SLIPPING CANE AND CRUTCH TIPS
PART I—STATIC PERFORMANCE OF CURRENT DEVICES

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INTRODUCTION

Undesired slipping or sliding of cane and crutch tips can lead to further injuries of those already handicapped. The problem is well known, yet the literature reflects relatively little sustained effort to improve slip characteristics. Kennaway (1) has suggested that skid-resistance depends upon hysteresis, which depends upon the material and the temperature, but that empirical trials are necessary. Practical notes on the art of cane-assisted gait have been given by Murphy (2). Cane forces have been examined by Murray, et al. (3,4).

This preliminary paper reports a reconnaissance of the slip performances of cane and crutch tips currently available to the disabled. This study is properly regarded as a point of entry into a difficult technical and clinical area. It is only by knowing currently available performance characteristics that we may seek means of improvement.

The conditions necessitating improvement in performance are precisely those that are poorly understood from the viewpoint of engineering mechanics. Thus, slippages on ice and on wet soapy tiles involve mechanisms that are neither of the dry-friction type nor of the hydrodynamic lubrication type, both of which are well defined. Instead, the domain of interest is that vague intermediate area termed "boundary lubrication" wherein the chemistry of the contacting surfaces is significant to the frictional process, in addition to the usual physical factors. Despite intensive effort by the automobile industry over many generations, the slip of rubber tires, studded tires, and chains on ice remains largely a matter of empirical testing

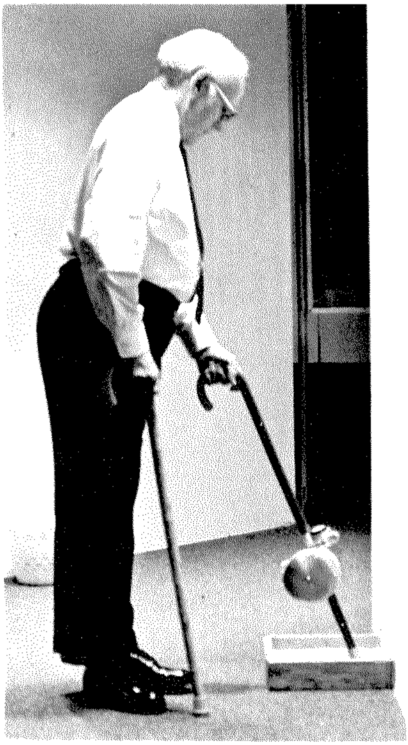
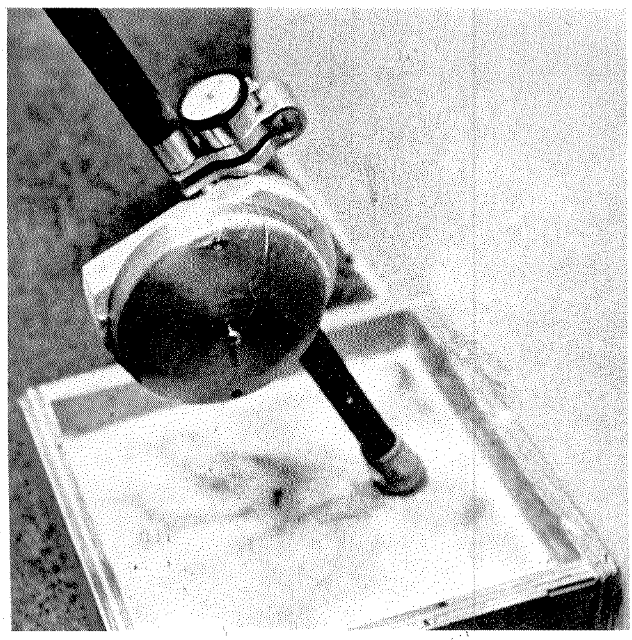


FIGURE 1.—Instrumented cane in use (soapy tile test). Operator plants cane vertically, increases load to a desired value and then slowly rotates cane about the tip until slip occurs.



and of compromises (5). It is, therefore, not surprising that the cane and crutch tip problem lacks an ideal solution.

As our concern is with the unresolved or potentially unsatisfactory aspects of contemporary devices, we have deliberately chosen two situations in which clinically there seems major risk of slip, in which to measure performances. There are slip measurements on (i) ice and on (ii) soapy wet tile of two types of surface roughness. What follows are cane and crutch tip performance results on these surfaces under slowly varying quasi-static conditions. Obviously, dynamic loads and many practical aspects must later be considered in selecting clinically useful solutions.

EXPERIMENTAL METHODS AND PROCEDURE

The basic measurement tool for the present preliminary experiments is a cane equipped with instrumentation (Fig. 1 and 2) indicating both the axial compressive load (termed "Thrust") and the angular attitude with respect to the vertical. A typical wooden

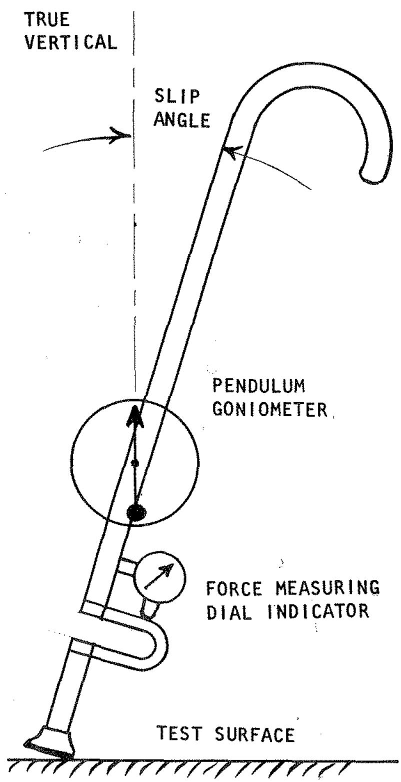


FIGURE 2.—Instrumented cane schematic. The pendulum goniometer reads the angle of inclination of the cane with respect to the vertical. The dial indicator is calibrated to reflect axial thrust loads.

orthopedic cane of approximately 1.0 in. (25 mm) diameter was used. Axial load is determined by measuring, with the aid of a dial indicator, the deflection of a small U-shaped member on the cane axis. (Adequate calibration is achieved by pressing the complete cane device against a bathroom scale.) Angular position from the vertical is determined by an indicator attached to a pendulum bob; in effect, a continuously-reading goniometer results. Both instruments have little friction or hysteresis; however, dynamic response is obviously of low quality. The pendulum is undamped and must be handled carefully to avoid acceleration errors. In each case the readout depends on the vision of the experimenter, with inevitable reaction-time and reading errors. Still, it is estimated that under the slowly moving dynamic tests employed in this work, axial load is maintained within ± 15 percent of the loads reported. Similarly it is estimated that angles reported are correct to within ± 3 deg.

In use, the instrumented cane is equipped with the tip selected for test and then slowly pressed against a test surface in a perpendicular attitude. When a desired loading is achieved, the cane is slowly rotated about the tip, maintaining a constant axial test load through operator feedback. The operator endeavors to provide only axial-thrust load and to minimize bending loads or torques at the handle. At some angle from the vertical, the cane will slip. The operator notes the angle at which slip occurs, and the test load.

The icy surface used in all ice tests was that of a commercial indoor ice skating rink. Tests were conducted immediately after the daily shaving, flooding, and refreezing operation employed to level the rink surface. The ice appeared clear, smooth and dry. Each test was conducted on a separate, fresh portion of ice.

Ice tests were conducted under differing air temperature conditions. Although the rink was enclosed, no air temperature regulation was available. Thus the air temperature tended to reflect outdoor ambient temperature. Two basic test air temperatures existed in the course of these tests; a low temperature in the 20's F (-7 to -1 deg Celsius) and a high temperature in the 40's F (+4 to +10 deg Celsius). The ice appeared solid and dry at all times. However, it appeared that the variable air temperature condition, possibly permitting a film of moisture at the higher air temperature, had an effect on the data. The following results carry temperature notations in the form of either an H (high temperature) or an L (low temperature).

Tested soapy tiles were of two basic types. One (quarry tile) offers a relatively rough surface and is frequently used in current kitchen and fast food restaurant design. The other tile is highly glazed and is similar to that seen in older bathrooms. The results note the tiles as "rough" and "smooth." In use, the tiles were flooded (covered) with a mixture of liquid hand soap and water.

Raw data resulting from tests of a typical cane tip are given in Figure 3. All test points are plotted, permitting an assessment of scatter. In each case, three data points were obtained at a given test parameter. The letter L superimposed on the ice results means that the data were gathered at a low test temperature as described above. All subsequent results are presented without data points, in the style of Figure 4, so as to gain clarity. The reader may be assured that the scatter throughout the test series is typified by the results as shown in Figure 3.

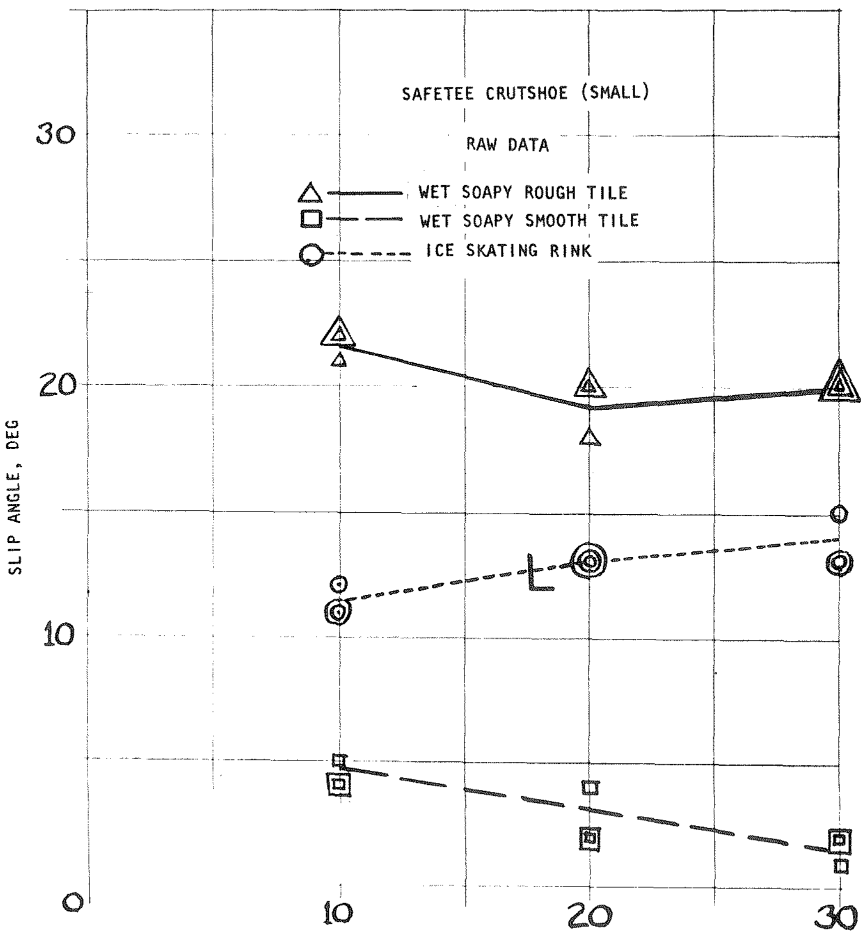


FIGURE 3.–Slip angle vs. cane-thrust on various test surfaces. This graph shows typical raw data: all data points have been plotted here to illustrate the scatter encountered in this work. Subsequent figures show only average values.

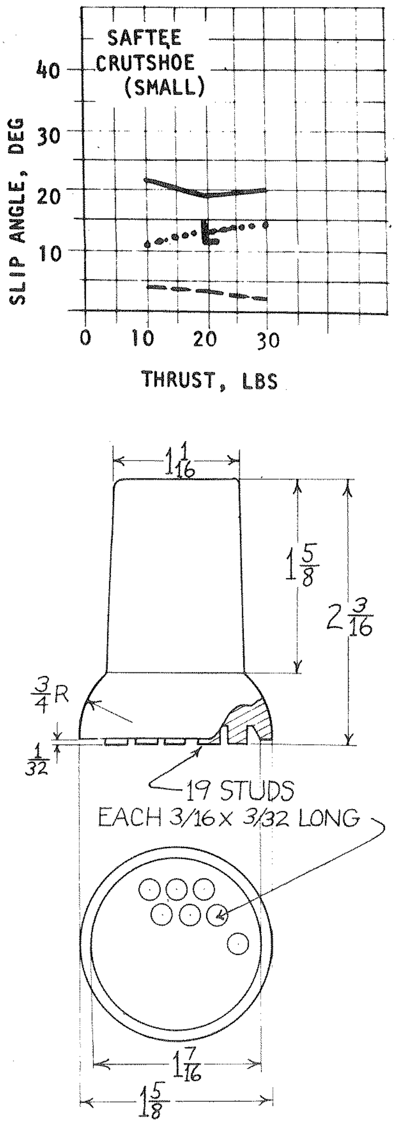


FIGURE 4.—Saftee Crutshoe (Small).

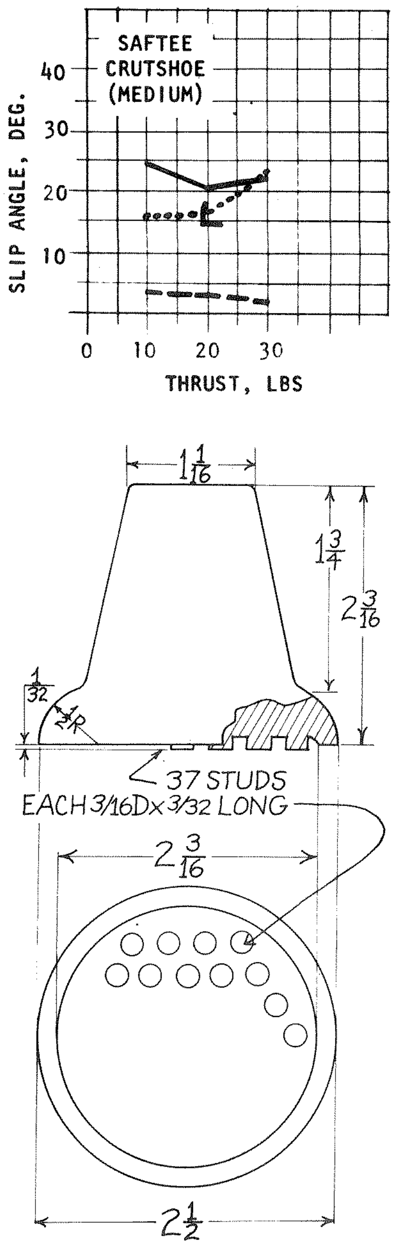


FIGURE 5.—Saftee Crutshoe (Medium).

FIGURES 4-17.—Slip angle vs. cane-thrust on various test surfaces. Lower figure portion shows the device tested.

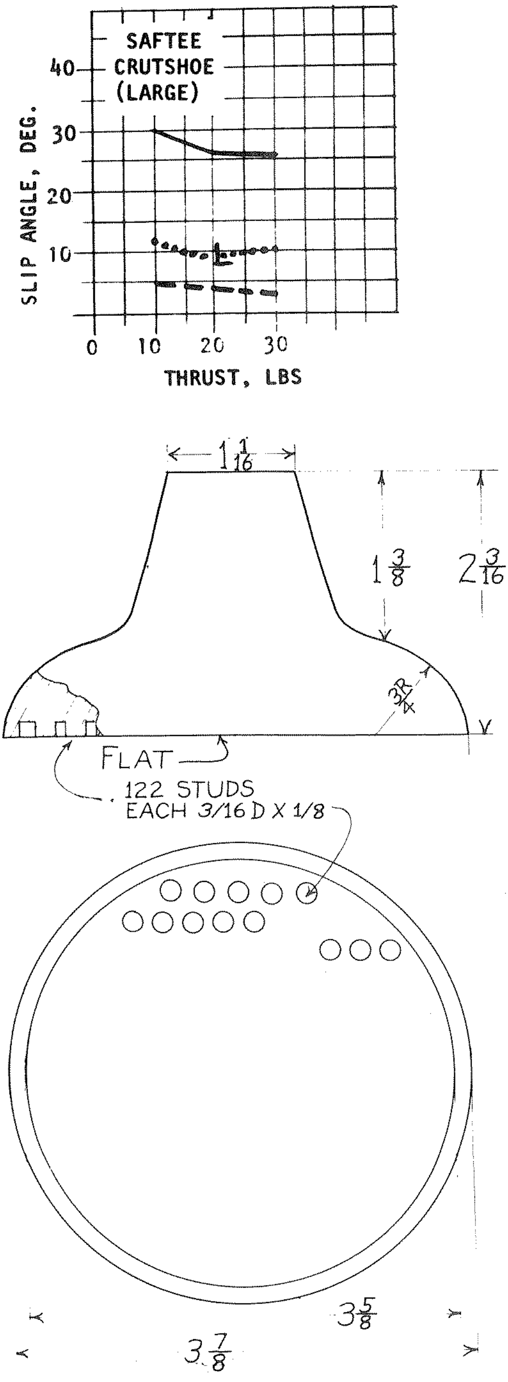


FIGURE 6.—Saftee Crutshoe (Large).

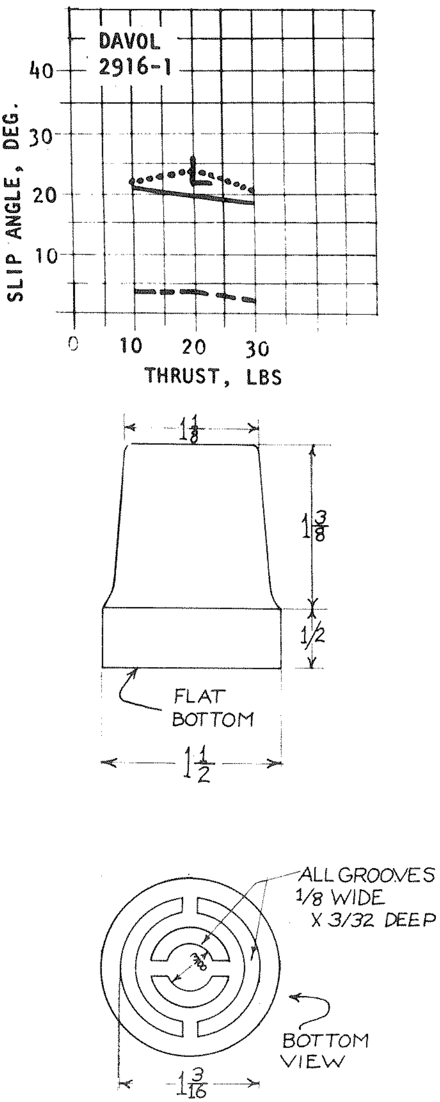


FIGURE 7.—Davol 2916-1

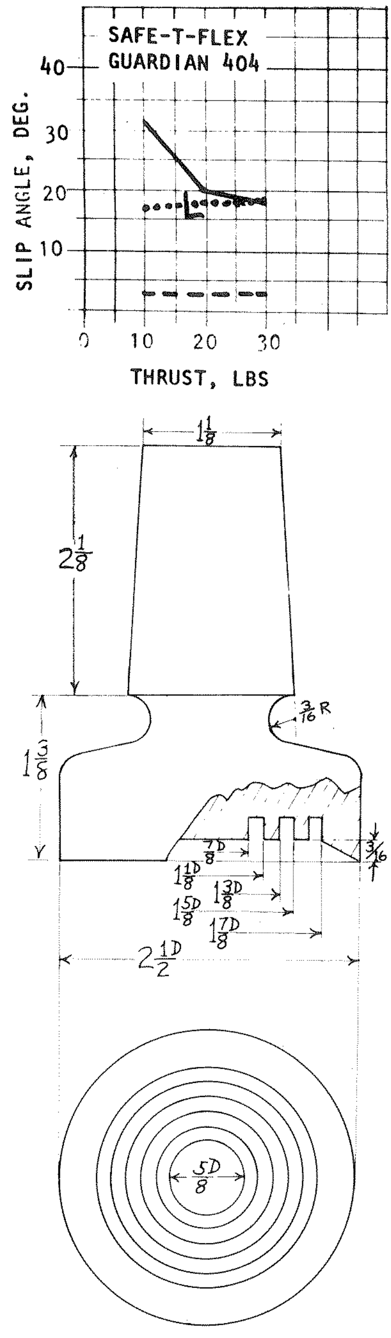


FIGURE 8.—Safe T Flex Guardian 404

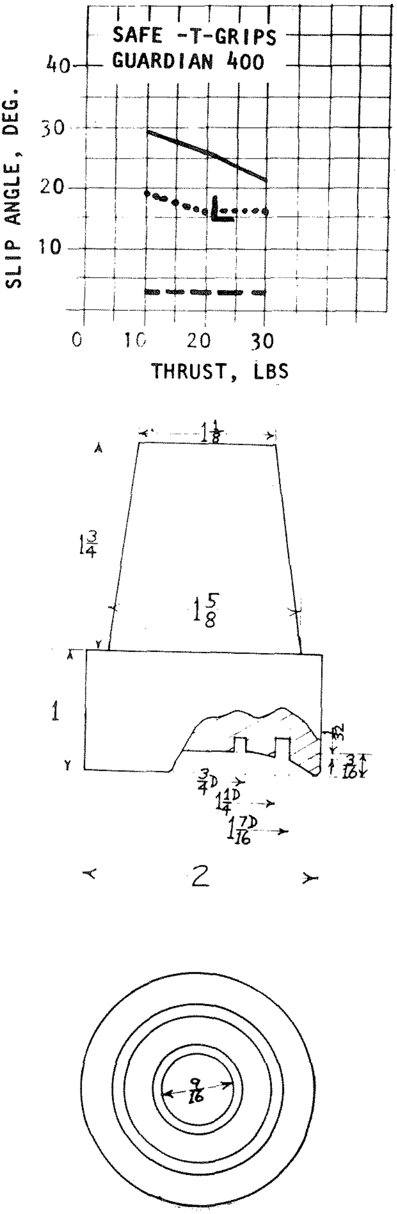


FIGURE 9.—Safe-T-Grips Guardian 400

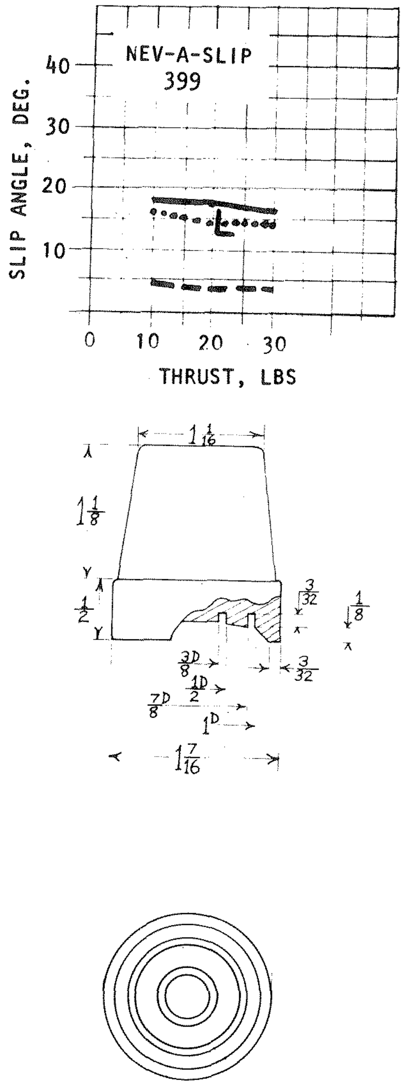


FIGURE 10.—Nev-A-Slip 399.

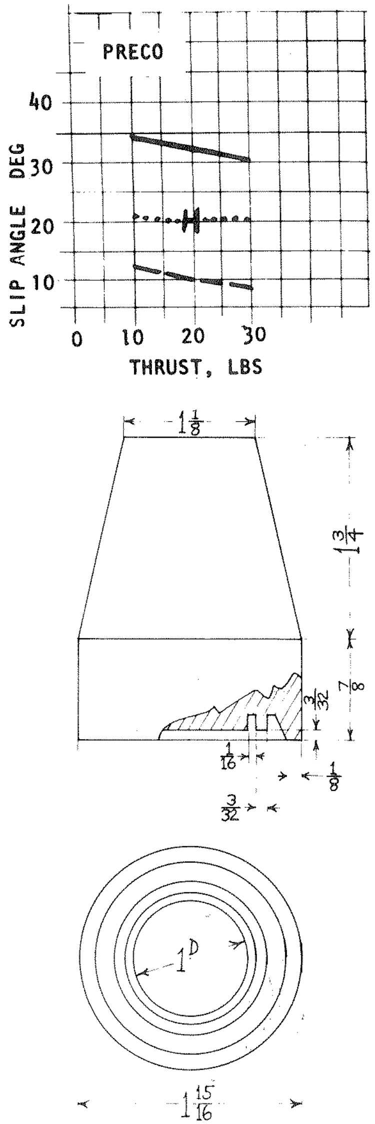


FIGURE 11.—PRECO (Precision Grinding and Manufacturing Co.)

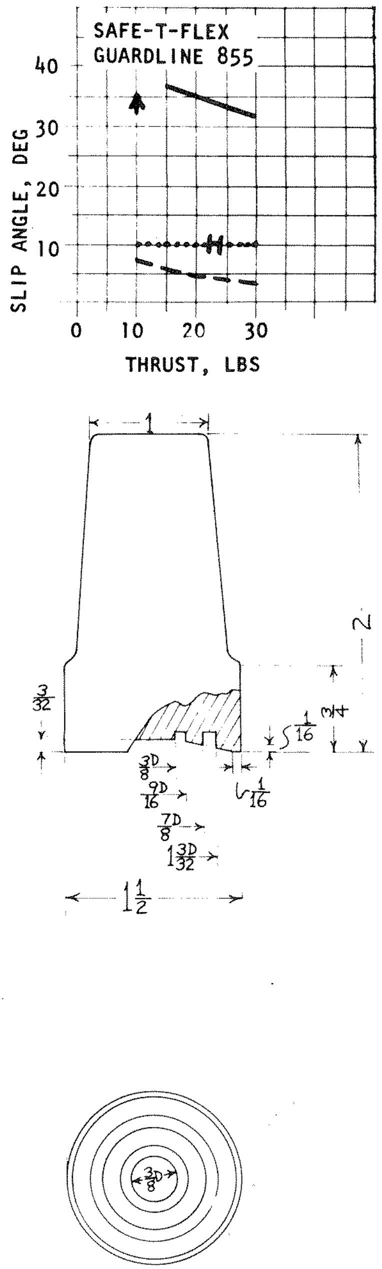


FIGURE 12.—Safe T Flex Guardline 855.

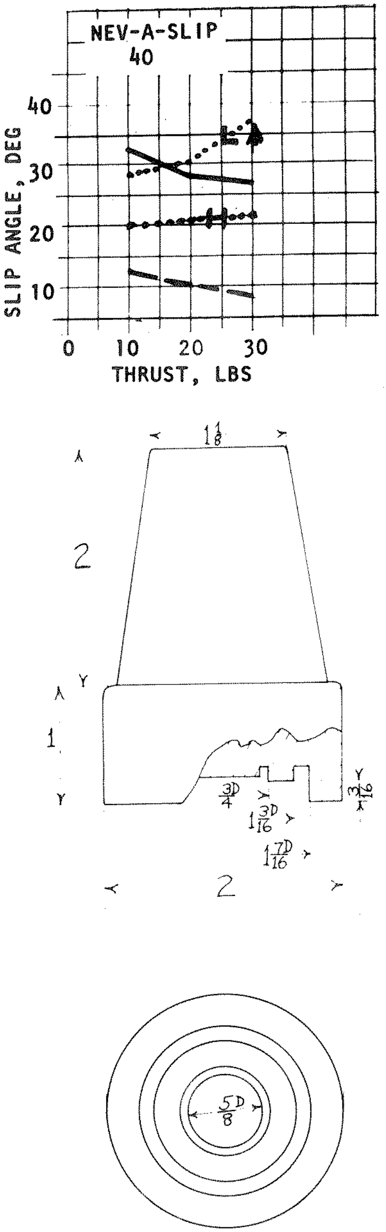


FIGURE 13.—Nev-A-Slip 40

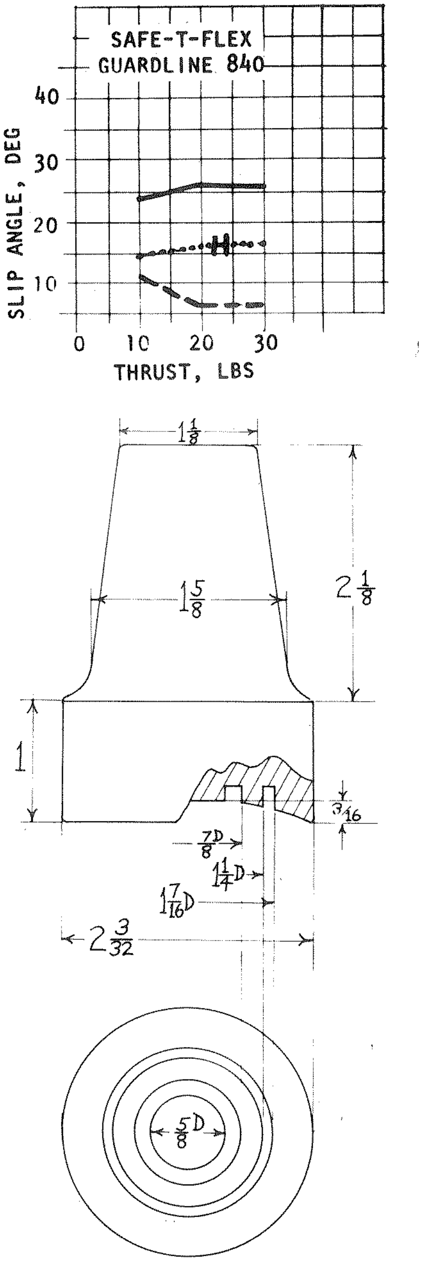


FIGURE 14.—Safe T Flex Guardline 840.

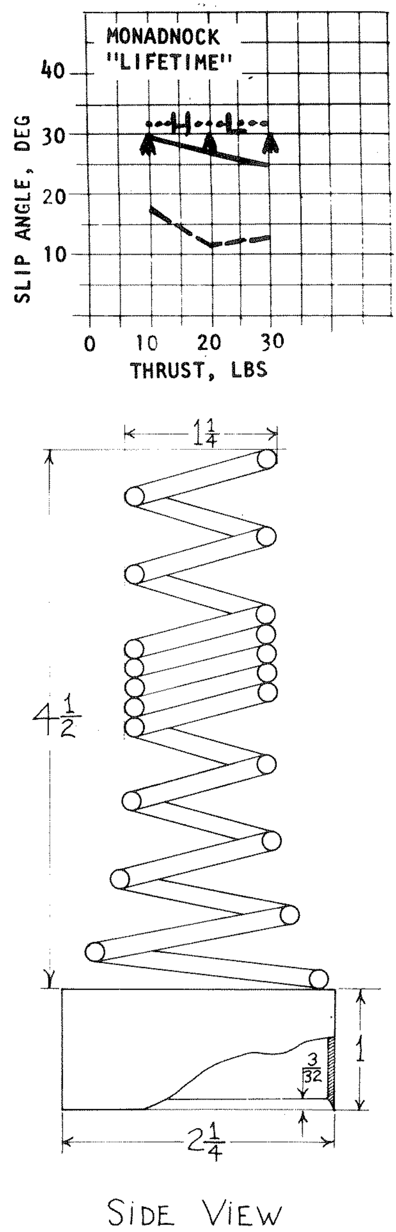
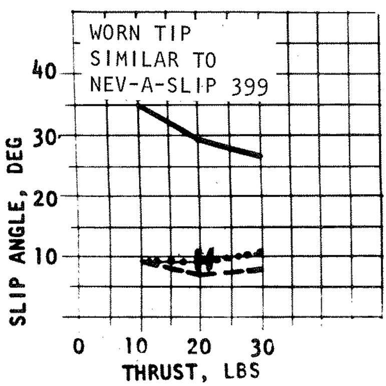


FIGURE 15.—Monadnock "Lifetime."



NOTE: See Figure 10 for drawing of similar device in normal condition.

FIGURE 16.—Worn Tip.

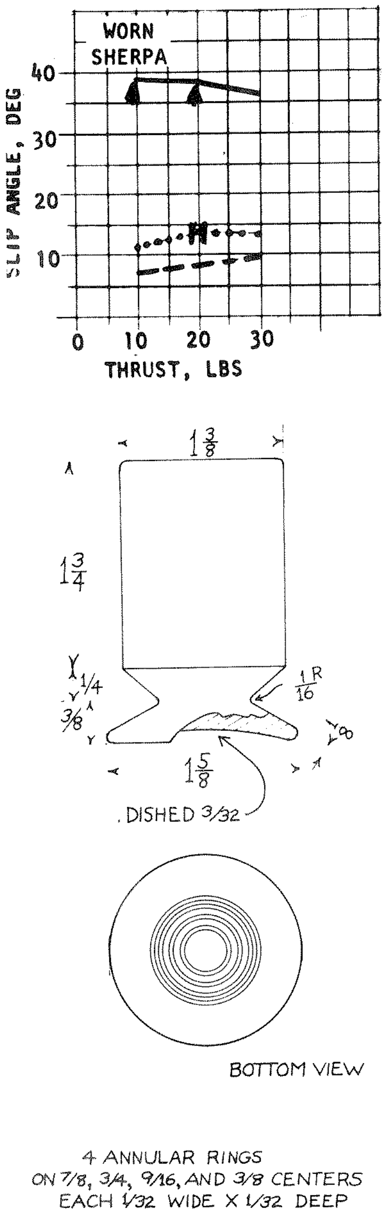


FIGURE 17.—Worn Sherpa.

RESULTS

In assessing slip results it is useful to have a tentative standard of acceptable performance; i.e., what angle of inclination from the vertical is actually used in deriving support by cane users? Such data (the working angle) must come from clinical tests and is not pursued here in depth. However, one of us does use a set of canes on an everyday basis. Observations of this subject indicate a maximum working angle of approximately 17 deg on a surface perceived as "safe." While the dangers of drawing conclusions from a single test subject are obvious, nonetheless some useful guidance may result from the following rule-of-thumb. Applying a safety factor of 1.5 to the measured working angle of 17 deg, we have a desired working angle of approximately 25 deg. Rule-of-thumb: *Any slip angle well below 25 deg can be dangerous; any slip angle well above 25 deg is likely to be safe.* The gross nature of the rule-of-thumb should be emphasized; it is useful only as a rough guide in selecting from an infinite number of situations a few test cases likely to be clinically significant.

A larger angle between cane shaft and vertical just before slippage occurs (slip angle) is viewed as clinically desirable, permitting the patient to take longer strides and to move more rapidly and confidently. Also, a larger angle implies that the patient can be more confident on sloping terrain, whether local driveways and ramps or major hills. The user may be intuitively estimating risks, shortening his stride and slowing down as he perceives greater danger.

The slip angle is analogous to the friction angle concept employed in engineering practice. While not given in this work, the conventional friction coefficient for any test situation is equal to the tangent of the slip angle. Thus for a 25 deg slip angle, the corresponding friction factor or coefficient is 0.46, etc.

Ice

The results of tests on the ice (Figs. 3-17) start with a group of crutch tips (Figs. 3-6) that are alike in configuration but markedly different in scale. Employing as a basic concept a series of short cylindrical rubber studs, creating a stippled pattern, the manufacturer has provided a small version (Fig. 3,4), a medium (Fig. 5), and a large model (Fig. 6). Of these, performance is best for the medium model. In all cases, performance on ice is mediocre. While a comparison of the various versions ostensibly appears to be a test of "footprints" or contact area effects, it is likely that the differing stiffness of the bodies of the various versions is a complicating factor. In particular the large version is so stiff that the base is unable to flex readily. Thus the result of employing this version at an angle to the ice is to place the entire tip at an angle to the surface, resting on only a few of the studs and preventing the development of a large "footprint." For this reason no clear conclusion concerning the value of "footprint" may be drawn from the series Figures 3-6.

A standard flat concentric-ringed cane tip (Fig. 7), with a small "footprint," is seen to perform on ice as well as any conventional device tested. Though all of the slip angles are below the desired 25 deg, most are above the observed 17 deg. Far larger concentric-ring concepts (Figs. 8,9, and 10), utilizing a recessed or dished interior and providing a relatively sharper rim, are not superior to the small, flat-ringed surface of the tip whose results appear in Figure 7. Small, dished, concentric-ring tips (Figs. 10 and 12) also do not perform as well as the flat-ringed tip.

The effect of air temperature above the ice may be seen in Figure 13 wherein similar runs were conducted at two different air temperatures. Note that the higher air temperature (in the 40's F) seriously reduces the slip angle obtainable at the ice as compared with the lower air temperature (in the 20's F). It appears that ice on the verge of melting is a more difficult design area than hard frozen ice. The item whose performance is given in Figure 13 is a particularly deep-dished, concentric ringed, large crutch tip, rather similar to the item tested in Figure 11. Performances of these items at the high air temperature are similar. Allowing for the effects of test temperature, the results of Figures 5,7,11 and 13 are roughly equal. This group contains the best results obtained from conventional devices. None of the tests on ice with the elevated air temperature meets the rule-of-thumb criterion (i.e., a slip angle of 25 deg) and probably the results shown in Figure 7 for low air temperature would deteriorate at higher air temperature.

All results discussed so far have dealt with brand-new devices. It also is of interest to evaluate worn devices by the same standard. Figures 16 and 17 give results of cane tips so badly worn and oxidized as to suggest junk. While the slip angle results obtained are mediocre, the performances are better than one might anticipate.

A Special Metal Device

Of all tested devices, the best performer on ice was the Monadnock Lifetime, a special metal device, given in Figure 15. The ice-gripping ability proved higher than the instrumentation capability, thus numerical data could not be obtained. However, all slip angles with this device are well above 30 deg under all axial-thrust loads and at both temperature conditions. The device relies on a sharpened steel ring to engage the ice. Once the ring is engaged, a large spring joining the ring to the cane permits angular deflection of the cane shaft without loss of contact between the ring and the ice. Clearly, friction is not the basic operating mechanism; large values of penetration into the ice are obtained (on the order of 1 mm). Certain practical disadvantages of weight, bulk, risk of damaging floors, inconvenience of adjustment, and safety are developed in the discussion below; nonetheless it should be stressed that the performance of this device on ice is outstanding.

Soapy Wet Tile

As noted, two types of tile surface were tested; one relatively rough and one quite slick. Cane tips proved sensitive to surface roughness. Large differences in slip angle resulted as a function of surface type. Many cane tips equaled or bettered our desired 25 deg working angle on the rough quarry tile (Figures 6, 11, 12, and 15), while performance on the slick tile proved universally poor.

Performance on one type of tile does not associate with performance on the other. Thus the best-performing unit on the rough tile (Fig. 12) achieves but a mediocre showing on smooth tile. Presumably, different frictional mechanisms are at work on the varying surfaces.

The worn-out devices offer performances that are the equal of any (Figures 16 and 17). This may be attributable to the visible shredding of bits of material under load. Apparently in this manner fresh cane tip surfaces were constantly presented to the soapy tile, preventing any soap buildup on the cane tip.

The Monadnock Lifetime metal-ring device (Fig. 15) scraped and scratched the tile, doing some small damage to both cane tip and tile. Performance proved fairly good, under conditions hardly appropriate for this device.

DISCUSSION

Some Cautions

The present introductory survey of static performance of currently available devices in challenging conditions is only a beginning. It does not test any single gross variable so systematically that firm conclusions can be drawn. Neither does it compare commercially available devices under a sufficiently wide range to permit formulation of specific prescription criteria or selection of a specific preferred make and model. This survey does not permit direct analyses of effects of hysteresis, modulus, or other properties of the material or of a basic design; e.g., stiffness of structure, "footprint" under load, rings versus stippled base, "dishing" of rings, diameter, etc. It is hoped that subsequent studies may help to clarify questions on these points.

Some Assets

The present preliminary studies do confirm that numerous cane tips of substantially differing design and materials allow adequate safety on numerous *dry* surfaces, such as carpet, dry vinyl tile, or smooth firm plastic, as indicated by pilot tests showing slip angles well over 30 deg. Even on virgin snow, a few pilot tests on a layer one-quarter-inch thick over a parking lot surface at 32 deg F, with 10 lb axial load on the cane, showed slip angles over 30 deg for two examples of ring-type tips, one new and the other badly worn and oxidized.

On ice, many cane tips are believed to offer fair performance under conditions of low temperature; few appear safe at elevated air temperatures.

On rough tile flooded with soapy water, many cane tips have been shown to offer adequate performance. Unfortunately, no tested cane tip offers acceptable performance on slick tiles flooded with soapy water.

Table 1 summarizes the performance characteristics of all tested cane tips in a qualitative manner.

Special Hazards

Most of the tests were conducted on situations intuitively perceived as particularly hazardous; smooth ice (at air temperatures below freezing and especially at higher air temperatures encouraging a thin film of moisture) and a set of wet, soapy tiles comparable to certain showers, bathrooms, kitchens, restaurants, etc. during bathing or after mopping or accidental spills. Under some of these conditions the angle at which slippage occurred was sometimes below 3 deg. Clinically, the user thus would have to keep the shaft very nearly vertical and would need to avoid sloping terrain.

TABLE 1.—*Summary: Qualitative Appraisal*[a] *of Performance*

Cane tip	Test condition		
	Wet soapy rough tile	Ice rink ice	Wet soapy smooth tile
Safetee Crutshoe (small)	Fair	Poor	Inadequate
Safetee Crutshoe (medium)	Fair	Fair-Poor	Inadequate
Safetee Crutshoe (large)	Good	Poor	Inadequate
Davol 2916-1	Fair	Fair	Inadequate
Safe T Flex (Guardian 404)	Fair	Fair-Poor	Inadequate
Safe T Grips (Guardian 400)	Good-Fair	Fair-Poor	Inadequate
Nev-A-Slip 399	Fair	Poor	Inadequate
Preco	Good	Fair-Poor	Inadequate
Safe T Flex (Guardline 855)	Excellent	Poor	Inadequate
Nev-A-Slip 40	Good-Fair	Fair	Inadequate
Safe T Flex (Guardline 840)	Fair	Fair-Poor	Inadequate
Monadnock "Lifetime"	Good	Excellent	Poor
Worn unit (with rings similar to Nev-A-Slip 399)	Excellent	Poor	Poor-Inadequate
Worn Sherpa	Excellent	Fair-Poor	Poor-Inadequate

[a]Ratings are estimates of performance. Appraisals in descending order are: excellent, good, fair, poor, and inadequate.

Empirically, a user is usually aware of increasing risk of slippage on obviously slippery surfaces. The user then walks more slowly with shorter steps, decreased shear between shoes and surface, decreased rotary motions of the pelvis and legs with consequent decreased torques about the vertical axes through the feet, and more nearly vertical canes or crutches. In particular, the user fears a sudden slippage with sliding friction catastrophically lower than static friction. All the defensive or precautionary measures seem to increase energy consumption per unit of distance walked.

Special Devices

Despite the apparent advantage of high friction on ice from special devices (e.g., the metal ring and spring of the Monadnock or the many rings, spikes, or other aids disclosed in patents and other literature) many users are reluctant to use such devices. In some senses, use of the retractable metal devices is comparable to use of removable tire chains on an automobile. The situations allowing clear superiority of a relatively complex, bulky, and heavy device are relatively rare for many users. Such situations often intermingle in a single trip with other situations where the device may scratch the floor, slip on terrazzo, or wear rapidly on concrete. The metal ring (Fig. 15) may be retracted upward by rotating it and its helical spring, but the user must balance himself somehow while sacrificing support to turn the cane or crutch upward to reach the ring to rotate it. Frequent adjustment is awkward and possibly hazardous. Perhaps the most serious drawback in using special devices is the risk of encountering *unexpected* small patches of dangerous terrain; e.g., ice with a film of water on a sunny day, in the midst of long stretches of safe dry concrete encouraging rapid gait with large shears and cane angles. Thus there are severe practical limitations to use of special aids, valuable as they seem to be for coping with certain major hazards.

Thrust Load

Thrust load was relatively easily controlled in these simple tests. Its influence, however, was not very clear. In some cases the slip angle increased appreciably with axial load. In others there was little change, or even some change from 10 to 20 lb followed by reversal at 30, and in a number of cases a substantial decrease in slip angle with increasing load. The reasons for this difference, presumably, lie in many differences among tips: the changing contact area or "footprint" as the rubber ridges or cylinders distort, the elastic bending or tilting of the entire structure with consequent changing angle of contact with the ground, or possibly a squeegee action of the rubber wiping the surface. Further experiments on more controllable designs are needed to separate variables.

Effects of Size

Figures 3-6 show tests of tips with superficially similar design (stippled base of small, short cylinders) but increasing size. The medium appears preferable. The three are *not* sufficiently geometrically similar, however, to permit precise comparison or firm conclusions.

Effects of Age

Normally one would tend to replace worn or aged, oxidized tips. Nevertheless a badly worn tip (with rings almost completely worn away) at least five years old performed modestly on ice at air temperature above freezing (Fig. 17). Both that tip and another of a different design (Fig. 16), which was so worn and oxidized that bits of rubber shredded away, performed surprisingly satisfactorily on wet soapy tiles. In the absence of further data, however, it still seems prudent to replace worn tips.

Future

More systematic tests with better control of variables are contemplated. Durometer (hardness) and type of rubber or plastic, and variations of hysteresis and stiffness with temperature, will be studied. Design affects "footprint," squeegee action, and inclination of the base. Crutches clearly apply far larger loads than those tested thus far. Perhaps novel designs can be developed.

CONCLUSIONS

A variety of commercially available cane and crutch tips were tested on surfaces of ice and soapy tile under varying axial (thrust) loads. The output measurement consisted of the angle between the vertical and the cane axis at which slip occurred. It was learned that:

1. From the viewpoint of a user, a minimal slip angle of roughly 25 deg is desirable.
2. On ice-rink ice, a number of cane tips approach the desired slip angle under conditions of low temperature; fewer appear safe at elevated air temperatures. Only one of the tested devices appears truly safe under any ice condition.
3. On rough tile flooded with soapy water, some cane tips offer adequate performance. However, no tested cane tip offers acceptable performance on slick tile flooded with soapy water.
4. There appears to be no simple relationship between the slip performance of a cane tip on ice-rink ice and that developed on soapy wet tiles.
5. No simple relationship between thrust load and slip angle emerged. Similarly, no simple relationship between contact area and slip appeared in the data.

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