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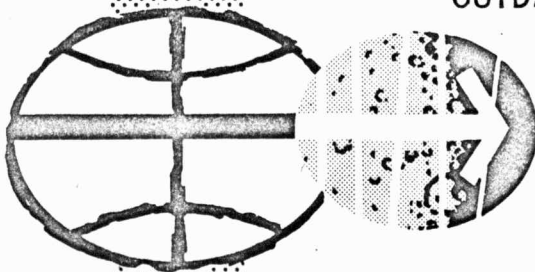
INTERNAL NOTE MSC - EG - 69 - 42

PROJECT APOLLO

SYSTEM PERFORMANCE WITH PROPOSED NEW DELTA
GUIDANCE REVERTED AS MUCH AS POSSIBLE TO
APOLLO 11 LM POWERED DESCENT GUIDANCE

R. A. LARSON
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GUIDANCE AND CONTROL DIVISION



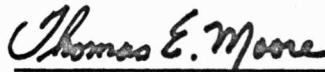
MANNED SPACECRAFT CENTER
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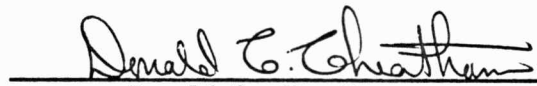
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SUMMARY

If the new delta guidance equations are implemented in the LGC, the present guidance system basically is maintained; because by proper selection of gains, the new acceleration equation gives the identical acceleration command of the present system. If these new equations were implemented and if insufficient time were available to determine and verify "optimum" system gains, the "nominal" gains which revert delta guidance back to the present system could be flown.

There are other guidance program changes; i.e., TGO calculations and the order of computation of other routines that go with the new delta guidance. There may not be enough software capability in the LGC to provide options on these items for reverting back to the present system. It is, therefore, the intent of this study to investigate system performance with these proposed changes with "nominal" gains in the guidance equation which maintain the present guidance acceleration commands. The determination of optimum gains for delta guidance is not a part of this study.

The results of this study show improvement of system performance with the incidental changes proposed with delta guidance--that is, these changes made to the present guidance system without regard to delta guidance results in performance improvement, especially with regard to redesignation characteristics. An even greater performance improvement would be available when optimum delta guidance gains are determined. A successful landing at a landing site that has a three degree slope, such as the approach to some possible landing points in Fra Mauro, may even require this new guidance.

INTRODUCTION

The Apollo 11 LM powered descent guidance guides the LM to fixed points in space with resulting unique trajectories calculated for off-nominal conditions produced by navigation error, terrain, landing site redesignation, and FTP thrust dispersions. A "delta guidance" modification to the present LM guidance which guides to a nominal trajectory was presented in reference 1. The advantages of this system, as shown in reference 1, are a potential reduction of altitude dispersion (caused by navigation-IMU errors and terrain slope) near the area of manual takeover (2000 ft range) by a factor of five, and a near elimination of fuel variation with FTP thrust level. An example of the third advantage of lower fuel penalty for a landing site redesignation was given in reference 2--a 3700 ft redesignation was made at one-fourth the cost with the Apollo 11 system.

Some modifications to the delta guidance of reference 1 have been suggested by Mr. Klumpp of MIT. The "new delta guidance" incorporating the basic concepts of Mr. Klumpp's suggestions are presented herein. This proposed guidance is more general than the Apollo 11 guidance because, by proper selection of gains, the Apollo 11 guidance is one of the many possible solutions of the proposed guidance. The basic guidance law of the Apollo 11 guidance can therefore be maintained, with the exception though, of other incidental changes such as the order of computation routines and mainly a new time-to-go routine. The purpose of this report is to evaluate the effect of these other incidental changes on system performance, with the proposed new delta guidance reverted as much as possible to Apollo 11 guidance.

GUIDANCE LOGIC

Guidance Equations

The Apollo 11 quadratic guidance law guides the vehicle to a set of aim conditions at a point in space. This point is achieved at a TGO (time-to-go) of zero. Off-nominal conditions during a LM descent resulting from navigation error, terrain slope, and landing site redesignations will produce an off-nominal trajectory which will converge back to the nominal as TGO approaches zero. The objective of delta guidance is to guide the vehicle back to the nominal trajectory at TGO greater than zero.

A nominal trajectory can be defined by specifying all of the coefficients (\overline{RD} - position, \overline{VD} - velocity, \overline{AD} - acceleration, \overline{JD} - jerk, and \overline{SD} - snap) of the quadratic guidance law. The Apollo 11 guidance uses only \overline{RD} , \overline{VD} , \overline{AD} , and one component of \overline{JD} . The equations for the nominal trajectory conditions \overline{AN} , \overline{VN} , and \overline{RN} can be seen in the TGO and guidance routines of figures 1 and 2.

The delta guidance of reference 1 consisted of the Apollo 11 quadratic acceleration command plus a delta term for guiding back to the nominal trajectory. The new delta guidance being proposed (as shown in figure 1) consists of the nominal quadratic acceleration, \overline{AN} , plus delta. It can be shown that this acceleration command equation is equivalent to that derived in the appendix of reference 1, of which the gains K_1 and K_2 , are directly related to the damping and natural frequency response of this position control system.

This new guidance equation is that of a general position control system, and it can be shown that one of the possibilities of this equation is that of the present guidance equation. By selecting the

K_1 and K_2 gains equal to $6/TGO$ and $12/TGO^2$, respectively; and by replacing \overline{AN} , \overline{VN} , and \overline{RN} with their respective equations, the proposed \overline{AG} equation on the right side of figure 1 reduces exactly to the Apollo 11 guidance equation shown on the left side of figure 1. It therefore follows, that if the new delta guidance is implemented in the LGC, the capability exists for reverting back to the Apollo 11 system by proper choice of gains. It also follows, though, that any undesirable trajectory dispersions with the present system can be reduced with the new guidance by proper choice of gains.

Velocity Control Throttle Logic

The first six minutes of powered descent with the Apollo 11 guidance is flown with the descent engine at the non-throttleable FTP position. After approximately six minutes, the velocity is reduced to a point such that the remainder of the braking phase can be flown at the lower throttleable region of about 60 percent of FTP. Fuel penalties are associated with this type of control because the braking phase must be designed to produce throttle recovery prior to higate for the lowest possible FTP thrust output--for higher FTP thrust levels, throttle recovery occurs early with a resultant fuel penalty. The objective of the velocity control throttle logic is to eliminate this fuel penalty by controlling the forward velocity to the nominal value at any given TGO. If the nominal velocity is defined as the velocity profile produced by a low FTP thrust engine, then a high thrust engine will be evident by a lower than nominal velocity at a given TGO. By temporarily throttling the engine down into the throttleable region, the velocity can be controlled back to nominal.

The throttle logic of reference 1 consisted of curve-fitting the nominal velocity profile and storing in the LGC the coefficients of that curve fit. The new proposal for this logic is to design the braking phase aim conditions so that a guidance thrust command approximately equal to a low engine FTP thrust profile is produced. The delta guidance nominal velocity (\overline{VN}) equation can then be used for the nominal velocity of the throttle logic. The throttle logic is shown in figure 1. If this throttle logic is implemented in the LGC, the capability exists for reverting back to the Apollo 11 system by merely adjusting the pulse test level (L_1) so that pulses will not occur. There is, of course, a difference in braking phase targets if the logic is not used; i.e., same type as Apollo 11 targets.

Other Guidance Logic Changes

The following other logic changes are proposed with delta guidance. These changes are of a nature so that it would be difficult to provide options of reverting back to the present logic. It is, therefore, the object of this report to investigate system performance with these changes by themselves. These changes are shown on figures 1 and 2. The following discussion will proceed down the right side of figure 1 as each change with respect to the Apollo 11 system is encountered.

Guidance Coordinate Orientation. - This routine used to be at the proposed new location in the guidance computation sequence. It was moved to its present location (see left side of figure 1) because of the UYGP dependence on TGO. If the routine were calculated before TGO, the possibility would exist of a drastic 180 degree rotation of the guidance coordinate axes which would then result in erroneous guidance commands. If the "K" term were zero, then it would be independent of TGO and the calculation could occur as proposed. For Apollo 11, a $K = 0$ for the approach phase was shown to have redesignation advantages and was flown. This report will demonstrate advantages of $K = 0$ for braking phase also. The desirability of the proposed sequence of the calculation is for the earliest possible orientation of guidance frame when lateral redesignations are encountered. The orientation is two seconds later with the Apollo 11 sequence.

Time-to-go Calculation. - The Apollo 11 TGO solution utilizes the Newton-Raphson iterative technique to solve for that value of TGO which satisfies the desired final jerk in the guidance Z-axis. Two undesirable features with this TGO are: (1) aim conditions are restricted to alternating signs in order to guarantee a TGO solution. The Apollo 11 aim point altitude had to be raised from 77 to 150 feet in order to obtain desired trajectory conditions with the restricted aim conditions. (2) The forward velocity-range profile can get much lower than nominal on redesignated trajectories.

The proposed TGO solution utilizes the Newton-Raphson iterative technique to solve for that value of TGO which makes the guidance Z-axis component of nominal range (RN) equal to the actual range (RZG), as shown on figure 2. Because any practical RZN vs TGO profile would be concave up over the range of TGO that could exist on a trajectory, a TGO solution will be guaranteed regardless of aim conditions. The proper selection of T_{max} (see figure 2) provides this guarantee. With the T_{min} logic of figure 2, redesignations could be permitted at any time in P64 (presently permitted only for TGO 30). If ever a redesignation too short were made ($TGO = T_{min}$ aim point change time), the system would merely proceed with the previous commands for 2 sec and then would go to P65.

For a given landing site redesignation, the proposed TGO will compute a smaller value than the Apollo 11 TGO. This smaller value of computed TGO should then result in less time to arrive at the new landing site and therefore, should use less fuel.

Lead Time Correction. - The acceleration command equation (guidance routine) on the left side of figure 1 is the basic quadratic equation but was not the one used for Apollo 11 flight. This equation was modified to include a lead time (2.2 sec) correction to prevent instability for small TGO. The remainder of this paragraph shows the reason for the instability. It is an axiom of control system theory that the outer loop response (position control) for stability should be slower than any of the following: inner loop response (velocity control), time delays (2 sec for DAP), transport delays (1.3 sec LGC computation delay), or sample data time intervals (2 sec).

The LGC stability problem is then obvious by inspecting the proposed \overline{AG} equation of figure 1. As previously stated, \overline{AG} on right is equivalent to \overline{AG} on left with gains K_1 and K_2 as indicated. The approximate time constant (τ) of the outer loop is $TGO/\sqrt{12}$ ($K_2 = W_n^2$, W_n = natural frequency, and $\tau = \frac{1}{W_n}$). The higher the value of τ , the slower the system response. For the approach phase, the minimum TGO is 10 sec which gives a $\tau = 3$ sec, which is of the same order as the inner loop delays, and therefore, system stability would be a matter of concern.

Stability can be maintained with the proposed \overline{AG} equated by merely limiting the K_1 , K_2 gains for that value of TGO at which the system is stable. The equation will then still continue to guide to the nominal trajectory with constant gains. The lead time correction of Apollo 11 is nowhere near as simple as this. The left side \overline{AG} equation of figure 1 contains gains that look like K_1 and K_2 , but they are not equivalent. If those gains were frozen, the vehicle would not be guided to the nominal.

Radial Acceleration Control. - If the new delta guidance with throttle logic is implemented and used, then there is no need for the radial control because the new guidance will maintain both radial and horizontal control at all times. The question remains though, that if delta is implemented but the throttle logic is not used, then should the radial control option be left in? The radial control was designed mainly for one-phase targeting which is not considered anymore. It's value to the Apollo 11 type trajectory is questionable.

TEST PLAN

Five runs were made for each of three guidance configurations, utilizing the Apollo 11 type trajectory in all cases. The three configurations were:

- a. Apollo 11 guidance logic.
- b. Apollo 11 guidance logic, except without radial control.
- c. New delta guidance with nominal gains so that acceleration command of present guidance, no throttle logic and no radial control.

The five runs were:

- a. Nominal
- b. THVH-1°; 3-sigma high thrust FTP engine, Nav and IMU errors that produce vehicle high, and a 1° terrain slope of terrain high.
- c. TLVL+1°; reverse of above conditions.
- d. Redesignation at a range of 20,000 ft of 4.5 degrees forward. and five degrees to the left.
- e. Redesignation at a range of 20,000 ft of 4.5 degrees forward.

The navigation-IMU errors were those used in reference 1; i.e., they produce an altitude error of ± 3000 ft at 300 sec after FTP, and a rate-of-descent error of 20 ft/sec at higate if no radar velocity updates prior to higate. The navigation error at FTP ignition was ± 1108 ft in the platform X-axis; no velocity error. The IMU error consisted of accelerometer bias and platform misalignment. The error magnitudes were $\pm .00492$ ft/sec² and ± 0.18 degrees, respectively, in each of three axes with the signs of each error/axes selected for worst effect on altitude.

In addition, nine runs of the above 15 run matrix were repeated using the Apollo 12 trajectory. All runs were started at the FTP initial conditions of the Apollo 11 (OT) trajectory--just the aim conditions were changed for the Apollo 12 runs. Delta guidance runs used nominal aim conditions plus jerk and snap coefficients of the nominal trajectory.

TEST RESULTS

Results of this study are tabulated on tables I(a to c) and II (a to c) for Apollo 11 and 12 trajectories, respectively. The tables show for the three guidance configurations, various parameters of interest starting at radar acquisition on table (a) to touchdown on (c). The discussion will proceed in the order of the proposed changes on figure 1. The proposed guidance equation (\overline{AG}), although used in this study, is not an issue in these results because only the nominal K_1 and K_2 gains were used. With these nominal gains, the new equation is identical to the present equation with the exception of "lead time" which will be discussed. The throttle logic, although implemented in this study, was disabled. The effects of the other guidance logic changes of the proposed new delta guidance follows.

Guidance Coordinate Orientation

In the proposed mechanization, the independence of this routine on TGO is an improvement in that it maintains lower terminal azimuth and lower maximum pilot roll attitude, as seen on table I(c). The Apollo 11 guidance without radial control used a $K = 0$ (see figure 1, Apollo 11 logic) compared to $K = 1$ for the braking phase of Apollo 11 guidance. The new delta, of course, produces equally lower quantities. Note also on table II(c) where $K = 0$ was also used for present guidance runs, the nominal azimuth and roll were the same for all three cases.

Time-to-go Routine

On a nominal trajectory when under throttle control, both equations for TGO should produce the same answer. But, when not under throttle control (FTP) where commanded accelerations are not being applied (i.e., until the new throttle logic is used), a different answer would be expected from the two TGO equations. At FTP ignition on the Apollo 11 trajectory with the same state vector conditions, the new TGO computes 558 sec compared to 590 sec with the present equation. The effect on the trajectory, though, with this TGO difference is surprisingly negligible as shown on the pitch profiles of figure 3 and the data on table I and II(a). For off-nominal conditions (tables I(b) and II(b)), the altitude dispersions at a range-to-go of 2000 ft are lower with the proposed system and are just slightly higher at $RGO = 20,000$ ft.

A major improvement with the new TGO can be seen in the redesignation characteristics of tables I and II(c). A redesignation from the Apollo 11 trajectory costs 70 percent more delta-V with the Apollo 11 TGO than with the proposed TGO. This cost difference is about 30 percent from the

Apollo 12 trajectory, of which the final approach was speeded up to improve redesignation characteristics. A comparison of redesignated pitch profiles is shown on figures 4 and 5. Figure 5 shows that with the proposed TGO the LM goes initially to a lower pitch attitude, holds that attitude for a while, and then converges to the nominal pitch profile to the new landing site.

A redesignation from the Apollo 11 trajectory, with Apollo 11 guidance, cost 52 percent more delta-V than with the Apollo 12 (faster approach) trajectory. This cost difference is reduced to about 17 percent with the proposed TGO for each trajectory. It might then be possible with better gains in the new acceleration equation (AG) to drive this difference to zero, so that redesignation characteristics would be practically independent of the trajectory's final approach speed, and therefore, the slower (more desirable to pilots) Apollo 11 trajectory (but with a lower logate that the new TGO will permit) could be used in the future.

Lead Time

The absence of the lead time correction in the proposed guidance contributes, along with the proposed TGO and absence of radial acceleration control, to the small differences in nominal trajectories as seen on table I(a). These differences are actually immaterial because LM descent targeting programs when given the guidance system to be used, will produce the aim conditions to provide the specified trajectory. The only question on lead time is then system stability at small TGO. The simulation of this study contains the transport and time delays of the LGC, but not a slosh model. No instability was observed in any of the runs with TGO going to its minimum of 10 sec. But, if an instability would exist in the actual system, then the solution as already stated would be to limit the K_1 , K_2 gains to the minimum TGO for stability. The limiting of these gains can also be accomplished by appropriate projecting of aim point targets, rather than programming limits on the quantities.

Radial Acceleration Control

The radial control which was designed to remove the inherent large dispersions of off-nominal, "one-phase" trajectories, apparently has the opposite effect on the "modified two-phase" Apollo 11 trajectory. As shown on table I(b), the altitude dispersion at 2000 ft range is lower with the Apollo 11 system if the radial control is removed. The dispersion at 20,000 ft range is larger, but the percentage difference is much smaller than at 2000 ft. The doubtful value of the radial control, based on these two runs and the fact that the throttle logic routine of

delta guidance if used would definitely not require radial control, would suggest that it be dropped.

CONCLUDING REMARKS

The effects of the incidental changes associated with the new delta guidance are:

New Time-to-go. - The only major difference in the Apollo 11 guidance and proposed guidance with nominal gains is a large improvement of redesignation characteristics. A redesignation from the Apollo 12 trajectory cost 70 percent more delta-V with the Apollo 11 TGO than with the proposed TGO. The effect of the proposed TGO on nominal trajectory shaping is negligible. For off-nominal conditions, the altitude dispersions in the area of manual takeover are smaller with the proposed TGO.

Guidance Coordinate Orientation. - The elimination of dependence of this routine on TGO (as was done for Apollo 11 in just the approach phase) results in the desirable characteristics of slightly smaller azimuth rotation of the guidance frame, and smaller roll attitudes.

Radial Acceleration. - The elimination of this routine results in smaller altitude dispersions in the area of manual takeover.

Lead Time Correction. - System stability is easily maintained with the proposed system by merely limiting the natural frequency response.

The new delta guidance is recommended for the following reasons: Landing sites with rough terrain approaches and sloped areas near the landing site are likely to be a problem for the Apollo 11 point guidance of providing desirable manual takeover conditions (approximately 2000 ft range-to-go). The more general delta guidance with properly selected gains should be capable of more nearly meeting the desirable takeover conditions. The question of gain values, though, need not be involved in a decision to use this proposed system because the Apollo 11 guidance law can be maintained with the proposed guidance. This study has shown that the incidental parts of the proposed guidance that are not revert-able to the present system have minor effects on the trajectory, with the exception of a large improvement of redesignation characteristics with the proposed TGO.

REFERENCES

1. Moore, T. E., McSwain, G. G., Montgomery, J.D.: Guidance Laws for Controlling Off-Nominal LM Powered Descent Trajectories Back to the Nominal. MSC Internal Note EG-69-9, February 28, 1969.
2. Moore, Thomas E.: Some Redesignation Characteristics Attributed to Slowing the LM Landing Approach Trajectory. MSC Internal Note EG-69-22, May 30, 1969.

TABLE Ia. - TEST CASES RESULTS WITH APOLLO 11 TRAJECTORY

		Radar Acquisition		Throttle Recovery Time Before Higate Sec	Higate Time From FTP Sec	Higate	
		Time From FTP, Sec	True Altitude Feet			Altitude Feet	Dispersion
Apollo 11 Guidance	Nominal	310	30961	116	478	7557	
	THVH -1°	294	36324	138	494	9783	3940
	TLVL +1°	308	26822	34	454	5843	
	Redes. @ R = 20K 2°F, 5°L	310	30961	116	478	7557	
	Redes. @ R = 20K 4.5°F	310	30961	116	478	7557	
Apollo 11 Guidance Without Radial Acceleration Control	Nominal	308	32109	120	480	7524	
	THVH -1°	300	37019	142	486	9714	4201
	TLVL +1°	310	26700	40	458	5513	
	Redes. @ 20K 2°F, 5°L	308	32109	120	480	7524	
	Redes. @ 20K 4.5°F	308	32109	120	480	7524	
Proposed New Delta Guid., Nom. Gains, TGO (RN), No Radial Control	Nominal	302	31530	118	480	7330	
	THVH -1°	290	36735	140	486	9487	4394
	TLVL +1°	308	25800	34	456	5093	
	Redes. @ 20K 2°F, 5°L	302	31530	118	480	7330	
	Redes. @ 20K 4.5°F	302	31530	118	480	7330	

TABLE Ib. - TEST CASES RESULTS WITH APOLLO 11 TRAJECTORY

		At 20,000 Ft Range		At 2000 Ft Range			At Altitude = 500	
		Altitude Feet	Dispersion	Altitude Feet	Dispersion	Forward Velocity Ft/Sec	Rate of Descent Ft/Sec	Forward Velocity Ft/Sec
Apollo 11 Guidance	Nominal	5838		518		68	16	67
	THVH -1°	7625	3059	915	571	66	16	42
	TLVL $+1^{\circ}$	4566		344		68	17	84
	Redes. @ R = 20K 2°F , 5°L	5838		292		63	17	91
	Redes. @ R = 20K 4.5°F	5838		96		58	21	133
Apollo 11 Guidance Without Radial Acceleration Control	Nominal	5825		518		69	16	67
	THVH -1°	7594	3127	896	503	66	16	43
	TLVL $+1^{\circ}$	4467		393		68	16.5	77
	Redes. @ 20K 2°F , 5°L	5825		308		63	17	91
	Redes. @ 20K 4.5°F	5825		98		58	21	133
Proposed New Delta Guid., Nom. Gains, TGO (RN), No Radial Control	Nominal	5743		540		67.8	15	65
	THVH -1°	7428	3198	872	430	67.6	16	44
	TLVL $+1^{\circ}$	4230		442		67.5	16	71
	Redes. @ 20K 2°F , 5°L	5743		381		66.9	15	86
	Redes. @ 20K 4.5°F	5743		248		66.5	15	121

TABLE Ic. - TEST CASES RESULTS WITH APOLLO 11 TRAJECTORY

		Redesignation Feet		Characteristic Velocity $\Delta \Delta V$ Ft/Sec	Azimuth at Landing Degrees	Maximum Pilot Roll Attitude Degrees
		Forward	Lateral			
Apollo 11 Guidance	Nominal	0	0	0	.3	.04
	THVH -1°	0	0	70	10	12
	TLVL $+1^\circ$	0	0	-80	8	8
	Redes. @ R = 20K 2°F, 5°L	2777	1949	107	15	14
	Redes. @ R = 20K 4.5°F	7554	0	247	.3	.04
Apollo 11 Guidance without Radial Acceleration Control	Nominal	0	0	0	.2	.01
	THVH -1°	0	0	76	6	7
	TLVL $+1^\circ$	0	0	-77	5	4
	Redes. @ 20K 2°F, 5°L	2777	1948	107	15	14
	Redes. @ 20K 4.5°F	7562	0	248	.2	.01
Proposed New Delta Guid., Nom. Gains, TGO (RN), No Radial Control	Nominal	0	0	0	.2	.01
	THVH -1°	0	0	51	5	7
	TLVL $+1^\circ$	0	0	-94	3	5
	Redes. @ 20K 2°F, 5°L	2794	1937	62	13	16
	Redes. @ 20K 4.5°F	7632	0	148	.2	.01

TABLE IIa. - TEST CASES RESULTS WITH APOLLO 12 TRAJECTORY

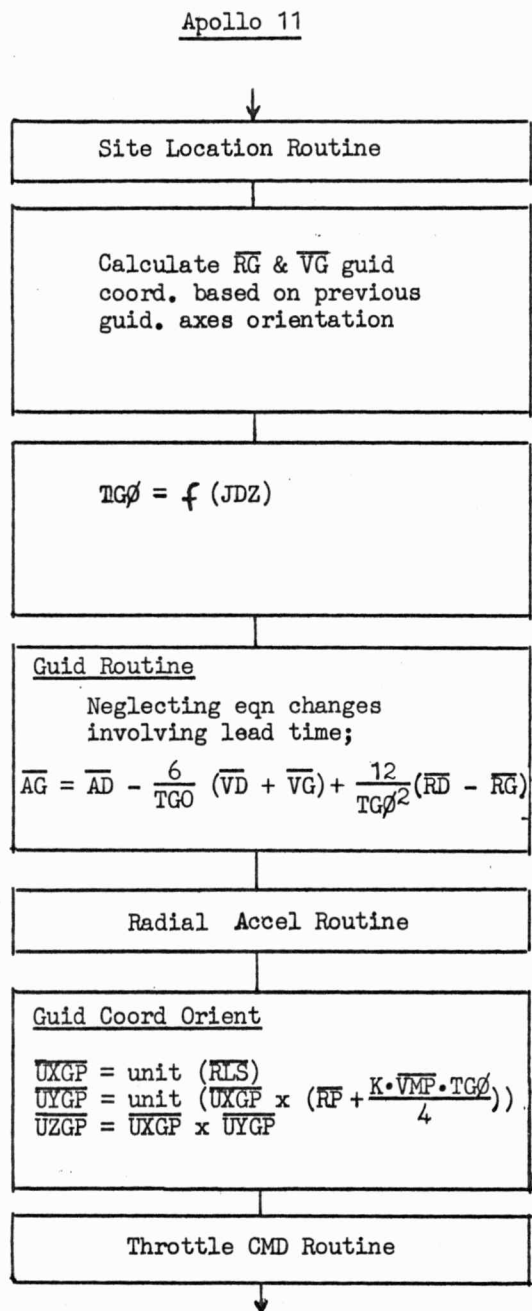
		Radar Acquisition		Throttle Recovery Time before Higate Sec	Higate Time from FTP Sec	Higate	
		Time from FTP Sec	True Altit. Feet			Altitude Feet	Dispersion
Apollo 11 Guidance	Nominal	304	31410	116	478	7639	
	THVH -1°	266	38112	140	484	9875	4109
	TLVL $+1^{\circ}$	306	26937	30	454	5766	
	Redes. @ R = 20K 2°F , 5°L						
	Redes. @ R = 20K 4.5°F	304	31410	116	478	7639	
Apollo 11 Guidance without Radial Accel Control	Nominal	302	32443	120	480	7665	
	THVH -1°						
	TLVL $+1^{\circ}$						
	Redes. @ 20K 2°F , 5°L						
	Redes. @ 20K 4.5°F						
Proposed New Delta Guid., Nom, Gains, TGO (RN), No Radial Control	Nominal	308	32113	120	480	7634	
	THVH -1°	298	37130	142	486	0057	4522
	TLVL $+1^{\circ}$	312	26500	38	458	5435	
	Redes. @ 20K 2°F , 5°L						
	Redes. @ 20K 4.5°F	308	32113	120	480	7634	

TABLE IIb. - TEST CASES RESULTS WITH APOLLO 12 TRAJECTORY

		At 20,000 Ft Range		At 2000 Ft Range			At Altitude = 500	
		Altitude Feet	Dispersion	Altitude Feet	Dispersion	Forward Velocity Ft/Sec	Rate of Descent Ft/Sec	Forward Velocity Ft/Sec
Apollo 11+	Nominal	5377		515		86	15	86
	THVH -1°	7259	3189	964	637	85	21	49
	TLVL $+1^{\circ}$	4070		327		86	15	113
	Redes. @ R=20K 2°F , 5°L							
	Redes. @ R=20K 4.5°F	5377		330		82	9.5	149
Apollo 11 Guidance without Radial Acceleration Control	Nominal	5380		523		86.5	15	85
	THVH -1°							
	TLVL $+1^{\circ}$							
	Redes. @ R=20K 2°F , 5°L							
	Redes. @ R=20K 4.5°F							
Proposed New Delta Guid., Nom. Gains, TGO (RN), No Radial Control	Nominal	5358		578		88	16	78
	THVH -1°	7253	3294	1036	610	88	22	48
	TLVL $+1^{\circ}$	3959		426		88	15	96
	Redes. @ 20K 2°F , 5°L							
	Redes. @ 20K 4.5°F	5358		398		87.6	10	121

TABLE IIc. - TEST CASES RESULTS WITH APOLLO 12 TRAJECTORY

		REDESIGNATION		CHARACTERISTIC VELOCITY $\Delta \Delta V$ Ft/sec	AZIMUTH AT LANDING Degrees	MAXIMUM PILOT ROLL ATTITUDE Degrees
		FORWARD	LATERAL			
Apollo 11 Guidance	Nominal	0	0	0	.2	.03
	THVH - 1°	0	0	58	6	5
	TLVL +1°	0	0	-103	3	2
	Redes. @ R = 20K 2°F, 5°L					
	Redes. @ R = 20K 4.5°F	8728	0	184	.2	.03
Apollo 11 Guidance without Radial Accel. Control	Nominal	0	0	0	.2	.03
	THVH -1°					
	TLVL +1°					
	Redes. @ 20K 2°F, 5°L					
	Redes. @ 20K 4.5°F					
Proposed New Delta Guidance, Nom. Gains, TGO (RN), No Radial Control	Nominal	0	0	0	.2	.03
	THVH -1°	0	0	43	4	5
	TLVL +1°	0	0	-71	3	1
	Redes. @ 20K 2°F, 5°L					
	Redes. @ 20K 4.5°F	8560	0	140	.2	.03



Note: $TG\phi$ is a positive number,
i.e., $TTF = -TG\phi$

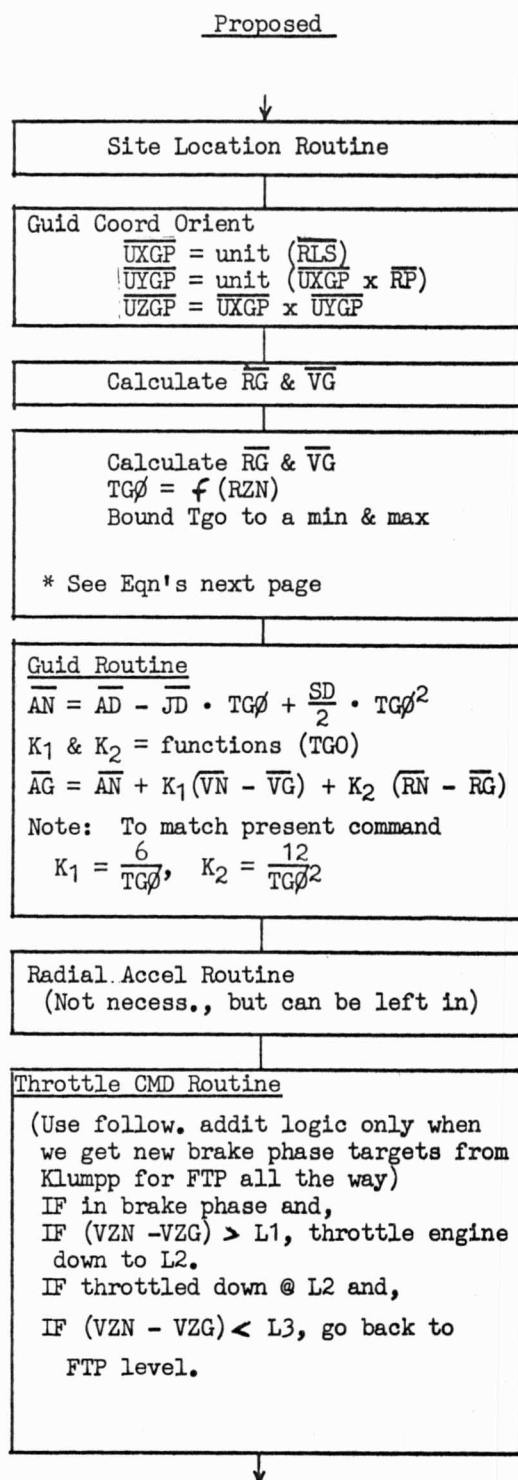


Figure 1.- Apollo 11 LMpowered descent guidance logic and
proposed delta guidance

* NEW TIME-TO-GO BASED
ON RANGE

Set Tmax & Tmin for braking or approach phase

$$\epsilon = \text{TG}\phi / 128.0$$

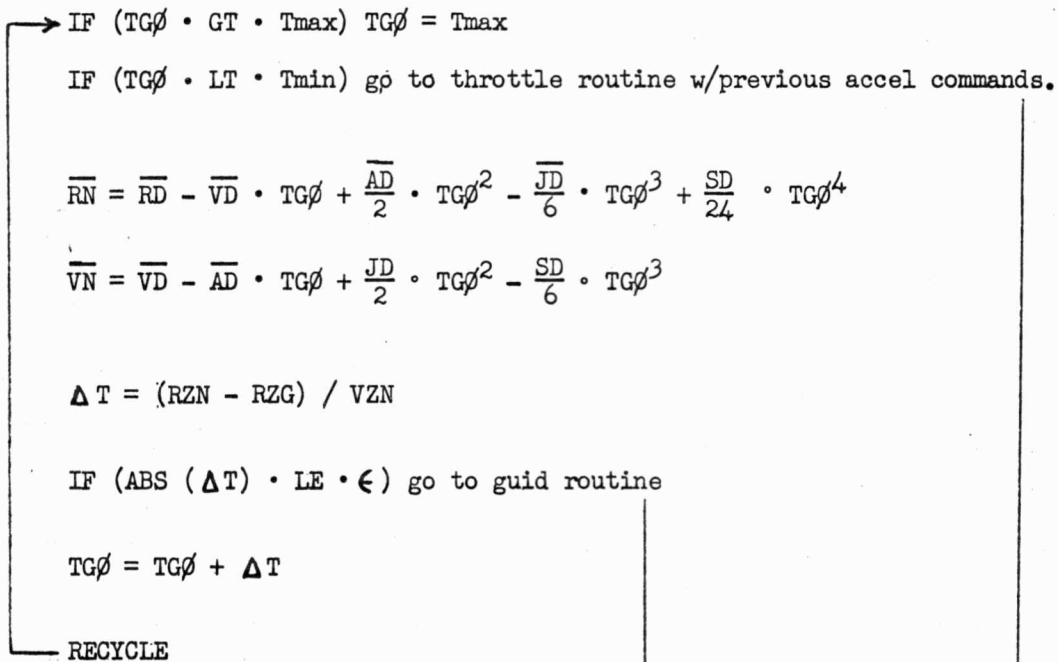


Figure 2. - TGO routine of proposed delta guidance

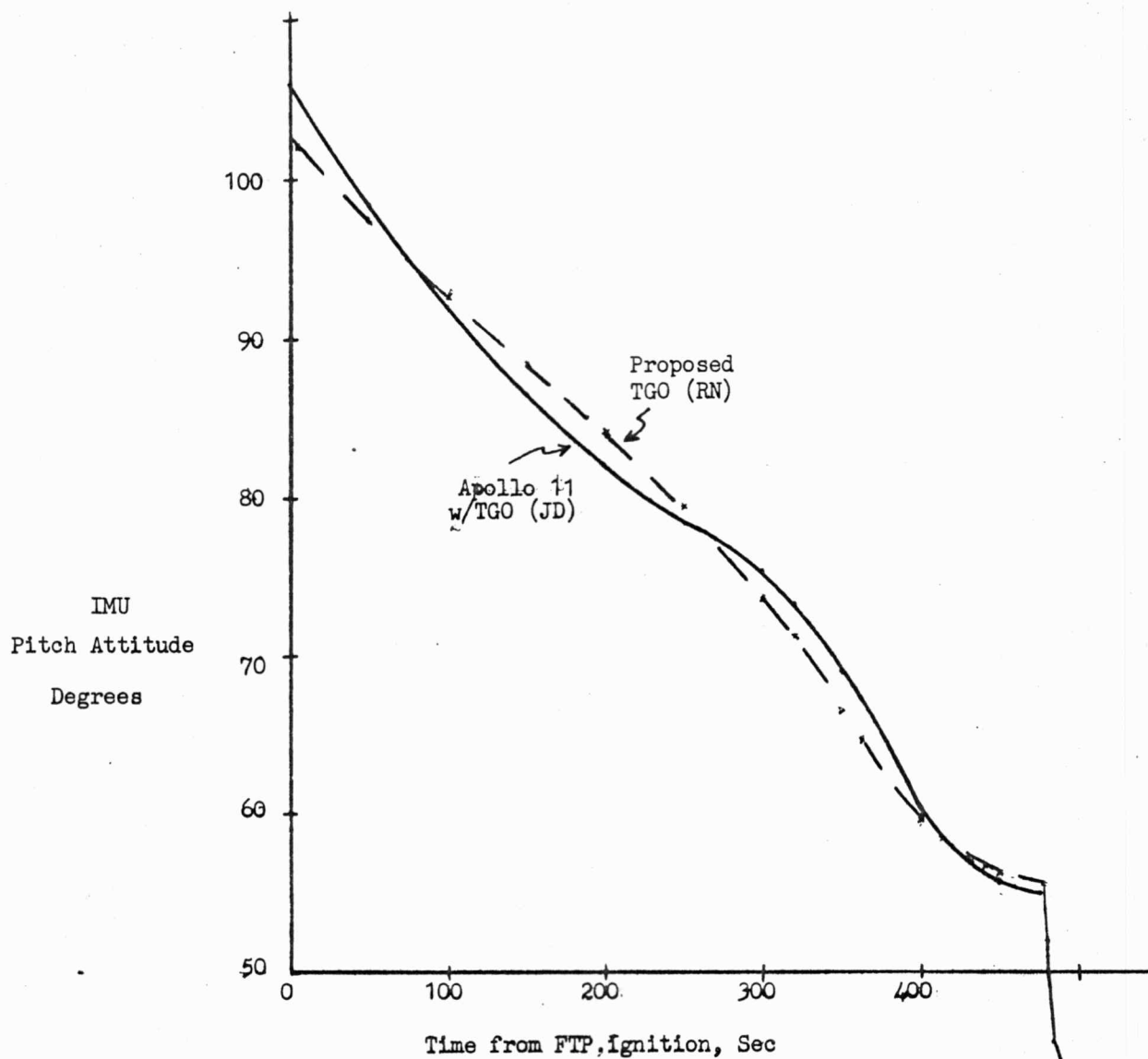


Figure 3. - Pitch profiles to higate with Apollo 11 and proposed guidance and with Apollo 11 trajectory

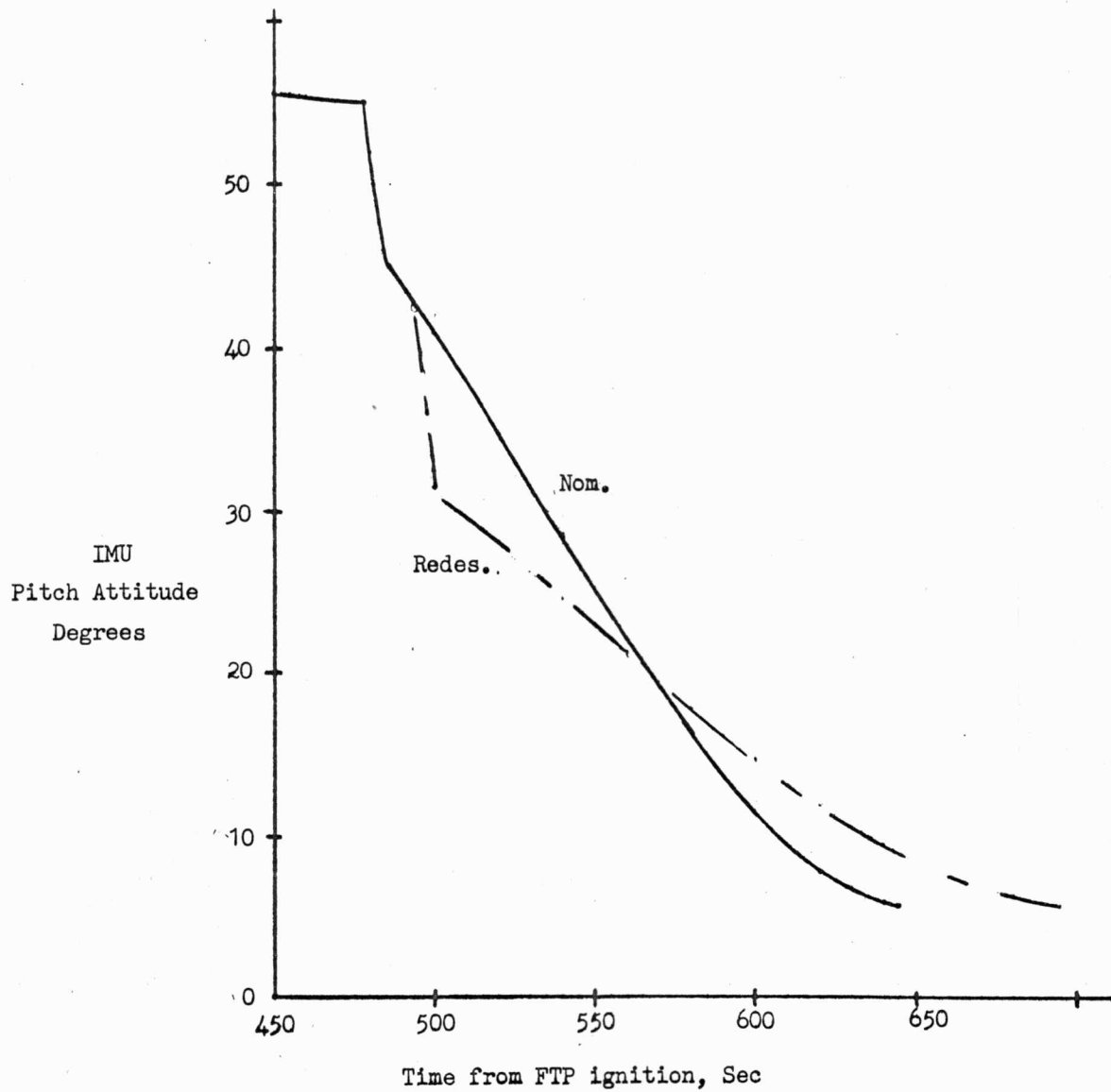


Figure 4. - Redesignated pitch profile to logate with ~~apollo~~ 11 guidance and Apollo 11 trajectory

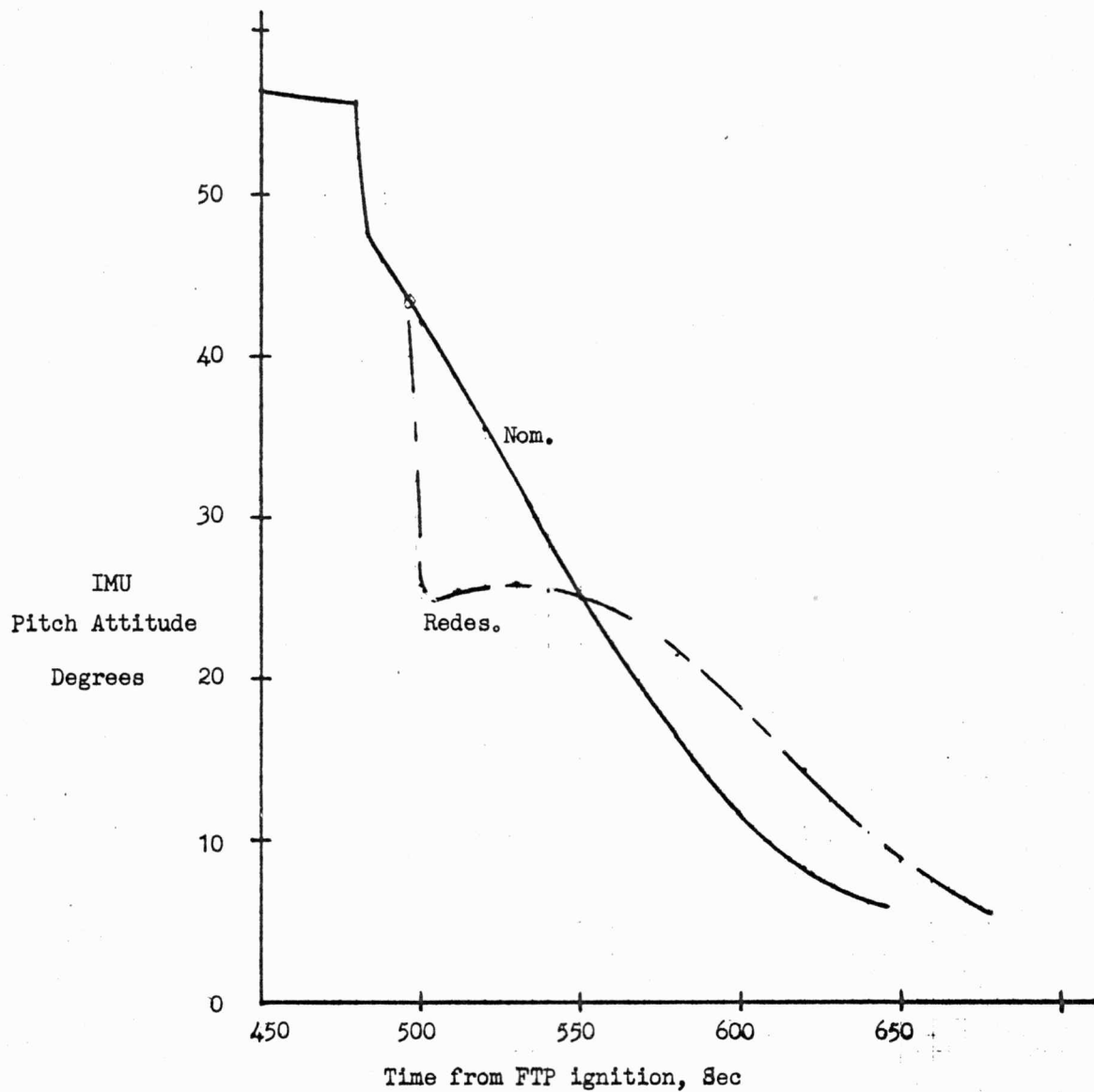


Figure 5. - Redesignated pitch profile to logate with proposed guidance and Apollo 11 trajectory