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I. N. 1009

TECHNICAL PROPOSAL

AUTOMATED FILM TRANSPORT STUDY

STAT

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SECTION I

INTRODUCTION

INTRODUCTION

In response to a formal request by the U. S. Government, [redacted] STAT proposes to study the loading, threading, transporting and flattening of roll film. The study will produce a base of technology applicable to future designing and specifying of image exploitation equipment.

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SECTION II

SCOPE

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SCOPE

The study will proceed in three phases (see App. C, Program Plan).

In Phase I the operational characteristics of concepts, designs and techniques currently employed in the handling of tape, film or strips will be ascertained by survey and other means.

In Phase II the data concerning these techniques and their operational characteristics will be screened.

Phase III will apply research to complete the evaluation of operational characteristics, study new applications for existing techniques, and examine the feasibility of new techniques.

A Final Report will result which will provide a coherent and useable statement of the operational characteristics of existing techniques as well as the results of new directions investigated.

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SECTION III

SUMMARY

SUMMARY

A base of technology useful in the design of new image exploitation systems will be the result of this study, as well as comprehensive yardsticks which, when applied to a proposed concept, design or technique, yield a meaningful statement of its relation to all existing concepts, designs or techniques.

The yardsticks will provide a means of controlling operational variables (image quality, transport speed, etc.) as well as practical considerations (development cost, production cost, production time) to preclude over-design, under-design, or duplication.

The development of the study will begin with an objective survey that empirically gathers all available information concerning devices that transport strip materials. This body of information will be categorized by type of device (viewers, projectors, printers, etc.). Then these categories will be classified and subgrouped by method of loading, threading, transportation, and flattening. Data fields for each subgroup will thus be formed (e.g., a range of transport speeds for the capstan-driven subgroup of viewers). In addition, engineering tests will be performed to investigate the possibility of extending the data fields (e.g., extending the range of transport speeds). Finally, the possibility of applying a technique gleaned from one subgroup to another will be examined (e.g., applying a technique found in a machine in the capstan-driven subgroup of viewers to a machine in the reel-driven subgroup of light tables).

The results of these efforts will be presented in a comprehensive but useable Final Report consisting of charts, graphs, textual material, and bibliography.

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SECTION IV

TASK ABSTRACT

Task Abstracts

Task 1. Preparation for Survey.

To prepare for the survey, state of the art approaches for roll film handling will be listed by the coznizant engineers [redacted] Equipment STAT to be listed will include at least the following: viewers, light tables, contact printers, projection printers, motion picture projectors, magnetic tape units, and film processors.

Known sources of information will also be tabulated. These will include established experts in their field from professional societies, designers and builders of equipment, users in and out of Government, and academicians.

Task 2. Survey Instrument(s)

The survey questionnaire will be shaped to solicit as much usable information as possible, without being so complex as to discourage potential respondees.

It is anticipated that more than one survey questionnaire will be used because of different approaches for each category or class of equipment. Separate requests will make it easier to focus on desired information by eliminating extraneous material. This survey material will be sent to those on the lists previously prepared.

Task 3 Literature Search.

To seek the present "state of the art" a search of the literature will be made for papers on all aspects of roll film handling and transport systems, as well as those dealing with positioning of film in both the lateral and transverse dimensions. The third axis (along the optical axis) is also of intense interest, as the third axis effects focusing and defines the plane of the field of view. The literature search will be conducted concurrently with the survey, so any information or leads turned up in the search can be used in the survey to the best advantage.

Government sources such as Recon Central will be consulted as well as the normal professional and trade publications pertinent to the field.

Task 4. Field Survey of Equipment.

It is felt that certain technical information can be acquired only from field trips to study specific equipment. The engineers can cut straight to the heart of the matter instead of waiting for responses which are hopefully pertinent. Valuable time will be saved by this expedient; much proprietary engineering data is unpublished and will require a competent technical observation to understand the subtleties and complexities of a system or design. Also, having a chance to talk to designers, users, and builders of equipment will give a broader view to the overall picture for those who avail themselves of the opportunity.

TASK 5. Data Screening

Data will be compiled and correlated several different ways. First the data will be grouped by type of machine. Then it will be organized by method of loading, threading, transporting and flattening. The operational limitations of these methods will be determined and reduced to useable data fields.

The data fields will be reduced to graphic form whenever possible, establishing parameters useful in applying the data.

Task 6. Determine Adequacy of Data.

The compiled and correlated data will be checked for relevancy, accuracy, and completeness.

At this stage it will be determined if the data is adequate.

Inadequate data will require resurvey. The depth and scope of the resurvey will be determined by the nature of the data inadequacy. New surveys may also be prompted by the results of the original survey.

Task 7. Organize Data for Final Report.

Data in its reduced, compiled and correlated forms will be organized for inclusion into the Final Report. The technical narrative will be supported by charts, graphs and nomographs.

To be meaningful, certain of the data will have to be combined with other data, to show system considerations. Again, these will be supported by graphs when this shows the results in the best possible light.

Task 8. Formulate Guidelines.

[redacted] feels that a set of useable guidelines is necessary to make the base of technology that will be established most valuable. STAT

This Task will consist of the drawing up of the guidelines, and associating these guidelines with the appropriate areas of data gathered in the survey. It is proposed that a major portion of the guidelines be in graphic form for most effective utilization by the user. In general, the guidelines will enhance the usefulness of the base of technology by providing an easy means to find the appropriate area of the technology for the application under consideration.

Task 9. Feasibility Investigation.

Based upon the results of the data collected in Phase I and screened and correlated in Phase II, some findings may suggest an innovation in automated roll film handling systems. These areas will each be looked at in terms of the potential system improvement, the effort estimated to gain that improvement, and the probability of achieving the estimated gain. Feasibility studies and experiments will be conducted where indicated. If extensive work (over 2 man weeks) would be needed to prove feasibility, customer approval would be secured before startup. Close liaison will be provided with the customer to insure that the direction of the effort will be to the customer's best overall interest.

Task 10. Customer Liaison.

Close liaison will be maintained with the customer during all three phases of the study effort.

Liaison is important during Phase I while the survey instrument is taking shape. During Phase II liaison will ensure continuity of thought and purpose.

[redacted] will be able to make presentations to the customer if required, to explain any phase of the program. STAT

In Phase III, close liaison with the customer will insure that any approved, applied research will be in a direction to produce the most useful data and support the recommendations stated in the study.

Task 11 Write Final Report.

[redacted] will write a Final Report, to be submitted after the formal work on the study is finished. STAT

The Final Report will contain the essence of the material in the monthly reports, the results of the survey, the reduced data, an explanation of the significance of the data, and the guidelines to make the data useful.

In addition, the results of all feasibility studies and experiments, and their significance will be included.

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SECTION V

TECHNICAL DISCUSSION

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TECHNICAL DISCUSSION

[redacted] engineers are already aware of some of the results the proposed study is designed to produce. This experience or understanding might be called "initial knowledge." Care must be exercised so it does not bias the data gathering effort, although it must be brought to bear at some point in the study or it would be wasted.

Phase I is structured to exclude "initial knowledge" bias. Then, after an unprejudiced effort has been made to accumulate all available data, the "initial knowledge" is incorporated into the Phase II data screening.

This Technical Discussion presents that "initial knowledge" concerning the loading, threading, transporting and flattening, and driving of film, as well as some discussion of film itself.

FILM LOADING

Loading and unloading film in a viewer or printer is often a tedious operation.

First, 40 lbs. or more of film must be lifted. Then the drive splines and supports must be adjusted to the proper width. After that, the splines must be removed or retracted. Finally, the splines must be engaged in the reel with one hand while the operator supports and guides the reel with the other.

Various solutions to these problems suggest themselves.

For instance, the reel locating points might be transferred from the equipment to the reels where they would act as a support while the drive member is engaged. Unfortunately, this might not be practical.

For one thing, there is the problem of existing hardware. Also, reels with extended pins would be more vulnerable to damage than in-use equipment. Storage and shipping would also be more difficult.

Solutions other than transferring the reel locating points have been attempted. For instance, other types of load mechanisms have been developed, such as:

Sliding members manually moved and locked.

Sliding members with detents manually moved and locked, or just detented.

One-side sliding member.

"Key skate" operated two side sliding members with fixed center.

Fixed adaptors added to make up the maximum dimension.

One-side loaders with a cantilevered shaft, with movable or detented shaft lock.

Reel-inserted shaft with drive members and lock.

The proposed study will produce operational data concerning these and other in-use methods as well as suggest new applications and methods.

FILM THREADING

Film threading is also an involved process.

After the reel of film is loaded, the free end must be manually threaded through the system to the take-up reel. There are automatic threaders, but most of them rely on sprocket wheels for advancing the film.

Light tables generally have the simplest threading mechanisms. The film is taken manually from the supply reel, over a roller at the feeder end of the table, over a second roller at the take-up end, thence to the take-up reel.

Slightly more complicated light tables involve split tables for stereo viewing. Between the tables a loop must be created to position the appropriate stereo frames under the microscopes. In these systems the film is taken manually from the supply reel, over a roller, across the first light table, and over another roller to a slack loop roller (or rollers). From there, the film is threaded through a similar assembly to the take-up reel. (See Fig. 1)

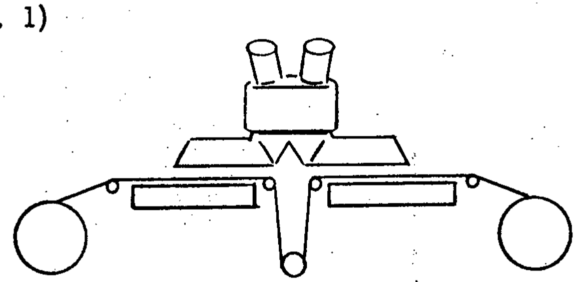

FIGURE 1

Film viewers can be as simple as a light table but are often considerably more complex, such as a scanning viewer (e.g. the Freon Gate VWFR, or VARISCAN) which involves capstans, dancing arm rollers, and reel torque motors.

In these more complex systems the film is manually pulled from the feeder roll through various rollers, around the capstan, and through more rollers to the take-up reel. (See Figure 2)

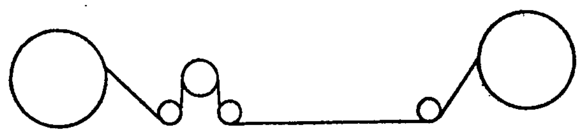

FIGURE 2

Innovative use of dancing rollers can simplify manual threading of viewers somewhat. The dancer is folded back so the film may be pushed straight through (See Fig. 3) and then is re-positioned, providing film wrap (See Fig. 4).

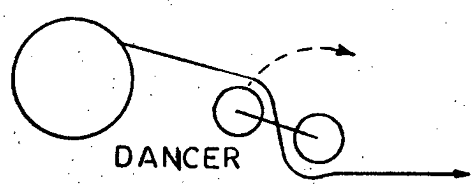

FIGURE 3

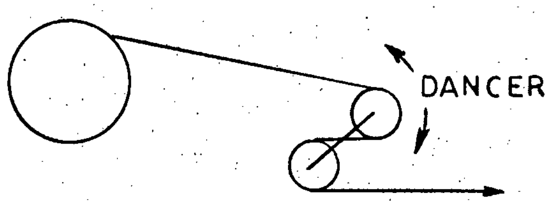

FIGURE 4

This folding dancing roller is a first step towards simplifying the film threading operation in these more complex viewers, although there is always room for improvement.

A German firm has used a similar idea in an 8mm sprocketed film projector. The film is threaded using the sprockets and brought into final position by a lever which snaps into position when tension is applied as the film attaches to the take-up reel.

Also, IBM has developed a magnetic tape automatic threader that uses rollers for rough alignment of the tape and a vacuum for drawing the tape into final alignment.

These developments or similar ones may prove applicable to roll film transport systems in viewers and printers but not without some study since, in viewers and printers, there are unique technical limitations not found in movie camera and magnetic tape applications. For example, viewers and printers are usually much larger and have structural limitations. Also, in printers two strips of film are involved.

FILM TRANSPORT

Besides the spool supports and drives with auxiliary equipment, film transport systems usually have a pair of rollers at the ends of the viewing area, light table proper, or film platen. When not clamped the film is suspended across the viewing area by these two rollers with more or less sag depending on the tension maintained on the film. It should be a simple matter to maintain sufficient tension so the amount of sag would be negligible. Often it is not, however, since the film must be supported and transported without appreciable stretching. Practical experience has demonstrated that in many cases the maximum permissible tension is not sufficient to hold the sag within the flatness requirements for optical viewing. This, together with the tendency of the film to curl upward at the edges, is the reason that the film is often clamped while being viewed. There are many cases, however, when clamping for optical viewing or projecting and unclamping for transport are inconvenient for the operator. Thus it would be useful to have some actual data on the amount of sag and curl for various widths and thicknesses of film when suspended over various lengths of span with specified amounts of tension. Data of this type should be rather easy to obtain, but apparently it has not previously been collected and organized in a manner appropriate to the rather large variety of cases which occur.

There might be a better technique than clamping for the cases where sag and/or curl with the simple suspension system are not within the desired limits of film flatness. Thus a means might be sought to produce partial film flattening in the viewing area without interfering with the viewing and, hopefully, without making solid mechanical contact with the film. There are at least two types of forces which conceivably might be useful in such film flattening: 1) electrostatic force, and 2) fluid (preferably air) pressure, possibly under dynamic (flow) conditions.

The problem of sag (but not that of curl) might be eliminated by suspending the film in a vertical plane over the viewing area, but there are many practical reasons for requiring a horizontal viewing area, hence only the latter will be considered here. For simplicity, only the emulsion-up situation will be discussed. Hence the curl will be in the direction of the edges turning upward. A means to provide downward forces along the edges of the film and upward pressure under the central viewing area of the film must be sought, both without mechanical contact and, at least in the latter case, without introducing anything which isn't transparent to visible light. A little experimenting shows that the magniture of these forces must be noticeably larger than the force which would be required merely to support the film against gravity but some study is needed to determine the actual values which these forces must have in order to produce the required degree of flattening.

A few simple computations indicate that electrostatic forces do not offer much in the way of potential usefulness. Thus: 5 mil cellulose acetate requires about 2.3×10^{-4} lb. (force)/sq. in. to support it against gravity. To provide this force by electric charge would require about 3.8×10^{-12} coulombs/mm^2 of surface charge, which would take an electric field in air of about 430 volts/mm. This is over 10% of the spark-over field for air. In other words, if the curl flattening forces were as much as 10 times the gravity support forces then the electrostatic field necessary would be sufficient for corona discharge in the air. Even if one felt inclined to use such large fields in the vicinity of film and/or humans it is doubtful that they could be obtained without the use of electrical conductors which are generally opaque to visible light. Thus it seems unlikely that any electrostatic film support systems will turn up during the study but, if such devices are found, they should be extremely interesting.

Potentialities for fluid support and flattening of the film do not appear so empty. 2.3×10^{-3} lb./in^2 of air pressure is practically nothing to achieve, although control may be a bit of a problem. First a non-contacting means to seal the edges is needed (assuming that two sides of the viewing area are sealed by the rollers). For the low pressure required here it appears that air knives along the edges might be sufficient. Thus a linear distribution of air bearings along both edges of the film is suggested (either above and below, or only above to conteract the upward curl force). Probably enough of the air flowing out of these bearings would pass between the film and the glass platen to provide the necessary support force under the central viewing area (in fact, it might be necessary to bleed off some of this air in order to not have too much pressure under the film), but if not, then such support pressure could be introduced separately.

Attaining the forces for partial flattening should be quite feasible, but controlling them properly might be another matter. It appears, in fact, that control of the pressures would need to be done so delicately that only a closed-loop type of control would be satisfactory. This would require developing a means for measuring the film elevation above the platten at the center of the viewing area. Perhaps a beam of collimated light directed transversely across the film so as to be partly above and partly below the median film plane could be utilized. Two photo detectors, one above and one below, could provide servo signals for the support pressure to maintain the film in the most nearly attainable flat surface. Study is needed to determine how flat the film could be maintained with such a system. It would appear that a fairly straight-forward study of the various forces as a problem in static equilibrium could be programmed for a digital computer. The output would be computations of the film surface configuration for various combinations of the variables: edge force, support pressure, length and width of fluid supported area, film tension, and film thickness, composition, etc. As an elaboration the feasibility of applying air jets to the most prominent bulges as a means of achieving greater flatness might be investigated. Such data as this, together with the required flatness for particular viewing conditions, would be helpful in estimating the value of various degrees of elaborateness in film support systems.

FILM FLATTENING

The required degree of film flatness (over the field of view, at least) would seem to be the same as the depth of focus for the optical system. The latter is often related to the size of the diffraction pattern for a diffraction limited system or to the size of

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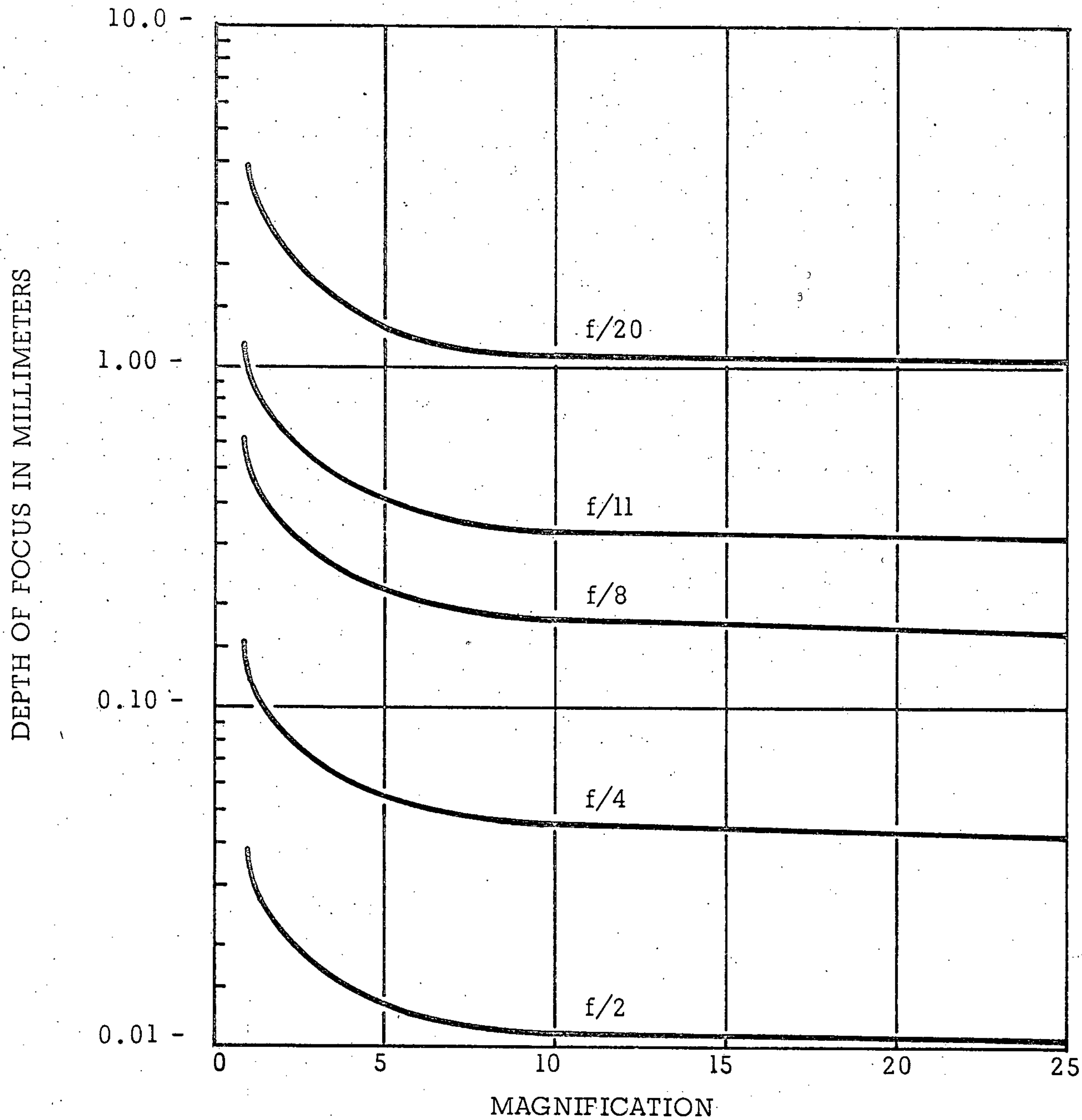
the circle of confusion for an aberrated system.* One can also consider the effect of focusing error on the modulation transfer function.** For this purpose one examines the magnitude of the quantity d/16 (f-number)^2, where d is twice the departure from "perfect" focus. It turns out that when this quantity is about one-fourth of a wavelength there is no noticeable change in the cutoff frequency but the modulation in the region of half of the cutoff frequency is dropped from about 40% to about 25%. If the same quantity is about one-half of a wavelength, however, the modulation at about half the cutoff frequency is dropped to zero - thus effectively halving the cutoff frequency. Thus one-quarter wavelength may be taken as a practical upper limit for the quantity defined above. The theory indicates that the f-number used in the defined quantity should be the <u>effective</u> f-number, which on the image side is (M + 1) times the nominal f-number (f/D), where M is the absolute value of the lateral magnification. For a viewer the corresponding value on the object side is of greater interest - hence the image side value should be divided by the longitudinal magnification, which is the square of the lateral magnification. The result of all this is plotted in Figure 5. During the proposed study these mathematical considerations would be applied to techniques uncovered when considering film flattening.

*Manual of Photogrammetry - page 90.
**Born and Wolf - Principles of Optics, pp 480-490



$$d = 2.4 \times 10^{-3} \left(\frac{M+1}{M}\right)^2 \left(\frac{f}{D}\right)^2$$

FIGURE 5: DEPTH OF FOCUS
vs
MAGNIFICATION

FILM DRIVES

In roll-film handling devices mechanisms are required to accommodate the film reels. These mechanisms provide a means for paying out or taking up film, and, in many cases, regulating the tension in the film.

Various means have been designed to accomplish these ends. In some cases, various film widths and reel diameters must be accommodated. In other cases the film is of fixed width and reel diameter but severe operating conditions are imposed upon the drive mechanism (such as in a film transport required to provide rapid random access to any frame).

A few of the film drive devices and systems which might be encountered in this study are discussed below.

DC or AC Constant Torque Reeling Systems are one of the simplest reeling systems available. They have been successfully used for a number of years in magnetic tape and film recording equipment as well as various types of cameras.

Power is usually supplied to the reel by an AC motor or DC motor with a series resistance inserted in the circuit to approximate constant current power source. Under these conditions a DC motor exhibits approximately constant torque regardless of speed and an AC motor can be made to behave in substantially the same manner. Generally the AC motors used in this type of device are specially-constructed units utilizing high resistance wound fields to limit the power dissipation of the motor which operates essentially under stall or semi-stall conditions.

Since the reel operates under constant torque conditions, the tension placed on the film is inversely proportional to the diameter of the film pack on the reel. Thus an auxiliary means of controlling the motion of the film (such as a capstan) is generally required.

This type of reeling mechanism is simple and inexpensive. Generally speaking, few relays and resistors are the only circuit elements required besides the motor itself. In many cases the motor shaft can be used to hold the film reel so an exceedingly simple electro-mechanical system results.

The disadvantages of this type of system are poor tension regulation and, because the motor is operating at near-stall, limited power obtainable without excessive heat generation. This type of system is best suited for light duty applications usually involving film of narrower widths where a relatively small amount of tension is required.

Eddy Current and Hysteresis Clutches and Motors will also probably be encountered in this study.

The Eddy Current Clutch is a variation of the Faraday or homopolar generator. It consists essentially of a rotating magnetic field proximous to a copper disc or cup. The motion of the magnetic field induces circulating currents in the copper part. These circulating currents produce a corresponding magnetic field in the copper part. If the copper part is rotatable it will attempt to follow the motion of the main rotating magnetic field. Thus a useable mechanical power output is obtained. The torque obtained is very nearly proportional to the strength of the magnetic field and to the difference between the rotational speeds of the rotating magnetic field and the movable copper part. If the magnetic field is produced by a wound coil it is possible to control the torque output of the device by varying the coil current. Since the copper disc or cup has no poles, the torque obtained from such a mechanism is completely free of any cogging or torque variations as a function of shaft position. Also, this type of device provides a well-damped dynamic characteristic and is suitable for situations requiring extremely delicate handling of the film.

One disadvantage of this type of drive is that a means for rotating the magnetic field is required. A relatively simple AC induction motor can be used. Also, power for the clutch can be derived from some other constantly rotating part in the film drive system. The efficiency of this type of drive is comparatively low although extremely high gain from the standpoint of the control voltage or current can be realized.

Hysteresis Clutches operate in a slightly different manner, but, generally speaking, have the same control characteristics. The driven rotating part is made from a ferrous material instead of copper and the induced magnetic field is caused by hysteresis of the iron material rather than by eddy currents. Hysteresis synchronous motors are often used as reeling devices in light duty applications. These motors consist of a wound stator with a relatively large number of magnetic poles very similar to that of a conventional AC induction motor. The rotor, however, is made from a cylindrical slug of steel containing a large percentage of cobalt which has a large-area hysteresis loop characteristic, and thus it is very easy for the stator to induce magnetic poles in the cylindrical structure. If the rotator is stalled or operating at less than synchronous speed, the energy required to move these magnetic poles within the rotor causes a torque output in the motor, thus making it useful for reeling applications. One interesting feature of this type of motor is that, if a direct current is applied to the motor winding (instead of the usual AC), the motor acts as an efficient dynamic brake. Thus the functions of reel driving and braking can be combined into a single unit.

DC or Constant Tension Reeling Systems are used when it is necessary or desirable to maintain constant tension in the film as it is wound or unwound from the reel. This can be accomplished by means of a proportional control system in which the torque applied by the reel drive motor is directly proportional to the radius of the film pack on the reel. This can be accomplished either by directly sensing the amount of film on the reel or by sensing the amount of tension in a storage loop in the film threading path. These two methods are discussed separately since each type of system offers its own advantages.

In Radius Sensing Systems the radius of the film on the reel can be directly sensed by a light radius arm and roller. It is usually possible to make this assembly light and small enough so the roller rides at the edge of the film, avoiding scratching the film

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in the viewing area. This system gives a direct measure of the amount of torque required to produce a constant tension in the film. Many alternate methods of radius sensing have been developed. One such is the photo-electric cell device which requires no mechanical contact with the film although, due to variable densities in the film, it is necessary to utilize somewhat more sophisticated error signal processing techniques in order to obtain a reliable control signal for the system.

One mistake commonly made in the design of radius sensing systems is the use of voltage sources to drive the reel motor. Under static conditions the current in the motor is a direct function of the voltage applied to the motor but, under dynamic conditions (that is, with the system in motion), the counter-emf generated by the motor either adds to or subtracts from the voltage applied to the motor. Thus, if a system generates a voltage applied to the motor proportionate to the radius of the film pack, the tension in the film strand will vary depending on the direction of motion of the motor. In order to maintain constant tension, therefore, it is necessary to use a controller which varies the current to the motor linearly with the radius of the film pack regardless of the motor speed.

In Tension Sensing Systems improved operating characteristics may be obtained by inserting a device in the film path which directly senses tension in the film. Tension sensing generally is accomplished by measuring the amount of film contained in a storage loop or festoon, arranged so the amount of film contained therein is a function of the tension in the system. Two commonly used devices for this are the spring-loaded dancer arm and the vacuum storage loop. In the former device a roller is loaded by a spring or torsion bar which has a linear spring rate. In the latter device the degree of force on the film is a function of the displacement of the film in the vacuum loop chamber. This type of system is a position servo loop and it is thus possible for the system to accommodate changes in tension caused by acceleration and deceleration of the film reels. Therein lies the principal advantage of tension sensing over radius sensing. The latter cannot accommodate the additional forces produced by accelerating or decelerating the reel. In many film transports, however, system accelerations are very low. Thus the additional complexity of the tension sensing system is warranted only in cases where rather good dynamic characteristics of film transport are required.

Besides reeling systems various means for controlling motion of the film in the film transport will be encountered in this study.

One of the simplest of these is by direct control of the power applied to the film reels. This type of system involves a minimal number of parts and provides a degree of control which is usually sufficient for positioning a given frame or location on the film at a particular point, as on a light table or measuring microscope. In many applications, such as in scanning or printing equipment, a closer degree of control is required because in a direct reel drive system the film velocity is dependent upon the amount of film on each of the reels in the system. While it is possible to sense the amount of film on each reel and compute a command velocity for the reel which is driving the system at that particular instant, this approach is usually somewhat complex from a control equipment standpoint and is often difficult to stabilize. Thus in film scanning or printing systems it is much more common to find some form of capstan drive which allows direct control of the film velocity with the reeling system serving only as the pay-out, take-up, and tensioning elements. Except in the case of a system using sprocketed film these capstan drives depend on drive friction between the film and the capstan roller for the required traction to control the film movement. This friction is found by the formula $F=E\mu\theta$, which shows the wrap to be as important as the coefficient of friction μ. Many means for increasing this traction have been developed, such as making the capstan from materials with a high coefficient of friction, using pinch rollers to force a high unit pressure on the capstan (thereby increasing its traction), and using vacuum manifold systems in which the film is clamped to the capstan by atmospheric pressure. Each of these systems offers advantages and disadvantages.

The use of a rubber capstan tire offers little damage to the film, but there is a practical limit to the amount of traction that can be obtained. Use of a pinch roller provides more traction but has the disadvantage that any dirt or dust in the film drive system may be ground into the film. The vacuum system utilizes a capstan perforated with small holes coupled to a suction system. It offers high traction with minimal film damage but tends in practice to be rather complicated mechanically to implement. Also these vacuum systems are generally quite noisy, an important objection where a large number of machines are co-located, or a high degree of concentration is required on the part of the operator. Nevertheless the vacuum capstan exhibits superb control characteristics entirely free from difficulties caused by air entrapment by the film which plagues the rubber tire capstan and, to a lesser extent, the pinch roller at high film transport speeds. Thus it is often used in automatic film handling systems.

Film Guiding and Registration is as important a consideration as control of film motion.

In many applications the transverse position of the film is as important as the longitudinal. This is particularly true in automated equipment making use of machine-readable coded information on the film. Effective means of guiding the film as it passes through the film transport have been developed, such as flanged rollers, guide shoes, slot guides, and other devices. Since the compliance of film varies with width, thickness, base material, and, to a certain degree, emulsion, it has been found that many different types of guiding devices are required for various film types and sizes. For example, narrow thin films can be considered more or less an elastic belt which can be guided by means of crowned rollers and shoes placed so that the edge of the film rides against them. Wide, thick film, on the other hand, tends to approximate an inelastic band and therefore an entirely different guiding technique is required. Generally speaking, the wider the film, the more difficult it is to use any sort of guiding system which relies on contact with the edge of the film; the film will simply ride up on the guide until the edge is damaged. Guiding of wide films is generally accomplished by alignment of the rollers and reels in the system to provide the proper film motion.

In any event, these film drive considerations are important when discussing film transport methods in viewers and printers.

FILM

Handling, tracking and slewing of film by equipment such as viewers, printers, light tables, etc., often degrades the emulsion or the base of film. In general, these degradations may be put into three categories: 1) dimensional changes, 2) physical damage to emulsion or base, and 3) dirt.

Dimensional changes are usually caused by the handling equipment applying undue stress, generally in the longitudinal direction. Ambient conditions such as relative humidity and temperature, and the condition of the film emulsion and base also contribute. Polyester base materials are less vulnerable to such stresses than triacetate base materials. In the case of triacetate materials moisture remaining in the emulsion or base after processing has considerable importance.

Dimensional changes are generally eliminated or minimized by proper engineering of the film handling equipment so no undue stress or tension is applied during operation. Proper engineering should insure minimum film to equipment surface contact. It is usually impossible to run film through any kind of equipment without touching at least the base and at times the emulsion. Even in a mechanical system completely devoid of rollers contacting the film, simply pulling the film from a roll and rolling it up again can cause some damage to the emulsion either by scraping it against the base, or by scraping it against captured foreign material within the roll.

Physical damage to emulsion or base is usually caused by contact with equipment surfaces. To minimize such damage, devices are often provided with free rolling parts wherever contact with the emulsion or base is necessary. In addition, these parts are generally constructed of low friction materials with smooth finishes. The scratching of films can also be caused by foreign particles within the equipment. At times such particles are pieces of the film or emulsion particles left after previous damage. Generally cleaning, continuous brushing, and air-blowing vacuum and/or anti-static systems are required to control the incidence of foreign particles.

Dirt is generally caused by ambient conditions and by past maintenance. Dirt on the film can be transferred to part of the equipment and re-transferred to another portion of the film later during operation. In addition, dirt can be transferred from one part to another of the film by contact during rolling up.

In addition to degradations, some of the characteristics of aerial films will require study. Some of those characteristics are already well documented.

Aerial films are manufactured basically for three functions: camera negative, duplicating, and color recording (including infrared Ektachrome). These films come in various widths from 70mm through 9-1/2 inch, and in various lengths from cut chip to several thousand feet. Aerial films are coated on two types of bases, polyester and triacetate, in base thicknesses from 2-1/2 through about 5-1/2 mils. Some of them have a clear or dyed gelatin coating on the base, while others have a static resistant or other type of backing. Scratching or abrading of film is essentially independent of film thickness, considering the gel back. Differences in base materials and thicknesses, however, effect dimensional stability. Polyester base resists stress far more than triacetate. Thicker bases will resist stress more than thinner bases. The ultra thin base film (1-1/2 mils)known colloquially as "Saran Wrap" is extremely difficult to handle and is a problem within itself usually requiring special equipment. In either case, caution must be taken in the design of equipment so the film will

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not be folded or rolled over upon itself during transportation. Film roll length effects the design of handling and printing equipment. A longer length of film is much heavier than a short length of film at any width, giving rise to the difficulties discussed earlier under Film Drives.

The following "basic film series" is a suggested cross-section of representative film types that should be considered in Phase II data screening. (See Figure 6.)

In addition to degradations and types of film, there are physical conditions of the film to be considered.

Film behavior varies with moisture content. At low relative humidities curl, shrinkage and brittleness are important. Curl interferes with smooth handling of film in a roll and brittleness could cause damage to the emulsion while the film is being handled. At high humidities softening of gelatin could cause breakdown of film imagery while the film is being handled. Ideally, films should be conditioned for a period of time subsequent to processing, in the ambient condition under which the film will be viewed. It might take a prohibitive length of time to obtain a constant moisture content gradient. Therefore, a practical balance between time needed for curing and operational requirements might be sought.

Temperature and relative humidity conditions might be experimentally controlled to determine their effect on film during

Film Type	Film No.	Base Type	Mean Base Thickness in Mils	Backing	Emulsion Thickness in Mils	Backing Thickness in Mils
Plus X Aerographic	2401	ESTAR	4	Clear Gel	0.30	0.26
Tri X Aerographic	2403	ESTAR	4	None	0.51	None
Fine Grain Aerial Duplicating	2430	ESTAR	4	None	0.15	None
Ektachrome Aero	8442	Triacetate	5.2		0.85	None
Aerial Duplicating Film	SO-122	ESTAR	2.5	Clear Gel	0.24	0.14

FIGURE 6: BASIC FILM SERIES

equipment operation. Figure 7 shows examples of the moisture gradients during the conditioning process at a particular temperature and relative humidity for triacetate and ESTAR base films.

Film strength, or tensile stress/strain properties, are also important. These tensile properties are closely related to flexural properties because film is subjected to flexing forces every time it goes over a roller.

Tensile properties are usually measured by the American Society for Testing Materials procedure D882-56T, "Tensile Properties of Thin Plastic Sheets and Films," and D1530-58T, "Tensile Modulus of Elasticity of Thin Plastic Sheeting." Typical tensile properties of Kodak aerial film are shown in Figure 8. It is rare that film handling equipment would put sufficient stress on film to cause visible stretching or tearing, but any stress put on the film must be kept below the yield point (a point not visually determinable), or film elasticity will be lost, and elongation or distortion will be permanent. Further strain on the film will break it. Figure 9 shows a curve from which the data in Figure 8 was taken. The yield point of aerial material varies between 35 and 70 pounds per inch of width, values significantly higher than the usual forces encountered in film handling equipment. Some continuous printers, however, may cause undue stress on film materials. The tensile forces associated with all film handling equipment encountered in this study will be considered.

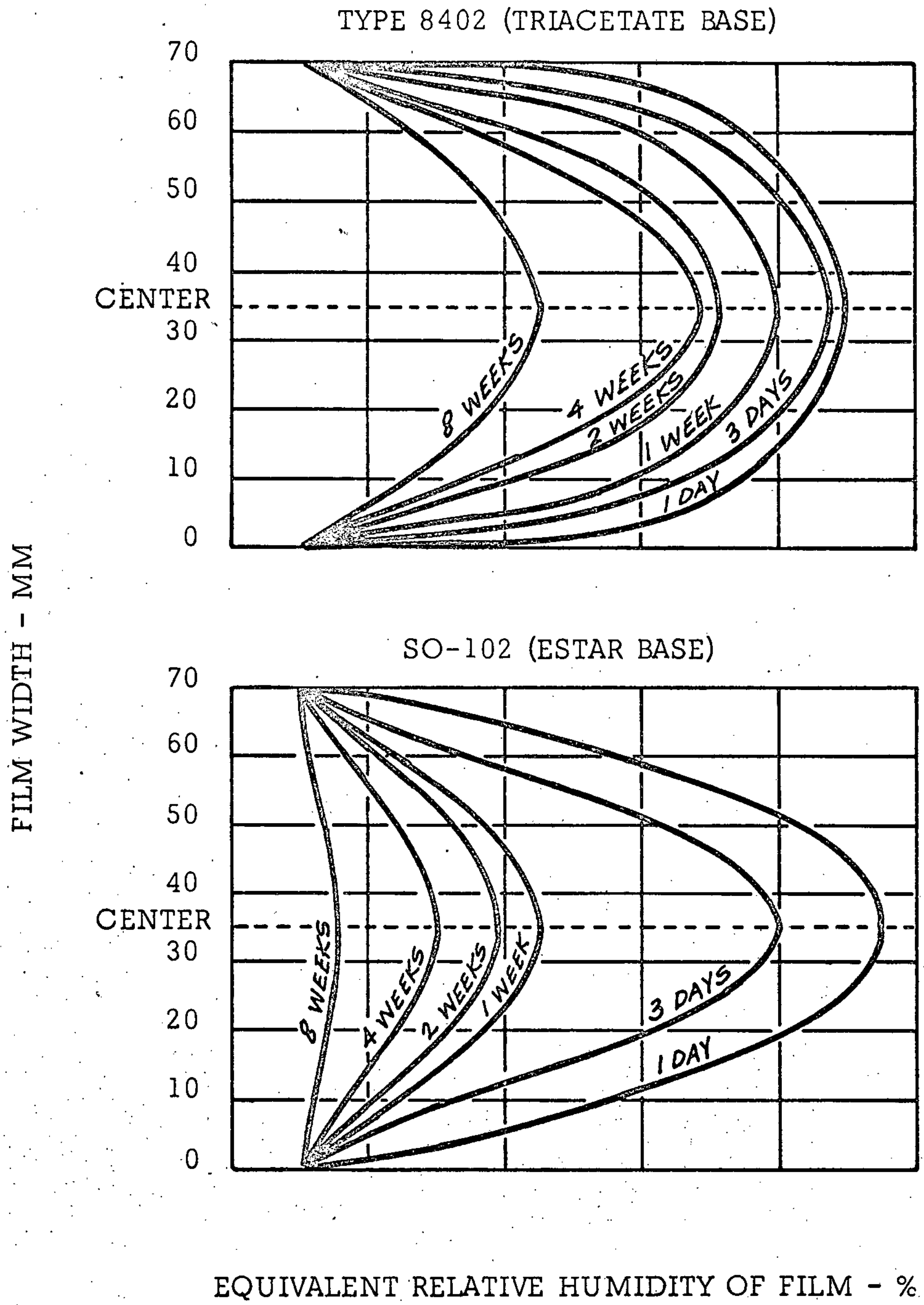

FIGURE 7: MOISTURE GRADIENTS

(All properties measured at 70 °F, 50% R. H. according to ASTM D882-56T, Method A)

FILM PRODUCT	Kodak Plus-X Aerographic Film, Type 5401		Kodak Plus-X Aerecon Film (Thin Base), Type 8402		Kodak Experimental Plus-X Aerial Film (Estar Thin Base), SO-102
TYPE OF BASE	Cellulose Acetate-Butyrate		Cellulose Triacetate		Estar Polyester
DIRECTION OF TEST	Length	Width	Length	Width	*
Yield Strength, psi	9,000	8,600	11,700	10,000	13,500
Yield Elongation, %	5.0	5.0	4.0	4.0	5.5
Break Strength, psi	9,800	9,000	15,700	13,000	25,600
Break Elongation, %	40	45	35	40	115
Toughness, in. lb./cu. in.	3,500	3,500	4,500	4,000	21,500
Young's Modulus, 10^5 psi	4.3	4.3	6.1	5.3	6.8

* The tensile properties of Estar base films are similar in all directions of the sheet; the small differences which may exist are not always between the length and width directions.

FIGURE 8: TYPICAL TENSILE PROPERTIES OF AERIAL FILMS

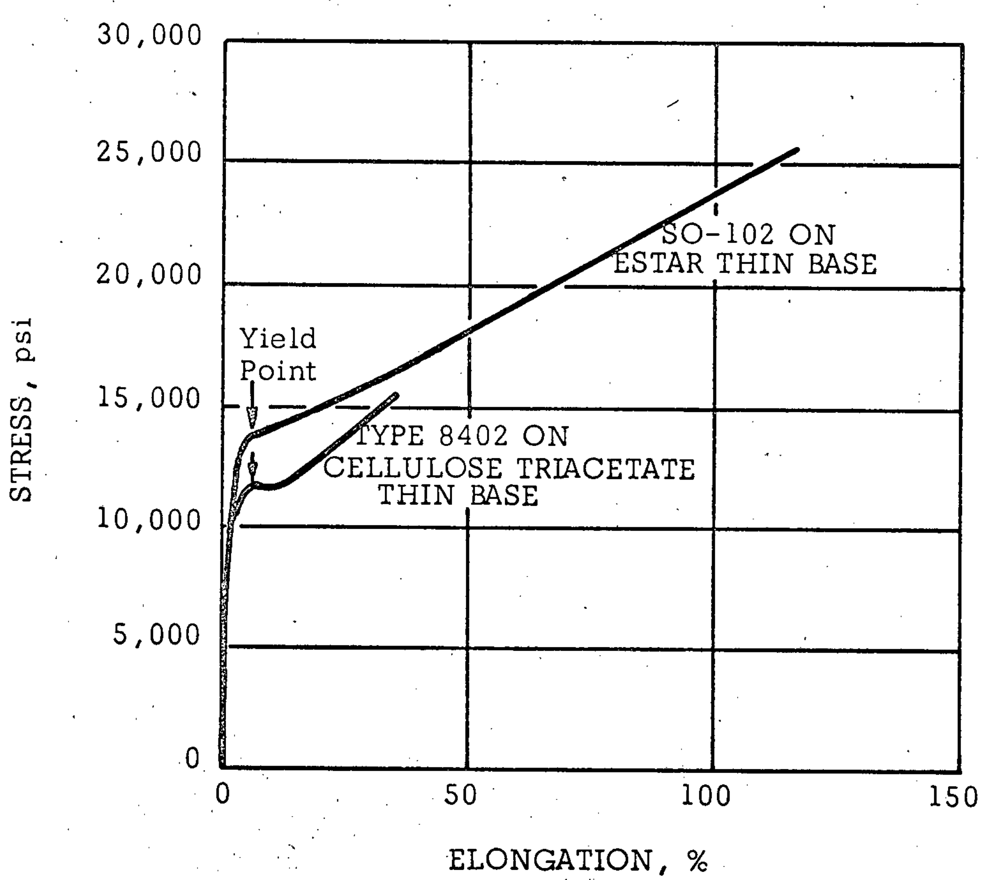

FIGURE 9: TYPICAL TENSILE STRESS-STRAIN CURVES

Tensile properties of film are quite dependent upon ambient conditions. Figures 10 and 11 show the effect of relative humidity and temperature on the tensile properties of three base materials.

Tear strength of film is also important. Tear strength usually is considered a strength for tear initiation and strength for tear propagation. These can be evaluated by the standard ASTM test method "Tear Resistance for Plastic Film and Sheeting," D1004-59T. Figure 12 shows typical tear values of Kodak Aerial films of different base thicknesses.

Another film condition is brittleness, which becomes a serious problem at low relative humidities and temperatures. In practical operating conditions it is not expected that temperatures will be too low, but low humidity conditions may occur in certain laboratories. Generally, brittleness does not cause the film to break but does damage the emulsion.

Film curl is caused by difference in humidity expansion between emulsion and the base support. Film is composed of a hydrophylic gelatin layer on top of an essentially hydrophobic film support. At extremely high relative humidity mechanical equilibrium is approached between the two layers. However, at normal or lower relative humidities the emulsion experiences a far greater dimensional contraction than the support. This causes the emulsion to pull the base into a curl.

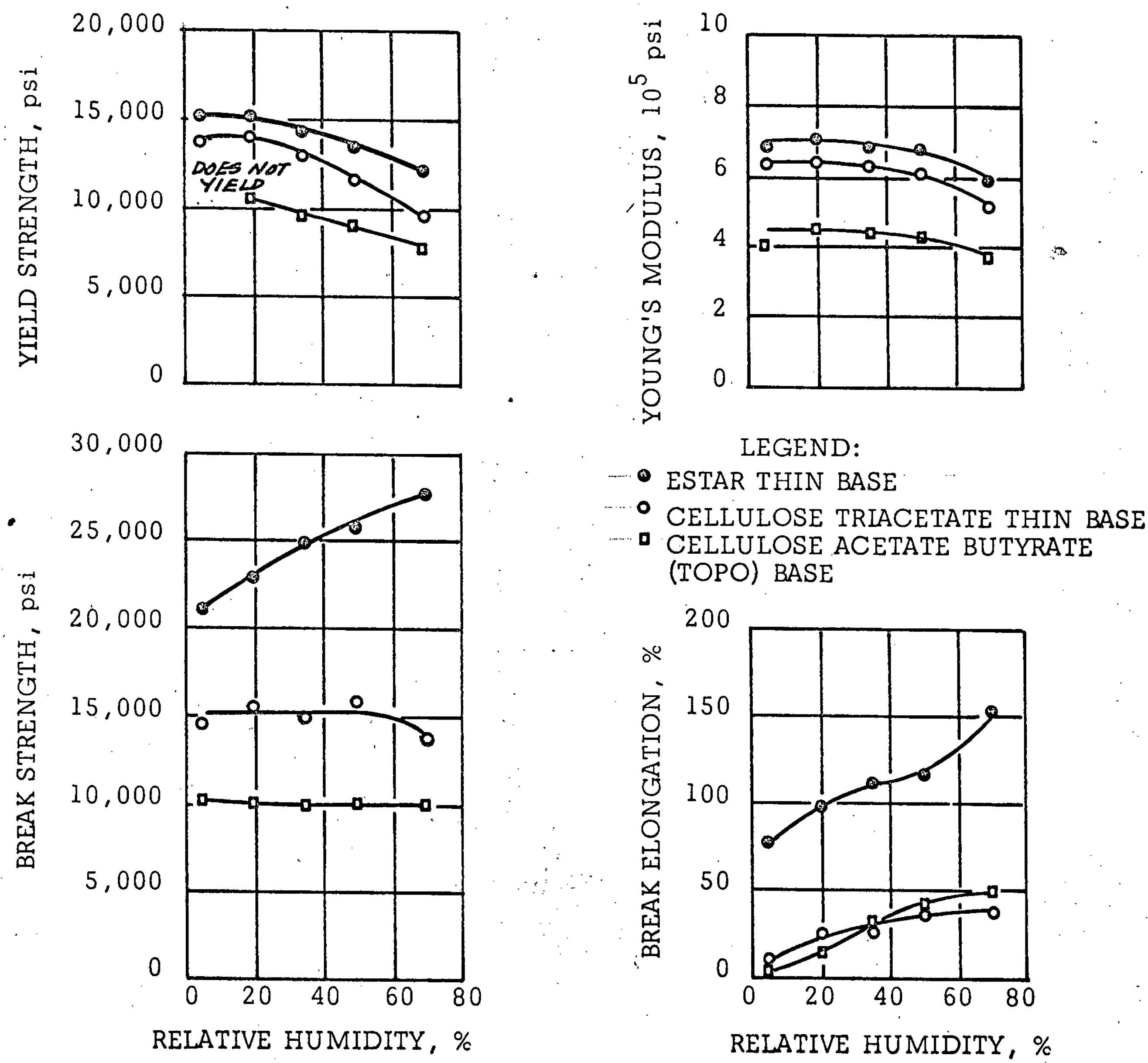

FIGURE 10: EFFECT OF RELATIVE HUMIDITY ON TENSILE PROPERTIES OF FILM

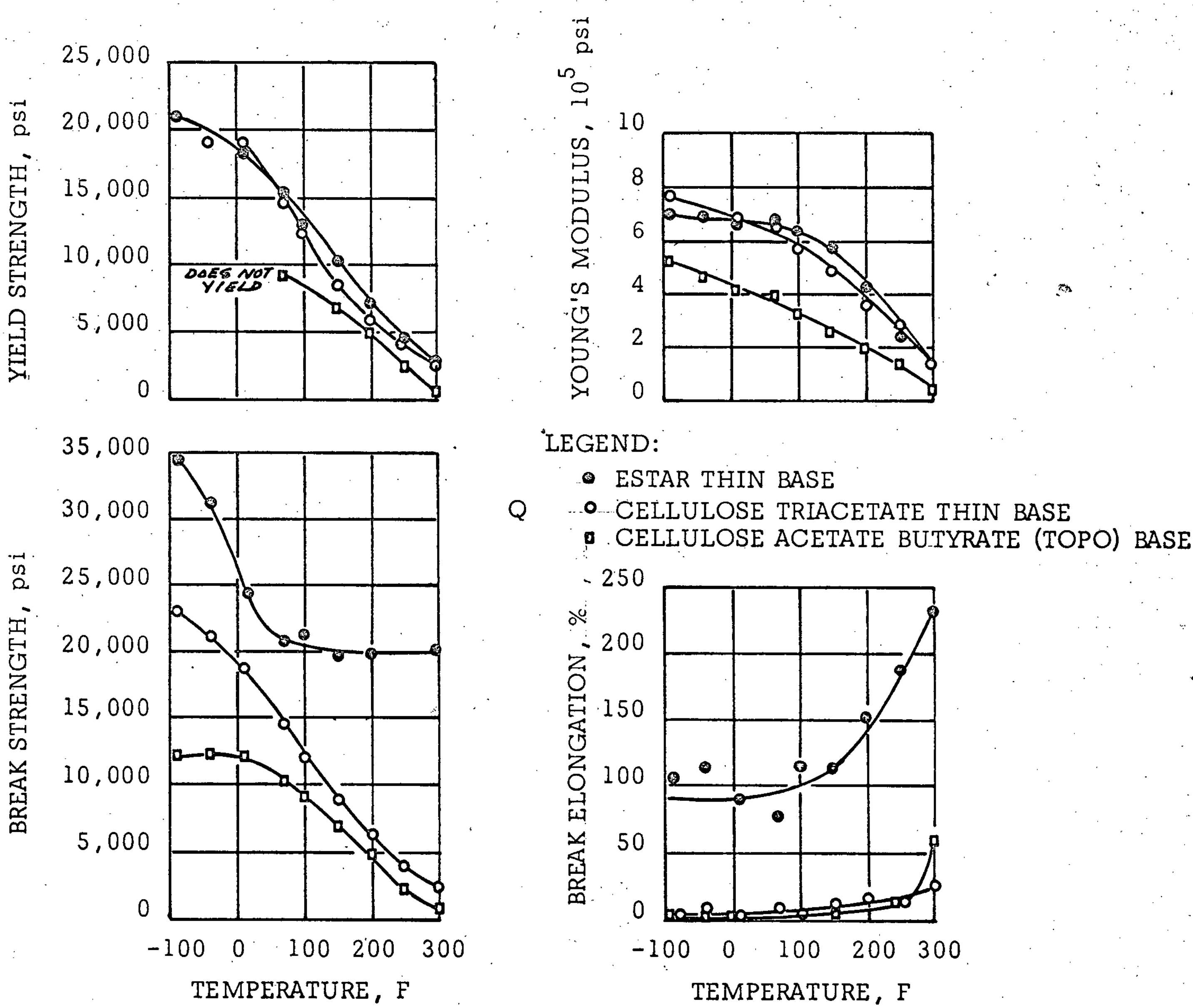

FIGURE 11: EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF FILM

TYPICAL TEAR VALUES OF KODAK AERIAL FILMS
(All properties measured at 70° F, 50% R.H.)

Film	Film Support	Nominal Support Thickness, Inches	Tear Strength, Lbs. Graves Tear*	Tear Strength, Lbs. Propagation**
Kodak Plus-X Aerecon Film (Thin Base), Type 8402	Cellulose Triacetate	.00275	6	.04
Kodak Plus-X Aerographic Film, Type 5401	Cellulose Acetate-Butyrate	.0052	8	.10
Kodak Plus-X Aerecon Film, Type 8401..................	Cellulose Triacetate	.0052	8	.10
Kodak Experimental Plus-X Aerial Film (Estar Thin Base), SO-102....................	Estar Polyester	.0025	12	.16
Kodak Experimental Plus-X Aerographic Film (Estar Base), SO-135....................	Estar Polyester	.0040	16	.19
Kodak Experimental Duplicating Film (Estar Thick Base), SO-117....................	Estar Polyester	.0070	32	.47

* = ASTM Method D1004-59T. ** = Tongue Tear Test.

FIGURE 12: TYPICAL TEAR VALUES OF KODAK AERIAL FILM

Curl can cause several problems, such as undue friction in types of equipment in which the curl direction is opposite to the intended film placement.

Films also have surface properties. Figure 13 illustrates the scratch resistances of unprocessed films. Generally scratch resistance is higher for film bases than emulsions. However, some films have a gel back coated base which lowers its resistance. It appears that there is no consistent difference in scratch resistance between unprocessed and processed film although there are indications that scratch resistance in processed films is affected by processing conditions. Scratch resistance is lowered as the relative humidity is raised, as shown by Figure 14.

Scratches are caused when the emulsion of base contacts the equipment or when dirt and dust particles infiltrate the film laps.

Emulsion scratches remove part of the imagery which destroys information. Scratches in the base can be as destructive. Obliteration of image information can easily occur due to light diffraction or scattering from base scratches.

Frictional forces must also be considered when examining film handling equipment. Drive rollers will have a higher film roller surface friction than idler rollers. Printers will employ friction in making good contact between negative and printing material

Surface	Scratch Resistance, Grams
Plus-X Aerial Emulsions (Types 5401, 8401, 8402, SO-102, SO-135)	5 - 15
Panatomic X Aerial Emulsions (SO-130, SO-136)	12 - 15
High Definition Aerial Emulsions (SO-132, SO-137)	6 - 15
Duplicating Aerial Emulsion (SO-117)	20
Gelatin Backings	4 - 18
Cellulose Ester Supports	12

FIGURE 13: SCRATCH RESISTANCE OF UNPROCESSED AERIAL FILMS

EFFECT OF RELATIVE HUMIDITY ON SCRATCH RESISTANCE OF UNPROCESSED KODAK PLUS-X AERECON FILM (THIN BASE), TYPE 8402. Measurements made at 70 F using 3-mil radius sapphire point. Scratch resistance is load required to produce a visible scratch.

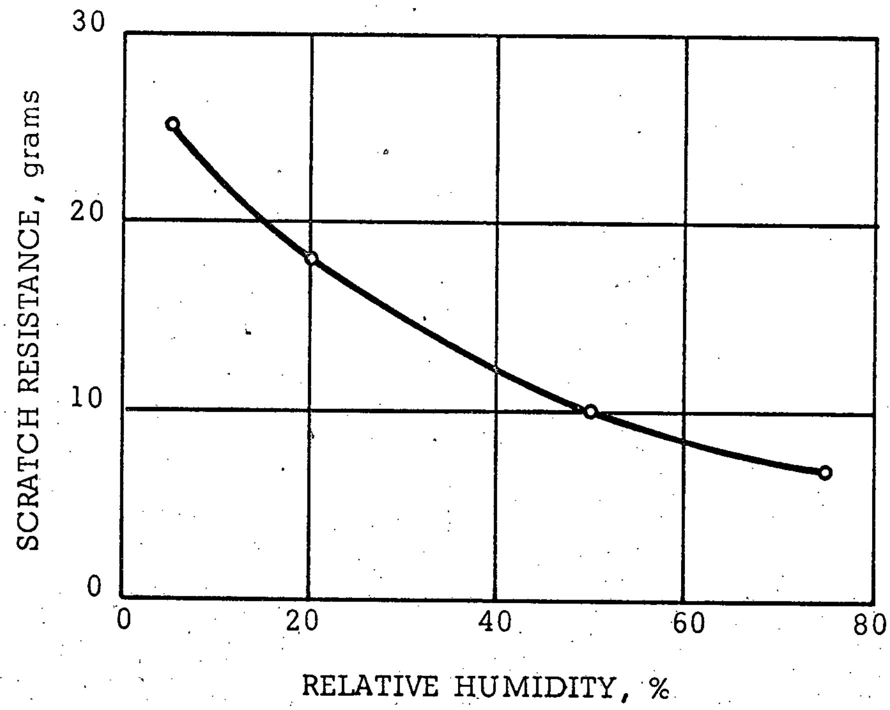

FIGURE 14: EFFECT OF RELATIVE HUMIDITY ON SCRATCH RESISTANCE OF AERIAL FILM

at the exposing surface. The difficulty is compounded when in the case of a continuous printer, contact must be made while the film is moving. It is of vital importance that any contact between two films while the films are moving have no relative motions between the two films.

Under certain conditions, friction between the film and other materials can cause a static charge buildup. Film is a poor conductor and will retain this charge. Examples of causes of static charge are slippage of film on itself, drag of film against the roller edge guides or pressure backs, and transfer of charge from other non-conductive charge-holding materials. Static charge attracts dust and dirt and can fog film by exposing static marks during operation in a printer. It is usually eliminated by static discharge instrumentation.

CONCLUSION

The preceeding discussion of film loading, threading, transporting and flattening, and driving, as well as film itself respresents some of the "initial knowledge" with which [redacted] would begin the proposed study. STAT

This knowledge will be of use in guiding the Phase I survey effort, but will not be allowed to bias it. During Phase II the "initial knowledge" will be incorporated into the over-all data screening proceedings.

APPENDICES

APPENDIX A - PERSONNEL

The scientists, engineers, and technicians [redacted] STAT
[redacted] STAT
comprise an experienced and technically diversified group. [redacted] staff members have made significant contributions to the fields of mechanics, electronics, physics, nucleonics, and photographic engineering. Experienced engineering administrators form a vigorous management team that maintains maximum program effectiveness. STAT

Engineering capability is maintained through contacts with consultants, scientific associations, and college programs. In addition, an education refund program supported by [redacted] STAT
[redacted] provides an opportunity for personnel to increase their professional knowledge under financial sponsorship of the company. STAT

Resumes of engineering managers and key technical personnel are included on the following pages.

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APPENDIX B

Manufacturing Facilities

Available during the experimentation effort is the [redacted] shop. This STAT
shop has facilities for doing precision work in metal and other materials. In addition to the usual lathes and mills there are precision grinding and lapping machines, and heliarc and gas welding equipment.

[redacted] has a complete quality control section, with instrumentation STAT
necessary for the precision work being done.

In addition, [redacted] has facilities for optical alignment and highly STAT
precise measurements. To insure precision, temperature controlled areas are used when indicated.

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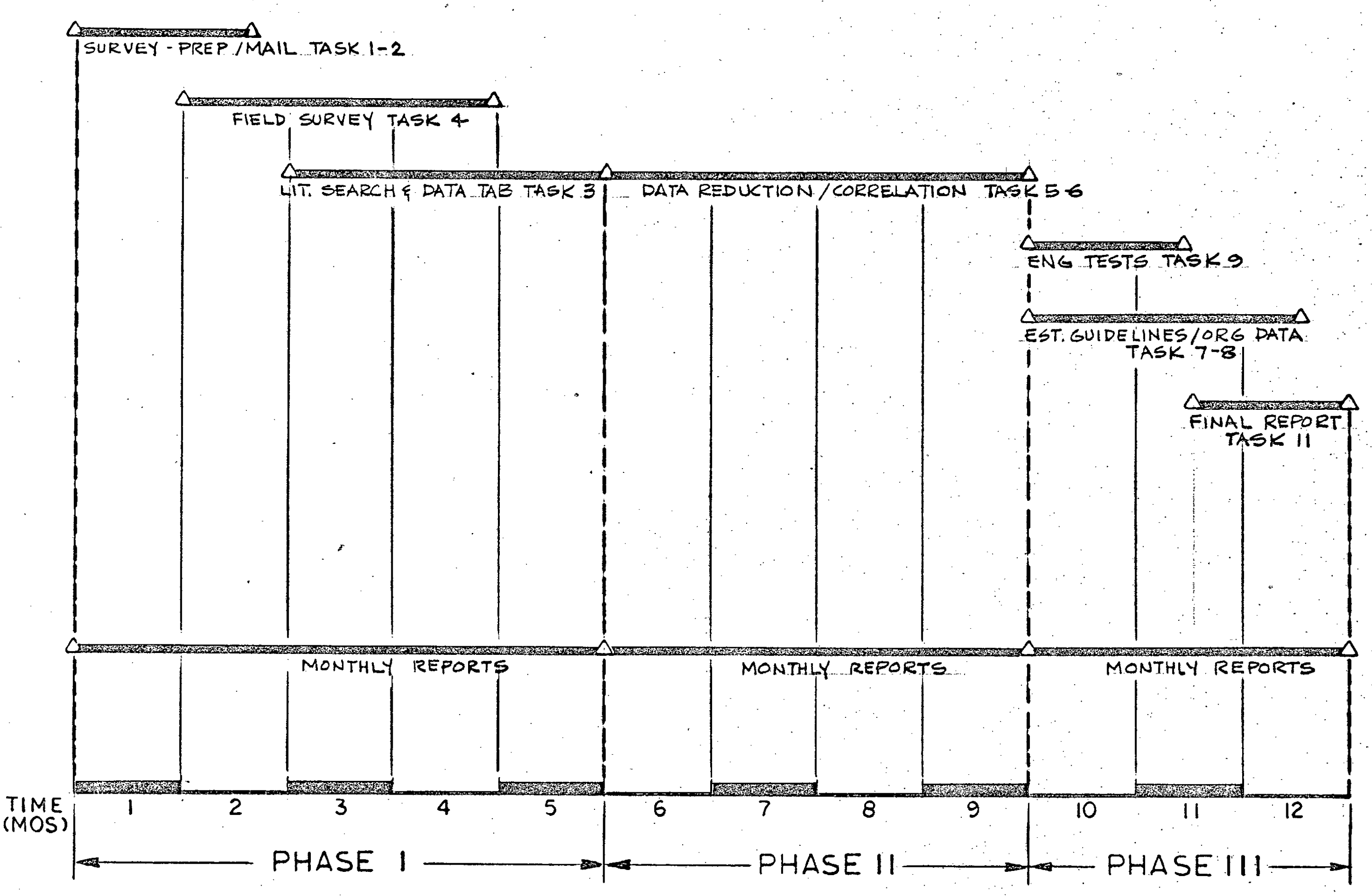
PROGRAM SCHEDULE
AUTOMATED FILM TRANSPORT STUDY
IN-1009



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