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APOLLO PROGRAM

RANGE DATA REQUIREMENTS FOR CSM ACTIVE RENDEZVOUS

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SUMMARY

During Apollo operations, it may become necessary for the CSM to be the active rendezvous vehicle. The adequacy of the CSM system to provide the crew sufficient navigation and guidance information to perform the task is dependent upon (1) the ground (MSFN) capability to initialize the LM/CSM state vectors in the CMC and (2) the onboard optical navigation capability of updating these state vectors. The CSM PNGCS processes optical target sighting data to improve the computer (CMC) state vector data and thus compute TPI and midcourse maneuver solutions which will provide satisfactory braking and intercept conditions.

However, in the event of a PNGCS component failure, adequate onboard information should be provided to insure a rendezvous intercept. Studies using a manned hybrid simulation have been conducted to evaluate problems associated with the onboard ranging information necessary to complete the rendezvous under various degraded cases of environment and system performance.

Conclusions are based on vehicle translational acceleration, lighting variations, crew loading, and state vector uncertainties.

INTRODUCTION

The problem of CSM-active rendezvous is different from previous spacecraft configurations due mainly to the absence of an independent range-measuring device on the CSM. In order to determine the magnitude and direction of transfer and midcourse maneuvers, initialized state vector knowledge must be improved as a result of sextant sightings with CMC processing. However, if the PNGCS is inoperative, the transfer (TPI) solution may be acquired from the ground. The solution is derived from information attained from MSFN tracking.

In either of these cases there may be errors in the knowledge of the state vectors which will result in an erroneous computation of the Terminal Phase Initiation (TPI). The net result of such errors is to cause dispersions which, if uncorrected, will result in missing the target vehicle. The size of the miss is a function of magnitude and direction of the state vector errors. Simulation studies have indicated that when the primary G&N is functioning and sextant sightings are taken it is possible to effect a rendezvous dependent only upon CMC rendezvous displays and computations. However, in the event of a primary G&N system failure, it is necessary to rely upon backup procedures.

A manned hybrid simulation was performed (1) to investigate the effect of state vector errors on rendezvous performance, (2) to evaluate existing backup procedures, and (3) to investigate the need for direct onboard range measuring data as an aid to backup procedures.

STUDY CONDITIONS

In the rendezvous simulation it was assumed that MSFN tracked the CSM in a 110 n mi earth orbit and the LM/S-IVB in a 120 n mi orbit. The initial condition errors were applied to put the CSM in an off-nominal state in position and velocity. It was further assumed that the MSFN provided a TPI solution which was used for the CSM maneuver.

The basic trajectory used for this study was the initial AS-258 CSM rendezvous with an unmanned LM/S-IVB. The state vector errors and their orientation 10 minutes prior to TPI for the individual CSM configurations were the initial conditions for the individual simulation runs and are contained in figs. 1 and 2. Sunset occurred at the start of the simulation run (TPI - 10 min).

If the primary G&N is totally operable, then rendezvous can be completed with 3δ MSFN state-vector initialization errors prior to TPI which are improved with sextant sightings. Where the only information available is MSFN tracking along with the resulting TPI solution, a backup maneuver chart has been developed which makes rendezvous possible with the same initial state vector errors (10,000 feet position and 10 ft/sec velocity) for every orientation of errors.

The Gemini type rendezvous charts also can be employed successfully with the same state vector errors of 10,000 feet position and 10 ft/sec velocity providing the CSM were equipped with some device which would measure and display range and range rate for the conditions encountered 10 min prior to TPI (nominally 32 n mi range for 10 n mi differential altitude). The resulting fuel expenditure would be less than for the aforementioned (no radar, no G&N) case.

DISCUSSION OF RESULTS

Rendezvous with Primary G&N

In this rendezvous mode it was assumed that the CSM had sextant tracking of the target up until 10 min prior to TPI. The TPI maneuver solution was calculated and executed and then followed by a set of 7 sextant sightings. A midcourse correction solution was then computed and executed on the basis of these sightings. At the completion of the midcourse maneuver (17 min after TPI) the pilot flew the remaining portion of the rendezvous using both the information available from the CMC and line-of-sight tracking of the target. It is assumed that a single man (LM rescue) rendezvous would require the crew member to make the TPI and midcourse maneuvers from the G&N station in the Lower Equipment Bay. He would transfer to the Command Pilot station for terminal braking.

The results of following such a procedure indicate that an efficient rendezvous (i.e., with reasonable ΔV expenditure) can always be performed.

Backup Rendezvous Procedures

The pacing problem of CSM-active rendezvous arises when the capability of acquiring and processing sextant data does not exist due to a system component failure. The only knowledge of the state vector in this case is from MSFN tracking prior to TPI.

The errors were assumed to be largest in the X direction (see fig. 2) at the start of the simulation run and smallest in the Y (out-of-plane) direction with the sense of all the errors to be uncorrelated.

A backup chart was developed that incorporated a line-of-sight rate correction and a range rate correction based upon a timed line-of-sight rate vs time after TPI. This scheme allowed a rendezvous on all error configurations with the total position error of 10,000 ft and velocity error of 10 ft/sec. Due to lack of adequate ranging information in the backup mode, the terminal conditions of the rendezvous were not operationally ideal. The final approach position varied (in local vertical coordinate system) from slightly below and behind to above and ahead together with a range of related terminal velocities (see fig 3).

Runs using the line-of-sight backup technique were accomplished where electronically generated range and range rate data were available for the last 5 n mi. No significant variation in fuel usage was apparent over the aforementioned (no range data) runs. However, in the cases where sunrise did not occur until the vehicle range was small ($R < .7$ n mi) satisfactory braking control was still effected in order to complete a successful rendezvous.

Rendezvous was also simulated with five percent error range and range rate information available to the pilot from the start of the run. In this situation Gemini type backup charts, which are range and range rate dependent, were used with the result that errors in the order of 10,000 ft and 10 ft/sec could be handled. Not only was rendezvous successful but terminal phase fuel expenditure was reduced by nearly 17% (see fig 4), and terminal conditions were much improved. The reason for the improved terminal conditions was due largely to the fact that the pilot could successfully comply with the braking schedule since he had some independent knowledge of his range and range rate and did not need to rely solely on visual cues such as target growth.

In the situation in which no ranging device is available, the pilot is reluctant to decrease his range rate until he is confident he is going to rendezvous. This results in high relative velocities at close range (one nautical mile) to the target. The X-axis translational control power of CSM at 30,000 pounds gross weight is approximately .39 ft/sec^2 which is adequate for braking. However, in higher weight configurations the braking capability would degrade linearly. Furthermore, if the preliminary rendezvous phasing (TPI/sunset relationship) varies in the order of six to ten minutes, it is conceivable that the CSM could be at ranges less than one mile prior to sunrise. This situation would markedly degrade the pilots ability to perform adequate braking-to-intercept.

Optical Ranging Devices

Optical ranging devices appear (from a theoretical standpoint) to have an application in the terminal phases ($R < 5$ n mi) of rendezvous. Such a device would aid the pilot in obtaining range data and estimated range rate in order to affirm (or deny) a positive closing rate and to aid in complying with a braking schedule.

A simulation of this situation was made by providing the simulator pilot with range data starting at a range of 5 n mi and the pilot had to estimate range rate by considering a $\Delta R/\Delta t$ plot. This seemed to work adequately enough to aid in the rendezvous and to improve the terminal conditions over those resulting from backup cases with no ranging data.

It is believed that there may be several operational constraints which may limit the effective use of such a device. Several such uninvestigated problems include single member crew operational timeline in using such a device, calibration difficulties encountered in making such a device usable in night-time conditions and an effective method by which the instrument could be used for range rate determination and the associated accuracy in such measurements.

CONCLUSIONS

1. In the primary G&N operation the information provided by the CMC as updated by sextant sightings is sufficient for rendezvous.

2. A backup rendezvous procedure has been developed which provides rendezvous capability although the fuel consumption may be slightly higher and the terminal lighting conditions can be operationally undesirable. Closing rates are typically high due to an inability to comply with the braking schedule.

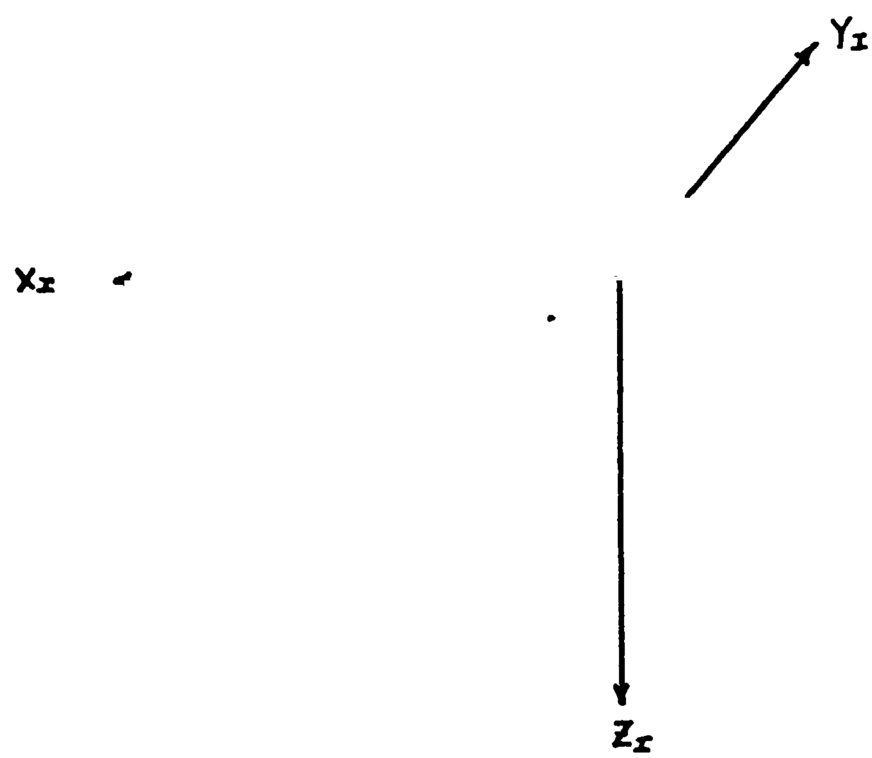
3. If a ranging device were provided on the CSM which would measure range and range rate slightly before TPI, then the Gemini charts will provide TPI and TPM maneuvers resulting in a normal rendezvous.

4. If a device were provided which accurately (±5%) measured range to 5 miles, a satisfactory technique exists in the line-of-sight backup chart for midcourse and braking. The ΔV improvement is negligible over the performance using the line-of-sight backup technique alone, but close in range data allows large initial errors to be accommodated safely in the event that they cause final braking to occur in darkness. The crew task load would be alleviated for all braking environments.

5. Optical ranging may improve the backup mode by making possible the compliance with the braking schedule if the possible environmental constraints are resolved.

RECOMMENDATIONS

As a minimum requirement, it is recommended that a range measuring device be provided on the CSM which is independent of environmental lighting and is compatible with a one-man crew timeline. This device should provide range data accurate to 5% at ranges up to 5 miles. No interface between the ranging device and the CMC is required. In selecting a ranging device, it should be kept in mind that a 10-20% saving in RCS fuel is possible in the backup mode if the range capability is extended to approximately 100 nautical miles.



The inertial axis system coincides at the start of the simulation with a local vertical system centered at the target vehicle. Thus, Z_I is along the radius vector to the earth, X_I is along the local horizontal, and Y_I completes the right - handed set.

Fig. 1 Orientation of the inertial axis system.

TABLE OF RELATIVE INERTIAL STATE VECTORS 10 MINUTES PRIOR TO TPI

(CSM RELATIVE TO TARGET VEHICLE)

Case	X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	RSS Pos. Err.	RSS Vel. Err.
Nominal	-179.315 ft.	0 ft.	61,504 ft.	34.96 ft/sec	0 ft/sec	-212.0 ft/sec	0 ft.	0 ft/sec
1	-177,524	-265	60,650	37.66	- .15	-213.3	2,000	3
2	-182,774	316	63,240	29.76	.32	-209.2	4,000	6
3	-170,270	327	63,290	32.3	-1.5	-220.8	10,000	10
4	-177,524	-265	60,650	32.26	- .15	-213.3	2,000	3
5	-182,774	316	63,240	40.16	.32	-209.2	4,000	6

Figure 2

Typical daylight conditions for back-up mode CSM active rendezvous without range and range-rate data available (daylight was assumed to occur 18 min after TPI).

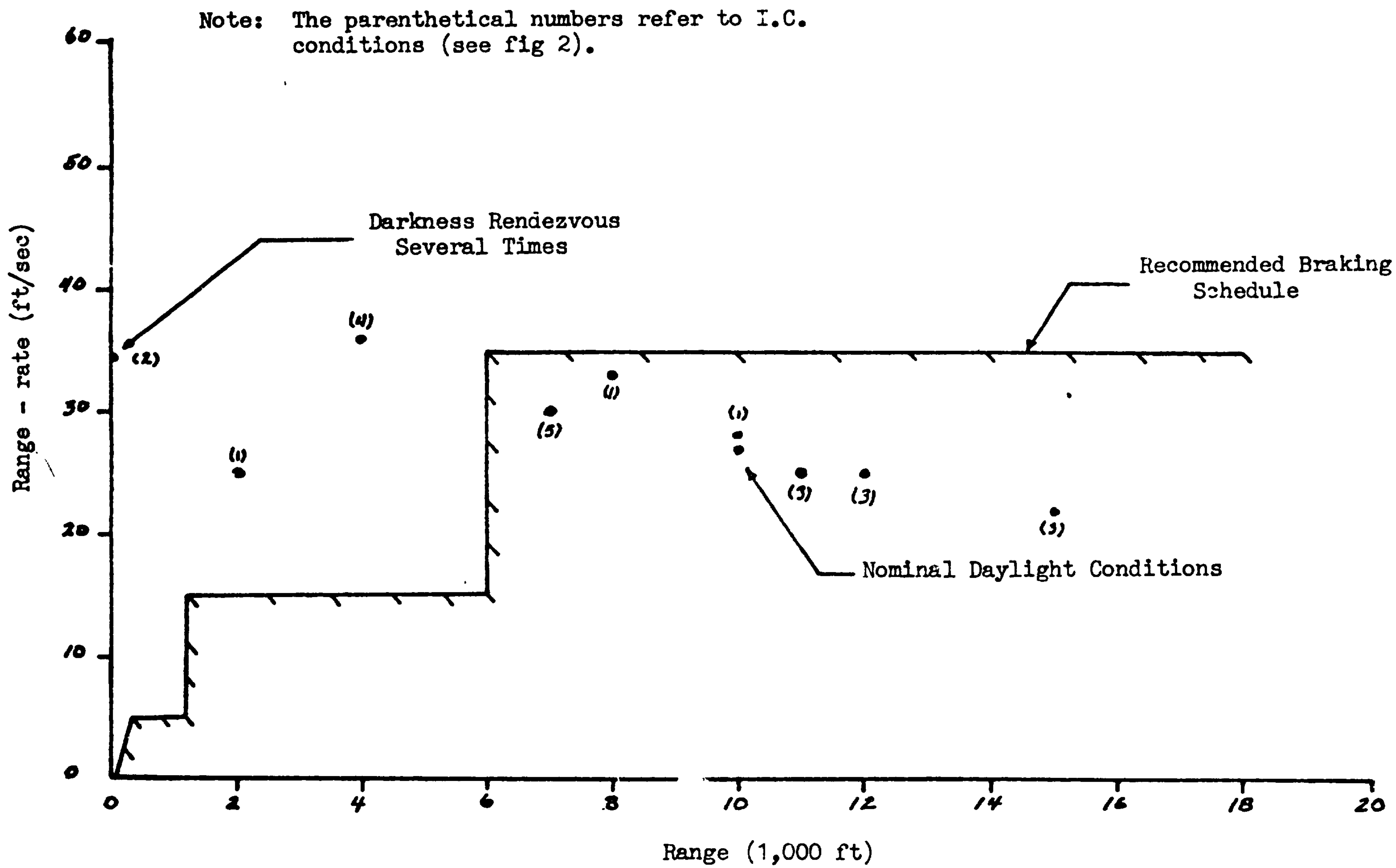


Figure 3

Comparison of ΔV usage for ranging available and not available at TPI

Mode	RSS Position Error	RSS Velocity Error	Translation Delta V
Ranging	4000 ft	6 ft/sec	95 ft/sec
"	"	"	102
"	"	"	86
"	"	"	100
Average	"	"	96
No Ranging	4000 ft	6 ft/sec	127
"	"	"	107
"	"	"	110
Average	"	"	115

Figure 4