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LUMINARY Memo #115

To: Distribution

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Subject: . Notes on Implementation of Delta-Guidance

A new lunar landing guidance scheme, which improves fuel efficiency and redesignation capability, called delta-guidance, has been coded for the LGC in a version of LUMINARY 118 called AMELIA. When delta-guidance comes on-line, which may be very soon, these remarks will apply to LUMINARY itself.

The incorporation of delta guidance comprised the following changes: -

(1) The erection of the guidance coordinate frame was simplified. Previously, time-to-go had to be between two pad-loaded criteria for the matrix CG, which defines the guidance frame, to be recomputed. This time check was removed as it is unnecessary. Now the CG matrix is computed throughout the braking and approach phases. Also, since it is desirable for the gain introduced in PCR 756 always to be zero, the term in the definition of the y-axis of the guidance frame which involved this gain was eliminated. The y-axis is now simply the normal to the plane defined by the line-of-sight vector to the landing site and the center of the Moon. Time-to-go is no longer part of the CG matrix computation. This fact permitted moving the guidance frame erection to a point before the time-to-go calculation and before the computation of position and velocity ($\underline{R}$GU and $\underline{V}$GU) in that frame. This in turn made the

initialization of the matrix CG in the ignition algorithm unnecessary, and it was deleted. The y-component of $\underline{R}$GU is now by definition zero. The out-of-plane term in the ignition algorithm time correction equation thus becomes meaningless. So the y-component of $\underline{R}$GU was replaced in that term by the y-component of $\underline{V}$GU and the constant KIGNY has a new meaning — it now relates out-of-plane velocity, rather than position, to light-up time. Finally, the following erasables were eliminated, all but the first pad-loads: ANGTERM, TCGIBRAK, TCGFBRAK, TCGIAPPR, TCGFAPPR, GAINBRAK, GAINAPPR.

(2) The time-to-go computation was changed. Time-to-go is now computed as a root of the following equation:

$$(RTGZ-RGUZ) + VTGZ\ t + ATGZ\ t^2/2 + JTGZ\ t^3/6 + STGZ\ t^4/24 = 0$$

where RTGZ, VTGZ, ATGZ, JTGZ and STGZ are z-components of the position, velocity, acceleration, jerk, and snap targets in guidance coordinates of the braking or approach phase and RGUZ is the z-component of spacecraft position in guidance coordinates. Routine ROOTPSRS is used, as before, but its inputs are tabulated in the VAC area, rather than in E7, permitting the liquidation of the nine-cell erasable TABLTTF. Time-to-go was renamed TTT — it used to be TTF — to emphasize that it is time-to-targets rather than time-to-end of phase. Accordingly, the following erasables were renamed:

TTF/8 became TTT/8
TTF/8TMP became TTT/8TMP
DELTTFAP became DELTTTAP

and the tag TTF/8CL became TTT/8CL. These name changes will require minor modification of some edit decks.

(3) The guidance equation itself was replaced. This equation, in which $\underline{A}CG$ is the total acceleration command in guidance coordinates and t is TTT:

$$\begin{aligned}\underline{A}CG = & (1/2 + B/6 + C/24)\underline{S}TG\ t^2 \\ & + (1 + B/2 + C/6)\underline{J}TG\ t \\ & + (1 + B + C/2)\underline{A}TG \\ & + ((B + C)\underline{V}TG - B\ \underline{V}GU)/t \\ & + C(\underline{R}TG - \underline{R}GU)/t^2\end{aligned}$$

replaces the old function of position, velocity and acceleration alone. In this computation the y-components of the targets $\underline{R}TG$, $\underline{V}TG$, $\underline{A}TG$, $\underline{J}TG$ and $\underline{S}TG$ are assumed to be zero. Consequently the y-components are not part of the new pad-load. The coefficients $(1/2 + B/6 + C/24)$, $(1 + B/2 + C/6)$, $(1 + B + C/2)$, $(B + C)$, B and C are pad-loaded in single-precision for each phase. They enter the computation in double-precision, but the effect of the meaningless lower order halves is insignificant. LEADTIME, a guidance equation constant formerly pad-loaded, is eliminated.

(4) The radial control equations were eliminated; good riddance.

(5) In the braking phase only, the method of controlling the throttle was drastically changed. The z-component of nominal velocity in guidance coordinates

$$VGZNOM = VTGZ + ATGZ\ t + JTGZ\ t^2/2 + STGZ\ t^3/6$$

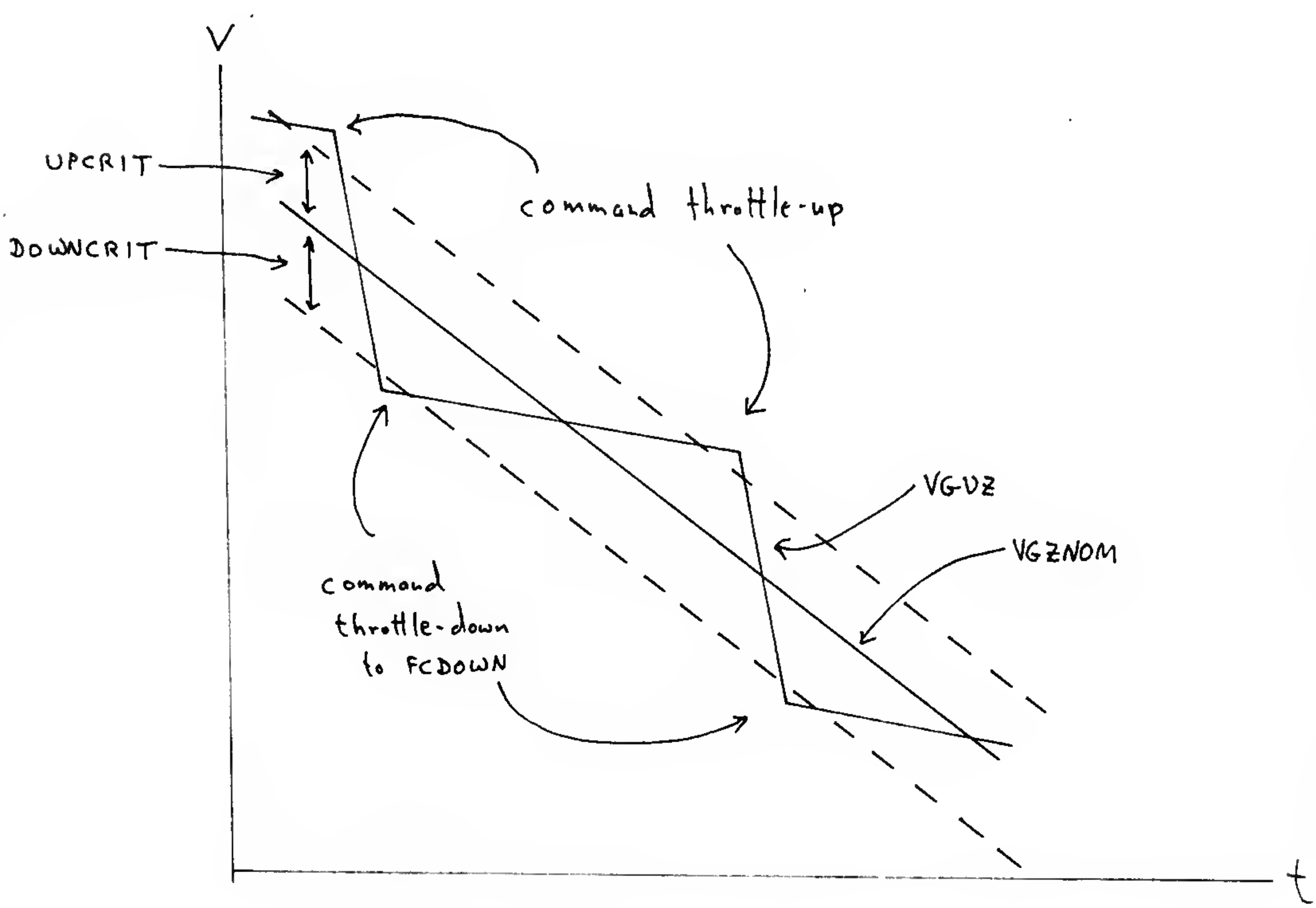
where t is TTT is used as a basis for commanding either maximum throttle or a low throttle setting specified by the pad-load FCDOWN.

If $(VGVZ - VGZNOM) \geq UPCRIT$, throttle-up to maximum.

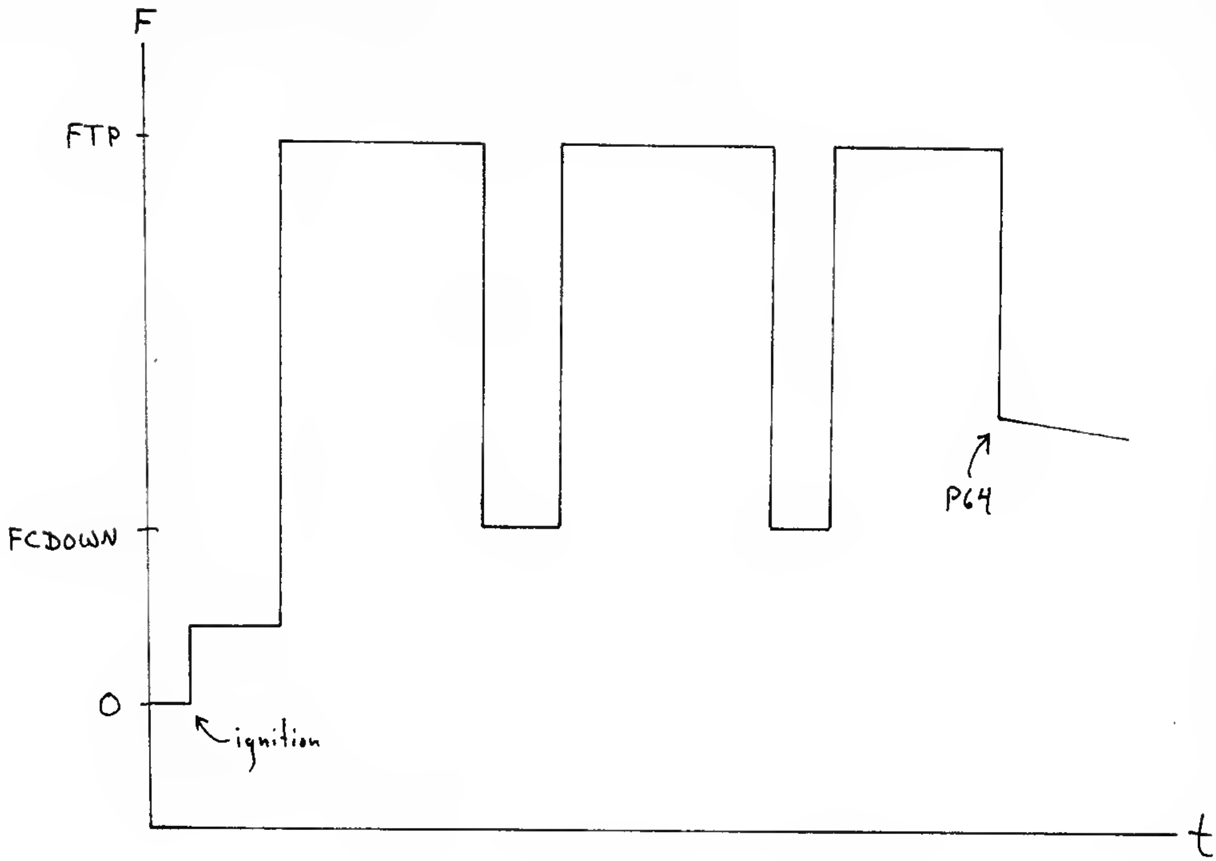
If $(VGUZ-VGZNOM) < DOWNCRIT$, throttle-down to FCDOWN.

Otherwise command no new throttle setting.

This logic will keep spacecraft velocity close to the nominal value throughout the braking phase, as shown in this diagram:



The throttle stays at maximum except for periodic pulse-downs making the braking phase throttle profile look like this:



The pulse-downs take the place of the old period of throttle control at the end of the braking phase. Like it they absorb variations in engine performance. This method required changes within the throttle routine. A new entry, FCTHROT, was provided which is called with desired throttle setting in throttle-counter units (about 2.7 pounds per bit) in A. The throttle erasable TTHROT was eliminated. FCDOWN, UPCRIT and DOWNCRIT are new pad-loads. Since the new logic does not preclude commanding the throttle to go down on successive passes, if the criterion DOWNCRIT is met each time, a throttle level rather than a change in throttle level is pad-loaded to be sent to the throttle routine. If a <u>change</u> were sent twice, the throttle would end up lower than intended.

(6) The redesignation logic was liberalized to accept redesignations up to the end of the approach phase. TREDES displayed in noun 64 reaches zero at the end of P64, not before. Of course a redesignation put in during the final seconds of P64 cannot be wholly obeyed, as the P65 guidance equation (and also the P66 equation) does not control position.

(7) The lunar landing pad-loads in the W-matrix area were changed. The quantities formerly loaded between TLAND and VIGN were all eliminated, and are replaced as mapped on the next page:

MNEMONIC	ECADR	SIZE	DESCRIPTION	UNITS OF
RBRTGX	2402	dp	braking phase position target, x-component	2^{24} meters
RAPTGX	2404	dp	approach phase position target, x-component	"
RBRTGZ	2406	dp	braking phase position target, z-component	"
RAPTGZ	2410	dp	approach phase position target, z-component	"
VBRTGX	2412	dp	braking phase velocity target, x-component, x 8	2^{10} m/cs
VAPTGX	2414	dp	approach phase velocity target, x-component, x 8	"
VBRTGZ	2416	dp	braking phase velocity target, z-component, x 8	"
VAPTGZ	2420	dp	approach phase velocity target, z-component, x 8	"
ABRTGX	2422	dp	braking phase acceleration target, x-component, x 32	2^{-4} m/cs^2
AAPTGX	2424	dp	approach phase acceleration target, x-component, x 32	"
ABRTGZ	2426	dp	braking phase acceleration target, z-component, x 32	"
AAPTGZ	2430	dp	approach phase acceleration target, z-component, x 32	"
JBRTGX	2432	dp	braking phase jerk target, x-component, x 256/3	2^{-18} m/cs^3
JAPTGX	2434	dp	approach phase jerk target, x-component, x 256/3	"
JBRTGZ	2436	dp	braking phase jerk target, z-component, x 256/3	"
JAPTGZ	2440	dp	approach phase jerk target, z-component, x 256/3	"
SBRTGX	2442	dp	braking phase snap target, x-component, x 512/3	2^{-32} m/cs^4
SAPTGX	2444	dp	approach phase snap target, x-component, x 512/3	"
SBRTGZ	2446	dp	braking phase snap target, z-component, x 512/3	"
SAPTGZ	2450	dp	approach phase snap target, z-component, x 512/3	"
BBR	2452	sp	braking phase guidance coeffocient B	2^8
CBR	2453	sp	braking phase guidance coefficient C	"
BAP	2454	sp	approach phase guidance coefficient B	"
CAP	2455	sp	approach phase guidance coefficient C	"
VCOEBR	2456	sp	braking phase B + C	"
ACOEBR	2457	sp	braking phase 2(1 + B + C/2)	"
VCOEAP	2460	sp	approach phase B + C	"
ACOEAP	2461	sp	approach phase 2(1 + B + C/2)	"
JCOEBR	2462	sp	braking phase 6(1 + B/2 + C/6)	"
SCOEBR	2463	sp	braking phase 24(1/2 + B/6 + C/24)	"
JCOEAP	2464	sp	approach phase 6(1 + B/2 + C/6)	"
SCOEAP	2465	sp	approach phase 24(1/2 + B/6 + C/24)	"
FCDOWN	2466	sp	throttle level for braking phase pulse-downs	2.7 2^{14} lbs.
UPCRIT	2467	sp	braking phase velocity criterion for throttle-up	2^7 m/cs
DOWNCRIT	2470	sp	braking phase velocity criterion for pulse-down	"