IITRI

MAGNETIC HEAD/TAPE INTERFACE STUDY FOR SATELLITE TAPE RECORDERS

Technical Report
Volume I

IITRI Project No. E6134
Contract No. NAS5-11622

Goddard Space Flight Center
Greenbelt, Maryland

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Volume I

Guidelines for Selection and Use

for

Magnetic Head/Tape Interface Study for Satellite Tape Recorders

(1 December 1968 - 31 December 1970)

Contract No. NAS5-11622

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February 1971

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NOTICE

THIS REPORT CONTAINS THE RESULTS OF TESTS DESIGNED TO ISOLATE THE EFFECTS OF HEAD, TAPE, AND OPERATIONAL PARAMETERS ON THE PERFORMANCE OF SATELLITE TAPE RECORDERS. BECAUSE OF CERTAIN UNIQUE REQUIREMENTS FOR SATELLITE RECORDERS, THE RESULTS ARE NOT DIRECTLY APPLICABLE TO CONVENTIONAL, GROUND BASED, COMMERCIAL OR HOME RECORDING SYSTEMS. THE INTENT OF THE PROGRAM WAS TO DEVELOP SOUND ENGINEERING TECHNIQUES FOR SELECTING AND USING TAPE IN SATELLITE APPLICATIONS IRRESPECTIVE OF MANUFACTURER, BRAND NAME, CATALOG NUMBER, OR THE APPLICATION FOR WHICH THE TAPES WERE DESIGNED. THE TEST RESULTS REPORTED SHALL BE CONSIDERED VALID FOR THE INDIVIDUAL REELS OF TAPE EVALUATED. NO PORTION OF THE TEXT OR DATA SHOULD BE INTERPRETED AS AN ENDORSEMENT OR CRITICISM BY IITRI OR NASA OF ANY COMMERCIAL PRODUCT OR MANUFACTURING ORGANIZATION.

SECTION I

INTRODUCTION

A continuing history of poor reliability in magnetic tape recorders has plagued the industry and the Goddard Space Flight Center, with which lies the responsibility of specifying future recording systems for satellite applications. Because many of the problems which contributed to the high failure rate were attributed to the interfacial conditions between the tape and heads, a research program was initiated to establish a better understanding of the chemical and physical factors involved. This program, entitled the "Head/Tape Interface Study," was conducted at the IIT Research Institute, and was designated IITRI Project No. E6134. The results of the program from its inception on 1 December 1968 through 31 December 1970 are discussed in this Technical Report.

This document is Volume I of a three-volume report on the Head/Tape Interface Study. It contains a list of guidelines for the design, selection, and use of magnetic heads and tape in unattended satellite applications. As such, this volume represents a fulfillment of the objectives of the program. Volume II discusses in detail the overall test program and summarizes the results which culminated in these guidelines. The procedures employed and data obtained are discussed in Volume III.

The first phase of this program was a survey of appropriate manufacturers and users in the satellite recorder industry. The purpose of this survey was to determine the extent to which problems have occurred, the nature of the failures, and what, if any, corrective actions have been taken. The results of this survey, discussed briefly in Volume II of this report, were categorized and used as the basis for establishing a plan of investigation for the more comprehensive second phase of the program.

The intent of Phase II of the program was to conduct a systematic analytical and experimental investigation to determine the underlying causes and mechanisms of failures at the head/tape interface. This was organized by establishing a number of hypotheses for each of the various problem areas studied. Extensive testing was then performed to isolate the effects of the various factors attendant to the head/tape interaction. The purpose was to establish correlations between these parameters and the failure modes which had been observed. The Phase II test program is described in Volume II of this report.

Results of the Phase II test program have indicated that certain parameters are highly significant in the final performance of a satellite recording system. These factors have been incorporated in the guidelines which comprise this document. It must be emphasized that the program was directed toward isolating significant parameters, rather than recommending commercially available brand names or type designations. As such, the guidelines are applicable for the selection of tape, for example, as well as the specific reel of tape to be used.

During development of the procedures used in evaluating the parameters which require measurement, emphasis was placed upon establishing tests not requiring complex equipment. As a result, several of the tests are indirect measurements of the factor being isolated. However, considerable care was exercised in maintaining correlation between the indirect and exact measurement of a property, thereby sustaining correlation with final performance. The exact measurement procedures utilized during the program are discussed in Volume III of this report. The special test equipment required is listed or described in detail, where applicable. The commercially available equipment required is listed in Appendix A.

A substantial portion of the test program was directed toward the determination of factors relating to the frictional drag and debris performance of the head and tape combinations. Hence, the guidelines presented were designed to minimize the occurrence of problems in these two areas. The guidelines have been organized in three sections. Section II includes parameters found to be significant in Tape Selection; Section III discusses Head Selection; and Section IV, Operational Constraints, deals with the use of the tapes and heads selected. The guidelines concerning those areas of the transport configuration which could ultimately affect the head/tape interface performance are also included in Section IV.

Finally, verification tests performed indicate that there are heads and tapes commercially available which conform to all the guidelines presented herein. Further, when used in accordance with those operational constraints recommended, they can be expected to perform satisfactorily for a period of one year.

SECTION II

GUIDELINES FOR TAPE SELECTION

Of the satellite magnetic tape recorder problems disclosed during Phase I of this program, perhaps the most serious was the lack of reliably uniform tape motion. This was due either to the "stick-slip" phenomenon, or, in the more catastrophic case, total adhesion of the tape to the head. Consequently, this aspect of the head-to-tape interface problem was the first and most comprehensively studied area of the program.

In order to define acceptable head or tape performance throughout the testing portion of the program, the adhesive properties were considered in terms of frictional drag forces. Therefore, the measurement of performance was either applied torque at the capstans or direct monitoring of drag forces at the head with strain gages. The point of failure for a tape-head combination was defined to be ten ounces of frictional drag while using half-inch-wide tape. The operational life was defined to be 10,000 passes of the tape over the head under tension.

The most prevalent problem disclosed during the Phase I survey was the accumulation of debris on the satellite recorder heads. This debris caused physical separation between the tape and heads, resulting in either an excessive number of dropouts or an overall reduction in reproduced output amplitude. This deterioration in performance, although not always catastrophic, was often the most serious problem confronting the manufacturers of recorders. This was particularly true for those systems operated at temperatures approximating room ambient.

During the testing program, an extensive analysis was conducted to identify the chemical structure of the various binder systems. The results of this effort, reported in

Volume III, indicated that several basically different binder formulations were included in the tapes tested. However, a considerable amount of chemical expertise and analytical equipment, which may not be available to the users of these guidelines, was required to obtain an adequate analysis. Furthermore, it was found that the several tapes having virtually the same binder chemistry showed markedly different frictional and shedding characteristics. It was, therefore, decided not to include the actual binder composition as one of the guidelines, but rather to concentrate on those parameters found to vary between brand designations, as well as between different reels of the same tape type.

A. Thermal Stability

The upper operating temperature limit, usually imposed by the particular recorder specifications, was found to be one of the most critical factors encountered in both the frictional and debris performance of the heads and tape. Several failure mechanisms, including binder softening and deposition of melted or plasticized debris on the head, were observed during the high temperature tests performed.

The thermal stability test procedure described is intended to identify those tapes whose frictional performance will be particularly sensitive to high temperature operation. Temperature, herein, refers to the ambient, steady-state measurement in the vicinity of the head, irrespective of whatever temperature rise may occur due to frictional heating. The maximum operating temperature to which tapes passing this test should be exposed is discussed in Section IV. However, it is suggested that this guideline be applied even though the enclosure temperatures may not be expected to reach the specified upper limit.

GUIDELINE - After two pieces of tape from the reel being considered are placed oxide to oxide and heated in accordance with the procedure described below, there should be no evidence of adhesion or oxide crumbling.

PROCEDURE - Remove a ten-inch sample length of tape from the reel with the necessary precautions to avoid contamination of the oxide surface. Fold the sample in half, oxide surface to oxide surface, thus forming a five-inch length. Firmly grip each end of this folded five-inch sample and center it over a 3/8-inch diameter rod heated to a temperature of 175°C (see Fig. 1). Apply sufficient pressure to wrap the sample around half the circumference of the heated rod, as shown in Fig. 2. Imitating a polishing motion, pull the tape backwards and forwards twice a second over a one-inch distance to either side of center, while maintaining adequate applied pressure to maintain continuous contact of the oxide surfaces.

After continuing this procedure for approximately five seconds, some slight shrinkage of the base material will be observed. Remove the sample from the heated rod and gently pull apart the two free ends of the tape. Observe the condition of the oxide surfaces.

After being subjected to the above procedure, the sample tape under investigation will fall into one of the following four categories.

1. <u>Total Adhesion</u> — Adhesion of the two oxide surfaces will result in the total removal of the oxide binder layer from the upper base material.

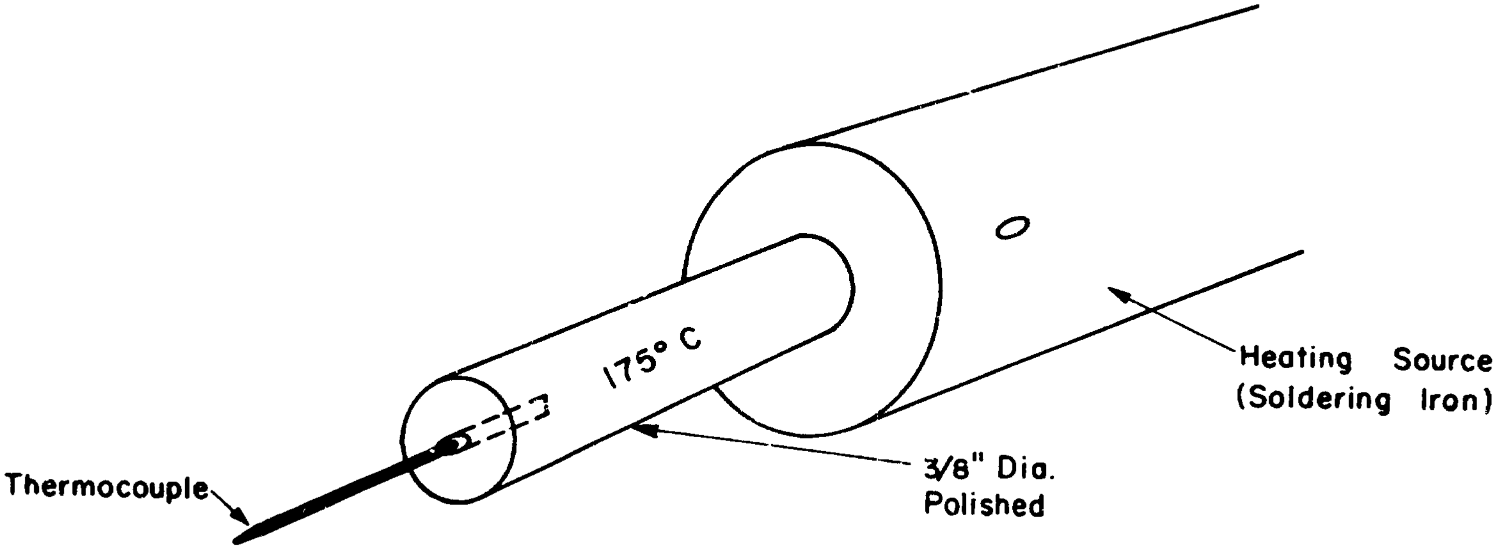

Fig. 1 THERMAL STABILITY TEST SETUP

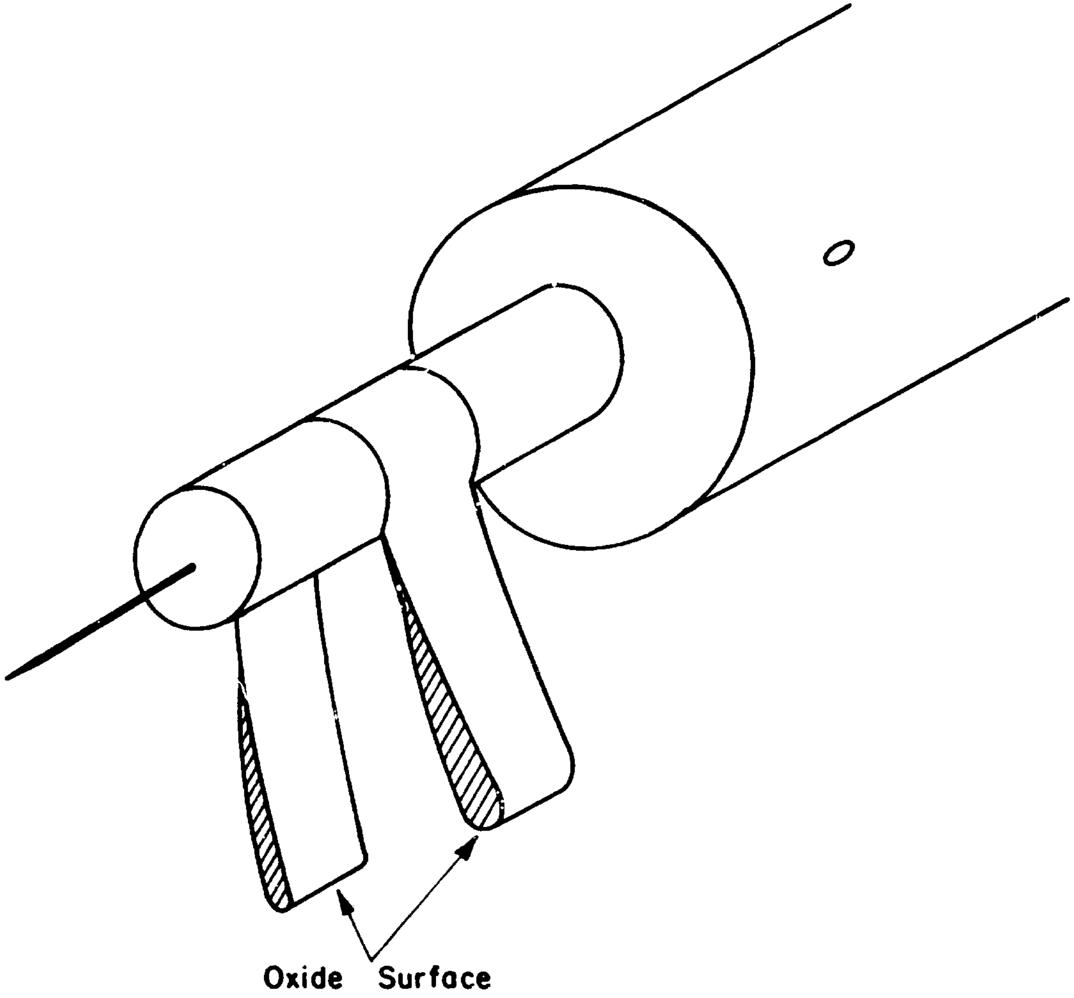

Fig. 2 THERMAL STABILITY TEST

2. Partial Adhesion — Partial adhesion will result in an observable roughness of the two oxide surfaces once the adhesion bond has been broken.

3. Oxide Crumbling — No adhesion will be experienced in this category, but severe oxide crumbling and flaking will be observed.

4. No Effect — A loss of surface shine and base shrinkage may be noted, but no adhesion or crumbling should be noted.

Tapes exhibiting any of the first three conditions have failed this test and should not be used. Because of the qualitative nature of this test, it is advisable to experiment with several older, Mylar-based tapes to establish a feeling for the pressure to be applied and the general appearance of the failures.

B. Lubricant Content

Most of the tapes examined during the program contained an additive in the binder system which was designed to reduce the frictional drag properties by lubricating action. Several types of lubricant additives were identified by chemical analysis, the most prevalent being organo-polysiloxanes. However, it was found that the quantity of lubricant contained in the binder system was more significant than the type, and further, that both upper and lower bounds should be placed upon this factor. The lower limit of percent lubricant content is necessary to obtain the desired reduction in coefficient of friction, while excessive quantities are believed to be a factor in weakening the integrity of the binder polymer system. Thus, the limitation on the maximum lubricant content has been established to minimize oxide binder debris.

The test recommended here will extract most commonly encountered lubricants, as well as some other low molecular weight materials. As such, it should properly be designated a Solubility Test. However, the majority of material removed has been found to be the lubricating additive. Further, excessive quantities of other low molecular weight materials are likely to be at least as detrimental to proper operation as the relatively inert lubricant commonly encountered.

GUIDELINE - The material extracted from a three-foot length of tape immersed in benzene (C_6H_6) for a period of twelve hours should be between 1.0% and 2.0% of the total weight of the binder system, including oxide. Further, the oxide binder coating should adhere to the substrate during and following immersion.

PROCEDURE - Cut a sample of tape three feet ($\pm$ 1/32 inch) long from the reel of tape being considered and carefully weigh it to within at least 100 micrograms using an analytical balance. Do not handle the tape with bare hands or lint producing gloves. A three-inch diameter petri disk previously balanced out on the scale is useful for holding the sample.

Totally immerse the tape in benzene, standing the tape on edge to allow wetting of the entire surface of the binder. After 12 hours, carefully remove the tape with tweezers and dry thoroughly. Re-weigh the sample to within 100 micrograms.

Compute the Mylar substrate weight using a density of 22.56 grams per cubic inch. For 36-inch lengths of 1/2-inch tape, the weight of commonly used substrate thicknesses is shown below:

Mylar Thickness	Weight
0.92 mil	0.37359 grams
1.42 mil	0.57663 grams

Subtract this weight from the two measurements made and compute the percent weight loss. The weight ratio of oxide to binder did not vary considerably between the tapes examined during the program. Therefore, this factor does not appreciably affect the determination of extracted materials when expressed as a percentage weight loss.

C. Resistivity

The surface resistance on the oxide side of the tape is related to the amount of carbon or graphite added to the overall binder composition. Carbon is generally added to the binder in order to increase conductivity, thereby reducing possible buildup of static charges when operated in a dry atmosphere. However, the addition of excessive carbon was found to have a weakening effect on the integrity of the binder system. In these cases, the carbon was observed as one of the constituents of the debris which accumulated.

GUIDELINE - The surface resistivity of the tape used should be greater than 0.5×10^7 Ω/sq. and less than 50×10^7 Ω/ sq. when measured at 71°F and 30% RH.

PROCEDURE - Carefully remove a sample of tape approximately one foot long from the reel being considered and place, Mylar side down, on a highly resistive block (glass or equivalent) in a container which can be sealed. Apply tension by attaching eight-ounce weights to both ends as shown in Fig. 3. Place a probe similar to that shown in Fig. 4 on the oxide surface of the tape with sufficient weight to produce an eight ounce normal load. Place a three-inch petri disk containing a saturated aqueous solution of $CaCl_2 \cdot 6H_2O$ (or equivalent to obtain 30% RH) in the container. Allow the tape to stabilize for 12 hours. Record the surface resistance using a high resistance ohmmeter equivalent to Item 2 of the required test equipment listed in Appendix A.

D. Chlorine Content

The presence of chlorine was detected in several of the tape types evaluated during the program. This was observed by means of the Beilstein test, and later verified by other reactions. Although the source of the chlorine was not determined, its presence or the possible formation of decomposition products could accelerate degradation of either the head surface or the binder polymer itself. In addition, tape types exhibiting a chlorine content also showed increased adhesive interaction with various head materials, particularly during a series of static tests conducted. Therefore, the Beilstein test has been incorporated as a tape selection guideline.

GUIDELINE - Those tapes exhibiting a positive test for chlorine should not be used in applications where the tape is expected to remain stationary against the head under tension for long periods of time.

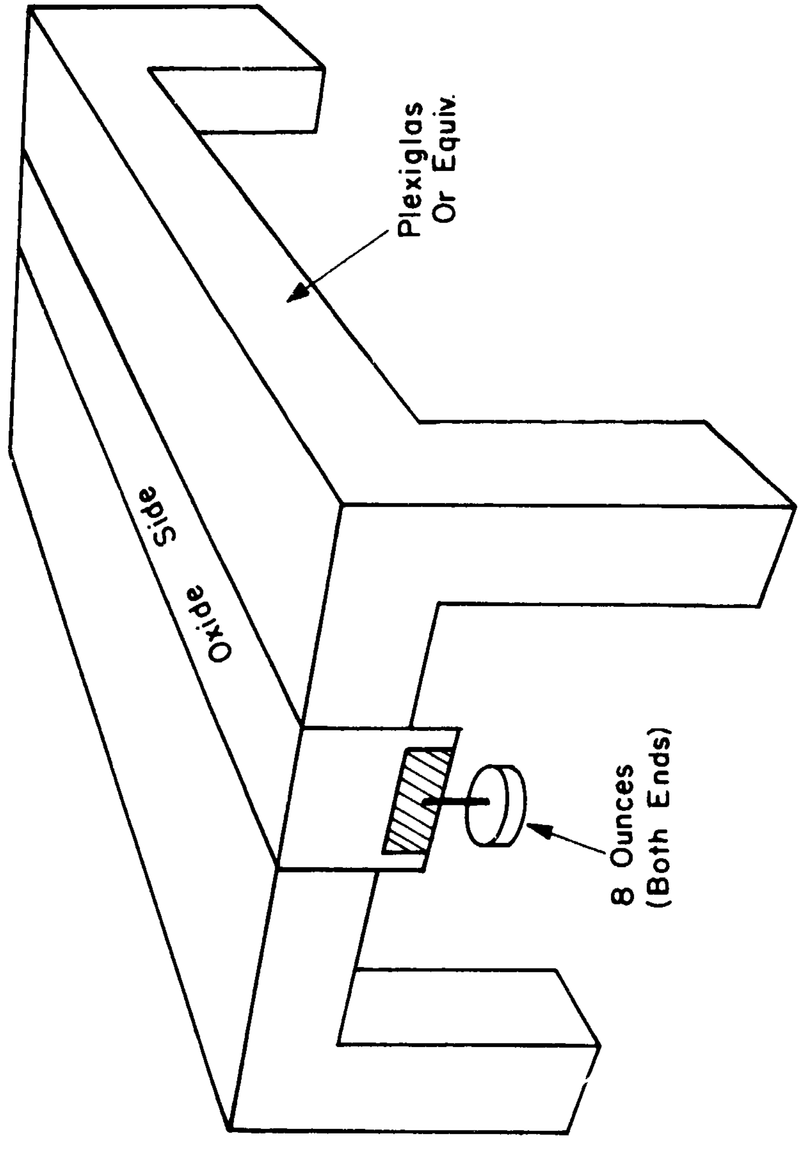

Fig. 3 RESISTIVITY TEST SETUP

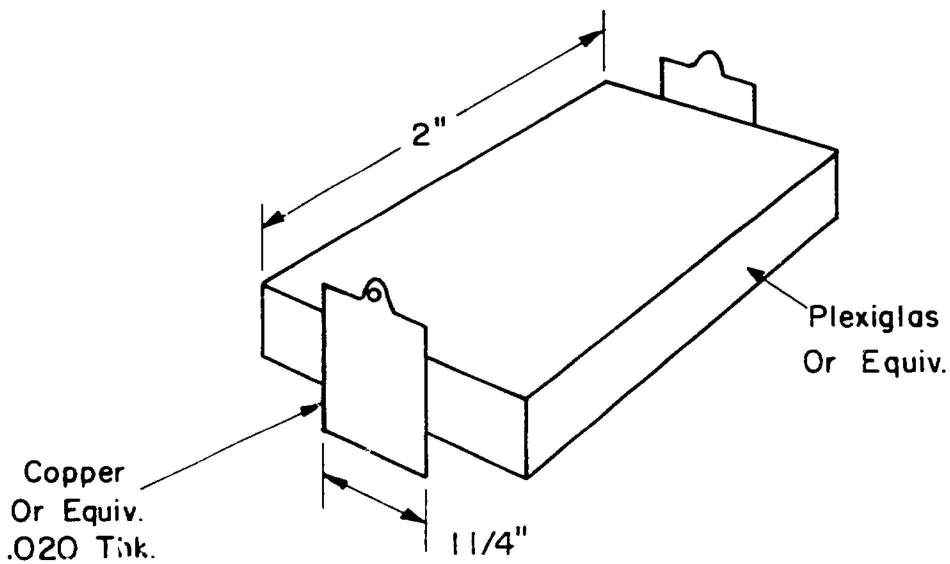

Fig. 4 RESISTIVITY TEST PROBE

PROCEDURE - While wearing protective gloves, remove a sample of tape from the reel to be used. Using a copper holder or spoon, place the tape in the flame of an ordinary Bunsen burner. The presence of a green flame indicates a chlorine containing compound in the tape.

E. Oxide Dispersion

Test results indicated that tapes having a uniform dispersion of the magnetic oxide, i.e., without agglomeration, tend to produce less debris with usage. This probably occurred because of local weakening of the binder system in the areas where clumps of oxide occurred. Oxide dispersion is commonly evaluated by examining cross-sections of tape using a transmission electron microscope. However, the test recommended in these guidelines is a dc noise test which, although sensitive to oxide surface finish and Mylar thickness variations, does allow monitoring of somewhat longer samples of tape. The wavelengths and bandwidths chosen for this test have been designed to minimize this dependence, and little correlation was observed between the noise and surface finish measurements conducted on the tape type used during the test program.

> GUIDELINE - The tape noise reproduced at 30 ips from a tape magnetized to saturation in one direction should be at least 63 db below the saturated signal output at 15 kHz over a 10-kHz total bandwidth.

PROCEDURE - Include as the basic equipment setup for this test a tape transport which handles tape reasonably well (i.e., low skew and flutter), a reproduce head with a track width of 50 mils, a low noise amplifier, and a bandpass filter operating at 15 kHz $\pm$ 5 kHz. The frequency response for the filter below 10 kHz and above 20 kHz should be -18 db per octave. Measure an rms voltage of a 15-kHz signal recorded to saturation without bias. Record the measurement in decibels above the system noise. Measure system noise with the tape running, but out of contact with head. Saturate the tape in one direction with either a permanent magnetic or sufficient dc current through the record head coil. Then record the rms measurement of the tape noise which should be at least 10 db above the system noise. The difference between the tape noise and the 15-kHz signal should be at least 63 db.

F. Flexibility

The stiffness of the magnetic tapes tested was also found to be a factor in predicting the tendency to produce oxide binder debris. It was not determined whether this relationship was due to the brittleness of the binder system or the presence of residual stresses. However, it was determined that the more flexible tapes were less likely to generate debris.

GUIDELINE - The defection of three inches of tape from the horizontal, when using the recommended procedure, should not be less than the following values for 1/2-inch tape.

Nominal Base Thickness (mils)	Deflection Degrees
1.0	30
1.5	35

PROCEDURE - Clamp a six-inch sample length of tape with the oxide surface down onto the test fixture (Fig. 5); allow three inches of tape to extend beyond the clamping point, with the tape assuming a natural arc of curvature. Compute the angle of curvature from the horizontal by measuring the horizontal and vertical coordinates from the free end of the sample tape to a point of clamping. Conduct this test under constant environmental conditions of temperature and humidity, 70°F ± 5°F, 30% ± 3% relative humidity.

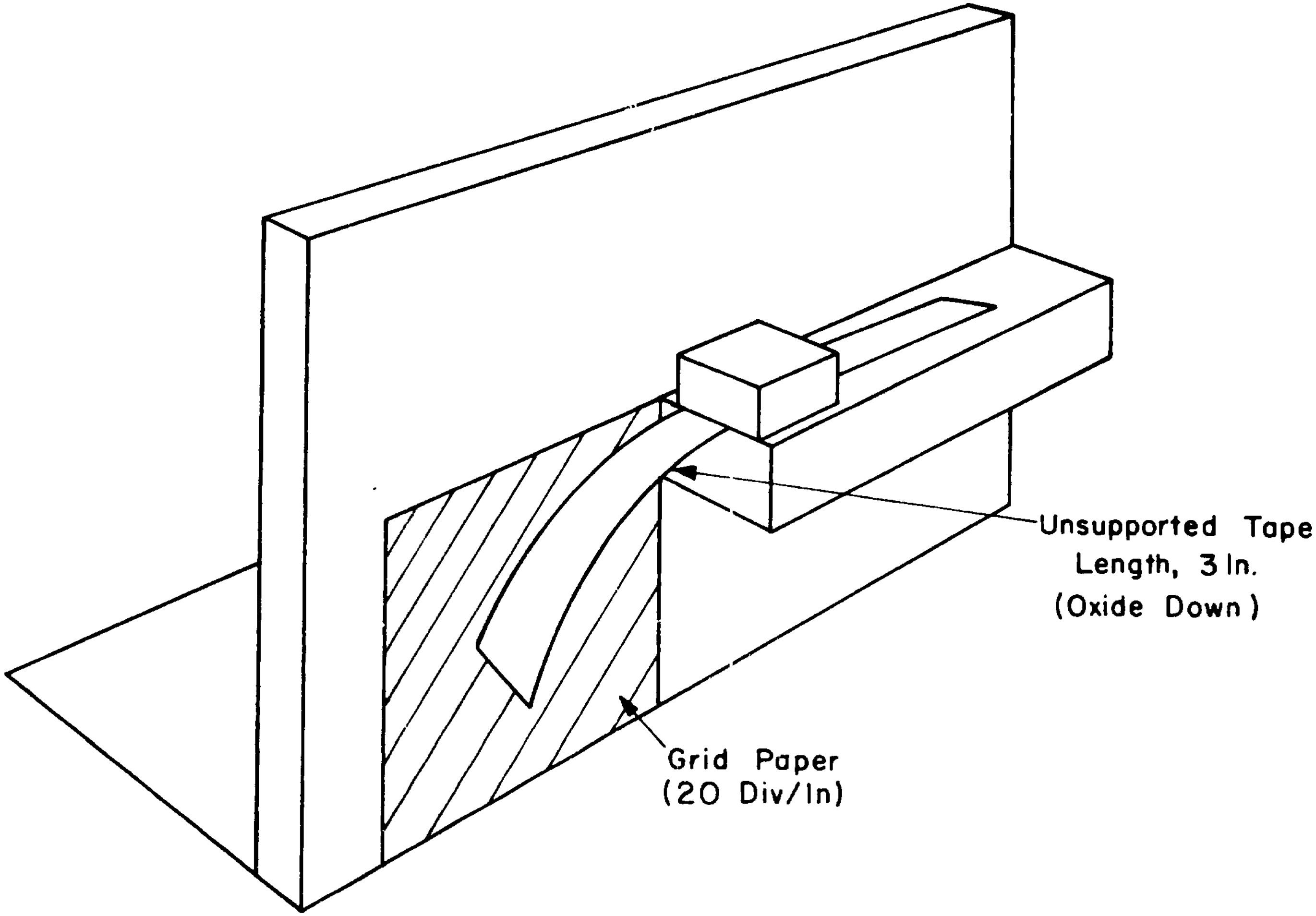

Fig. 5 FLEXIBILITY TEST FIXTURE

SECTION III

GUIDELINES FOR HEAD SELECTION

Several sources encountered during the Phase I survey indicated that the performance of their equipment was strongly influenced by the tape being utilized and somewhat independent of the heads. This conclusion was not verified during Phase II. In fact, it was observed that both the materials and condition of the front surface of the heads were significant factors in the frictional drag and debris accumulation measured with various head and tape combinations. Markedly different results were obtained, in some cases, by changing the head material while using samples of tape from the same reel. Although the parameters relating to tape binders and additives were found to be very significant, the fulfillment of a year's reliable operation for a satellite recorder ultimately relies upon the proper selection and use of both tape and heads.

Although this section of the report deals primarily with the selection and evaluation of heads, one parameter, radius of the profile, is found in Section IV because of the intimate relationship between head radius and the choice of tape tension and wrap angle.

A. Head Material

Throughout the testing program, the effect of head material was found to be a significant factor in establishing the frictional drag characteristics of a head/tape combination. It was also found that the condition of the front surface of the heads was an important factor in the generation of debris regardless of the tape employed. Since a number of the observed adhesion failures were preceded by excessive buildup of debris on the heads, some interrelationship existed between the two areas. Thus a single guideline consistent with the requirements of both low drag and debris could be formulated.

GUIDELINE - The core and block materials used in the front face of the head in the contact area should fall in the category of "hard" materials, i.e., greater than 100 Rockwell B; brass should be avoided.

PROCEDURE - The hardness of various typical head materials is generally available in the literature. Alfenol and Alfesil were found to be preferable magnetic materials. Chrome, stainless steel, and Havar were found to be preferable nonmagnetic materials. Aluminum, although not a hard material, was found to be preferable to brass.

B. Voids

Extensive examination of the causes of debris on head surfaces in localized areas indicated that a discontinuity or void often became a "trap" for a particle of loose dust or oxide. This, in turn, caused tape damage and an accelerated rate of debris accumulation. Such voids should ideally be eliminated completely. However, numerous instances of heads containing discontinuities smaller than cited in the guidelines were successfully used on tests during the program. No evidence of excessive debris build-up was found during examination following completion of these tests.

GUIDELINE - Voids or gaps between laminations or other discontinuities on the front face should be less than 50 microinches in width.

PROCEDURE - The entire contact area of the head should be examined along the vertical centerline using a microscope with a magnification of at least 480X. See recommended test equipment.

C. Surface Finish

The surface finish of a head is most accurately measured using equipment which runs a stylus across the contact area. However, this method, found to scratch the head being measured, is not recommended. Therefore, optical techniques are suggested for measuring this parameter.

GUIDELINE - There should be no scratch in the direction of tape motion on the contact surface of the head that is deeper than 12 microinches. Also, there should be no scratches perpendicular to the direction of tape motion.

PROCEDURE - Mount the head being considered on an interference microscope, and examine the contact area along the vertical centerline. Scratches causing a light band deflection of more than a one-band interval with white light ($\lambda/2$ = 12 microinches) are not acceptable. Remove any scratches not in the direction of tape motion by shuttling a high grade instrumentation tape over the head at low tension and moderate speed.

SECTION IV

GUIDELINES FOR ESTABLISHING OPERATIONAL CONSTRAINTS

Even with the proper selection of heads and tape to minimize both frictional drag and debris, the manner in which the combination is utilized has been found to be a substantial determinant of the final performance. Therefore, this section is predicated on the basis that a tape and head combination has been selected which conforms to the previous two sections. Two categories of operational constraints -- Environmental and Mechanical Tape Handling -- have been isolated. Included in the tape handling discussion are guidelines for the interfacial conditions, such as wrap angle and head radius, as well as constraints on the tape transport path configuration.

A. Environment

The survey results obtained during Phase I indicated that the majority of satellite recorders were sealed in containers, thus allowing the manufacturer to select both the relative humidity and atmosphere. The upper temperature limit, however, was generally dictated by the equipment specification. Therefore, temperature, found to be one of the most critical parameters in both the adhesion and debris tests, has been defined in terms of operational life.

1. Temperature

> GUIDELINE - Recorders utilizing tape and heads meeting the adhesion and debris guidelines can be expected to operate satisfactorily up to 10,000 passes at temperatures up to 45°C. Recorders specified for operation up to 65°C cannot be expected to operate for more than 3,000 passes.

2. Relative Humidity

The relative humidity to which the tape was subjected at the upper temperature limit was an important factor in the accumulation of oxide binder debris. Specifically, it was found that the largest quantities of debris were generated at the two extreme values of the humidities examined. These were approximately 0% and 45%. However, the debris produced in very dry atmospheres was itself very dry, resembling a powder, while the debris at 45% RH often resembled a solidified material which had been melted. The lowest quantities of debris accumulation were measured following tests conducted at 15% and 30% RH.

In general, it was found that the best frictional drag performance occurred with atmospheres containing low relative humidities. However, this effect was most prominent at the higher temperatures tested, and drag was somewhat independent of humidity at temperatures near room ambient.

3. Atmosphere

Tests were conducted in two atmospheres during the program: air and nitrogen. No significant difference was observed.

B. Tape Handling

The improper utilization of a properly selected head and tape combination can eventually result in unreliable operation. Utilization herein refers to the transport handling of the tape, as well as the mechanical interfacial configuration between the tape and head. For example, it was reported during the Phase I survey, and verified during the testing program, that tape tension was an important factor in the determination of both the adhesion and debris performance of a system. However, it was also noted that the effects of increased tensions throughout the tape path were not seriously considered in the assessments of failures that subsequently occurred. In general, the design of the entire tape path as well as the relationship between tension and wrap angle at the heads were found to be critical parameters in establishing reliable recording systems.

1. Head to Tape Contact

The storage and retrival of information using a satellite recorder requires intimate contact between the tape and head. This is primarily due to the well known spacing losses encountered at short wavelengths. Therefore, when designing a system, it is first necessary to determine the head pressure required for the particular application.

GUIDELINE - The required normal force at the gap line should be defined by maximizing the reproduce output signal of the shortest wavelength being reproduced.

Three parameters must then be adjusted to obtain the required head pressure for a given tape (i.e., known flexibility). They are tape tension, wrap angle, and head radius. The relationship between these parameters has significant bearing on the reliability of the overall system, in terms of minimizing both frictional drag and debris. Two equations govern the interaction of these factors:

$$\text{Head Pressure} = \frac{To\varepsilon^{\mu\frac{\vartheta}{2}t}}{rw} \quad \text{at the gap line}$$

$$\text{Drag} = To(\varepsilon^{\mu\vartheta t} - 1)$$

Where:

T_o = Tape tension on low tension side of the head

μ = Coefficient of friction

θ_t = Total wrap angle

r = Head radius

w = Tape width

The first equation indicates that head pressure is strongly dependent upon both tension and head radius, but relatively independent of wrap angle (neglecting air bearing effects at high tape speeds). Frictional drag, however, is strongly influenced by both tension and wrap angle. Therefore,

GUIDELINE - Tape wrap angle should be minimized.

Throughout the test program, the quantity of debris generated and the head wear were found to be more dependent upon contact area than frictional drag. It can be seen from the expression above that reducing the head radius, r, will in increase the head pressure. At the same time, reducing the head radius will decrease the head-to-tape contact area. Therefore,

GUIDELINE - The minimum head radius consistent with the packing density of the information being stored should be utilized.

This generally allows obtaining the necessary head pressure without resorting to excessive tape tension.

The tape tension should then be adjusted to obtain the predetermined required head pressure. Although increasing the tension will also increase the resultant drag, the significant relationship is between drag and total normal force. Tape tension alone was not the cause of degradation at the head/tape interface. Therefore,

> GUIDELINE - The maximum tape tension should be defined by the tape path and tape pack stress considerations discussed in a subsequent guideline in this section.

2. Tape Path Design

The stress levels to which the tape is subjected throughout the tape path will ultimately affect the debris and dropout performance of the overall system. Measurements of the stress-strain characteristics of tape as well as uncoated Mylar indicated that a region of nonlinearity exists in the region of 6500 psi. Conservative mechanical design would dictate that the tape should not be stressed to the extent that operation in this region is encountered.

> GUIDELINE - The maximum stress level in the tape should not exceed 3000 psi at any point in the tape path.

PROCEDURE - The techniques for computing stress in the oxide and substrate layers of the tape are discussed in detail in Volume III of this report. Included in this discussion are the analytical solutions for cylindrical, canted, and crowned rollers as functions of the mechanical tape properties; the roller and crown dimensions; the angle of cant; the wrap angle of the tape; and tape tension. Presented with the equations are graphs showing typical cases and a computer program to facilitate computation.

It should be noted that the oxide layer of the tape is actually in compression rather than tension in many cases where the oxide is against the guide, capstan, or head. It was not determined during this program whether the effects of alternately stressing the oxide in tension and compression were detrimental. It is known, however, that the stress level should be minimized through conservative design of the tape path elements.

3. Number of Heads

During the testing program, an increase in frictional drag was observed when the period of time between passes of tape over the head was very short, e.g., two seconds. Such a situation is not generally encountered unless more than one head is placed in the tape path. Therefore,

> GUIDELINE - The number of heads should be minimized. Erase heads should be out of contact when possible.

If the particular recorder application requires the use of separate read and write heads, the tape wrap angle should be minimized for each of the heads. The wrap angle need not be the same for all heads.

4. Break-In

GUIDELINE - A break-in period of 200 passes is advisable. Following this break-in the head should meet the surface finish guidelines of paragraph III.B.3. Observation of a deep scratch, indicating repeated damage by debris in the same area, should be cause for replacing the tape and relapping the head.

APPENDIX A

MAGNETIC TAPE EVALUATED

Throughout the program, a number of tape types produced by several manufacturers were evaluated. These tapes, listed below, were purchased and tested between 1 July 1969 and 31 December 1970. Lot or batch identification numbers are included, as variations in certain parameters may occur between reels or batches of the same tape type designation.

Manufacturer	Type Designation	Lot Number
Ampex	772	29G8306-4 (1 Reel Unknown)
Bell and Howell	W4	10027834
Dupont	Crolyn	8322711036102 8322711036119 (1 Reel Unknown)
Graham Magnetics	Epoch IV	8B20558B-15
IBM	500	0 6 072271
Memorex	63L	15092-A2-6A 15092-A1-17A
Memorex	79L	E59159-C2-5D ME56857-A1-5B
Memorex	Quantum	27E-HJ-3712C-A1- M30160-B3 (2 Reels)
3M	351	64748043029 64748043046
3M	551	67618-71-11-41 67618-71-12-41
3M	700	72729-99-000-37

Manufacturer	Type Designation	Lot Number
3M	777	63904-390-1011 63904-370-1036
3M	851	65849-6-10-9
3M	871	69333-3-10-16 69333-6-20-19 74921-10-10-12 74768-5-11-9
3M	888	55512-46-10-17 67760-40-11-12 (1 Reel Unknown)
3M	8119	72347-01-10-41
3M	MTA 20302	70773-03-10-19
3M	MTA 20294	64883-1-2-2
3M	MTA 20478	75450-06-000-38
RCA	617	No Designation - Not a Commercial Tape