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PROJECT APOLLO

A PILOTED SIMULATION STUDY TO EVALUATE THE DOCKING CONTROL OF THE LM/ATM VEHICLE

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SUMMARY

A piloted simulation study of the LM/ATM docking with the cluster arrangement was conducted in the Guidance and Control Division. The objective of the study was to determine if the LM/ATM could be controlled and successfully docked with the cluster arrangement under the following vehicle conditions: (1) solar panels extended, no jet failures, (2) solar panels extended, jets one and three failed off, (3) solar panels retracted, no jet failures, and (4) solar panels retracted jets one and three failed off.

The simulated cockpit contained LM translational and rotational hand controllers, a reticle, and pitch and roll error meters. The cluster was represented by an electronically generated plane 8 by 64 feet with a target at one end and displayed to the docking window through a virtual image system. The control mode simulated was rate command attitude hold using the AGS. It was assumed that in the panels extended configuration all four downward firing thrusters had deflectors to reduce jet impingement on the solar panels and the effective thrust was only 50 pounds per engine as opposed to 100 pounds per engine on all other thrusters. For the main set of data runs, the vertical c.g. position was eight feet below the plane of the RCS thrusters. A few runs were made with this distance reduced to six feet. The equations of motion were completely linearized, orbital mechanics was neglected, and inertia coupling terms were omitted. Three pilots were used and all flew each configuration five times for a total of sixty data runs.

The results indicate that all configurations could be successfully docked but under jet failed conditions it might not be possible with the backup system without a precise display of closing velocity.

INTRODUCTION

The LM/ATM is configured such that the c.g. is several feet from the plane of the RCS thrusters. Consequently, any lateral translation commands also place moments on the vehicle. In addition, there is considerable difference in the moments of inertia between solar panels extended and solar panels retracted configurations, and therefore, the acceleration capability is considerably different. Also, with the solar panels extended the downward firing thrusters impinge on the solar panels and deflectors may be necessary which will reduce the effective thrust of these engines.

This simulation was undertaken to study the effects of these problems in controlling the vehicle in a terminal docking maneuver. The results reported herein are qualitative in nature since a complete reduction of data and analysis has not yet been accomplished.

Description of the Simulation

Visual Displays

The cluster was represented by a electronically generated plane 64 by 8 feet. The docking target was represented by two one-foot squares, with connecting diagonals, located three feet from one end of the cluster and centered with respect to the width. These squares were a different color than the rectangular plane. The cluster was displayed in the cockpit docking window through a virtual image system. The pilot had a collimated reticle in the docking window for sighting on the docking target of the cluster. Because of the two-dimensional target, pitch and roll attitude error meters were added to the cockpit to the right of the docking window. Although this is not presently configured in the LM, it is representative of information obtainable from a three-dimensional cluster and docking target. Figure 1 is a representative drawing of the visual displays.

Control System

The control system simulated was the AGS with the descent control loop gains. The control mode was rate command attitude hold. The commands from the rotational and translational hand controllers were input into a functional model of the Attitude and Translation Control Assembly (ATCA), built by the Control Systems Development Branch. The ATCA outputs were applied to the equations of motion.

Equations of Motion

The EOM were completely linearized and orbital mechanics was omitted. The control moment equations used only jet terms and all inertia coupling terms were omitted. These approximations appear valid in view of the limited excursions in attitude, small attitude and translations commands, and the short time involved in a data run. Figure 2 is a block diagram of the simulation showing the cockpit with visual displays, the ATCA, and the EOM. It was assumed that in the panels extended configuration all four downward firing thrusters had deflectors to reduce jet impingement on the solar panels and the effective thrust was only 50 pounds per engine as opposed to 100 pounds per engine on all other thrusters. The extended solar panels were considered rigid for this study. For the main set of data runs the vertical c.g. position was eight feet below the plane of the RCS thrusters. A few runs were made with this distance reduced to six feet.

Data Runs

Five sets of initial conditions were used in the simulation. All of these had an initial separation distance of 50 feet with initial attitude offsets in all three axes. Each of the sets had initial translation displacements in one or both axes. In addition, all but one initial condition had translation velocity in one, two, or all three axes.

The basic data is based on three pilots flying each initial condition, or fifteen runs, for each of four configurations of the LM/ATM. The basic data runs were made with the c.g. eight feet below the RCS plane. Some additional runs were made with this distance reduced to six feet. The four basic configurations were: (1) solar panels retracted with no jets failed, (2) solar panels retracted with jets one and three failed off, (3) solar panels extended with no failures, and (4) solar panels extended with jets one and three failed off.

Results and Discussion

Success Criteria

A docking run was considered successful if the contact conditions were within the following limits: (1) axial velocity .1 to 1 ft/sec, (2) radial velocity less than 0.5 ft/sec, (3) angular velocity less than 1 deg/sec, (4) radial alinement less than one foot, (5) angular alinement between plus and minus 10 degrees, and (6) rotational alinement between plus and minus 10 degrees.

Effect of Initial Conditions

A wide range of initial conditions was used in the simulation since docking interface conditions have not been defined. Some of the initial conditions were a significant contributing factor to the failed runs discussed later. Some initial conditions of the magnitude used would probably have been apparent to the pilot prior to a separation distance of 50 feet. In these cases he would have spent less time recognizing his situation and would have been quicker to correct initial errors. There were no failures to meet the docking criteria when conditions at 50 feet were nearly static and near perfect alinement even with jet failures present.

Effect of Jet Failures

All failure cases were jets one and three failed off. As a result of this failure roll and pitch maneuvers also produced an axial acceleration. With the panels retracted, minus pitch or plus roll commands produced a resultant 100 pounds of axial thrust toward the target. With the panels extended, plus pitch and minus roll commands produced a resultant 100 pounds of axial thrust away from the target. The fact that roll and pitch maneuvers accelerated the vehicle toward the target with the solar panels retracted and away from the target with panels extended was probably the main reason for pilot preference of extended panels under failed conditions. There was also a net translation force for roll and pitch maneuvers with no failures and the panels extended, but this provided axial acceleration away from the target and therefore, did not create a situation requiring the immediate attention of the pilot. In the primary control mode the maneuvering program would compensate for the failures and the axial accelerations would not occur.

Failed Runs

Five of the sixty basic data runs had one or more parameters outside the success criteria at contact.

a. In the panels retracted configuration with no jets failed, one data run had an axial velocity of 1.1 ft/sec. This is attributable to pilot inability to accurately determine axial velocity plus attempting to minimize fuel consumption. All other parameters were well within the success criteria on this run and a slightly more cautious approach velocity is within pilot capability for this configuration with little or no additional effort.

b. In the panels retracted configuration with jets one and three failed off, there was one complete failure case where the pilot lost sight of the target in the docking window and passed by the cluster. The technique used was such that while attitude alinement corrections were being made and translation offsets were being taken out there was a resultant force toward the target. In addition, there was an initial velocity toward the target and initial velocities in the other two axes. The result was that by the time the pilot recognized the high closing velocity, it was too late to prevent losing sight of the cluster in the docking window and passing to the side of it. Two differences between the simulation and the actual vehicle will probably prevent this from occurring in an actual mission. One is that when the primary mode is used, known failures should be compensated for by the maneuvering program so that net forces toward the target should not occur. Second, the pilot would most likely be aware of the large initial conditions at 50 feet from the target and would have probably stopped the closing velocity before making other maneuvers.

c. There were three failures in the panels extended configuration with jets one and three failed. Two of these were in axial velocity alone, 1.07 ft/sec, and 1.65 ft/sec. These are partially attributable to the same causes examined in the first failure discussed. In addition, since there were jets failed in the braking direction which caused unwanted torques when braking, there was a reluctance to reduce a marginally high velocity when all other parameters looked good on approach to contact. Again, these unwanted torques should not be a problem in the primary system and there should be less reluctance to braking close to the target under failure conditions. The third failure in this configuration had an axial velocity of 1.7 ft/sec and a radial alinement of 1.23 ft at contact. Again, this was a situation where a closing velocity was developed in taking out other initial conditions, consequently the pilot concentrated on reducing this closing velocity and in so doing developed some translation offsets prior to contact. This situation would most likely have been prevented by docking with the primary control system and recognizing initial conditions earlier.

Fuel Use

In view of the range of initial conditions used and since the backup control system was simulated instead of the primary, actual fuel numbers may not be representative of a real mission. On the other hand, the relative increase in fuel use for different configurations should be representative. The lowest fuel use configuration was panels retracted with no failures. The average of the fuel used for the five initial conditions in this configuration is referred to as the base fuel use. When jets were failed, the fuel use went up 56% in this configuration. With the panels extended and no failures the fuel use was up 84% from the base. When failures were added in the panels extended configuration, the fuel use was up 100% from the base number.

Pilot Ratings

With no jet failures, the pilots indicated the panels retracted the easiest configuration to control, but with jets one and three failed the pilots preferred panels extended. One configuration, panels retracted with jets one and three failed off, had an average pilot rating that indicated it was doubtful that the primary mission could be accomplished. But since this was a failure case and the rating is unacceptable only for normal operation, and since the backup control system was used, the configuration should not be considered an unacceptable one.

Six Foot c.g. Runs

A limited number of runs were made with the c.g. six feet below the RCS plane as opposed to eight feet. The pilots indicated it was a slightly easier control task but no difference in performance or fuel use was noted.

CONCLUSIONS

The simulation study indicates all configurations would be controllable in the primary mode with or without jet failures, and in the backup mode without jet failures. It is doubtful that the docking criteria assumed could be met with an acceptable level of confidence in the backup control mode with jet failures existing. It depends on the ability to achieve nearly static conditions with close to perfect alinement prior to 50 ft. A precise display of closing velocity within 50 ft would probably make this an acceptable condition.

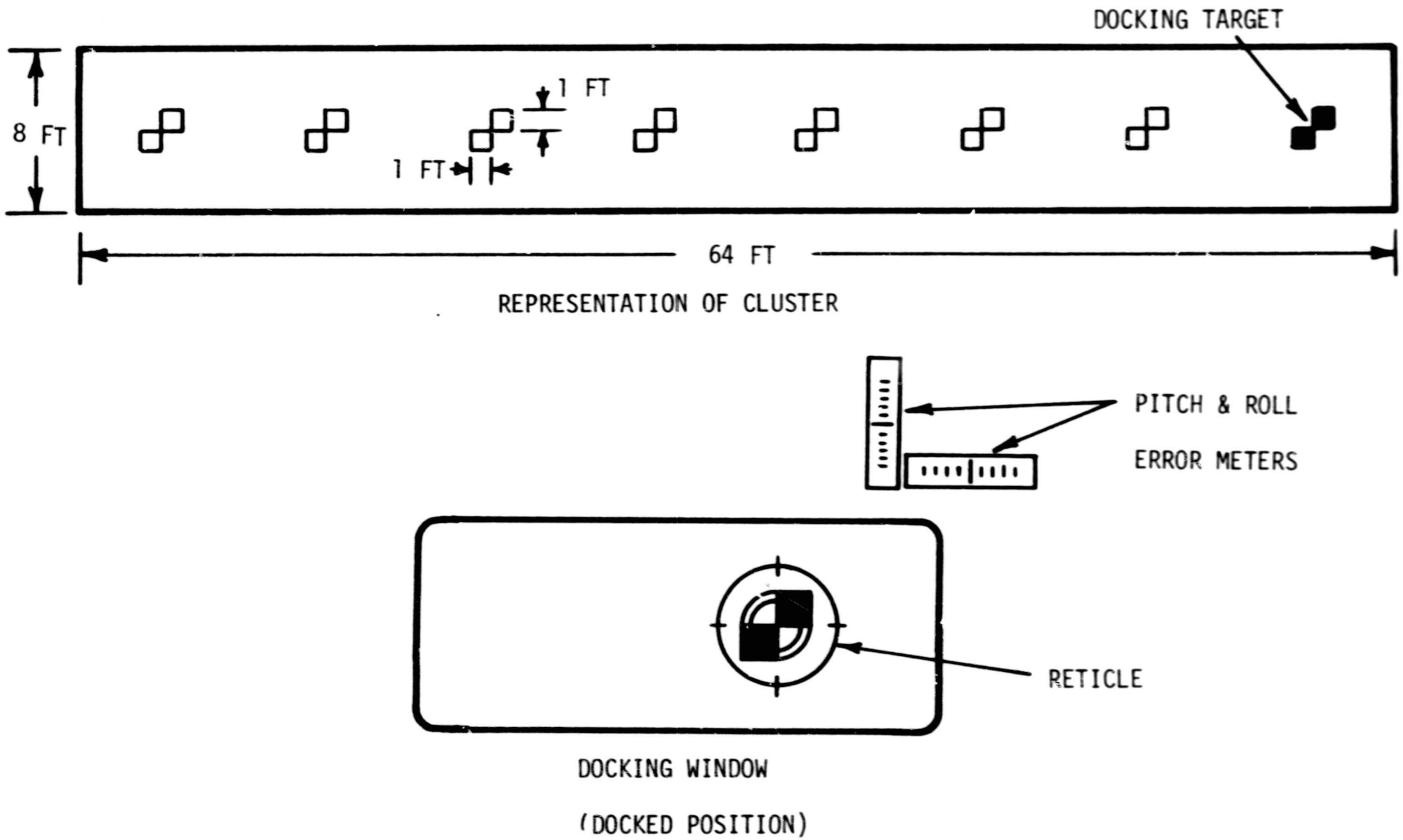

Figure 1. - Visual displays

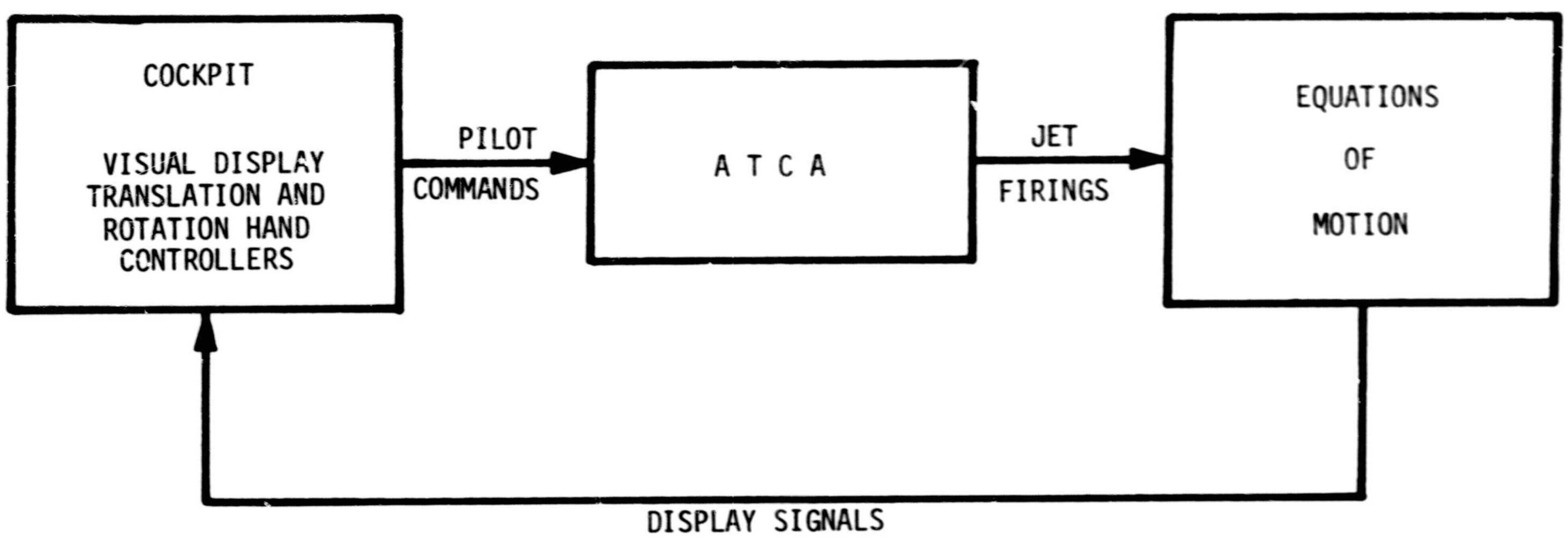

Figure 2. - Block diagram of simulation mechanization