NCAR-TN-44

Balloon Strain Relief System

A research program conducted for the
National Center for Atmospheric Research
by the Engineering Systems Division
of Raven Industries, Inc.
Sioux Falls, South Dakota

September 1969

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
Boulder, Colorado

PREFACE

This report was prepared for the NCAR Scientific Balloon Facility as one of a continuing series of research and development projects undertaken to extend the capabilities of scientific ballooning. The work was performed under subcontract by Raven Industries, Inc. (Raven Report No. 0368).

SUMMARY

A balloon strain relief system for use during pre-launch activities was developed and its effect on balloon tensile strength was examined. The system consists of inflatable clamps which surround a portion of the balloon below the inflated bubble and thus relieve the strain on the lower portion of the balloon. Various clamp materials and balloons and tensile test specimens from the balloons were laboratory tested. Such a restraint system was deemed feasible if a limited localized loss in film tensile strength could be tolerated.

CONTENTS

TABLES

FIGURES

INTRODUCTION

The work reported here was funded by the National Aeronautics and Space Administration under Prime Contract No. NASr-185, and performed for the National Center for Atmospheric Research under subcontract No. NCAR 44-67.

Objective of the project was to develop a device to be clamped around a balloon below the bubble during inflation to restrain buoyant tension without damage to the balloon.

A satisfactory device would allow the bubble to be inflated without extending the balloon full length, thus permitting layout direction and time of payload attachment to be independent of inflation.

PHASE I STUDY

The objectives of the Phase I program were to conduct a literature search for information applicable to a balloon strain relief system, to investigate static coefficients of friction between balloon films and candidate balloon clamp pad materials, to investigate balloon damage criteria, and finally, to review the clamping problem and propose a solution to it.

LITERATURE SEARCH

The literature search disclosed a limited amount of information applicable to a balloon strain relief system. The available information pertained primarily to damage criteria and frictional properties for balloon film. Reference to the information obtained from the literature search is made where applicable and the references are listed at the end of this report.

DETERMINATION OF COEFFICIENTS OF FRICTION

Since the anticipated balloon restraint device will "clamp" the balloon film, the coefficients of friction for balloon films and candidate clamp materials were primary considerations for determining the feasibility of such a device. The information for coefficients of friction for balloon films disclosed in the literature search (Refs. 1 and 2) was limited to a study by General Mills, Inc., for balloon film on film only, and only for a low contact pressure. The friction tests were conducted at both room temperature and -50°C. Test results indicated that unlubricated polyethylene exhibited essentially no difference in the static coefficient of friction for the two test temperatures at a contact pressure of 0.2 psi.

To obtain the additional friction information necessary for a feasibility study and for design of a balloon restraint clamp, an investigation of the basic coefficients of friction was conducted. A schematic representation of the apparatus used to determine the static coefficients of friction is illustrated in Fig. 1. Test specimens were attached to the upper surface of the moving carriage and the lower surface of the metal sled. The two contacting surfaces were closely machined and polished, and a layer of 1/8 in. foam rubber was wrapped around the sled before the film was attached to allow intimate contact between the two surfaces. The weighted sled provided the normal test load. Contact pressure was changed merely by changing the weight on the sled. Motion was obtained by pulling the moving carriage. The sled was prevented from moving by a cord attached to the load cell that was used to measure the frictional force.

Several parameters influence the static coefficient of friction (Ref. 1). Among these are time of contact, contact pressure, ambient temperature, and surface contaminants or lubricants. Friction test conditions were limited as follows:

1. The time of contact was limited to ~10 sec prior to application of the pulling force.
2. Contact pressures were limited to ~1 to 13 psi.
3. Friction tests were conducted at room temperature (~25°C).
4. Sample materials were kept as free from contaminants as possible during the dry friction tests. For tests with lubricated balloon film, polyethylene powder was used as the lubricant for polyethylene film, and cornstarch as the lubricant for Mylar and scrim Mylar.

The results of the dry static coefficient of friction tests are presented in Table 1. The given values are averages of readings taken for at least three samples of the same material. Multiple samples were used to minimize the effect of possible sample contamination. The data are for film on film, for film on candidate clamp pad material, and for various contact pressures.

The balloon films tested for both dry and lubricated friction were polyethylene, Mylar, and scrim Mylar; the candidate clamp pad materials tested were butyl coated nylon (both sides), neoprene coated nylon (both sides), and neoprene coated nylon (one side only). The surfaces of the butyl coated nylon and neoprene coated nylon were not completely smooth; slight impressions from the weave of the nylon base material were visible. The neoprene coating was softer on the nylon with one side coated; only very slight impressions from the nylon weave showed on the neoprene surface.

The dry static coefficient of friction for Mylar changed little between 1.3 and 3 psi contact pressure, but increased substantially from 0.25 at 3 psi to 0.37 at 13 psi contact pressure.

The dry static coefficient of friction for scrim Mylar increased from 0.25 at 1.3 psi contact pressure to 0.48 at 13 psi contact pressure for the rough (dacron) side sliding on a rough side. Similarly, for a smooth (Mylar) side sliding on a smooth side the coefficient increased from 0.28 to 0.47 for the same contact pressures.

The dry friction test results indicated no appreciable change in the static coefficient of friction for polyethylene on poloyethylene when the contact pressure was changed from 1 to 13 psi. The static coefficient of friction averaged between 0.50 and 0.53 for the test conditions.

In summary, the dry friction test data indicated that when the contact pressure was increased from 1 to 13 psi, there was some increase in the film-to-like-film coefficient of friction for Mylar and scrim Mylar, but no appreciable change for the polyethylene.

The results of the static coefficient of friction tests for balloon film lubricated with polyethylene powder and cornstarch are presented in Table 2. It should be noted that the static coefficient of friction varied considerably with the amount of lubrication present. The coefficient of friction was lowest with some optimum amount of lubricant, but was higher if the amount of lubricant present were more or less than this. The given values represent the range of friction obtained by varying the amount of lubrication.

The friction data for lubricated Mylar and polyethylene balloon film indicate that the static coefficient of friction is substantially reduced by cornstarch and polyethylene powder lubricants for both film-to-film and film-to-clamp pad material.

BALLOON DAMAGE CONSIDERATIONS

An additional consideration was the possible damage to the balloon film resulting from clamping. The literature search disclosed information pertaining to balloon damage criteria from two research studies performed by General Mills, Inc. One study was undertaken to determine the effect of manmade creases on the tensile properties of Mylar and polyethylene, and the other study was made to determine the effect of pre-stressing on the tensile properties of polyethylene.

Work by General Mills, Inc. (Ref. 1) indicated that creasing Mylar and polyethylene at pressures of ~5 psi for 7 and 14 days, respectively, did not appreciably change the tensile strength of the balloon film in the machine direction. The reference report stated "only a token number of specimens broke at the crease." Although test specimens for the crease study were creased for longer periods of time than would be required for the balloon clamp application, the results are considered of value.

Since higher clamping pressures normally allow use of smaller clamping areas, the effect of creasing balloon film at higher pressures was investigated. Samples of 0.75 mil polyethylene, 0.75 mil Mylar, and scrim Mylar (0.5 mil Mylar on 0.6 oz/sq yd leno weave dacron scrim) were cut to 1 × 8 in. size in both the machine and transverse directions. Three different sample configurations were tested for each material: a creased configuration, a pressed configuration, and an untouched (control) configuration. The first (creased configuration) was creased at room temperature at right angles to the long edge between a flat, smooth 1 × 7 in. steel bar surface and a flat, smooth granite slab at ~15 psi. The second (pressed configuration) was pressed between the steel bar and granite slab but without a crease. After the samples were creased or pressed for 3 hr they were tensile tested with the untouched (control) samples.

The tensile test investigations were conducted at ~25 °C (room temperature) and at -60°C. The elongation rates were 18 in./min for polyethylene, 0.2 in./min for Mylar, and 2 in./min at room temperature and 0.2 in./min at -60°C for scrim Mylar. Three specimens were tested for each material and sample configuration at each condition. A summary of the tensile test results is presented in Table 3 for creased Mylar, polyethylene, and scrim Mylar.

For the polyethylene, test data indicate that creased sample strengths were generally at least as great as pressed sample strengths, and that the creases produced under these particular conditions did not appreciably lower the ultimate and yield strengths of the material tested. In fact, the tensile test data for -60°C indicate that pressing and/or creasing the samples may even have increased the yield and ultimate strengths over that of the untouched samples.

Test data for the scrim Mylar at -60°C were incomplete because not all samples in the transverse direction had been cut with the same number of threads. However, data at -60°C indicate a possible loss in yield and ultimate strengths in the machine direction. The test data at room temperature indicate no appreciable loss in yield or ultimate strengths for creased scrim Mylar. It appears that handling and possible contact with dust may have more to do with some of the losses of strength than creasing, since the pressed sample indicated approximately the same strength loss as the creased sample.

The crease test data for Mylar indicate a possible loss in ultimate strength for the creased samples for the room temperature tensile test. However, since the pressed samples showed a similar deviation in strength from the untouched samples, the ultimate strength loss may rather be a matter of exposure of both creased and pressed samples to dust, which could have been pressed into the film during tests.

Another area of possible film damage that could result from clamping the balloon film in a restraining clamp is the effect of locally stressing the balloon film to near its yield point while the balloon is restrained by the clamp. Such local stresses might be caused by the tensile load transfer from the load tapes to the balloon film near the clamp, or by clamping wires or cordage located inside the balloon with the balloon film. An investigation of the effect of pre-stressing polyethylene balloon film as a function of stress magnitude has been conducted by General Mills, Inc. The results of one study (Ref. 3) indicated that pre-stressing of polyethylene film at room temperature for up to 24 hr at stresses equal to 70% of yield stress had no pronounced detrimental effect on the mechanical properties of the film. The changes observed were either too small to be conclusive or not of a detrimental nature. Results of a second study (Ref. 4) indicated that pre-stressing polyethylene film at room temperature for periods up to seven days at stress equal to 70% of the yield point does not seriously alter the mechanical properties of the film: a 10% decrease in ultimate stress and strain and a rise in the cold brittle point to a maximum of 3°C were observed.

The balloon damage criteria established thus far indicate that it may be possible to clamp a balloon at pressures up to 15 psi or greater without appreciably damaging the balloon. The friction test results indicate that balloon clamp dimensions compatible with launch operation requirements may be possible if high clamping efficiency can be achieved. The following calculation illustrates the magnitude of the forces and dimensions required for such a balloon clamp.

Assume as typical a 9 million cu ft natural shape balloon fabricated of 0.75 mil polyethylene, and having hot jet seals and load tapes. We may assume 1100 lb payload weight and 950 lb balloon weight, for a total weight of 2050 lb. Further, we assume the balloon gross lift equals the total weight, and add 10% for buoyancy, which gives 2255 lb.

The inflation bubble length would be $\sim$71 ft of gore length from the top of the balloon. If we assume that the balloon clamp is located

~9 ft from the launch spool, the clamp will be located 80 ft from the top of the balloon, where the circumference of the balloon is ~510 ft.

If we discount the weight of the balloon bubble, the balloon clamp would have to resist a tension of ~2255 lb.

If we were to neglect the load tapes and assume the load distributed evenly throughout the film, we may calculate the balloon film tensile force per inch of circumference due to the balloon lift to be

$$\frac{2255 \text{ lb force}}{510 \text{ ft} \times 12 \text{ in.}} = 0.368 \text{ lb/in.}$$

With a clamp inflatable pad pressure of 20 psi and a coefficient of friction of 0.1 (for lubricated balloon film), the total normal clamping force required (assuming frictional force effective on both sides of clamp) would be 11,300 lb. Thus the required clamp pad area would be ~565 sq in. A clamp pad width of 30 in. would require an effective clamp pad length of 19 in. The actual length of the pad required will vary with the clamp pad area efficiency obtainable.

The effect of clamping many layers of folded and wrinkled balloon film (with or without load tapes, cordage, etc.) on balloon damage, clamp efficiency, and coefficients of friction was not known. In addition, it was not known which balloon clamping configuration would yield the best efficiency with the least balloon film damage. For example, restraining the balloon film between opposing inflatable clamp pads might be more effective than restraining the film between a clamp pad and a fixed surface, or multiple clamp pads might be more effective than one large pad. Because most of these questions could be resolved by testing an experimental clamping device, the Phase II study was undertaken.

PHASE II STUDY

The objectives of the Phase II study were to design, fabricate, and test a laboratory model clamp. Testing was to include restraining actual balloon sections with the laboratory clamp to determine clamping efficiency and the relationship of such restraint to balloon damage. This phase of the study was expected to establish the feasibility of the balloon strain relief device, any limitations with respect to the restraint device itself, and compatibility of the device with balloon launch operations.

LABORATORY CLAMP DESIGN

The primary design objective of the laboratory balloon clamp was to restrain the balloon without damage to the film. A pneumatic clamp pad was selected because it offers uniform pressure distribution on the clamped balloon film, thus avoiding the uneven clamping pressures which could result in local film damage. Exact clamping pressure may also be more easily controlled and measured using a pneumatic clamp.

The actual configuration of the pneumatic clamp was selected to permit maximum flexibility during the test phase for modifications. Ease of fabrication and the need to change the size of the clamping area dictated the choice of module clamp pads. The clamp pad configuration selected for the testing is illustrated in sketches (Figs. 2, 3, and 4) and photographs (Figs. 5 and 6).

The manner in which the clamp pad modules are held in the clamp structure is sketched in Fig. 4 and can be seen in the photographs (Figs. 5 and 6). The clamp design provided for clamp pads opposing each other on both surfaces of the clamp, with the option of having pneumatic clamp pads on only one surface of the clamp and a flat surface on the other. The clamp design also allows spacing of the individual clamp pad modules from a snug, shoulder-to-shoulder fit to a separation of 6 in. or more.

The laboratory clamp was sized to accommodate the surplus balloons to be used for testing, with sufficient margin to allow a wide range of clamping pressures and clamp pad areas. The clamp was sized to accommodate a folded balloon width of up to 28 in. and to accommodate a maximum of six clamp modules, each 6 in. deep, for a total physical clamp depth of 36 in.

The material chosen for the clamp pad inflatable unit to be fabricated for initial testing was 4.4 oz nylon coated with 6 oz/sq yd neoprene. The clamp pad configuration was as sketched in Fig. 2, but with dimension A equal to 1.4 in.

After initial testing, the clamp pad inflatable unit was fabricated of a heavier material to allow clamping pressures of 50 psi or greater. The material chosen was 2 ply nylon, 5 oz/sq yd/ply, coated with neoprene for a total weight of 45 oz/sq yd. The 1.4 in. depth of the inflatable pad was increased to 2.1 in. (see dimension A, Fig. 2) so that the clamp pads would accomodate variations in total thickness of the balloon films, wires, and cords to be clamped when the clamp pads were not spaced shoulder to shoulder. The changed module functioned well with both balloon configurations tested.

LABORATORY CLAMP TESTING

Test Materials and Equipment

Two tailored, natural shape, polyethylene balloons were furnished by NCAR for the laboratory tests. The smaller balloon was a 0.75 mil, 32 gore, tapeless balloon with hot jet seals. The inflated balloon volume was 500,000 cu ft and the diameter was 86 ft. The balloon had a bundle of 18 wires in a sleeve attached to one of the gores, which extended from the top end fitting to the bottom end fitting. Four of the wires had outside diameters of ~1/8 in.; the other 14 wires had outside diameters of ~1/16 in. The wires were slightly twisted into a rope shape.

The larger balloon was a 1.5 mil, 75 gore, taped balloon with hot jet seals. The ultimate strength of the load tapes was ~450 lb. The balloon volume was 2.94 million cu ft and the diameter was 200 ft. Two small wires, ~1/16 in. diam, extended from the top end fitting to the bottom end fitting, and a heavy nylon cord of tubular weave inside the balloon extended from the bottom end fitting to near the top of the balloon. The balloon was folded to a width of less than 25 in. in the as-packed condition for the top two-thirds of its length, but the lower one-third was folded as wide as 36 in.

The laboratory clamp was as described above (Figs. 5 and 6). The spacing between opposing clamp pads was adjusted with the threaded tie rods that restrain the upper clamp surface. Air pressure to the pneumatic clamp pads was controlled with a pressure regulator, and the pressure was held the same for all clamp pads.

Test Criteria

The primary objectives of clamp testing were to determine clamping efficiency and the relationship of clamping to balloon damage. So that the test results could be correlated to an eventual operational damping system, the test condition tensile loads were controlled to simulate loads that might occur in actual balloon operations.

Tensile loads for the balloon test sections approximated the maximum loads to which the balloon film would probably be exposed. This maximum tensile load was estimated as follows.

The maximum tensile load (per inch of balloon circumference at the balloon clamp) for a 0.75 mil tapeless balloon would occur for a 3 million cu ft balloon of ~450 lb, i.e., a gross weight of ~900 lb. The gross bubble lift would be ~900 lb, and the required bubble length ~54 ft. This would place the clamp where the balloon circumference is ~4950 in. The tensile load would be 990/4950, or ~0.2 lb/circumference inch. This value was used as the balloon tensile load for most of the clamp restraint tests conducted for the 0.75 mil balloon.

Similarly, for the 1.5 mil taped balloon it was assumed that the maximum gross load of a 2.94 million cu ft balloon would be 4400 lb, resulting in a tensile load of ~0.6 lb/circumference inch at the clamp. For good correlation of film damage, and since the 1.5 mil balloon had load tapes, it was thought that it might be desirable to test clamp only those areas of the balloon which had a gore width similar to that which would be clamped in an actual balloon launch. It was expected that transfer of the tensile loads from the tape to the balloon film might cause some film damage.

The balloon test sections were clamped and held under tension for ~1 hr to simulate actual balloon launch conditions. Slide test data were taken to determine the relative clamping efficiency of the various test configurations. All clamped balloon sections were completely visually inspected with polarized light after clamping to determine film damage. The severity of creases and of other possible damage was compared to previous test samples to determine which clamping configurations, clamping pressures, and clamp loading techniques resulted in the least damage to the balloon film. The clamp restraining force was measured with a direct reading dynamometer.

Clamp Test Procedure

To simulate as closely as possible the restraint of a balloon during inflation of the bubble, an actual section of the balloon was used. The balloon sections were ~15 to 35 ft in length and restrained at one end with a balloon end fitting. The other end of the balloon section was placed in the laboratory clamp in the as-folded configuration, just as it had been taken from the shipping box. The direct reading dynamometer was in series with a chain hoist that was used to place the required tension on the balloon end fitting.

Special care was taken to keep the balloon and clamp pads free from dust and other contaminants to minimize damage to the clamped balloon film. It was not feasible to keep the sleeve free from all dust and contaminants because of the handling required. However, to minimize contamination, the sleeve that protects the balloon during packing and storage was not removed from the area to be clamped until just before testing.

For initial testing, the balloon film was in direct contact with the neoprene clamp pads. This test configuration resulted in some abrasion and local stretch damage to the balloon film layers closest to the clamp pads. The clamp pads were then covered with four layers of 4 mil commercial grade polyethylene. (Commercial grade polyethylene was selected because the balloon sleeves used for packing and shipping balloons are usually of this material.) Covering the clamp pads substantially reduced the abrasion damage to the balloon film, but local stretch damage was still present, appearing almost entirely near the first clamp pad. The location of stretch damage indicated that during loading the first clamp pad was apparently bearing a substantial part of the tensile load, with subsequent clamp pads being loaded successively less.

In an attempt to load the clamp pads evenly, a sleeve of 4 mil commercial polyethylene was placed around the balloon portion to be clamped, and polyethylene (poly) powder was liberally applied between the polyethylene pad covers and the polyethylene sleeve. The addition of the poly powder lubricant substantially reduced the tensile load that the first clamp pad could restrain. Once this maximum was exceeded the balloon would slide very slowly until the next clamp started to deform and become loaded; as the total clamp restraint load was increased each successive pad would become loaded. This method of preparing the clamp and balloon was successful in eliminating most, if not all, of the local stretch of balloon film resulting from unequal clamp pad loading.

With the application of poly powder a balloon sleeve was used initially to keep the poly powder out of the inner folds of the balloon and to avoid the possibility of adjacent layers of balloon film slipping with resulting shear damage to the balloon. A number of tests were later conducted without the sleeve, and with poly powder applied between the balloon and the poly clamp pad covers; on only one occasion was there apparent abrasion and stretch damage to a small area (~36 sq in.) of the 0.75 mil balloon. It is presumed that such stretch damage can occur when the poly powder is not evenly applied, or when some spots are not lubricated at all.

As mentioned earlier, the 0.75 mil test balloon used had a bundle of 18 wires in a sleeve attached to the outside of the balloon at one of the gore seams. This bundle of wires was kept inside the clamped area, but to the side, away from the other balloon film, to prevent damage to the balloon. Since the balloon was folded and packed with the wires near the outside edge of the folded balloon, this procedure caused no operational difficulty.

The two wires and the nylon cord inside the 1.5 mil balloon caused no noticeable damage up to and including 35 psi clamping pressure; however, there were slight impressions of the nylon cord visible on the immediately adjacent balloon film layers for clamping pressures of 25 psi or higher. Above 35 psi the nylon cord and wires caused visible film damage in the form of small pinholes and local deformation or extrusion of the film.

Most of the clamp tests were conducted at room temperature (~24°C). However, five clamp tests were conducted at hot and cold temperatures, to determine whether material damage and/or clamping efficiency would differ greatly from results of room temperature tests.

Two clamp tests were conducted at a temperature of -6.5°C; this was accomplished by cold soaking the clamp and balloon test section outside overnight and testing outside the following morning. Three clamp tests were conducted at ~52°C; this was accomplished by placing the clamp and balloon section in an enclosure heated to 52°C.

When the balloon was placed in a sleeve and clamped with the pads covered with polyethylene film and lubricated with poly powder, it was observed that the 1.5 mil balloon could sometimes be slid through the clamp as much as 3 or 4 ft without damage to the balloon. Since the coefficient of friction for the lubricated polyethylene sleeve on the lubricated polyethylene clamp pad cover is less than for the different layers of balloon film on each other, the balloon tends to slide as one large "belt." However, this could not be repeated reliably and consistently.

When a balloon is placed in the clamp with essentially the same folds it had in the storage box, there is considerably more material at the center than near the edges, where there may be as few as two layers. The clamp pads place the same pressure, and therefore approximately the same restraining force, on the two layers at the edge as on the many layers at the center. Since the same "pull" force is required to slide multiple layers or two layers, the layers at the edge are stretched, and the film may even be torn. This type of film damage was much more pronounced with the 0.75 mil balloon because the wires in the sleeve at the edge of the balloon were restrained by the clamp, with only the tension of the balloon sleeve to slide them through the clamp. However, this uneven sliding did not cause balloon film damage when the balloon was allowed to slide only a few inches to load all the clamp pads successively.

The clamping configuration that consistently resulted in the least damage to the balloon film utilized opposing clamp pads, a polyethylene clamp pad covering, and a polyethylene sleeve with poly powder between the sleeve and the polyethylene clamp pad covering.

Clamp Test Results

The clamp test data for the testing performed with the laboratory clamp and the 0.75 mil and 1.5 mil polyethylene balloons are presented in Tables 4 and 5. The tabulated data indicate the extent of the testing performed. The terms listed in the tables are self explanatory, except for the T/PA term. This term is obtained from the clamp restraint force, T, the clamp pad pressure, P, and the nominal clamp pad area, A. This clamping parameter for the slide data could be termed an effective coefficient of slip friction, which is a function of the clamping configuration, the balloon film, and any balloon film lubricants. The effect of the balloon film lubricant must be emphasized. Although an effort was made to apply the same amount of polyethylene powder for each test, the actual amounts were different. This difference can be noted in Fig. 7, which presents slip T/PA as a function of clamping pressure.

The data as presented in Fig. 7 indicate, with the exception of a few data points, that the clamping pad configuration of "pad-opposing-pad" has a higher clamping slip coefficient (in the range of 0.28 to 0.38) than does the configuration of "pad-opposing-flat-plate" (in the range of 0.20 to 0.32). The few data points that are not in general agreement with most of the data are believed to be the result of different amounts of poly powder on the clamp pads. Thus, it would appear desirable to have a "pad-opposing-pad" clamp configuration for balloons with a large net inflation bubble lift because the minimum clamp area required would be less than for a "pad-opposing-plate" clamp configuration.

The magnitude of the slip coefficient for any of the clamp pad configurations could be increased by reducing the concentration of the balloon lubricant; however, this would reduce the possibility of equal loading of each clamp pad and perhaps increase the possibility of balloon film damage.

The slip coefficient, T/PA, appears to increase slightly with clamp pad pressure. Part of this effect is believed to result from some thinning down of the concentration of the balloon film lubricant, since the leading edge of film at the first clamp pad may be scraped clean as the balloon slips through the clamp.

The slip coefficient data for the 0.75 mil tapeless balloon are apparently lower than for the 1.5 mil taped balloon. This difference could derive from the effect of the load tapes. The clamping slip coefficient data of Fig. 7 indicate that the number of clamp pads does not appreciably affect the magnitude of the clamping slip coefficient.

The data of Fig. 7 can be used to determine the size of the clamp needed to restrain polyethylene balloons with a required force. A curve such as that presented in Fig. 8 can be developed for a minimum T/PA determined from Fig. 7. A minimum T/PA is used to assure that the clamp will restrain the balloon at the desired clamping pressure. Two separate curves were developed for the clamp sizing chart. One was for the "pad-on-pad" clamp configuration (for a constant T/PA of 0.28) to be used for the 1.5 mil taped balloon; the other (for a constant T/PA of 0.19) was for the "pad-on-plate" clamp configuration to be used for the 1.5 mil taped balloon, and for the 0.75 mil balloon with either clamp configuration. As noted on Fig. 8, the curve is intended only for the clamping configuration where the clamp pads are covered with polyethylene film and the balloon is covered with a polyethylene sleeve, with poly powder between the clamp pad cover and sleeve.

The first curve on Fig. 8 may be used as follows. Assume a 3 million cu ft balloon with load tapes, and a net inflation bubble lift of 3000 lb. The desired minimum clamp restraining force would be ~3300 lb, allowing for some "cushion." We then assume a desired clamping pressure of 25 psi, which gives a T/A of 7.0. The estimated required clamp area would be

$$A = \frac{T}{T/A} = \frac{3300}{7.0} = 470 \text{ sq in.}$$

<u>Damage Evaluation of Clamped Balloon Film</u>

As stated above, the balloon film sections for each test were inspected visually after the clamp tests to determine which balloon clamping configurations, pressures, and techniques resulted in the least apparent damage to the balloon film. Preliminary room temperature tensile tests of a small number of 0.75 mil balloon film samples clamped at 10 and 20 psi indicated a slight increase in average yield strength for both machine and transverse directions, and a slight decrease in average ultimate strength only for the transverse direction.

After considerable clamp testing had been completed, balloon test sections were selected for evaluation of balloon film damage. Samples for tensile testing were taken from areas of clamped balloon film where crease damage from clamping was most severe on the basis of visual inspection under polarized light. Little time was spent testing the areas of clamped balloon film which were not damaged, since clamping without visible damage was not considered to result in lower film tensile strength.

The results of the damage evaluation of clamped balloon film by tensile test are presented in Tables 6 and 7. Table 6 presents the maximum, minimum, and average tensile strengths (in pounds) for the samples tested, and Table 7 presents the deviation (in percent) in strength of the clamped balloon film compared to the strength of unclamped balloon film.

The test samples were 1 × 8 in. and were pulled at a strain rate of 20 in./min at room temperature and at a strain rate of 5 in./min at -60°C. Twenty-five samples were tested for each direction and temperature, for a total of 100 samples for each balloon clamp test selected for tensile test.

The first balloon test sections chosen for damage evaluation were 2-13 and 1-14. These sections had been clamped at 35 and 20 psi, respectively; they were selected for tensile testing because this clamping configuration resulted in the smallest proportion of damaged areas.

For the 0.75 mil balloon (1-14) clamped at 20 psi, the tensile test results in Table 7 indicate that the average ultimate strength in the machine direction at room temperature is 9% lower for the clamped film than for the unclamped film. The average yield and ultimate strengths for the clamped film at -60°C are both higher by more than 10%.

The tensile test results (Table 7) for the 1.5 mil balloon (2-13) clamped at 35 psi are similar to that of sample 1-14 described above. The average ultimate strength for the clamped film at room temperature is slightly less than 20% lower in the machine direction than that for unclamped film. The average yield and ultimate strengths at -60°C and the average yield strength at room temperature for the clamped film is approximately the same as, or slightly greater than, the strengths of the unclamped film.

A study of Table 6 (which presents the actual maximum, minimum, and average strength values for the samples tested) will show a comparable result. Only the ultimate strength in the machine direction at room temperature is adversely affected. After the above results from the tensile test evaluation were obtained for samples 1-14 and 2-13, it was decided that additional balloon sections clamped at lower clamping pressures should also be evaluated. Accordingly, test samples 1-13 and 2-11 were selected, using the same basic criteria as the earlier (1-14 and 2-13) test samples except that thest tests were conducted at lower clamping pressures.

For the 0.75 mil test sample (1-13) which was clamped at 15 psi, the tensile test results (Table 7) indicate a slight drop (less than 4%) in average yield and ultimate strengths except for the transverse direction at room temperature, where the yield and ultimate strengths are slightly greater than that for unclamped film. The results (Table 6) indicate a similar trend for the maximum, minimum, and average values for the tensile strengths of the clamped balloon film.

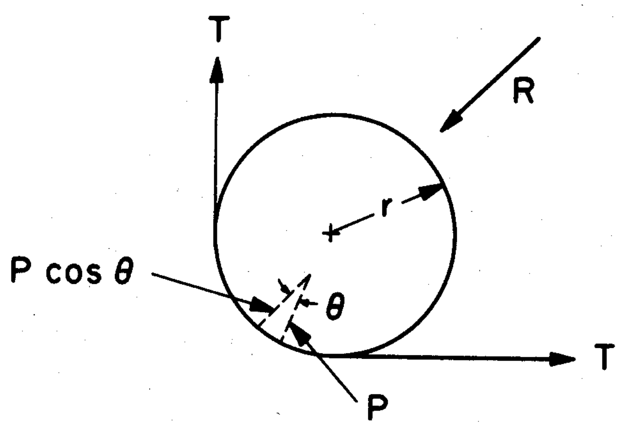
The test results (Table 7) for the 1.5 mil test sample (2-11) which was clamped at 20 psi, indicate a substantial loss in average yield strength (9 to 13%) for both machine and transverse directions at -60°C compared to the unclamped balloon film or the balloon film clamped at 35 psi in test 2-13. The tensile test results (Table 7) for 2-11 at room temperature indicate only a slight gain or loss in average yield and ultimate strengths (4% or less) for clamping the film at 20 psi. The maximum and minimum strength values for 2-11 (Table 6) also indicate the loss in strength.

It may be of value to examine the pressure to which the balloons are exposed during a "spool" launch. A very brief and approximate sample calculation is given for determining the spool contact pressure for the balloon film layers adjacent to the launch spool.

We may assume

1. a balloon with a net bubble lift, T, of 3450 lb (the conditions of test sample 2-13),
2. a launch spool 4 in. in radius, r, and
3. a balloon width at spool of 26 in.

The assumed launch configuration is indicated below.



Pressure at the launch spool surface is equal for the 90° contact arc. The reaction force, R, for a unit width of the launch spool utilized is

$$R = \sqrt{T^2 + T^2}$$

equal to the vectorial addition of the pressure, p, on the launch spool, which is

$$2rp \int_0^{45} \cos \theta d\theta = 1.414 \text{ rp}$$

$$R = \sqrt{T^2 + T^2} = 1.414 \text{ rp}$$

or

$$p = \frac{R}{1.414\ r} = \frac{188}{1.414 \times 4} = 33 \text{ psi}$$

where

$$R = \frac{\sqrt{T^2 + T^2}}{26} = 188 \text{ lb}$$

Thus the approximate pressure on the balloon film at the launch spool is 33 psi for this example. Perhaps there would be some merit in evaluating the tensile properties of balloon film exposed to a spool launch to determine whether there is a comparable loss in tensile properties.

CONCLUSIONS

The results of the tests performed with the clamped polyethylene film balloon sections indicate that a balloon restraint device is feasible if limited damage can be tolerated. There is some damage to the clamped balloon film if the best clamp test procedures are followed. The required clamp size would be feasible for most applications.

Damage to the balloon film is summarized in the damage evaluation section of this report and in Tables 6 and 7. There is some decrease in tensile strength for balloon films clamped at pressures between 15 and 35 psi, but the loss in tensile strength of the damaged balloon film appears neither to be consistent nor a direct function of clamping pressure. The ~19% loss in ultimate tensile strength in the machine direction at room temperature for test sample 2-13, which was clamped at 35 psi, was not evident in test sample 2-11, which was clamped at a lower pressure of 20 psi; however, test sample 2-11 showed a loss of ~10% in average yield and ultimate tensile strengths in the machine and transverse directions at -60°C, which test sample 2-13 did not show.

The ~19% loss in average ultimate strength in the machine direction at room temperature was the only loss in average strength of the sample 2-13 test results. It should be emphasized again that the samples for the tensile test damage evaluation were taken from areas of the selected clamped balloon test sections which were most severely damaged by clamping.

It is difficult to evaluate how loss in tensile strength for the clamped balloon film may affect the probability of a successful balloon flight. A slight loss in tensile strength probably would increase the chance for a balloon failure, but the use of a balloon restraint device for some launch conditions may greatly enhance the probability of a successful launch, thus tending to increase the probability of a successful flight.

It should be noted also that the pressures to which the balloon film is exposed at the launch spool are of the same magnitude as those in the laboratory balloon clamp. The example given for a spool launch in the damage evaluation section of the report estimated a contact pressure of the balloon film layers nearest the launch to be 33 psi for a balloon (26 in. wide in the launch spool) restrained at 3450 lb. It may be advisable to evaluate the tensile strength of balloon film exposed to a launch spool under simulated launch conditions to determine whether crease damage similar to that encountered with the balloon clamp is now being experienced with spool launches.

There is a clamping pressure limitation for the balloon clamp. Visual inspection with polarized light indicates that damage to the balloon film becomes more pronounced as the clamping pressure exceeds 35 psi for the 1.5 mil polyethylene and 20 psi for the 0.75 mil polyethylene balloons. These pressures, however, would be sufficient for most applications.

Table 1

SUMMARY OF DRY FRICTION TESTS

Material Attached to Carriage	Contact Area (sq in.)	Contact Pressure (psi)	Static Coefficients of Friction			
			Material Attached to Sled			
			Polyethylene (1.5 mil)	Mylar (0.75 mil)	Scrim Mylar [(a)]	
					Rough Side	Smooth Side
Same as sled sample	14	1.3	0.53	0.27	0.25	0.28
Same as sled sample	6	3	0.53	0.25	0.30	0.26
Same as sled sample	6	13	0.50	0.37	0.48	0.47
Butyl coated nylon	14	1.3	0.57	0.70	0.63	0.65
Butyl coated nylon	6	13	0.50	0.85	0.61	0.50
Nylon	14	1.3	0.31 [(b)]	0.48	0.20	0.21
Nylon	6	13	0.25	0.34	0.33	0.15
Neoprene coated nylon	14	1.3	0.41	0.48	0.43	0.38
Neoprene (soft) coated nylon	14	1.3	0.62	0.83	0.86	0.80

(a) 0.5 mil Mylar on 0.6 oz/sq yd leno weave dacron (one side)

(b) 0.75 mil polyethylene

Table 2

SUMMARY OF LUBRICATED FRICTION TESTS

Material Attached to Carriage	Contact Area (sq in.)	Contact Pressure (psi)	Static Coefficients of Friction			
			Material Attached to Sled			
			Polyethylene (1.5 mil)[a]	Mylar (0.75 mil)[b]	Scrim Mylar[c]	
					Rough Side	Smooth Side
Same as sled sample	14	1.3	0.12-0.35	0.18-0.26	0.25-0.26	0.15-0.27
Butyl coated nylon	14	1.3	0.17-0.35	0.20-0.38	0.41-0.47	0.18-0.41
Nylon	14	1.3	0.17-0.21	0.20-0.29	0.20-0.25	0.15-0.21
Neoprene coated nylon	14	1.3	0.15-0.24	0.27-0.40	0.37-0.38	0.17-0.38
Neoprene (soft) coated nylon	14	1.3	0.12-0.49	0.26-0.42	0.50-0.80	0.28-0.45

(a) Lubricated with polyethylene powder

(b) Lubricated with cornstarch

(c) 0.5 mil Mylar on 0.6 oz/sq yd leno weave dacron (one side); lubricated with cornstarch

Table 3

EFFECT[a] OF CREASES[b] ON BALLOON FILM YIELD AND ULTIMATE STRENGTH IN AVERAGE PERCENT DEVIATION FROM UNTOUCHED MATERIAL

Test Film	Pull Direction	-60°C		Room Temperature	
		Yield Strength	Ultimate Strength	Yield Strength	Ultimate Strength
0.75 mil Mylar	Machine	+5.4	+2.3	-4.9	-12.2
	Transverse	-1.8	-9.1	+4.2	-19.6
	Machine	(+1.2)	(-5.0)	(-3.9)	(-22.3)
	Transverse	(-1.8)	(-1.0)	(+3.1)	(-20.2)
0.75 mil Polyethylene	Machine	+21.4	+6.5	-3.0	+1.6
	Transverse	+14.6	+14.9	-9.3	+0.4
	Machine	(+9.3)	(-1.8)	(0)	(+2.8)
	Transverse	(+7.3)	(+7.3)	(-7.5)	(+0.4)
Scrim Mylar (0.5 mil) Mylar on 0.6 oz/sq yd leno weave dacron scrim	Machine	-16.0	-6.6[c]	+0.5	-2.5
	Transverse			+2.1	-9.6
	Machine	(-8.5)	(-11.4)[c]	(-1.9)	(+0.8)
	Transverse			(+5.6)	(-6.8)

(a) Given numbers are the average percent strength deviations for creased and pressed samples relative to the untouched control samples. Numbers in parentheses are the average percent strength deviations for the *pressed* samples, and numbers not in parentheses are the average percent strength deviations for the *creased* samples.

(b) Creased samples were creased normal to the pull direction at 15 psi for 3 hr; pressed samples were pressed at 15 psi for 3 hr.

(c) Data for transverse direction of scrim Mylar at -60°C was inconclusive because not all samples had the same number of threads.

Table 4

CLAMP TEST DATA SUMMARY

0.75 mil BALLOON, 500,000 cu ft VOLUME

Test No.	Clamp Configuration: No. Clamp Pads, Top	No. Clamp Pads, Bottom	Material in Contact with Balloon Film	Horizontal Clamp Pad Spacing (in.)	Clamp Activity	Clamp Width (in.)	Clamp Depth (in.)	- A - Clamp Area (sq in.)	- P - Clamp Pad Air Pressure (psi)	- T - Clamp Pull (lb)	Balloon Gore Width (in.)	Balloon Circum-ference at Clamp (in.)	Balloon Film Tension (lb)	- P × A - Clamp Normal Force (lb)	$\frac{T}{PA}$ (a)	Comments
1-1	2	Plate	Neoprene coated nylon	Snug	Hold			264	10	210	-	-	-	2640		Clamp pads for tests 1-1 to 1-9
1-3	2	Plate	The clamp pad inflatable	↓	Hold			144	2	410	40.6	1300	0.31	288	1.42	are "light" neoprene
1-4	2	Plate			Press	12	12	144	10	0	-	-	-	1440	-	coated nylon
1-6	2	Plate	Two layers of 4 mil commercial		Hold	16	12	192	10	300	-	-	-	1920	0.16	
1-7	2	Plate	polyethylene on pads		Hold	18	12	216	10	325	-	-	-	2160	0.15	Polyethylene powder placed
1-8	1	1	Neoprene coated nylon inflat-able pad		Hold	19	6	114	10	275	-	-	-	1140	0.24	inside balloon folds
1-9	1	1			Hold	18	6	108	20	275	-	-	-	2160	0.13	
1-10	3	3	One layer of 4 mil commercial		Slip	21	18	378	25	450	-	-	-	945	0.48	Clamp pads are "heavy"
1-10	3	3	polethylene for sleeve and		Hold	21	18	378	10	900	100	3200	0.28	3780	0.24	neoprene coated nylon for remain-
1-11	3	3	pads; covered with four layers		Hold	21.5	18	287	10	650	98	3135		2870	0.23	der of tests with 0.75 mil balloon
1-12	2	Plate	of 4 mil poly powder between		Slide	20	12	240	7	625	96	3070		1680	0.37	
1-12	2	Plate	sleeve and poly pad covers.		Hold	20	12	240	10	850	96	3070		2400	0.35	
1-13	1	Plate	↓		Slide	20	6	120	10	400	96	3070		1200	0.33	
1-13	1	Plate			Hold	20	6	120	15	625	96	3070		1800	0.34	
1-14	1	1			Slide	20	6	120	15	460	89	2850		1800	0.26	
1-14	1	1			Hold	20	6	120	20	565	89	2850		2400	0.24	
1-15	2	2			Slide	18	12	216	5	360	82	2620	0.14	1080	0.33	
1-15	2	2			Hold	18	12	216	10	525	82	2620	0.20	2160	0.24	
1-16	2	2			Hold	15	12	180	20	450	62	2000	0.23	3600	0.13	
1-17	2	2			Hold	15	12	180	10	500	74	2360	0.21	1800	0.28	
1-18	1	1			Hold	16	6	96	30	500	70	2240	0.22	2880	0.17	
1-19	1	1	↓	↓	Hold	16	6	96	30	730	76	2430	0.30	2880	0.25	

(a) T/PA for the slide data could be considered an effective clamping slip coefficient, but one which is greatly affected by the concentration of polyethylene powder lubricant present at the clamping surfaces.

TABLE 4 (Continued)

Test No.	Clamp Configuration: No. Clamp Pads, Top	Clamp Configuration: No. Clamp Pads, Bottom	Clamp Configuration: Material in Contact with Balloon Film	Clamp Configuration: Horizontal Clamp Pad Spacing (in.)	Clamp Activity	Clamp Width (in.)	Clamp Depth (in.)	– A – Clamp Area (sq in.)	– P – Clamp Pad Air Pressure (psi)	– T – Clamp Pull (lb)	Balloon Gore Width (in.)	Balloon Circum- ference at Clamp (in.)	Balloon Film Tension (lb)	– P × A – Clamp Normal Force (lb)	$\frac{T}{PA}$ (a)	Comments
1-20	1	1	One layer of 4 mil commercial polyethylene for sleeve and pads; covered with four layers of 4 mil poly powder between sleeve and poly pad covers.	Snug	Hold	17	6	102	40	525	82	2620	0.20	4080	0.13	
1-21	1	1			Slide	16	6	96	7	–	76	2430	0	672	–	
1-21	1	1			Hold	16	6	96	30	725	76	2430	0.30	2880	0.25	
1-22	1	1	No sleeve on balloon – only four layers of 4 mil poly over clamp pads. Poly powder between balloon and poly pad covers		Slide	17	6	102	8	270	84	2690	0.10	816	0.33	
1-22	1	1			Hold	17	6	102	30	540	84	2690	0.20	918	0.31	
1-23	1	1			Slide	17	6	102	9	280	87	2780	0.10	918	0.30	
1-23	1	1			Hold	17	6	102	20	560	87	2780	0.20	2040	0.27	
1-24	1	1			Slide	20	6	120	9	275	86	2720	0.10	1080	0.25	Water mist was sprayed on the balloon before clamping
1-24	1	1			Hold	20	6	120	20	550	86	2720	0.20	2400	0.23	

(a) T/PA for the slide data could be considered an effective clamping slip coefficient, but one which is greatly affected by the concentration of polyethylene powder lubricant present at the clamping surfaces.

Table 5

CLAMP TEST DATA SUMMARY

1.5 mil BALLOON, 2.94 million cu ft VOLUME

Test No.	Clamp Configuration: No. Clamp Pads, Top	No. Clamp Pads, Bottom	Material in Contact with Balloon Film	Horizontal Clamp Pad Spacing (in.)	Clamp Activity	Clamp Width (in.)	Clamp Depth (in.)	- A - Clamp Area (sq. in.)	- P - Clamp Pad Air Pressure (psi)	- T - Clamp Pull (lb)	Balloon Gore Width (in.)	Balloon Circumference at Clamp (in.)	Balloon Film Tension (lb)	- P × A - Clamp Normal Force (lb)	T/PA (a)	Comments
2-1	3	3	Two-ply nylon -- neoprene coated	Snug	Hold	18	18	324	15	1000	40	3000	0.33	4860	0.21	
2-2	3	3	"	↓	Hold	16	18	280	15	1500	40.5	3000	0.50	4320	0.30	
2-3	3	3	Four layers of 4 mil commercial	↓	Hold	20	18	360	25	1700	36	2700	0.63	9000	0.19	Lots of corn- starch from mfg.
2-4	3	3	polyethylene covering pads	↓	Hold	22	18	396	35	1900	34.5	2600	0.73	13800	0.14	
2-5	3	3		↓	Hold	25	18	450	25	3200	77	5770	0.52	11250	0.27	
2-6	3	3	Above pad cover plus two layers	↓	Slide	24	18	432	7	1050	74.5	5550	0.19	3020	0.35	Polyethylene powder added
2-6			of commercial 4 mil poly for sleeve	↓	Hold	24	18	432	25	3000	74.5	5550	0.54	10800	0.28	between sleeve and pad cover
2-7	3	Plate	↓	↓	Slide	24	18	432	11	1200	65	4880	0.25	4670	0.26	↓
2-7	3	Plate	↓	↓	Slide	24	18	432	18	2250	65	4880	0.47	7780	0.29	↓
2-7	3	Plate	↓	↓	Hold	24	18	432	25	3000	65	4880	0.61	10800	0.28	↓
2-7	3	Plate	↓	↓	Hold	24	18	432	30	3350	65	4880	0.69	12960	0.26	↓
2-8 }	3	3	↓	↓	Slide	24	18	432	10	1000	-	-	-	4320	0.23 }	Test not completed
2-8 }	Test not completed		↓	↓	Hold	24	18	432	25	2800	-	-	-	10800	0.26 }	
2-9	3	3	↓	↓	Slide	24	18	432	10	1300	-	-	-	4320	0.30	↓
2-9	3	3	↓	↓	Slide	24	18	432	20	2900	-	-	-	8640	0.34	↓
2-9	3	3	↓	↓	Slide	24	18	432	30	4350	-	-	-	12960	0.34	↓
2-9	3	3	↓	↓	Slide	24	18	432	34	5800	-	-	-	14690	0.40	↓
2-9	3	3	↓	↓	Hold	24	18	432	40	6200	-	-	-	17280	0.36	↓
2-10	3	3	↓	↓	Slide	23.5	18	423	10	1400	-	-	-	4230	0.33	↓
2-10	3	3	↓	↓	Slide	23.5	18	423	20	2830	-	-	-	8460	0.33	↓
2-10	3	3	↓	↓	Slide	23.5	18	423	30	4700	-	-	-	12700	0.38	↓
2-10	3	3	↓	↓	Hold	23.5	18	423	40	6200	-	-	-	16900	0.36	↓

(a) T/PA for the slide data could be considered an effective clamping slip coefficient, but one which is greatly affected by the concentration of polyethylene powder lubricant present at the clamping surfaces.

Table 5 (Continued)

Test No.	Clamp Configuration: No. Clamp Pads, Top	No. Clamp Pads, Bottom	Material in Contact with Balloon Film	Horizontal Clamp Pad Spacing (in.)	Clamp Activity	Clamp Width (in.)	Clamp Depth (in.)	- A - Clamp Area (sq in.)	- P - Clamp Pad Air Pressure (psi)	- T - Clamp Pull (lb)	Balloon Gore Width (in.)	Balloon Circumference at Clamp (in.)	Balloon Film Tension (lb)	- P × A - Clamp Normal Force (lb)	$\frac{T}{PA}$ (a)	Comments
2-10	3	3	Above pad cover plus two layers of commercial 4 mil poly for sleeve	Snug	Slide	23.5	18	423	35	6025	-	-	-	14810	0.406	Polyethylene powder added between sleeve and pad cover
2-11	3	3			Hold	26	18	468	20	3240	72	5400	0.60	9360	0.35	
2-12	3	3	Four layers of 4 mil commercial poly on pads plus two layers of 4 mil poly for sleeve		Hold	26	18	468	30	3240	72	5400	0.60	14050	0.23	
2-13	3	3			Hold	26	18	468	35	3450	76	5700	0.60	16400	0.21	
2-14	3	3			Hold	26	18	468	40	3600	80	6000	0.60	19100	0.19	
2-15	3	Plate			Slide	25	18	450	10	-	85	6370	-	4500		
2-15	3	Plate			Slide	25	18	450	20	2200	85	6370	0.35	9000	0.24	
2-15	3	Plate			Slide	25	18	450	30	3200	85	6370	0.50	13500	0.24	
2-15	3	Plate			Slide	25	18	450	35	3600	85	6370	0.57	15750	0.23	
2-15	3	Plate			Hold	25	18	450	40	3850	85	6370	0.61	18000	0.21	
2-16	4	Plate	Four layers of 4 mil commercial poly over clamp pad and one layer of 4 mil poly for sleeve		Slide	26	24	624	20	2900	87	6530	0.45	12500	0.23	Polyethylene powder between pad cover and sleeve
2-16	4	Plate			Slide	26	24	624	25	3600	87	6530	0.55	15600	0.47	
2-16	4	Plate			Hold	26	24	624	30	3900	87	6530	0.60	18720	0.21	
2-17	5	Plate			Slide	25	30	750	10	1500	90	6750	0.22	7500	0.20	
2-17	5	Plate			Slide	25	30	750	20	3200	90	6750	0.47	15000	0.21	
2-17	5	Plate			Hold	25	30	750	25	4050	90	6750	0.60	18750	0.22	
2-18	6	Plate			Slide	26	36	900	10	2000	92	6900	0.29	9000	0.22	
2-18	6	Plate			Slide	25	36	900	20	4000	92	6900	0.60	18000	0.23	
2-18	6	Plate			Slide	25	36	900	22	4150	92	6900	0.60	19800	0.21	
2-18	6	Plate			Hold	25	36	900	25	4150	92	6900	0.60	22500	0.18	
2-19	2	Plate			Slide	25	12	300	10	900	93	6970	0.13	3000	0.30	
2-19	2	Plate			Slide	25	12	300	20	1900	93	6970	0.27	6000	0.32	
2-19	2	Plate			Slide	25	12	300	30	2900	93	6970	0.42	9000	0.32	

(a) T/PA for the slide data could be considered an effective clamping slip coefficient, but one which is greatly affected by the concentration of polyethylene powder lubricant present at the clamping surfaces.

Table 5 (Continued)

Test No.	Clamp Configuration: No. Clamp Pads, Top	No. Clamp Pads, Bottom	Material in Contact with Balloon Film	Horizontal Clamp Pad Spacing (in.)	Clamp Activity	Clamp Width (in.)	Clamp Depth (in.)	- A - Clamp Area (sq in.)	- P - Clamp Pad Air Pressure (psi)	- T - Clamp Pull (lb)	Balloon Gore Width (in.)	Balloon Circum-ference at Clamp (in.)	Balloon Film Tension (lb)	- P × A - Clamp Normal Force (lb)	$\frac{T}{PA}$ (a)	Comments
2-19	2	Plate	Four layers of 4 mil commercial poly over clamp pad and one layer of 4 mil poly for sleeve	Snug	Slide	25	12	300	40	4100	93	6970	0.59	12000	0.34	
2-19	2	Plate			Hold	25	12	300	45	4200	93	6970	0.60	13500	0.31	
2-20	3	3	Four layers of 4 mil commercial poly over clamp pads and one layer of 4 mil commercial poly for sleeve		Slide	24	18	432	10	1325	-	-	-	4320	0.32	Polyethylene powder between pad covers and sleeve
2-20	3	3			Slide	24	18	432	20	3000	-	-	-	8640	0.35	
2-20	3	3			Slide	24	18	432	30	5200	-	-	-	12960	0.40	
2-20	3	3			Hold	24	18	432	40	6200	-	-	-	17280	0.36	
2-21	2	2		6	Slide	24	12	288	10	850	-	-	-	2880	0.30	
2-21	2	2		6	Slide	24	12	288	20	1800	-	-	-	5760	0.31	
2-21	2	2		6	Slide	24	12	288	30	2800	-	-	-	8640	0.32	
2-21	2	2		6	Slide	24	12	288	35	3400	-	-	-	10080	0.34	
2-21	2	2		6	Hold	24	12	288	40	4000	-	-	-	11520	0.35	
2-22	3	3		Snug	Hold	25	18	450	40	3960	88	6600	0.60	18000	0.22	
2-23	3	3			Slip	25	18	450	35	1300	83	6220	0.21	1570	0.83	Clamp and balloon in 52°C environment
2-23	3	3			Hold	25	18	450	40	4000	83	6220	0.64	18000	0.22	
2-24	2	2	Four layers of 4 mil commercial poly over clamp pads and no sleeve; poly powder between balloon and pad covers		Slip	24	12	288	10	1300	78	5050	0.22	2880	0.45	
2-24	2	2			Slip	24	12	288	20	2700	78	5850	0.46	5760	0.47	
2-24	2	2			Hold	24	12	288	30	3100	78	5850	0.53	8650	0.36	
2-25	2	2			Slip	24.5	12	294	6	1000	74	5550	0.18	1760	0.57	Clamp and balloon in 6.5°C environment
2-25	2	2			Hold	24.5	12	294	30	3300	74	5550	0.60	8820	0.37	
2-26	2	2			Slide	26.5	12	318	5	650	67	5030	0.13	1590	0.41	Clamp and balloon in 52°C environment
2-26	2	2			Slide	26.5	12	318	10	1400	67	5030	0.28	3180	0.44	
2-26	2	2			Hold	26.5	12	318	20	3000	67	5030	0.60	6360	0.47	

(a) T/PA for the slide data could be considered an effective clamping slip coefficient, but one which is greatly affected by the concentration of polyethylene powder lubricant present at the clamping surfaces.

Table 6

AVERAGE,[a] MAXIMUM, AND MINIMUM TENSILE STRENGTHS[b] FOR CLAMPED AND UNCLAMPED BALLOON FILM

Balloon Film	Clamp Test No.	Clamping Pressure	Pull Direction	-60°C, 5 in./min Strain Rate						Room Temperature, 20 in./min Strain Rate					
				Yield Strength (lb)			Ultimate Strength (lb)			Yield Strength (lb)			Ultimate Strength (lb)		
				Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min
0.75 mil Polyethylene	Control sample (untouched)	--	Machine	5.40	0.46	3.74	5.52	4.56	3.90	1.19	1.08	0.91	2.61	2.17	1.86
	1-14	20	"		(c)		6.18	5.29	4.54	1.23	1.14	1.06	2.21	2.01	1.72
	1-13	15	"	5.08	0.30	3.39	5.08	4.51	4.22	1.23	1.06	0.94	2.73	2.09	1.69
	Control sample (untouched)	--	Transverse	4.76	0.38	3.99	5.10	4.40	3.99	1.10	1.02	0.92	3.08	2.55	2.11
	1-14	20	"		(c)		5.66	4.92	4.32	1.22	1.15	1.03	2.62	2.16	1.62
	1-13	15	"	4.77	0.21	3.69	4.77	4.26	3.70	1.20	1.05	0.98	3.32	2.58	1.78
1.5 mil Polyethylene	Control sample (untouched)	--	Machine		(c)		9.98	9.21	8.33	2.36	2.16	2.00	5.00	4.02	2.67
	2-13	35	"		(c)		11.00	9.55	8.30	2.38	2.14	1.90	3.78	3.28	2.70
	2-11	20	"	9.23	0.88	7.15	9.29	8.20	7.49	2.27	2.12	1.97	4.85	3.86	3.26
	Control sample (untouched)	--	Transverse		(c)		10.80	9.39	7.78	2.40	2.09	1.82	5.57	4.39	2.65
	2-13	35	"		(c)		10.30	9.44	8.52	2.35	2.10	1.86	4.19	3.52	2.99
	2-11	20	"		(c)		9.37	8.16	7.11	2.40	2.16	2.02	5.09	4.52	3.70

(a) 25 tensile samples, each 1 × 8 in. wide, were tested at each condition for a total of 100 samples for each clamp test.

(b) The tensile test samples were taken from the most severely creased areas of the clamped balloon film.

(c) Yield strength was equal to ultimate strength.

Table 7

DAMAGE EVALUATION

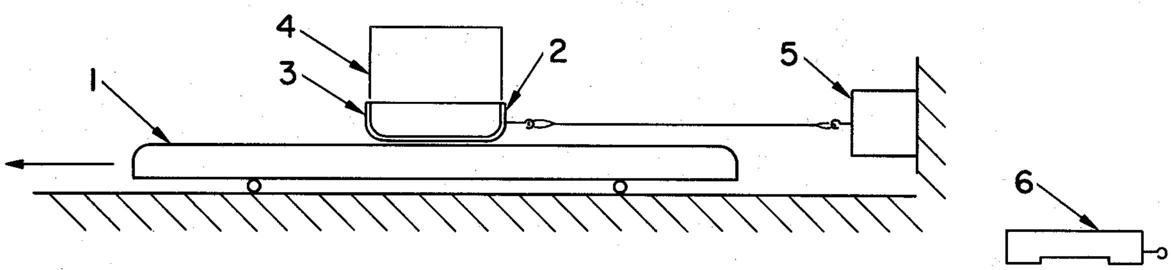
Average[a] Percent Deviations in Tensile Strength[b] of Clamped from Unclamped Balloon Film

Balloon Film	Clamp Test No.	Clamping Pressure (psi)	Pull Direction	-60°C 5 in./min Strain Rate		Room Temperature 20 in./min Strain Rate	
				Yield Strength	Ultimate Strength	Yield Strength	Ultimate Strength
0.75 mil Polyethylene	1-14	20	Machine	+18.6	+16.0	+ 5.6	- 9.2
	1-13	15	"	- 3.6	- 1.1	- 1.9	- 3.7
	1-14	20	Transverse	+12.3	+11.8	+12.7	-15.3
	1-13	15	"	- 3.9	- 3.2	+ 2.9	+ 1.2
1.5 mil Polyethylene	2-13	35	Machine	+ 3.7[c]	+ 3.7	- 0.9	-18.4
	2-11	20	"	-14.6	-11.0	- 1.9	- 4.0
	2-13	35	Transverse	+ 0.5[c]	+ 0.5	+ 0.5	-19.8
	2-11	20	"	-13.1[c]	-13.1	+ 3.3	+ 3.0

(a) 25 tensile samples, each 1 × 8 in. wide, were tested at each condition for a total of 100 samples for each clamp test.

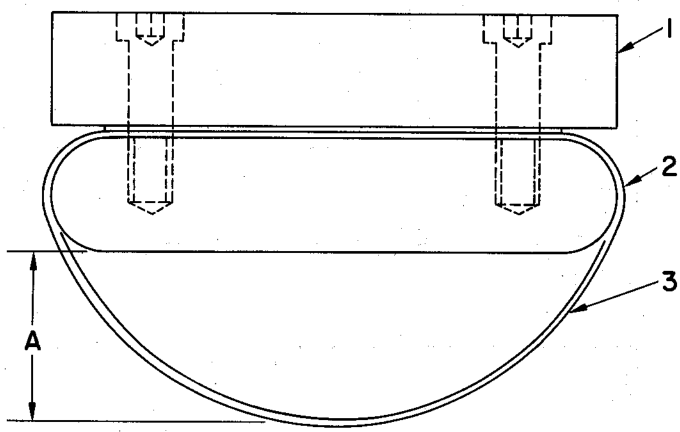
(b) The tensile test samples were taken from the most severely creased areas of the clamped balloon film.

(c) Yield strength was equal to ultimate strength.



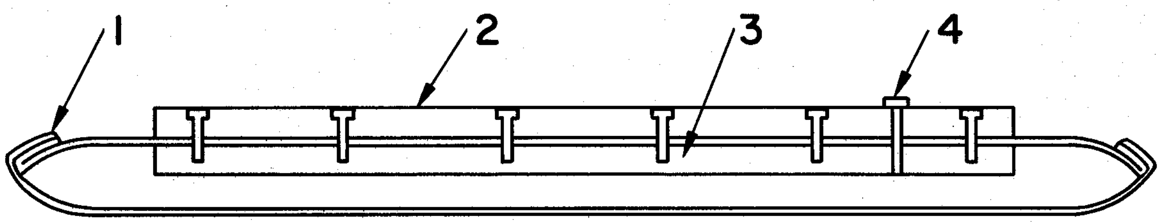
1 Moving carriage
2 Metal sled (1.4 sq in. contact area)
3 1/8 in. Foam rubber
4 Weight
5 Load cell
6 Metal sled (6 sq in. contact area)

Fig. 1 Friction apparatus.



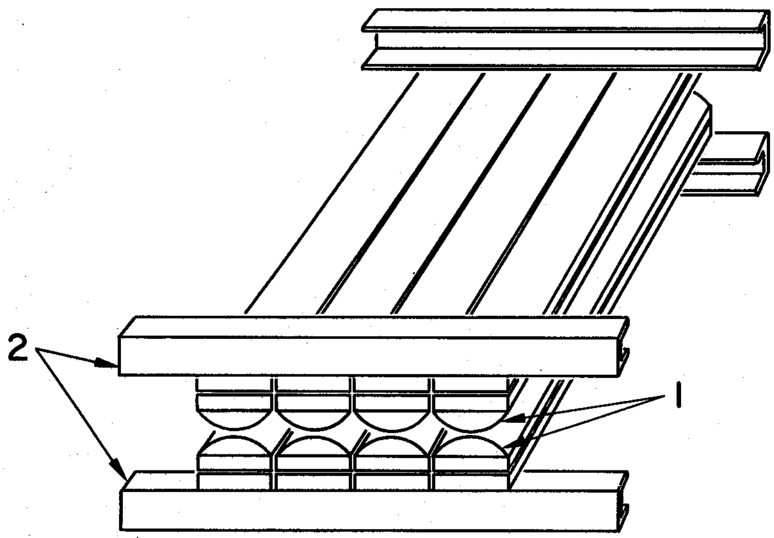
1 Solid aluminum (1X6 in.)
2 Solid aluminum (1X6 in.) with full radius corners
3 Gas barrier for inflatable modules

Fig. 2 End-sectional view of pneumatic clamp pad.



1 End seal for gas barrier
2 Solid aluminum
3 Solid aluminum
4 Pressure fitting for inflation

Fig. 3 Cross-sectional view of pneumatic clamp pad.



1 Inflatable pad modules
2 Support structure

Fig. 4 Multiple module array for pneumatic clamp pad.

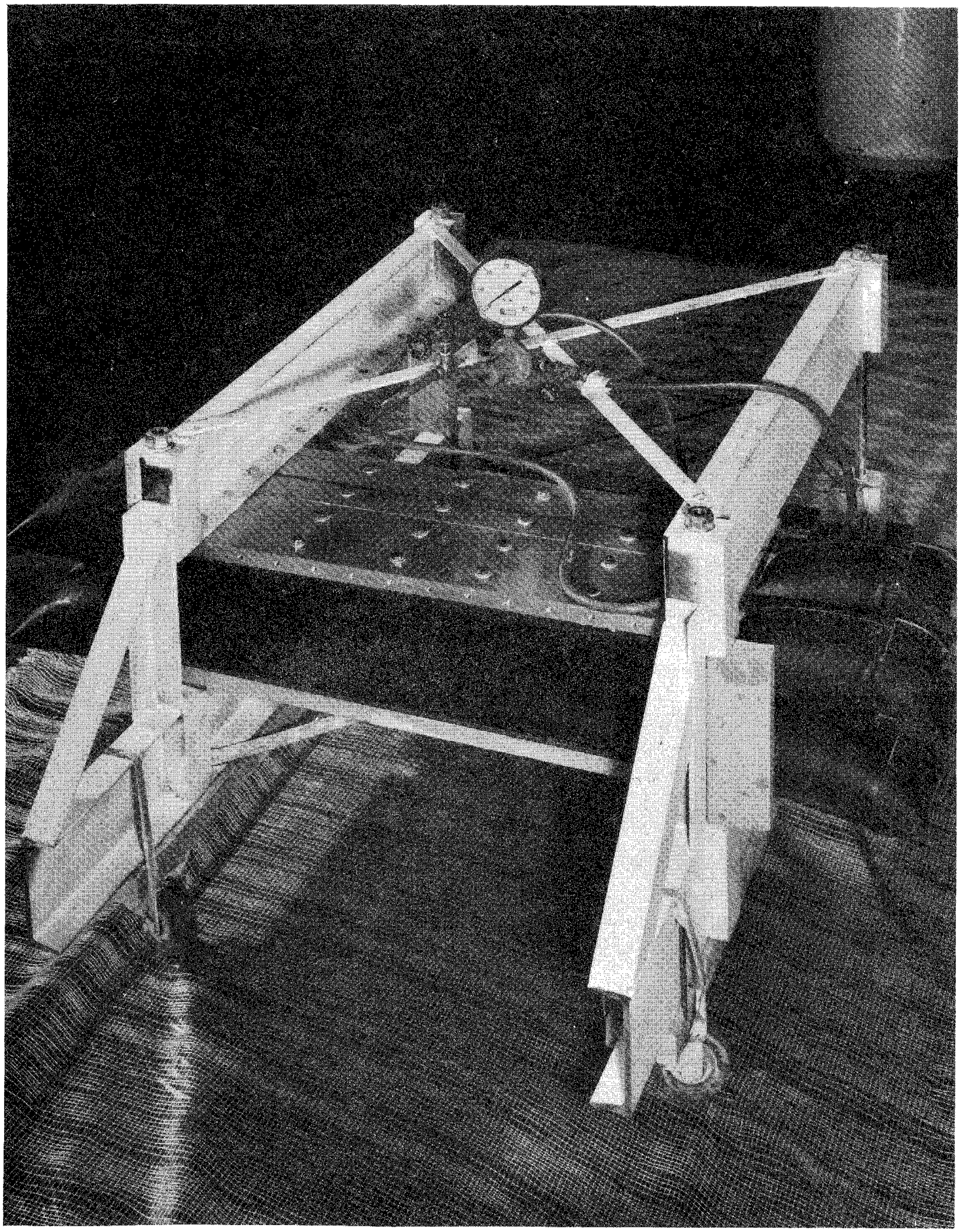


Fig. 5 Laboratory balloon clamp apparatus.

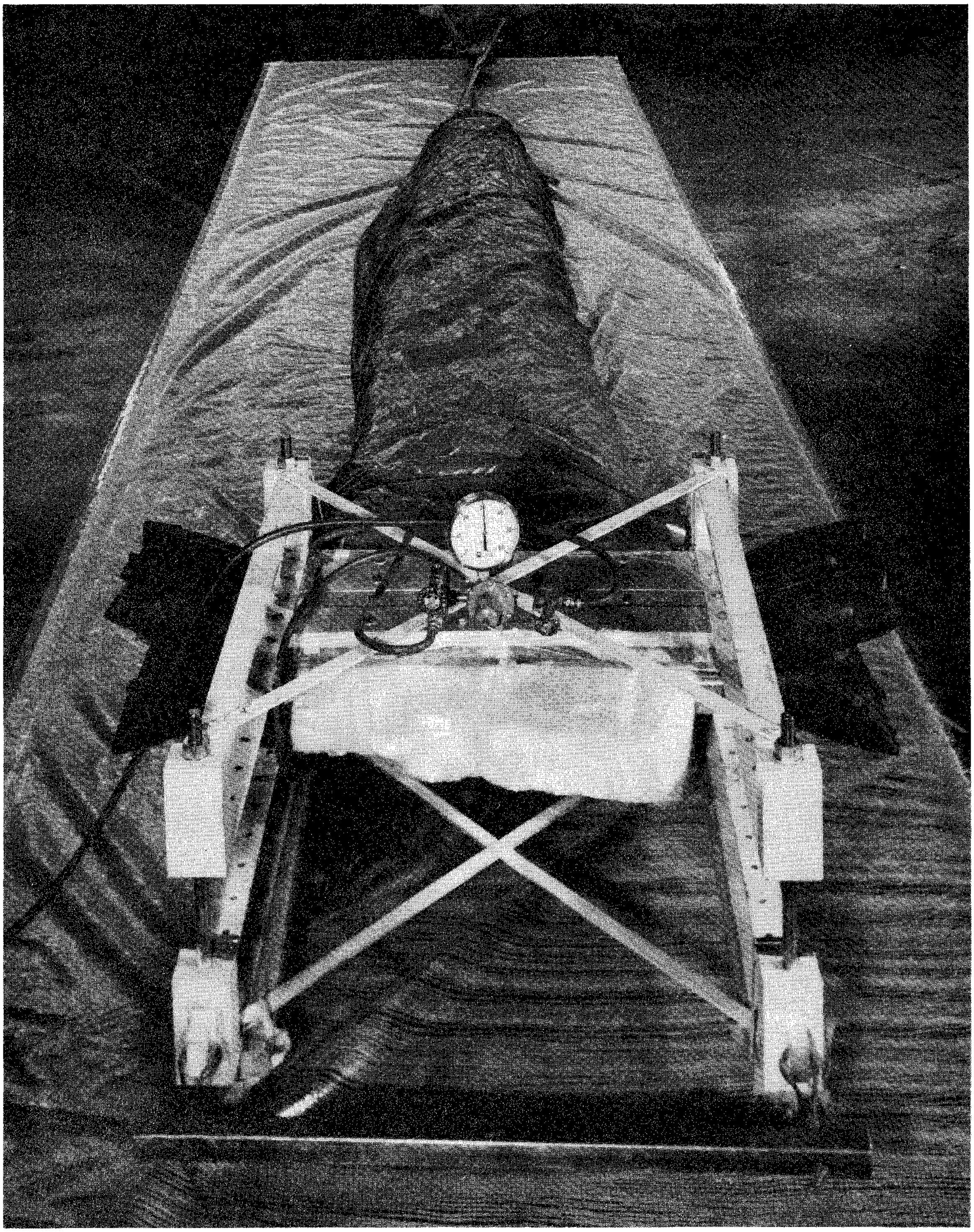


Fig. 6 Laboratory balloon clamp test.

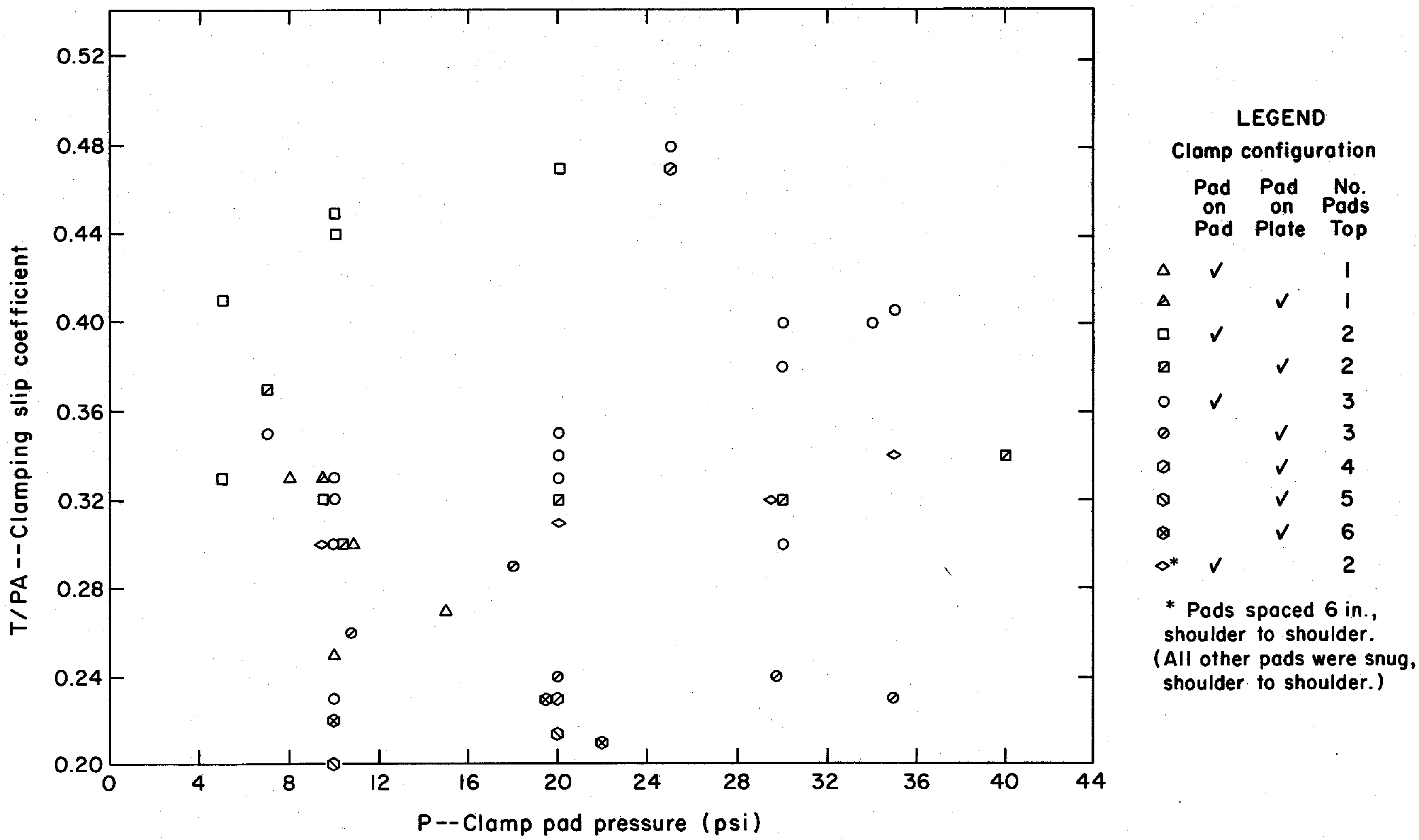


Fig. 7 Clamping slip coefficient for laboratory clamp.

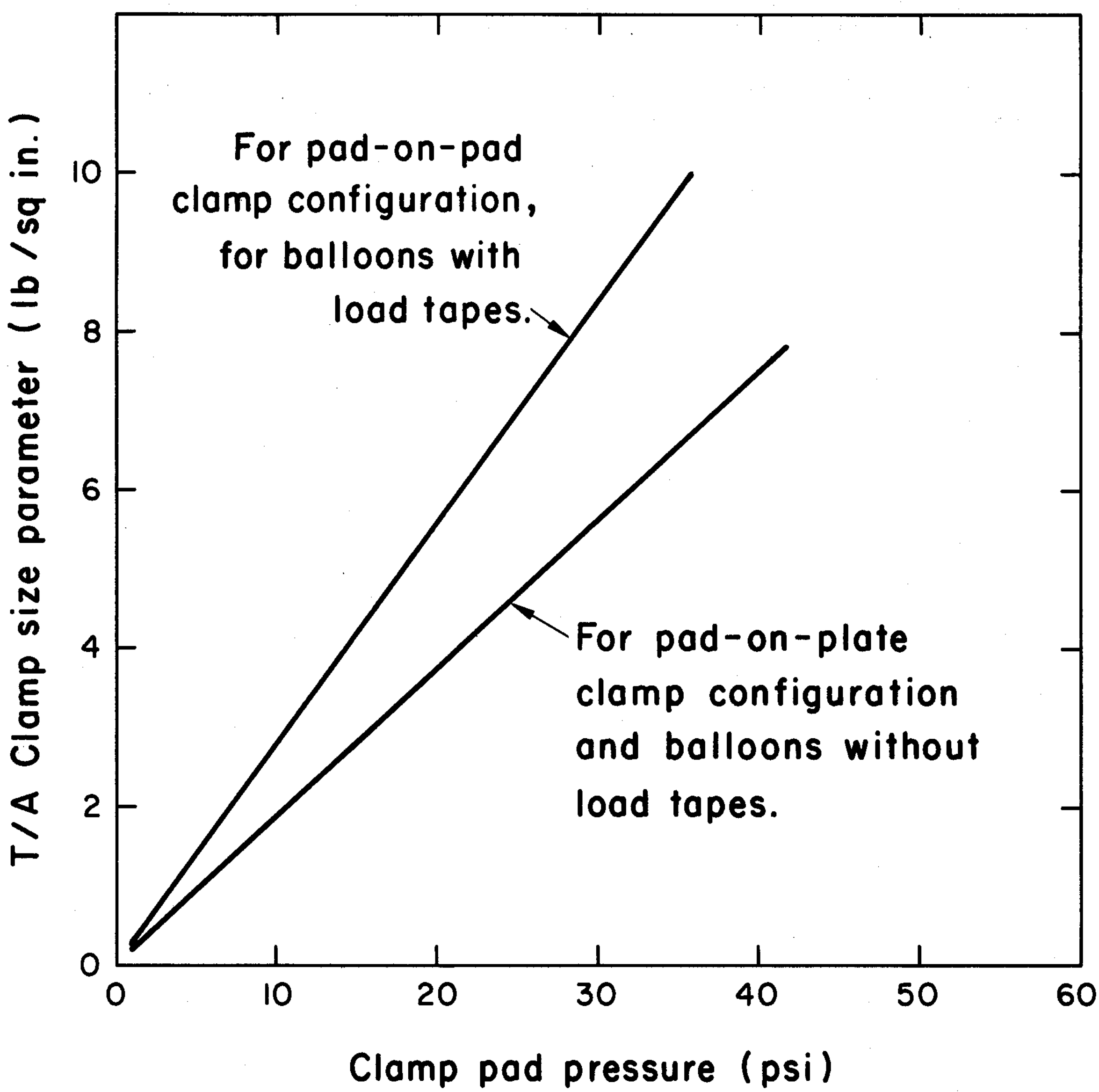


Fig. 8 Estimated clamp sizing parameter.

REFERENCES

1. *Balloon Barrier Materials*, Mechanical Division of General Mills, Inc., Rept. No. 1671, 19-29, 31 March 1957 (AD-117157).

2. *Balloon Barrier Materials*, Mechanical Division of General Mills, Inc., Rept. No. 1633, 35-38, 10 December 1956 (AD-110240).

3. *Balloon Barrier Materials*, Mechanical Division of General Mills, Inc., Rept. No. 1709, 1-6, 12 June 1957 (AD-117221).

4. *Balloon Barrier Materials*, Mechanical Division of General Mills, Inc., Rept. No. 1760, 2-4, 14 September 1957 (AD-133801).