MEMO

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Subject: Backing Up Failed CDUs

This memo presents an erasable program, and related procedures, developed by the authors for backing up one or more failed CDUs during landings, ascents, and aborts. For the benefit of anyone who came in late, here is a survey of the path that led to this result. At first MIT's efforts were directed toward the limited problem of frozen CDU counters. We proposed to fly noun 22 using AGS attitude-hold (since the PGNCS autopilot would obviously be hors de combat), and concentrated on finding ways to eliminate the thrust-offset error of up to 7^{o} introduced into noun 22 by FINDCDUW. When these techniques proved unweildy, it was noticed that an erasable program executed between Servicer and Guidance could place the XNBPIP vector in the DELV cells, and this would convince FINDCDUW that thrust was along the spacecraft x-axis, and thus zero the thrust-offset error in noun 22. This 9 word erasable program was partially tested at Grumman. Its difficulties were that it had to be renewed by the Astronaut via the DSKY following a P70 or P71 abort, and that it covered only frozen CDU failures. It was because this was considered an unlikely form of CDU failure that a broader solution was sought.

On the next page are the procedures proposed. On the following pages the erasable program is described.

Procedures to Back Up Failed CDUs

Before selection of P63:

Load erasable program. (See loads on pages 9-11.)

Before PDI:

GUID CONT to AGS

PGNCS MODE to OFF

Manual ullage.

Manual engine-on.

Between PDI and throttle-up (or earlier, see page 5):

V 21 N 1 E 335 E 250 E. (Activates erasable program.)

After throttle-up:

V 16 N 87 E. (This monitor may be requested earlier but N87 contains garbage until guidance starts at throttle-up.)

Use R1 for pitch. Use R2 for roll. Yaw to zero before V57.

Features

All parts of the LGC program will work properly except the Landing Analog Displays and the Redesignator. The cross-pointers will give velocities in the downrange and crossrange rather than the body-oriented forward and lateral directions. The Redesignator should not be enabled — flashing N64 in P64 should not be PROCEEDed on — because if it is, hand controller deflections used in flying AGS attitude-hold will be interpreted by the PGNCS as site redesignations.

LR updates may be enabled (subject to confirmation in tests). Either the N87 monitor will have to be key-released occasionally to look at DELTAH, or else the ground will have to monitor it and tell the Astronaut when V57 is appropriate.

Subject to the assumptions below, the erasable program can cope with a failure of all three CDUs. Failures in which one or two remain healthy may make minor modifications desirable, as discussed on page 8.

The erasable program is restart protected and will continue to work through a P70 or P71 abort.

Assumptions

It is assumed that the platform is stable and correctly aligned for landing. It is also assumed that there is time to load and check the erasable program before the landing must begin. In other words, the failure must occur between alignment and the selection of P63. This unfortunately excludes failures detected at activation time — intuitively the most likely case — unless someone finds a way to align the platform despite faulty CDUs.

The CDU failures covered by the erasable program presented here include <u>both</u> quiescent and hunting CDUs. In other words, failures in which the CDU freezes at some value, <u>and</u> failures in which the CDU is being incremented or decremented erroneously, no matter at what rate, are covered. Failures in which a bit is broken, so that the CDU can change its value in big jumps, make use of the LR to update the PGNCS state vectors unadvisable, but otherwise they are covered too, except for the possibility that GLOCKMON might be led to believe that gimbal lock has occured.

Description

The erasable program consists of two parts. One is executed every 2 seconds between Servicer and Guidance. The other is executed every 20 ms. as part of the downrupt.

The 2 second routine computes the desired CDUY and CDUZ values from the thrust-axis commanded by guidance (UNFC/2), and puts them in N87 where they may be monitored using V16 and flown using the AGS autopilot — thus short-circuiting FINDCDUW. R1 gives CDUYD, R2 gives CDUZD. N87 was chosen because it uses the right scaling routine and because it lies in unswitched erasable memory. N22 cannot be used because FINDCDUW, which computes it, may still be functioning. (No way is available to turn off FINDCDUW 100% of the time.) The 2 second routine also computes the actual gimbal angles which would show up in CDUY and CDUZ if they were not sick, from the DELV vector — under the assumption that there is little thrust offset. The desired and "actual" CDUs are extracted from the UNFC/2 and DELV vectors, respectively, using the following expression of the spacecraft x-axis in stable member coordinates:

$$\underline{XNB} = (\cos CDUY \cos CDUZ,\ \sin CDUZ,\ -\sin CDUY \cos CDUZ).$$

Thus the arcsin of the middle component of DELV (or UNFC/2), unitized, is CDUZ (or CDUZD). Then, after the middle component is zeroed and the vector unitized again, the first and third components, respectively the cosine and negative sine of CDUY (or CDUYD), are used to find that angle. The 2 second routine is put in the Servicer loop by the 20 ms. routine, as told below.

Like the DSKY backup program, the second part of the CDU backup program is executed every 20 ms. as part of the downrupt. It zeroes CDUX and plugs the values computed by the 2 second routine into the CDUY and CDUZ registers. Since this setting occurs every 20 ms. no CDU can read a value more than 6400 x .020 = 1.6° from the value computed from DELV. This adds new meaning to the problem of lost downrupts, but these computed "actual" CDU angles should nevertheless remain accurate enough to permit LR updates, and to prevent GLOCKMON from sensing gimbal lock if CDUZ is runaway. The 20 ms. routine also insures that AVGEXIT contains the address of the 2 second routine (661), and that the return from the 2 second routine is to the appropriate guidance program. This makes it necessary for the Astronaut to start up the 20 ms. routine only — it in turn starts up the 2 second routine — and also lets the erasable program survive the P70-P71 lead-in, where a new value is put into AVGEXIT. The 20 ms. routine restart protects itself, and every pass it increments REDOCTR by 100 to show the ground, via downlink, that it is functioning. The only gap in the 20 ms. routine's restart protection is during antenna repositioning at high-gate, when a <u>hardware</u> restart would kill it. However, the 2 second routine, which as part of the Servicer job is fully restart protected, insures that the 2o ms. routine is on the air. Thus the only real vulnerability is in the event that P70 or P71 is selected at the same moment as a hardware restart at high-gate. This seems avoidable.

Starting the Erasable Program Earlier

On page 2 the keystrokes to activate the erasable program are specified for between PDI and throttle-up. Normally, this is the last possible moment before it is needed. If, let us say, CDUZ were runaway, it might be needed earlier to keep GLOCKMON from sensing apparent gimbal lock (CDUZ greater than 85°) and throwing the IMU into coarse align — which is definitely undesirable. The only problem with starting it earlier is that between TIG-30 and ullage the 2 second routine would compute "actual" CDUs from a DELV that contains only uncompensated PIPA bias, and could point in any direction. So the computed CDUs could be crazy. Fortunately, since the single-precision arcsin routine used never outputs an angle greater than 81.4°, even if the DELV vector's magnitude were all along the stable member y-axis, CDUZ would never be computed as in gimbal lock. Also, even at maximum rate of 6400 pps, it could never reach 85° before the 20 ms. routine comes around to set it again. Putting crazy values into the CDU counters has no other pernicious effect.

Memory Utilization

The erasable program here described uses all of three core sets and most of vac area 5. Normally a landing never needs these areas. The only cells unused in vac 5 are two of the four cells overwritten on restarts (the other two are used as temporaries) and the last two. The erasable program is given on the next two pages.

address	octal	meaning		
0250	00300	TC	0300	
0251	54032	TS	CDUX	subro at 0300 returns with zero in A
0252	10752	CCS	PHASE1	
0253	00261	TC	0261	
0254	05355	TC	PHASCHNG	
0255	07011	OCT	07011	
0256	77777	OCT	77777	
0257	00311	OCT	00311	
0260	10100	OCT	10100	
0261	34770	CA	1SEC	to tell the ground that we are on the air
0262	26320	ADS	REDOCTR	
0263	77776	MASK	7776	non-functional: reserves core set
0264	41251	CS	AVGEXIT	
0265	60267	AD	0267	
0266	10000	CCS	A	
0267	00661	OCT	00661	positive impossible
0270	00250	OCT	00250	positive zero impossible
0271	00273	TC	0273	
0272	00676	TC	0676	
0273	31251	CA	AVGEXIT	
0274	54674	TS	0674	
0275	30267	CA	0267	
0276	00675	TC	0675	
0277	77776			not executed: reserves core set
0300	30270	CA	0270	
0301	54335	TS	DNTMGOTO	
0302	44744	CS	BIT1	
0303	54263	TS	0263	reserves core set 6
0304	54277	TS	0277	reserves core set 7
0305	54313	TS	0313	reserves core set 8
0306	34746	CA	ZERO	
0307	54660	TS	VAC5USE	reserves vac area 5
0310	00002	TC	Q	
0311	00300	TC	0300	
0312	05263	TC	TASKOVER	
0313	77776			not executed: reserves core set

address	octal	meaning		
0660	00000			not executed: reservès vac area 5
0661	00300	TC	0300	
0662	06060	TC	INTPRET	compute CDUDs from UNFC/2
0663	77575	VLOAD	EXIT	
0664	03252		UNFC/2	
0665	00710	TC	0710	
0666	53345	DXCH	AZ	
0667	06060	TC	INTPRET	compute CDUs from DELV
0670	77575	VLOAD	EXIT	
0671	00325		DELV	
0672	00710	TC	0710	
0673	52703	DXCH	0702	
0674		TC	guidance	inserted by 20 ms. routine
0675	55251	TS	AVGEXIT	
0676	00006	EXTEND		
0677	30703	DCA	0702	
0700	52034	DXCH	CDUY	
0701	03532	TC	DNPHASE2	
0702 } 0703 }	used for storage of values for CDUY and CDUZ			
0704	overwritten on restart: used for return address by subro at 0710			
0705	overwritten on restart: used for temporary storage by subro at 0710			
0706 } 0707 }	not used			
0710	00006	EXTEND		
0711	22704	QXCH	0704	
0712	06060	TC	INTPRET	
0713	77456	UNIT	EXIT	
0714	30157	CA	MPAC +3	
0715	04607	TC	BANKCALL	
0716	61656	CADR	SPARCSIN -1	
0717	54705	TS	0705	
0720	06060	TC	INTPRET	
0721	53434	RTB	UNIT	
0722	63671		ZEROMID	
0723	77776	EXIT		
0724	22154	LXCH	MPAC	
0725	40161	CS	MPAC +5	
0726	04607	TC	BANKCALL	
0727	61606	CADR	ARCTRGSP	
0730	22705	LXCH	0705	
0731	00704	TC	0704	

Possible Modifications

In the event that one or more CDUs remain normal, it may be desirable to make minor modifications to the erasable program to permit making use of the data they provide. If CDUX is okay, the word at 0251 should be changed to 30000 (CA A) to prevent it from being overwritten. Similarly, if CDUY is healthy the word at 0700 should be 22034 (LXCH CDUZ), and if CDUZ is healthy 0700 should be 54033 (TS CDUY). The only reason to make more drastic changes to the erasable program in the event of one or two good CDUs would be to save a little computation time. Note that if CDUY and CDUZ were both okay word 0700 could be changed to 30000 (CA A), but in this case it would be better to do without the erasable program entirely, since the FINDCDUW computed values in N22 are accurate.

The PGNCS digital autopilot is turned off to releive the LGC of 20% computation time. This time would be needed if all three CDUs were failed in their runaway mode — in which they would create 3 x 6400 x 11.72 microseconds = 22.5% time-loss. To gain still more time FINDCDUW could be prevented from operating most of the time if the necessary words could be found to set a component of UNWC/2, the window-command vector, to POSMAX. This would cause the UNIT operation on UNWC/2 in FINDCDUW to overflow, and at that FINDCDUW would give up. This seems superfluous however, since even with the estimated 5% consumed by the erasable program and three runaway CDUs there would be at least 5% margin in all phases.

Loading the Erasable Program

Five separate loads are necessary. The LGC must be in P00. The erasable location for which a particular entry is destined is given to the right.

Load 1:

V 71 E	
24 E	
250 E	
300 E	250
54032 E	251
10752 E	252
261 E	253
5355 E	254
7011 E	255
77777 E	256
311 E	257
10100 E	260
34770 E	261
26320 E	262
77776 E	263
41251 E	264
60267 E	265
10000 E	266
661 E	267
250 E	270
273 E	271
V 33 E	

Load 2:

V 71 E	
24 E	
272 E	
676 E	272
31251 E	273
54674 E	274
30267 E	275
675 E	276
77776 E	277
30270 E	300
54335 E	301
44744 E	302
54263 E	303
54277 E	304
54313 E	305
34746 E	306
54660 E	307
2 E	310
300 E	311
5263 E	312
77776 E	313
V 33 E	

Load 3:	V 71 E	
	24 E	
	660 E	
	E	660
	300 E	661
	6060 E	662
	77575 E	663
	3252 E	664
	710 E	665
	53345 E	666
	6060 E	667
	77575 E	670
	325 E	671
	710 E	672
	52703 E	673
	E	674
	55251 E	675
	6 E	676
	30703 E	677
	52034 E	700
	3532 E	701
	V 33 E	

Load 4:	V 71 E	
	24 E	
	710 E	
	6 E	710
	22704 E	711
	6060 E	712
	77456 E	713
	30157 E	714
	4607 E	715
	61656 E	716
	54705 E	717
	6060 E	720
	53434 E	721
	63671 E	722
	77776 E	723
	22154 E	724
	40161 E	725
	4607 E	726
	61606 E	727
	22705 E	730
	704 E	731
	V 33 E	

Load 5:	V 72 E	
	7 E	
	1251 E	
	3656 E	1251
	702 E	
	E	702
	703 E	
	E	703
	V 33 E	

Note that Load 5 includes data necessary if the erasable program is to be started up prior to TIG-30.

If there is a restart between loading the erasable program and turning it on, recheck erasable program.