NASA SP-307

REPORT OF THE TAPE RECORDER ACTION PLAN COMMITTEE

March 21, 1972

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWORD

A NASA/AF Tape Recorder Action Plan Committee (TRAP) was formed in January 1972 to investigate tape recorder problems and to recommend an action plan to NASA management. The committee members are–

John R. Scull, Chairman	JPL
Warren C. Apel	JPL
John M. Hayes	GSFC
Lt. Col. Russell B. Ives	USAF
Vernie H. Knight, Jr.	LaRC
Merrill S. Nourse	ARC
Donald R. Smith	MSC
Neil P. Zylich	GSFC

The committee collected data on tape recorder failure history, pinpointed problem areas, discussed needed technical and management changes, and proposed an action plan for the recommended approaches.

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CONTENTS

I. SUMMARY

CONCLUSIONS

Tape recorders are the most failure-prone component in U.S. spacecraft (ref. 1).

The flight recorder is one of the most important subsystems on the spacecraft. Loss of the ability to record in Earth-orbit missions results in the use of costly ground stations to obtain relatively small amounts of data. Loss of ability to record in planetary missions results in loss of most of the mission scientific data.

The recorder is a sensitive and delicate mechanical mechanism that is affected by operating and storage time and the environment to which it is subjected. It has been constrained to work on minimum power, at a minimum weight, and at a minimum size. All recorder transports have a definite limit on their operating life; tape and mechanical parts–such as springs, belts, and bearings–will wear out and cause the recorder to malfunction.

The small quantity of tape recorders produced for each separate project and the resulting restricted amount of test time contributes to reduced tape recorder reliability.

Research and development on tape recorders has been decreasing over the period of the last several years.

Emphasis on spacecraft system contracting and the project form of management structure has caused a heavy dependence on industry for tape recorder technological support. This has resulted in a large number of different types of tape recorders being developed for the various NASA projects.

The amount of recorder technology transfer from project to project has been generally inadequate because of the lack of strong continuous participation by tape recorder discipline or skill groups within most NASA centers along with the absence of intercenter communications and coordination in this field.

A single lead center at the component level of tape recorders is not appropriate because each project/center must retain the ultimate responsibility for the success or failure of its assigned missions and the components required to support them.

RECOMMENDATIONS

Additional research and development in the areas of tape, heads, bearings, lubricants, and belts is required to obtain information so that reliable tape recorder components can be standardized.

Increased level of support and technical direction to each project should be provided within each center from a tape recorder skill group so that experience from one project can be effectively transferred to another.

When spacecraft system contracts are used, strong consideration should be given to providing the tape recorder as Government-furnished equipment.

A limited set of standardized tape recorders should be defined that will satisfy most known manned spacecraft requirements. Ideally, a different limited set of tape recorders could be defined for many of the near-Earth-orbit spacecraft requirements, but it is doubtful that these limited sets of recorders could meet the requirements of weight- and power-limited spacecraft having unique scientific payloads.

Additional intercenter (and interservice) coordination and information exchange on the subject of tape recorders are needed. This should take several forms:

(1) Review by tape recorder experts in other centers of RFP packages prior to release to obtain recommendations and to see if an already developed recorder could meet the requirements.
(2) Participation of tape recorder experts from various centers in design reviews.
(3) Formation of an intercenter (interservice) tape recorder working group that would meet at least every 6 months. This working group would provide a mechanism for information exchange on recent failures and the resulting corrective action and for coordination of the research and development needs and results from each of the centers. Monthly newsletters could fulfill the need for more timely or important information.

ACTION PLAN

MSC Responsibility

Assign responsibility to MSC to perform analysis and generate specifications for a limited set of tape recorders that will satisfy most of the future manned missions.

Milestones:

Tape Recorder Analysis Report, June 1, 1972

Tape Recorder Standard Specifications, December 1, 1972

Funding responsibility: OMSF

GSFC Responsibility

Assign responsibility to GSFC to perform analysis and generate specifications for a limited set of tape recorders that will satisfy many of the future near-Earth unmanned satellite missions.

Milestones:

Tape Recorder Analysis Report, June 1, 1972
Tape Recorder Standard Specifications, December 1, 1972

Funding responsibility: OSS and OA

Intercenter Working Group Responsibility

Establish an intercenter flight magnetic tape recorder working group that will meet every 6 months (or more often, as needed). The purpose of this working group will be to provide an information exchange between centers on commonality, standards, current tape recorder problems, solutions, reliability data, and advanced development (A/D) tasks. The meeting location should be rotated to each center in turn so that all centers will be visited within a few years. (The chairman will have responsibility for a monthly newsletter.)

Milestones:

Working group nominations from centers, April 1, 1972
First meeting, May 1, 1972

Funding responsibility: centers

JPL and Additional GSFC Responsibility

Assign the responsibility to JPL and GSFC to develop a coordinated NASA program for the solution of the basic tape recorder technology problems; i.e., tape, heads, bearings, lubricants, belts, etc. The coordinated program should eliminate duplication of effort (unless parallel approaches are desirable) and should provide a technique for NASA-wide dissemination of the results of the investigations.

Milestones:

Program assignments for Fiscal 1973, April 1, 1972, and yearly thereafter
Reports to centers at 6-month intervals (coordinated with working group meetings)

Funding responsibility: OSS, OA, and OAST

II. HISTORICAL BACKGROUND

GSFC TAPE RECORDER COMMITTEE

A GSFC committee chaired by William K. Ritter was formed in October 1966 to investigate and report on problems in spacecraft tape recorders related to GSFC satellite programs. The final report of this committee, dated May 12, 1967, was released for "Internal Use Only."

The report concluded that although the malfunctions and experience with tape recorders were not sufficiently well documented to provide a clear assessment of past troubles, most problems were not a result of advanced technology but were related to lack of attention to detail design, workmanship, or care in assembly. Three critical design problems identified were bearing lubrication, tape, and heads, with belt technology also listed as not being well understood.

The primary recommendations of the "Ritter Report" were to centralize the responsibility for tape recorders at GSFC into one technology skill group; establish an interim tape recorder working group to recommend uniform approaches by various GSFC projects; and make various specific suggestions in procurement, electronic design, mechanical design, lubrication, and testing.

Although the committee report was not officially implemented at GSFC, several of the recommendations, including a partial centralization of tape recorder technology, have been carried out.

CENTER REPRESENTATIVES' MEETING

As a result of a tape recorder failure in the SAS 1, the Deputy Administrator requested OART[1] to review the NASA tape recorder situation. Representatives from the Guidance, Control, and Information Systems Division of OART, Langley Research Center, and Goddard Space Flight Center met on June 17, 1971, and reviewed the status of unmanned spacecraft tape recorders.[2]

The primary conclusions resulting from this meeting were that tape recorders had not improved since the 1967 study, failures appeared to be random, each mission independently developed its own tape recorders, and good engineering (not technical breakthroughs) was required to improve lifetime and reliability.

[1] Now OAST.

[2] Spacecraft Tape Recorders, Memorandum to AD/Deputy Administrator from RD-M/Deputy Associate Administrator (Management), OART, 1971.

The meeting recommended that research and development on solid-state memories should be emphasized, OSSA[3] should act as the focal point for increased tape recorder reliability and standardization, and that additional OSSA resources should be applied to the development of several GSFC recorders that might become the nucleus of a NASA family of standard tape recorders.

SPACE VEHICLE ADVISORY COMMITTEE RECOMMENDATIONS

The NASA Space Vehicle Advisory Committee reviewed the standardization of spacecraft components that was reported to Dr. Fletcher and Dr. Low in the Research and Technology Advisory Council meeting on June 23, 1971, and the NASA general management meeting in July 1971. As a result, Dr. Low assigned the Associate Administrator of OART the task of implementing a forceful plan to standardize tape recorders.[4]

The primary recommendations from OART were that the advent of the shuttle would dictate lower costs for payload components by having standard or common hardware items for ordinary housekeeping functions of the payload. A preliminary action plan for standardization of tape recorders was recommended by OART that centralized responsibility for all NASA tape recorders at GSFC and charged OSSA with the overall management responsibility.[5] The schedule for the action plan was to form a study team to recommend standardization guidelines by July 1972 with the development of NASA standard tape recorder specifications by 1974. This schedule was considered too slow by Low and Fletcher when presented at the NASA general management meeting in November 1971.

PLANNING RESEARCH CORP. REPORT

The Planning Research Corp. (PRC) recently published a reliability study of spacecraft from 1958-70 (ref. 1). This report summarizes the failure data from a sample of 304 launches from 41 programs of the United States, divided into two periods: 1958-67 and 1968-70. The major conclusions of the report are:

> (1) The success of spacecraft operation is only slightly affected by most reported incidents of anomalous behavior, (2) randomly occurring piece-part failures form a distinct minority of all anomalous behaviors in operational spacecraft, (3) the occurrence of the majority of anomalous incidents could have been prevented prior to launch . . . .

Relative to tape recorders, the PRC report states,

> The most failure-prone component appears, as it did in the earlier study, to be the magnetic tape unit with 38 failures occurring on 138 units observed. The failure

[3] Now OSS and OA.

[4] Standardization of Spacecraft Components, Memorandum to RS/Director, Shuttle Technologies Office, OART, from R/Associate Administrator, OART, July 26, 1971.

[5] Standardization of Tape Recorders (Plan Outline by RET/Chief, Data Systems Branch, OART), Aug. 9, 1971.

> rate for magnetic tape units in the combined sample (1958-70) is 40 failures per million hours—a significant increase over that reported in the earlier sample (1958-67) (28 failures per million hours). All other components have decreased failure rates compared to the rates reported earlier.

Although the report concludes that wear of hardware units is not a general problem in the case of magnetic tape units, a factor of nearly 10 to 1 improvement in failure rate results from standby or unpowered dormant status compared to power-on operating status.

OTHER RELATED REVIEW BOARDS

An important factor cited by several failure review boards is the need for a unified or coordinated approach so that experience on one program could be an effective guide for another.

The report on "The Review of Observatory-Class Spacecraft Project Practices" dated October 1966 states:

> Policies should be established within the center for the uniform usage of the best of the design practices available from the current projects.

The "Report of the Delta Launch Vehicle System Review Board" dated December 17, 1971, states:

> The Project Office has relied heavily upon the prime contractor for technical judgment and there is little evidence of Government penetration of the program by other than the Project Office personnel, and then primarily at the systems level. It is recommended that GSFC make available from its technical manpower sufficient expertise to provide Government assessment of the effectiveness of the contractor's engineering on Delta at the subsystem level.

It is apparent that little or no corrective action has been taken over the last 5 years because most of the same problems and recommended actions appear in one review board report after another.

III. TRAP COMMITTEE ACTIVITIES

During the latter part of 1971, sufficient interest had been aroused in the questionable performance of tape recorders aboard spacecraft to warrant the formation of a task group to look into the problem. Dr. Low requested OART to take the initiative in defining a plan and agency policy for developing guidelines and standards relating to spacecraft tape recorders. Jackson responded with the formation of a TRAP Committee that was required to report its findings by mid-February 1972.

The first meeting of the TRAP Committee was held at NASA Headquarters, Washington, D.C., on January 21, 1972, with all members present. Following opening remarks by Chairman Scull, Charles Pontious, Deputy Director of Guidance Control and Information Systems, OART, presented an overview on why the group was formed and what it was expected to accomplish. Each committee member was charged to obtain applicable data from his center in the format used by Warren Apel. The next meeting was scheduled for January 31, 1972, at JPL in Pasadena, Calif. The data format was subsequently modified by a telegram from Scull dated January 1972.

The TRAP Committee met at JPL from January 31 through February 3, 1972. Each member of the committee presented his data, and, following the final presentation, the data were reviewed and correlated by the committee as a whole. Twelve areas were identified as weak links in the hardware or managerial aspects of tape recorder reliability. These 12 areas were then ranked in order of importance. JPL tape recorder personnel were interviewed; however, no vendors were visited. The remainder of the time was devoted to the managerial facets of the problem, and two committee members were assigned to each of the four parts of the action plan.

The TRAP Committee met at GSFC from February 8 through February 11, 1972. The data base was updated with additional information from the committee members. Comments from several tape recorder contractors, previously gathered on visits by John Hayes, were reported to the committee. GSFC tape recorder laboratories were visited and personnel were interviewed. The subjects of standardization, lead centers, management approach, failure history, recommendations, and the action plan were discussed and documented.

Final editing of the report was accomplished by the committee chairman at JPL from February 14 through February 28, 1972.

Initial review of the committee's recommendations were made by OART management on March 6 and 7, 1972; results were presented to the NASA General Management meeting on March 21, 1972.

IV. CHOICE OF TAPE RECORDERS FOR SPACECRAFT DATA STORAGE

For over 20 years the magnetic tape recorder has been used as a data storage device in numerous projects. The magnetic tape recorder dates to World War II, this innovation being followed by magnetic core memories, the semiconductor transistor, storage tubes, and heat-deformable plastic films. Even after such a long period of development, the tape recorder is one of the weakest links in today's spacecraft. Although the tape recorder has a tarnished record for spacecraft applications, it is still the clear choice for a usable data storage subsystem during the next few years.

The metal oxide silicon (MOS) and bipolar memories are presently impractical for 10^8 to 10^9 bits of storage. Based upon current trends, it will probably be at least 1974, or possibly 1976, before they become a challenge to the tape recorder. During this period, the spacecraft data storage requirements will probably escalate to 10^9 to 10^{10} bits, causing a further delay in the ability to replace the tape recorder with some other technique. The unique position of the tape recorder to serve in this capacity can be appreciated from a close look at some comparative parameters.

Present technology can produce a tape recorder with 50 tracks, recording at 10 000 bits/in., and using 0.5-mil tape, which may be equated at 2000 layers/in^3. This yields a density of 1.6×10^{10} bits/lb. Assuming electrical contact with each bit, solid-state methods are far less dense. Laser writing on storage film appears competitive, but the registration problems during the reading mode are not yet solved.

A convenient unit for comparison of weight is bits per pound (fig. 1). Studies show a feasible upper limit of 10^{10} bits/lb for tape recorders, with most of the weight residing in the mechanical transport. The nearest competitors, in order of importance, are the bubble memory, plated wire, and large-scale integration techniques. If current trends are projected, it can be seen that the rate of change of weight with respect to capacity is less for tape recorders than for other methods.

Current tape recorders contain about 2×10^5 bits/in^3. Although this is far superior to core and large-scale integration estimates, it still falls far short of a theoretically attainable 2×10^9 bits/in^3. One explanation for the four-order-of-magnitude difference is that size constraints have been relaxed to obtain reliability. Anticipated advances in technology may permit closing this gap.

The tape recorder is not without drawbacks. The data storage must be done serially, it is chemically complex, and moving parts degrade its reliability to a

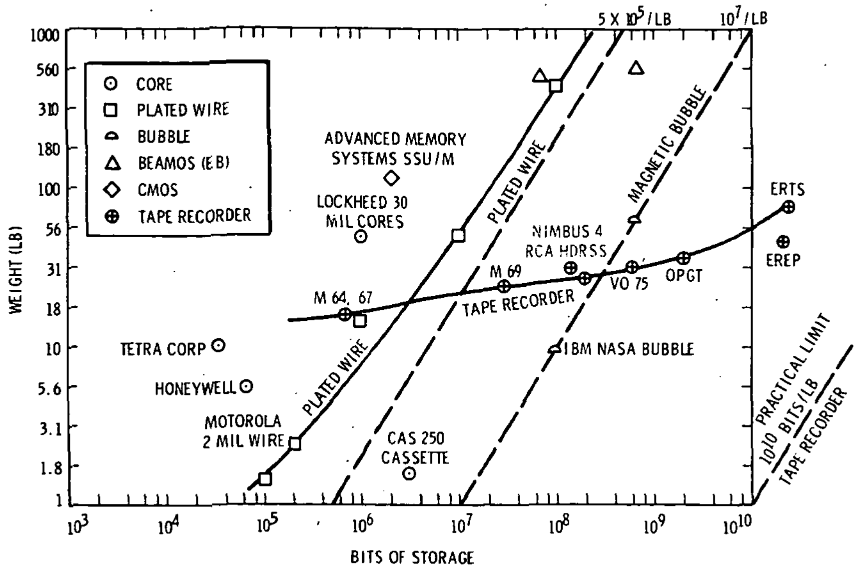

Figure 1.–Mass memories weight versus capacities. (BEAMOS (EB) = beam metal oxide semiconductor; CMOS = complementary metal oxide semiconductor; HDRSS = high data-rate storage system; OPGT = Outer Planets Grand Tour.)

point where it does not compare favorably with other components of the spacecraft system. These deficiencies are offset by the uncontestable fact that, as a data storage subsystem, the tape recorder is vastly superior to all other techniques in cost, density, size, and weight. Tape recorders are not only competitive today, but they have a potential for improvement by several orders of magnitude. It seems both feasible and reasonable to exploit this potential with a vigorous research and development effort.

V. DATA BASE AND CORRELATIONS

DATA BASE

Each committee member was asked to supply data on the flight tape recorders for which his organization has had responsibility. These data included technical performance characteristics in space, operating performance history, and management and cost data. It was decided to limit the time period for study from 1962 to the present, including known future requirements. Data were obtained for 163 launches representing 36 recorder designs and 10 tape recorder manufacturers. Contributing agencies were GSFC, MSC, LaRC, ARC, JPL, and USAF (Space and Missile Systems Organization, Air Force Cambridge Research Laboratories). These data are tabulated in appendix A.

The technical characteristics are considered to be accurate. Some of the operating time data are estimated, and much of the project cost and applied manpower data are fairly rough estimates, but are adequate for the purposes of this study.

The conclusions of this study are heavily influenced by the data from Goddard Space Flight Center, as shown in figures 2 and 3, because of all NASA

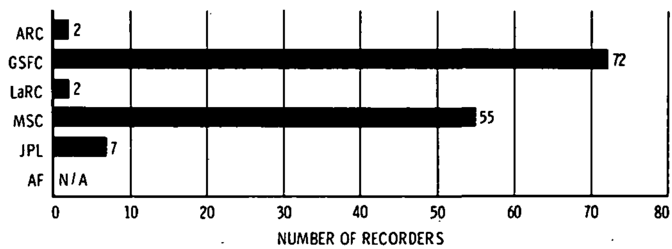

Figure 2.–Number of recorders launched.

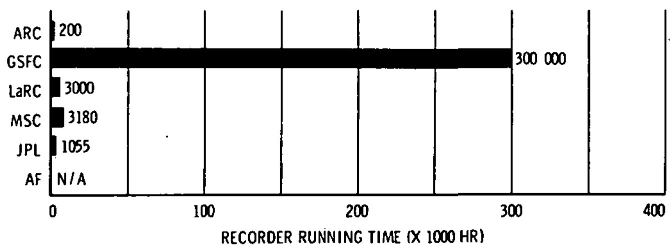

Figure 3.–In-space recorder running time.

programs, GSFC programs account by a large margin for the most operating time in space and the largest number of recorders launched. The Air Force has launched more recorders than GSFC and probably accounts for more in-space operating time, but these data were not available to the committee in time to be included in the report.

DATA CORRELATION

Given the mass of data of appendix A, it should be possible to correlate high failure rates to certain characteristics of the recorders. As with any collection of data, care must be taken in its interpretation. A significant sample size must be used, and the data must be derived assuming the same ground rules. Unfortunately, the sample size of some data is small; for instance, JPL has had no failures in space, but these recorders only account for less than 1000 hr of the total of 300 000 operational hours of the whole data base.

Failure rates as discussed in this report refer to number of failures divided by the in-space operating time of the particular device. Standby time is not included, as it was in the PRC report, therefore failure rates as discussed here are considerably higher than those derived in the PRC report. Statistical theory has not been applied to the data in terms of determining confidence levels of the data.

The total failure rate of all NASA recorders studied was plotted as a function of time in figure 4. It appears that the current failure rate is the same as it was 10 years ago, although it has fluctuated within the time scale.

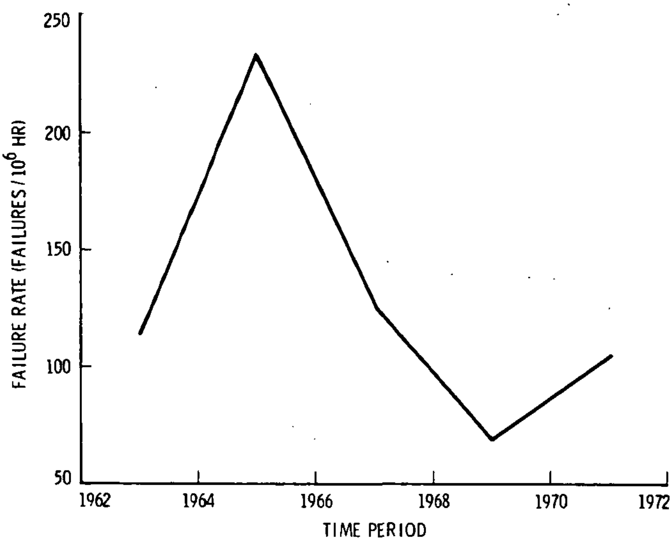

Figure 4.–NASA tape recorder failure rate.

Failure rates for the three generic types of recorders (coaxial reel using negator springs, coplanar reel using peripheral belt, and endless loop) were tabulated as a function of responsible center and time, as shown in table 1. The coaxial-negator recorder is slightly more reliable than the endless loop recorder. The coplanar-peripheral drive recorder has had no failures in space, but the operating time is very small compared to the other units.

Failure rates for each center were plotted in figure 5, using the data of table 1. Although these numbers result from the data, it should be noted that of the 72 recorders launched by GSFC, 31 ultimately failed,, whereas of the 55 recorders launched by MSC, only 4 failed, the rest fulfilling the given mission. The short MSC missions distort the failure rate because their successful recorders accumulate relatively little operating time.

TABLE 1.–*Failure Rates for Types of Recorders by Agency*

Recorder	Failures/hours of operation					Total
	1962-1964	1964-1966	1966-1968	1968-1970	1970-1972	
Coaxial-negator:						
GSFC	0/210 0	1/170 52	6/558 45	3/342 00	3/421 60	13/151 357
MSC	–	3/825	0/822	1/125 6	0/280	4/318 3
ARC	–	–	0/300	–	–	0/300
LaRC	–	0/100 0	0/200 0	–	–	0/300 0
Total	0/210 0	4/188 77	6/589 67	4/354 56	3/424 40	17/157 840
Failures/10^6 hr	0	212	102	113	71	108
Coplanar-peripheral: JPL	–	–	–	–	0/640	0/640
Failures/10^6 hr	–	–	–	–	0	0
Endless loop:						
GSFC	5/417 60	2/680 5	7/450 72	2/514 14	2/398 4	18/149 035
JPL	–	0/221	0/38	0/98	–	0/357
Total	5/417 60	2/702 6	7/451 10	2/515 12	2/398 4	18/149 392
Failures/10^6 hr	120	285	155	39	502	121
Grand total	5/438 60	6/259 03	13/104 077	6/869 68	5/470 64	35/307 872
Failures/10^6 hr	114	232	125	69	106	114

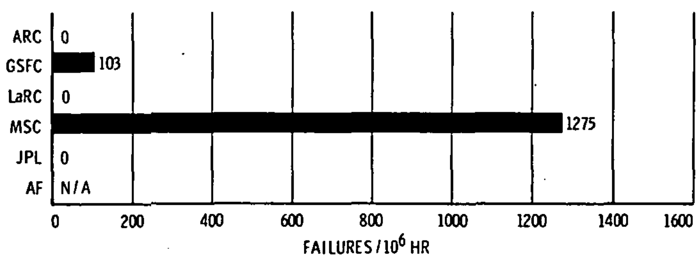

Figure 5.–In-space failure rate by center.

The kinds of failures were tabulated in table 2. Most of the failures fall into the same categories that have been identified as weak areas in previous studies; namely, tape, heads, bearings, and the endless loop pack.

TABLE 2.–*Component Failure Rates*

Component	Failure rate	
	Failures	Failures/10^6 hr[a]
Bearings	12	39
Endless loop tape pack	7	[b]47
Head/tape	6	19
Electronics	2	7
Other	8	26
Total	35	138

[a]Total recorder hours = 308 000.
[b]Endless loop hours = 149 000.

TABLE 3.–*Failure History of Bearings by Lubricant Type*

Lubricant type	Failures/bearing hours	Failures/10^6 bearing hours
Oil	$11/(3.698 \times 10^6)$	2.97
Grease	$1/(1.932 \times 10^6)$	0.52

Bearing failures, the largest category in table 2, are usually a result of lubricant problems. An analysis was made of the failure history of bearings using oil and grease as lubricants (table 3). The oil has usually been per MIL-L-6085A (ref. 2) and the grease usually Andok C.

CONCLUSIONS

Some conclusions can be reached from examination of the accumulated data:

(1) The failure rate of spacecraft recorders has, on the average, remained about the same over the last 10 years.
(2) The continuing problems are with bearings, lubrication, tape, and heads.
(3) Greased bearings exhibit a lower (by a factor of 5) failure rate than oiled bearings.
(4) Reel-to-reel recorders have been slightly more reliable than endless loop recorders.

RECOMMENDATIONS

The following recommendations can be made from the data:

(1) Develop a well-funded program for determining the best bearing lubrication systems for use on spacecraft recorders.
(2) Continue funding investigation into the head/tape interface and the development of reliable head and tape components.
(3) Consider the use of reel-to-reel recorders over endless loop recorders.

VI. AREAS OF CONCERN

Some conclusions have been drawn from examination of the data. Several other areas of concern, both technical and managerial, were examined, based on the experience of the committee members. The technical areas of concern were verified by the data; however, most managerial areas of concern are not evident in the data base and are more subjective.

METHODOLOGY

After the data from each source had been carefully reviewed, an attempt was made to identify and rank the prime causes of tape recorder failures (table 4). Each member of the committee was polled for his input based both on the data and his experience; 12 categories were selected. These problem areas included both hardware and managerial items of concern.

TABLE 4.—*Ranking of Causes of Tape Recorder Failure*

Cause	Hardware	Management	Both hardware and management
Lead time		5	12
Tape	2		3
Lubricants	3		4
Bearings (motors)	4		7
Heads	1		1
Belts	5		10
Relays	6		11
Procedures		1	2
Degree of supervision		2	5
Inadequate design		3	6
Electronic components	7		9
Research and development funding		4	8

In an effort to obtain an objective ranking of the categories, the members of the committee rated each of the 12 items independently. The individual expressions of opinion for a given item were then summed in a weighted manner to produce an overall ranking for that category. The results were expressed in three forms: hardware, management, and their combination.

HARDWARE

The failure of any device is due to the ultimate failure of some piece of hardware, although the underlying reason could be because of management policy, procedural inadequacy, or some other software problem. The hardware components that have caused the majority of the failures of spacecraft tape recorders have been, and continue to be, bearings, usually involving failure of the lubrication, tape, heads, and belts. The following paragraphs discuss these areas in a general sense.

Designing stability into the various friction-dependent interfaces found in magnetic tape transports has always been a significant concern. Though many component relationships are affected by frictional characteristics, the principal functions that typically depend on friction in tape recorder operation are speed reduction, tape drive, friction-type braking, and change of speed or direction. The majority of present mechanizations typically involve pulleys, belts, and clutches that have all been used in spacecraft tape recorder designs. The main concern is consistency of performance. It is not sufficient for a friction-drive system to transmit a required amount of torque. That process must be predictably smooth and consistent under all conditions so as to reduce tape motion variations (flutter and skew) and attendant data signal degradation to a minimum. In braking and clutching operations, the rate of change must be repeatable to preclude the possibility of loss or misinterpretation of valuable data.

The problems of designing in these areas relate to the nature of friction itself. Friction characteristics vary widely among various materials and their combinations. They are affected in numerous ways by component geometry and physical characteristics, applied forces (such as those imposed by drive belt tensions), and environmental influences (temperature, humidity, and medium). Meeting friction requirements is a complex design problem involving chemical, physical, and mechanical considerations. The problem has been aggravated in the past by a lack of sufficient knowledge of, and control over, the physical properties of such elements as magnetic tape, plastic drive belts, and capstan materials.

There are other aspects of tape recorder operation where friction plays a major role. For example, performance integrity is very sensitive to tape/head drag characteristics. The same applies to bearings in the various rotating elements. Although friction and drag are sometimes desirable for damping purposes (stationary tape guides are sometimes employed for this reason), the attendant problems of wear, heat, and debris generation, along with power loss, are dominant disadvantages. The frequently unpredictable and inconsistent characteristics of magnetic tape can, under certain conditions, lead to stick-slip or total adhesion of the tape to the head, resulting in wide variations in tape speed and drive motor torque fluctuations as well as tape damage. The very possibility of occurrence of these phenomena has imposed design overkill techniques in other areas, such as servomotor and drive train design, that may not otherwise have been necessary. The geometry and the materials of construction of the magnetic heads themselves have a significant effect on the drag and friction characteristics at the tape/head interface. The tape/head interface is now viewed as a critical transport design problem involving the selection of tape, magnetic head design, environment, and the load factors: tape tension, speed, and wrap angle.

Bearing friction must also be considered. The relatively low drag caused by bearing friction, even with grease lubricants (ball bearings are typically used) is generally of minor concern, but erratic behavior is intolerable and usually constitutes a failure mode. The main problem is acquiring sufficient knowledge and appropriate design techniques to insure predictable and consistent operation of bearings at all speeds and under various environmental conditions. Another problem is that of lubricant migration away from the bearing surfaces. There are techniques (involving the use of barrier films) that appear to be effective in minimizing this problem in some applications. They have other drawbacks, however, including extreme vulnerability to surface scratch damage, that can result in accelerated lubricant migration. Barrier films should not be applied to spacecraft tape recorder bearings without further investigations and tests. Bearing seals can be employed, but at a cost of greater friction drag and additional wear surfaces.

Although there is not necessarily any direct correlation between friction and wear, those components involved in friction-related interfaces are subject to wear, and thus become potential sources of debris. Thus, magnetic tape, heads, drive belts, bearings, guides, pulleys, and other surfaces subjected to sliding contact are suspect. Fatigue and surface damage (due to stress variations) of certain elements, notably magnetic tape and drive belts, resulting from repeated bending and flexing, are another source of debris. Collection of debris on mating surfaces can also accelerate wear and may also contribute, along with the debris-forming damage itself, to signal performance degradation by contamination of the tape/head interface and to system flutter by contamination of belt/pulley interfaces and bearing surfaces.

Component and material selection as well as their method of combination must be given careful consideration. For example, magnetic tapes vary widely in their compatibility with different head materials and construction and their reaction to environments and modes of use, as well as in signal performance characteristics. The fact that a tape performed well for one application does not insure its future success under even slightly varied conditions. The problem is aggravated by the fact that different lots of tape procured under the same specification frequently vary in critical parameters. This is true of many other elements such as polyester belts.

Of no less concern is hardware design. Component geometry and metrology and tape transport topology have a significant effect on fatigue, wear, and performance characteristics of the elements involved. The relationships of surface finish and material hardness, pulley complement and bend radii, and the loads imposed on bearings, tape, and belts are factors that must be considered in their proper perspective.

The concern for wear leads to consideration of the problem of consumable elements. Magnetic tape is the main consumable in a tape recorder; others include the magnetic heads and the bearing lubricant. All are "used up" in the sense that they wear out, and their performance is degraded with time and use. Magnetic tape is usually the life-limiting element, and more demanding applications in terms of tape usage and storage life make the search for improved or substitute materials and fabrication techniques even more urgent. Metal-based tape is being given careful consideration as an alternate to the presently used plastic tapes. It appears attractive, from a signal performance standpoint, as well as promising in terms of significantly better stability and durability. A valid concern, however, is its adverse effect on head wear in dry transport applications. Pending further metal tape development, reliance on plastic tapes for spacecraft tape recorder use hinges on the success of efforts to specify the characteristics required for those applications and to design tapes to fulfill these requirements. Unfortunately, little help can be expected from the tape manufacturing industry because of the relatively small market for such tape. Consequently, obtaining sufficient knowledge about both metal and plastic tapes, to the extent that desirable characteristics can be specified, promises to be a costly and time-consuming endeavor.

The modes of operation influence to a great extent the design and selection of tape recorder components. Intermittent or stop/start operation and rapid speed changes are of particular concern to the designer. This type of operation subjects magnetic tape and drive train components (belts) to repeated life-limiting stress cycling. Bearings and lubricants experience the most severe degradation effects during transient modes when localized loads and temperatures and marginal lubrication conditions can far exceed those that exist under steady-state operation. Head and tape wear are also accelerated during intermittent operation. Extended periods of idleness impose problems equally important at the head/tape and bearing/lubricant interfaces.

The subject of environment covers many areas that must be examined during component selection and transport design. These areas include vibration, shock, temperature, magnetic fields and radiation, and corrosive elements. With regard to vibration, the prime objective is isolation of the many delicate subassemblies in the tape recorder so as to minimize the effects of high-energy resonant modes. It involves the determination of component natural frequencies and interface transmissibilities, which are often complex. The consequences of adverse vibration effects are structural and element fatigue failure, destruction of lubrication, bearing brinneling, and wear and fretting corrosion at component interfaces.

CENTER MANAGEMENT ORGANIZATIONAL STRUCTURE

Forms of Organization

In general, there are two basic organizational structures for research and development laboratories: the functional organization and the project organization. To achieve the advantages of both functional and project structure, many research and development organizations have adopted a hybrid type of structure referred to as a matrix form. Within NASA, both the project and the matrix organizational form have been used. The project form of organization is defined as one in which the project manager has direct authority to supervise the work of engineers and scientists working on his project. These people are physically moved to the project office and are administratively assigned to the project. In the matrix form of organization, the project manager has the full range of management functions, but the bulk of the people doing the substantive work on the project are administratively assigned to other directorates, divisions, branches, etc. Personnel assigned to a given project are not physically moved but remain with their functional element. The project manager works directly with the assigned individual and not through the functional manager.

Utilization of Personnel

In the matrix form, the assignment of an individual in one of the functional elements to a particular project is done on the basis of the level of competence or specialty required for that particular project. The assignment is made by the functional manager, who is thoroughly cognizant of the range of capabilities within his group. The determination of specialties required is accomplished by discussion between the project manager and the functional manager. This selection process by a manager who is primarily project knowledgeable and one who is functionally knowledgeable results in the optimum match of an individual to a particular assignment. In selecting personnel for a project form of organization from existing functional units, the above procedure is normally not as effective, the functional manager, having little stake in the project and wanting to maintain the most effective functional unit, is not properly motivated to select the optimum individual. The decision to employ outside consultants and the implementation of such a requirement is more efficiently handled with the matrix form. Normally, a particular functional group has existing working relationships with outside consultants and can more quickly select the correct consultant for a particular project. It seems likely that the matrix organization is better suited than the project form of organization to support a broader and perhaps a higher general level of technical capability among engineers and scientists.

Manpower Flexibility

The ability of management to move staff from one project to another, that is, to effect manloading, is facilitated or hindered by organizational structure. Matching the workload with the work force for maximum utilization is a difficult problem in the project form of organization. Complaints of not having enough work to keep busy, to being overworked, are common at various phases of a project. In the matrix system, this presents no problem because most of the individuals are assigned work on more than one project, and they automatically work on another project when work requirements drop off in a higher priority project. It is usually difficult to reabsorb the project people back into functional units in a smooth fashion during the termination phase of a project in the project structure. To transfer the project people to a new project as an old one is phased out is wasteful of personnel in that the new project may require different types of competence. The normal solution is to make do with the expertise of the old project group, resulting in a less effective group. This lack of flexibility tends to cause project-structured programs to linger on, proposing changes or additions to the original project in an attempt to keep it alive.

Technology Transfer

Technology transfer (transfer of new information, techniques, etc., within the organization) in the matrix system is normally done verbally within the functional unit. Its evaluation and application to other projects through the normal structure of the functional unit is rapid and unhindered, and the engineer or scientist is able to keep abreast of the latest developments in his field through the give-and-take among other specialists in his group. In the project system, technology transfer to and from groups outside the project is more likely to be through documentation that usually is implemented at a low priority level, resulting in time lag. Also, infrequent contact is maintained with others in the technical specialty, hindering ability to keep abreast of the state of the art.

Project Communications

In the matrix system, there are some problems in communication due to physical dispersion of personnel throughout the center. In the project form, because of the single project assignment, understanding of the relationship between functions is normally good, resulting in less communication problems. Most personnel are under one roof; therefore, general meetings or smaller cross-discipline meetings are more easily arranged. However, in most projects using the matrix system, the project manager is able to overcome this problem by being attentive and establishing a good esprit de corps within the project.

Authority

In a well-organized center where lines of communication are well established, the matrix form of structure provides the project manager with sufficient authority to perform his task. Normally, the project importance to the overall center is well known by the functional manager. However, it is important at the inception of a project that the Center Director issue a directive to the functional supervisors (Division Chiefs, Branch Chiefs, Section Heads) of all employees assigned to the project, and also to the employees involved, naming the individuals assigned to the project, defining their responsibilities, and giving priority to the responsibility assigned.

Organizational Structure Recommendation

The Tape Recorder Action Plan Committee recommends, in light of the foregoing, that the matrix form of organization be implemented by the centers for the management of projects, particularly those in which a spacecraft tape recorder is one of the subsystems. Present trends in research and development management also point in this direction.

IN-HOUSE CAPABILITIES

In-house capabilities should be maintained and perhaps further developed to maintain a high level of competence in the spacecraft tape recorder field. NASA should not have to rely on the outside nor be dependent on the private sector for this competence. It is recommended that there be more cross-fertilization and more interaction among the spacecraft tape recorder skill groups at the various NASA centers. Tape recorder contracts should be adequately monitored and directed by tape recorder experts within the centers.

The level of program support of each center was compared by calculating the ratio of tape recorder project costs to the level of in-house support, in man-years (MY). The results (fig. 6) show that JPL provides a relatively high level of in-house support to the programs as shown by a low value of cost per man-year. This includes system design activity, contract monitoring, and subsystem test. The other centers, however, rely heavily on the recorder contractor or prime contractor, with little in-house support. It is felt that more in-house support would result in more reliable recorders.

LEVEL OF A/D FUNDING

Data were gathered on the level of A/D funding for tape recorders over the last few years. Tape recorder A/D within NASA has been carried out by GSFC, MSC, and JPL. The level of funding is shown in figure 7. The A/D funding prior to fiscal 1968 has, for the most part, been directed toward the development of new recorder configurations for future requirements. Beginning in fiscal 1969, money has been spent on the investigation of recorder component problems, such as the head/tape interface.

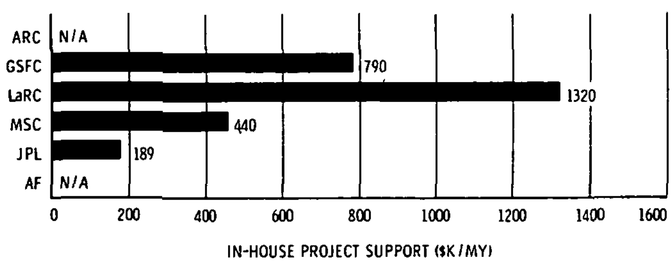

Figure 6.–Level of in-house project support.

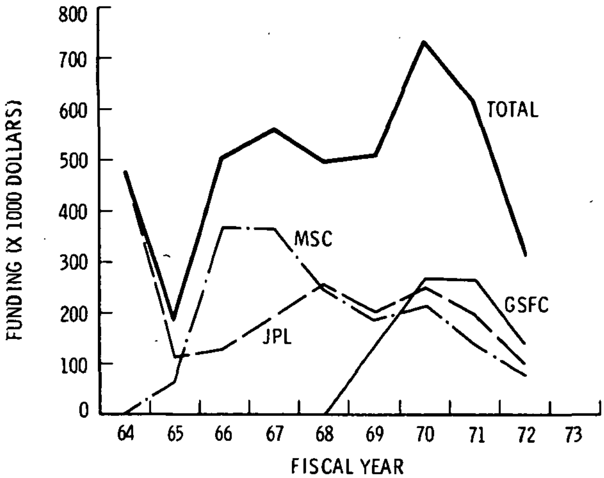

Figure 7.–Tape recorder A/D funding.

A/D at GSFC has consisted of preliminary design and breadboard construction for advanced programs, and a major study of the head/tape interface. Current A/D funding at GSFC is directed toward development of a 5-year recorder, a fluid-filled recorder, a multitrack (50 track/in.) recorder, and a small long-life reel-to-reel recorder. All but the last item are being done under contracts to industry, monitored by one man at GSFC. The last item is being done in-house.

A/D at MSC has consisted of the development of a portable tape recorder for advanced manned experiments, a video recorder, and a versatile modular tape recorder. Current A/D at MSC consists of finishing the program to develop a modular tape recorder for advanced manned logistics and orbiting station vehicles. This system would, because of modularity, have flexibility to meet changing mission requirements and would provide for in-flight maintenance, thus increasing reliability.

A/D at JPL has consisted of the development of the endless loop tape recorder for the earlier Mariner missions, various recorder breadboards using new techniques, a peripheral drive transport, various component developments, and several advanced program studies.

Current A/D at JPL has been directed toward the development of a long-life recorder for the OPGT. This work has entailed design of a recorder system, a breadboard hydrofilm transport, and an architecturally equivalent model tape recorder. Now that the OPGT project has been redirected, there is no currently programed tape recorder A/D at JPL.

The trend, as seen from the figure, is to less A/D funding in the future; however, because the reliability of spacecraft tape recorders has not improved overall in the last 10 years, A/D money should continue to be made available for recorder design improvements and investigation into recorder component problems, such as bearing lubrication, tape, and heads.

PREFERRED TYPE OF CONTRACT

Because of the developmental nature of this type of contract, it has proven advantageous to go to a cost-reimbursable contract rather than a fixed-price contract. In most cases, it is preferable that the tape recorder be procured separately and then turned over to the prime contractor as Government-furnished equipment. This practice allows closer design review and contract monitoring than would be possible under procurement through a prime contractor where the tape recorder would be subcontracted.

PROCUREMENT OF QUALITY FLIGHT RECORDERS

The procurement of quality recorders for flight spacecraft requires special attention to the critical parts of the recorder transport and a strong reliability and quality assurance program. The critical items as discussed earlier include bearings, tape, heads, belts, and motors, all of which are procured by the recorder manufacturers. Solid requirements for procurement and/or test of these parts, the transport, and the complete recorder are essential. These requirements must be in the recorder procurement specification to insure that the recorder manufacturer understands and plans to comply with the necessary procedures to produce a quality recorder at the time he bids on the recorder. The procurement specifications should contain specific directions on design of the recorder in addition to the performance requirements. This will insure the carryover of successful techniques and the use of NASA-preferred designs.

Critical-component procurement and test requirements should be included in the tape recorder procurement specification. Examples of some component specifications used by GSFC and JPL are included in appendix B.

INTERCENTER COMMUNICATION

The first meeting of the TRAP Committee was probably the first time that tape recorder people from each center had met together. NASA-wide information interchange on tape recorders has been nonexistent. There has been some informal communication between GSFC and JPL, but only because of the need to gather information to solve specific problems. It is obvious that each center shares the same problems with tape recorders and a means should be developed to share information and disseminate program results. To this end, the committee recommends that an intercenter tape recorder working group be established, made up of key recorder individuals from each center, to meet at least twice per year, for the purpose of disseminating information and to monitor and coordinate A/D within the centers so as to efficiently use resources. The chairman of this group should publish a periodic newsletter to keep members current on tape recorder developments.

FAILURE REPORTING AND FOLLOWUP

The failure reporting practices of each of the centers were examined and discussed. It was determined that each center follows the basic procedures as called out in NPC 200-2, but with separate individual procedures for each center. There may be too much reliance on the prime contractor for failure report followup and closeout for those programs that employ prime contractors. The committee recommends that the functional skill group in the cognizant center for the program be in the failure report closeout cycle.

It would be desirable for each center to have access to the failure reports from other centers. To avoid the problems of more distribution lists, the previously recommended working group should be the means for disseminating pertinent failure data between centers.

RECOMMENDATIONS

Recommendations from this section on areas of concern are–

(1) Centers should use a matrix form of organization.
(2) In-house capabilities in tape recorder expertise should be increased.
(3) Tape recorder contracts should be more adequately managed and monitored by the centers. JPL procedures seem adequate.
(4) Cost-type contracts are preferred.
(5) A/D resources should be increased for tape recorder design improvements and component development.
(6) Procurement specifications should be tightened.
(7) An intercenter tape recorder working group for the interchange of data should be formed.
(8) The centers should be more actively involved in the closeout of failure reports.

VII. SPECIAL TOPICS

The committee was asked to address two topics: (1) Should there be a lead center for tape recorders within NASA and (2) How can NASA spacecraft tape recorders be standardized?

LEAD CENTER

There are economical advantages to having a lead center manage all of NASA's magnetic tape recorder activities; even so, there is sufficient rationale for its exclusion. It is generally recognized that the responsible center for a project must develop and maintain an in-depth technical skill in the flight hardware in order to properly support the flight missions. This can be done by a lead center or contractor providing the trained personnel as required, or by the responsible center developing the talent in-house. This type of temporary project support can most economically be provided by one well-equipped laboratory to perform all tape recorder development, qualification, and flight support rather than equipping several similar laboratories. Furthermore, the total number of personnel skilled in a particular technical area such as tape, heads, bearings, etc., would also be optimized. However, past experience has shown that it is difficult to establish an effective communications link between the concerned centers.

In addition, outside personnel tend not to get involved or accept the responsibility for the success of the project to the same degree as in-house personnel. It is, therefore, recommended that each center with spacecraft project responsibility involving magnetic tape recorders develop, maintain, and provide technical project support for their individual missions within the constraints of the recommended standardization policies. As future tape recorder problems occur, the responsible center should resolve them, documenting the cause and solution to the problem, and disseminate the report to the other NASA centers. However, to eliminate duplication and insure maximum effectiveness of future research and development applicable to magnetic tape recorders, all research and development procurement specifications for $50 000 or more should be disseminated to tape recorder people throughout NASA for review and comments.

STANDARDIZATION

Past history of spacecraft recorder development has shown little trend toward standardization, with each project separately developing tape recorders to meet its particular mission. This tailoring of tape recorders to each payload has generally been justified by the limited size, weight, and power available on the spacecraft and by the unique data characteristics of each science package.

There is general agreement within the committee that standardization in the tape recorder area will provide long-range improvements in reliability. However, additional information must be obtained on bearings, lubricants, belts, tape, and heads before tape recorder components can be standardized, and there is great sensitivity against any concept for providing one standard set of tape recorders for deep space, near-Earth orbit, and manned missions.

To obtain an indication of common requirements so as to explore the possibility of standardization, a histogram was constructed of the bit capacity of past and future NASA digital tape recorders. Figure 8 shows the capacity ranging from 10^5 to 5×10^{10} bits with the largest number in the 2×10^7 to 6×10^7 bit range. The requirements for future Earth satellite and planetary programs are shown to spread over the same 10^5 to 5×10^{10} bit range. The record rates for these future recorders are also noted and range from 200 bits/sec to 15 megabits/sec. Standardization of these recorders is not possible because of the wide range of bit capacity and data-rate requirements.

Histograms were also constructed for record data rate and playback data rate, as shown in figures 9 and 10. These figures show the wide range of data rates that had been and will be accommodated by previous and future spacecraft tape recorders. Again, standardization would be difficult from the standpoint of data rates. Record rates vary with the scientific payload, and playback rates with the capability of the communication downlink. Because of the high cost of operating the ground-tracking and data-acquisition systems,

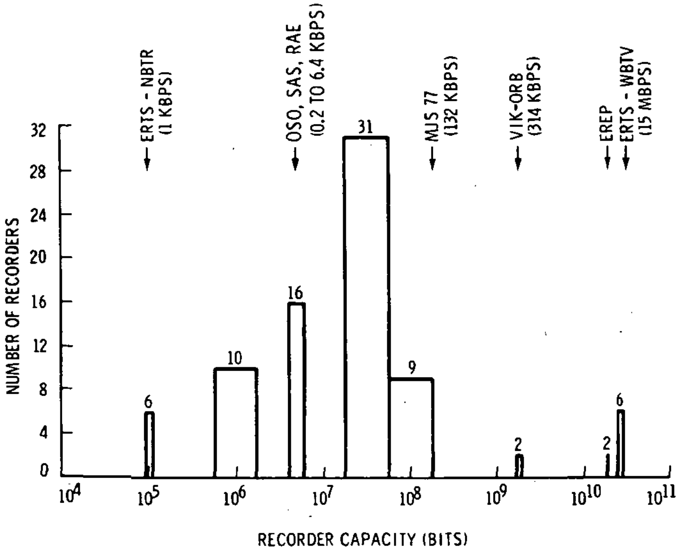

Figure 8.—Recorder capacity. (NBTR = narrowband tape recorder.)

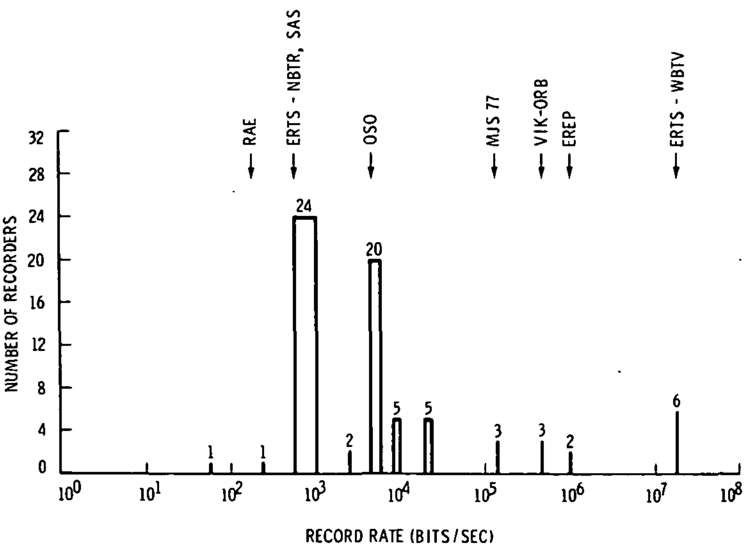

Figure 9.—Record data rate.

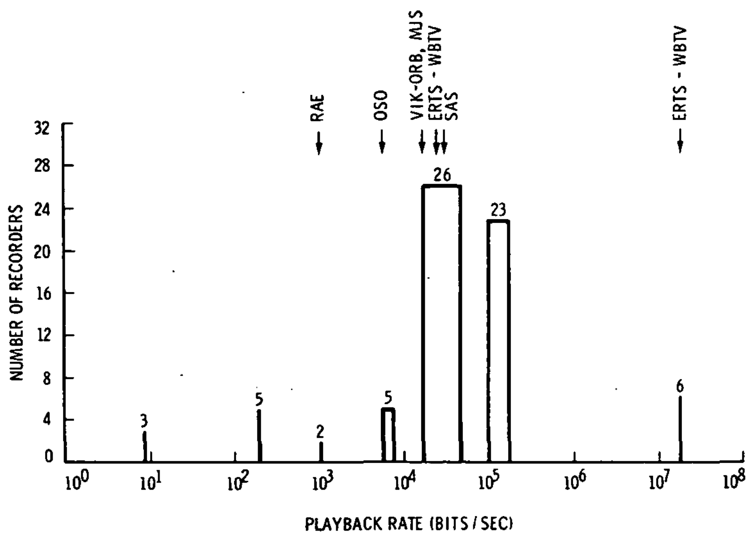

Figure 10.—Playback data rate.

and the considerable resources expended to increase the capability of these systems, the playback rate of the onboard tape recorders must be optimized as much as possible to the maximum downlink data-rate capability. It was agreed, however, that a set of standardized recorders could probably be specified for most future manned missions and another set of standardized recorders could be specified for many unmanned missions.

Effort should be directed toward developing standard components for tape recorders, such as bearing modules, tape, heads, motors, and so forth. The task of design of recorder systems could then begin with these standard components and proceed with the modifications necessary to satisfy the particular requirements of each payload.

Appendix A

TAPE
RECORDER
DATA
BASE

	GSFC										
Parameter	UK 1	UK 2	EGO	POGO 1	POGO 2	OAO	AE 2	AE's C, D	AVCS	MRIR	MRIR-TM
Manufacturer[a]	Raymond	Lockheed	RCA	RCA	RCA	RCA	Lockheed	Odetics	RCA	Lockheed	Lockheed
Mission	UK 1	UK 2	OGO's 2, 3, 5	OGO's 2, 4	OGO 6	OAO 2	AE 2	AE's C, D	Nimbus 1, 2, ESSA 1, 3, 5, 7, 9 ATS	Nimbus 2	Nimbus 3
Launch date	1963	1964	1964, 66, 68	1965, 67	1968	1967	1965	Future	1966-69	1966	1969
Number of recorders per spacecraft	1	1	2	2	2	1	1	1	2	1	2
Number of recorders of type launched	1	1	6	4	2	1	1	–	13	1	2
Capacity bits	N/A	N/A	43×10^6	43×10^6	43×10^6	43×10^6	2×10^6	11.8×10^7	N/A	6×10^6	6×10^6
Data rate, bits/sec (or Hz if so labeled)											
Record	0-300 Hz	0-300 Hz	1K	4K	8K	1042	8.6K	16.4K	0-60 kHz	2K	1K
Playback	0-15 kHz	0-15 kHz	64K	128K	128K	66.7K	8.6K	131.1K	0-60 kHz	52K	26K
Power, W											
Record	0.25	0.25	7	7	7	7	0.23	5.5	11	2	2
Playback	–	1.5	14	14	14	14	0.30	7.7	18	8	8
Weight, lb	–	3.25	17	17	17	17	–	17	18	10	10
Volume, in.^{3}	–	–	1080	1080	1080	3500	–	600	1000	310	310
Bit error probability	N/A	N/A	10^{-5}	10^{-5}	10^{-5}	10^{-5}	2×10^{-5}	10^{-5}	N/A	10^{-5}	10^{-5}
Type of transport[b]	EL	EL	C-N	C-N	C-N	C-N	EL	C-N	C-N	EL	EL
Tapes											
Manufacturer[c]	3M	3M	MEM	MEM	MEM	MEM	3M	–	3M	3M	3M
Type	LR 1220	LR 1220	62L	62L	62L	62L	LR 1220	–	591	22049	22760
Length, ft	126	130	1200	1200	1200	1200	180	1200	1200	350	350
Width, in.	1/4	1/2	1/2	1/2	1/2	1/2	1/4	1/4	1/2	1/4	1/4
Number of tracks	1	1	9	9	9	9	2	2	4	8	1
Track density, tracks/in.	4	4	18	18	18	18	8	8	8	8	1
Packing density, bits/in./track	1300 cycles/in. PFM	1300 cycles/in.	3390	3390	3390	3390	960	4000	670 cycles/in.	250	1000
Tape speed, in./sec											
Record	0.25	0.25	0.296	1.18	2.36	0.296	9	4	30	0.45	0.45
Playback	12.0	12.0	18.96	37.9	37.9	18.96	9	32	30	11.7	11.7
Head material	Brass/μ	Aluminum/μ	Brass/μ	Brass/μ	Brass/μ	Brass/μ	Alum/Alfesil	Alum/Alfesil	Aluminum/μ	Aluminum/μ	Aluminum/μ
Bearing lubricant	GE F50 oil	MIL-L-6085	MIL-L-6085	MIL-L-6085	MIL-L-6085	MIL-L-6085, Andok C motor	MIL-L-6085	Andok C grease	Silicone grease	MIL-L-6085	MIL-L-6085
Gas fill	90% N_2, 10% He	90% N_2, 10% He	Ar	Ar	Ar	Ar	–	90% N_2, 10% He	90% N_2, 10% He	90% N_2, 10% He	90% N_2, 10% He
A/D cost	None	None	None	None	None	None	None	None	None	None	None
Project costs	–	50K	2M				100K	750K	3M	300K	60K
Cost per recorder flight unit	–	40K	150K	150K	150K	210K	50K	83K	100K	31K	31K
In-house manpower, my	–	0.5	2				0.5	1	0.5	0.5	2
Project cost per in-house manpower, ks/my	–	100	1000				200	750	6000	720	2
Contract type	CPFF	FP	CPFF	CPFF	CPFF	CPFF	CPFF	CPIF	CPFF	FP	FP
Total mission life, hr	2160	0	44 000, 30 600	17 500	28 600	30 600	2200	12 000	6 months to 2 yr	2400	3250
Operational life,[d] hr	2160F	0F	2720, 7760, 5700, 3441, 1547F, 5700	4852F, 8293F, 4269, 4445F	7600, 7600	28 000F	180F	N/A	300, 200F, 400, 400, 600F, 400, 400, 400, 400, 400, 400, 0F, 400	2400F	20F, 3250F
Failure rate, failures/operational hours	1/2160	1/0	1/26 868	3/21 859	0/15 200	1/28 000	1/180	N/A	3/4700	1/2400	2/3270
Failure rate, failures/10^6 hr	463	∞	37	137	0	36	5555	N/A	638	417	612
Failure mode	Radiation damage	Motor driver phase shift circuit	Motor bearing lube	Motor bearing lube	Still running	Old age	Loss of phase relation data clock	N/A	Capacitor, silicone oil used	Tape jam or motor bearing lube	Tape jam or lube failure
Recorder type	Analog	Analog	Digital	Digital	Digital	Digital	Digital	Digital	Analog	Digital	Digital

	GSFC																	
Parameter	HRIR	OSO's 1 to 4	OSO's 5, 6	OSO 7	OSO's I, J	RAE 1	RAE B	PCM	AVCS R	Tiros video	SR	ITR incremental	HDRSS	SAS	SCMR	WBTV	NBTR
Manufacturer[a]	RCA	Raymond	Raymond	Raymond	–	Lockheed	Lockheed	Raymond	RCA	RCA	RCA	RCA	RCA	GSFC	Odetics	RCA	Leach
Mission	Nimbus 1, 2	OSO's 1 to 4	OSO's 5, 6	OSO 7	OSO's I, J	RAE 1	RAE B	Tiros 2, 3, 4, 7, Nimbus 1, 2, B	ITOS 1, NOAA 1	Tiros 1 to 11	ITOS 1, NOAA 1	ITOS 1, NOAA 1	Nimbus 3, 4	SAS 1	Nimbus E	ERTS	ERTS
Launch date	1964-66	1963, 65, 67	1969	1971	Future	1968	Future	1960-67	1970	1960-66	1970	1970	1969, 1970	1970	Future	Future	Future
Number of recorders per spacecraft	1	2	2	2	–	1	1	1	2	2	2	1	2	1	–	–	–
Number of recorders of type launched	2	8	4	2	–	1	1	7	4	22	4	2	4	1	–	–	–
Capacity bits	8×10^5	2.4×10^6	4.8×10^6	5.2×10^6	85×10^6	5.8×10^6	2.25×10^6	6×10^6	N/A	N/A	N/A	10^6	1.4×10^5	6×10^6	N/A	3×10^{10}	1.2×10^5
Data rate, bits/sec (or Hz if so labeled)																	
Record	2.5K	400	800	800	6.4K	400	200	1K	60 kHz	60 kHz	0-450 Hz	45	4K	1K	0-60 kHz	15M	1K
Playback	20K	7.3K	14.6K	14.6K	–	10K	1K	30K	60 kHz	60 kHz	0-7.2 kHz	6K	130K	30K	0-60 kHz	15M	24K
Power, W																	
Record	7.5	1.3	1.3	1.3	5	0.75	1.1	2	19.8	19	7.5	2.4	8	0.8	14.5	95	7.4
Playback	10	5.5	5.5	5.5	12	1.25	1.6	5	16.1	19	10	5	15	4.0	15.5	95	14.2
Weight, lb	17	9.5	9.5	9.5	14	8	8	10	18.7	10	18.7	5.25	31	6	21.4	76	13
Volume, in.^{3}	1000	211	211	211	580	170	170	320	1200	400	1155	336	1510	220	774	3400	432
Bit error probability	–	10^{-5}	10^{-5}	10^{-5}	10^{-6}	–	–	10^{-5}	N/A	–	10^{-5}	10^{-5}	10^{-5}	10^{-4}	–	10^{-5}	10^{-6}
Type of transport[b]	C-N	EL	EL	EL	–	EL	EL	EL	C-N	C-N	C-N	C-N	C-N	EL	C-3C	CP-RH	C-RR
Tapes																	
Manufacturer[c]	3M	3M	3M	3M	–	3M	3M	3M	3M	3M	3M	3M	RCA	3M	3M	3M	3M
Type	591	8998	8998	8998	–	1220	156	LR 1220	551	592	551	590	617	LR 1220	900	MTA 20237	551
Length, ft	1200	300	300	300	–	240	240	250	1360	400	1360	90	800	300	1770	2000	1550
Width, in.	1/2	1/4	1/4	1/4	–	1/4	1/4	1/4	1/4	3/8	1/4	1/4	1/2	1/4	1/4	2	1/4
Number of tracks	4	1	1	1	–	1	1	1	3	2	3	3	5	1	3	1 transverse, 3 longitudinal	1
Track density, tracks/in.	4	4	4	4	–	4	–	1	12	8	12	12	10	4	3	100	1
Packing density, bits/in./track	670	670	1340	1340	–	2000	1000	1250	670 cycles/in.	–	2000	300	3100	1667	6300 Flux reversals per inch	7500	700
Tape speed, in./sec																	
Record	3¾	0.6	0.6	0.6	–	0.2	0.2	0.4	30	50	1.875	0.05	1.3	0.6	42	12	1.43
Playback	30	11	11	11	–	5	1.0	12	30	50	30	6.67	42	18	42	12	34.3
Head material	Aluminum/μ	Brass/μ	Brass/μ	Brass/μ	–	Aluminum/μ	Aluminum/μ	Brass/μ	Brass/μ	Aluminum/μ	Brass/μ	Brass/μ	Brass/μ, alum/Alfesil	Alum/Alfesil	Alum/Alfesil	Alfecon-II	Havar/Alfesil
Bearing lubricant	Silicone grease	MIL-L-6085	MIL-L-6085	MIL-L-6085	–	MIL-L-6085	Andok C grease	MIL-L-6085	Andok C grease	Silicone grease	Andok C grease	–	Andok C grease	MIL-L-6085	Andok C grease	Andok C grease	Andoc C grease
Gas fill	90% N_2, 10% He	70% N_2, 10% He, 20% Freon	70% N_2, 10% He, 20% Freon	70% N_2, 10% He, 20% Freon	–	90% N_2, 10% He	90% N_2, 10% He	90% N_2, 10% He	90% N_2, 10% He	90% N_2, 10% He	–	–	Air, 20% Rh	–	–	Air, 50% Rh	90% N_2, 10% He
A/D cost	None	None	None	None	None	None	None	None	None	None	None	None	100K	None	N/A	475K	None
Project costs	300K	800K			–	250K	200K	500K	1M	1M	800K	200K	8M	300K	500K	7M	590K
Cost per recorder flight unit	100K	70K	80K	80K	–	75K	100K	30K	200K	50K	200K	75K	250K	19K	125K	450K	100K
In-house manpower, my	0.25	3			–	0.5	0.5	1	0.5	1	0.25	None	3	8 (all labor done in house)	1	9	0.5
Project cost per in-house manpower, ks/my	1200	270			–	500	400	500	2000	1000	3200	N/A	2700	75	500	780	1100
Contract type	CPFF	FP	FP	FP	–	CPFF	CPFF	CPFF	CPIF	CPFF	CPIF	–	CPFF	All in house	CPFF	CPFF	CPFF
Total mission life, hr	3940	11 436, 4036	26 496, 21 648	2976	N/A	2200	N/A	625, 6000, 2400, 100, 0, 2000, 30 000	13 100, 6000	–	13 000, 6500	7200, 3600	23 700, 15 100	–	–	–	–
Operational life,[d] hr	300, 3000F	600F, 948F, 900F, 10 488F, 6000, 1536F, 0, 3500F	13 248, 13 248, 10 824, 10 824	0F, 2976	N/A	2200F	N/A	6000, 625, 100F, 2400F, 2000F, 0, 30 000	900 ITOS, 900, 450 NOAA, 450	150 each	6000 ITOS, 6000, 3000 NOAA, 3000	7200F ITOS, 1460F NOAA	3000F, 3000F 4000F, 8800	1008F	–	–	–
Failure rate, failures/operational hours	1/3300	4/16 472	0/48 144	1/2976	N/A	1/2200	N/A	3/41 125	0/2700	0/3300	0/18 000	2/8660	3/18 800	1/1008	N/A	N/A	N/A
Failure rate, failures/10^6 hr	303	243	0	336	N/A	454	N/A	73	0	0	0	231	160	992	N/A	N/A	N/A
Failure mode	Bearing lube silicone oil instead of grease	Tape pack (3), bearing tape pack (4)	Still running	Spilled tape, launch vehicle still running	N/A	Flutter	N/A	Bearing or tape pack, clutch, unknown	S/C failure, S/C turned off	N/A	S/C failure, S/C turned off	Head/tape dropouts	Tape debris, bearing failure	Tape jam or bearing	N/A	N/A	N/A
Recorder type	Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital	Analog	Analog	Analog	Digital	Digital and analog	Digital	Analog	Digital	Digital

	MSC							
Parameter	Gemini biomedical	Gemini PCM	MTR-1200	10-126B/TE-2	CM FQR	CM DSE	LM DSEA	EREP
Manufacturer[a]	Cook	RCA	Leach	Genisco	Leach	Leach	Leach	Ampex
Mission	Geminis 1 to 12	Geminis 1 to 12	Apollo	Apollo	Apollo	Apollo	Apollo	Skylab
Launch date	1964-66	1964-66	1963-65	1965-66	1966-68	1966-71	1969-71	Future
Number of recorders per spacecraft	1	1	1	1	1	1	1	2
Number of recorders of type launched	12	12	4	2	5	13	7	–
Capacity bits	N/A	7.5×10^7	N/A	N/A	N/A	1.2×10^9	3.6×10^6	2.2×10^{10}
Data rate, bits/sec (or Hz if so labeled)								
Record	0-100 Hz	5.12K	100 Hz-50 kHz	100 Hz-50 kHz	50 Hz-50 kHz	50 Hz-12.5 kHz	300 Hz-3 kHz	125K, 1000K
Playback	0-100 Hz	112.6K	100 Hz-50 kHz	100 Hz-50 kHz	50 Hz-50 kHz	400 Hz-100 kHz	300 Hz-3 kHz	125K, 1000K
Power, W								
Record	1.2	12.5	73	93	45	40	2.1	175, 140
Playback	N/A	–	N/A	N/A	N/A	40	N/A	175, 140
Weight, lb	4	14.5	35	53	40	40	2.2	48
Volume, in.^{3}	100	431	480	950	1425	1250	50	2182
Bit error probability	N/A	10^{-5}	N/A	N/A	N/A	10^{-7}	3×10^{-5}	5×10^{-6}
Type of transport[b]	RR	C-RR	RR	RR	RR	RR	RR	RR
Tapes								
Manufacturer[c]	3M	3M	3M	3M	3M	Kodak (CEC)	Ampex	3M
Type	888	490	999	999	2261	216687	143	888
Length, ft	880	2300	750	2250	2250	–	450	7000
Width, in.	1/2	1/4	1	1	1	1	1/4	1
Number of tracks	7	2	14	14	14	14	4	28
Track density, tracks/in.	14	8	14	14	14	14	16	28
Packing density, bits/in./track	3400 cycles/in.	2730	3333 cycles/in.	3333 cycles/in.	3333 cycles/in.	8500	160	16 700
Tape speed, in./sec								
Record	0.0293	1-7/8	15	15	15	1-7/8, 7-1/2	0.6	60, 7 1/2
Playback	N/A	41-1/4	N/A	N/A	N/A	7-1/2, 60	N/A	N/A
Head material	–	Alum/Alfenol	–	–	Alum/Alfesil	Alum/Alfesil	Alum/Alfesil	Soft
Bearing lubricant	FS1265 F44	Barden grease, G8, oil 0-11	–	Barden grease, G-14	Versilube, F-50, VV545	NPT 3, Aeroshell 15	NPT 3, FS 1281	Nydgel 816, Aeroshell 7A, MIL-L-6085
Gas fill	N/A	–	–	–	Vented	Vented	Vented	Vented
A/D cost	200K	None	None	None	None	None	None	–
Project costs	1.2M	2.7M	330K	590K	1.4M	8.3M	2.6M	4M
Cost per recorder flight unit	20K	40K	17K	40K	60K	80K	40K	300K
In-house manpower, my	4	6	7.5	10	4.5	7.5	4.3	5
Project cost per in-house manpower, ks/my	300	452	44	59	302	1102	617	800
Contract type	–	–	–	–	–	–	–	CP, FP
Total mission life, hr	0.3-100 each	0.3-201	0.4 each	0.5 each	0.5 each	0.5-237	0-10	–
Operational life,[d] hr	0-100 each	0.3-201	0.4 each	0.5 each	0.5 each	0.5-237	0-10	34
Failure rate, failures/operational hours	1/803	2/836	0/1.6	0/1	0/2.5	1/1481	0/55	–
Failure rate, failures/10^6 hr	1245	2392	0	0	0	675	0	–
Failure mode	Improper loading of tape	Bearings	N/A	N/A	N/A	Case design, vent valves	N/A	–
Recorder type	Record only; analog	Digital	Record only; analog	Record only; analog	Record only; analog	Analog and digital	Record only; analog and digital	Record only; Miller code; digital

	JPL							LaRC		ARC		
Parameter	MM 64	MVM 67	MM 69 digital	MM 69 analog	MM 71	MVM 73	VO 75	Injun	Viking lander	Biosatellite	Type 28	–
Manufacturer[a]	Raymond/TI	Raymond/TI	Lockheed/TI	Lockheed/TI	Lockheed/ Motorola	Lockheed/TI	–	Leach/SUI	Lockheed	Cook	Kinelogic	Odetics
Mission	Mariners 3, 4	Mariner 5	Mariners 6, 7	Mariners 6, 7	Mariners 8, 9	Mariner J	Viking	Injuns 4, 5	Viking	Bios 1 to 3	–	–
Launch date	1964	1967	1969	1969	1971	Future	Future	1964-68	Future	1966-67	–	–
Number of recorders per spacecraft	1	1	1	1	1	1	1	1	1	1	–	–
Number of recorders of type launched	2	1	2	2	2	N/A	N/A	2	N/A	3	–	–
Capacity bits	5.2×10^6	4.8×10^5	2.3×10^7	N/A	1.8×10^8	1.8×10^8	1.3×10^9	4×10^7	4×10^7	N/A	1.73×10^8	3.24×10^5
Data rate, bits/sec (or Hz if so labeled)												
Record	10.7K	66.7	16.2K	8.5 kHz-30 kHz	132.3K	117.6K, 2.4K	301.7K, 16K, 4K, 1K	810	4K, 16K	0-100 Hz	10K	60
Playback	8.3	8.3	270	1.2 kHz-4.3 kHz	1K-16K	22K, 7.4K	1K-16K	32.4K	250-16K	0-100 Hz	50K	1380
Power, W												
Record	3	7	20	23	22	27	100	3.4	10	2	20	3
Playback	4	6	18	19	18	16	20	5	10	2	30	7
Weight, lb	17	17	21	21	24	24	50	7.5	19	5.2	15	10
Volume, in.^{3}	481	541	532	532	770	770	2000	270	660	N/A	540	364
Bit error probability	10^{-5}	10^{-5}	10^{-5}	N/A	10^{-5}	10^{-5}	10^{-5}	–	10^{-4}	–	10^{-6}	10^{-6}
Type of transport[b]	EL	EL	EL	EL	CP-P	CP-P	CP-P	C-N	CP-RR	RR	CP-P	C-N
Tapes												
Manufacturer[c]	3M	3M	3M	3M	3M	3M	3M	3M	Univac	3M	3M	3M
Type	MT 1353	MT 1353	MTA 22760	MTA 22760	MTA 20250	MTA 20250	MTA 20250	551	Phosphor bronze	LR 1411	MTA 20250	951
Length, ft	330	50	370	370	550	550	1000	1800	650	880	1100	180
Width, in.	1/4	1/4	1/4	1/4	1/2	1/2	1/2	1/4	1/2	1/2	1	1/4
Number of tracks	2	2	4	4	8	8	8	2	4	7	5	2
Track density, tracks/in.	8	8	16	16	16	16	16	8	8	14	5	8
Packing density, bits/in./track	833	833	1500	1580 cycles/in.	3400	3400	6667	1000	1300	3400 cycles/in.	2600	150
Tape speed, in./sec												
Record	12.8	0.08	12.0	12	19.4	17.3-0.37	47.5-0.15	0.8	12.3, 3.075	0.0293	3.56	0.4
Playback	0.01	0.01	0.2	1.71	2.4-0.15	2.9-1.1	2.4-0.15	32	12.3-0.19	0.0293	19	9.2
Head material	Brass/μ	Brass/μ	Brass/μ	Brass/μ	Brass/μ	Brass/μ	Havar/Alfesil	Aluminum/μ	Havar/Alfesil	–	–	Ferrite/Alfesil
Bearing lubricant	MIL-L-6085	MIL-L-6085	MIL-L-6085	MIL-L-6085	MIL-L-6085	MIL-L-6085	–	Bray NPT-3	Wet vac-coat	FS 1265 F44	–	Andok C grease
Gas fill	90% N_2, 10% He	90% N_2, 10% He	90% Ar, 10% He	90% Ar, 10% He	90% Ar, 10% He	90% Ar, 10% He	–	–	–	–	–	–
A/D cost	524K	None	None		959K	0	0	None	None	–	–	–
Project costs	1035K	250K	4330K		3166K	1200K	–	68K	2.2M	–	–	48K
Cost per recorder flight unit	100K	50K	200K		250K	–	–	25K	275K	–	–	24K
In-house manpower, my	6.8	3	17		22	4	–	0.5	2	1	–	–
Project cost per in-house manpower, ks/my	152	84	255		144	300	–	136	1100	–	–	–
Contract type	CPFF	CPFF	CPAF	CPAF	CPFF	CPIF-AF	–	FP	–	CPAF	–	–
Total mission life, hr	0, 26 000	4300	3600	3600	0, 5800	N/A	–	10 800, 30 000	–	100	–	–
Operational life,[d] hr	0, 221	38	49	27, 31	0, 640	N/A	–	1000, 2000	–	100	–	–
Failure rate, failures/operational hours	0/221	0/38	0/98	0/58	0/640	N/A	–	0/3000	–	0/300	–	–
Failure rate, failures/10^6 hr	0	0	0	0	0	N/A	–	0	–	0	–	–
Failure mode	Launch vehicle failure	N/A	N/A	N/A	Launch vehicle failure	–	–	N/A	–	N/A	–	–
Recorder type	Digital	Digital	Digital	Analog	Digital	Digital	Digital	Digital	Gear driven; sterilizable; digital	Analog	Digital	Digital

K = 10^3; M = 10^6. [a]TI = Texas Instruments Inc.; SUI = State University of Iowa. [b]C = coaxial; 3C = 3 capstan; CP = coplanar; EL = endless loop; N = negator; P = peripheral; RH = rotary head; RR = reel-to-reel. [c]MEM = Memorex. [d]F = time to failure.

Appendix B
EXAMPLES OF COMPONENT SPECIFICATIONS USED BY GSFC AND JPL

BEARING PROCUREMENT AND TEST REQUIREMENTS

The bearings are one of the most critical parts of a flight tape recorder. They are one of the leading causes of recorder failure in orbit and thus require special attention to achieve quality performance. A good bearing procurement specification must include the following:

(1) *Lot control that shows traceability to the original batches of raw material and to the heat-treating operation.*—It is required that each bearing in a lot be made from the same batches of raw material; manufactured with the same tooling, machinery, and processing procedures; inspected and tested with the same equipment; and lubricated from the same lot of lubricant.

(2) *Serialization of all bearings with a permanent marking.*—Duplex pairs shall be serialized with a common number for each bearing in a pair plus a letter suffix on one of the pair to distinguish it from the other.

(3) *Material and lubricant specifications to meet the bearing performance requirements.*

(4) *Dimension and tolerance requirements including geometry, ball tolerances, and finish and lubricant quantity.*

(5) *Functional testing and inspection on a 100-percent basis including smoothrator test, MIL-STD-206 (ref. 3) torque test, and size coding.*—The bore diameter and outside diameter of each bearing shall be measured. The bearings shall be segregated into nine groups representing three gradations in bore diameter and three gradations in outside diameter. Each group shall span a diametral range of 50 μin.

(6) *Lot sample source inspection of each bearing lot.*—Twenty bearings randomly selected from each bearing lot shall be used as a sample. Ten bearings shall be given inspection testing that includes visual inspection, MIL-STD-206 (ref. 3) torque trace test, smoothrator test, dimensional characteristics, and disassembly with dimensional measurements of all parts including balls. Ten bearings shall be given an

operational test that includes MIL-STD-206 torque trace and thermal cycle to − 40° and 280° F (1 hr at each); five of the bearings shall be run at 30 rpm and the other five at 6000 rpm for 240 hr; the torque tests shall be repeated before disassembly and inspection of all parts.

After the bearings are received by the recorder manufacturer and installed into their bearing modules, the following tests shall be run:

(1) First "feel" test
(2) First coastdown test (3 runs from 2500 rpm)
(3) Temperature soak at − 15° F for 1.5 hr
(4) Temperature soak at 150° F for 1.5 hr
(5) Second "feel" test
(6) Second coastdown test
(7) Twenty-four-hr run-in at 1000 to 1500 rpm at 100° F
(8) Third "feel" test
(9) Third coastdown test
(10) Run-out test

It has been found through experience that the 24-hr run-in at 100° F test is an excellent method of eliminating poor performance bearings. If a significant percentage of bearings from one lot fails this test, the whole lot is rejected.

TAPE TESTING AND STORAGE

The tape used in flight recorders has been a problem in the past and continues to be a problem at the present time. Tape is called the uncontrollable variable in recorders because the recorder industry has no control over the tape manufactured by the tape producers and has to take what is produced and try to use it. The problems vary from moderate to severe depending on the type of recorder and required mission life. The following items are required with respect to the handling and selection of tape for a flight recorder:

(1) Serialization by reels of all tape to be used on a program
(2) Tape storage in a temperature and humidity controlled environment
(3) Thermal stability, lubricant content, carbon content, chlorine content, oxide dispersion, and flexibility tests (ref. 4)
(4) Run-in of 400 passes over dummy heads prior to installation in the recorder
(5) Operation at a temperature of less than 45° C prior to and during flight

HEAD PROCUREMENT AND TEST

The recorder heads require attention because the tape must contact the heads and this interface is critical to the performance of the recorder. The following items are important requirements with respect to head materials, use, and test:

(1) The contact area should contain materials whose hardness is greater than 100 Rockwell B.
(2) Voids or gaps should be less than 30 μin. in width to minimize wear.
(3) Heads with scratches deeper than 12 μin. in the wear area should be rejected or relapped to preserve tape life.
(4) Perform temperature soak at -12° and 65° C for 12 hr at each temperature with thin absorbent material (onion paper) over heads to check for weepage. Also check for core shift.
(5) Hidden shields should be used wherever possible.
(6) The tape wrap angle should be held to a minimum consistent with the longest wavelength recorded.
(7) Head radius should be no larger than needed to obtain tape-to-head pressure for the shortest wavelengths recorded.
(8) The tape tension should be no greater than needed for allowable tracking tolerances, and guide contours should not create localized areas of stress greater than 3000 psi.

MOTOR TESTS

The recorder motors in themselves have not been a problem; however, the motor bearings have resulted in a significant number of recorder failures. The following tests should be required on a flight recorder program:

(1) Torque tests at room temperature to evaluate initial motor performance
(2) Torque tests at 10° C below qualification limits to evaluate low-temperature performance
(3) Torque tests at 10° C above qualification limits to evaluate high-temperature performance
(4) Initial concentricity check
(5) Temperature cycle: -30° to 60° C, five cycles, 4 hr at each temperature
(6) Torque tests at room temperature to evaluate performance after temperature cycle
(7) Vibration test to evaluate mechanical workmanship
(8) Torque tests at room temperature to evaluate performance after vibration test
(9) Final concentricity check to determine mechanical integrity of motor bearings

ELECTRONIC SUBASSEMBLIES

The recorder electronics have not had a significantly high failure rate; however, they cannot be neglected. A strong test program is required to be performed by the recorder manufacturer. Each subsystem at the printed circuit board level (i.e., motor drive electronics, record electronics, etc.) should be tested to the following requirements:

(1) Functional test at room temperature
(2) Functional test at 10° C below qualification limits to evaluate low-temperature performance
(3) Functional test at 10° C above qualification limits to evaluate high-temperature performance
(4) Permanent installation of selected components if required
(5) Temperature cycle
(6) Functional test at room temperature to evaluate performance after temperature cycling
(7) Conformal coating if required
(8) Vibration test to evaluate mechanical workmanship
(9) Functional test at room temperature to evaluate performance after vibration test

LIFE TESTING OF TRANSPORT

The recorder transport must be life tested to determine whether it will meet the intended mission life of the spacecraft. Every program of three or more flight recorders should have at least one life test. On programs with a new transport design, at least three life tests must be run. Two should be accelerated life tests and the other an operational cycling life test. The objective of the life tests should be to prove the design of the recorder transport.

RECORDER FLIGHT ACCEPTANCE TESTS

The flight recorder acceptance test is a very important part of the quality recorder program. The requirements should be put in the recorder specification and should include the following:

(1) The recorder shall operate when subjected to vibration levels consistent with the launch vehicle environment. During each axis of vibration, continuously record input current to the recorder and measure the record and playback current after each axis; also, measure the jitter after each axis. Vibration testing of a flight recorder should be held to a minimum. For example, flight recorders that will be in the flight spacecraft during spacecraft vibration should not be subjected to full vibration prior to installation. A workmanship shake is enough prior to installation in the spacecraft, usually random vibration to flight levels. Plastic covers should be used to observe the transport during vibration.
(2) Seal and leak test the recorder.
(3) A room temperature test shall be performed to completely evaluate the recorder ability to meet the requirements of the specification.

(4) A temperature and operational cycle test of at least 100 hr must be run. The recorder shall be operated while being subjected to five cycles between the temperature extremes equal to the qualification levels. The length of the high and low dwell period is 12 hr. On the first cycle at low and high temperatures, the recorder shall be given a complete functional test at each temperature. After each of the remaining dwell periods, the record and playback current, jitter, head output, and data output shall be measured.
(5) A second room temperature test to completely evaluate the recorder ability to meet the requirements of the specification must be performed.
(6) The recorder is then depressurized and the covers removed for inspection. A thorough inspection is made of the transport, especially the head/tape interface, for any sign of abnormal debris buildup.
(7) The covers are then replaced, and the recorder sealed and leak tested.
(8) A thermal vacuum test is then performed at qualification temperature levels with a 12-hr soak at the low and high temperatures prior to running full functional tests at these temperatures.
(9) A final room temperature full functional test is then run.
(10) Prior to shipment of the recorder, all test data and records of the recorder and subassemblies are reviewed for acceptability.

RELIABILITY

The reliability and quality assurance program for a quality flight recorder should emphasize the necessity of the following to eliminate poor workmanship and mechanical malfunctions:

(1) A full-time quality control specialist to monitor all assembly and testing of the recorder
(2) Reliability engineering involvement in each step of the design, fabrication, and testing of the recorder, especially the transport
(3) A class 10 000 clean room with humidity control and laminar flow benches for assembling the recorder
(4) Configuration control of all parts used in the recorder with special emphasis on change control and accurate and complete part drawings and specifications
(5) Program documentation and daily log books to be kept on each recorder from the time tape is installed in it
(6) Model-shop-type approach rather than production-line handling; each recorder handled as a qualification unit
(7) Continuity of personnel on the recorder program as much as possible; consistent use of the same mechanical and electrical technicians

BEARING PROCUREMENT SPECIFICATIONS

This specification defines the dimensions and design and performance requirements for preloaded, duplex pairs of precision instrument ball bearings. These bearings will be used in the engineering model transport (EMT) on the Viking Orbiter 1975 data storage subsystem. All elements of the bearings shall conform to the dimensions and requirements as specified herein.

Applicable Documents

The following documents form a part of this specification to the extent specified herein. Unless otherwise specified in this text, the current issue of each document shall apply. In the event of a conflict between this document and any referenced document, this document shall govern.

Specifications: references 2 and 5
Standards: references 3 and 6

Requirements

Design and Construction

The bearings shall be designed and constructed to meet the requirements specified herein. Except as otherwise specified in this document or in the purchase order, the details and dimensions of the bearing components shall be optional with the bearing manufacturer.

Basic Dimensions

Each EMT will require the following preloaded duplex bearing pairs (which will be termed one "EMT-bearing set"): two R6 (0.3750 (inside diameter (ID)) by 0.8750 (outside diameter (OD)) by 0.2812 (width) in.) duplex pairs with spacers, two R4 (0.2500 (ID) by 0.6250 (OD) by 0.1960 (width) in.) duplex pairs with spacers, six R3 (0.1875 (ID) by 0.5000 (OD) by 0.1250 (width) in.) duplex pairs with spacers, and two R3 (0.1875 (ID) by 0.5000 (OD) by 0.1960 (width) in.) duplex pairs without spacers.

Dimensional Tolerances

The dimensional tolerances of all bearing components shall meet or be better than those specified in reference 6.

Race and Ball Material

The material for the balls and races shall be American Iron and Steel Institute (AISI) 440 consumable-electrode vacuum-melted stainless steel.

Shields

All duplex bearing pairs with spacers shall have double shields for each bearing. Duplex pairs without spacers shall have a single shield for each bearing, located on the outside face of each bearing with respect to preloaded condition. The material for the shields shall be AISI 302 of 305 authentic stainless steel.

Retainers

Retainers for all bearings shall be of one piece snap-in-type construction. Material for the retainers shall be cotton cloth phenolformaldehyde laminate. All retainers shall be vacuum impregnated with the base oil of the grease (in the case of grease lubrication) and with the lubricant oil in the case of oil lubrication. The amount of lubricant retained shall be from 2 to 4 percent of the retainer dry weight.

Radial Play

Radial play for all bearings shall be 0.0003 to 0.0005 in.

Radial Eccentricity

For all bearing sizes, both the inner and outer race eccentricity is to be a maximum of 0.000 050 in. High points of eccentricity of each race shall be marked as described in the subsection entitled "Marking."

Preloading

All bearing pairs shall be duplexed back to back. Preloading may be accomplished by grinding the spacers to the different length required to achieve the preload, or by using equal-length spacers and grinding the inner bearing races to achieve the offset required for the preload.

Finish

All stainless steel bearing parts shall be passivated after final machining as specified in reference 5.

Lubrication

For the bearings covered by this specification, an oil or grease lubricant shall be used. The type of lubricant, oil or grease, shall be as specified herein. It shall be designated by the dash-number of each duplex pair as follows:

10045716–Ax

↳ *designates oil lubricant*

10045716–Bx

↳ *designates grease lubricant*

The oil lubricant shall be Winsor L 245X (ref. 2), which is manufactured by F. E. Anderson Oil Co., Portland, Conn. The oil shall be filtered through a 1.2-μm maximum filter prior to application to the bearings.

The grease lubricant shall be Andok C, which is manufactured by Humble Oil & Refining Co., Houston, Tex. The amount of fill for all grease-lubricated bearings shall be 18 to 22 percent of the open bearing volume.

Marking

The inner ring and outer ring of each bearing shall be marked to show the high point of radial eccentricity if eccentricity is larger than 25 μin. For eccentricities less than 25 μin., no markings are required. Markings are to be on the outer faces of inner and outer races with respect to the preloaded condition. Each duplex bearing pair and its matched spacer set shall be marked with a single V across the OD of the bearing-spacer-bearing stackup to assure correct alinement of the. matched set at assembly. Each matched duplex bearing-spacer set shall be serialized. Each separable component of a set shall be marked with the set serial number. Location of serial numbers may be on either face of the bearing races and spacers.

Quality Assurance Provisions

All performance tests and inspections shall be performed on a 100-percent basis by the manufacturer. Detailed records of all tests and inspections shall be supplied with each shipment. All records shall reference the applicable matched duplex set serial numbers. JPL reserves the right to witness any or all tests.

Dimensional Inspection

The following physical characteristics shall be recorded by the manufacturer (all records shall reference the matched duplex set serial number):

For each individual bearing of each matched set:

(1) Inner race bore diameter
(2) Outer race outside diameter
(3) Inner race radial eccentricity
(4) Outer race radial eccentricity
(5) Radial play

For the matched duplex set:

(1) Inner race stack height
(2) Outer race stack height

In addition, the manufacturer shall certify conformance of all nonrecorded parameters to the requirements specified herein.

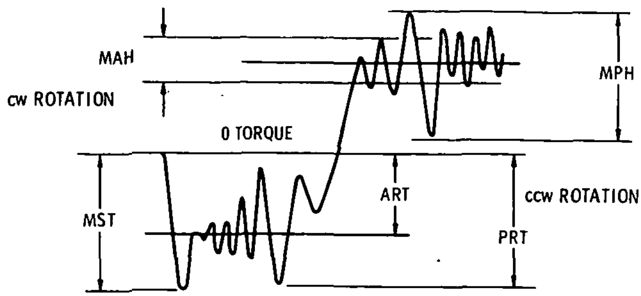

Figure B-1.—Definition of torque characteristics.

Smoothrator Test

A smoothrator test shall be performed on each individual bearing prior to lubrication. Dirt count for all bearings shall be zero.

Static and Dynamic Load-Deflection Test

A static and dynamic load versus axial deflection test shall be made for each duplex bearing-spacer set. The load versus deflection graph of the gage's x-y plotter shall be properly labeled and supplied with each set.

Low-Speed Torque Ripple Test

A low-speed torque ripple test in accordance with reference 3, part 1, except as noted, shall be performed for each duplex bearing-spacer set. The torque tester used shall conform to or exceed the requirements of reference 3, part 2. The test shall be performed with the bearings lubricated and shielded as specified herein and mounted with the spacers as a preloaded set. For each set, maximum starting torque (MST—the initial restraining torque that must be overcome to start rotation of the bearing), peak running torque (PRT—the single largest peak value observed in any one direction or rotation of the test cycle), average running torque (ART—the sum of the distance from 0 torque in each direction (clockwise (cw) and counterclockwise (ccw)) to the average value of the hash divided by 2), maximum peak hash (MPH—the maximum peak-to-peak hash value observed in either direction (cw or ccw)), and maximum average hash (MAH—the width of the hash band excluding the outstanding major peaks in any one direction (cw or ccw)) shall be recorded. These parameters shall be minimized as much as possible; they are illustrated in figure B-1.

Visual Inspection

The packaged, bearing-spacer sets shall be visually inspected, using a minimum 10X power magnifier, for cleanliness, proper markings, possible surface finish damage, and package sealings.

Packaging and Preparation for Delivery

Packaging

Bearings and spacers shall be packed in individual plastic bags filled with 100 percent nitrogen and sealed airtight. Each such package set shall be packed in a rigid plastic container and labeled with part number, applicable dash number, and serial number.

Preparation for Delivery

The supplier shall submit a certificate of compliance with all requirements of this specification and all required test data for each duplex bearing-spacer set at the time of shipment.

GUIDELINES TO OBTAIN 10 000 PASSES OF COMMERCIAL INSTRUMENTATION TAPE IN AN UNATTENDED SATELLITE RECORDER

To achieve 1 year of reliable tape use (10 000 passes), commercial magnetic tape must first be selected correctly, heads must meet specific design requirements, and then both must be correctly used in combination.

The primary failures associated with heads and tapes are—

(1) Tape-to-head motion irregularities leading to flutter and jitter, or total stoppage occurring either with or without damage to the tape
(2) Loss of signals because of tape damage in which debris has become deposited in the wear area of the heads

Simple guideline tests have been devised to assist the recorder designer in selecting tapes that exhibit properties resistant to damage from temperature or the physical stresses of bending and tension.

To select a reel of tape from the recorder from a commercial offering, a small specimen taken from the candidate reel should be tested for the following:

(1) *Thermal stability.*—Observe the effects on the binder system following a procedure of momentarily heating a tape folded back onto itself to 175° C. Freedom from adhesion or crumbling when unfolded signifies an acceptable tape insofar as binder durability at an operating temperature of 45° C.
(2) *Lubricant content.*—Accurately weigh a short length of tape before and after exposure to a benzene solvent. The weight difference, where greater than 2 percent of the original, indicates an excess of additive that can weaken the chemical bonds in the binder leading to debris. A difference less than 1 percent signifies insufficient lubricant needed for smooth sliding over the heads.
(3) *Carbon content.*—This is determined indirectly by measurement of the binder resistivity with a special easily made tool. Excessive

carbon also weakens the integrity of the binder system, but a minimum is required for prevention of static charge buildup.

(4) *Chlorine content.*–Observe if a green color appears when the tape on a copper holder is introduced to a burner flame. Presence of chlorine leads to binder decomposition when the tape is held stationary against the heads for long periods of time

(5) *Oxide dispersion.*–This is indirectly assessed by a measurement of electrical noise detected when the tape is moved at 30 in./sec over a test head. Noise levels of −63 dB or less than saturated signals of 15 kHz on a 10-kHz band indicate a good uniform dispersion of oxide wherein the absence of agglomerations prevents binder weakening.

(6) *Flexibility or brittleness.*–Measure the deflection of a cantilevered tape sample. For example: for a 1-mil total thickness, angular deflection of 30° or greater signifies a flexibility unlikely to yield debris.

Head material and construction should be specified as follows:

(1) The front face (contact area) should contain materials whose hardness is greater than 100 Rockwell B; brass should be avoided. Excessive head wear, although ordinarily benign in the life of the unattended tape recorder, contributes to ultimate failure by destroying the tape surface.

(2) Voids or gaps should be less than 50 μin. in width to minimize tape wear.

(3) Heads with scratches deeper than 12 μin. in the wear area should be rejected or relapped to preserve tape life.

The head-to-tape geometry needed for 10 000 passes is as follows:

(1) Tape wrap angle should be a minimum consistent with the longest wavelengths recorded.

(2) Head radius should be no larger than needed to obtain tape-to-head pressure for the shortest wavelengths recorded.

(3) The tape tension should be no greater than needed for allowable tracking tolerances, and guide contours should not create localized areas of stress greater than 3000 psi.

Operational guidelines include–

(1) A break-in period of 200 passes to assess tape and heads by visual inspection

(2) An operating temperature no greater than 45° C

(3) A relative humidity of 15 percent in the inert gas or air enclosed

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NASA-Langley, 1972 —— 30

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