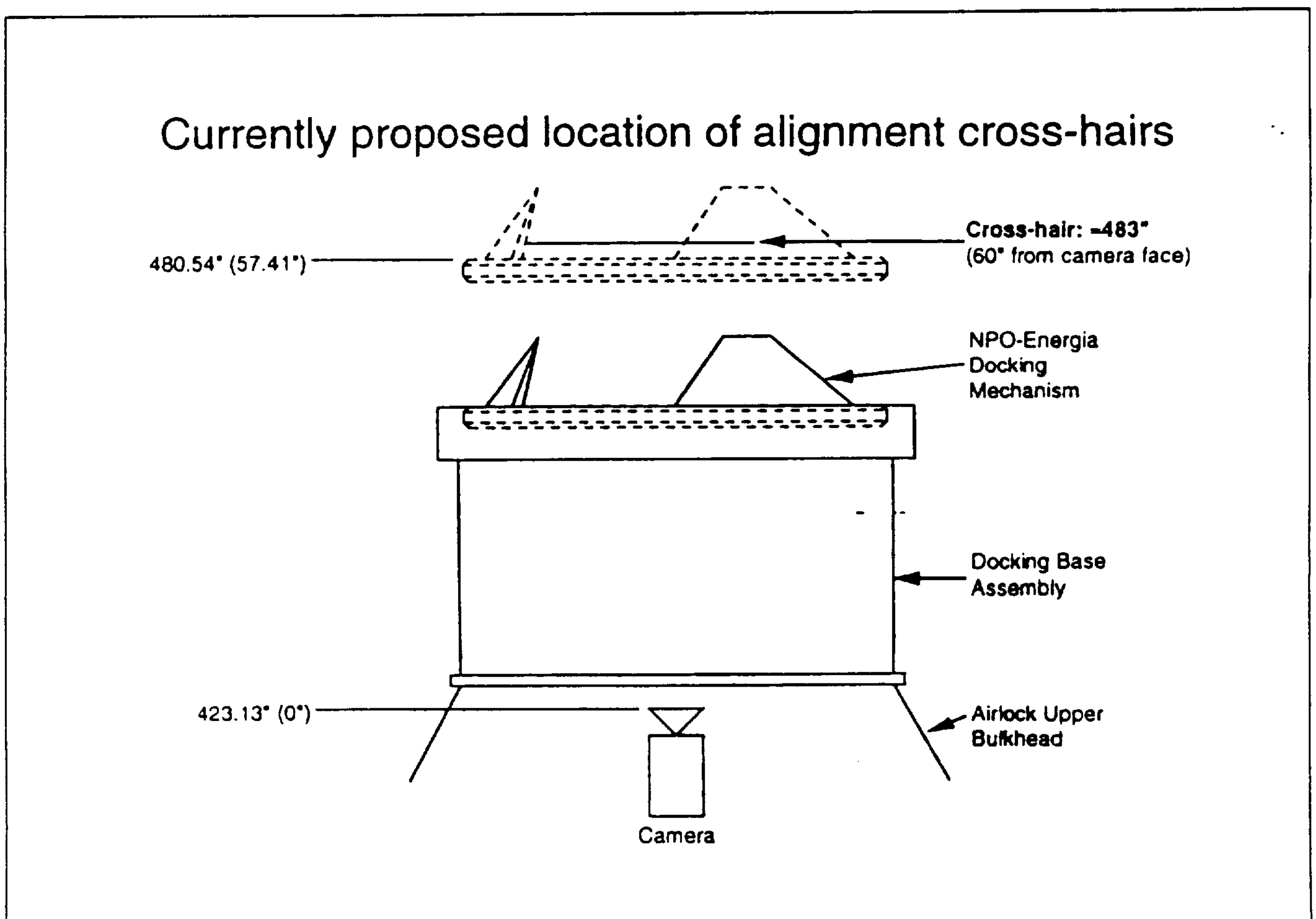

Figure 2. Proposed location of alignment crosshair.

2.4 Camera Configuration

The camera system consisted of a flight-like centerline-mounted CTVC, three monitors, and a video recorder. The centerline camera was mounted to a tripod in the external airlock looking up through the hatch window, and it was wired to the flight deck closed circuit television (CCTV) panel. The image in the centerline camera was viewed through the two color television monitors (CTVMs) on the flight deck in the A3-1 location and a CTVM mounted on the FFT access platform. The camera was mounted so that its lens was approximately 2.75 inches below the hatch window, and centered on the window. The orientation of the camera was such that the Orbiter body +x axis was "up" in the monitor view, and the +y axis was "left" in the monitor view. Camera control was via panel A7 on the flight deck. Optical alignment was accomplished by a combination of the camera's internal crosshairs and the camera crosshair system mounted in the docking adapter. No other payload bay cameras were used in this test.

2.5 Lighting System

The lighting system (fig. 3) consisted of a bulkhead flood light, a bulkhead-mounted overhead docking light, two truss-mounted docking lights, and two lights mounted inside the Orbiter docking adapter. Note that in figure 3, although the two truss lights are on the starboard side of the vehicle, they are still referred to as the port truss and starboard truss lights in order to be consistent with the nomenclature on the data recording sheets and test plan. The port refers to the port-most light, and the starboard refers to the starboard-most light.

Because of difficulties in obtaining lights for the test, the overhead docking light and remote manipulator arm (RMA) lights were considered interchangeable for this test. According to JSC Lighting Lab and ILC experts, little difference should be noticed between these two lights within a 200-foot range, which is well within the range of this test. Technical characteristics of the lights follow.

Characteristic	RMA Light (28vdc)	Docking Light (36 vdc)
Beam Spread	50° @10% of max intensity	40° @10% of max intensity
Kelvin Temp	2950	2925
Intensity	2097 Lumens	2150 Lumens
Size	5x5x6	5x5x5

All of the lights, except the payload bay floods and the bulkhead flood, were tested in the lighting lab to ensure that they were within specification. Only one light was not: the light in the overhead docking position on the Orbiter bulkhead was one foot-candle below specification.

Section 3
Test Methods

The docking sequence between the Mir and the Space Shuttle was simulated in the Shuttle mockup area, JSC building 9a. The FFT served as the Orbiter, and a mockup of the Mir hatch and docking adapter portions was lowered from a crane to simulate the docking. The Orbiter portion was outfitted with the external airlock, which contained the centerline camera and docking adapter based on the proposed design. The payload bay lighting was flight-like, as described in the lighting portion of this test report. The tests, consisting of 30 runs, each with unique lighting, were conducted under darkened conditions on June 23 from 5:30 p.m. to 11:00 p.m., and on June 24 from 5:30 p.m. to 8:00 p.m.

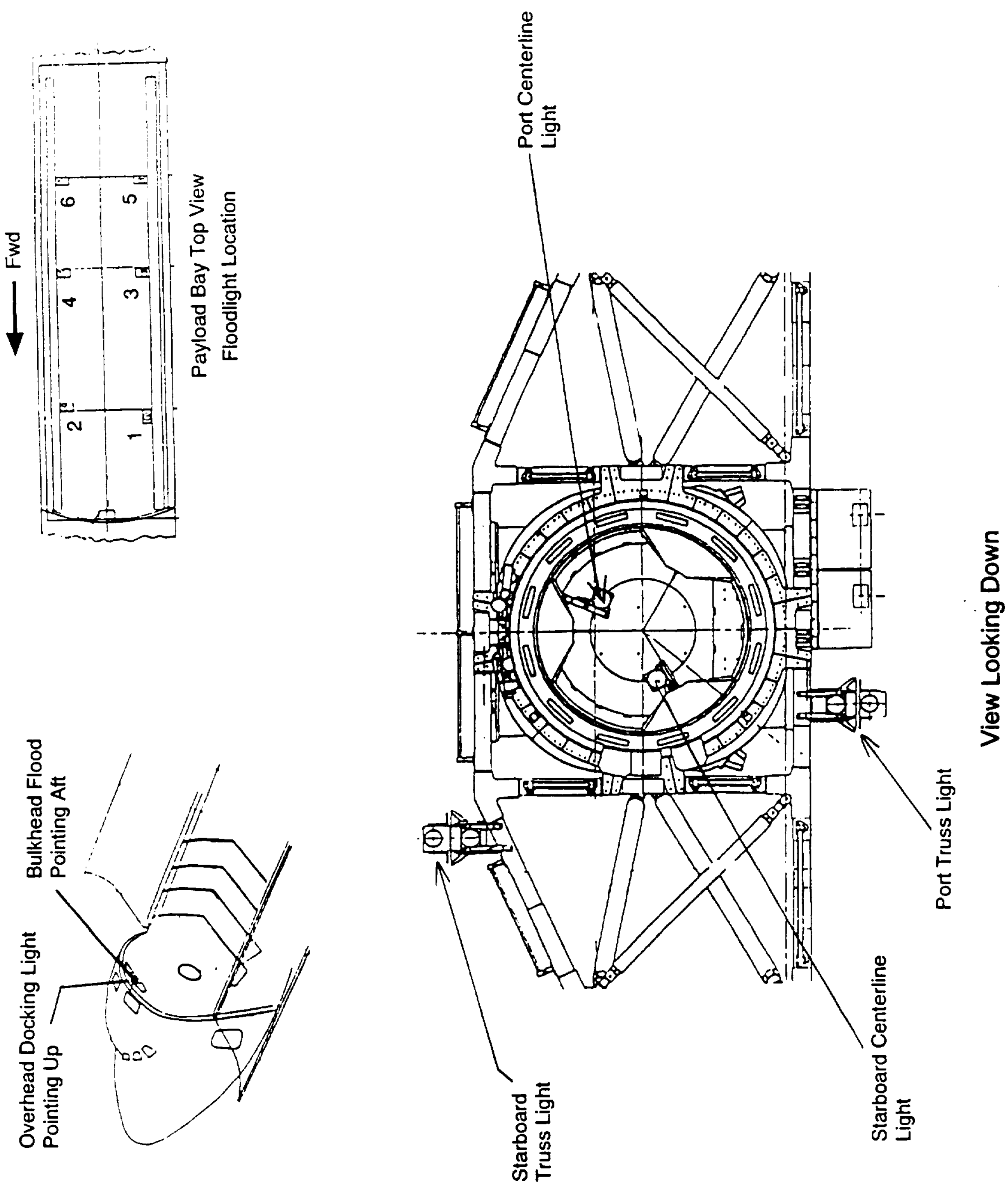

Figure 3. Lighting System.

3.1 Test Scenario

Each of the 30 tests was run under a unique lighting condition, as shown in table 1. In each test the Mir mockup was raised to approximately 15 or 20 feet above the Shuttle docking adapter, then lowered to within a couple of inches of contact. The Shuttle docking ring was extended off the adapter by 12 inches, based on the proposed design at actual contact. The Mir was lowered at a rate of 0.07 feet per second to correspond as closely as possible to the 0.1 feet per second docking design closing velocity. The tests as run are designated in table 1.

3.2 Test Questions

After each test, the subjects completed the End-to-End Questionnaires on viewing conditions. At the end of all the testing, the General Crosshair Questionnaires were completed. The subjects were asked to rate each of these questions on a scale of 1 to 5 according to the categories listed in section 3.2.3.

3.2.1 End-to-End Questionnaires

The End-to-End Questionnaires were completed by the test subjects after each test. The questionnaire consisted of the following four questions.

1. Resolution of the Target: How would you describe the resolution of the docking target relative to what you would expect to see in order to accomplish a successful docking (consider limited obstruction or shadowing caused by external crosshairs)?

2. Field of View: How would you describe the field of view through the camera relative to what you would require to perform a successful docking?

3. Light Level: How would you describe the overall lighting levels relative to what you would require to perform a successful docking (consider blooming)?

4. Light Placement: How would you describe the position of the lights relative to what you would require to perform a successful docking (consider shadowing)?

3.2.2 General Crosshair Questionnaires

The General Crosshair Questionnaires completed by the subjects at the end of all the test runs consisted of the following four questions.

1. Crosshair Cues: How would you describe the external crosshair as an aid to alignment of the target at approach distances of 3 to 5 feet or greater?

2. Crosshair Cues: How would you describe the external crosshair as an aid to alignment of the target at approach distances of 3 to 5 feet or less?

3. Electronic Overlay Cues: How would you describe the electronic overlay as an aid to alignment of the target at approach distances of 3 to 5 feet or greater?

4. Electronic Overlay Cues: How would you describe the electronic overlay as an aid to alignment of the target at approach distances of 3 to 5 feet or less?

3.2.3 Definition of Categories

The following categories were used to rate each of the questions. Each category was assigned a numerical designator, with 1 being the best and 5 being the worst.

1. Completely Acceptable—Design is adequate to perform docking. No changes are needed.

2. Reasonably Acceptable—Design is adequate to perform docking. Changes are desirable but not required for success.

3. Borderline—Docking could probably be performed, but conditions would make it uncertain and possibly unsuccessful.

4. Reasonably Unacceptable—A successful docking is unlikely.

5. Completely Unacceptable—Docking would not be attempted because of safety concerns.

3.3 End-to-End Tests

Table 1 identifies the lighting conditions that were tested. The numbering system is unique, and test 18 was deleted because it was a duplicate of a previous test. Note that the aft two payload bay floods were always off because of thermal constraints with the Spacelab.

Section 4
Test Results

4.1 Presentation of the Data

The raw data from the questionnaires has been placed into matrix format and is enclosed in Appendix B.

4.2 Ranked Data

Table 2 shows averaged test subject responses to the end-to-end data from appendix B, ranked from 1 (best) to 5 (worst) for each of the four questions.

4.3 Photography and Video Recording

Each test run was recorded on video and a 5-minute summary video was made to demonstrate some of the lighting conditions.. The video will be retained at JSC by Phil Mongan and Jay Legendre until the completion of STS-71. Photographs were also taken of the test setup, giving various views of the approach as seen from the aft flight deck windows. (There are no photos of the view through the centerline camera.) Photographs have been assigned NASA numbers (S93-037561 through S93-037571) and are retained in the JSC Image Sciences Division for use by NASA and NASA contractor personnel.

Table 1. Test Matrix

Test Run	Payload Bay Floods 1	2	3	4	5	6	OH Docking	Bulkhead Flood	Port Truss	Stbd Truss	Port Centerline	Starboard Centerline
1	off	off	off	off	off	off	on	on	on	on	on	on
2	off	on	off	on	off	off	on	on	on	on	on	on
3	on	on	on	on	off	off	on	on	on	on	on	on
3a	on	on	on	on	off	off	on	off	off	off	off	off
4	off	off	off	off	off	off	on	on	off	off	on	on
5	off	off	off	off	off	off	on	on	on	off	on	on
6	off	off	off	off	off	off	on	on	off	on	on	on
7	off	off	off	off	off	off	on	on	on	on	off	off
8	off	off	off	off	off	off	on	on	on	on	on	off
9	off	off	off	off	off	off	on	on	on	on	off	on
10	off	off	off	off	off	off	on	on	off	on	off	on
11	off	off	off	off	off	off	on	on	on	off	on	off
12	off	off	off	off	off	off	on	on	off	on	on	off
13	off	off	off	off	off	off	on	on	on	off	off	on
14	off	off	off	off	off	off	on	off	off	off	off	off
15	off	off	off	off	off	off	off	off	off	off	off	on
15a	off	off	off	off	off	off	off	off	off	off	on	off
16	off	off	off	off	off	off	off	off	off	off	on	on
17	on	on	on	on	off	off	on	on	on	on	off	off
19*	on	on	on	on	off	off	on	on	on	on	on	on
20	on	on	on	on	off	off	on	off	on	on	off	off
21	off	on	off	on	off	off	off	off	off	off	off	off
50	off	off	on	off	off	off	on	off	on	on	off	off
51	off	off	on	on	off	off	on	off	on	on	off	off
52	off	on	on	on	off	off	on	off	on	on	off	off
53	off	on	off	on	off	off	on	off	on	on	off	off
54	on	on	off	on	off	off	on	off	on	on	off	off
55	on	on	off	off	off	off	on	off	on	on	off	off
56	on	off	off	off	off	off	on	off	on	on	off	off
57	off	on	off	off	off	off	on	off	on	on	off	off

* Denotes test run at 24 vdc. or equivalent.

Table 2. Relative Rankings of the Test Runs With Respect to Each Question

Resolution		Field of View		Light Level		Light Placement	
Test	Average	Test	Average	Test	Average	Test	Average
51	1.1	5	1.0	6	1.0	17	1.0
52	1.1	6	1.0	11	1.0	52	1.1
4	1.2	8	1.0	16	1.0	4	1.3
5	1.2	9	1.0	19	1.0	3a	1.3
6	1.2	10	1.0	4	1.2	54	1.4
8	1.2	11	1.0	5	1.2	20	1.4
11	1.2	12	1.0	8	1.2	5	1.5
12	1.2	13	1.0	12	1.2	2	1.6
2	1.2	15	1.0	15a	1.2	3	1.6
16	1.4	16	1.0	54	1.3	16	1.6
19	1.4	17	1.0	1	1.3	19	1.6
15a	1.4	19	1.0	51	1.4	21	1.6
50	1.4	20	1.0	52	1.4	51	1.6
53	1.4	21	1.0	3	1.4	6	1.7
54	1.4	15a	1.0	53	1.5	50	1.7
55	1.4	51	1.0	55	1.5	53	1.7
57	1.4	52	1.0	2	1.6	55	1.7
3	1.4	53	1.0	10	1.6	11	1.8
3a	1.4	54	1.0	13	1.6	12	1.8
17	1.5	57	1.0	15	1.6	15a	1.8
1	1.6	1	1.1	20	1.6	56	1.9
9	1.6	2	1.1	57	1.6	57	1.9
20	1.6	50	1.1	17	1.8	1	1.9
56	1.7	55	1.1	9	1.8	8	2.0
10	1.8	56	1.1	50	1.9	9	2.4
13	1.8	4	1.2	3a	1.9	10	2.4
15	1.8	3	1.2	56	2.0	13	2.4
21	2.0	3a	1.2	7	2.7	15	2.6
7	2.8	7	1.3	21	2.8	7	2.8
14	5.0	14	5.0	14	5.0	14	5.0

Section 5
Analysis of the Data

Establishing an acceptable cutoff ranking of 2.0 based on the categories in section 3.2.3 will ensure visibility conditions sufficient for a successful docking. A ranking greater than 2.0 would introduce some amount of risk into the docking, and success could not be guaranteed.

Each test should be considered a docking. If any one of the four questions for a particular test is ranked greater than the 2.0 cutoff, that docking might have been unsuccessful. On table 2, a line has been drawn in the column for each question so that everything from 1.0 through 2.0 falls above the line and everything greater than 2.0 falls below the line.

It should be noted that test 14 was an extreme case to simulate the effects of having only the overhead docking light. This is not indicative of any reasonable failure scenario, because a docking would not usually be attempted with only one operational light.

5.1 Field of View

Responses to the field of view question were the most consistent, with the lowest collective average rankings. This consistency was expected because the field of view was fixed for this test through the 4-inch hatch window. The low average indicates that the field of view through the 4-inch hatch window, with the camera lens about 2.75 inches below the window, is adequate.

5.2 Resolution

The resolution also scored consistently good except in two test runs: test 14, which was the extreme case, and test 7, which had both centerline lights turned off and all of the payload bay flood lights turned off. In test 7, as the Orbiter and Mir neared contact, the lighting levels became so low that the resolution became grainy and degraded to a level which would have introduced an element of risk to a successful docking.

The resolution question was designed to determine if the optical quality of the hatch window and the camera system were adequate to support the docking. The consistently good scores indicate that the window and camera system provide adequate resolution to perform a successful docking.

5.3 Light Levels

Three tests were ranked greater than the 2.0 threshold in the lighting level category. Since low lighting level degrades the resolution, if the windows and camera system were good, the lighting levels and resolution answers should show some consistency. As they were on the resolution question, tests 7 and 14 are greater than the adequate threshold. Additionally, test 21 was graded greater than a 2.0. Note that test 21 was borderline in the resolution also, which emphasized the consistency between lighting levels and resolution.

The reflection of the lights off the unpainted docking target bolts was noticeable, but not a problem for the docking. Additionally, there were no light reflection problems off the laser reflector. Again, the consistently good scores indicate that the lighting levels are adequate to perform a successful docking.

5.4 Light Placement

It is obvious from the rankings shown in table 2 that the placement of the lights is important to the acceptability of the design. Six tests were scored greater than a 2.0, largely because of unacceptable shadowing under the various failed light conditions. In some of these cases, specifically failures of one centerline light, the shadow of the docking target standoff cross looks very similar to the standoff cross itself. The only way to distinguish the two is by the white dot in the middle of the standoff cross. Additionally, the shadow can obscure the tips of the cross, or the alignment hash marks on the base of the target. Failures of other lights such as the truss lights or payload bay floods create shadowing, but not to an unacceptable level.

The shadows can be dealt with by providing light in locations which will offset them. Assuming overall light levels are acceptable, this can be accomplished by operational workarounds. For example, if a particular light failure creates a bad shadowing effect, other lights could be turned off or on to alleviate this problem. Therefore, the existing light placement is acceptable for performance of a successful docking.

5.5 Unsuccessful Runs

The potentially unsuccessful docking runs are summarized in table 3. The test runs are ranked according to their worst score of each of the four questions, because that is the score which would cause the unsuccessful docking.

Table 3
Ranking of Potentially Unsuccessful Dockings
According to their Worst Score of the 4 Questions

Test	Average
9	2.4
10	2.4
13	2.4
15	2.6
7	2.8
21	2.8
14	5.0

It should be noted that only one of the test runs failed totally with a score of 5. This test was an extreme case designed to show the importance of the overhead docking light. As can be seen from the score, the overhead docking light does not provide much light on the target by itself.

Scores on all other runs averaged between 2.0 and 3.0, indicating that the docking probably could have been performed. These runs all have one thing in common; the port centerline light is failed. A port centerline light failure casts a shadow to the right as viewed on the monitor, which can obscure the tip of the target cross and the alignment hash marks on the target. A failed port centerline light tended to create undesirable shadows when the Mir and Shuttle were close to docking, whereas a failed starboard centerline light created undesirable shadows at the farther distances. This shadow can be eliminated by turning off the opposite centerline light, but as can be seen in test 7 results, the lighting levels become so low that the scores remain in the 2.0 to 3.0 range. These resulting low light levels can be alleviated by turning on at least one payload bay flood light, as was done in tests 50 through 57.

To recap, if a port centerline light fails and at least one payload bay flood is on, the starboard centerline light can be turned off, and the lighting levels and shadowing will be acceptable, as was shown in test run 50. If this procedure is used, tests 9, 10, 13, and 7 could be moved up to the adequate threshold. The only remaining questionable tests are 15, 21, and 14, which are extreme cases and not indicative of situations we would expect to see during a docking.

It was the general feeling of the test subjects that the existing lighting configuration provides enough light, and if individual switching is available, enough flexibility to accommodate a successful docking.

5.6 External Crosshairs

The raw data from the General Crosshair Questions is presented in appendix B. The data are averaged and ranked in table 4. The four questions referred to in this table are given in section 3.2.2.

It can be seen that the external crosshairs are more effective for target alignment at close distances than at far distances, but they are not the preferred method of alignment in either case. The reason for this is that through most of the approach, in order to bring both the crosshair center ring and the target in focus at the same time, the camera has to be zoomed out so far that the image of the target is smaller than what is preferred by the test subject.

The external crosshairs also caused a slight blurring of the image when both centerline lights were on, but not to the extent that they would interfere with a successful docking. This blurring was not apparent with both centerline lights turned off. The external crosshairs did, however, perform well for aligning the camera prior to the testing.

Table 4
General Crosshair Questions Ranking

Question	Avg
1. External X-hair, > 5 ft.	2.9
2. External X-hair, < 5 ft.	2.1
3. Electronic X-hair, > 5 ft.	1.4
4. Electronic X-hair, < 5 ft.	1.1

5.7 Electronic Crosshairs

The data from the electronic crosshairs are also presented in table 4. These clearly act as an aid to alignment of the target at all distances. It should be noted that two different electronic crosshairs are available to the crew: green and white. The green ones are actually the true center of the image, but the white ones are very close to the same location.

The test subjects felt that the green crosshairs were too bright and too thick. If they are to be used they should be dimmable and thinner. The white crosshairs, however, worked very well, although some subjects would have preferred these be dimmable also.

5.8 Overlay

Some subjects thought it would be beneficial to place a grease pencil mark on the monitor screen to indicate the center, and turn off the electronic crosshairs altogether. The monitor screen, however, is coated with an anti-static film which is easily rubbed off, therefore preventing the use of a grease pencil. An overlay was taped to the front of the monitor to simulate this concept, which appeared to work well for some of the subjects.

Section 6
Conclusions and Recommendations

The conclusions and recommendations address the specific objectives: resolution, field of view, light placement, light levels, failed lights, the need for docking adapter lights, and camera alignment system.

6.1 Resolution

The resolution of the system is adequate as it is. The window provides sufficient clarity and does not need to be replaced with an optical quality window. The resolution of the CTVC system is also adequate.

6.2 Field of View

The field of view through the 4-inch hatch window was adequate with the camera lens placed about 2.75 inches below the window. No changes are required to the systems' field of view.

6.3 Light Placement

The placement of the lights was the most important factor in determining the success of the docking. Some failed light conditions cause shadowing which can obscure important alignment cues. This can be alleviated by subsequently turning on or off other lights which will have the effect of eliminating or washing out a particular shadow. The test subjects felt that light diffusion in ground testing causes shadows to not be as distinct as they would be in space. Consequently, bad shadows on the ground would be even worse in space. Based on this, it is important that the flight deck crew have individual switching capability for the lights which will be used in the docking to offer maximum flexibility of shadow management. No changes in the placement of lights are recommended.

6.4 Light Levels

The light levels are adequate as designed to perform a successful docking. The centerline camera does a great job compensating for low light levels. In general, there is good illumination of the docking target, and blooming from the unpainted stainless steel bolts or target laser reflector does not create a problem. The standard Orbiter flashlight was used from the aft flight deck, but the Mir forward petal blocked the light beam from reaching the target, rendering the flashlight useless for target illumination. No changes in the light levels or number of lights are recommended.

6.5 Failed Lights

Failed light conditions can impact lighting levels and cause shadowing. The system as designed should be able to sustain reasonable light failures and still provide enough light to complete the docking. Some light failures, especially a failure of one of the centerline lights, will cause adverse shadowing. A failed port centerline light tended to create undesirable shadows when the Mir and Shuttle were close to docking, and a failed starboard centerline light created undesirable shadows at the farther distances. In these adverse shadowing cases, individual switching can be used to provide an acceptable lighting environment. Failure of both centerline lights will not be a problem if at least one payload bay floodlight is working. Procedures for light management will be crew dependent and should be developed during the simulated docking runs for the mission.

6.6 Docking Adapter Lights

Some subjects preferred the docking adapter lights on and some preferred them off. Most, though, did not like one on and one off. Either way, adequate light exists as long as at least one payload bay flood is operational. It is recommended that the docking adapter lights be retained to offer maximum flexibility to deal with other light failures and user preference.

6.7 Alignment Crosshairs

Most subjects felt that the green electronic crosshairs were too bright and thick. The white crosshairs performed well, but according to the CTVC experts, were not exactly in the center of the image.

The external crosshairs perform well in aligning the camera. The external crosshairs, however, were not the preferred method of aligning the Orbiter with the target on the Mir. Additionally, the external crosshairs caused a slight blurring of the image with both centerline lights on, but not to the extent that they would interfere with the success of the docking.

No specific recommendations will be given relative to which crosshairs should be used because this is largely operator dependent. The most popular alignment aids were the white crosshair or an overlay. The green crosshairs should be made dimmable if their use is expected. Also, before procedures are developed, further investigation is needed to determine if the white crosshairs are accurate enough and are interchangeable with the green crosshairs throughout the camera alignment and target alignment phases of flight.

Adequate alignment mechanisms certainly exist, and it should be at the discretion of the crew and procedures developers to determine the actual method of alignment that will be used.

Appendix A

Participating and Supporting Organizations

Participating Organizations

The following organizations participated in running and/or planning this test.

Flight Crew Operations Directorate/CA - Input to test configuration and procedures, and flight crew contacts

Astronaut Office/CB - Input to test configuration and procedures

Flight Design and Dynamics Division/DM - Operations input to test configuration and procedures

Tracking and Communications Division/EE - Camera equipment

Flight Data Systems Division/EK - Lighting equipment

Rockwell - Building the docking adapter and Mir interface mockups, and providing drawings to support camera and lighting identification

Flight Crew Support Division/SP - Mockup and trainer support, lighting expertise, miscellaneous hardware support, and Test Director

Cargo Engineering Office/TJ - Inputs on Mir configuration. Provide Mir docking target

Orbiter Avionics Systems Office/VG - Project Office contact for overall test

Flight Support Equipment Office/VP - Contract authority over Rockwell-supplied hardware and support to overall test configuration

Test Support Personnel

The following personnel were responsible for various aspects of planning, conducting, and reporting associated with the test. Phone numbers are in area code 713 unless otherwise noted.

Name	Function	Phone
SP3/Phil Mongan	Test Director	483-2137
VG/Tom Grace	Project Office contact	483-3431
VG/Stu McClung	Project Office contact	483-3015
VP5/Anselmo Lozano	Docking Adapters	483-6339
VP4/Ragan Edmiston	Project Office contact	483-0956
RI, ZC20/Bob Groo	Docking Adapters	338-6319
RI, FB-94/Chuck Lyttle	Rockwell Cameras	(310)922-0683
RI, FB-94/Emmett Shepherd	Rockwell Lighting	(310)922-0683
SP5/David Ray	FFT & 9a Ops	483-5928
SP5/Dennis McClain	Mechanical Tech	483-6329
SP5/John Murphy	Electrical Tech	483-2174
SP5/David Wood	Mechanical Tech	483-2131
SP5/Steve Elliott	Technician Support	483-2148
SP5/Barry Kazilas	Mechanical Tech	483-6334
EE2/Wendell Rowan	TV & Video System	483-0177
EE2/Gene Beck	TV & Video System	483-0182
EK2/Diana Schuler	Lighting Hardware	483-1512

SP3/Chuck Wheelwright	Lighting Lab Support	333-7815
SP3/Jennifer Toole	Lighting Lab Support	333-7611
SP3/Jay Legendre	Alignment Crosshairs	483-3697
SP3/Carlos Sampaio	Alignment Crosshairs	483-9719
SP3/Terry Flemming	Alignment Crosshairs	483-6044
TJ2/Greg Lange	Docking Target	483-1176
DM43/Lynda Gavin	Rendezvous Ops	483-8007
CA3/Bill Ehrenstrom	Crew Support	244-8530
CA4/Russ Filler	Crew Support	244-8621
CB/Carl Meade	Astronaut Office	244-8701

Test Subjects

The following people were used as test subjects to evaluate the proposed design. The subjects all have significant experience in understanding what is important to see on the monitor in order to perform a successful docking.

Name	Function
SP3/Jay Legendre	Man-Systems
DM4/Lynda Gavin	Rendezvous Ops
DM3Jeannette Gillogly	Rendezvous and Prox Ops Working Group (RPOWG)
C87/Pete Spehar	RPOWG
B14/Julia Chu	RPOWG
CB/Carl Meade	Astronaut
CB/Kevin Chilton	Astronaut
CB/Steve Nagel	Astronaut
CB/Norm Thagard	Astronaut
CB/Brent Jett	Astronaut
CB/Dave Walker	Astronaut
CB/Jim Bagian	Astronaut
CB/Don McMonagle	Astronaut
CB/Frank Culbertson (observer only)	Astronaut

Appendix B

Raw Data

Test Subject Responses to the End-to-End Questions

Test	Question	Avg	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7	Subjet 8	Subject 9	Subject 10	Subject 11	Subject 12	Subject 13
			Test Subject Scores												
1	Resolution	1.6	2	1	1	2	2	2	1	1	2				
1	Field of View	1.1	1	1	1	1	1	1	1	1	2				
1	Light Level	1.3	1	1	1	2	2	2	1	1	1				
1	Light Placement	1.9	3	2	1	2	1	3	2	1	2				
2	Resolution	1.2	2	1	1	1	1	2	1	1	1				
2	Field of View	1.1	1	1	1	1	1	1	1	1	2				
2	Light Level	1.6	2	1	1	2	2	2	1	2	1				
2	Light Placement	1.6	2	2	1	2	1	1	1	2	2				
3	Resolution	1.4	2	1	1	1	2	2	1	1	2				
3	Field of View	1.2	2	1	1	1	1	1	1	1	2				
3	Light Level	1.4	3	1	1	1	2	2	1	1	1				
3	Light Placement	1.6	3	1	1	2	2	1	1	2	1				
4	Resolution	1.2		1		1	1	2	1		1				
4	Field of View	1.2		1		1	1	1	2		1				
4	Light Level	1.2		1		1	1	2	1		1				
4	Light Placement	1.3		1		2	1	2	1		1				
5	Resolution	1.2		1		1	2	1	1		1				
5	Field of View	1.0		1		1	1	1	1		1				
5	Light Level	1.2		2		1	1	1	1		1				
5	Light Placement	1.5		1		2	2	2	1		1				
6	Resolution	1.2		1		1	2	1	1		1				
6	Field of View	1.0		1		1	1	1	1		1				
6	Light Level	1.0		1		1	1	1	1		1				
6	Light Placement	1.7		2		2	2	2	1		1				
7	Resolution	2.8		1		3	3	3	3		4				
7	Field of View	1.3		1		1	1	1	3		1				
7	Light Level	2.7		3		3	3	2	3		2				
7	Light Placement	2.8		2		3	2	3	3		4				
8	Resolution	1.2		1		1	1	2	1		1				
8	Field of View	1.0		1		1	1	1	1		1				
8	Light Level	1.2		1		2	1	1	1		1				
8	Light Placement	2.0		2		2	2	3	2		1				
9	Resolution	1.6		1		1	2	3	1						
9	Field of View	1.0		1		1	1	1	1						
9	Light Level	1.8		2		2	2	2	1						
9	Light Placement	2.4		3		2	3	3	1						
10	Resolution	1.8				1	1	3	1			3			
10	Field of View	1.0				1	1	1	1			1			
10	Light Level	1.6				2	2	2	1			1			
10	Light Placement	2.4				2	3	3	1			3			
11	Resolution	1.2				1	1	2	1			1			
11	Field of View	1.0				1	1	1	1			1			
11	Light Level	1.0				1	1	1	1			1			
11	Light Placement	1.8				2	2	2	1			2			

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Test Subject Responses to the End-to-End Questions

		Test Subject Scores													
Test	Question	Avg	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7	Subjet 8	Subject 9	Subject 10	Subject 11	Subject 12	Subject 13
12	Resolution	1.2				1	1	2	1			1			
12	Field of View	1.0				1	1	1	1			1			
12	Light Level	1.2				1	1	2	1			1			
12	Light Placement	1.8				2	2	2	1			2			
13	Resolution	1.8				1	1	3	1			3			
13	Field of View	1.0				1	1	1	1			1			
13	Light Level	1.6				2	2	2	1			1			
13	Light Placement	2.4				2	3	3	1			3			
14	Resolution	5.0				5	5	5	5			5			
14	Field of View	5.0				5	5	5	5			5			
14	Light Level	5.0				5	5	5	5			5			
14	Light Placement	5.0				5	5	5	5			5			
15	Resolution	1.8				1	1	3	2			2			
15	Field of View	1.0				1	1	1	1			1			
15	Light Level	1.6				2	2	2	1			1			
15	Light Placement	2.6				2	3	3	2			3			
16	Resolution	1.4				1	1	2	1			2			
16	Field of View	1.0				1	1	1	1			1			
16	Light Level	1.0				1	1	1	1			1			
16	Light Placement	1.6				2	1	2	1			2			
17	Resolution	1.5				1	2	2				1			
17	Field of View	1.0				1	1	1				1			
17	Light Level	1.8				2	2	2				1			
17	Light Placement	1.0				1	1	1				1			
19	Resolution	1.4				1	1	2				1	2		
19	Field of View	1.0				1	1	1				1	1		
19	Light Level	1.0				1	1	1				1	1		
19	Light Placement	1.6				2	2	2				1	1		
20	Resolution	1.6				1	2	2				1	2		
20	Field of View	1.0				1	1	1				1	1		
20	Light Level	1.6				1	3	2				1	1		
20	Light Placement	1.4				2	1	2				1	1		
21	Resolution	2.0				1	2	3				2	2		
21	Field of View	1.0				1	1	1				1	1		
21	Light Level	2.8				2	4	4				2	2		
21	Light Placement	1.6				1	1	2				2	2		
3a	Resolution	1.4	2	1	1	1	2	2	1	1	2				
3a	Field of View	1.2	2	1	1	1	1	1	1	1	2				
3a	Light Level	1.9	3	1	1	2	2	3	2	1	2				
3a	Light Placement	1.3	1	1	1	1	1	2	1	2	2				
15a	Resolution	1.4				1	1	2	1			2			
15a	Field of View	1.0				1	1	1	1			1			
15a	Light Level	1.2				1	1	2	1			1			
15a	Light Placement	1.8				2	2	2	1			2			

Test Subject Responses to the End-to-End Questions

Test	Question	Test Subject Scores													
		Avg	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7	Subjet 8	Subject 9	Subject 10	Subject 11	Subject 12	Subject 13
50	Resolution	1.4				1	2	2	2			1		1	1
50	Field of View	1.1				1	1	1	2			1		1	1
50	Light Level	1.9				2	2	2	2			1		2	2
50	Light Placement	1.7				2	2	1	2			2		2	1
51	Resolution	1.1				1	1	2	1			1		1	1
51	Field of View	1.0				1	1	1	1			1		1	1
51	Light Level	1.4				1	2	2	1			1		1	1.5
51	Light Placement	1.6				2	2	2	1			2		1.5	1
52	Resolution	1.1				1	1	2	1			1		1	1
52	Field of View	1.0				1	1	1	1			1		1	1
52	Light Level	1.4				1	2	2	1			1		2	1
52	Light Placement	1.1				2	1	1	1			1		1	1
53	Resolution	1.4				1	2	2	2			1		1	1
53	Field of View	1.0				1	1	1	1			1		1	1
53	Light Level	1.5				2	2	2	1			1		1	1.5
53	Light Placement	1.7				2	2	2	1			2		2	1
54	Resolution	1.4				1	2	2	2			1		1	1
54	Field of View	1.0				1	1	1	1			1		1	1
54	Light Level	1.3				1	2	2	1			1		1	1
54	Light Placement	1.4				2	1	1	1			2		1.5	1
55	Resolution	1.4				1	2	2	2			1		1	1
55	Field of View	1.1				1	1	1	2			1		1	1
55	Light Level	1.5				2	2	2	1			1		1	1.5
55	Light Placement	1.7				2	2	1	2			2		2	1
56	Resolution	1.7				2	3	2	2			1		1	1
56	Field of View	1.1				1	1	1	2			1		1	1
56	Light Level	2.0				2	3	2	2			1		2	2
56	Light Placement	1.9				2	3	1	2			2		2	1
57	Resolution	1.4				1	2	2	2			1		1	1
57	Field of View	1.0				1	1	1	1			1		1	1
57	Light Level	1.6				1	3	2	2			1		1	1.5
57	Light Placement	1.9				2	2	2	2			2		2	1

Test Subject Responses to the General Crosshair Questions

#	Question	Avg	General Crosshair Question Scores												
			Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7	Subjet 8	Subject 9	Subject 10	Subject 11	Subject 12	Subject 13
1	X-hair, far	2.9		5	2	4	4	4	1	2	1		3		
2	X-hair, close	2.1		3	2	3	3	3	1	1	1		2		
3	Electronic, far	1.4		1	2	2	1	2	2	1	1		1		
4	Electronic, close	1.1		1	2	1	1	1	1	1	1		1		

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13. ABSTRACT *(Maximum 200 words)*

A series of tests was run to verify that the design of the centerline color television camera (CTVC) system is adequate optically for the STS-71 Space Shuttle Orbiter docking mission with the Mir space station. In each test, a mockup of the Mir consisting of hatch, docking mechanism, and docking target was positioned above the Johnson Space Center's full fuselage trainer, which simulated the Orbiter with a mockup of the external airlock and docking adapter. Test subjects viewed the docking target through the CTVC under 30 different lighting conditions and evaluated target resolution, field of view, light levels, light placement, and methods of target alignment. Test results indicate that the proposed design will provide adequate visibility through the centerline camera for a successful docking, even with a reasonable number of light failures. It is recommended that the flight deck crew have individual switching capability for docking lights to provide maximum shadow management and that centerline lights be retained to deal with light failures and user preferences. Procedures for light management should be developed and target alignment aids should be selected during simulated docking runs.

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