WHY DATA SYSTEM STANDARDS

W. B. POLAND, Jr., R. T. FITZGERALD, and R. J. COATES
Goddard Space Flight Center
National Aeronautics and S ace Administration
Greenbelt Maryland.

Summary This paper discusses some ideas about data system standards which have been developed at the Goddard Space Flight Center (GSFC) of NASA over a period of about nine years, mainly as the result of experience gained in using the Space Tracking and Data Acquisition Network (STADAN), a collection of tracking, command, and telemetry stations for ground support of scientific satellites. The authors have found that the purposes and uses of data system standards are often misunderstood. To aid in clarifying this situation, they have described the growth and current implementation of the working approach to standards at GSFC. This approach is conditioned by the operating environment and by a number of administrative decisions, which are discussed. The areas ‘ included in the existing GSFC standards and some of those planned for future coverage are described, and some considerations bearing on the feasibility of combining GSFC and other data system standards are examined.

Introduction GSFC has maintained its own standards activity, the Data Systems Requirements Committee (DSRC), since 1960, and has developed a group of data system standards which differ substantially from the best known standards in this area, the MIG 106 series Telemetry Standards (currently 106-66)[1]. A simplified diagram of the systems to which these standards apply is shown in Fig. 1.

Standards of this type, called “system standards”, are only remotely related to the standards most people think of when the subject is mentioned: namely, such things as a platinum-iridium meter bar or standard capacitor preserved at the National Bureau of Standards at Gaithersburg, Maryland, and elsewhere. Such devices are used primarily to ensure reproducibility of measurements at different places and times, and as such are of great importance to technology., Data system standards, on the other hand, are useful mainly to promote compatibility between the complex data systems in use today and to establish tolerable performance thresholds. Because the names of both types of standards are similar and because the same user groups tend to be concerned with them, users and even groups charged with writing system standards, occasionally misapply measurement criteria to data system standards. The purpose of this paper is to define and discuss a reasonable approach to the development and use of data system standards, with emphasis on how the standards approach functions as an efficient means for coordinating diverse requirements.

History The committee responsible for developing system standards at the Goddard Space Flight Center was created by the Center's Director in 1960 for two basic reasons: it was felt important for the purpose of economy to eliminate needless redundancy in data system development; in addition, various situations arising in checking and operating the spacecraft then extant had illustrated the necessity for guaranteeing a minimum level of performance (especially with respect to security in command systems). The telemetry standards adopted were based an systems then in use: the PC24 standard followed the Orbiting Geophysical Observatory (OGO) satellite, while the PFM (Pulse Frequency Modulation) standard followed the Explorer XII telemetry system.

The requirement for establishing a minimum performance criterion was illustrated sharply when certain spacecraft exhibited false command responses with simple tone command systems with no spacecraft address. Experience showed that, both before and after launch, false Commanding by non-N&SA transmitters might occur. In fact, the Alouette spacecraft (S-27) initially experienced extraneous commanding during its ground testing phase because of RFI and hence the command system was changed to the GSFC standard address system. The orbiting spacecraft was also equipped to record the receipt of extraneous tones. Now the longest lived satellite supported by GSFC, Alouette has not had trouble with false commanding of the spacecraft in spite of routinely experiencing numerous false tones per orbit. This performance is due to the discrimination provided by the address scheme.

In the period of standards activity at GSFC, the ground installations have increased greatly in complexity and the investment has grown accordingly. The equipment complement at various stations has been increased to include, to name only a few systems, Goddard Range and Range Rate (GRARR) systems to augment the Minitrack tracking capability, 5 kw command transmission systems, multifunction phase-lock telemetry receivers, versatile PCM Data Handling Equipment (PCM/ERE), 85-foot dish antennas, etc. The total value of this complex exceeds 100 million dollars. The output of the STADAN stations is distributed to three principal areas (see figure) at GSFC, each representing a major investment: Telemetry Process Facility, Satellite Control Centers, and GSFC Computation Facility. The Goddard standards have developed into a major tool for insuring an efficient passage of data through this complex.

Environment for Standards At GSFC, data systems standards are written primarily to promote compatibility between future satellite project requirements (which tend to be unique) and the already established capabilities of multi-project data-system ground installations. Thus system standards typically represent constraints placed on spacecraft systems design by the ground systems that will support them. As a result, a natural and usually constructive contest sometimes develops between the designers of unique systems who want ultimate flexibility and peak performance, and the multi-project people who want to maximize both performance and system usage. offsetting this problem, however, are the economies and improved efficiency resulting from effective use of the system standards (GSFC currently supports between 40 and 45 earth orbiting scientific satellites as well as some others, and receives weekly from ground sites around the world about 1,800 reels of magnetically recorded data tapes).

As illustrated in simplified form in the figure, data flows from the spacecraft to STADAN and GSFC facilities. Usually, there are three interlocking communications loops for an operating satellite for tracking, command, and telemetry. In addition, within each loop, there are several link-interfaces composed either of commercial equipment or unique subsystems developed by GSFC for particular spacecraft. The GSFC data system standards usually apply to these link-interfaces and to other areas where system interference can occur.

Properties of System Standards The environment within which the system standards operate is inherently somewhat better controlled for GSFC than for the DoD ranges, and this accounts for some of the differences between the NASA and IRIG standards. The GSFC data systems standards are obligatory on all projects managed by GSFC or supported by STADAN or the GSFC data processing facilities, whereas the status of IRIG 106-66 has been primarily advisory. A STADAN user may not be allowed to launch without either conforming to the system standards or obtaining permission to deviate from the standards. As a result, GSFC system standards are sometimes more specific and restrictive than IRIG standards. IRIG, on the other hand, has tended to avoid (recently) specifying performance levels except where compatibility requires it, concentrating rather on defining measurement techniques and parameters.

The philosophy usually followed in formulating the GSFC standards is to state functional requirements only, avoiding details of implementation except where necessary. Thus to prevent radio frequency interference, we give channelization rules and an attenuation profile for carrier components outside the channel. Sometimes, however, the operating distinction between a functional description of a system and a description of its implementation is difficult to make, and we are forced to specify technical details. An example is provided by the command standards, in which the character of the transmitted signal is given in great detail and is required to be observed rigidly.

Returning to the distinction between classical standards and data system standards, we note a very important operating difference: whereas a classical standard's value lies primarily in its absolute accuracy and stability, the value of a system standard depends much more on its timeliness. This subtle point probably causes more problems than any other in the use of system standards. Since system standards are intended to ensure only compatibility and minimum performance, the type of precision normally associated with classical standards is not needed. System standards usually deal with man-made entities as opposed to physical properties; they are usually based on what has been implemented, rather than on basic physical qualities, and are therefore subject to justifiable change (always with timely notice). It is occasionally difficult for some system-standards people and others to shake off the feeling that a system standard should not be published until it is as firmly established as the value of the speed of light or the gravitational constant.

It also follows that system standards do not operate like laws or a judicial system; i.e., the system-standard philosophy is not that all things not specifically prohibited are permissable. On the contrary, ensuring satisfactory compatibility and performance demands that a proposed system for which no applicable standard exists must be treated like a violation of the system standards in that a specific determination of acceptability must be made. The reason is clear: only permissable and standardized spacecraft systems will necessarily be compatible with existing or planned ground systems.

Many people take the position that standards are here to be obeyed without question and find it difficult to accept the fact that a well defined mechanism for obtaining permission to deviate from a standard, when necessary, is an integral part of the system. However, as noted above, system standards can be restrictive, and may, if the users just accept them without proper question, forestall system optimization or use of new and improved technology. The concept of challenge is important and should always be remembered by those charged with implementing system standards. At GSFC, two methods are used to circumvent this difficulty. Projects may request, and frequently receive, waivers of specific system-standards requirements. Also, the committee responsible for the standards works continuously (with assistance from various ad hoc subcommittees it appoints as needed) to create new system standards or revise and update old ones. With such measures, the users continuously profit from an exact and proper application of system standards.

How GSFC Standards Operate Most frequently, the GSFC system standards apply to transactions across data system interfaces, defining the properties and contraints needed to establish subsystem compatibility and minimum acceptable performance thresholds. The system standards have four major objectives:

(a) multi-project usefulness of costly ground support facilities; i.e., avoidance of unnecessary and premature obsolescence of multi-project ground systems
(b) specified minimum level of system performance
(c) workable requirements for each part of the spacecraft/STADAN/data processing complex
(d) interface compatibility between systems

The work directly related to any spacecraft at GSFC is handled by a project organization and goes through a number of steps in a quite well defined cycle in the course of its development. The central figure in such activities is the Project Manager, who has the principal responsibility for making the Project function successfully. In addition to support from a Project Scientist, Tracking Scientist and others, the Manager usually has a small staff working directly for him, and can also command varying contributions of effort from cadres assigned to him from the staffs of the various GSFC support groups. Among his many duties is responsibility to assure that an appropriate subset of the following requirements has been met:

(a) all systems used conform to GSFC standards
(b) in special cases where unique requirements make it necessary to deviate from the standard systems, application is made to the DSRC for a waiver of standards for each non-conforming system. If the waiver is not granted by the DSRC, an appeal may be made to the Director, GSFC.
(c) denial of a waiver establishes a firm requirement for the project to conform to standards

GSFC policy requires that systems using GSFC facilities or managed by GSFC personnel must adhere to one of these acceptable alternatives.

Waivers ordinarily have been granted by the DSRC for one of several reasons:

(a) the requested deviation from the standards has no appreciable impact on facility operations, but is demonstrably beneficial to a project
(b) the deviation has an impact, but is so promising for improved performance that its experimental use is technically justified
(c) conformance to the standards would be so inefficient for a given project that a deviation is technically justified
(d) the standard systems are basically incapable of meeting the requirements for a given spacecraft

The DSRC considers only the technical aspects of waiver requests. If economic, administrative, or other factors must be considered, they are presented to the Director.

The above concepts which are essentially management requirements, have been developed over a period of about 9 years. Some of these concepts are enshrined in official management instructions, others are still developing. Taken together, they have produced a fairly high degree of conformance to standards among spacecraft projects: more than two thirds at last count.

In addition to management requirements, there are inducements for projects to observe the standards. For example, it is generally true that a project requiring substantially modified facilities must pay the costs for changes, whereas conformance to the standards reduces these larger costs to just operating expenses. Another inducement results from the fact that the frequency-control group at GSFC is properly represented on the standards committee. As a result systems requiring assignment of rf spectrum, chronically in short supply, are closely checked for conformance to the appropriate parts of the standards. Other proper management mechanisms aimed at creating a tendency for systems to conform to standards unless specific reasons dictate otherwise are continuously being worked out. Happily, there seems to be a natural trend for projects to conform; the standard approach provides reliable and effective solutions to system coordination problems. After all, a project having limited resources cannot afford to reinvent solutions to all its problems.

It is sometimes felt that standards may create serious obstacles to progress in solving data systems problems. Standards have been charged with carrying the danger of creating many bad effects*; e.g., blocking creativity and encouraging inertia, difficulty of interpretation and enforcement, limited applicability, and obsolescence. The authors recognize that each of these faults could arise in some circumstances; however, our experience has indicated that in practice they do not pose a serious problem and that the increased efficiency resulting from making multiple use of proved solutions far outweighs the constraints imposed by standards. The operational advantages of using standard approaches in a network of remote stations or in facilities handling a large data volume must not be underestimated.

Interaction of the GSFC Standards with Projects There are three basic situations which affect the way GSFC system standards are used: the inception of a project, system changes in a continuing project, or the addition of new spacecraft data systems previously not standardized.

In the first instance, standards may operate to guide the early development of data system planning. Rather than being an onerous burden, standards often operate at this point to eliminate equally attractive alternatives and simplify the job of planning. This is a particularly important phase both to a project and to those who benefit from the standards, since choices made early often are costly to modify later; conformance to the system standards for a,lengthy project may be determined simply by the initial adherence to standards in the early stages of system planning.

---

*For this list and a discussion of possible effects, the authors are indebted to H. J. Peake of GSFC.

In the second instance, system standards are often invoked during the intermediate or later stages of a program as new systems are introduced or new requirements arise. This process is most frequently followed when a flight project requests a waiver of system standards requirements from the DSRC and is denied the waiver.

In the third instance, there is a natural but, of course, undesirable tendency for the standards to get behind actual use. The result is that much of the effort of the DSRC has been spent on writing standards to remain abreast of current practice in the support facilities. Many of the existing standards have been written around existing systems, but a major effort is continuously expended on the timely development of standards for systems that are presently under development. This is a difficult task since it must be accomplished with limited operational knowledge. Our experience is, however, that it is possible to satisfy the necessary standard objectives.

Areas Covered by the Standards The GSFC Aerospace Systems Standards [2] contain three sections at present: Telemetry, Command and Associated Systems, as shown in Table I. One tracking standard dealing with the Minitrack beacon is included under Associated Systems. A standard for the new Goddard Range and Range Rate tracking system is in preparation. Several other standards in process include: coded PCM, magnetic tape units, orbital data format, FM/FM telemetry (restricted use only), and ground time code.

Pulse Frequency Modulation (PFM) is a non-IRIG PAM/FM system unique to GSFC. It has been one of the two major forms of modulation used at GSFC since the beginning of the space program. When properly instrumented it exhibits some of the desirable properties of the most sophisticated coding methods. However, using recently developed techniques, PCH coding systems can now be designed to provide equal or better performance without undue penalties of complexity, weight, etc. Also, there is a strong desire in the data processing area to make the greatest possible use of PCM telemetry rather than other forms of modulation for reasons of operating efficiency. Accordingly, PFM will be eliminated from the rosier of standard telemetry systems, and work is proceeding on development of a standard for convolutional PCM coding. As other systems are superceded, they too will cease to be considered standard.

It appears necessary to create a standard for FM/FM telemetry for analog channels, even though it is not operationally desirable. It is likely that this standard will limit the use of FM/FM as much as feasible, and will attempt to follow IRIG wherever possible. It must, however, deal with some areas not treated in the IRIG standards: compensation for tape playback at accelerated speeds (either in a spacecraft or on the ground) and transmission of reference frequencies suitable for a restricted system bandwidth.

Coordination with Other Standards The Goddard standards program continues to profit from interaction with the IRIG and makes use of IRIG standards whenever possible. The desirability of merging GSFC standards with the IRIG or other standards has been considered. It must be carefully examined, however. The unique feature of the GSFC environment, the very large flux of incoming data (approximately 10^{12} bits/year) creates requirements not experienced elsewhere. For example, the IRIG standards can afford to permit pre-detection recording with its high consumption of tape in order to minimize operator error and equipment complexity at the remote DoD stations, whereas this is not feasible in a system already generating nearly 2,000 reels a week. For similar reasons, the IRIG standard does not include provision for handling multi-channel FM subcarriers at faster than real speed. Several other examples could be cited. In general, combining the GSFC standards with others would be feasible only when all systems concerned are characterized by requirements for multi-satellite support and a large data volume. This point of view is reenforced by the anticipated tripling of the flow of data into GSFC by 1980.

There is also an important philosophical difference between the IRIG Telemetry Working Group and the DSRC. The current IRIG standards specify performance levels, dimensions,or other quantitative factors on where compatibility requires it; wherever possible, they avoid citing performance levels and are confined to specifying test methods and conditions. In contrast, the GSFC standards are intended to include minimum acceptable performance levels as an integral part. Combining the two standards would require resolving this conflict in approach.

It would appear that a good argument can be made for maintaining separate systems of standards for NASA and DoD, provided close attention is given to maintaining liaison. Similar attention should of course be directed toward coordination with the Electronics Industries Association (EIA) standards and others.

Trends Experience with the development of the GSFC standards has led to a number of rather concrete ideas about how standards should operate, and has suggested areas for future investigation. As an example, the question of whether standards should precede the adoption of a system or merely record general practice is effectively answered by the production of both types of standards. Because it would be desirable from the user’s viewpoint, Goddard will consider specifying the time interval over which a standard is to be effective. System test procedures have not yet been treated, but this treatment seems essential if consistent determinations are to be achieved. Finally, although much progress has been made in finding ways to induce painless acceptance of the standards early in the life of a project, there are still too many instances in which requests for waivers arrive too late for proper evaluation and action; however, a major effort to improve this situation is underway.

Conclusions Goddard's program of standards development and applications aver nearly a decade has contributed extensively to ground support of the unmanned scientific satellite program. Space-ground links for highly complex missions have supported more than 100 spacecraft projects. The standards provide an effective tool for the difficult task of ensuring efficient operation of a complex of large systems for supporting multiple users.

To avoid a number of inherent dangers, the standards require constant attention from a staff of competent technical personnel representing the groups most directly concerned with the systems involved. If this task is done well, the standard taken as a system will have enough flexibility to accommodate the needs of various users. As a consequence, users gain improved over-all system performance without undue restrictions.

An important part of a standards system is the method for gaining compliance. A workable administrative approach is essential for this. In addition, various measures can usually be found which create an added incentive for compliance to the standards. Actually, when a set of data system standards has been in effect for some time and when users have become sophisticated through experience, acceptance of the standards is often spontaneous.

There is a tendency to want to standardize all the operations of different U.S. groups in the area of data systems, and to combine their different standards. As we have seen, this is not necessarily desirable. Standards are helpful when properly related to a particular type of technical environment and organization. If standards applicable to one situation were applied indiscriminately to another, a serious detriment might result. On the other hand, actively pursued liaison between standards groups can produce a valuable transfer of information, as has been the case between the IRIG Telemetry Working Group and the DSRC.

Data systems standards in their current form are a relatively new phenomenon arising as a response to the problems created by large data systems. Although they have proved useful, the concept of their role in the technology of data systems is still in a state of advancing development. As understanding of their use increases, one can expect the standards technique to be extended into other areas.

TABLE I

GSFC Aerospace Data System Standards

Part 1	-	Telemetry Standards Pulse Code Modulation Telemetry Pulse Frequency Modulation Telemetry Pulse Amplitude Modulation Telemetry
Part II	-	Command Standards Tone Command Standard Tone Digital Command Standard PGM Command Data System Standard
Part III	-	Associated System Standards Radio Frequency and Modulation Standard for Space-to-Ground Telemetry Spacecraft Clock System Standard Spacecraft Minitrack Signal Source Standard Magnetic Tape Track Standard

References

1. Inter-Range Instrumentation Group (IRIG) Document 106-66, prepared by the Telemetry Working Group, Inter-Range Instrumentation Group, Range Commanders Council, available through Secretariat, Range Commanders Council, White Sands, Missile Range, New Mexico 88002.

2. Aerospace Data Systems Standards, document X-650-63-2 (with changes), available from The Director, Goddard Space Flight Center, Greenbelt, Maryland 20771; Attention: Chairman, Data Systems Requirements Committee, Code 520.

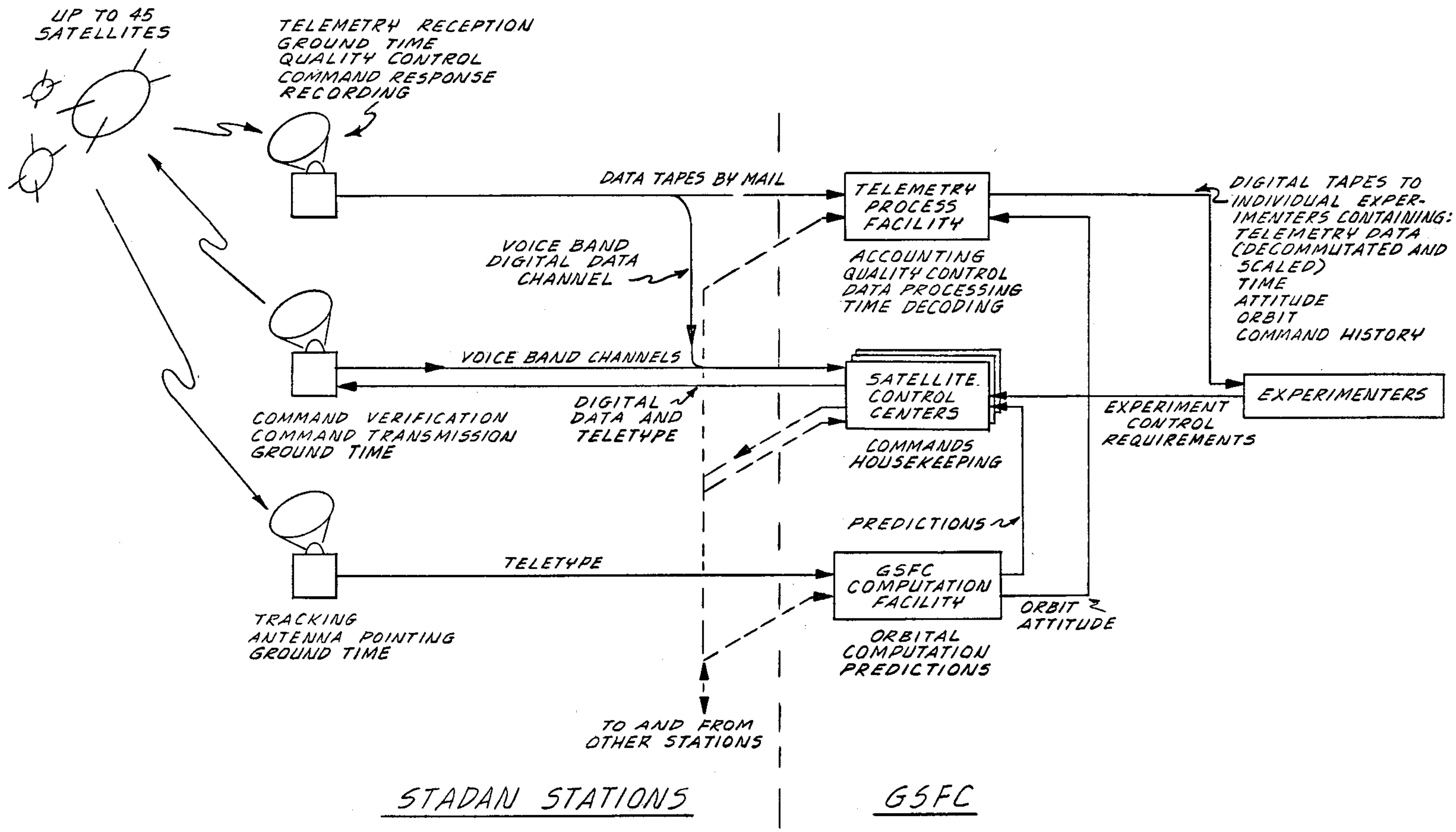

FIG. 1: SIMPLIFIED DIAGRAM OF A TYPICAL GSFC DATA SYSTEM NETWORK CONFIGURATION