To: OBAD Working Group
From: Bob McCutcheon
Date: July 31, 2003
Subject: FHST Star Density Study

This memorandum presents the results of a star density study conducted to determine the likelihood that sufficient stars will be available both for FHST rate control and FHST mapping in the two gyro science (TGS) control mode. With the exception of pointings away from the galactic plane for FHSTs 2 and 3, the study suggests that star availability is sufficient for the proposed on-board attitude determination (OBAD) and flight software (FSW) design.

Method

The study was conducted as follows:

1. Alignment matrices were adjusted so that all three FHSTs are oriented along the –V3 axis
2. For a selected V1 axis pointing, HST was rolled through a full 360 deg at 0.05 deg steps so that the FHSTs swept out a great circle on the celestial sphere.
3. At each 0.05 deg roll step, the numbers of *quality* and *reduced-quality* stars (terms to be defined below) in the FHST fields-of-view were counted.
4. Star counts at each of the 7200 roll steps were combined to identify those roll regions with fewer than three stars, fewer than two stars, or no stars at all.

Table 1 lists the five V1 axis orientations (galactic coordinates) selected for the study along with a description of the resulting FHST great circles. These orientations were selected to allow sampling of FHST star availability both in the galactic plane, where star densities are at their highest, and in less dense regions far from the galactic plane.

Table 1. V1 Axis Pointings and Resulting FHST Great Circles

V1 Axis Pointing		**FHST Great Circle Description**
l (deg)	**b** (deg)	
0.0	0.0	Passes through north and south galactic poles (ngp and sgp), intersecting galactic plane at l=90 and l=270 deg
45.0	0.0	Passes through ngp and sgp, intersecting galactic plane at l=135 and l=315 deg
90.0	0.0	Passes through ngp and sgp, intersecting galactic plane at l=0 and l=180 deg
135.0	0.0	Passes through ngp and sgp, intersecting galactic plane at l=45 and l=225 deg
0.0	90.0	FHST great circle is in the galactic plane

As noted above, both *quality* and *reduced-quality* stars counts were considered. Table 2 describes in detail the selection criteria that were used for the two categories. The difference between the two categories can be summarized at a high level by noting that *quality* stars are stars that would be considered as candidate reference stars by PASS Mission Scheduler (MS), whereas the *reduced-quality* criteria admit several categories of stars that normally would not be accepted as reference stars. Of these *reduced-quality* criteria, allowing usage of stars with near neighbors has the greatest effect on increasing the star numbers. The question of whether it is appropriate to use *reduced-quality* stars in OBAD will be addressed further in the conclusions section.

Table 2. Criteria for Selection of Quality and Reduced-Quality Stars

Selection Criteria	Quality Stars			Reduced Quality Stars			Comments
	FHST-1	FHST-2	FHST-3	FHST-1	FHST-2	FHST-3	
Limiting v magnitude	5,8 & 6,7	6,1	6,3	same			from Ed Kimmer's Sensitivity Calibration XI
Brightest v magnitude	2,0	2,0	2,0	same			
Reject variable stars?	Yes	Yes	Yes	same			3607 of 39102 stars are variables
Reject NGC objects?	Yes	Yes	Yes	same			
Reject mult stars with negative or default mag difference?	Yes	Yes	Yes	**No**	**No**	**No**	6981 of 39102 stars are multiples; 383 multiples have default magnitude difference
Reject secondary & tertiary components of multiple stars?	Yes	Yes	Yes	same			
Minimum allowable magnitude difference between two brightest components of multiple star	2,0	2,0	2,0	**0,0**	**0,0**	**0,0**	
Reject distance (arcmin) for stars with near neighbors no more than 2.0 mag dimmer	25,0	25,0	25,0	**-9999,0**	**-9999,0**	**-9999,0**	3927 of 39102 stars have default NN distance. (Using -9999 allows use of default NN distance stars.) Allowing NNs has the greatest effect in increasing star availability.
Reject stars with default V magnitude?	Yes	Yes	Yes	same			1094 of 39102 stars have default V magnitude
Reject stars with default magnitude uncertainty?	Yes	Yes	Yes	**No**	**No**	**No**	1156 of 39102 stars have default magnitude uncertainty
Reject stars with default (B-V) color index?	Yes	Yes	Yes	**No**	**No**	**No**	87 of 39102 stars have default (B-V) color index
Maximum allowable proper motion (arcsec/year)	27,0	27,0	27,0	same			Max proper motion for all stars in catalog is 10.1 arcsec/yr in RA and 5.8 arcsec/yr in Dec
Maximum allowable position error (arcsec)	15,0	15,0	15,0	same			

From Table 2 note in particular that the three FHSTs have different limiting magnitudes. The limiting magnitudes listed for FHSTs 2 and 3 are those for threshold 6 (i.e., *wide open*), whereas the limiting magnitudes for both thresholds 5 and 6 are listed for FHST-1. FHST-1 is the most sensitive of the three trackers, and this increased sensitivity has caused FHST map problems through the years when FHST-1 has become *stuck* at one edge of the FOV (presumably due to high star densities) and has thereby failed to carry out a full FOV map. This problem has been solved operationally by commanding that all FHST-1 maps be conducted at threshold 5. For the purposes of the present study, separate sets of star counts have been carried out at thresholds 5 and 6.

Results

Tables 3, 4, and 5 present summary statistics describing those regions in the five FHST great circle bands with 0-2, 0-1, or 0 *quality* stars. Tables 6, 7, and 8 present the same statistics for *reduced-quality* stars. A number of conclusions can be drawn from these tables:

1. When FHST-1 is operated at threshold 5, there will be substantial regions of the sky where fewer than three stars will be in the FOV. For *quality* stars, a full 84.75 out of 360 deg in the galactic plane have fewer than three stars, and in the worst of the normal-to-the-galactic-plane (NGP) great circles, this grows to a whopping 158.85 out of 360 deg! Even for *reduced-quality* stars, the NGP great circles have between 52 and 80 deg where there are fewer than three stars. Only in the galactic plane and only for *reduced-quality* stars can one be confident that FHST-1, operated at threshold 5, will nearly always have at least three stars in the FOV.
2. There are also substantial regions in both the galactic plane and NGP great circles where FHSTs 2 and 3 have fewer than three *quality* reference stars. These regions are smaller than for FHST-1, however. FHSTs 2 and 3 **always** had at least three *reduced-quality* stars when pointed in the galactic plane. There are regions in the NGP great circles where FHSTs 2 and 3 have fewer than three *reduced-quality* stars, but these regions are substantially smaller than for *quality* stars. In terms of star availability, one can say that for both *quality* and *reduced-quality* stars, FHST-2 is roughly twice as good as FHST-1 (threshold 5). FHST-3 is twice as good again.
3. When operated at threshold 6, FHST-1 has greatly superior star availability than either FHSTs 2 or 3. Out of all the great circles sampled, only two isolated orientations were found where FHST-1 (threshold 6) did *not* have at least three stars.
4. FHST-1 (threshold 6) always had at least one *reduced-quality* star in the FOV, and only one pointing was found where FHST-1 did not have at least one *quality* star.
5. Very few pointings were found where FHSTs 2 and 3 did not have at least one *non-quality* star in the FOV. A small number of regions were found, however, where FHSTs 2 and 3 did not have at least one *quality* star in the FOV.

Conclusions

Different conclusions can be drawn from this study depending on whether or not it is reasonable to use *reduced-quality* stars for OBAD rate control and mapping.

Recalling that the acceptance or rejection of stars with near neighbors constitutes the main difference between *quality* and *reduced-quality* stars, I suggest that use of *reduced-quality* stars is appropriate for most OBAD functions. PASS Mission Scheduler (MS) rejects stars with near neighbors that could fit within the FHST instantaneous FOV (IFOV) together with the reference star and thereby cause the FHST to report a blended position rather than the reference star position. This rejection is appropriate for reference stars, where the error introduced by a blended position can be large enough to cause

failure of the FHST update and/or failure of the subsequent guide star acquisition. This phenomenon has been well studied throughout the operational history of HST.

For OBAD rate control, however, it is immaterial whether the position of a single star or a blended star is used. It is important only that the measured position be stable. Although there have been instances through the years where an FHST has been observed to *bounce* back and forth between two closely spaced stars of nearly equal magnitude, this has been the exception, not the rule.

For the first OBAD FHST map and attitude correction, the possible error introduced by a star with a near neighbor is insignificant compared to the total attitude error that is to be corrected. I conclude from this that it is acceptable to use *reduced-quality* stars for the first map and attitude correction.

For the second OBAD FHST map and attitude correction, on the other hand, it may be preferable to use only *quality* stars to ensure the best possible attitude correction prior to guide star acquisition. It is worth noting, however, that PASS Fine Attitude (FINATT) does not explicitly reject stars with near neighbors during its star identification and attitude determination process.[1]

With this discussion of *quality* vs. *reduced-quality* stars as background, I suggest the following conclusions from this star density study:

1. There is very little chance of not finding a star for rate control in any of the three trackers. Risk of not finding a star is greatest for FHST-1 operated at threshold 5, and thus it may be best to operate FHST-1 at threshold 6 when searching for a rate control star.
2. For the first OBAD map and attitude correction, it may be possible to establish preferential rules for selecting one FHST over another in those cases where more than one FHST is available. For example, when all FHSTs are oriented not in the galactic plane, FHST-3 is more likely to have three stars in its FOV than is either FHST-2 or FHST-1 (threshold 5). Also, an FHST that is pointed near the galactic plane is more likely to have three stars available than is an FHST pointed out of the plane. Finally, regardless of pointing, FHST-1 (threshold 6) has a greater likelihood of having three stars available than do either FHST-2 or 3.
3. For the second OBAD map and attitude correction, it will be preferable to have the planning and scheduling systems select the FHSTs based on the numbers of *quality* stars in the FHST FOVs.
4. For both rate control and mapping, the FSW should consider a failure mode in which the threshold of FHST-1 can be switched from threshold 5 to 6 when insufficient stars are found at threshold 5.

The weakest link in the current OBAD design may be the first map and attitude correction. Given the possibly large attitude error upon exit from M2G mode, we will

[1] It is possible, however, that based on large fit residuals, stars with near neighbors are rejected by FINATT **after** the first attempt at attitude determination.

not know for certain ahead of time how many stars we will find in the map FHST. Despite the suggestions given in conclusion 2, there may be some orientations where we just are not lucky and will find that we do not have enough stars for star identification and attitude determination. The chance that this will happen is quite small if we are using FHST-1 (threshold 6) or if we are pointing near the galactic plane, but there is a small but real chance that we will not find sufficient stars if we are pointing away from the plane and are using FHSTs 1 (threshold 5), 2, or 3.

For further study, the present investigation could be extended to other regions of the sky. I doubt, however, that the star availability numbers in other regions will differ substantially from those in the representative regions considered here.

Table 3. Report of Great Circle Regions with 0-2 *Quality* Stars in FHST FOV

V1 Axis Orientation (deg)		Great Circle Galactic Equator Intersections (deg)			FHST-1 (thresh-old 5)	FHST-1 (thresh-old 6)	FHST-2	FHST-3
l	b	l1	l2					
0	0	90	270	**No. roll ranges with < 3 stars**	36	6	29	11
				No. roll ranges > 2 deg	16	1	7	3
				No. roll ranges > 5 deg	7	0	4	3
				No. roll ranges > 8 deg	5	0	2	0
				Longest roll range (deg)	17,90	4,30	9,95	7,70
				Total roll range (deg)	123,65	7,50	61,30	29,10
45	0	135	315	**No. roll ranges with < 3 stars**	25	5	25	22
				No. roll ranges > 2 deg	14	2	12	7
				No. roll ranges > 5 deg	9	0	8	4
				No. roll ranges > 8 deg	7	0	5	2
				Longest roll range (deg)	24,65	2,65	12,35	9,55
				Total roll range (deg)	158,85	7,55	94,55	51,20
90	0	0	180	**No. roll ranges with < 3 stars**	29	8	21	21
				No. roll ranges > 2 deg	13	1	10	6
				No. roll ranges > 5 deg	8	0	4	2
				No. roll ranges > 8 deg	6	0	3	0
				Longest roll range (deg)	15,15	2,50	14,70	7,30
				Total roll range (deg)	112,45	6,85	71,60	41,25
135	0	45	225	**No. roll ranges with < 3 stars**	36	2	34	20
				No. roll ranges > 2 deg	15	1	12	5
				No. roll ranges > 5 deg	9	0	4	1
				No. roll ranges > 8 deg	8	0	3	1
				Longest roll range (deg)	16,10	2,65	10,70	10,70
				Total roll range (deg)	130,25	4,55	79,30	33,85
0 (north galactic pole)	90	NA (great circle in galactic plane)	NA	**No. roll ranges with < 3 stars**	25	8	16	14
				No. roll ranges > 2 deg	14	2	8	4
				No. roll ranges > 5 deg	6	0	2	0
				No. roll ranges > 8 deg	3	0	1	0
				Longest roll range (deg)	11,90	3,65	10,85	4,70
				Total roll range (deg)	84,75	11,55	45,70	23,60

Table 4. Report of Great Circle Regions with 0-1 *Quality* Stars in FHST FOV

V1 Axis Orientation (deg)		Great Circle Galactic Equator Intersections (deg)			FHST-1 (thresh-old 5)	FHST-1 (thresh-old 6)	FHST-2	FHST-3
l	b	l1	l2					
0	0	90	270	**No. roll ranges with < 2 stars**	15	2	8	5
				No. roll ranges > 2 deg	6	0	1	1
				No. roll ranges > 5 deg	4	0	1	1
				No. roll ranges > 8 deg	2	0	0	0
				Longest roll range (deg)	8,60	0,00	7,20	5,95
				Total roll range (deg)	47,05	0,35	19,95	9,25
45	0	135	315	**No. roll ranges with < 2 stars**	23	3	18	9
				No. roll ranges > 2 deg	13	0	5	4
				No. roll ranges > 5 deg	6	0	0	0
				No. roll ranges > 8 deg	0	0	0	0
				Longest roll range (deg)	6,75	1,15	4,95	4,70
				Total roll range (deg)	72,70	2,20	31,55	19,95
90	0	0	180	**No. roll ranges with < 2 stars**	15	3	13	8
				No. roll ranges > 2 deg	8	0	3	3
				No. roll ranges > 5 deg	4	0	2	1
				No. roll ranges > 8 deg	1	0	1	0
				Longest roll range (deg)	8,75	0,30	8,75	6,10
				Total roll range (deg)	43,95	0,30	23,50	13,70
135	0	45	225	**No. roll ranges with < 2 stars**	13	2	9	5
				No. roll ranges > 2 deg	9	0	3	0
				No. roll ranges > 5 deg	4	0	2	0
				No. roll ranges > 8 deg	1	0	0	0
				Longest roll range (deg)	10,20	0,25	7,35	1,90
				Total roll range (deg)	52,15	0,35	21,55	4,60
0 (north galactic pole)	90	NA (great circle in galactic plane)	NA	**No. roll ranges with < 2 stars**	17	2	12	6
				No. roll ranges > 2 deg	4	2	2	2
				No. roll ranges > 5 deg	1	0	0	0
				No. roll ranges > 8 deg	1	0	0	0
				Longest roll range (deg)	9,80	2,20	2,60	2,20
				Total roll range (deg)	25,40	4,25	11,55	6,90

Table 5. Report of Great Circle Regions with 0 *Quality* Stars in FHST FOV

V1 Axis Orientation (deg)		Great Circle Galactic Equator Intersections (deg)			FHST-1 (thresh-old 5)	FHST-1 (thresh-old 6)	FHST-2	FHST-3
l	b	l1	l2					
0	0	90	270	**No. roll ranges with 0 stars**	4	0	2	1
				No. roll ranges > 2 deg	2		1	1
				No. roll ranges > 5 deg	0		0	0
				No. roll ranges > 8 deg	0		0	0
				Longest roll range (deg)	4,30		2,60	2,60
				Total roll range (deg)	8,00		2,95	2,60
45	0	135	315	**No. roll ranges with 0 stars**	9	0	3	2
				No. roll ranges > 2 deg	1		1	1
				No. roll ranges > 5 deg	0		0	0
				No. roll ranges > 8 deg	0		0	0
				Longest roll range (deg)	2,50		2,50	2,50
				Total roll range (deg)	11,95		5,25	4,10
90	0	0	180	**No. roll ranges with 0 stars**	6	0	4	3
				No. roll ranges > 2 deg	1		1	1
				No. roll ranges > 5 deg	1		1	1
				No. roll ranges > 8 deg	0		0	0
				Longest roll range (deg)	5,40		5,40	5,40
				Total roll range (deg)	7,15		6,05	5,65
135	0	45	225	**No. roll ranges with 0 stars**	9	0	4	1
				No. roll ranges > 2 deg	3		1	0
				No. roll ranges > 5 deg	1		0	0
				No. roll ranges > 8 deg	0		0	0
				Longest roll range (deg)	5,35		2,35	0,10
				Total roll range (deg)	14,50		6,05	0,10
0 (north galactic pole)	90	NA (great circle in galactic plane)	NA	**No. roll ranges with 0 stars**	3	1	1	1
				No. roll ranges > 2 deg	0	0	0	0
				No. roll ranges > 5 deg	0	0	0	0
				No. roll ranges > 8 deg	0	0	0	0
				Longest roll range (deg)	1,90	1,05	1,05	1,05
				Total roll range (deg)	4,70	1,05	1,05	1,05

Table 6. Report of Great Circle Regions with 0-2 *Reduced-Quality* Stars in FHST FOV

V1 Axis Orientation (deg)		Great Circle Galactic Equator Intersections (deg)			FHST-1 (thresh-old 5)	FHST-1 (thresh-old 6)	FHST-2	FHST-3
l	b	l1	l2					
0	0	90	270	**No. roll ranges with < 3 stars**	17	1	10	7
				No. roll ranges > 2 deg	10	0	3	1
				No. roll ranges > 5 deg	5	0	3	1
				No. roll ranges > 8 deg	2	0	1	0
				Longest roll range (deg)	12,15	0,10	9,60	5,30
				Total roll range (deg)	61,35	0,10	28,65	12,05
45	0	135	315	**No. roll ranges with < 3 stars**	22	0	14	6
				No. roll ranges > 2 deg	11		3	2
				No. roll ranges > 5 deg	5		3	1
				No. roll ranges > 8 deg	2		0	0
				Longest roll range (deg)	18,40		6,60	5,10
				Total roll range (deg)	79,80		26,20	12,45
90	0	0	180	**No. roll ranges with < 3 stars**	18	1	10	10
				No. roll ranges > 2 deg	7	0	4	3
				No. roll ranges > 5 deg	5	0	2	1
				No. roll ranges > 8 deg	3	0	1	0
				Longest roll range (deg)	11,35	0,20	11,35	5,40
				Total roll range (deg)	52,70	0,20	26,80	13,15
135	0	45	225	**No. roll ranges with < 3 stars**	27	0	27	10
				No. roll ranges > 2 deg	10		6	0
				No. roll ranges > 5 deg	7		1	0
				No. roll ranges > 8 deg	4		0	0
				Longest roll range (deg)	13,55		7,35	1,70
				Total roll range (deg)	79,65		36,10	6,00
0 (north galactic pole)	90	NA (great circle in galactic plane)	NA	**No. roll ranges with < 3 stars**	2	0	0	0
				No. roll ranges > 2 deg	0			
				No. roll ranges > 5 deg	0			
				No. roll ranges > 8 deg	0			
				Longest roll range (deg)	1,80			
				Total roll range (deg)	2,25			

Table 7. Report of Great Circle Regions with 0-1 *Reduced-Quality* Stars in FHST FOV

V1 Axis Orientation (deg)		Great Circle Galactic Equator Intersections (deg)			FHST-1 (thresh-old 5)	FHST-1 (thresh-old 6)	FHST-2	FHST-3
l	b	l1	l2					
0	0	90	270	**No. roll ranges with < 2 stars**	8	0	5	1
				No. roll ranges > 2 deg	3		2	0
				No. roll ranges > 5 deg	3		1	0
				No. roll ranges > 8 deg	1		0	0
				Longest roll range (deg)	8,60		5,95	4,95
				Total roll range (deg)	24,45		11,90	4,95
45	0	135	315	**No. roll ranges with < 2 stars**	15	0	4	3
				No. roll ranges > 2 deg	3		2	1
				No. roll ranges > 5 deg	1		0	0
				No. roll ranges > 8 deg	0		0	0
				Longest roll range (deg)	5,95		4,50	4,50
				Total roll range (deg)	26,55		8,30	4,60
90	0	0	180	**No. roll ranges with < 2 stars**	8	0	7	2
				No. roll ranges > 2 deg	4		2	1
				No. roll ranges > 5 deg	2		1	0
				No. roll ranges > 8 deg	0		0	0
				Longest roll range (deg)	5,55		5,55	4,55
				Total roll range (deg)	19,45		11,55	4,80
135	0	45	225	**No. roll ranges with < 2 stars**	11	0	5	0
				No. roll ranges > 2 deg	4		0	
				No. roll ranges > 5 deg	2		0	
				No. roll ranges > 8 deg	0		0	
				Longest roll range (deg)	6,50		1,95	
				Total roll range (deg)	25,45		3,70	
0 (north galactic pole)	90	NA (great circle in galactic plane)	NA	**No. roll ranges with < 2 stars**	0	0	0	0
				No. roll ranges > 2 deg				
				No. roll ranges > 5 deg				
				No. roll ranges > 8 deg				
				Longest roll range (deg)				
				Total roll range (deg)				

Table 8. Report of Great Circle Regions with 0 *Reduced-Quality* Stars in FHST FOV

V1 Axis Orientation (deg)		Great Circle Galactic Equator Intersections (deg)			FHST-1 (thresh-old 5)	FHST-1 (thresh-old 6)	FHST-2	FHST-3
l	b	l1	l2					
0	0	90	270	**No. roll ranges with 0 stars**	2	0	1	1
				No. roll ranges > 2 deg	1		1	1
				No. roll ranges > 5 deg	0		0	0
				No. roll ranges > 8 deg	0		0	0
				Longest roll range (deg)	4,30		2,60	2,60
				Total roll range (deg)	5,45		2,60	2,60
45	0	135	315	**No. roll ranges with 0 stars**	2	0	1	1
				No. roll ranges > 2 deg	1		0	0
				No. roll ranges > 5 deg	0		0	0
				No. roll ranges > 8 deg	0		0	0
				Longest roll range (deg)	2,50		1,50	1,50
				Total roll range (deg)	4,10		1,50	1,50
90	0	0	180	**No. roll ranges with 0 stars**	3	0	2	1
				No. roll ranges > 2 deg	1		1	1
				No. roll ranges > 5 deg	0		0	0
				No. roll ranges > 8 deg	0		0	0
				Longest roll range (deg)	3,90		2,30	2,30
				Total roll range (deg)	5,20		2,55	2,30
135	0	45	225	**No. roll ranges with 0 stars**	4	0	1	0
				No. roll ranges > 2 deg	0		0	
				No. roll ranges > 5 deg	0		0	
				No. roll ranges > 8 deg	0		0	
				Longest roll range (deg)	1,15		0,00	
				Total roll range (deg)	1,25		0,00	
0 (north galactic pole)	90	NA (great circle in galactic plane)	NA	**No. roll ranges with 0 stars**	0	0	0	0
				No. roll ranges > 2 deg				
				No. roll ranges > 5 deg				
				No. roll ranges > 8 deg				
				Longest roll range (deg)				
				Total roll range (deg)				