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PROCESS AND METHODOLOGY OF DEVELOPING CASSINI G&C TELEMETRY DICTIONARY

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ABSTRACT

While the Cassini spacecraft telemetry design had taken on the new approach of "packetized telemetry", the AACS (Attitude and Articulation Subsystem) had further extended into the design of "mini-packets" in its telemetry system. Such telemetry packet and mini-packet design produced the AACS Telemetry Dictionary, iterations of the latter in turn provided changes to the former. The ultimate goals were to achieve maximum telemetry packing density, optimize the "freshness" of more time-critical data, and to effectuate flexibility, i.e. multiple AACS data collection schemes without needing to change the overall spacecraft telemetry mode. This paper describes such a systematic process and methodology, evidenced by various design products related to, or as part of, the AACS Telemetry Dictionary.

INTRODUCTION

An efficient ground data system and effective telemetry data processing / analysis system stem from good engineering design with respect to timeliness, frequency, accuracy, and sufficiency of the data contents in the telemetry stream. The human interaction with the data, thence consumption of the data, can also be enhanced by human-engineered telemetry displays and systematic organization of the telemetry measurements.

Such objectives can be achieved, in part, by an up front design of a flexible and efficient telemetry handling system on board the spacecraft, and of an equally efficient ground data analysis system. A common thread between the flight and ground systems is the Telemetry Dictionary.

In the present context, the Telemetry Dictionary is more than just a collection of telemetry measurements with their descriptions, arranged in some alphabetical ordering. The development process of the Dictionary is intertwined and iterative with the design process of the telemetry system. In fact, the Dictionary is not simply the child-of-the-parent of the telemetry design; it is also the parent-of-the-child. The Dictionary evolves from the telemetry design process; and through iterations, the Dictionary development in turn provides improvement and optimization to the telemetry design.

This iterative process was particularly necessary for the Cassini AACS (Attitude and Articulation Subsystem) because of its new approach of using a "packetized telemetry" system versus the widely used "time division multiplex" (TDM) system. The AACS further extended the packet design to include the "mini-packet" design.

The ultimate goals of the mini-packet and packet telemetry design were to achieve maximum telemetry packing density, optimize the "freshness" of more time-critical data, and to effectuate flexibility, i.e. multiple AACS data collection schemes without needing to change the overall spacecraft telemetry mode.

The Cassini AACS telemetry design also responded to the object-oriented design approach of the AACS flight software. The fundamental entity of telemetry collection was to be based on each software object. A bottoms-up approach was used to assemble and analyze the telemetry measurements per software object. A database was constructed in which each measurement (i.e. record) was associated with attributes including measurement-number (E-numbers in Cassini), mini-packet, software object, channel[1] type, bit assignment, scale factor etc.

[1] "Channels" are herein used synonomously with telemetry "measurements", and should not be confused with "telecommunication channel, bandwidth".

Through iterative analysis, the collection of measurements was screened, organized, and assigned to the fundamental unit of a telemetry mini-packet. Mini-packets were created that grouped measurements by similar functions and/or similar collection periods. A systematic optimization of mini-packet assignments led to the consolidation of the database, from which statistics were synthesized and analyzed. AACS telemetry modes were designed corresponding to the overall spacecraft telemetry modes - a virtue of the flexibility of a mini-packet packetized telemetry system. Telemetry maps specifying the periodicity of telemetry mini-packets were designed, satisfying overall spacecraft telemetry bandwidth allocation requirements.

This paper describes such a systematic process and methodology, evidenced by various design products related to, or as part of, the AACS Telemetry Dictionary. This work was performed during the first part of Fiscal Year 1994, and was completed before the AACS Flight Software Critical Design Review.

FEATURES OF A TELEMETRY DICTIONARY

References to the AACS Telemetry Dictionary of Galileo (ref. 1), Mars Observer (ref. 2), and Cassini (ref. 3) reveal the common features of a telemetry dictionary of a major-size spacecraft. Putting aside those spacecraft-specific design features that should always be documented, the following list shows the major features to be included in the telemetry dictionary:

- Spacecraft telemetry system description
- Subsystem (e.g. AACS) telemetry system desciption
- Telemetry design: data acquisition, processing, storing, and transmission; telemetry maps, rates, modes (overall spacecraft mode versus subsystem mode)
- Telemetry detailed design: data format, headers, trailers, fillers, engineering "transfer frames", major frames
- Telemetry packets, mini-packets
- Special telemetry modes
- Telemetry Indices: by channel number, display mnemonics, data type, subsystem association, flight software name, and frequency (periodicity)
- Telemetry data sheet (by channel number)
- Telemetry subcommutation map (for TDM) design; packet and mini-packet tables (for "packetized" design)
- Telemetry modes, transitions, relationship between spacecraft mode and subsystem (telemetry / operation) mode
- Parent-to-child relationship between channels (child-channels are usually derived in Ground Data System in order to relieve spacecraft downlink burden)

Spreadsheet or database documentation of channel data is ideal not only for sorting / indexing purposes, but also invaluable in the analysis / synthesis of telemetry modes, rate (periodicity) association, decommutation and mini-packet / packet design. Spreadsheet columns, i.e. attributes, should at least include channel number, display mnemonics, data type, subsystem association, flight software name, and frequency (periodicity).

In fact, the basis of the Cassini AACS Telemetry Dictionary used for the mini-packet / packet design, rate group association, and overall downlink channel bandwidth optimization, was a spreadsheet documentation of all telemetry channels.

Additional attributes included in the Cassini AACS Telemetry Dictionary spreadsheets were associations to software object, hardware unit, and mini-packet function (hence mini-packet name). Desired data frequency (periodicity) was a very important attribute, used in the iterative design of the mini-packets. The desired periodicity expressed the "freshness" requirement, and was represented by cardinal ratings of F, FM, M, MS, and S (i.e. fast, fast-medium, medium, medium-slow, and slow). Attributes of data types (signed integer, unsigned integer, floating-point, digital, state and ASCII) and number of data bits were included for channel bandwidth optimization and statistics summarization.

PACKET / MINI-PACKET DESIGN vs TDM (Time Division Multiplex) DESIGN

The gist of the design differences between packet / mini-packet design versus TDM design is the absence vs presence of a "telemetry decommutation map".

In a TDM design, a channel will be included in the telemetry stream (regardless of whether the stream is to be downlinked or stored on-board) at a fixed location according to the decommutation map. A map covers all locations of a complete unit of telemetry stream (also known in Galileo as Major Frame, in Mars Observer as Engineering Transfer Frame). At a given bit rate, the "frame" always spans the same duration of time. (Hence, the scheme is called TDM.)

Within a decommutation map, the same channel can appear once or multiple times. In the former case, the channel is said to be in the "slow deck"; in the latter, "medium" or "fast" deck, depending on the repetition rate. In Galileo, there are basically three rates, the "ninety-one-deck", "thirteen-deck", and "zero-deck", ranging from slow to fast. For 1200 bps telemetry rate, the periods are 60 2/3 sec., 8 2/3 sec, and 2/3 sec. In Mars Observer, in the 2000 bps Engineering Mode, there are the 32 sec., 8 sec., 1 sec. "-decks" for the flight computer processed data.

Decommutation maps are large. There can be multiple maps, one for each Spacecraft "mission" mode. In Mars Observer, there are four modes: Engineering, Mission, Emergency and Safe Mode; with different bit rates ranging from fast to slow, respectively. In Galileo, even though bit rate can change from 1200 bps down to 8 bps, the same decommutation map still applies; however, there is an extra "Variable Telemetry Map" that can be selected from four choices. All Variable Telemetry Maps provide 22.5 (16-bit) words, equivalently 18 plus 9 one-half channels at the zero-deck rate.

Changes to decommutation maps are possible normally via memory loads at specific memory addresses. Such a change process is labor-intensive.

For Cassini, if TDM were used, the maps would be even larger (about five times as large as Galileo, and one-and-a-half times larger than Mars Observer). This is not simply due to complexity of the spacecraft, i.e. number of subsystems, but is due to increase of compuation power of the on-board computers.

Without using the packet / mini-packet design, Cassini would suffer excessive sluggishness in AACS telemetry - where the fastest allocation downlink rate was at 1896 bps, with 576 bps allocated to AACS.

The mini-packet design provides AACS with total freedom to assign desired / appropriate mini-packets to the fixed packet size allocated to AACS. Each Spacecraft Subsystem is allocated a certain packet size. Multiple (not necessarily integral number of) packets can be included in an "engineering transfer frame".

Flexibility is achieved by associating AACS Telemetry Modes for certain AACS Operation Modes, and against all Spacecraft Mode. Instead of having the TDM decommutation map(s), maps of telemetry channels in mini-packets (regardless of modes), and maps of mini-packets in packets (per AACS Telemetry Mode) are stored. The first set of maps are much smaller than a TDM decommutation map. The second set of maps are basically tables of "(m,n) frequency" allocation of mini-packets to packets.

"(m,n)" frequency in Cassini means that, for that AACS Telemetry Mode, m mini-packets will be contained in n packets. E.g. (8,1) is the fastest rate and (1,64) is the slowest rate in Cassini. At an AACS packet period of 8 sec., they represent mini-packet periods of 1 sec and 512 sec.

For more details on TDM, mini-packets, guaranteed delivery of mini-packets in packets, see (ref.1 - 4)

CASSINI PROCESS & METHODOLOGY of Telemetry Dictionary Development

The Cassini AACS telemetry design and Telemetry Dictionary development was an interactive and iterative process. Using project organization terminology, it was a cooperative task performed between the AACS Subsystem Group, Control Analysis Group, Flight Software Group, Hardware & Electronics Group, and the Ground Data Systems / Mission Operations Group.

While generic telemetry channel requirements were synthesized by the Subsystem Group, specific candidates were proposed by the Hardware Group, Analysis Group, and the Software Group. Inheritance from the Galileo and Mars Observer designs was duly observed. In fact, a one-to-one comparison was made between the Galileo AACS Telemetry Dictionary and the candidate Cassini Dictionary, revealing potential omissions and confirming completeness.

From the respective AACS Groups, requirements for candidate telemetry channel, periodicity, data bits (resolution, precision), and format were drawn on hardware (sensors, actuators, hardware-to-electronics interfaces); control states, intermediate and observable variables; flight computer hardware data, hardware configuration and overall fault protection data. The Ground System Group was consulted regarding mission operations requirements and channel bandwidth optimization. Human engineered mnemonics and channel type assignment were prescribed to all measurements, conforming with JPL's AMMOS (Advanced Multi-Mission Operations System) ground software standards.

The object-oriented software design of the AACS flight software design (some 20 objects) (ref. 5) provided an easy association of telemetry to software objects. The list of object names and their statistics are given in Table 1. (The Telemetry Manager is one such object.) Table 2 is a sample of this initial compilation of telemetry dictionary, for the Software Object of "Accelerometer_Telemetry_Manager". Since object-oriented software design has distinct input output data flow, the same telemetry can be tapped from either the source or destination. A rule of thumb was adopted to tap the telemetry from the source, unless certain functional groupings made it more desirable to tap from the destination.

A spreadsheet for all telemetry channels was then composed, where all attributes were entered, including their cardinal ordering of periodicity.

At that point, mini-packets were designed which attempted to group telemetry by

- functionality
- similarity in periodicity requirement
- manageable size of mini-packet.

The number of mini-packets were kept to a minimum, compromising with the uniformity (diversity) of the functionality and periodicity of the channels grouped within the same mini-packet.

The mini-packet attribute was then added to the spreadsheet. With each iteration, new packet / mini-packet design was synthesized and their statistics analyzed. Iterations on the spreadsheet, good engineering practice, and negotiations with the engineer(s) requiring the specific channels (and other requirements), then led to a compromised mini-packet design.

While the design work was approaching completion, bandwidth allocation had yet to be analyzed. This was when the cardinal ordering of mini-packet periodicity was translated into ordinal (m,n) association.

New spreadsheets were prepared (Table 3), which were linked to the Telemetry Dictionary spreadsheet, linked for channel attributes such as data bit size and mini-packet association. An iterative analysis and synthesis further led to optimized (m,n) periodicity associations, addition/deletion/merging of mini-packets, and final assignment of channels to mini-packets.

Finally, an overall design of AACS Telemetry Modes, corresponding to all AACS Operation Modes and Spacecraft "Mission" Modes led to more rounds of iterations and finalization of the telemetry design, mini-packet / packet design, and, above all, the AACS Telemetry Dictionary.

Samples of the Final Dictionary (as of Jan., 94) are given in Table 4 and 5, where the telemetry channels are ordered by channel-numbers (i.e. "E-numbers", also by Software Objects), and by mini-packets.

All in all, 1088 channels in 67 mini-packets were assembled in the AACS Telemetry Dictionary. Out of these 67 mini-packets, 6 contained the less used off-diagonal covariance and Kalman gain elements (161 measurements), which are non-essential during normal mission operations. Eliminating those left 947 measurements in 61 mini-packets. A total of seven telemetry maps corresponding to 7 AACS telemetry modes were constructed. These modes are: (1) Record; (2) Nominal Cruise; (3) Medium Slow Cruise; (4) Slow Cruise; (5) Orbital Ops; (6) Δv; (7) ATE (Attitude Estimator) Calibration. These 7 maps cover all spacecraft telemetry modes. For further information about mode transitions, and for details of the AACS Telemetry Dictionary, refer to (ref. 3 and 6.)

CONCLUSION

The process of bottoms-up development, use of human engineering skills, and the construction of the database had permitted a systematic way of sorting, synthesizing and analyzing all Cassini AACS telemetry measurements. Maximizing the use of database formulas and linking databases also permitted expedient parametric variation and analysis of bottom-line figures; examples of the latter were dictionary statistics, and bandwidth consumption (vs allocation) for specific telemetry modes. Hence, an effective and flexible packet / mini-packet design scheme.

This process of developing the packet / mini-packet design and the establishment of the AACS Telemetry Dictionary had proven to be closely intertwined and cross-productive. The end result also provided the design for the "Telemetry Manager" flight software object. The process helped to bind a contract, i.e. interface specification of telemetry measurement between software objects. It further provided important feedback to software control algorithm designers for finalizing design parameters.

In conclusion, not only was this Cassini process a means to an end - the Telemetry Dictionary, it was also a team-player in the overall AACS flight software design.

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TABLE 1. Summary Statistics - # of Channels vs Software Object

Software	Object	Hdwe ass'n	# channels	Notes
ACL	Attitude Control	Software	29	
ACM	Attitude Commander	Software	43	
ADC	Attitude Determinat'n Commander	Software	1	
ATE	Attitude Estimator	Software	244	161 cov & K not essential
CFG	Configuration Manager	XXX	124	
CMD	Command Manager	Software	15	
CMT	Constraint Manager	Software	13	
FPA	Fault Protection & Analyzer	XXX	280	24 assigned; 256 TBD
FPR	Fault Protection Recovery	Software	3	
FSX	Flight Software Executive	EFC	71	
IOUmgr	Input_Output_Unit Manager	XXX	54	
IVP	Inertial Vector Propagator	Software	1	
MOD	Mode Commander	Software	5	
PROM	PROM_Control	Software	6	
SID	Star ID (identification)	Software	64	
TLM	Telemetry Manager	Software	2	
XBA	Cross-string Bus Adapter	Software	24	
ACC	Accelerometer Manager	Hdwe_Mgr	7	
EGA	Engine Gimbal Actuator	Hdwe_Mgr	10	
IRU	Inertial Reference Unit	Hdwe_Mgr	12	
PMS	Propulsion Module System	Hdwe_Mgr	10	
RWA	Reaction Wheel Assembly	Hdwe_Mgr	48	**TOTAL # ch.'s = 1094**
SRU	Stellar Reference Unit	Hdwe_Mgr	18	less non-ess. ATE = 933
SSA	Sun Sensor Assembly	Hdwe_Mgr	10	less TBD FPA ch = 677

Table 2. Telemetry List for Accelerometer_Manager Software Object

Ch	Ch# (new#)	Mnemonics	Mini Pkt#	Attribute prime	Hardware associat'n	Software object	Rate cruise*	Notes	Type	Bit	Scale Factor
E	1001	ACC__state	4	Sfwe_State2	ACC	HdweMgr	M		S	4	
E	1002	ACC_calBIAS	21	deltaV	ACC	HdweMgr	Z	"driftDelta" - calib prior to deltaV	I	16	
E	1003	deltaV_ACC	21	deltaV	ACC	HdweMgr	Z	"deltaV" - after scale factor compensatic	I	16	
E	1004	ACC_totBIAS	21	deltaV	ACC	HdweMgr	MS	"drift"= driftNominal+driftDelta	I	16	
E	1005	deltaV_tmtg	21	deltaV	ACC	HdweMgr	Z	"deltaVTimeTag", used to compute "diffTin	U	16	
E	1006	ACC_tmtg	21	deltaV	ACC	HdweMgr	Z	"timeTag"; 8+8 bits	U	16	
E	1007	raw_ACC_CT	22	IRU/ACC_data	ACC	HdweMgr	MS	"accumDeltaV" - before scale factor compe	I	16	
Legend: Rate (cruise F = fast; M = medium; S= slow; FM = medium fast; MS = medium slow: Z = zero, except in special mode											
E	1394	ACC_cycle	26	IRU/ACC_stat	ACC	CFG	S		U	8	
E	1395	ACC_ONtime	26	IRU/ACC_stat	ACC	CFG	S	unit in second	U	16	
E	1650	ACC_RESETct	37	Reset_count	ACC	IOU_mgr	S		U	8	
E	1665	ACC_ERR	38	Bus_error	ACC	IOU_mgr	S		U	8	
E	1666	ACC_ERR_ct	38	Bus_error	ACC	IOU_mgr	S		U	8	
E	2035	ACC_val_ERR	46	Anomaly_st2	ACC	FPA	MS	ACC_mgr: "accTooBigFault"	D	4	
E	2036	ACC_drf_ERR	46	Anomaly_st2	ACC	FPA	MS	ACC_mgr: "driftTooBigFault"	D	4	

Table 4. AACS Telemetry Dictionary - sorted by Channel# and Software Object (page 1 of XX)

Ch	Ch# (new#)	Mnemonics	Mini Pkt#	Attribute prime	Hardware associat'n	Software object	Rate cruise*	Notes	Type	Bit	Scale Factor
E	1001	ACC__state	4	Sfwe_State2	ACC	HdweMgr	M		S	2	1
E	1002	ACC_calBIAS	21	deltaV	ACC	HdweMgr	Z	ACC_mgr: "driftDelta" - calib prior to de	I	16	5.0 E6
E	1003	deltaV_ACC	21	deltaV	ACC	HdweMgr	Z	ACC_Mgr: "deltaV" - after scale factor cc	I	20	500
E	1004	ACC_totBIAS	21	deltaV	ACC	HdweMgr	Z	ACC_mgr: "drift"= driftNominal+driftDelta	I	16	5.0 E6
E	1005	deltaV_tmtg	21	deltaV	ACC	HdweMgr	Z	ACC_mgr: "deltaVTimeTag", used to compute	U	20	BITcrop
E	1006	ACC_tmtg	21	deltaV	ACC	HdweMgr	Z	ACC_mgr: "timeTag"; 12+8 bits	U	20	BITcrop
E	1007	raw_ACC_CT	22	IRU/ACC_data	ACC	HdweMgr	MS	ACC_Mgr: "accumDeltaV" - before scale fac	I	24	1
E	1021	momUNLOADst	3	Sfwe_State	Sfwe	ACL	FM	RCS/ACL: "inactive/THRUSTR_WARMUP/UNloadi	S	2	1
E	1022	MANUVR_st	3	Sfwe_State	Sfwe	ACL	FM	TVC/RCS_deltaV/ACL: "off/TVC_enabled/RCS	S	2	1
E	1023	ATT_CNTR_st	4	Sfwe_State2	Sfwe	ACL	M		S	4	1
E	1024	POSdadBND_X	6	SC_pointg2	Sfwe	ACL	S	RCS/ACL: changes by +/-20% during cruise;	U	16	1.0 E5
E	1025	POSdadBND_Y	6	SC_pointg2	Sfwe	ACL	S	RCS/ACL: changes by +/-20% during cruise;	U	16	1.0 E5
E	1026	POSdadBND_Z	6	SC_pointg2	Sfwe	ACL	S	RCS/ACL: changes by +/-20% during cruise;	U	16	1.0 E5
E	1027	RATEddBND_X	6	SC_pointg2	Sfwe	ACL	S	RCS/ACL: constants	U	16	1.0 E6
E	1028	RATEddBND_Y	6	SC_pointg2	Sfwe	ACL	S	RCS/ACL: constants	U	16	1.0 E6
E	1029	RATEddBND_Z	6	SC_pointg2	Sfwe	ACL	S	RCS/ACL: constants	U	16	1.0 E6
E	1030	ddBND_IbitX	6	SC_pointg2	Sfwe	ACL	S	RCS/ACL: impulse bang-bang ctrl S/C att c	U	16	TBD
E	1031	ddBND_IbitY	6	SC_pointg2	Sfwe	ACL	S	RCS/ACL: impulse bang-bang ctrl S/C att c	U	16	TBD
E	1032	ddBND_IbitZ	6	SC_pointg2	Sfwe	ACL	S	RCS/ACL: impulse bang-bang ctrl S/C att c	U	16	TBD
E	1033	POSerr_X	8	Att_cntrl	Sfwe	ACL	FM	Same measurement for RCS,RWA,TVC. RCS: de	I	16	2.0 E5
E	1034	POSerr_Y	8	Att_cntrl	Sfwe	ACL	FM	Same measurement for RCS,RWA,TVC. RCS: de	I	16	2.0 E5
E	1035	POSerr_Z	8	Att_cntrl	Sfwe	ACL	FM	Same measurement for RCS,RWA,TVC. RCS: de	I	16	2.0 E5
E	1036	RATErr_X	8	Att_cntrl	Sfwe	ACL	FM	Same measurement for RCS/RWA/TVC. RCS: de	I	16	1.0 E6
E	1037	RATErr_Y	8	Att_cntrl	Sfwe	ACL	FM	ditto [IRU res of 0.25μrad/pulse/0.25 sec	I	16	1.0 E6
E	1038	RATErr_Z	8	Att_cntrl	Sfwe	ACL	FM	ditto [IRU res of 0.25μrad/pulse/0.25 sec	I	16	1.0 E6
E	1039	cmdTORQUE_X	11	RWA cntrl	Sfwe	ACL	Z	RWA/ACL: Different form RWA_TQ's. Here:	I	16	2.0 E5
E	1040	cmdTORQUE_Y	11	RWA cntrl	Sfwe	ACL	Z	RWA/ACL: Different form RWA_TQ's. Here:	I	16	2.0 E5
E	1041	cmdTORQUE_Z	11	RWA cntrl	Sfwe	ACL	Z	RWA/ACL: Different form RWA_TQ's. Here:	I	16	2.0 E5
E	1042	cmd_S/C_H_X	11	RWA cntrl	Sfwe	ACL	Z	RWA/ACL: Different from ATE's momemntum	I	16	1.0 E3
E	1043	cmd_S/C_H_Y	11	RWA cntrl	Sfwe	ACL	Z	RWA/ACL: Different from ATE's momemntum	I	16	1.0 E3
E	1044	cmd_S/C_H_Z	11	RWA cntrl	Sfwe	ACL	Z	RWA/ACL: Different from ATE's momemntum	I	16	1.0 E3
E	1045	cmd_thrustX	21	deltaV	Sfwe	ACL	Z	TVC/ACL: "TsubC"	I	16	TBD
E	1046	cmd_thrustY	21	deltaV	Sfwe	ACL	Z	TVC/ACL: "TsubC"	I	16	TBD
E	1047	cmd_thrustZ	21	deltaV	Sfwe	ACL	Z	TVC/ACL: "TsubC"	I	16	TBD
E	1048	BURN_time	21	deltaV	Sfwe	ACL	Z	16+8 bits. 0.004 sec res 2^16 = 65536 sec	U	24	BITcrop
E	1049	deltaV_pred	21	deltaV	Sfwe	ACL	Z	TVC/ACL: predict of the time profile of T	U	20	500
E	1061	TURN_status	3	Sfwe_State	Sfwe	ACM	FM	"Completed/Rate_Matching/POS_matching/COA	S	2	1
E	1062	ATT_CMD_st	4	Sfwe_State2	Sfwe	ACM	M		S	4	1
E	1063	cmdSC_Q1	5	SC_pointing	Sfwe	ACM	MS	"base_attitude"	I	16	32768
E	etc	etc	etc	etc.	etc.	etc.	etc.	etc.	etc	etc	etc

Table 3: AACS "Record" Telemetry Mode* - Mini-Packet Assignment Map
(576 bps AACS allocation)

AACS Packet Size (bits) = 4608
Header Size (bits) = 96
Assignable Space (bits) = 4512

AACS Packet Period (sec) = 8
Assignable Bit Rate (bps) = 564

Mini-Pkt#	Mini-Packet Name	# channels	Size (bits)	n	m	Period (sec)^	bps	% Bandwidth
1	Estimated Attitude	6	132	8	1	1	132.00	23%
2	Hardware Configuration	13	184	1	4	32	5.75	1%
3	Software State	8	69	2	1	4	17.25	3%
4	Software State_2	30	144	1	2	16	9.00	2%
5	Spacecraft Pointing	15	264	1	2	16	16.50	3%
6	Spacecraft Pointing_2	20	528	1	32	256	2.06	0%
7	Turn telemetry	19	328	1	32	256	1.28	0%
8	Attitude Controller	6	120	4	1	2	60.00	11%
9	Constraint Attitude Control	10	184	1	64	512	0.36	0%
10	RWA General Data	8	120	1	16	128	0.94	0%
11	RWA Controller	10	184	1	16	128	1.44	0%
12	Attitude Estimator (ATE) Metric	9	168	4	1	2	84.00	15%
13	Attitude Estimator (ATE) Data	22	376	1	2	16	23.50	4%
14	ATE Auto-Calibration Data	12	216	1	8	64	3.38	1%
15	ATE Star Pre-Filter Data	22	376	1	8	64	5.88	1%
16	ATE Covariance Data	12	216	1	64	512	0.42	0%
17	ATE Kalman Gain Data	9	168	1	64	512	0.33	0%
18	SID: Star 1 & 2 Data	10	184	2	1	4	46.00	8%
19	SID: Star 3,4 & 5 Data	19	308	1	2	16	19.25	3%
20	SID: Calibration-Type Data	34	632	1	16	128	4.94	1%
21	ΔV Maneuver Data	12	248	1	32	256	0.97	0%
22	IRU & ACC Output Data	9	176	1	4	32	5.50	1%
23	SSA & SRU Output Data	22	264	1	4	32	8.25	1%
24	RWA Output Data	28	440	1	32	256	1.72	0%
25	VDE & EGE Data	14	200	1	4	32	6.25	1%
26	IRU & ACC Statistics	6	96	1	64	512	0.19	0%
27	SSA & SRU Statistics	8	120	1	64	512	0.23	0%
28	EGA Statistics	12	184	1	64	512	0.36	0%
29	RWA Statistics	16	248	1	64	512	0.48	0%
30	PMS LatchValve & ME Statistics	15	176	1	64	512	0.34	0%
31	PMS Thruster Cycles	16	280	1	16	128	2.19	0%
32	PMS_A FireTime	8	216	1	16	128	1.69	0%
33	PMS_B FireTime	8	216	1	16	128	1.69	0%
34	PMS CatBedHeater Cycles	16	280	1	16	128	2.19	0%
35	AFC Errors	13	288	1	64	512	0.56	0%
36	EFC Errors	28	540	1	64	512	1.05	0%
37	Reset Counters	15	144	1	64	512	0.28	0%
38	AACS Bus Errors	30	264	1	64	512	0.52	0%
39	Prime AFC Hardware Status	20	404	1	8	64	6.31	1%
40	Backup AFC Errors	9	184	1	64	512	0.36	0%
41	Backup EFC Errors	20	328	1	64	512	0.64	0%
42	Backup AFC Hardware Status	20	372	1	64	512	0.73	0%
43	Bus Message Status	18	256	1	1	8	32.00	6%
44	Fault Protection Status	17	412	1	4	32	12.88	2%
45	Anomaly Status	13	176	1	8	64	2.75	0%
46	Anomaly Status 2	10	76	1	8	64	1.19	0%
47-54	High Water Marks	128	280 x 8	1	64	512	4.38	1%
55-62	Persistence High Water Marks	128	280 x 8	1	64	512	4.38	1%
102/../5	ATE Covariance Data 2/.../5	105	1776	0	64	#DIV/0!	0.00	0%
106	ATE Kalman Gain Data 2	36	600	0	64	#DIV/0!	0.00	0%
		Total #ch's	Total #bits				Total bps	Total bdwth
		1094	13865				534.33	95%

* This "Record" Telemetry Mode is one out of 7 modes: (1) Record; (2) Nominal Cruise; (3) Medium Slow Cruise; (4) Slow Cruise; (5) Orbital Ops; (6) delta_V; (7) ATE (Attitude Estimator) Calibration.

^ Cardinal vs Ordinal Rating of Periodicity: F=(8,1),(4,1) FM=(2,1),(1,1) M=(1,8),(1,16) S=(1,32),(1,64)

Table 5. AACS Telemetry Dictionary - sorted by Mini_Packet# (page 1 of XX)

Ch	Ch# (new#)	Mnemonics	Mini Pkt#	Attribute prime	Hardware associat'n	Software object	Rate cruise*	Notes	Type	Bit	Scale Factor
E	1121	BODY_Z_RA	1	Est_Att	Sfwe	ATE	F	20 bit: 6 µrad resolution	I	20	2^19/π
E	1122	BODY_Z_DEC	1	Est_Att	Sfwe	ATE	F	20 bit: 6 µrad resolution	I	20	2^19/π
E	1123	BODY_Z_TWIS	1	Est_Att	Sfwe	ATE	F	20 bit: 6 µrad resolution	I	20	2^19/π
E	1124	X_rate	1	Est_Att	Sfwe	ATE	F		I	16	2.0 E5
E	1125	Y_rate	1	Est_Att	Sfwe	ATE	F		I	16	2.0 E5
E	1126	Z_rate	1	Est_Att	Sfwe	ATE	F		I	16	2.0 E5
			1								
E	1381	BUS_prime	2	Hdwe_config	EFC	CFG	M		D	16	1
E	1382	SNSR_pwr	2	Hdwe_config	Hdwe	CFG	M		D	8	1
E	1383	ACTR_pwr	2	Hdwe_config	Hdwe	CFG	M		D	8	1
E	1384	SNSR_prime	2	Hdwe_config	Hdwe	CFG	M		D	4	1
E	1385	ACTR_prime	2	Hdwe_config	Hdwe	CFG	M		D	8	1
E	1386	SNSR_hlth	2	Hdwe_config	Hdwe	CFG	M		D	16	1
E	1387	ACTR_hlth	2	Hdwe_config	Hdwe	CFG	M		D	16	1
E	1388	VDE_pwr	2	Hdwe_config	PMS	CFG	M		D	12	1
E	1389	VDE_prime	2	Hdwe_config	PMS	CFG	M		D	12	1
E	1390	VDE_hlth	2	Hdwe_config	PMS	CFG	M		D	20	1
E	1391	RCS_prime	2	Hdwe_config	PMS	CFG	M		D	8	1
E	1392	RCS_A_hlth	2	Hdwe_config	PMS	CFG	M		D	16	1
E	1393	RCS_B_hlth	2	Hdwe_config	PMS	CFG	M		D	16	1
			2								
E	1021	momUNLOADst	3	Sfwe_State	Sfwe	ACL	FM	RCS/ACL: "inactive/THRUSTR_WARMUP/UNloadi	S	2	1
E	1022	MANUVR_st	3	Sfwe_State	Sfwe	ACL	FM	TVC/RCS_deltaV/ACL: "off/TVC_enabled/RCS	S	2	1
E	1061	TURN_status	3	Sfwe_State	Sfwe	ACM	FM	"Completed/Rate_Matching/POS_matching/COA	S	2	1
E	1127	SunEphm_chk	3	Sfwe_State	Sfwe	ATE	FM	SSA sun_vect not equal (with tolerance) t	S	1	1
E	1541	CMT_status	3	Sfwe_State	Sfwe	CMT	FM	"Nominal/noJ2000/withJ2000/timeout"	S	2	1
E	1741	AACS_mode	3	Sfwe_State	Sfwe	MOD	FM		S	4	1
E	1742	AACS_stat1	3	Sfwe_State	Sfwe	MOD	FM		D	16	1
E	1743	AACS_stat2	3	Sfwe_State	Sfwe	MOD	FM		D	16	1
			3								
E	1023	ATT_CNTR_st	4	Sfwe_State2	Sfwe	ACL	M		S	4	1
E	1062	ATT_CMD_st	4	Sfwe_State2	Sfwe	ACM	M		S	4	1
E	1111	ADC_state	4	Sfwe_State2	Sfwe	ADC	M		S	4	1
E	1128	ATT_EST_st	4	Sfwe_State2	Sfwe	ATE	M		S	4	1
E	1129	deltaV_ESst	4	Sfwe_State2	Sfwe	ATE	M	TVC/RCS_delta_V/ACL: "idle/acc/timer/impu	S	2	1
E	1542	AVOID_state	4	Sfwe_State2	Sfwe	CMT	M	"Celestial_vect/body_vect"	S	4	TBD
E	1543	PTGviolatST	4	Sfwe_State2	Sfwe	CMT	M	"body_vect/thermal violation_duration"	S	4	TBD
E	1001	ACC__state	4	Sfwe_State2	ACC	HdweMgr	M		S	2	1
E	1561	EGAA_state	4	Sfwe_State2	EGA	HdweMgr	M		S	2	1
E	1562	EGAB_state	4	Sfwe_State2	EGA	HdweMgr	M		S	2	1
E	1711	IRUA_state	4	Sfwe_State2	IRU	HdweMgr	M	"on/off"	S	2	1
E	1712	IRUB_state	4	Sfwe_State2	IRU	HdweMgr	M	"on/off"	S	2	1
E	1713	IRUA_status	4	Sfwe_State2	IRU	HdweMgr	M	"max_pulse_viol;max_acc_viol;A&B_consiste	D	8	1
E	1714	IRUB_status	4	Sfwe_State2	IRU	HdweMgr	M	"max_pulse_viol;max_acc_viol;A&B_consiste	D	8	1
E	1761	PMSA_state	4	Sfwe_State2	PMS	HdweMgr	M	"on/off;idle;ME_critical_enabled;ME_pulse	D	8	1
E	1762	PMSB_state	4	Sfwe_State2	PMS	HdweMgr	M	"on/off;idle;ME_critical_enabled;ME_pulse	D	8	1
E	1791	RWA1_state	4	Sfwe_State2	RWA	HdweMgr	M		S	3	1
E	1792	RWA2_state	4	Sfwe_State2	RWA	HdweMgr	M		S	3	1
E	1793	RWA3_state	4	Sfwe_State2	RWA	HdweMgr	M		S	3	1
E	1794	RWA4_state	4	Sfwe_State2	RWA	HdweMgr	M		S	3	1
E	1931	SRUA_state	4	Sfwe_State2	SRU	HdweMgr	M		S	2	1
E	1932	SRUB_state	4	Sfwe_State2	SRU	HdweMgr	M		S	2	1
E	1961	SSAA_state	4	Sfwe_State2	SSA	HdweMgr	M	"on/off"	S	2	1
E	1962	SSAB_state	4	Sfwe_State2	SSA	HdweMgr	M	"on/off"	S	2	1
E	1963	SSAA_status	4	Sfwe_State2	SSA	HdweMgr	M	"auto/grd_cmd'd_thrshld;sun_there;sun_sta	D	8	1
E	1964	SSAB_status	4	Sfwe_State2	SSA	HdweMgr	M	"auto/grd_cmd'd_thrshld;sun_there;sun_sta	D	8	1
E	1731	IVP_status	4	Sfwe_State2	Sfwe	IVP	M	ala GLL IVP_Stat	S	4	1
E	1851	SID_state	4	Sfwe_State2	Sfwe	SID	M	states in transition diagram	S	4	1
E	1981	AACStlmMode	4	Sfwe_State2	Sfwe	TLM	M		S	4	1
E	1982	SCtlm_mode	4	Sfwe_State2	Sfwe	TLM	M		S	4	1
			4								
E	1063	cmdSC_Q1	5	SC_pointing	Sfwe	ACM	MS	"base_attitude"	I	16	32768
E	1064	cmdSC_Q2	5	SC_pointing	Sfwe	ACM	MS	"base_attitude"	I	16	32768
E	1065	cmdSC_Q3	5	SC_pointing	Sfwe	ACM	MS	"base_attitude"	I	16	32768
E	1066	cmdSC_Q4	5	SC_pointing	Sfwe	ACM	MS	"base_attitude"	I	16	32768
E	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc	etc	etc