LINE-OF-SIGHT GUIDANCE TECHNIQUES FOR MANNED ORBITAL RENDEZVOUS

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ABSTRACT

A study is made of the inertial rotation of the line-of-sight throughout three dimensional Keplerian rendezvous trajectories. A simple, yet very meaningful method of classifying rendezvous trajectories through the use of "Rendezvous Parameters" is presented. Simple approximate expressions are derived in terms of these parameters which greatly facilitate the analysis of rendezvous guidance.

The noncoplanar aspects of rendezvous are analyzed by a method, valid for low relative inclinations, which, based on two brief target position observations, permits the simple calculation of the out-of-plane velocity change required to shift the relative line of nodes to a predetermined point.

These principles are then applied to a specific rendezvous mission situation, namely the NASA Gemini rendezvous mission. A rendezvous guidance technique, designed to extend man's control capabilities, is derived, whereby, through a sight reticle programmed to vary inertially for a selected exact nominal Keplerian trajectory, the astronaut can initiate, monitor and correct his intercept to maintain a collision course up to the braking or velocity matching maneuver.

This optical method of rendezvous is thoroughly analyzed and, through a digital computer simulation, found capable of performing successful rendezvous within prescribed velocity change limitations for significantly large uncertainties in the knowledge of initial orbit conditions and for significant errors in observations, tracking, and thrust correction application. The results of the study of the specific mission application are then demonstrated to be directly extendible both to a wide range of near-Earth manned orbital operations including targets of extreme ellipticity, and to orbital operations in the vicinity of the Moon.

CHAPTER 1
INTRODUCTION

1.1 The Rendezvous Problem

The rendezvous problem as treated herein is concerned with the maneuvers required of one space vehicle, termed the interceptor, to establish and maintain a collision course with another space vehicle, termed the target, up to the final braking or velocity-matching maneuver. In general, the target is assumed to be non-maneuvering and in an orbit in the near vicinity of a central attracting body such as the Earth. Futher, subsequent to orbit injection of the interceptor, both vehicles are assumed to be essentially free from the effects of atmospheric drag.

The motion of the two vehicles, treated as point masses, is considered primarily from the geometrical aspect of the relative motion of the target vehicle as seen from the interceptor. This motion is considered to consist of relative range changes and angular rotation of the LOS (line-of-sight) relative to some convenient coordinate frame.

The guidance techniques for achieving rendezvous, as developed in this investigation, are based on the premise that angular LOS motion of the target may at times be the only tracking information available to the interceptor. Only the orbital injection and perhaps initial corrective maneuvering of the interceptor are based on ground tracking and a knowledge of the target orbit ephermeris. The guidance equipment required for initiating and completing the intercept,however, is self-contained in the interceptor vehicle.

1.2 Potentialities of Line-of-Sight Guidance Techniques

In general, the ability to perform rendezvous missions in space utilizing only LOS angular tracking information has two potential applications. Either the range information is intentionally absent due to equipment limitations, or some component failure in the primary guidance system prevents the use of the anticipated complete automatic tracking information.

The first case is usually characteristic of intercepts of a passive or uncooperative target. The complexity of radar equipment to acquire a target and supply range and angle tracking information is considerably increased when the target is not equipped with a transponder beacon. Weight and power considerations also may prohibit the use of such radar systems at the ranges desired for intercept initiation. Alternatives to microwaves involve the use of angle trackers varying from the ultraviolet to the infrared spectrum. Eventually such devices may be coupled with laser or simple radar ranging equipment. It is quite probable that angle tracking information would be available at considerably greater ranges than range tracking information. As a result, it may very well be desirable to perform initial intercept maneuvers utilizing only LOS angular tracking data. Operational missions in this category would include rescue, repair or inspection of disabled or alien space vehicles.

The second case for the application of LOS guidance techniques implies a back-up guidance mode to complete a rendezvous intercept of a cooperative target in the face of primary guidance equipment malfunctions. Requirements for such a back-up might stem from a desire to increase the probability of overall mission success by protecting against failures of radar tracking or data processing and computation equipment. Angle tracking data for LOS guidance might consist of astronaut observations of a flashing light on the target through a referenced optical sight or the output of an automatic tracker of some target spectral emissions. Since such equipment would be of a back-up nature, it should be as simple and reliable as possible and ideally independent of the primary guidance system components. The exact form of mechanization and degree of complexity of the back-up mode will be subject to many trade-off considerations, the spacecraft configuration and specific mission requirements. Operational missions which might employ such a back-up mode of rendezvous guidance are the Gemini mission, the Apollo landing abort maneuvers or rendezvous from the lunar surface and various future space station ferry missions.

The guidance techniques and orbit considerations discussed in this investigation are generally applicable to either the passive target situation or the back-up mode application. The prime emphasis, however, is directed toward back-up utilization to enhance the chances of mission success. In particular, the Gemini mission has been selected as a specific illustrative application.

CHAPTER 2

REVIEW OF CURRENT RENDEZVOUS CONCEPTS

2.1 General

Rendezvous of space vehicles has received widespread attention in the past several years. Many of our national space programs, both civilian and military, are involved intimately with the problems of rendezvous. Of the many published works, the references by Houbolt (23) and Thompson (51) offer excellent general treatment and summaries.

The basic rendezvous problem is usually subdivided into maneuvering phases. Though these phases vary considerably depending on specific approaches and in many cases overlap, they may be categorized as follows:

(1) Ascent or Approach Phase
(2) Intercept or Terminal Phase
(3) Braking and Docking Phase

The distinction that separates the first two phases is that for the ascent or approach phase, the relative motion is inferred from the separately determined motion of the two vehicles; whereas during the intercept or terminal phase, the relative motion is obtained directly from observations of the target made by the interceptor. The approach phase, which can be considered to start at interceptor lift-off, may be either a direct or indirect ascent type, and the desired end conditions may or may not be a near-collision course. The desired end condition of the intercept phase is to maneuver the interceptor onto a precise collision course with the target. In some concepts this may be combined with a portion of the final braking maneuver. The rendezvous culminates in the last phase with the vehicles at zero relative velocity either in soft contact or a prescribed station-keeping orientation.

2.2 The Ascent or Approach Phase

As the earth's rotation causes the interceptor launch site to approach the target orbit plane, there are two position variations that strongly influence the launch timing and subsequent interceptor maneuvering during the approach phase. The first is the position or "phase angle" of the target in its orbit relative to the interceptor, and the second is the position of the interceptor relative to the target orbit plane or "planar displacement".

When the phase angle determines the launch time, direct ascent maneuvers may be executed. In this case the orbit injection or termination of the thrusted ascent of the interceptor is planned to occur either in the close vicinity of the target or in such a way that the interceptor is on a coasting near-collision course with the target. In general, a planar displacement will exist for a direct ascent, and can be compensated for by a combination of a turning maneuver of the booster, which is termed "yaw steering", and a plane change of the interceptor as it passes through the target orbit plane.

On the other hand, when a small tolerance in the planar displacement determines a time period for acceptable launches and phase angle dictates only a desired but not required launch time, then an indirect ascent utilizing an intermediate near-coplanar interceptor orbit is employed. This intermediate orbit is caused to have a period different from the target orbit so that a catch-up or phase rate exists between the two vehicles. Then at some subsequent time, perhaps following an interceptor orbit change, acquisition of the target by the interceptor is made and the intercept or terminal phase is begun.

In the special case of target orbits for which a zero planer displacement exists simultaneously with a favorable phase angle, a coplanar direct ascent maneuver may be accomplished. These target orbits which have a particular period or semi-major axis length are termed "Rendezvous Compatible Orbits". A rather complete treatment of these special situations is given by Petersen in reference (37).

2.21 Direct Ascent

Direct ascent affords the opportunity to complete the rendezvous maneuver in a minimum amout of time, yet the demands on the launching