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COMPARISON OF THE ATLAS/CENTAUR (SURVEYOR) AND IGM GUIDANCE CONCEPTS

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ABSTRACT

The current IGM guidance concept and the Atlas/Centaur (Surveyor) guidance concept are both quite capable of performing the guidance functions associated with (1) injection into near-circular earth orbits ranging outward to synchronous altitude, or highly eccentric earth orbits; (2) injection into lunar or interplanetary transfer orbits; (3) deboost into orbit about a planetary body, and (4) deboost into a landing ellipse (assuming no atmosphere) from which soft-landing procedures may be initiated. Neither concept in its current form is considered capable of performing midcourse corrections nor orbit modification maneuvers in general, unless a data link is used to supply steering parameters directly for these maneuvers.

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SUMMARY

The current IGM guidance concept and the Atlas/Centaur (Surveyor) guidance concept are both quite capable of performing the guidance functions associated with (1) injection into near-circular earth orbits ranging outward to synchronous altitude, or highly eccentric earth orbits; (2) injection into lunar or interplanetary transfer orbits; (3) deboost into orbit about a planetary body, and (4) deboost into a landing ellipse (assuming no atmosphere) from which soft-landing procedures may be initiated. Neither concept in its current form is considered capable of performing midcourse corrections nor orbit modification maneuvers in general, unless a data link is used to supply steering parameters directly for these maneuvers.

I. INTRODUCTION

This document answers various pertinent questions concerning the feasibility of using the Atlas/Centaur (Surveyor) guidance concept or the Iterative Guidance Mode (IGM) concept to perform the guidance functions for (1) injection into near-circular earth orbits ranging outward into lunar or interplanetary transfer orbits, (3) midcourse corrections, (4) deboost into orbit about a planetary body, (5) orbit modification maneuvers, and (6) deboost into a landing ellipse (assuming no atmosphere) from which soft-landing procedures may be initiated.

There are three basic reasons for making this comparative analysis: (1) the possibility of using one concept for all guidance functions throughout the entire mission; (2) the excellent performance of both concepts on actual flights; and (3) to determine if either concept has advantages that would reduce the time delay from mission definition to flight ready soft-ware availability, thus accommodating mission changes that may occur unexpectedly during interplanetary launch opportunities.

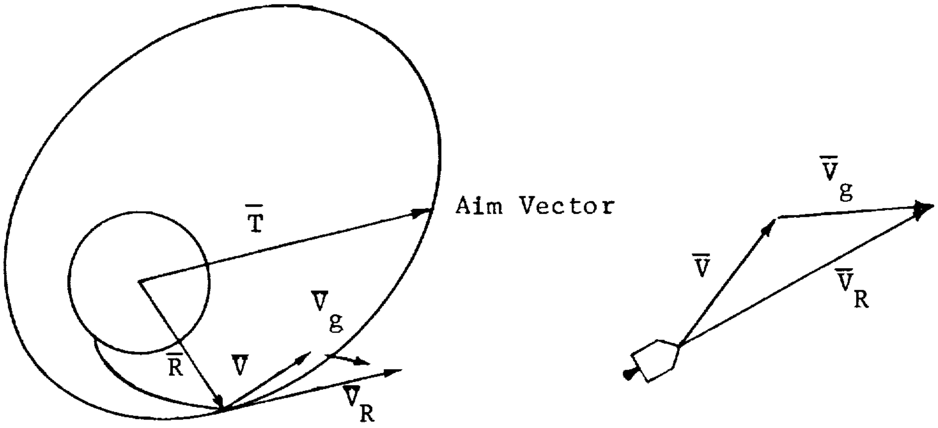
Each question is treated as a separate topic, and the answer is given for both the Atlas/Centaur and IGM concepts in a comparative text.

II. WHAT ARE THE MISSION LIMITATIONS?

The Atlas/Centaur (Surveyor) guidance concept is based on the use of a specified aim vector and conic equations to compute the required velocity vector, and velocity-to-be-gained techniques (References 1, 2 and 3).

The vector difference (Figure 1) between this required terminal velocity and the current velocity represents the velocity-to-be-gained. The concept requires steering to null this velocity-to-be-gained.

The steering is determined such that the vehicle thrust vector is directed with a pitch and yaw offset relative to the velocity-to-be-gained vector. These offsets are a function of the velocity-to-be-gained vector, the aim vector, the current position vector, and the energy-to-be-gained. The velocity-to-be-gained concept and the steering law relationships are shown in Figure 1, $\overline{C}$ being the offsets or shaping vector. The $\overline{C}$ must be determined via empirical analysis. The analyst may use an onboard functional form to define $\overline{C}$ to upgrade performance or accomplish other desired objectives.



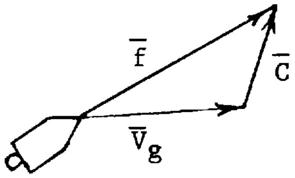
$\overline{V}_R$: Required Terminal Velocity Vector

$\overline{V}$: Current Vehicle Velocity

$\overline{V}_g$: Velocity-to-be-gained

Steering Law for the Atlas/Centaur, Reference 3, Sections 2.1.4, 2.1.5, and 2.1.6:

$$\overline{f} = \overline{V}_g + \overline{C}$$



$\overline{C}$: A vector of shaping parameters

$\overline{f}$: The steering vector

Figure 1 - Velocity-to-be-Gained and Atlas/Centaur Steering Relationship

This concept has been extensively studied and applied for both low and high altitude earth-satellite orbit injection (Reference 4), injection into lunar transfer orbits (References 1, 2 and 4), injection into interplanetary transfer orbits (Reference 4), and deboost into orbit about a planetary body (Reference 1). Both direct ascent and earth parking orbit modes were studied for the ascent-to-injection phase. For other applications, this concept has not been analyzed. From a theoretical standpoint, this concept will perform the guidance function to achieve any mission objective that can be expressed in terms of the specified aim vector, the conic parameters associated with the required terminal velocity, and the offset shaping functions. This means that it cannot handle the midcourse corrections or the orbit trim maneuvers unless a data link is used to supply directly the velocity-to-be-gained vector.

As an example of the further flexibility of the Atlas/Centaur guidance technique, consider its application for deboosting into landing ellipse (assuming no atmosphere) from a satellite orbit. The aim vector would be directed (approximately) through the landing site, having magnitude equal to the radius at which soft-landing procedures are to be initiated. Desired terminal energy (C_3) and the true anomaly of the aim vector are the inputs that assure the aim vector occurs at the desired location and has the desired magnitude. Thus, there may be a coast between cutoff and initiation of the soft-landing procedures, but one is assured of passing through the aim vector at the periapsis of the landing ellipse. There is no positive control over the inclination of the terminal ellipse, nor the location of the line of nodes, but in healthy flight situations these deviations would not be significant.

The Saturn V Iterative Guidance Mode (IGM) is based upon (1) the specification of desired terminal values for (R, V, γ, I, Ω) or implementation of some method to compute those values from other desired terminal functions, such as has been done using the lunar hypersurface; (2) the analytic solution of an approximate variational formulation of a time optimal problem; and (3) the inverse of this solution to yield steering functions.

The IGM steering equations take the form

$$\chi_p = A + Bt \quad \text{and} \quad \chi_y = C + Dt$$

(due to the simplified variational formulation, and the fact that terminal range is not constrained), where A, B, C, D, and t are computed as functions of the current state conditions and the desired terminal conditions, "t" being the time-to-go.

The current IGM implementation introduces empirical constants or shaping parameters that may be used to upgrade vehicle performance or to accomplish some other objective (Reference 6). These empirical constants appear in the equations for predicting terminal range angle, and for computing the A, B, C, D, and t steering parameters. Recent reformulation of the IGM has made it possible to reduce the number of empirical constants to one, that one being in the computation of the terminal range angle.

This concept has been extensively studied and applied for both high and low altitude earth satellite orbit injection (Reference 10), injection into lunar transfer orbits (Reference 7), and injection into interplanetary transfer orbits (unpublished results of R. M. McCraney, Northrop Corporation).

Some study has been done on deboost into orbit about a planetary body (Reference 9) and also on deboost into a landing ellipse from a satellite orbit (Reference 8). Other applications of this concept have not been analyzed. In theory this concept will perform the guidance function to achieve any mission objective that can be expressed functionally such that the desired terminal conditions (R, V, γ, I, Ω) can be extracted from these functions and for which the empirical shaping parameters (constants in IGM) can be established. This means that IGM cannot handle the midcourse corrections nor the orbit trim maneuvers unless a data link is used to supply directly the steering parameters.

The reason neither Atlas/Centaur nor IGM can perform the midcourse correction, or the orbit trim maneuver is this: It is not currently known how one could express the objectives of these maneuvers in functional form such that the inputs required by the software packages could be determined from these functions. However, this is not to imply that it could not be worked in later. In fact, it appears that if one has enough time, ingenuity, and resources he can make either of these concepts do almost any guidance function under near-nominal flight conditions. This statement can also be made for almost any other guidance concept. Granted all this, the fact remains that some concepts offer more mission flexibility, are more physically realistic, are more easily modified, etc., than others, and at this point one could not recommend that either of these concepts be modified to perform other guidance functions.

Other than the factors discussed above, the major operational disadvantages of both guidance concepts are primarily due to two factors: the use of the empirical constants or shaping parameters and the use of fixed point digital computer programs (with the associated rigidly fixed scaling coefficients) in each software package. The range of applicability of such coefficients or shaping parameters is not known generally, but only for certain specific, well-defined missions.

III. HOW ARE DAILY LAUNCH WINDOWS TREATED?

Basically, both the Atlas/Centaur and IGM concepts are the same; they both use empirically derived polynomials to compute the launch time dependent parameters.

The Atlas/Centaur package uses two classes of polynomials (Reference 5). One class has day-dependent coefficients with launch time as the independent variable to compute the unit aim vector, desired injection energy, and two shaping parameters. The other class has launch time dependent coefficients and the component of the unit aim vector in the launch azimuth direction as the independent variable to compute another shaping parameter.

The IGM concept uses three classes of polynomials (Reference 6). One class has day-dependent coefficients with launch time as the independent variable to compute launch azimuth. A second class has launch azimuth as the independent variable to compute the desired terminal inclination (I) and location of the descending node (Ω_D). The third class has day-dependent coefficients and uses a linear relationship in launch time and the "opportunity-out-of-parking orbit" as the independent variable to compute the inputs for the lunar hypersurface, namely, injection C_3, eccentricity, and the angle between the perigee vector and the minus aim vector. Interplanetary missions or other intercept missions could be implemented using the same techniques.

IV. HOW DO THE ON-BOARD IMPLEMENTATIONS COMPARE?

The Atlas/Centaur guidance implementation primarily consists of a special-purpose, fixed-point digital computer and an inertial navigation system. The digital computer has a memory capability of 3000 words of 25 bit length, and computational speed capability of updating the guidance every 1 to 1.5 seconds (Reference 3).

Both the digital computer and the inertial navigation system for the Saturn guidance implementation appear to offer more capabilities than the Atlas/Centaur concept requires for implementation. The Saturn digital computer is a general-purpose, fixed-point system with a memory capacity of 4096 words per memory module, words of 28 bit length (Reference 11). These modules can be added as required up to a total of eight modules.

V. WHAT ARE THE ACCURACY AND PERFORMANCE CAPABILITIES?

The terminal accuracy of both guidance concepts has been evaluated for lunar missions, with results indicating that concept-produced terminal errors are much less than system implementation errors. It can be assumed that similar results would be obtained for interplanetary missions.

As to performance, the velocity-to-be-gained concept of Atlas/Centaur makes no claim of optimality. The IGM concept, previously discussed, is based upon some considerations as to optimality. In practice, the empirical shaping parameters in either system are the critical factors in how well they perform. Either system can be tuned to give excellent performance results.

VI. WHAT ARE THE MISSION REDEFINITION TIME DELAYS?

A distinction is made here between alternate mission and mission redefinition. Mission redefinition implies those mission changes made before launch. Alternate mission implies those changes in mission made inflight. In either case, the mission change could be just a change in the inputs to the software, or it could imply a mission of a completely different class. If the change is simply a change in the inputs, the time delay is only that time required to target the new mission.

The Atlas/Centaur targeting procedures are fully automated, and References 3 and 4 indicate that a new mission can be targeted in a matter of days; a week appears to be a conservative estimate. As was brought out in a presentation to Dr. von Braun, the IGM concept can be targeted to a new mission in about a week; thus, the two concepts appear to be equivalent in this respect.

This estimate of a week does not include changing scaling coefficients in the software package, rewiring of any fashion, or recheckout of new on-board software packages.

At present both concepts treat only one class of missions (one formulation of desired end conditions). To add other classes of missions would require extensive analysis, development, and modification.

VII. HOW ARE IN-FLIGHT ALTERNATE MISSIONS IMPLEMENTED?

Provision has been made in the IGM guidance software package for abort and alternate mission capability in the event of a system malfunction (Reference 6). The system is capable of achieving parking orbit insertion with a single engine out during first or second stage burns, and achieving the primary mission if engine-out occurs during latter portions of these burns. Direct staging capability now exists and dual engine out capability can be added, if needed.

No provision has been made for alternate mission capability in the Atlas/Centaur concept.

It seems that for either concept a data link to read in a new set of input constants (assuming care has been taken not to violate the accuracy range of the scaling coefficients) is all that is required to handle alternate missions of the same class as the prime mission. This implies that one can generate input constants in real time or that sufficient prelaunch studies have been made to cover all alternate mission situations.

VIII. CONCLUSIONS

Both the Atlas/Centaur guidance concept and the IGM guidance concept offer a high degree of mission flexibility. It is found that both concepts can perform the guidance functions for (1) injection into near-circular earth orbits ranging outward to synchronous altitude, or highly eccentric earth orbit, (2) injection into lunar or interplanetary transfer orbits, (3) deboost into orbit about a planetary body, and (4) deboost into a landing ellipse (assuming no atmosphere) from which soft-landing procedures may be initiated. It is found that neither concept will perform the guidance function for (1) midcourse maneuvers or (2) the general orbit modification maneuvers, unless a data link is used to supply those steering parameters directly. It is felt that the major operational disadvantages of both techniques are due to their use of empirical shaping parameters, and fixed-point digital computer programs in their software packages.

Both techniques handle daily launch windows the same way. Empirically generated polynomials are used to compute the inputs that vary across the launch window.

The on-board implementations are not greatly different, although the Atlas/Centaur package may not use as much memory as the IGM.

Both concepts are adaptive (use current measurements), and the empirical shaping factors of either technique can be tuned to produce excellent performance results. However, one should keep in mind that malfunctions could destroy the validity of the parameters of either technique.

Either guidance technique can be targeted to a new mission in a matter of days. This estimate does not include changing scaling coefficients in the software package, rewiring of any fashion, nor recheckout of new on-board software packages.

It is felt that either technique can handle alternate missions if a data link is provided to read in a new set of inputs, assuming care has been taken not to violate the accuracy range of the empirical shaping parameters and scaling coefficients, and that the functional representation of the alternate mission is the same as the prime mission.

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APPROVAL

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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