Engineering Sensors for the Cassini Spacecraft

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This intent of this section is to review the subsystems of the Cassini spacecraft, and to discuss the types of types of devices that are used to collect engineering data for each of these subsystems. This section will provide a summary of the different types of sensors used by the Cassini spacecraft, and within each subsystem.
The Cassini spacecraft is a large interplanetary spacecraft that was developed by the Jet Propulsion Laboratory. It was launched in October of 1997, and it will arrive at Saturn in July of 2004. The spacecraft has a dry mass of 3132 Kg (6905 lbs.).

The data presented in this paper is a quick assessment of a Cassini telemetry database. The purpose of this analysis was to gain a simple understanding of the types of engineering telemetry items generated by a spacecraft of this class. As such, there are probably errors in this analysis, and the Cassini project will not verify the accuracy of this analysis.

1 Summary of Subsystem Sensor Requirements

This section will provide a summary of the engineering sensors used on the Cassini spacecraft. There will be further discussions, following in this section, on a brake down of the engineering sensors for each of the spacecraft subsystems.

An electronic copy of the database used to create the Cassini project telemetry dictionary was obtained and used for this analysis. This database contained information on 4392 different telemetry items that are in the Cassini telemetry return link. The analysis was performed by looking at those telemetry items that were identified as being implemented by one of the engineering subsystem. This means that all of the telemetry items for the spacecraft science instruments were ignored. This brought down the total number of telemetry items from 4392 to 2501. However, a number of these telemetry items were spare items in the telemetry format. So when the spares were also deleted, then the total was brought down to 2434. This is the total on which the following analysis was based. Taking this information, the report's author categorized each telemetry item into a telemetry type. This assignment was based mostly on the name of the telemetry item. The categories that were used are:

- Temperature: a temperature measurement on a particular element, device, component, or structure
- Voltage: a voltage that is measured as a primary or secondary power distribution voltage. Therefore, these are voltages associated with the power distribution subsystem, or in a power converter in a particular subsystem. Voltages that actually measure another type of parameter were not included in this category.

- Current: a current that is measured as a primary or secondary power distribution current. Therefore, these are currents associated with the power distribution subsystem, or in a power converter in a particular subsystem.
- Flight Software Counter: a counter implemented in the flight software where an event or other item is counted, for each time the event occurs.
- Flight Software Trap: is to be an indication that a certain event has occurred, or that the flight software has executed a certain element of the flight software code.
- Flight Software: is all other health indications or telemetry from the flight software, including present values of variables within the flight software.
- Analog: are measurements of any type of physical parameter that has the characteristics of an analog measurement.
- Status: A simple indication of an event, or a set of events. It is an indication of the present status of a measurement or event.
- Discrete: is an event or state of an element of the subsystem or spacecraft hardware. A discrete is different from a status in that it is tied directly into the state of the hardware.

The following tables show the results of this analysis.

TABLE 1. RAW DATA ON CASSINI SENSORS BY TYPE FOR EACH SUBSYSTEM.

Numbers of Sensors by Type for each Cassini Subsystem													
Subsystem ID	Subsystem	Temp	Voltage	Current	FSW Ctr	FSW Trap	FSW	Analog	Status	Discrete	Spare	Total w/o Spare	Total
2001	STRU	3	0	0	0	0	0	0	0	0	0	3	3
2002	RFS	16	16	10	3	0	15	62	51	0	0	173	173
2004	PPS	10	19	376	0	0	0	0	0	108	24	513	537
2006	CDS	4	36	0	0	0	256	0	0	0	0	296	296
2007	AACS	26	2	4	115	0	618	7	329	0	43	1101	1144
2009	CABL	0	0	0	0	0	0	0	8	0	0	8	8
2010	PMS	171	0	0	0	0	0	67	0	0	0	238	238
2012	DEV	6	0	0	0	0	0	0	11	0	0	17	17
2014	EPS	13	0	0	0	0	0	0	0	0	0	13	13
2016	SSR	4	8	0	0	0	0	0	0	0	0	12	12
2017	ANT	12	0	0	0	0	0	0	0	0	0	12	12
2018	RFIS	8	2	6	0	0	0	14	1	14	0	45	45
All		276	83	396	118	0	889	150	400	122	67	2434	2501

Table 1 is a shows the results of the raw data analysis. The totals for each type of sensor are shown for each subsystem. The spacecraft totals are also shown.

TABLE 2. PERCENTAGE DATA ON CASSINI SENSORS BY TYPE FOR EACH SUBSYSTEM.

Percentage Each Sensor Type by Subsystem												
Subsystem ID	Subsystem	Temp	Voltage	Current	FSW Ctr	FSW Trap	FSW	Analog	Status	Discrete		Total w/o Spare
2001	STRU	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		100%
2002	RFS	9.25%	9.25%	5.78%	1.73%	0.00%	8.67%	35.84%	29.48%	0.00%		100%
2004	PPS	1.95%	3.70%	73.29%	0.00%	0.00%	0.00%	0.00%	0.00%	21.05%		100%
2006	CDS	1.35%	12.16%	0.00%	0.00%	0.00%	86.49%	0.00%	0.00%	0.00%		100%
2007	AACS	2.36%	0.18%	0.36%	10.45%	0.00%	56.13%	0.64%	29.88%	0.00%		100%
2009	CABL	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%		100%
2010	PMS	71.85%	0.00%	0.00%	0.00%	0.00%	0.00%	28.15%	0.00%	0.00%		100%
2012	DEV	35.29%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	64.71%	0.00%		100%
2014	EPS	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		100%
2016	SSR	33.33%	66.67%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		100%
2017	ANT	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		100%
2018	RFIS	17.78%	4.44%	13.33%	0.00%	0.00%	0.00%	31.11%	2.22%	31.11%		100%
All		11.34%	3.41%	16.27%	4.85%	0.00%	36.52%	6.16%	16.43%	5.01%		100%

Table 2 shows the same data; however, percentages are shown for each subsystem. Therefore, reading across a row, we can see the percentage of sensors of a particular type that are in a particular subsystem. For example, we can see that temperature sensors make up 9.25% of all sensors in the RFS subsystem.

TABLE 3. PERCENTAGE DATA ON CASSINI FOR EACH SUBSYSTEM BY SENSOR TYPE.

Percentage Sensors Each Subsystem by Sensor Type										
Subsystem ID	Subsystem	Temp	Voltage	Current	FSW Ctr	FSW Trap	FSW	Analog	Status	Discrete
2001	STRU	1.09%	0.00%	0.00%	0.00%		0.00%	0.00%	0.00%	0.00%
2002	RFS	5.80%	19.28%	2.53%	2.54%		1.69%	41.33%	12.75%	0.00%
2004	PPS	3.62%	22.89%	94.95%	0.00%		0.00%	0.00%	0.00%	88.52%
2006	CDS	1.45%	43.37%	0.00%	0.00%		28.80%	0.00%	0.00%	0.00%
2007	AACS	9.42%	2.41%	1.01%	97.46%		69.52%	4.67%	82.25%	0.00%
2009	CABL	0.00%	0.00%	0.00%	0.00%		0.00%	0.00%	2.00%	0.00%
2010	PMS	61.96%	0.00%	0.00%	0.00%		0.00%	44.67%	0.00%	0.00%
2012	DEV	2.17%	0.00%	0.00%	0.00%		0.00%	0.00%	2.75%	0.00%
2014	EPS	4.71%	0.00%	0.00%	0.00%		0.00%	0.00%	0.00%	0.00%
2016	SSR	1.45%	9.64%	0.00%	0.00%		0.00%	0.00%	0.00%	0.00%
2017	ANT	4.35%	0.00%	0.00%	0.00%		0.00%	0.00%	0.00%	0.00%
2018	RFIS	2.90%	2.41%	1.52%	0.00%		0.00%	9.33%	0.25%	11.48%
All		100.00%	100.00%	100.00%	100.00%		100.00%	100.00%	100.00%	100.00%

Table 3 shows the same data again, however the percentages are shown for each sensor type. So, reading down a column, we can see the percentages of each type of sensor in a particular subsystem. For example, 5.80% of all temperature sensors are in the RFS subsystem.

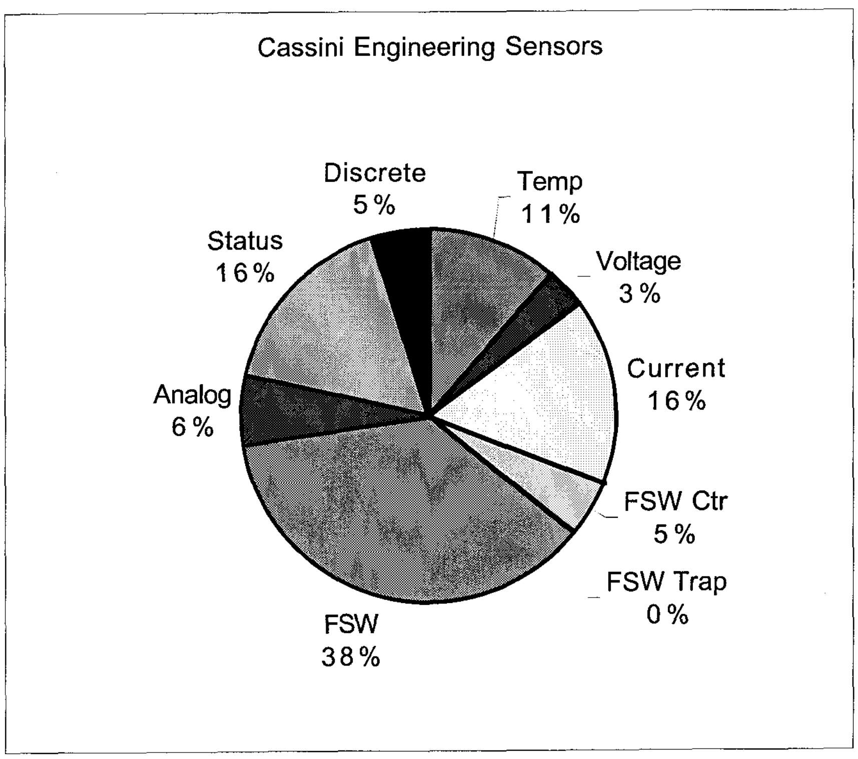

FIGURE 1. BREAKDOWN OF ALL CASSINI ENGINEERING SENSORS BY TYPE.

Finally, we see in Figure 1 a graphical summary of the breakdown of sensors used on the Cassini spacecraft by type. This figure is a summary of the information in the last row of Table 2.

2 Subsystem Sensor Requirements

This section will discuss the breakdown of the types of sensors that are used by each subsystem. Therefore, this information will just be a graphical form of the data that is shown in each row of Table 2.

2.1 Command and Data Subsystem

We can see this breakdown of sensors for the Cassini spacecraft Command and Data Subsystem (CDS). The CDS is the equivalent to the Command & Data Handling Subsystem, which is a more generic name for these spacecraft functions.
As we see in Figure 2, most of the information in the telemetry for the Cassini CDS is information on the operation of the CDS flight software (FSW), 87% of the CDS total. However, these measurements may not be very typical for our purposes. All of these telemetry items are used to downlink the contents of the memory load bit map area of the CDS memory. The remaining 13% of the telemetry items are physical measurements of by the CDS hardware. About 12% of the total for the sensors are voltage measurements. These measurements are of output voltages from power converters, which are used by the CDS and other subsystems. Measurements for other subsystems are included in the CDS total, because the engineering tree and analog-to-digital converters are usually located in the CDS. The remaining telemetry items (1%) are of temperatures of CDS equipment.

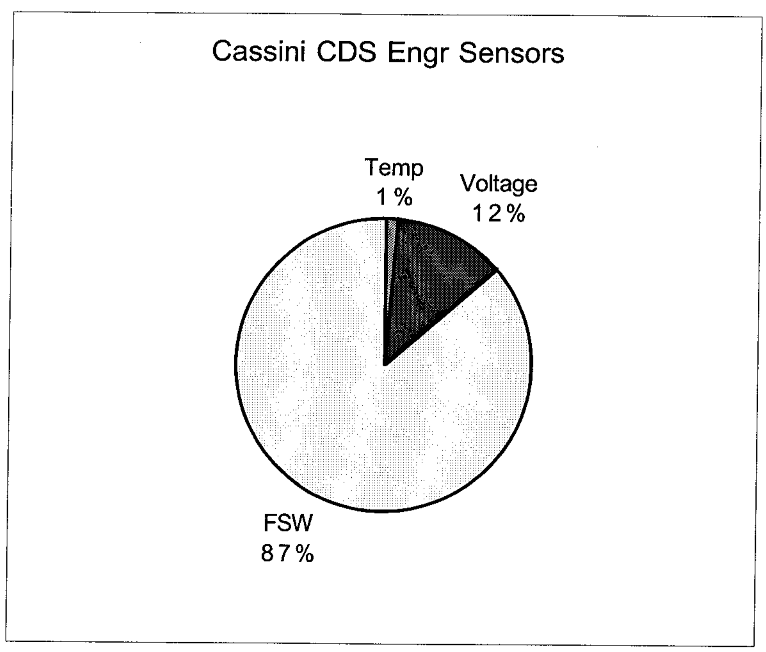

FIGURE 2. BREAKDOWN OF CASSINI CDS ENGINEERING SENSORS BY TYPE.

2.2 RF Communications Subsystem

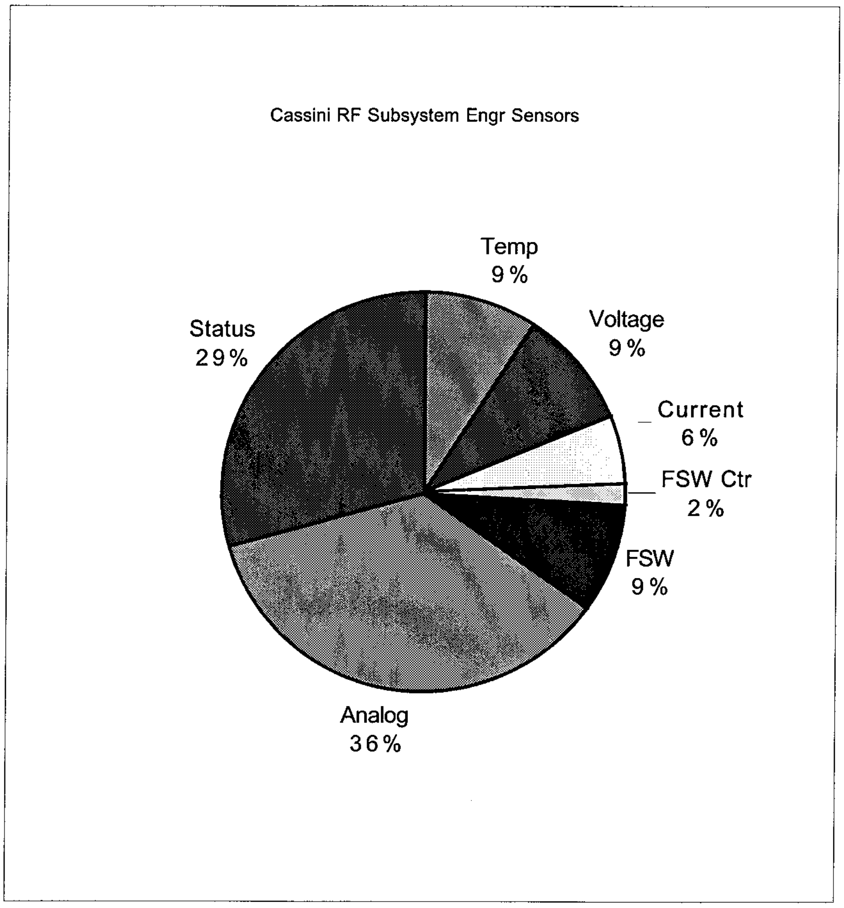

FIGURE 3. BREAKDOWN OF CASSINI RFS ENGINEERING SENSORS BY TYPE.

Figure 3 shows the breakdown of the telemetry items for the RF Subsystem (RFS) on the Cassini spacecraft. We can see that about 9% of these telemetry items are for temperatures of different RF Subsystem equipment, and another 9% are for voltage telemetry items, which are for the measurement of important RFS power converter outputs and reference voltages. Similarly, 6% of the measurements are for current measurements, which are for monitoring the input current for some of the RFS equipment. About 11% of the telemetry items are for flight software measurements, which are of various types of software counters, states, and status words.
The largest group of telemetry items, 36%, is the analog measurements. For the Cassini RFS, these measurements are a combination of various engineering measurements that are taken inside of the RFS. These are all used to monitor the health and operation of the subsystem hardware. And finally, the status measurements are the final 29% of the measurements. These status measurements are an indication of the state of the RFS hardware, and how it is being operated.

2.3 Attitude & Articulation Control Subsystem

Figure 4 is a breakdown of the sensors that are used by the Attitude and Articulation Control Subsystem (AACS) on the Cassini spacecraft. This diagram shows what types of sensors are used in the AACS.

From this figure, we see that about 2% of the measurements are temperatures of hardware elements of the AACS subsystem. The measurements for voltages, currents, and analog (0.18%, 0.36%, and 0.64% respectively) are a small number of measurements. However, for the AACS, these measurements seem to have been picked in order to further understanding the health of the elements of the AACS hardware.

The telemetry items for the flight software make up about 97% of all of the items for the AACS subsystem. While a significant number of the telemetry items are FSW counters (10%), there are a large number (30%) of software status measurements, while the largest proportion of telemetry items (57%) are variables in the AACS FSW, and other FSW indications.

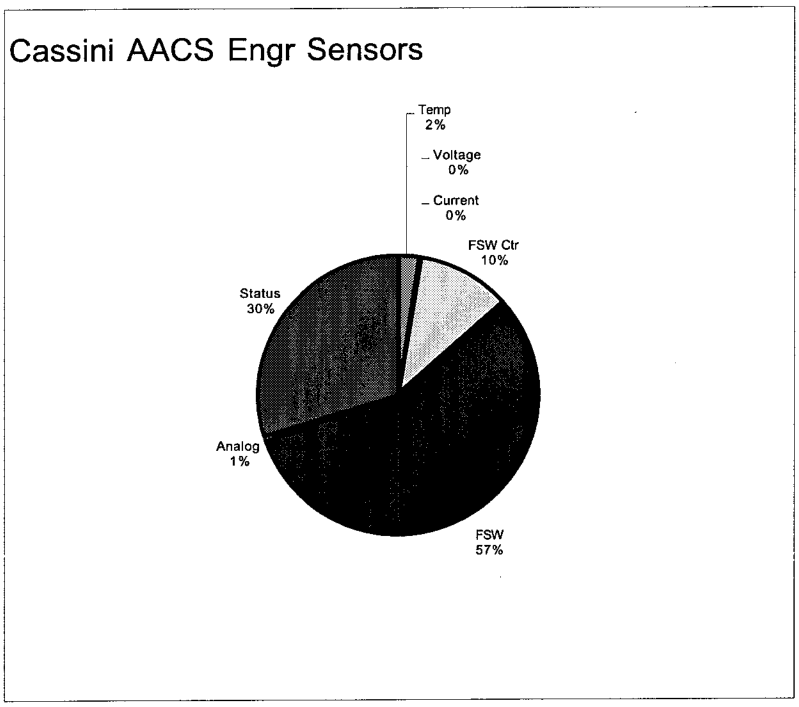

FIGURE 4. BREAKDOWN OF CASSINI AACS ENGINEERING SENSORS BY TYPE.

2.4 Propulsion Module Subsystem

The Cassini Propulsion Module has the same functionality that a combined Orbit Maneuver subsystem and Reaction Control subsystem would have. This would be where the Orbit Maneuver subsystem is used for major propulsion events. However, on the Cassini spacecraft, these functions are combined into the Propulsion Module subsystem.

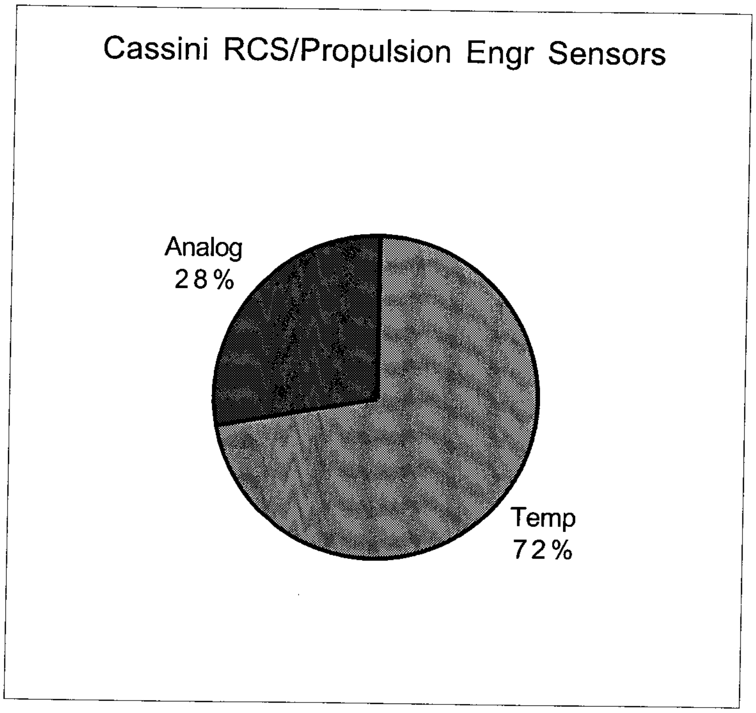

FIGURE 5. BREAKDOWN OF CASSINI PROPULSION MODULE ENGINEERING SENSORS BY TYPE.

On the Cassini spacecraft, there are only two types of sensors used on the Propulsion Module Subsystem. Temperature sensors (Figure 5) make up 72% of the sensors in this subsystem, while the remaining 28% of sensors are various analog measurements.

2.5 Navigation and Guidance Subsystems

The Navigation subsystem will keep track of the vehicle position. Navigation sensors, digital electronics, and software will dominate the implementation of this subsystem. For the Cassini spacecraft, Navigation is performed on the ground with the assistance of the RF subsystems. Therefore, there is no specific subsystem, which contains the guidance, navigation and control functions. So there are no sensors for this subsystem.

2.6 Electrical Power Subsystem

For the Cassini spacecraft, the Power Pyro subsystem will provide the electrical power generation, distribution, and management. As part of this task, is the distribution and control of the electrical power for pyro devices onboard the spacecraft. This is where the name of the Power Pyro subsystem comes from.

From Figure 6 we can see that the current measurements are the most important engineering measurement for the Cassini Power Pyro Subsystem. These measurements make up 73% of the total number of measurements. The next largest class is for discrete measurements of the EPS equipment, which consist of 21% of the total measurements.

The rest of the measurements are made up of 4% for voltage measurements, and 2% for temperature measurements.

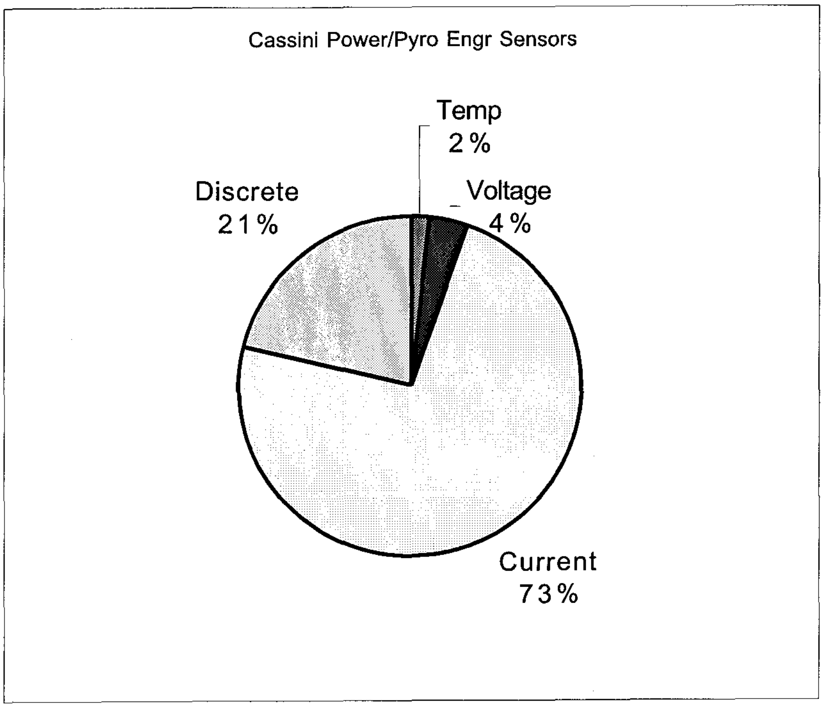

FIGURE 6. CASSINI POWER PYRO SUBSYSTEM SENSORS BY TYPE.

2.7 Thermal Control Subsystem

On the Cassini spacecraft, no telemetry channels are called out for specific thermal subsystem sensors. It is assumed that all Thermal Control Subsystem sensors would be temperature measurements, which are listed under the subsystem of the device that is being measured, or current sensors for heaters, which are listed as part of the Power Subsystem.

However, we should remember at this point that 11.34% of the Cassini engineering sensors are temperature sensors.

2.8 Mechanical Devices

We can see in Figure 7 that the sensors in the Mechanical Devices Subsystem of the Cassini spacecraft are in two types. The temperature sensors account for 35% of the sensors. Status indications of the mechanical devices account for the rest of the sensors, 65%.

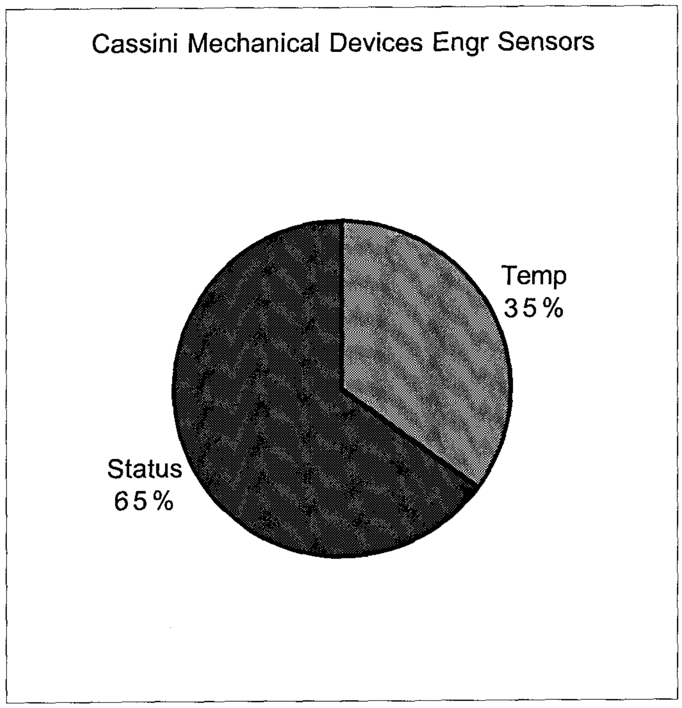

FIGURE 7. CASSINI MECHANICAL DEVICES SUBSYSTEM SENSORS BY TYPE.

2.9 Vehicle Structures

For the Cassini spacecraft, 100% of the structural sensors are temperature sensors, as shown in Figure 8. However, there are only three sensors for the Structure subsystem onboard the Cassini spacecraft.

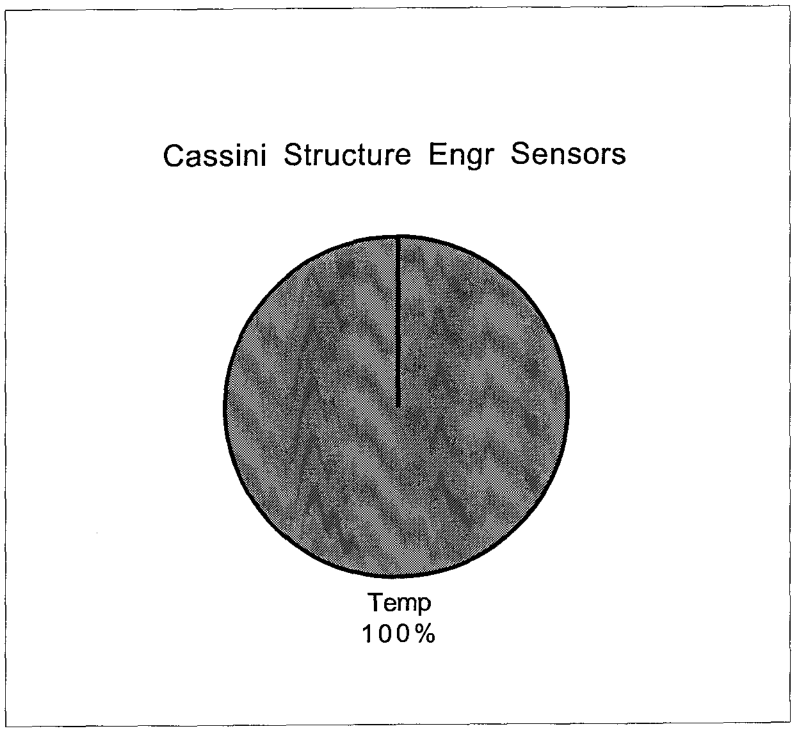

FIGURE 8. CASSINI STRUCTURAL SUBSYSTEM SENSORS BY TYPE.