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# IMPROVED KNEE PROTECTIVE DEVICES FOR MINE WORKERS

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY & HEALTH

# IMPROVED KNEE PROTECTIVE DEVICES FOR MINE WORKERS

## INTRODUCTION

Although most miners who kneel or crawl in their work do use those knee protective devices (knee pads) presently on the market, there are many indications that they are not completely satisfactory. A U. S. Bureau of Mines Coal Mine District Manager said that inspectors working out of his office could choose either of two kinds of knee pads, but both were "not satisfactory." A storekeeper in a "low coal" mining region said that his store had regular buyers of the knee pads it stocked and he believed that: "If there was anything better, it would be on the market."

The protective devices in use today typically consist of strap-on pads made of a thick resilient material with a flexible, wear-resistant outside shell. The configuration and the method of fastening suggest that the pads have been designed to be worn while kneeling on a dry, relatively smooth surface, but that little consideration has been given to such matters as their comfort and position-retention while the wearer is standing or walking, and there is ample evidence that existing pads don't prevent such maladies as pre-patellar bursitis--"miners' knee."

## PURPOSE

A research and development study was conducted to: —

A. Determine the design requirements for knee protective devices (knee pads) to be used in mine situations where the workmen must work and crawl on their knees.

B. Develop a prototype device to alleviate injury, disease, and disabling discomforts.

# IMPROVED KNEE PROTECTIVE DEVICES

# FOR

# MINE WORKERS

By:

Ernst P. Thal-Larsen and Robert B. Sleight

With the assistance of
Alan M. Peabody, M.D. and
C. A. Stevenson, M.D.

Sponsor:

Division of Technical Services,
National Institute for
Occupational Safety and Health,
United States Department of Health,
Education and Welfare,
1014 Broadway
Cincinnati, Ohio 45202

Project Officer: Francis J. LaPallo

Contract No.: HSM 099-71-5

Century Research Corporation
4113 Lee Highway
Arlington, Virginia 22207

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Ernst P. Thal-Larsen, Robert B. Sleight, Alan M. Peabody, and C. A. Stevenson.

PERFORMER: Century Research Corp., Arlington, VA.
Contract PHS-HSM-099-71-5

SPONSOR: National Inst. for Occupational Safety and Health, Cincinnati, OH.

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KEYWORDS: *Industrial hygiene, *Protectors, *Mining, *Occupational safety and health.

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# Summary Report

# IMPROVED KNEE PROTECTIVE DEVICES FOR MINE WORKERS

by

Century Research Corporation, January 1972*

SUMMARY REPORT

There are approximately 95,000 actively working coal miners in this country. Roughly one third of these, or 30,000, can be classified as "low coal" miners. (Source: U. S. Bureau of Mines, 1969 data.) Working in narrow coal seams where the tunnel ceiling height ranges roughly between two and four feet, these men spend the majority of their working time lying, sitting, squatting or kneeling when stationary or being transported, and crawling or "duck walking" when moving under their own power.

In addition, there are approximately 1,000 U. S. Bureau of Mines inspectors and supervisors as well as a sizable number of State mine inspectors whose work may take them into mines where they will have to work or crawl on their knees.

It becomes obvious that adequate knee protection is of great importance to this group to help them perform their task effectively and as comfortably as possible.

The protective devices (kneepads) suitable for use by coal miners that are available in the U. S. today all contribute to greater comfort and protection against injury. The degree of comfort and protection afforded varies with the type of pads used. The nature of the work performed makes one pad

*Sponsored by: National Institute for Occupational Safety and Health.

more suitable than another; for instance, a motor-man who is on his knees only part of the time and does not have to crawl much, demands less of his knee pads than an inspector who routinely has to crawl a mile or more through low coal tunnels.

In spite of the use of protective knee pads, the incidence of knee injuries, ailments, and minor knee complaints has remained high enough to justify an investigation into the cause and the nature of such knee ailments, and a research and development project aimed at minimizing them through the development of more effective protective equipment.

Century Research Corporation has now completed such a project, the end-result of which is this report summarizing our method of investigation, our findings, and our recommendations; performance and design specifications for improved protective knee pads, design justification for such knee pads, and three sets of prototype pads of the above mentioned design.

The research method used consisted of a preliminary literature search, attendance at pertinent medical lectures given by and for orthopaedic surgeons, and examination of hospital records and U. S. Bureau of Mines Incident and Accident reports for statistical data on the incidence of knee injuries among low coal miners. A survey was made of U. S. and foreign manufacturers of industrial protective equipment and of their products to determine the state-of-the-art. Several models of knee pads were purchased for evaluation purposes. Background information for the performance and design specifications for the new knee pads was obtained through on-site observations of, and interviews with low coal miners and Federal and State mine inspectors, and through consultations with an orthopaedic surgeon, a physician, and several orthopaedic technicians.

One of the principal performance specifications setting the present design apart from the currently available knee pads is the requirement for an even distribution of the load on the knee while the wearer is kneeling or crawling. The result is an orthopaedically correct cushion, which alleviates the pressure concentrations underneath the patella and the tibiar tubercle that normally occur when a person kneels or crawls, and that are the principal causes for painful, swollen knees and pre-patellar bursitis in "low coal" miners.

This cushion has a relatively high profile compared to most of the currently available knee pads. This in turn led to the requirement for a semi-rigid outer shell, designed to provide the wearer added stability, and to prevent "roll under," where the wearer's knee rolls off the pad, a condition a number of the miners interviewed complained about.

Several plastics and elastomer manufacturers and fabricators were consulted regarding construction materials and production methods. A patent search was made covering all existing U. S. patents to date on protective knee pads.

Performance and design specifications were drawn up and experimental prototype design begun. Mock-ups were made of several configurations and evaluated before the prototype was selected. Three pairs of the recommended knee protective devices have been fabricated and submitted to the National Institute for Occupational Safety and Health.

# Introduction and Purpose

# Literature Search

## PERTINENT LITERATURE

Although tangentially related literature was found, the only really pertinent study we encountered was the work in 1965 by Dr. Sharrard for the National Coal Board in England. This work was done in Britain and was concerned with the British coal miners who work on their knees a great deal. We will quote significant portions of Sharrard's study.

"In most of the common kneeling postures the part of the knee that must take pressure is a triangular area bounded by the lower part of the patella proximally with the femoral condyles on either side of it and the tibiar tubercle distally. It is here that the pressure effects are the greatest". . .

. . . "The normal response of the skin to intermittent pressure, especially if combined with friction, is to produce hyperkeratosis of the horny layer. Thickening of the skin in this area is the hallmark of kneeling miners and, in itself, is harmless. Much sweating, due to heat and humidity in deep seams, or dampness may cause maceration of the horny layer and render the skin more liable to injury and infection" . . .
. . . "Acute aseptic bursitis is the most important pathological lesion arising as the result of kneeling in miners. . . Chronic aseptic bursitis is the commonest lesion of all in kneeling miners" . . .

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[1]Sharrard, W.J.W. Pressure effects on the knee in kneeling miners. <u>Annals of the Royal College of Surgeons of England</u>, Vol. 36, Jan.-June, 1965, 309-324.

. . . "any device for the prevention or minimization of bursitis should include some mechanism to cushion the violent alternations in pressure on the knee. Most of the knee pads in common use are not very effective in doing this" . . .

Dr. Sharrard developed a knee pad which he felt would alleviate some of the deficiencies of existing protective devices. These pads, however, apparently have never been produced.

Other pertinent articles wefound are:

Brantigan, O. C. & Voshell, A. F.
"The Mechanics of the Ligaments and Menisci of the Knee Joint"

Cooke, F. W., Ph.D. & Nagel, D. A., M.D.
"Combined Medical-Engineering Study of Injury and Damage to the Knee Joint in Impact"

Edwards, R. G., Lafferty, J. F., Lange, K.O.
"Ligament Strain in the Human Knee Joint"

Evans, F. G. & Thomas, C. C.
"Stress and Strain in Bones"

Helfet, A. J., M.D., M.CH.
"Management of Internal Derangements of the Knee"

Moseley, H. F.
"Disorders of the Knee"

Sharrard, W. J. W., M.D., F.R.C.S.
"Haemobursa in Kneeling Miners"
"Aetiology and Pathology of Beat Knee"

Shinno, N.
"Modus of Movement of the Knee"
"Functional Significance of the Patella in the Movements of the Knee"

# Field Observations and Contacts

## FIELD OBSERVATIONS AND CONTACTS

In September 1971 investigators of Century Research Corporation visited in the "low coal" sections of West Virginia, approximately from Charleston to Princeton, in order to become oriented to the problems of knee protection requirements and to talk with knowledgable persons in these locales. Active miners and their supervisors, West Virginia Department of Mines inspectors, U. S. Bureau of Mines inspectors, and medical specialists were consulted.

The good and bad features of existing pads were thoroughly reviewed in relation to the practical needs for protection to meet the operating situations in "low coal" mining.

Instances of "miner's knee" (pre-patellar bursitis) were observed as well as soreness. Some men were seen to be doing routine administrative work instead of inspection to recover from soreness, others were observed to be working while in pain from bursitis. First-person reports were obtained of miners who suffered a sudden onset of painful knees after years of no trouble.

Both good and bad features of presently used types of knee pads were documented by direct query of users and observation of the pads in use. Sets of the four pads presently used by the miners were purchased at prices ranging in local outlets from $3.19 to $8.25.

Hospital records of knee ailments were studied and consultations were held with an orthopaedic physician who is the most experienced in the country with miners' knee ailments.

Some additional details of these observations and consultations are noted below.

Several long-time mine workers displayed thickened skin at the knee and evidence of past abrasions severe enough to leave scars.

"Learning how to crawl" may sound like a childish exercise, but some miners apparently are more effective at crawling than others. Some crawl on hands and knees with feet hardly touching ground; some point their feet back; others keep them at right angles to their legs so that their toes are more or less perpendicular to the ground. Some low coal miners have wrist problems instead of or as well as knee problems. The extent of wrist ailments was not evaluated, but when specifically queried many miners indicated it was unpleasant and even painful.

Of the four types of pads observed in use, the red National Mine Services (NMS) pads outnumbered the other types. Next came an equal number of the Judson pads and the German-made (Nierhaus) pads. The least frequently seen was the Rockmaster pad. (This was not a thorough market appraisal.)

Prices of the different types of pads vary from location to location but at typical stores in the Beckley area, prices were as follows:

| | |
|---|---|
| Judson pads: | $3.19 |
| Red NMS pads: | $4.98 |
| Rockmaster pads: | $6.75 |
| German pads: | $8.25 |

Replacement parts for the German pads were as follows:

Rubber strap-fastening buttons:

| | |
|---|---|
| Singles (rear) | $0.29 |
| Doubles (front) | $0.35 |

Straps*:

| | |
|---|---|
| Short (rear) | $0.53 |
| Long (front) | $0.65 |

Among the miners interviewed, we noticed a trend in regard to their opinions about knee pads: The costlier the pads a miner was using, the more convinced he was that there wasn't anything better on the market. Although there were more users of the red NMS pads than any other type we saw, they had, on the whole, more critical things to say about their pads than the users of the two more expensive ones. Those using the Judson pads had less to say about the whole subject of knee pads, presumably because they were less plagued by knee problems and felt no requirement for more comfort, better protection, and spending more money.

Only a cursory evaluation was possible of the advantages and disadvantages of the presently used pads. Most have chafing straps, most cause sweating, straps on some require frequent replacing, some wear out rapidly, on some sharp objects protrude through and into the knee, on

*One miner pointed out to us that the rubber straps on his two-year-old German pads were thicker and seemed more elastic than those on later models. This appears to be a case of factory policy of planned absolescence, or possibly the replaceable straps and buttons are not original equipment. Many miners cut their own straps out of inner tube material.

most there is a tendency for the knee to roll off the pads, some wear for years while others last only a few months.

Inspectors and miners were observed to be temporarily off-the-job because of knee ailments. There was reported to be an adaptation period of several days when changing from "standing" work to "crawling" work; this involves whole body adjustment as well as knee sensitivity adaptation.

An attempt to review medical records at a southern West Virginia hospital/clinic was relatively unproductive because records of out-patients (the majority of knee cases) are not kept in the usual case files. The cases available, though, did confirm the prevalence of pre-patellar bursitis and popliteal cysts.

An orthopaedic surgeon with much experience in treating miners' knee ailments made several suggestions:

With regard to pre-patellar bursitis, he says that many orthopaedists aren't familiar with the typical "miner's knee". Some bursae get to be as big as a tennis ball. Bursa is a sack between skin and tibiar tubercle, (the uppermost forward part of the shin bone). Repeated pressure between the bone and an outside surface such as the ground causes the bursa to fill with fluid in order to provide a cushion to protect the bone. The bursa is usually filled with clear liquid, sometimes there is pus in it, in which case it usually is a painful one.

The routine medical treatment is to drain the bursa after first locally anaesthetizing the knee. In some cases he has withdrawn as much as 2 liquid ounces from one bursa. After draining, cortico-steroid is injected into the bursa.

Bursitis cases are considered an industrial disease for low coal miners, and are compensible. A lot of miners either don't know that or prefer to get their wages rather than wait for temporary disability compensation, so few of them stay off the knee for a week after it has been drained, and they're crawling on it again the next day. Result is they're back with the same complaint within a few months. (Century Research Corporation investigators interviewed one miner who had had his knee drained the day before.)

This orthopaedist thinks knee pads should extend below the tibiar tubercle. He thinks it would be good to have a ring-shaped or horseshoe-shaped build-up of cushioning material around the patella and the tibiar tubercle.

Straps should be more elastic than leather, and wider, to reduce the likelihood of cysts in back of the knees. He has seen miners who installed pads inside pockets sewn on their pants knees. He thinks some type of metal mesh over the pants knees would keep them from wearing out too fast when this type of protection is used. (Note: An experienced mine manager reported that in the "old days" padded pants were worn by some miners and were liked but presented a difficulty in drying when they became wet in working or were laundered.)

This physician believes that another common miner's knee injury, torn menisci and/or tendons, cannot be avoided by wearing knee pads or even braces. He thinks it would be desirable to make knee pads as free from moisture as is possible, but he doesn't think moisture is an important factor in knee ailments other than skin problems. He thinks arthritis is not caused or made worse by moisture, but by temperature change, especially cooling.

Necessity is the mother of invention, so the saying goes, and to some extent this is exemplified by modifications made by knee pad users. The following modifications, excluding jury-rigged repairs using wire and string, were observed:

Red NMS pads that were cut off just below the wearer's tibiar tubercle;

Rockmaster pads that were cut on top to conform to the wearer's leg contour;

Knots in the straps of the red NMS pads to keep them from slipping out of the pad;

Replacement of cushions in Judson pads by thicker cushions, or by two layers of cushioning material;

And one case of a user of Nierhaus pads who decided to work in spite of a case of bursitis. He carved a doughnut-shaped cushion out of a used red NMS pad and installed it inside his Nierhaus pad to keep the pressure off the painful spot. It was so comfortable that he installed one in the other pad as well and kept them in after his bursitis had subsided.

In summary, the limited field observations which were possible yield a great deal of practical benefit in developing improved knee protective devices. It is recommended that additional contacts with users be sponsored including in-use evaluation under simulated and actual working conditions.

Besides the contacts made in the coal mining regions a large number of contacts were made with scientists, medical specialists, manufacturers, and others throughout the United States and several foreign countries.

On the several pages that follow (Figures 1-11), a few of the "on-site" situations which were encountered are presented. These photographs demonstrate that miners are working with knee ailments; miners are ingenious with various modifications and repairs; also the environmental situations which the miner and his knee protective devices face are shown to be arduous and demanding. They even show a general need for research and development on devices, equipment and clothing to fully protect and facilitate the miner while at work.

Fig. 1. "Miner's Knee," or pre-patellar bursitis, is one of the commonest knee ailments among kneeling miners, and one that the newly developed experimental knee pad hopes to reduce significantly. The example pictured above is a relatively mild case. The right knee of the miner on the next page (Fig. 2) is more severely afflicted. Both miners were actively working when these photographs were taken.

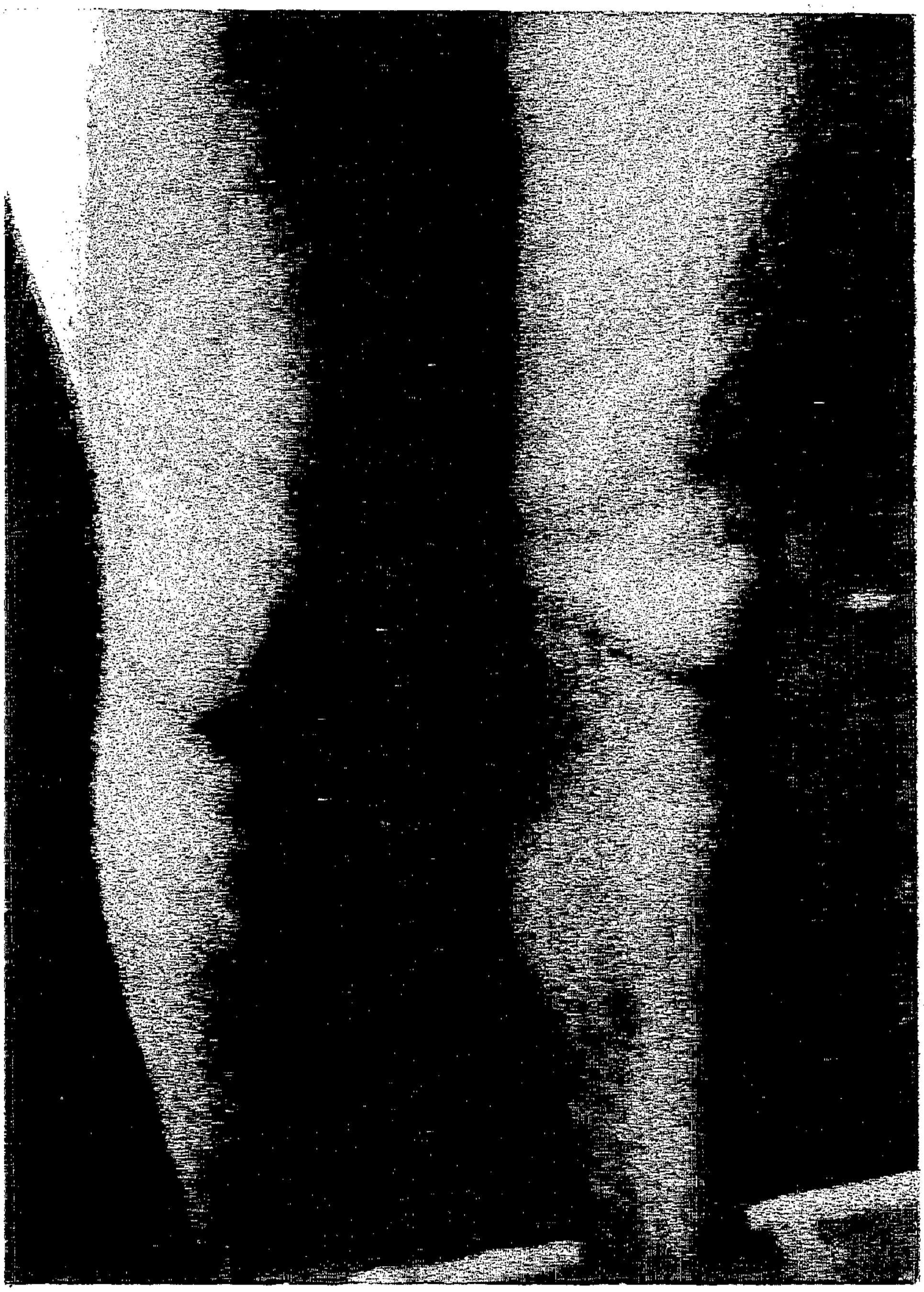

Fig. 2. Pre-patellar bursitis.

Fig. 3. Examples of various types of knee pads presently used, and different ways of attaching them. The inspector on the far left is wearing brand new pads with leather straps; the foreman in the right foreground is leaving the top straps of his pads undone.

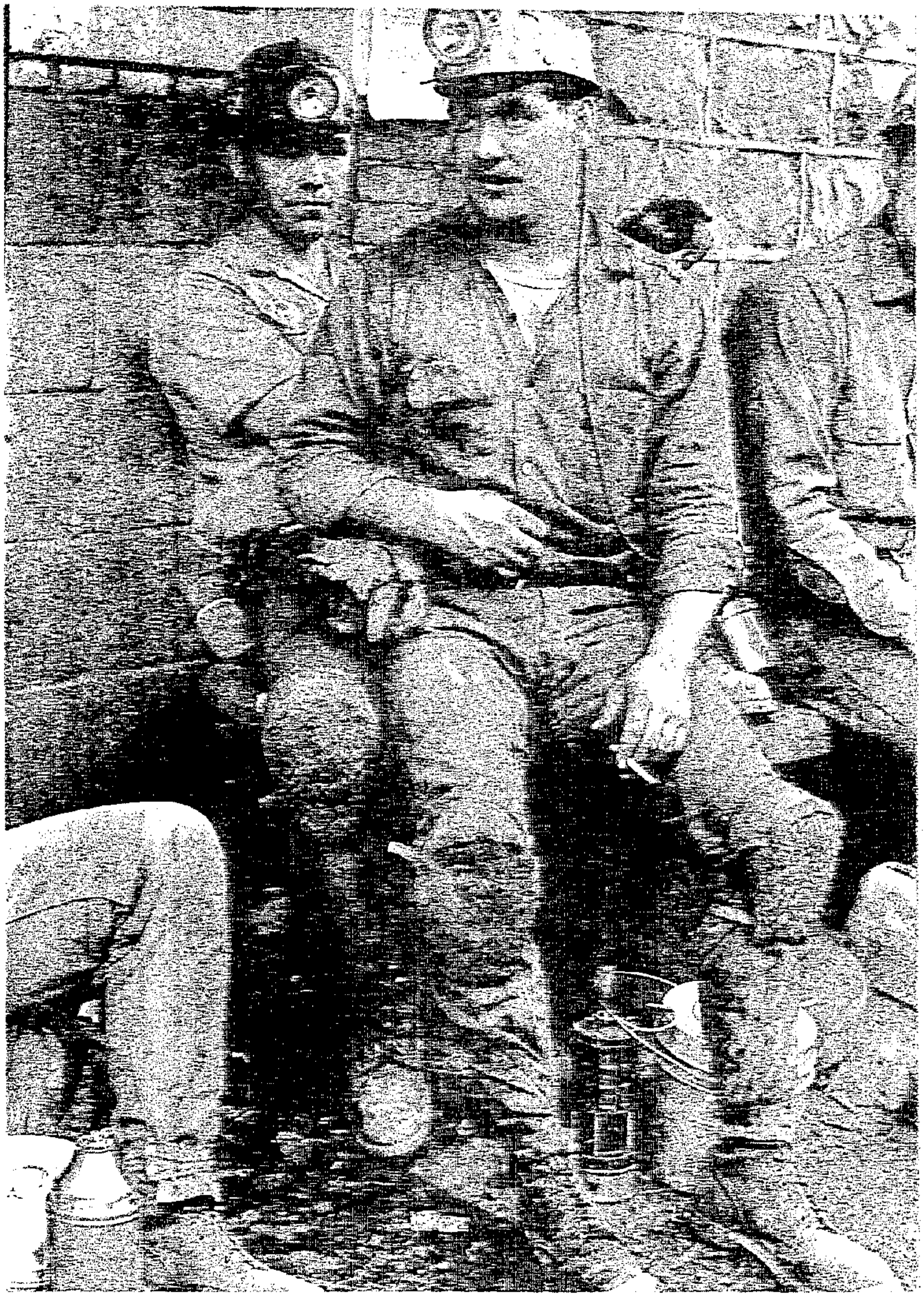

Fig. 4. Preference of one knee while working result in uneven wear of a pair of knee pads. Lower ends of the pads on the miner in the foreground have been cut off to reduce chafing on the shins.

Fig. 5. Clinging mud and grit indicate the degree of moisture and the type of surface encountered in a typical low coal mine.

Fig. 6. Home made repairs. The original straps broken, this miner replaced them with similar but wider ones, cut out of an old inner tube.

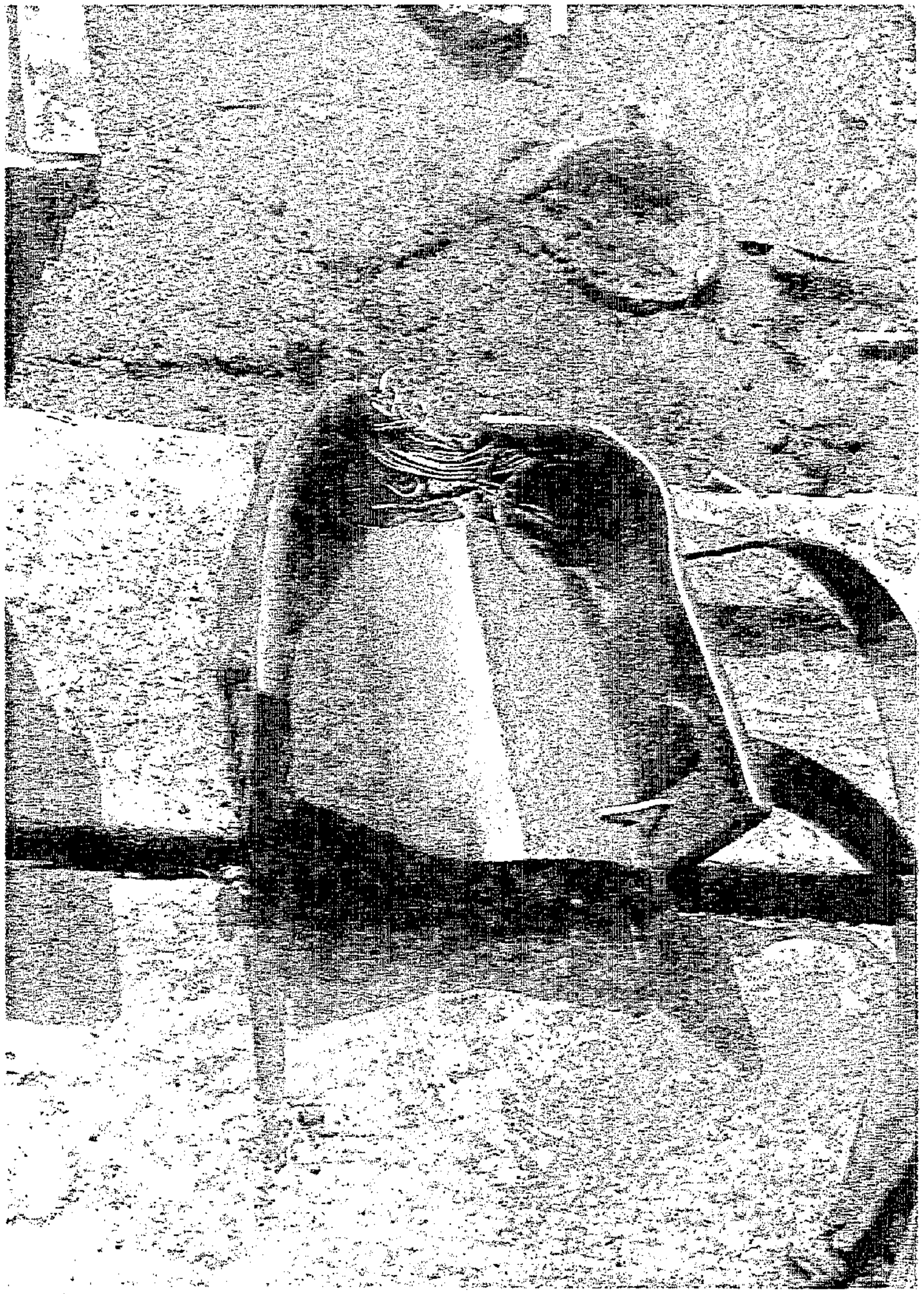

Fig. 7. On-the-spot repair of a torn knee pad.

Fig. 8. Knee pads are not as important to this motorman as they are to his co-workers who must kneel and crawl more; a couple of discarded pads of different types, held on with jury-rigged straps, are adequate for him.

Fig. 9. Improvisation: an extra inner cushion is added to make the pads more comfortable.

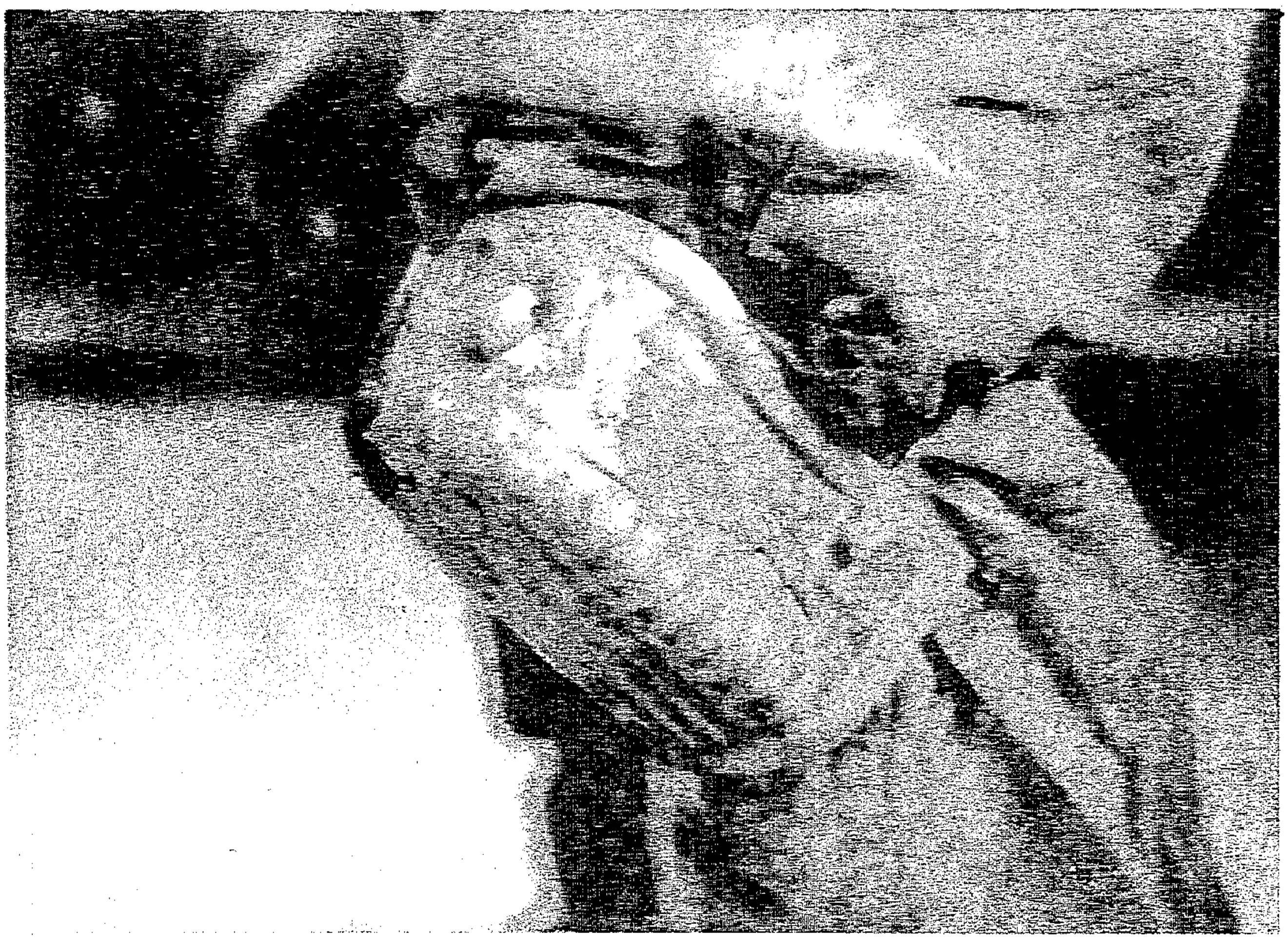

Fig. 10. Emergency repair: a well-worn pad is held on by what appears to be a single boot lace.

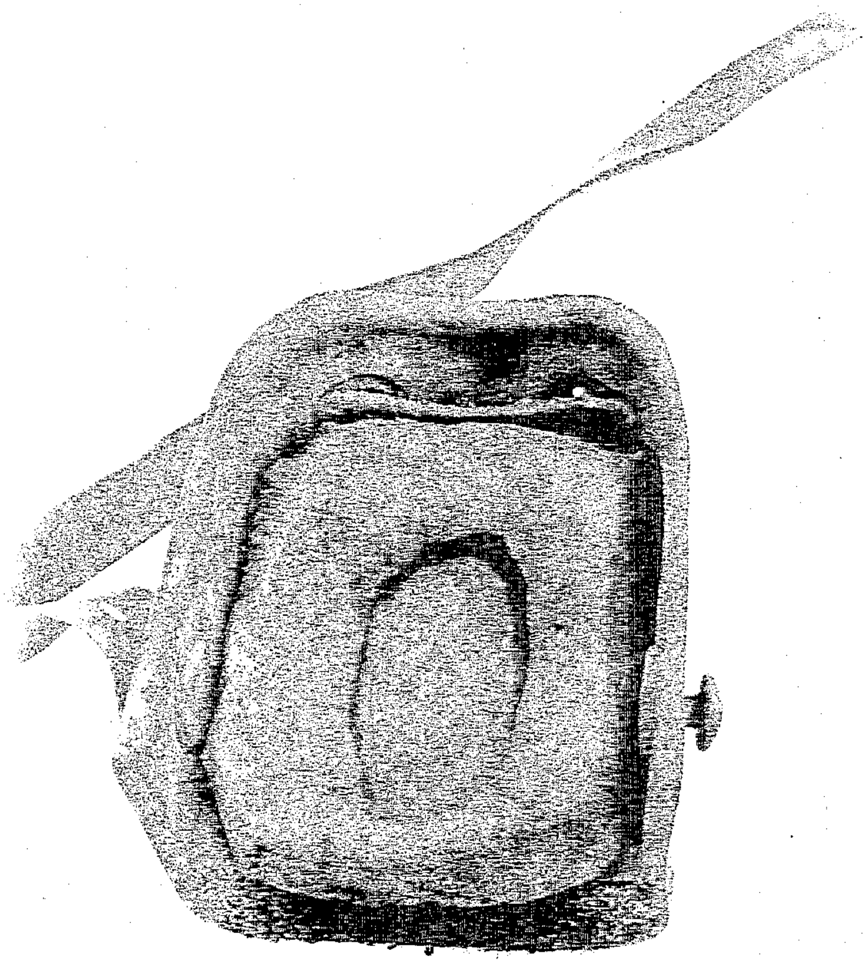

Fig. 11. Improvisation: The owner of this pad installed an extra cushion of his own design to reduce pressure on a bursitis-afflicted knee.

## Body Size of Coal Miners

# COMPARISON OF BODY SIZE OF COAL MINERS AND USAF FLYING PERSONNEL

As part of a study performed for the U. S. Bureau of Mines in 1970, Century Research Corporation obtained height and weight measurements of 126 coal miners who wear knee pads on their job.

In the following graphs, the central tendencies and the distribution of these height and weight figures are shown. The mean of each graph is then compared to the mean height and weight of USAF flying personnel.[1] The close similarity between the body size of miners and the military personnel justifies the use of the USAF data on knee measurements as applied to the coal miners.

Body dimensions, derived from a large sample of flying personnel,[2] are noted below. These apply to thigh and knee only.

In another Air Force study sizes were assigned eight categories; given here are "small regular" through "medium regular" to "extra large long."

| Dimension (Circumference in inches) | Size Category | | |
|---|---|---|---|
| | Small Regular | Medium Regular | Extra Large, Long |
| Lower thigh | 15.50 | 16.75 | 18.25 |
| Knee | 14.75 | 15.50 | 16.75 |

(Lower thigh circumference is measured around the thigh at a level just above the patella.)

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[1]U.S. Air Force, Anthropometry of Flying Personnel, 1950, WADC Technical Report 52-321, Wright Air Development Center, September 1954.

[2]U.S. Air Force, Anthropometric Data in Three-Dimensional Form: Development and Fabrication of USAF Height-Weight Manikins. Technical Documentary Report No. AMRL-TDR-63-55, September 1954.

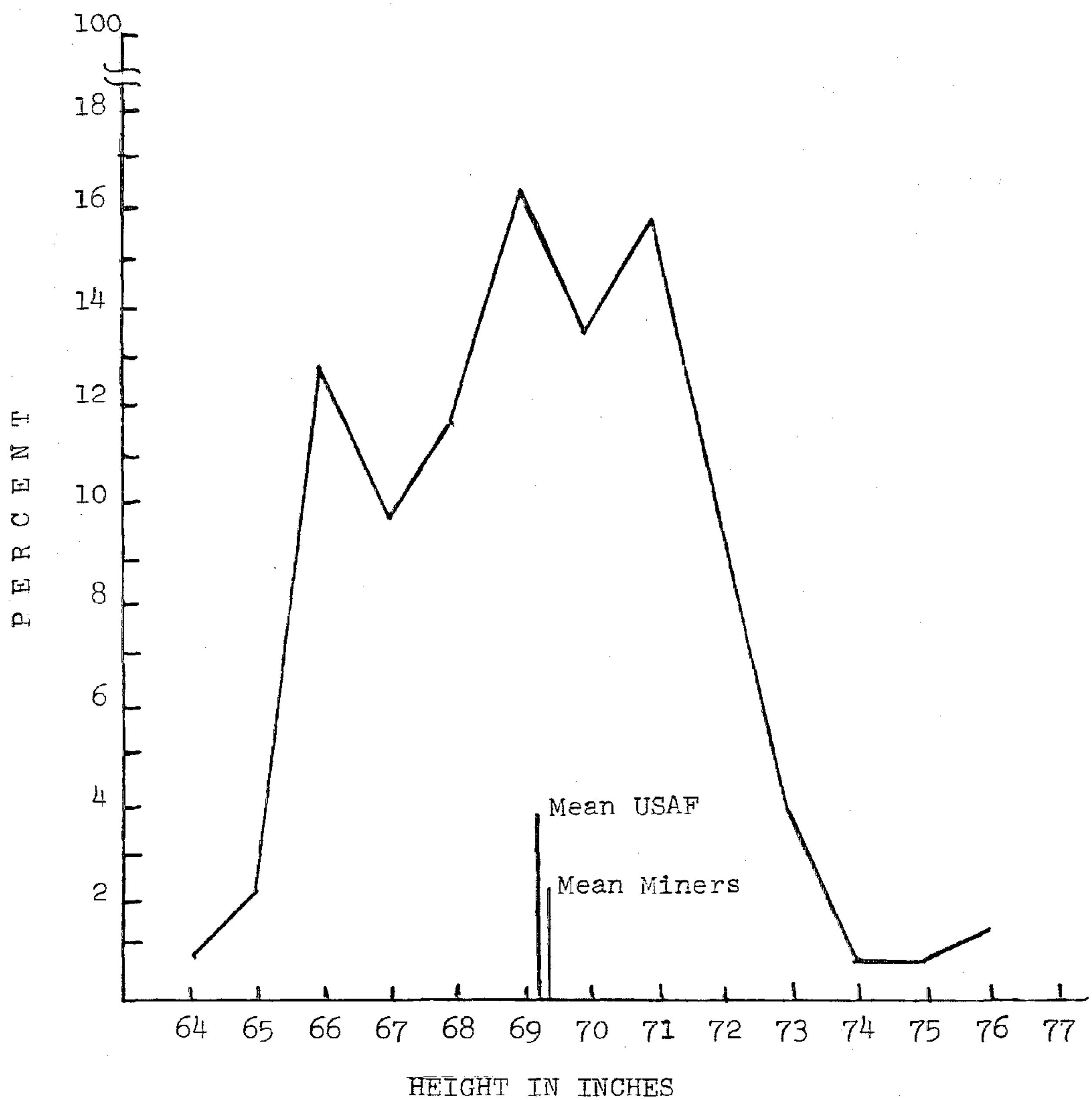



Fig. 12 Distribution of height of coal miners.

(Mean height of miners· 69.3"

Mean height of USAF personnel: 69.11")

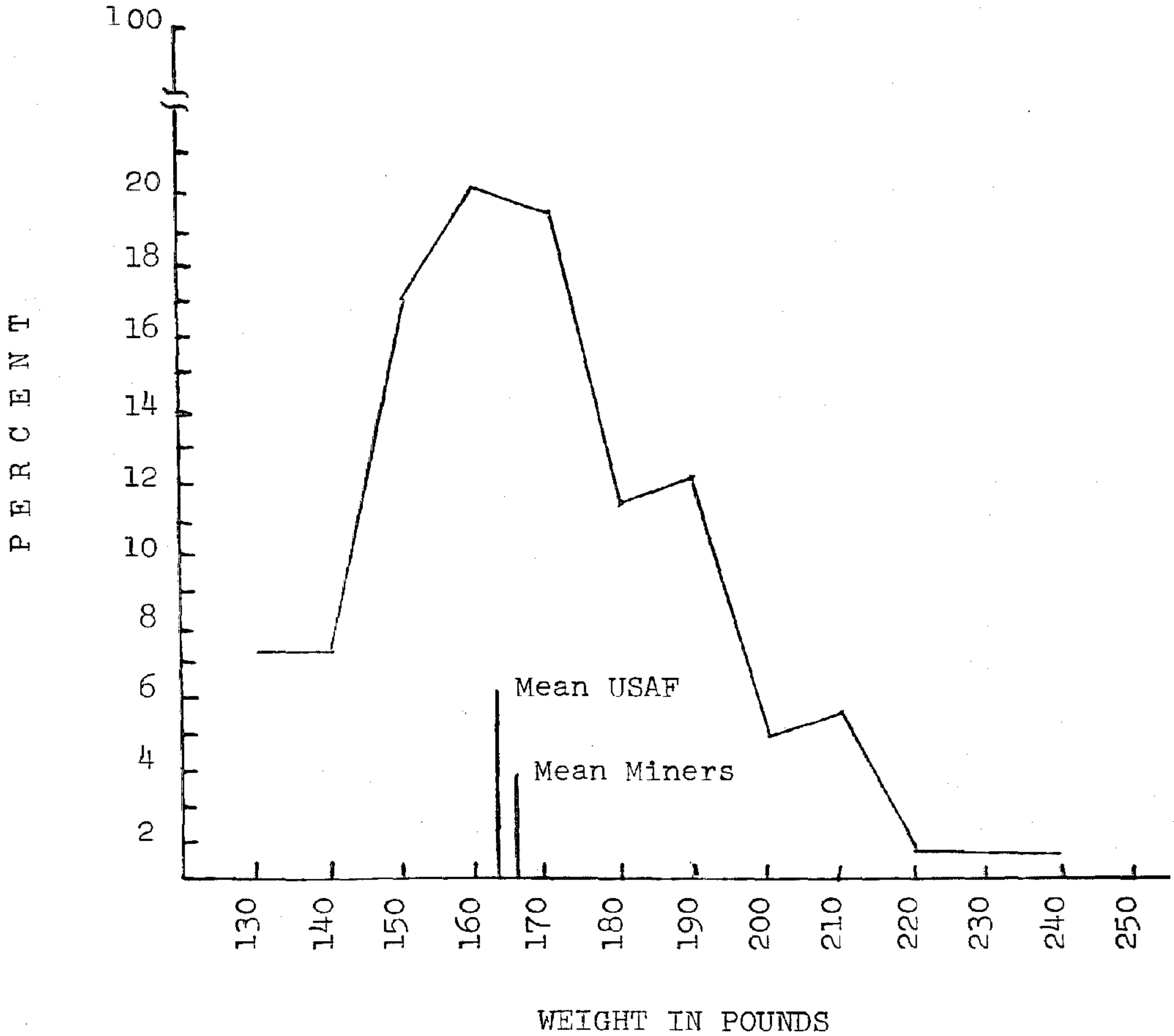



Fig. Distribution of body weight of coal miners.
(Mean weight of miners: 166 lbs.
Mean weight of USAF personnel: 163.7 lbs.)

Assuming the cross section of the lower thigh and the knee to be a $55^{\circ}$ ellipse (in which the width of the ellipse compares to its length roughly as 4:5) with the narrowest measurements across the ellipse corresponding to the width of the thigh or knee, then the widths corresponding to the above circumference are·

| Dimension (Width in inches) | Size Category Small Regular | Medium Regular | Extra Large, Long |
|---|---|---|---|
| Lower thigh | 4.48 | 4.78 | 5.22 |
| Knee | 4.10 | 4.48 | 4.78 |

All of the above measurements were made on the bare leg. Obviously, lower thigh and knee circumference and width measurements vary with the amount of clothing worn.

Winter clothing worn by underground miners, of course varies, but frequently consists of long underwear plus two pairs of trousers. These would measure approximately 0.3" thickness when lightly compressed. Thus, to the overall width of the knee, this adds 0.6".

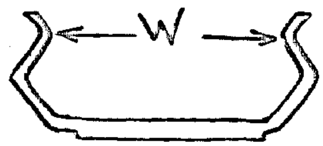
Combining all of the above data, this gives the following reasonable values for knee width measurements:

"Small Regular": 4.10" + 0.60" = 4.70"

"Medium Regular": 4.48" + 0.60" = 5.08"

"Extra Large, Long": 4.78" + 0.60" = 5.38"

Since only the lower one-third of the elliptical cross section of the knee needs to be accommodated by the outer shell, minimum inside width measurements for the two recommended sizes, based on the above knee width data, are as follows·




For small and medium size, "W" = 4.6 inches

For large size, "W" = 5.1 inches

With the recommended pad the top is levelled outward so the leg can slide into the pad with a slight side pressure thus being exerted in order to make a seal to keep grit out. The flexible side will give sufficiently to prevent irritating the side of the knee. The size of the submitted prototype is approximately that of existing knee pads.

# Material Selection

## MATERIAL SELECTION FOR THE OUTER SHELL OF THE PROTECTIVE KNEE PAD

Having compared the mechanical properties of about forty families of plastics as well as their relative costs, and then having compared them with the elastomers, it became evident that the elastomers' mechanical properties lend themselves much better to fabrication of an effective, relatively inexpensive outer shell for the protective knee pad.

They provide a much greater range in flexibility from rigid to resilient, and, unless one considers the relatively expensive plastics, the elastomers provide greater wear resistance across the board, especially abrasion resistance.

The following tables compare four of the most feasible elastomers with each other in the categories that were judged significant in selecting the material for the outer shell of the knee pad.

The choices were made out of fifteen of the most widely used elastomers. A comparative value has been assigned to each elastomer, judging its desirability on the basis of a given primary requirement plus a given secondary requirement. The fifteen elastomers were then compared to each other as to desirability in each of the categories listing different primary and secondary requirements. Only the top three contenders were taken out of each comparison and assigned numbers 1, 2 and 3. For example, in Table 1, cost is the primary consideration, and the elastomers' performance in any of nine other physical characteristics categories is the secondary consideration. It can be seen that in the category where "wear resistance" is the second most important requirement, synthetic rubber and styrene-butadiene are tied for first choice; an elastomer not considered for this particular application is the second best choice; and natural rubber is the third best choice where minimum cost and wear resistance are the two most important requirements.

In Table 2, the same requirements are listed as in Table 1, but here "wear resistance" is considered to be the most important requirement. If "impact resistance" is considered as the second-most important requirement, natural rubber, synthetic rubber and styrene-butadiene would all be tied for first choice, and neoprene would be the second best choice.

Tables 3 and 4 are based on the same principle, listing "tear resistance" and "impact resistance" as their primary considerations, respectively.

Explanatory Notes

The following notes provide additional information about those listed requirements that are not completely self-explanatory.

Minimum Cost -

Refers to the cost of the raw material, as compared to that of other elastomers; low cost would be on the order of from 10¢ to 15¢/lb. per truckload.

Wear Resistance -

Refers to the type of wear brought about by abrasion.

Low Temperature Resistance -

Comparative rate at which loss of flexibility takes place. For the elastomers mentioned in these tables, most drastic changes in flexibility occur in the -10° to -25°F temperature zone. The brittle point, at which the elastomer shatters on sudden bending or impact, is in the -60° to -80°F temperature zone for the elastomers concerned.

Heat Resistance -

Of relatively little consequence, since performance degradation for all four of the elastomers concerned begins only at temperatures above 200°F.

Weather Resistance -

Refers to prolonged exposure to sunlight, ozone, oxygen.

No entry of 1, 2 or 3 means that the elastomer concerned does not rate a 1st, 2nd or 3rd choice out of 15 in the particular combination of primary and secondary requirements in which the "no entry" occurs.

COMPARATIVE QUALITIES OF FOUR ELASTOMERS

Table 1

Primary Factor:
Minimum Cost

| Secondary Factor | Elastomer | | | |
|---|---|---|---|---|
| | Natural Rubber (NR) | Synthetic Rubber (IR) | Neoprene (CR) | Butadiene-Styrene (SBR) |
| Wear Resistance | 3 | 1 | | 1 |
| Tear Resistance | 2 | 1 | | 1 |
| Impact Resistance | 3 | 1 | | 1 |
| Water Resistance | 3 | | | 2 |
| Low Temperature Resistance | 2 | | | |
| Oil Resistance | | | 1 | |
| Heat Resistance | | 2 | | 2 |
| Weather Resistance | 3 | 2 | | 2 |
| Bonding Capability | 2 | 1 | | 1 |

COMPARATIVE QUALITIES OF FOUR ELASTOMERS

Table 2

Primary Factor:
Wear Resistance

| | Elastomer | | | |
|---|---|---|---|---|
| Secondary Factor | Natural Rubber (NR) | Synthetic Rubber (IR) | Neoprene (CR) | Butadiene-Styrene (SBR) |
| Minimum Cost | 2 | 1 | | 1 |
| Tear Resistance | 1 | 1 | 2 | 2 |
| Impact Resistance | 1 | 1 | 2 | 1 |
| Water Resistance | 2 | 2 | | 2 |
| Low Temperature Resistance | | | 2 | |
| Oil Resistance | | | 2 | |
| Heat Resistance | 2 | 2 | 2 | 2 |
| Weather Resistance | 2 | 2 | 1 | 2 |
| Bonding Capability | 1 | 1 | 1 | 1 |

COMPARATIVE QUALITIES OF FOUR ELASTOMERS

Table 3

Primary Factor:
Tear Resistance

| Secondary Factor | Elastomer | | | |
|---|---|---|---|---|
| | Natural Rubber (NR) | Synthetic Rubber (IR) | Neoprene (CR) | Butadiene-Styrene (SBR) |
| Minimum Cost | 1 | 3 | | 3 |
| Wear Resistance | 1 | 2 | 2 | 2 |
| Impact Resistance | 1 | 2 | | 2 |
| Water Resistance | 1 | 1 | | 2 |
| Low Temperature Resistance | 1 | | 2 | |
| Oil Resistance | | | 3 | |
| Heat Resistance | 1 | | | |
| Weather Resistance | 2 | | 3 | |
| Bonding Capability | 1 | 3 | 3 | 3 |

COMPARATIVE QUALITIES OF FOUR ELASTOMERS

Table 4

Primary Factor:
Impact Resistance

| Secondary Factor | Elastomer: Natural Rubber (NR) | Synthetic Rubber (IR) | Neoprene (CR) | Butadiene-Styrene (SBR) |
|---|---|---|---|---|
| Minimum Cost | 2 | 1 | | 1 |
| Wear Resistance | 2 | 2 | | 2 |
| Tear Resistance | 1 | 2 | | 2 |
| Water Resistance | 2 | 2 | | 1 |
| Low Temperature Resistance | | 2 | | 1 |
| Oil Resistance | | | 2 | |
| Heat Resistance | 1 | 1 | | 1 |
| Weather Resistance | 2 | 2 | | 2 |
| Bonding Capability | 1 | 1 | | 1 |

## INTERPRETATION OF TABULAR DATA

Table 1. With minimum cost the primary factor is material selection, the order of the most desirable material selection would be as follows;

1st choice: Styrene-Butadiene (SBR)
2nd choice: Synthetic Rubber (IR)
3rd choice: Natural Rubber (NR)

Table 2. If wear (abrasion) resistance is considered the primary factor, the results would be similar to those of Table 1:

1st choice: Styrene-Butadiene (SBR)
2nd choice: Synthetic Rubber (IR)
3rd choice: Natural Rubber (NR)

Table 3. With tear resistance the primary factor, the result is:

1st choice: Natural Rubber (NR)
2nd choice: Synthetic Rubber (IR)
3rd choice: Styrene-Butadiene (SBR)

Table 4. When impact resistance is considered as the primary factor, the best choices line up as follows:

1st choice: Natural rubber (NR)
2nd choice: Styrene-Butadiene (SBR)
3rd choice: Synthetic Rubber (IR)

In the mining application, wear resistance is a primary requirement, followed by tear and impact resistance. Since Styrene-Butadiene ranks consistently relatively high in these requirements and compares favorably in price with the other elastomers concerned, it is a highly desirable material for the outer shell.

Special Note About Urethane

Since all four tables were compiled with the cost consideration as one of the two most important factors, some other highly qualified materials have been omitted from the tables. Among these, the urethanes rate the best with regard to mechanical properties. Solid polyurethane with a hardness of 70-durameter rates higher than styrene-butadiene in abrasion resistance, and compares favorably in all the other categories mentioned in the tables. The inner cushion could be made of the same raw material, urethane foam, which could be a factor in overall production cost. The price of the urethanes is considerably higher than the other elastomers, however, in the area of $1.00 to $1.50/lb. per truckload.

## Performance Specifications and Design Justifications

Special Note: The following section discusses the development of two preliminary prototypes which were later superceded and that of a third, which is the prototype submitted. Only one type of cushion, the second to be developed, is submitted.

PERFORMANCE SPECIFICATIONS AND
DESIGN JUSTIFICATIONS FOR
KNEE PROTECTIVE DEVICES
(PROTOTYPES 1, 2. and 3)

## PERFORMANCE SPECIFICATIONS

### Outer (Protective) Shell

The prototypes described herewith all consist of two major components· an outer shell which serves to provide a footing and traction and which protects the knee from bruises, cuts and abrasions caused by contact with the ground; and an inner cushion, designed to distribute the load on the knee over as large an area as possible under a variety of knee positions, to absorb shocks, and to reduce friction between the knee and the outer shell.*

An investigation of the environmental conditions in coal mines which largely determine the performance specifications for the outer shell of the knee pad has led to the following requirements for material and design of the shell·

Wear resistance (abrasion). The material shall be highly resistant to abrasion. The design shall be such as to minimize areas of concentrated abrasion other than treads molded into the sole of the shell to improve traction.

Impact resistance. The material shall be highly resistant to shattering, rupture or deformation due to impact.

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*A thorough investigation of the physical properties of a number of elastomers has led us to the conclusion that none meet the requirements for both the protective shell and the cushion. Therefore. our development has been along the lines of a pad consisting of the two components made of different materials.

Resistance against sharp objects (puncture resistance). The material shall be resistant to puncture by sharp objects likely to be found in a mine, such as jagged rocks.

Tear resistance (toughness). The material shall be highly resistant against tear through shearing action once an incision is made.

Water resistance. The mate ial shall not absorb water or be in any way affected by regular immersion in water.

Resistance against chemicals. The material shall not be adversely affected by calcium, weak sulphuric acid solutions or occasional contact with hydraulic fluid and mineral oil.

Temperature range. The material shall not be significantly affected by temperatures between -20°F and 160°F.

Weight. The material shall be comparable in weight to the neoprene compounds found in most currently used knee pads.

The design of the shell must provide protection from the area immediately above the knee cap down to the uppermost part of the shin bone. Protection to the sides of the knee is desirable, but of relatively minor importance.* Bulk of the shell must be kept to a minimum both in length and width.

The configuration shall be such that adequate protection as mentioned above is afforded while the wearer is in a kneeling position and a minimum of rubbing or chafing results when the wearer is walking. Openings in the shell must be kept to a

---

*See "Design Justifications"

minimum to avoid collecting grit or mud. Whatever material does enter the shell must be easy to remove, preferably without the wearer having to remove the pad.

The shell bottom or sole shall be of a size and shape that does not impede the wearer's stability while kneeling and while crawling on uneven surfaces; it shall provide adequate traction on such surfaces; and it shall have enough ground contact area to minimize wear.

## The Inner Cushion

As mentioned before, the function of the inner cushion is to distribute the load on the knee to as large an area as is possible, to absorb shocks, and to reduce friction between the knee and the outer shell. In performing this function, it is desirable that the cushion keep the knee as dry as possible by causing a minimum amount of sweating, and by forming an effective barrier against outside moisture.

The required physical properties of the material for the cushion vary with the configuration of the cushion; for example, its thickness determines the density or relative hardness of the material. The thinner the cushion, the more density is required to prevent the cushion from "bottoming out" under full load.

The cushion may consist of a single type of material throughout, in which case the material must be non-water absorbent and highly tear-resistant, or it may be a sponge type core inside a resilient moisture-proof envelope which protects the core from abrasion and the wearer's knee from moisture.

Chemical resistance requirements for the cushion material are similar to those for the outer shell material; i.e., the cushion shall not be adversely affected by calcium, weak sulphuric acid solutions, or occasional contact with hydraulic fluid and mineral oil.

As to temperature range, the cushion material shall not be significantly affected by temperatures between -20°F and 160°F.

The cushion shall be designed to provide comfortable support to the knee in typical kneeling positions, and while crawling, over extended periods of time. It shall distribute the load on the knee while the wearer is kneeling or crawling, in such a way as to minimize pressure concentrations on bony protrusions such as the patella, the tibiar tubercle, or the upper portion of the shin bone. The cushion must not restrict the wearer while walking, or cause discomfort.

It shall cause a minimum of sweating and shall not allow outside moisture to reach the knee through its upper surface. It shall be of a configuration that discourages entry of foreign matter such as grit or mud between it and the knee. Removal of such matter should be a simple operation and should not require removal of the knee pad.

The cushion shall be installed inside the outer shell in a secure manner that keeps it firmly in place while in use, and that prevents unintentional removal from the shell.

Fastening Device

The device which holds the knee pad in place during use shall be sturdy but not bulky. It must be simple to fasten, adjust, and loosen. It shall hold the knee pad firmly in the desired position during use with a minimum of chafing or binding and it shall cause no objectionable sweating. It shall not allow the knee pad to sag or creep up while the wearer is walking.

Fastening straps on most currently used knee pads require frequent repair or replacement. The proposed fastening device shall be of sufficiently rugged construction to minimize the need for repair or replacement. It shall be so designed that if replacement is required, it can be easily and quickly done without the need for special equipment.

## DESCRIPTIONS AND DESIGN JUSTIFICATIONS

(See dimensional sketches)

Prototype No. 1

Proposed shell material: Polyurethane, .125" thick, harness 70-durometer.

Proposed cushion material: Medium to high density, fine pore, closed cell polyurethane resilient foam, bonded to the upper structure of the outer shell with dimethylformamide or any of five other recommended solvents.

Prototype No. 1. originated following the theory that a semi-rigid support contoured to the knee joint in a flexed position would provide more evenly distributed support than the traditional flat cushion. The theory further held that with this design, pressures on the knee would remain more or less even during use, regardless of the unevenness of the surface knelt on or crawled over, because of the rigidity of the snugly fitting cup around the knee joint. In the currently used knee pads, the shell is resilient, allowing an unevenness on the surface to be transmitted to the knee through the shell, resulting in an area of concentrated pressure on certain areas of the knee. (See Fig. 14.)

The upper and lower structures of the outer shell form an integral part. The reason for this configuration is twofold: (1) the contour-molded cup around the knee joint does not have the amount nor the shape of surface required for the bottom of the knee pad; and (2) the present configuration offers significant shock absorption.

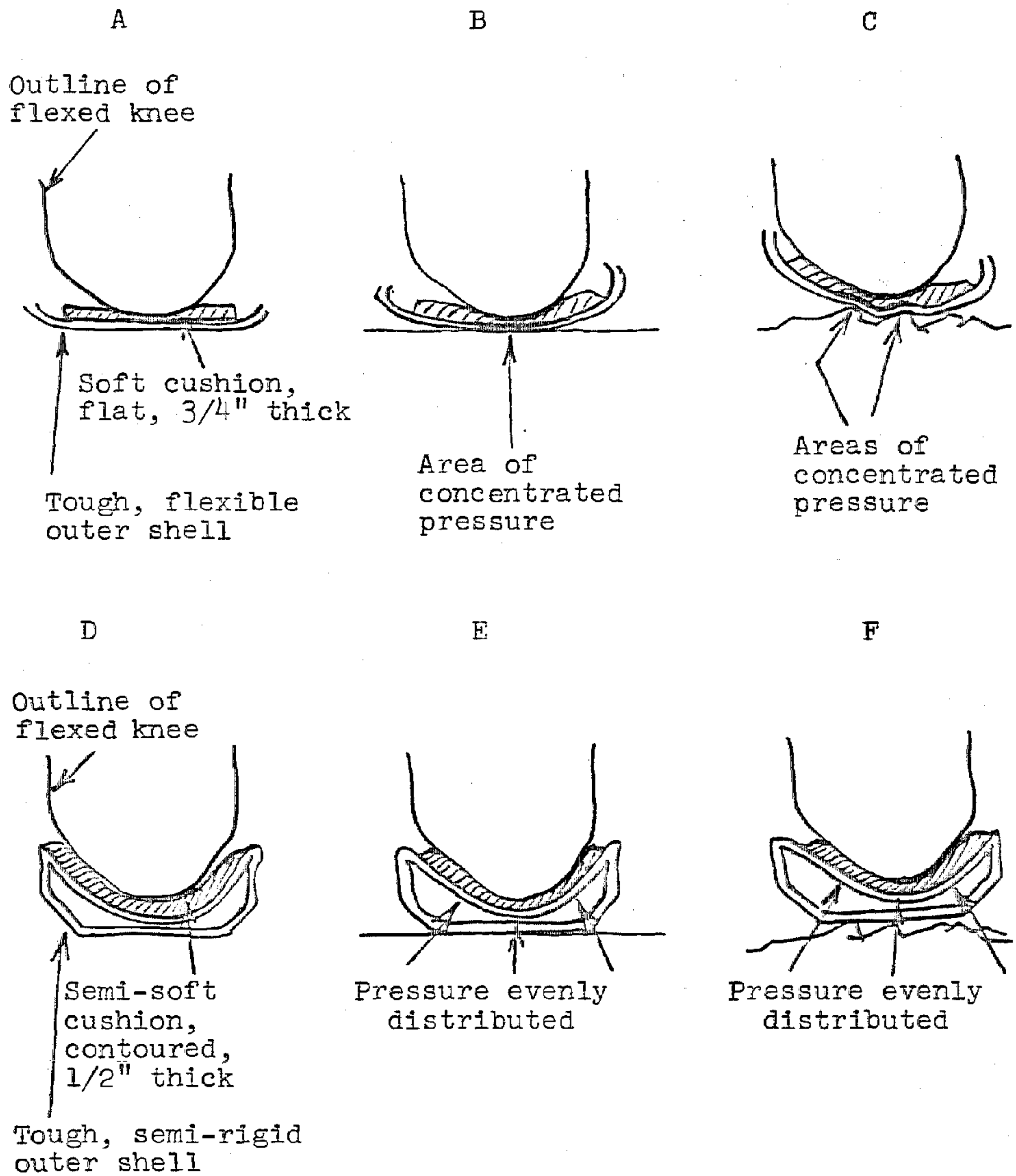



Fig. 14. Pressure patterns of various knee pads. (Top) Diagram of commonly used knee pad (A), being used on a flat surface (B), and on an uneven surface (C). (Bottom) Diagram of prototype of proposed knee pad (D), being used on a flat surface (E), and on an uneven surface (F).

Consideration was given to combining the semi-rigid knee support cup with a flexible lower structure. The advantage of such a combination would be an even greater shock-absorbing capability. But discussions with plastics fabricators have since led us to conclude that the improvement would probably not be enough to justify the added cost of manufacture of this modification.

The bottom surface of the sole was made flat, obviously, for stability. Overall width was determined by the width of the knee support cup plus the side supports joining it to the lower structure of the shell. The diagonal side portions of the sole were added for three reasons: (1) to provide some stability when the wearer is half sitting-half kneeling with the side of the knee resting on the ground; (2) a 90° edge would provide an area of greater than average wear; and (3) a 90° angle would concentrate loads in a narrow area, encouraging cracks to form along the edge.

The forward section of the bottom is slanted upward for the same structural and wear reasons as the sloping sides. From the wearer's point of view, the slant helps when crawling.

The knee support cup of prototype No. 1 is snug fitting. Molded on one of three sizes of molds depicting a knee in fully flexed position, it fits the knee with approximately 1/4" of space all around between it and the knee, which is taken up by the cushion and the wearer's clothes. The snug fit necessitates differently shaped cups for the right and the left knee, mirror images of each other, like shoes.

The cushions inside the cups are also asymmetrical mirror images of one another to fit the contours of the cups.

The snug fit around the knee joint also helps prevent the entry of grit, mud or other foreign matter between the knee and the pad.

Perforation of closed-cell foam cushions, or molded pebble patterns on an impermeable envelope over a sponge cushion, would minimize sweating.

Prototype No. 2

Proposed Shell Material: Polyurethane* .125" thick; hardness 70-durometer.

Proposed Cushion Material: Medium density, fine pore, closed cell polyurethane resilient foam, bonded to the upper structure of the outer shell with dimethylformamide or any of five other recommended solvents.

The design of prototype No. 2 is basically similar to that of No. 1 with the following changes made for the reasons given: because of the significant change in shape which the knee joint makes when going from the fully flexed to the semi-flexed position, a single mold was made to represent the knee joint in multiple positions between fully flexed and semi-flexed (at a right angle), similar to a multi-exposure photograph. The resulting knee support cup was shallower than No. 1, providing somewhat less protection to the sides of the knee, and requiring a somewhat thicker cushion. (Results of our survey of miners and mine inspectors have indicated that injuries or painful blows to the sides of the knee are so rare that we consider the side-protection feature a relatively unimportant one.) The pressure points were eliminated in all kneeling positions between fully flexed and semi-flexed. The fit was still snug enough, however, that the requirement for separate right and left knee support cups remained. A single shape of cushion will comfortably fit both the left and the right cup.

Before a third prototype of this group was developed which was to have been molded on a composite of both left and right knees in multiple flexed positions, further discussions with plastics fabricators pointed up the significantly lower manufacturing cost of a different configuration using a basically three-sided rather than four-sided shell. Since a high manufacturing cost would obviously result in a high marketing price, the rest of our prototype research has been concentrated on this less costly configuration, but incorporating the same basic design principles.

Prototype No. 3

Proposed Shell Material: Polyurethane, 1.25" thick; hardness 70-durometer.

Proposed Cushion Material: Molded, fine pore, closed cell polyurethane resilient foam.

Prototype No. 3 consists of an outer shell which is a barge-shaped structure, open at the rear, and with the same basic bottom shape as Nos. 1 and 2, for the same reasons. The shell measures 9" long by 5" wide. (See dimensional sketches.)

Being a semi-rigid structure, the shell's profile has been kept low so as to prevent chafing against the front part of the lower thigh when the wearer is standing or walking. (See Fig. 19.)

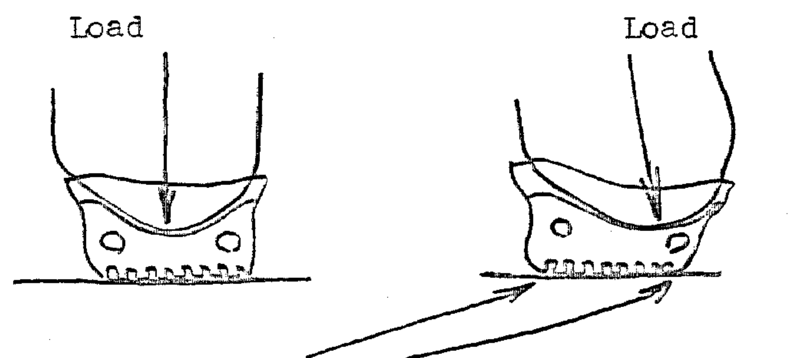
One of the conclusions resulting from interviews with miners and mine inspectors was that there are individual preferences for degrees of softness and overall height of knee pads. Another finding was that some users preferred a certain type of knee pad, the German-made Nierhaus pad, for its comfortable support, but ended up using another type because of the tendency of the Nierhaus pad to "roll under" under a side load. (See Fig. 15.)

For this reason, three types of cushions were developed for prototype No. 3, each differing in configuration, softness and height.

The first cushion is shaped like a doughnut, measuring 5" outside diameter, 3" inside diameter and 1" thick. It is to be molded of high-density, self-skinning polyurethane closed-cell foam. When installed, it becomes narrower and longer, measuring 4" outside width, 2" inside width, approximately 6" outside length and 4" inside length. Elastic tension pushes it against the curved sides of the shell, keeping it in place. When in use, the tibiar tubercle and the lower part of the patella fit inside the opening of the doughnut.

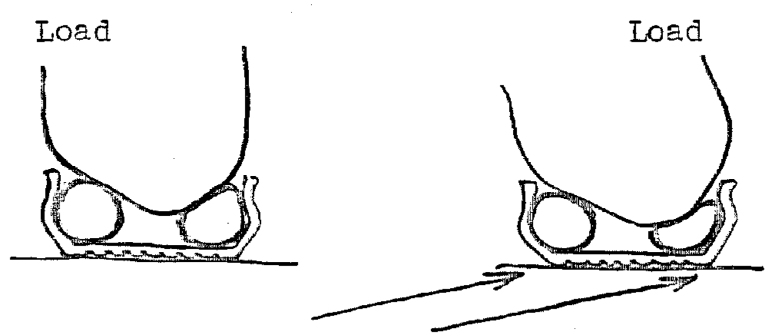
The wearer's weight is borne by the upper part of the shin bone resting on the aft or rear end of the doughnut, the portions of the knee joint on either side of the patella, resting on the sides of the doughnut, and the midsection of the patella which is supported by the forward section of the doughnut.

A




Pad deforms under side load, "roll under" starts.

B




Pad maintains original shape under side load.

Fig. 15. Effect of side load on high profile knee pads with flexible shell (A) and with semi-rigid shell (B).

The second cushion consists of a cylinder, 17" long, 1-1/2" in diameter, and made of the same material as the first cushion, but of a lower density. When installed, it is bent into a horse-shoe shape with an outside width of 4", an inside opening 1" wide and 6-1/2" long, and an overall length of 8".

This cushion supports the bearer's weight along two rectangular areas on either side of the patella and the tibiar tubercle, removing pressure from the pre-patellar bursa. (See Fig. 16.) In front, the cushion curves snugly around the patella, minimizing openings through which grit or mud can enter between it and the wearer's knee. (See Fig. 17.)

The cushion is held in place by elastic tension and by two "Velcro" fasteners, bonded to it and to the inside of the outer shell. The prototypes submitted were equipped with this cushion.

The third cushion that was developed for prototype No. 3 was designed for those users whose preference tends towards a high profile, very soft pad. The cushion is molded of soft, low density foam and measures 3" thick. It is rectangular in shape, approximately 4" wide by 8-1/2" long. An oval shaped hole, measuring approximately 2" by 3-1/2" is located in the forward center section of the cushion. The tibiar tubercle and the lower part of the patella fit into this opening when the knee is flexed, and all the load is removed from those two areas and distributed evenly to the surrounding areas of the knee joint.

The cushion may be molded out of a single piece of closed cell polyurethane low density resilient foam which is perforated for ventilation, or it may consist of two parts: a fine-pore

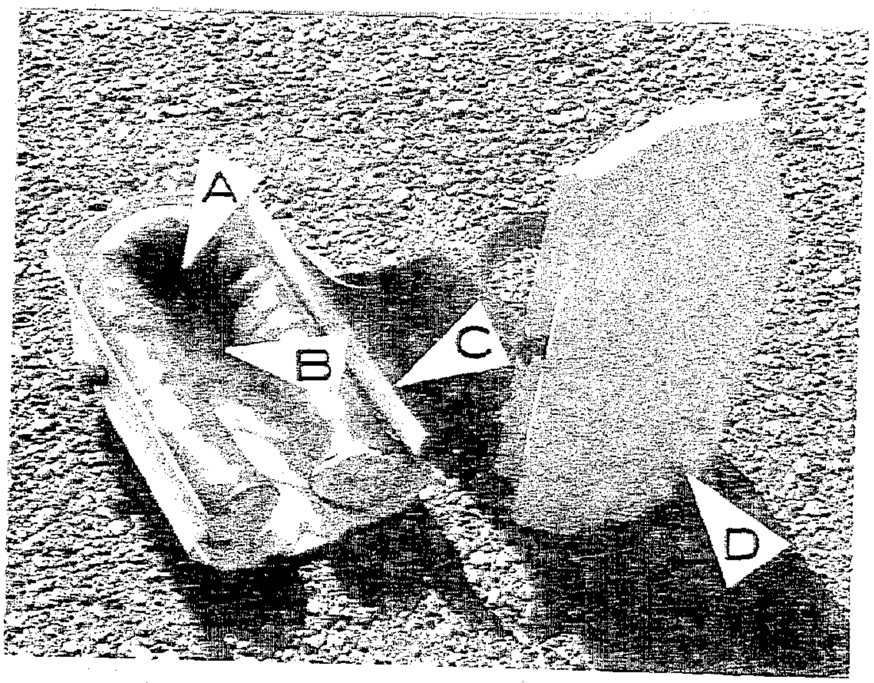



Fig.16 Approximate position of the patella (A) and the tibiar tubercle (B). Sides of shell are flared to prevent chafing (C). Molded tread design improves traction (D).


Fig. 17 The wearer's knee is snugly cradled in a contoured cushion (A).

latex sponge cushion covered on top and on the sides by a neoprene or comparable resilient impermeable material approximately 0.1" thick, with a pebble or other pattern molded in it to aid ventilation.

The single piece cushion would obviously be the least expensive. However, field tests would have to establish whether or not an unprotected low density foam will hold up under the strenuous conditions to which it will be subjected in a mine.

## The Fastening Strap

Material: Neoprene, 0.05" thick;
"Velcro" fastener with buckle, or
neoprene buttons.

The two major complaints about knee pad fastening straps noted by our investigators during the knee pad user survey were that they broke too easily, chafed the back of the knee area, caused popliteal cysts, and were generally uncomfortable. Further investigation showed that the narrow, non-elastic straps made of leather or cloth were the worst offenders in causing discomfort. Those regularly available straps judged most comfortable by users were thin (0.05") rubber or neoprene, just under an inch wide. But these same straps were rated low in durability. Also it was noted that "homemade" replacement straps made of old inner tubes were often wider.

All of the knee pads observed in use by our investigators had originally been sold with two straps, one which would go around the leg at the knee and one immediately below. It was noted that a number of users had either removed the upper straps from their knee pads altogether, or left them undone or very loosely fastened. They gave two reasons for doing this: the upper strap irritated the area behind the knee, especially on the hamstring, when it was tightened and the wearer was working in a kneeling position or crawling; the other reason given was that two straps caused too much bulk in back of the knee, causing a binding type of discomfort when the knee was flexed.

The material chosen for the prototype fastening strap was neoprene, because:

1. It has good resilience.
2. It is easily cut to shape.
3. It is cheap. (An auto or truck inner tube can be cut to make replacements.)

The recommended fastener consists of a single strap, contoured to pass around the leg below the knee, yet hold the upper or forward part of the knee pad firmly in place. The extra width of the strap (approximately 2" wide at its narrowest point) will help make it more durable than the currently used neoprene straps. The strap is perforated for ventilation.

Strap-to-shell connection is by three neoprene buttons installed in three holes in one side of the shell.

Fastening and adjusting the knee pad is through a fourth neoprene button; three button holes (slit-shaped) in the strap provide for comfort adjustment. (See Fig. 18.)

An alternative method for adjustable fastening is through a "Velcro" loop strap-and-buckle arrangement that is quick and eas;


Fig.18 Fastening strap is contoured (A) to provide adequate fastening while causing minimum chafing. Strap is ventilated (B) for additional comfort.

to adjust, and appears strong and durable. However, difficulties in attaching the "Velcro" to the neoprene strap make the first-mentioned fastening method more feasible at present. This fastening method merits additional study, however, because of its infinite adjustability and quick attach and detach characteristic.


Fig. 19 Top front rim (A) of the outer shell is cut low to avoid chafing when walking.

# Notes on the Submitted Prototype

## NOTES ON THE SUBMITTED PROTOTYPE FOR A PROTECTIVE KNEE DEVICE FOR MINE WORKERS

The prototypes submitted embody the design recommendations and the material selection made earlier during this study.

The method by which these prototypes were manufactured, however, is entirely different from the mass production method for which they were designed, and some significant differences between the prototype and the production model must be pointed out.

### The Outer Shell

The outer shells of the prototypes have been shaped through a process called vacuum forming, which lends itself to economical molding of simple forms in relatively small quantities. The process requires a certain amount of manual labor which is the main cause for the diminishing returns. In addition, vacuum forming is limited to shapes of more or less uniform wall thickness. The treads on the soles of the prototype shells are hollow for this reason, and reinforced areas through variations in wall thickness do not appear. Also, the treads do not run the full width of the knee pad bottom on the prototypes as a result of the vacuum forming process.

The production method recommended for the outer shell, if quantities of 3,000 or more are to be produced, is injection molding. This process is more highly automated, and it allows for different wall thicknesses. The tooling up cost for this process is considerably higher, however, and would be about \$3500 - \$4500 for this particular shape.

The recommended production configuration of the shell would compare to the prototypes submitted as follows·

Material. Styrene-Butadiene (SBR) or polyurethane, depending on cost considerations.

Material hardness. Same as prototype, 70-durometer.

Material finish. Dull black.

Overall size and configuration. Same as prototype, except for treads which will run the full width of the knee pad bottom.

Wall thickness. 0.125 inches throughout, except for a double thickness (0.250") bead, .375 inches wide, running along the entire rim on the outside of the shell. Rim should be rounded.

Treads. Same as prototype, except the treads should be solid, and the inside bottom of the shell, flat.

## The Inner Cushion

The configuration of the inner cushions of the prototype knee pads, and their physical characteristics such as water resistance of the outer skin, flexibility, and resilience are all as recommended for the production models, except that the diameter of the submitted cushion is $1\frac{1}{2}$", whereas the diameter of the recommended production cushion is $1\frac{3}{4}$". For the material, self skinning neoprene or polyurethane foam is recommended, again dependent on cost. The foam would be a fine pore, open cell type, with a skin thickness of approximately 3/32". Like the prototype, the skin would not cover the ends of the cushion, allowing moisture to enter and to be squeezed out freely.

From the point of view of production cost it would be significantly more economical to mold the cushion as a straight cylinder and bend it into shape before installing it rather than molding it in a horseshoe shape.

The Fastening Strap

Same as prototype; die-cutting rather than molding would be most economical production method for the strap itself.

The rubber grommets used to fasten the strap to the knee pad are borrowed from an existing, German made knee pad, the Nierhaus pad, made by Continental Rubber Works.

When designing the mold for production of the fastener buttons, it is suggested that the design be changed to make the fastener more adaptable for use with a semi-rigid outer shell. (See page B-10, Appendix B).

APPENDIX A

INTERVIEW GUIDE

Note: The form which is attached hereto was used as a guide in interrogation of men who were experienced in using knee pads.

## INTERVIEW GUIDE

(Knee Pad Project)

We are doing a study regarding the use and effectiveness of protective knee pads by men in coal mining. We plan to use the information for the development of knee pads that provide better protection and are more comfortable than those now in use. (Our company is sponsored in this research program by the Bureau of Occupational Safety and Health of the U. S. Department of Health, Education and Welfare.)

I will ask you some questions regarding your work and working conditions. All of the questions are related to knee protection and what can be done to improve it.

* * * * * * * * * * * *

Interviewer's initials ________ Date ________

Facility name or number ________________

Interviewee:

I. USBM employee ______ Age ____ Height ____ Weight ______

Inspector ______

Other (specify) ________________

How long in job requiring knee pads ____________ years

II. Mining Co. employee ______ Age ____ Height ____ Weight ______

Job name ________________

How long in job requiring knee pads ________ years

(Optional) ( Name ________________
( Address ________________
( Phone ____________

Range of height of ceiling worked under, in inches: ______ to ______
Average height most frequently worked under: ________ inches.

Approximately how many hours a day spent kneeling ________.
Approximately how many hours a day spent crawling ________.

Experience impact (blows, etc.) on knees as well? Yes____ No____

Type: ____________________________________________

Floor surface moist: most of time___ sometimes___ never___
Wet, w/standing water: most of time_____ sometimes_____ never____
Chemicals on ground: oil_____ gas______

other____________

Protruding nails, wood splinters, other sharp objects:
frequently_____ rarely_________

PRESENTLY USED PADS

Type: Nat'l Mine Svce. Co. (Red)_____ MSA (Judson, black)________

Other________________

Cost: Approx. $____________

Now have how many pairs?__________

If more than one pair, do you wear them alternately?________

Last approx. how long?___________months

Where bought? Company owned store_____ Local equipment Co._______

Other______________________________________

Wear them always________ most times______ rarely_________
If type has two straps, wear them crossed______ parallel_______

During work, straps have to be adjusted

| | frequently | sometimes | rarely |
|---|---|---|---|
| while kneeling............... | | | |
| while crawling............... | | | |
| while standing............... | | | |
| or walking............. | | | |

Adjustment of straps is required because pads tend to

| | sag | creep up | rotate sideways |
|---|---|---|---|
| while kneeling .............. | | | |
| crawling .............. | | | |
| standing .............. | | | |
| or walking .............. | | | |

Straps bind

| | frequently | sometimes | rarely |
|---|---|---|---|
| while kneeling .............. | | | |
| crawling .............. | | | |
| standing .............. | | | |
| or walking .............. | | | |

| Straps chafe | frequently | sometimes | rarely |
|---|---|---|---|
| while kneeling ........... | | | |
| crawling ........... | | | |
| standing ........... | | | |
| or walking ........... | | | |

Number of layers of clothes worn under or over kneepads:

| | under | over |
|---|---|---|
| Summer | ___ | ___ |
| Winter | ___ | ___ |

Do pads cause sweating? Yes_____ No______ Somewhat_______
Does sweat tend to collect in them_______ or is it absorbed by inner pad______ or clothes______
When working on moist floor, do pads absorb moisture? Yes___No___
Do they tend to slip on moist surfaces? Yes___ No____
Do they tend to collect grit? Yes_____ No____

Do they provide adequate comfort
to underside of knee while working in a kneeling position on rough, uneven surface? Yes____ No____
to sides of knee while working in a kneeling position on rough, uneven surface? Yes____ No____
to underside of knee while crawling on such a surface?Yes___No__
to sides of knee while crawling on such a surface? Yes___No__

Do they provide adequate protection
from impact with rough, uneven floor
to underside of knee? Yes___No____
to sides of knee? Yes___No____

Comments:______________________________________________

______________________________________________

against cuts or punctures from sharp objects or protruding nails while crawling
to underside of knee? Yes___No___
to sides of knee? Yes___No___

Comments:______________________________________________

______________________________________________

from impact with objects other than floor? Yes___No____

Comments:______________________________________________

Have you ever had a knee injury during the course of your work?
Yes____ No_____
Were you wearing knee pads at the time? Yes____ No_____
What type injury? Fracture_____ Dislocation____ Laceration____
Puncture____ Torn ligament(s)____ Severe trauma (blow)____

Other______________________________________________

Have you ever had knee problems other than traumatic injuries, such as bursitis____ arthritis_____ or just plain sore or stiff knees________?

Other________________________________________

Was this especially bothersome
all the time_____ during work_____ after work_____ ?

Have you "customized" or altered your knee pads? Yes____ No____

If so, how?________________________________________

________________________________________

________________________________________

If you were to design your own pads from scratch, what improvements would you design into them, as compared to the type you now use.

Comfort. Make inside softer______
Make inside more form fitting_____
Make cooler to wear______
Make drier to wear______
Make warmer to wear on cold floor______
Make attachment less chafing_____
Make attachment less binding_____
Make pads stay in place better______

Other________________________________________

________________________________________

________________________________________

Protection: Make outer shell more resistant
against impact_______
against cuts & punctures_____
Make them longer to protect part of shin as well______
Wrap around more to protect sides of knees more______

Other________________________________________

________________________________________

________________________________________

Overall Design Features

Make more resistant against abrasion____

Improve bond between inner cushion and outer shell____

Build pads into trouser legs______

Make them easier to adjust______

Make inner cushion and outer shell to be worn separately______

Other suggestions ______________________________

______________________________

______________________________

Do you think color is of importance, for instance would it be helpful to have pads made with high-visibility finish?

Yes______ No______ Explain: ______________________

Developing a new product costs money. Do you think it is worth spending some more of your money on knee pads than you are now, if the pads were more comfortable, gave better protection, and lasted longer than those you now use?

Yes______ No______

If yes, about how much would you be willing to pay for a pair? $______

Reason______________________________

______________________________

______________________________

Additional comments: ______________________________

______________________________

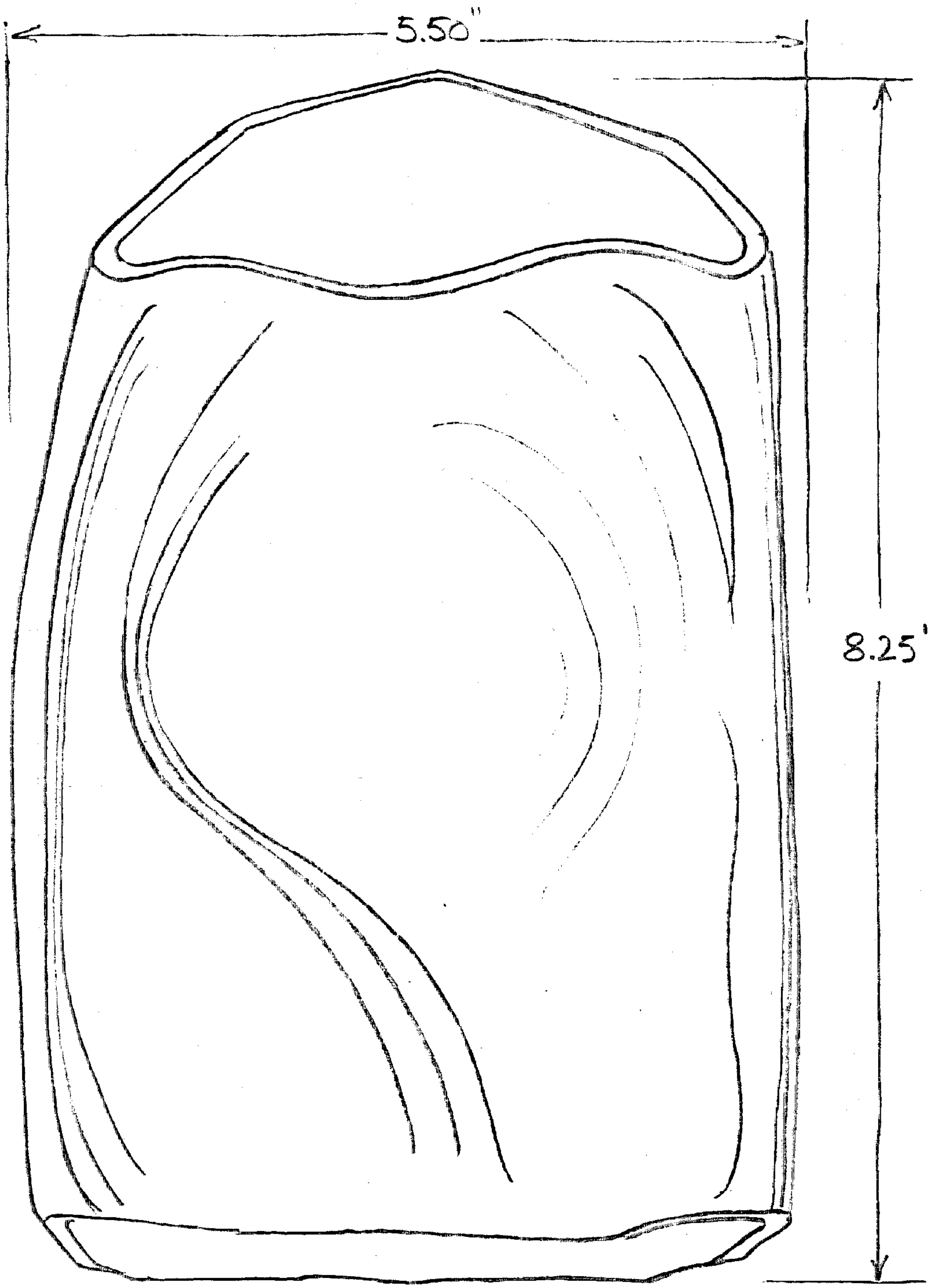
______________________________

CENTURY RESEARCH CORPORATION, 4113 Lee Highway, Arlington, Va. 22207

APPENDIX B

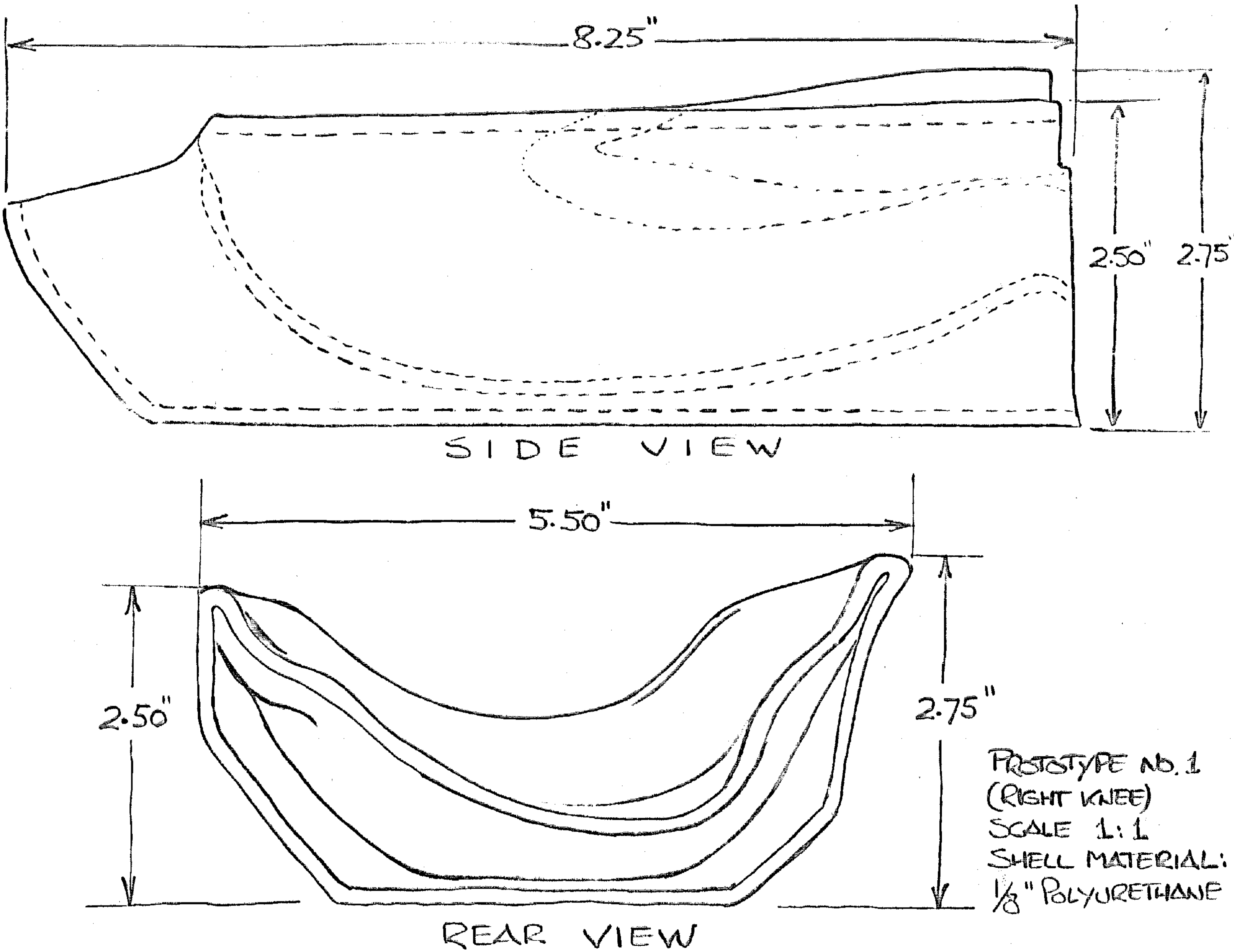
DIMENSIONAL SKETCHES

Note: Sketches of Prototypes 1, 2 and 3, showing top, side and end views of each prototype are shown on the following pages.

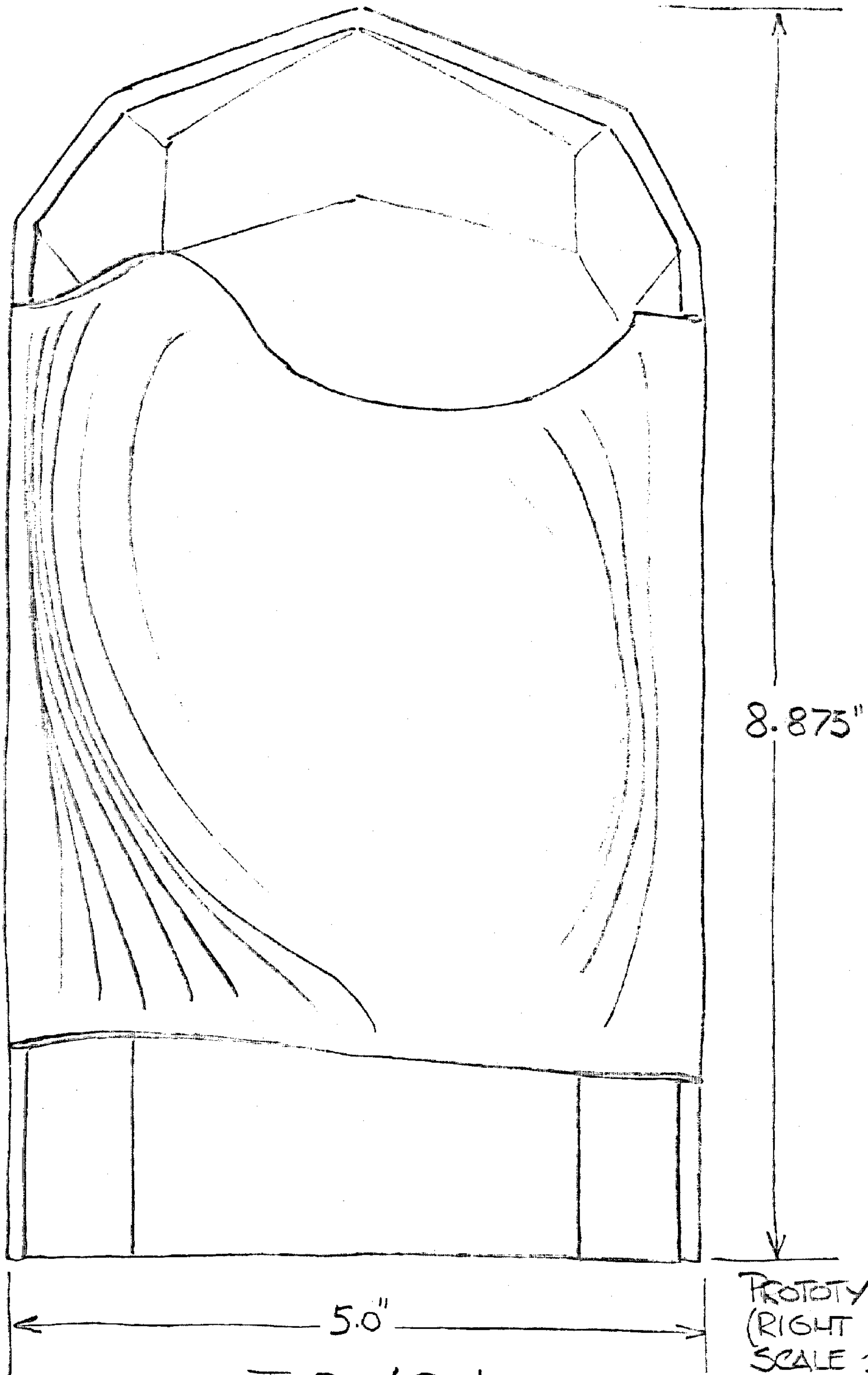



TOP VIEW

PROTOTYPE No. 1
(RIGHT KNEE)
SCALE 1:1
(SHELL MATERIAL:
1/8" POLYURETHANE)

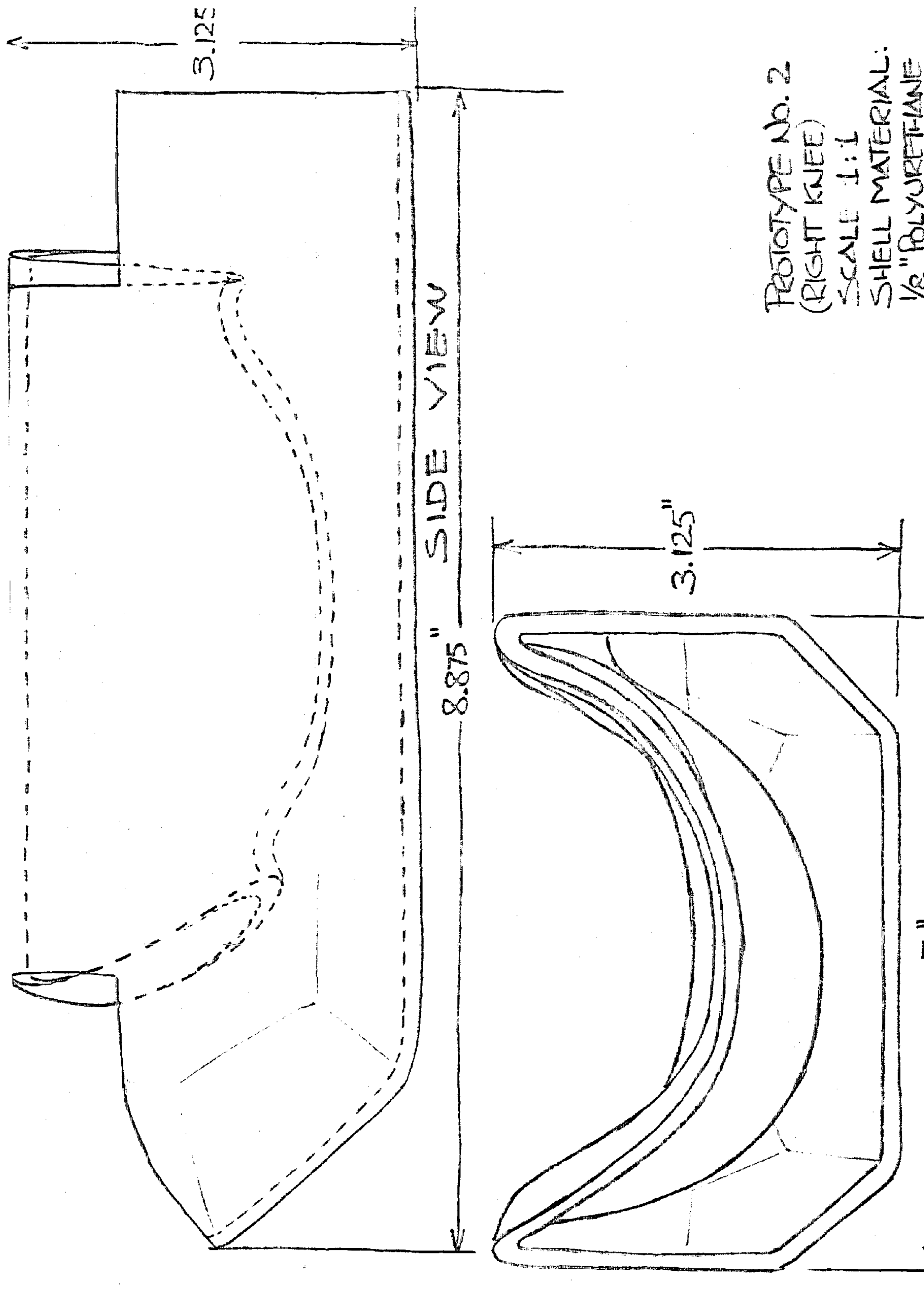



PROTOTYPE NO. 1
(RIGHT KNEE)
SCALE 1:1
SHELL MATERIAL:
1/8" POLYURETHANE

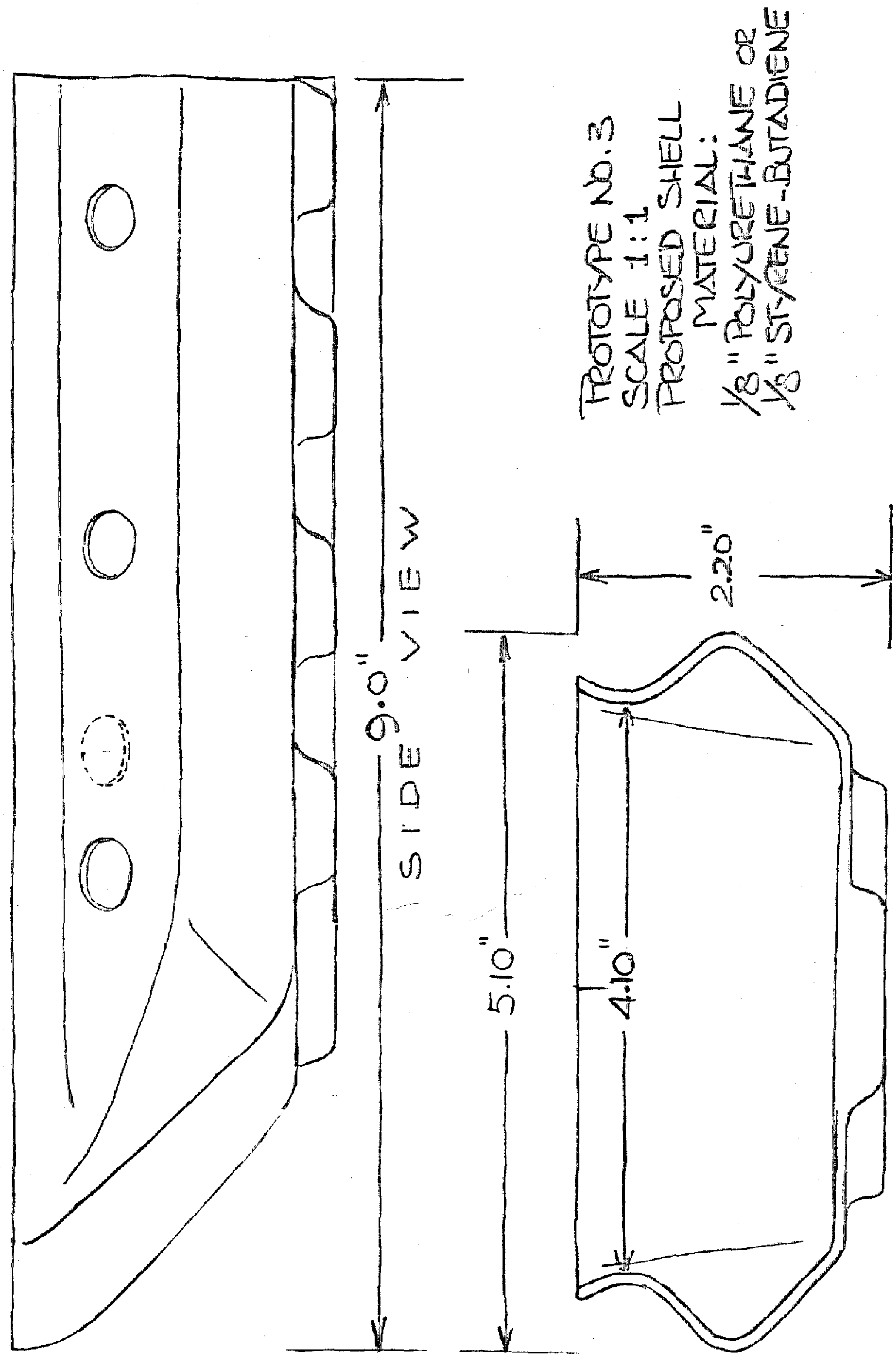


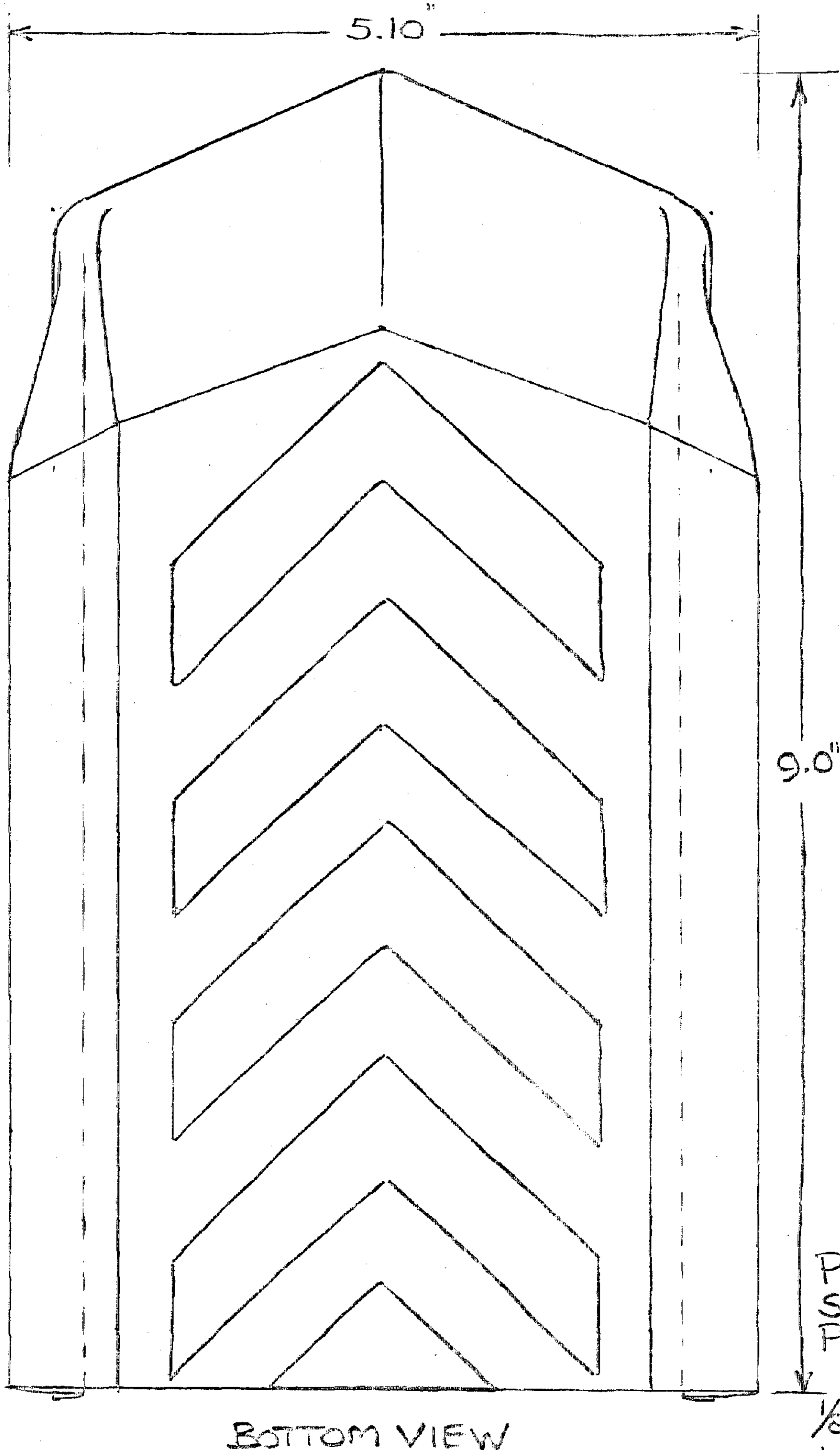

TOP VIEW

PROTOTYPE NO. 2
(RIGHT KNEE)
SCALE 1:1
(SHELL MATERIAL:
1/8" POLYURETHANE)

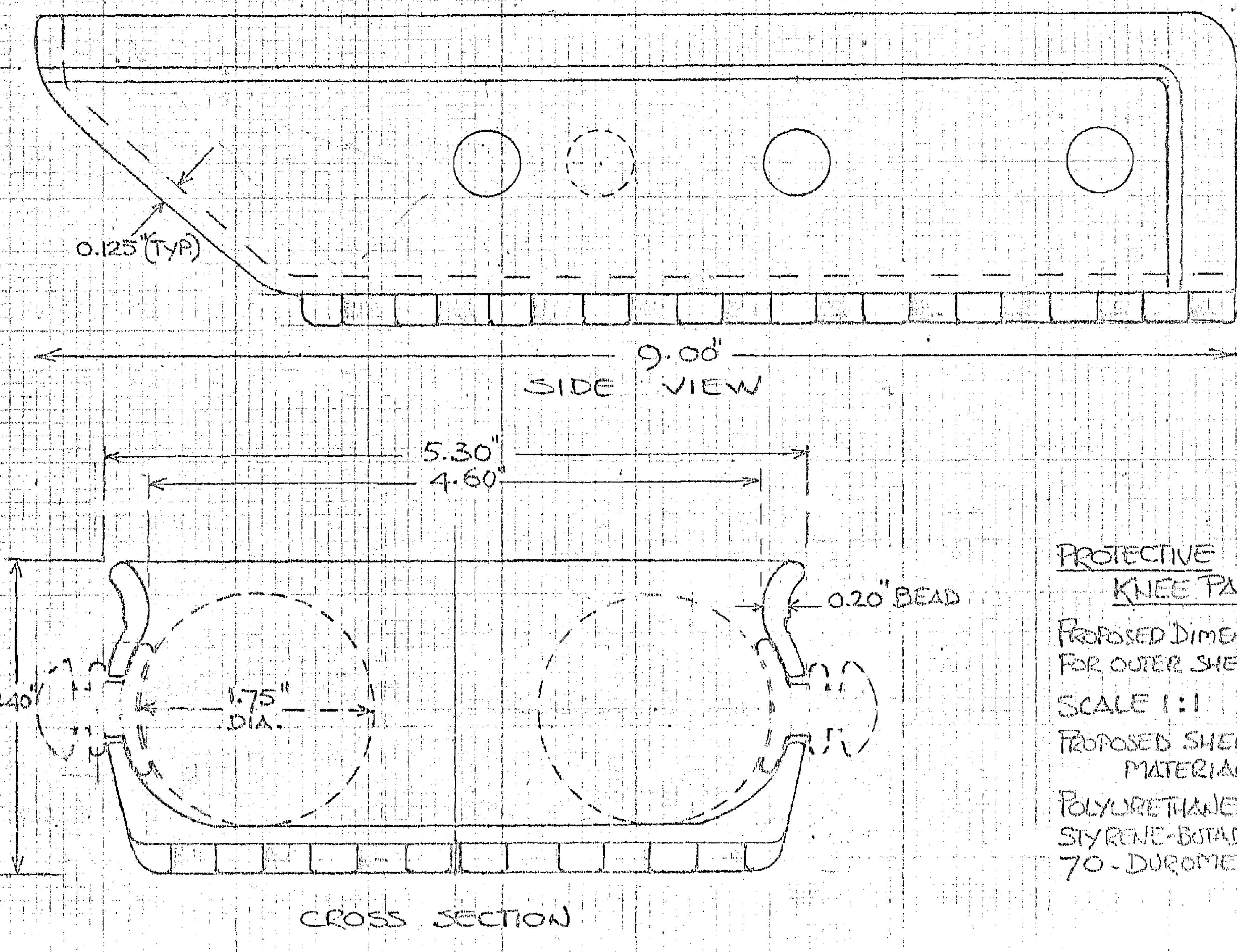


SIDE VIEW
3.125
8.875"
REAR VIEW
3.125"
5"
PROTOTYPE No. 2
(RIGHT KNEE)
SCALE 1:1
SHELL MATERIAL:
1/8" POLYURETHANE


SIDE VIEW
9.0"
5.10"
4.10"
2.20"
REAR VIEW
PROTOTYPE NO. 3
SCALE 1:1
PROPOSED SHELL
MATERIAL:
1/8" POLYURETHANE OR
1/8" STYRENE-BUTADIENE




PROTOTYPE NO. 3
SCALE 1:1
PROPOSED
SHELL MAT'L.:
1/8 POLYURETHANE
OR
1/8 STYRENE-BUTADIENE



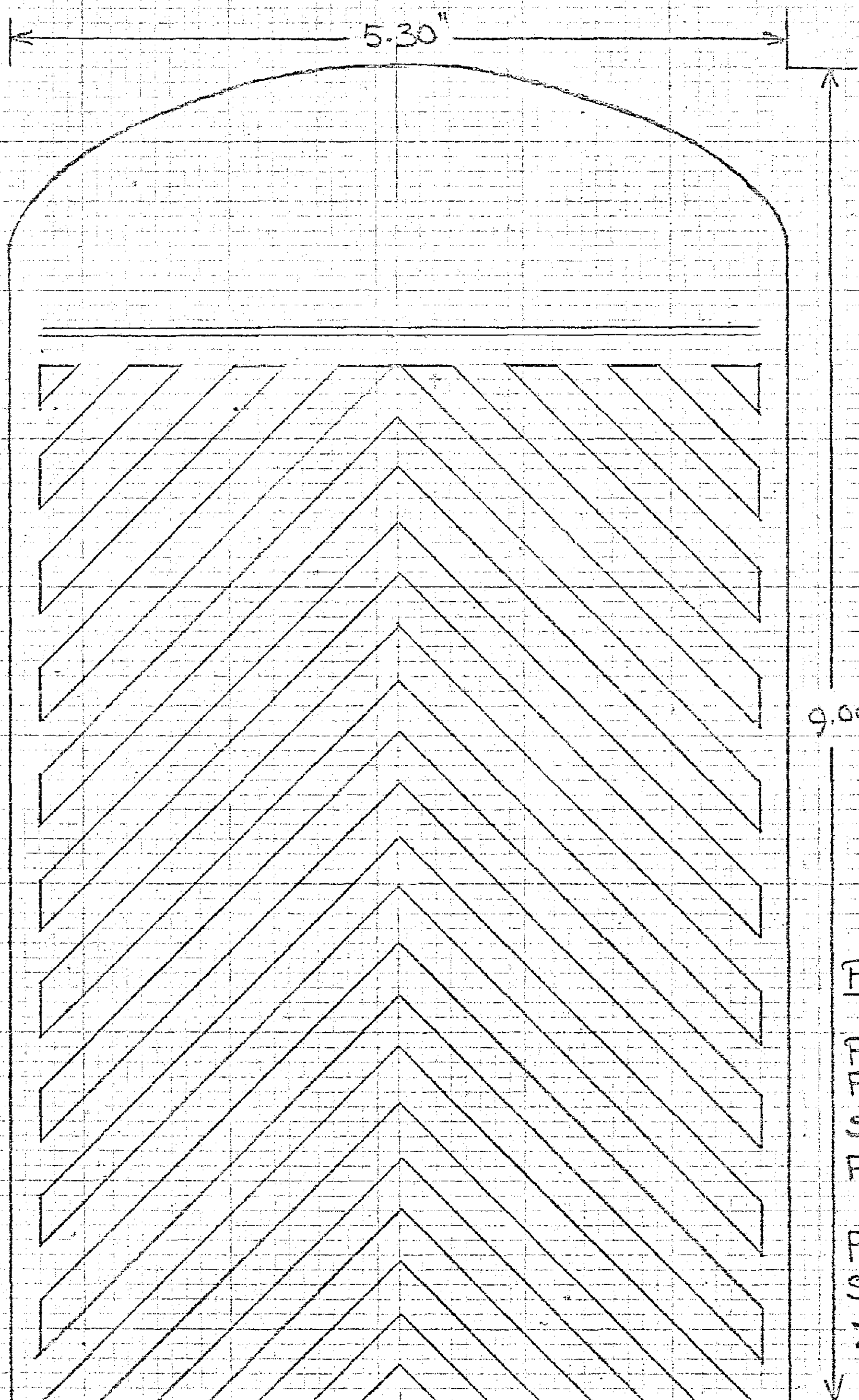

PROTECTIVE KNEE PAD

PROPOSED DIMENSIONS FOR OUTER SHELL

SCALE 1:1

PROPOSED SHELL MATERIAL:

POLYURETHANE OR STYRENE-BUTADIENE, 70-DUROMETER




BOTTOM VIEW

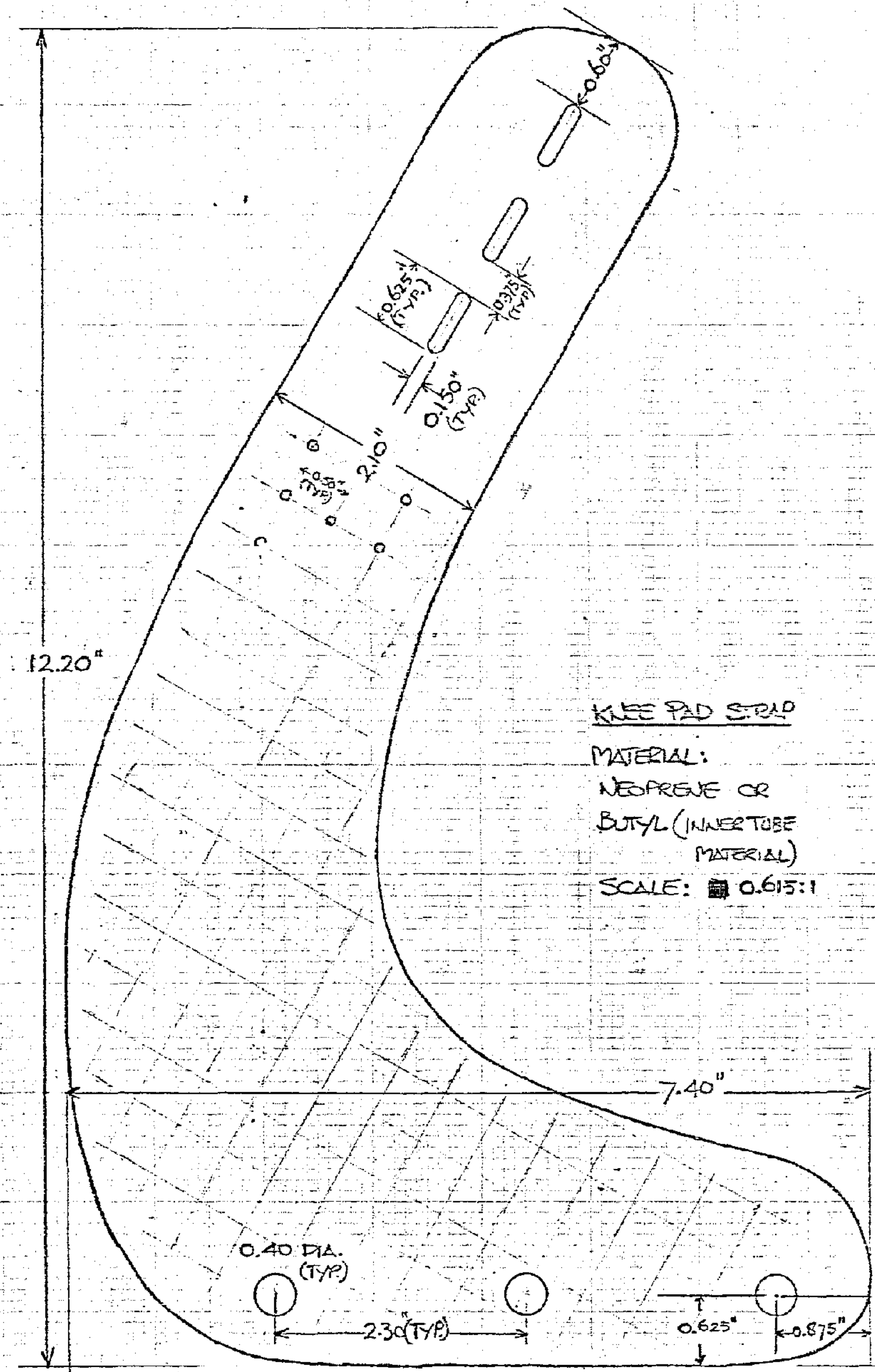
PROTECTIVE KNEE PAD

PROPOSED DIMENSIONS FOR OUTER SHELL

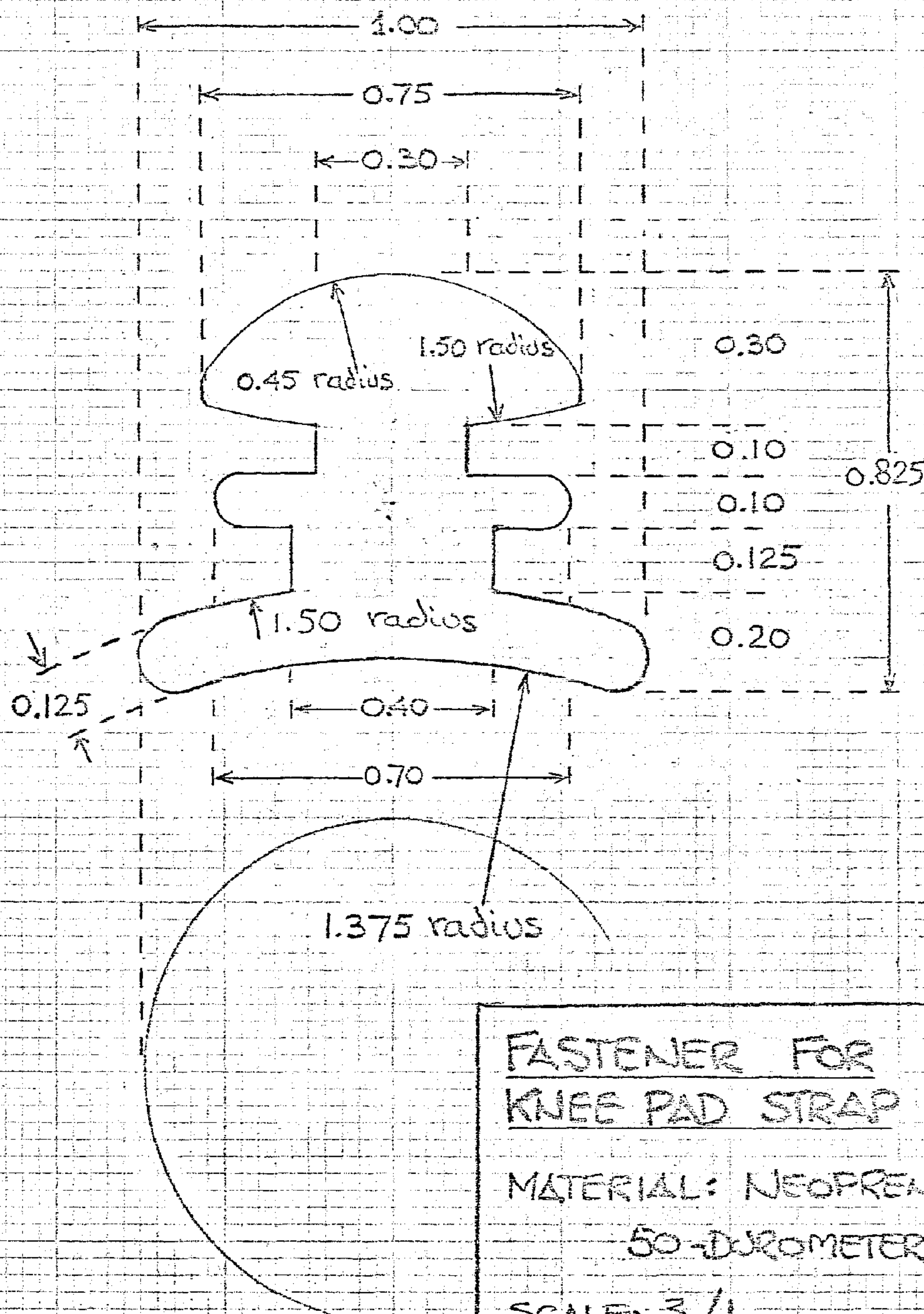
SCALE 1:1

PROPOSED SHELL MATERIAL:

POLYURETHANE OR STYRENE-BUTADIENE, 70-DUROMETER



12.20"
0.60"
0.625" (TYP.)
0.375" (TYP.)
0.150" (TYP.)
2.10"
0.50" (TYP.)
KNEE PAD STRAP
MATERIAL:
NEOPRENE OR
BUTYL (INNER TUBE MATERIAL)
SCALE: 0.615:1
7.40"
0.40 DIA. (TYP.)
2.30" (TYP.)
0.625"
0.875"




FASTENER FOR KNEE PAD STRAP

MATERIAL: NEOPRENE, 50-DUROMETER

SCALE: 3/1

(MEASUREMENTS IN INCHES)