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MEDICAL SCHOOL
Department of Physical Medicine and Rehabilitation
Orthetics Research Project

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# DESIGN FEATURES OF THE MICHIGAN FEEDER—A PRELIMINARY REPORT

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# I. INTRODUCTION

To select an appropriate area for initial study, existing orthetic devices for the upper extremity were surveyed. The frequency with which the various devices are prescribed, the frequency of repairs required, the cost of repairs, and opinions of informed people about the nature and extent of problems associated with the use of each device, as well as suggestions for improvement, were considered, as were the relative importance of the device to the patient, the feasibility of changing the design, and the probability that the design work would provide a well-rounded introduction of the committee to the principles and problems associated with orthetic design in general.

On the basis of these considerations, the feeder was selected as a starting device. It is still considered as the "work horse" orthesis for the polio patient with severely involved upper extremities; there are an estimated 15,000 such patients in the United States today. Over the years, since its introduction at Warm Springs during World War II, the feeder has often meant the difference between significant upper extremity function, and no function at all for these patients.

Basically, the feeder is a device for balancing out gravity forces while still permitting motion at the shoulder and elbow. It is concerned primarily with restoring different hand placements and hand orientations. It is not concerned directly with hand manipulative function.

But the feeder is far from being as simple as it seems. Its application to severely paralyzed patients, whose available muscle strength is measured in ounces rather than pounds, demands that it permit maximum use of these meager forces. It must allow unobstructed movement through the important degrees of freedom required by functional activities, and yet maintain throughout such movement the balance characteristics necessary to prevent adverse action of gravity forces.

The complexity of the demands of upper extremity function on this device has in the past discouraged analytical efforts to optimize its operation, and thus, presumably, left an appreciable margin for improvement. Consideration of the feeder was expected, also, to introduce the general principles and problems which might be encountered in design of any orthetic system effecting hand placement and orientation, as well as problems connected with combining engineering principles and anatomical considerations.

## II. CONVENTIONAL FEEDER TYPES

Conventional feeders are available in two basic designs, the "suspension feeder" and the "link feeder." These differ primarily in their method of supporting the forearm trough.

### A. SUSPENSION FEEDER

The suspension feeder operates as a pendulum, with the trough suspended from an overhead bar (Fig. 1). A spring is sometimes inserted in the suspension link to provide limited vertical movement of the trough (via "bouncing" or exertion of sustained upward or downward force on the trough) depending on the stiffness of the spring. Because of the pendulum nature of the system, horizontal movement is limited by the tendency of gravity to restore the trough to a rest position directly under the point of suspension.

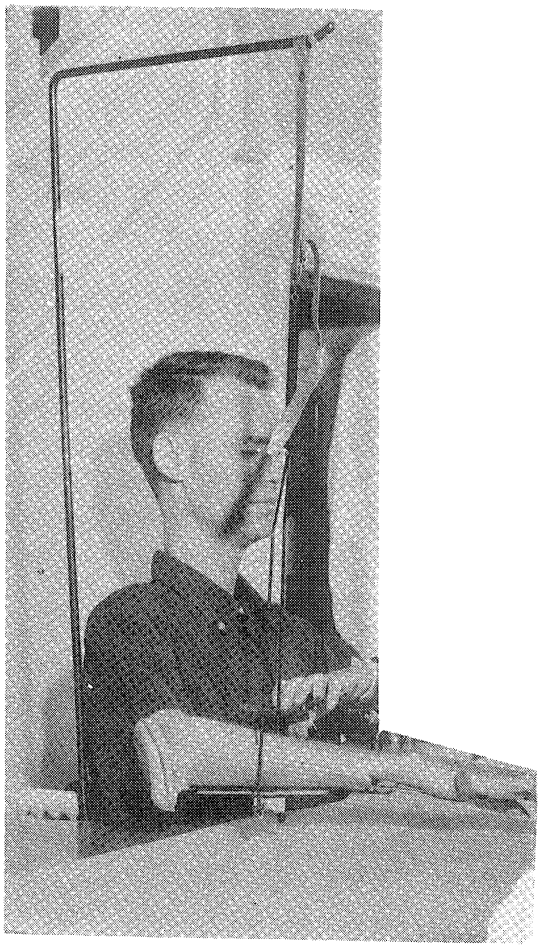

Fig. 1. Conventional suspension feeder.

B. LINK FEEDER

Free horizontal trough movement in any direction is provided in the conventional link feeder (also known as the "ball bearing" feeder) by a series of two nominally horizontal links connected to each other and to the frame of a wheel chair by means of ball bearings. Between the second (distal) link and the trough is a small vertical third link, the lower end of which fits into a vertical axis ball bearing, and the upper end into a bearing having a nominally horizontal axis. This latter bearing enables the trough to pivot in a vertical plane, and the hand to move vertically. In this report it is called the trough pivot, or simply the pivot. The link feeder is illustrated in Fig. 2.

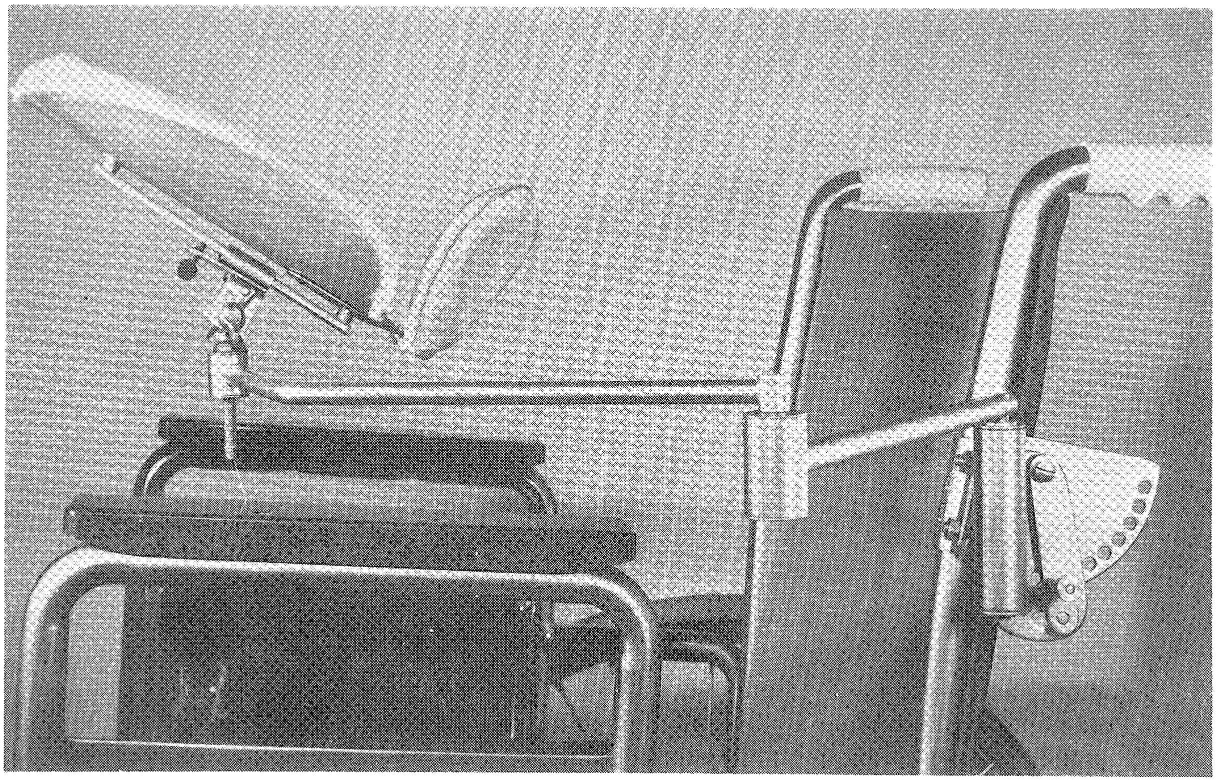

Fig. 2. Conventional link feeder.

## III. BASIC FEEDER GEOMETRY

To define certain terms which will be useful in subsequent sections of the report, the basic geometric considerations associated with feeder motion are summarized below.

In mechanics, the location and orientation of rigid bodies are commonly described in terms of the six degrees of freedom. This same notation is appropriate for describing the position and orientation of the hand and feeder. Figure 3 illustrates the six-degree-of-freedom concept with reference to an airplane.

The degrees of freedom are defined with respect to an arbitrary coordinate system determined by three mutually perpendicular axes, commonly designated as X, Y, and Z. In Fig. 3 these axes are shown aligned with the aircraft as a matter of convenience. Movement of the aircraft parallel to its initial position along the X, Y, and Z directions constitute the three translational degrees of freedom necessary to define the location of the aircraft. Rotation of the aircraft about each of the three axes constitute the three rotational degrees of freedom necessary to define its orientation or attitude. For example, the angle of rotation about the Y axis defines the direction in which the aircraft is heading, the angle of rotation about the Z axis defines its angle of pitch (i.e., ascending or descending), and the angle of rotation about the X axis defines its angle of roll.

For convenience, the coordinate system for the link feeder is taken as illustrated in Fig. 4 (forearm approximately horizontal) and Fig. 5 (forearm inclined). Both figures show the origin of the coordinate system (O) to be at the intersection of the trough pivot axis with a vertical plane through the forearm axis. The Z axis is defined as the trough pivot axis. The X axis is defined as the direction perpendicular to Z in which the trough pivot axis is free to move. Feeder constraints limit the trough pivot axis to locations in the XZ plane. This plane will be referred to as the "work-plane." The Y axis is perpendicular to the work-plane and passes through O. The work-plane is nominally horizontal, but adjustment of the feeder linkage permits it to be tilted in accordance with individual needs.

In Fig. 4, the forearm axis lies in the work-plane and coincides with the X axis. In Fig. 5, the forearm axis is inclined, and its projection on the work-plane coincides with the X axis. If the forearm were further inclined until it was perpendicular to the work-plane, the Y axis would then coincide with the forearm axis.

The link feeder permits movement of the trough through four of the six degrees of freedom—two of translation and two of rotation. Translation is permitted in the X and Z directions but not in the Y direction, as the trough

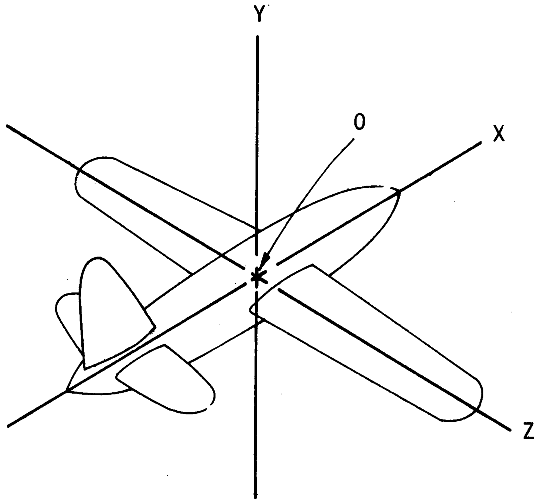


Fig. 3. Coordinate system of an airplane.

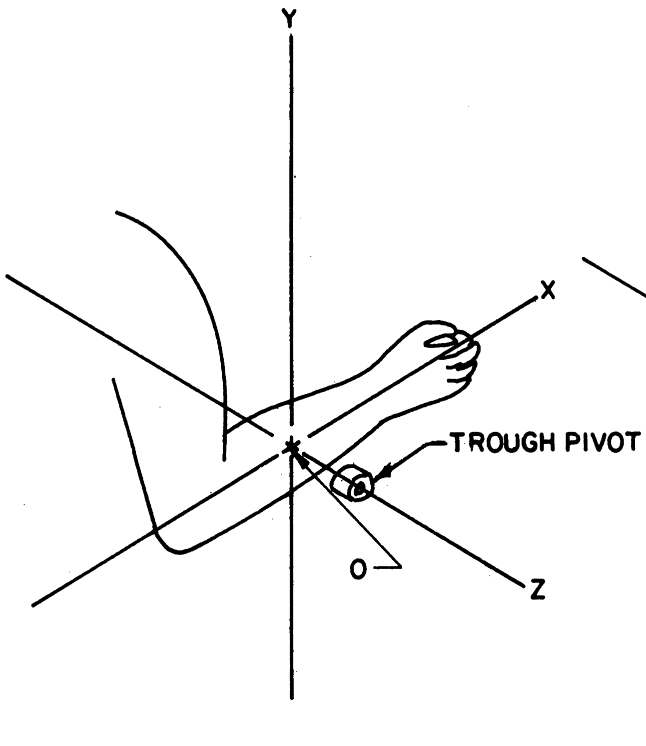


Fig. 4. Coordinate system (forearm horizontal).

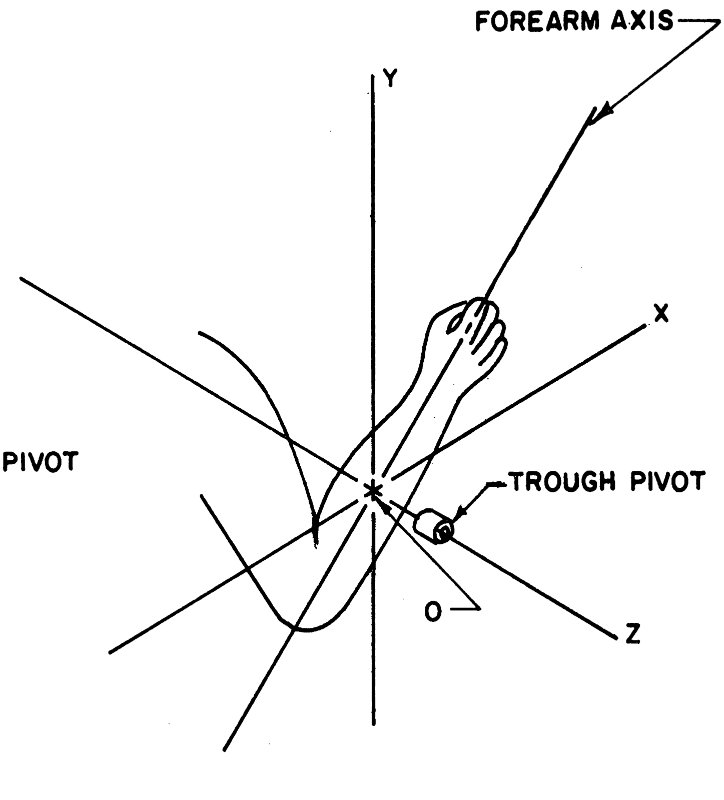


Fig. 5. Coordinate system (forearm inclined).

pivot is constrained to remain in the work-plane. Rotation is permitted about the Y and Z axes. Rotation about the X axis is not possible as this would take the trough pivot axis out of the work-plane. One significant implication of this feeder restraint is that supination-pronation of the trough is possible with the forearm perpendicular to the work-plane (essentially vertical), but not possible with the forearm parallel to the work-plane (essentially horizontal).

The geometry of the suspension feeder is basically the same as that of the link feeder except that the trough pivot is constrained to remain on a spherical surface rather than on a plane. The center of curvature of the spherical surface is the overhead point of suspension. By varying the location of the suspension point and the distance between the suspension point and trough pivot, it is possible to adjust the radius of curvature and the orientation of the spherical working surface.

## IV. PROBLEMS ASSOCIATED WITH CONVENTIONAL FEEDERS

### A. SUSPENSION FEEDER

A basic disadvantage of the suspension feeder lies in its limitation of horizontal hand excursion because of gravitational restoring forces. The magnitude of this limitation depends, of course, on the length of the pendulum arm. In a typical situation this limitation can be considerable, as evidenced in Fig. 6.

The suspension feeder also has the problem of protusion and conspicuousness of the overhead bar assembly. Similarly, the spring, sometimes added to the suspension mechanism to provide a little vertical trough movement, often reduces the fulcrum action of the pivot during vertical hand movement. Because of these disadvantages, the suspension feeder has been largely replaced in practice by the link feeder.* The latter has most of the advantages of the suspension feeder and few of the disadvantages. This project, therefore, has concerned itself primarily with the link feeder.

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*The suspension feeder was found to have one special advantage when used during experimental procedures. When fitted with an extremely long suspension cord, e.g., 18-20 feet, it possesses a nearly flat work"plane" which is inherently accurate and can be readily reproduced. It can thus provide a useful approximation of the work-plane of the link feeder without introducing the errors due to faulty construction or imperfect alignment of the linkage system. At the same time, by shifting the trough with respect to the point of suspension attachment, any desired tilt of the work"plane" can be obtained.

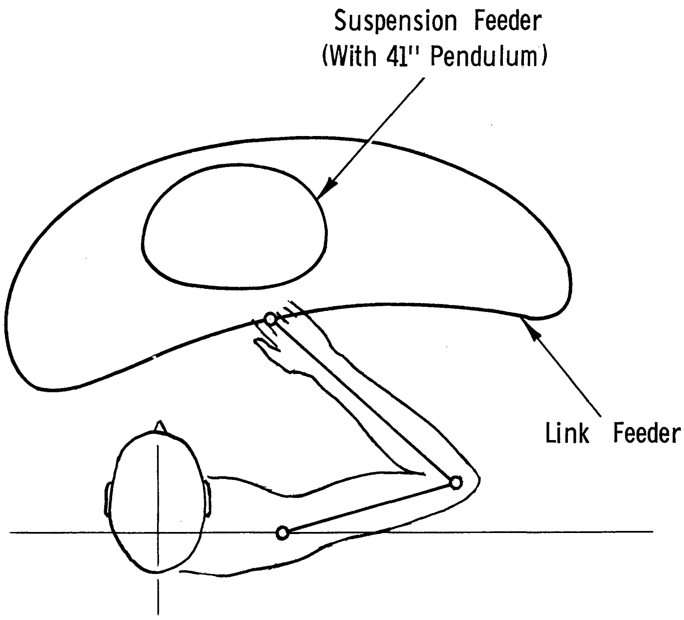



Fig. 6. Horizontal hand excursion of patient in a) a suspension feeder, and b) a link feeder with 7 oz. force directed away from hand rest point.

B. LINK FEEDER

A study of the difficulties encountered in using the conventional feeder, as revealed in the preliminary device survey, shows that they can be grouped for the most part into the following categories:

1. Inadequate control of gravity forces for the various feeder functions.
2. Imprecise adjustment control of trough height relative to the trunk.
3. Protrusion of feeder parts.
4. Support of the forearm by the trough.
5. Lack of explicit principles of feeder operation based on an understanding of feeder-extremity mechanics.

A sixth category could be added, namely, problems relating to mechanical failures such as parts bending, breaking, binding, or loosening. The solution of these problems involved the application of relatively straightforward principles of mechanical design. Hence, this aspect of the study will not be elaborated upon, except for the presentation of photographs and drawings of the proposed link feeder (Figs. 9-15).

The specific nature of the problems associated with each of the first four categories will be discussed below. The fifth problem, that of lack of analytical treatment of feeder function, is considered in a separate report, Tech. Report No. 4, Theory of Function of the Michigan Feeder, which includes an analysis of the available motions and of the forces acting to produce or constrain them. From this, principles of feeder adjustments are derived, and a procedure for applying them to patients is suggested. For amplification of the material that follows, reference will be made to this report when appropriate.

1. Control of gravity forces.—Figures 1 and 2 show that, in both the suspension and the link feeder, the location of the pivot along the forearm axis can be altered with an adjustment. Depending on which side of the balance point* the pivot is located, the system is either "hand-heavy" or "elbow-heavy" when the forearm is horizontal. With the pivot directly below

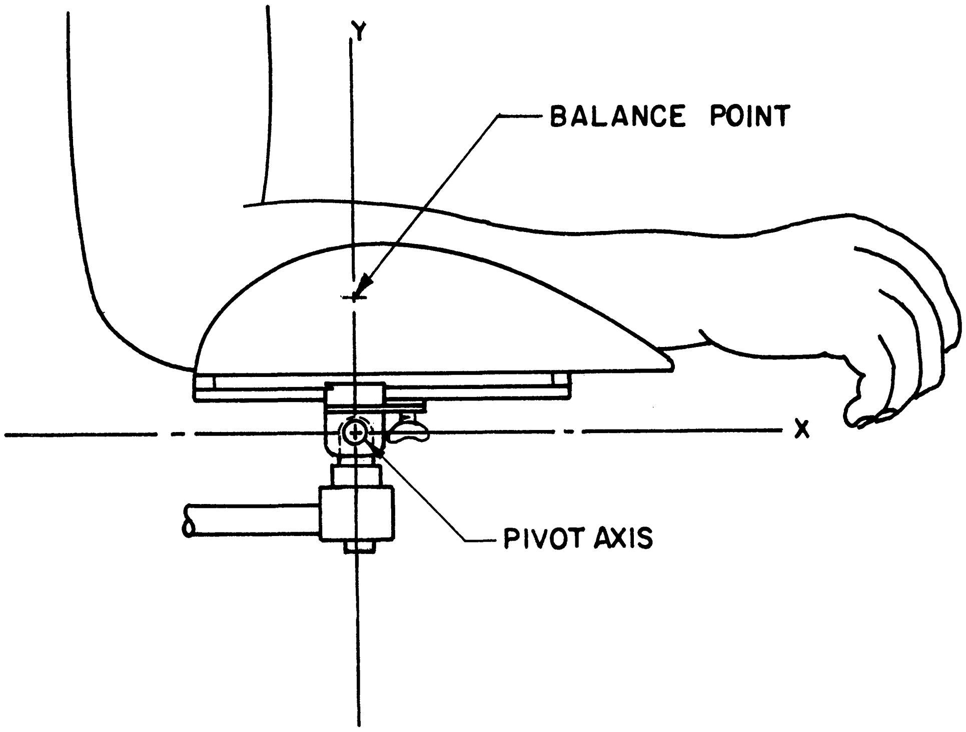



Fig. 7. Conventional pivot assembly and X-adjustment mechanism.

*The feeder-extremity system is considered "balanced" (with respect to forearm inclination) when a flail arm can remain at rest over a substantial working range of forearm angles. The location of the pivot axis (or, more precisely, its intersection with the XY plane) corresponding to this balanced condition is called the "balance point" of the system, shown in Fig. 7.

the balance point, as in Fig. 7, the forearm is balanced when horizontal, but is "hand-heavy" when inclined downward, and "elbow-heavy" when inclined upward. The control over gravity forces which can be exercised is limited and relatively crude, and "stops" must be provided to prevent extremes of forearm inclination.

Pivot adjustments are herein labeled with reference to the horizontal forearm position illustrated in Figs. 4 and 7. A pivot adjustment in the direction of the forearm axis is called the X adjustment and an adjustment perpendicular to the forearm axis is called the Y adjustment. As illustrated in Fig. 7, conventional feeders provide an X adjustment but, in general, not a Y adjustment. Furthermore, the Y setting of the pivot is usually well below the balance point so that gravity forces can in no way be balanced throughout a range of forearm inclination. Even the X adjustment is often unsatisfactory because the slider bar with locking setscrew shown in Fig. 8 fails to provide a practical means of making fine adjustments.

The action of gravity forces is also affected significantly by the tilt of the work-plane. The leveling (or controlled un-leveling) of the work-plane influences the tendency of the trough pivot to move in an anterior or posterior direction (pitch adjustment), and in a medial or lateral direction (roll adjustment). Some feeders (Fig. 2) provide a coarse control of work-plane tilt in one plane (only) through use of a step-wise adjustment of the angle of the proximal link with the wheel chair frame. The tilt can also be varied by rotation of the clamp about the vertical frame member, which is itself inclined a few degrees. Bending of the links has also been used as a means of adjustment. However, no conventional feeder is known to provide independent precision control of gravitational forces introduced through work-plane pitch and roll adjustment.

2. Adjustment of trough height.—The height of the trough, or more precisely, the trough pivot relative to the trunk, has important effect on the geometry of the system. It controls both the height of the forearm and the angle of forearm inclination when the hand is at the mouth. Although hand height relative to the work surface is also affected, this consideration is less important since the latter usually can be adjusted to accommodate the feeder.

For functional purposes, both hand height and forearm inclination should be established within a relatively small range. Since all the adjustments have a secondary effect on trough height, it often becomes necessary to reset the pivot height after changing these other adjustments. (Tech. Report No. 4—Section VII-F.)

In conventional feeders, pivot height can be varied by loosening and sliding up and down the clamp linking the feeder to the wheel chair frame. This method of adjustment presents several relatively minor problems:

(a) tools are required, (b) fine adjustments are difficult to make, and (c) the weight of the system must be supported while making the change.

3. Protrusion of feeder parts.—For a feeder to perform its function, it must usurp to itself a zone of space free of other objects. The smaller this zone, the closer to the patient can be placed objects important to his activities, and the less are the demands on the environment.

During vertical inclination of the forearm, the factor limiting trough proximity to a work surface is, of course, the protrusion below the pivot of the elbow, or of the structure supporting the elbow. When the conventional "donut" is used for this support, as much as 1—1-1/2 inches of additional clearance must be provided between trough and work surface (Fig. 1).

Similarly, the protrusion of the trough undercarriage is a factor limiting clearance of objects on the work surface during horizontal hand movement. The conventional undercarriage protrudes downward as much as two inches (Figs. 1 and 2).

Proximity of objects on the lateral side of the feeder is limited by the maximum lateral protrusion of the linkage during movement. This is reported to be excessive in the conventional link feeder.

4. Support of forearm in trough.—The trough supports the forearm, cradle-fashion, leaving the hand free, or, if the wrist is flail, supported by an extension. Problems have arisen, however, in judging the best compromise in trough dimensions and configuration to provide adequate support without impeding function unnecessarily. For example, the constraining action of the trough inherently offers resistance to active forearm supination-pronation, yet in some cases fails to hold the forearm in place adequately.

Problems are encountered also in the structure used to bear the weight of the forearm when vertical. Traditionally, this structure has been a padded "donut" (Figs. 1 and 2), but on some feeders a "triceps strap" connected to the trough by outriggers has been used (Fig. 8).

The donut provides a positive support, but impedes elbow extension, causes objectionable pressure on the ulnar nerve at the elbow, and protrudes below the elbow when the forearm is inclined vertically. The triceps pad gives better pressure distribution and virtually eliminates protrusion below the elbow. In its conventional form it restricts elbow flexion, but to a lesser degree than the donut. The triceps pad also has the disadvantage of failing to restrict a tendency for the vertically inclined forearm to pronate and swing outward in patients having excessive elbow flexion restraints and lacking biceps or supinator function (a not uncommon combination).

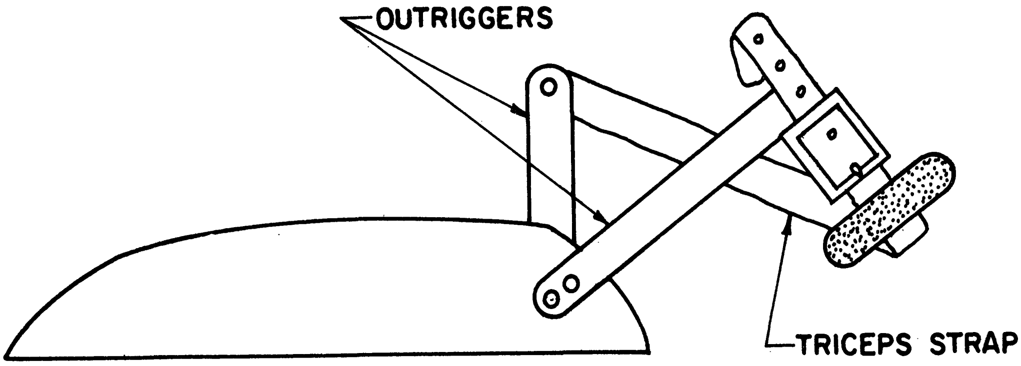



Fig. 8. Trough with conventional "triceps strap" for supporting the vertical forearm.

## V. DESIGN CHANGES INCORPORATED IN THE MICHIGAN FEEDER

Components of the Michigan feeder are illustrated in Figs. 9-14. The design changes incorporated are discussed below.

### A. DESIGN CHANGES AFFECTING CONTROL OF GRAVITY FORCES

As described in Part III, four of the six possible degrees of freedom are available to the feeder: two rotational and two translational movements. It is possible to control with considerable precision the magnitude and direction of gravitational effects on each of these degrees of freedom with four adjustments:

1. Twc adjustments to control the position of the pivot relative to the balance point of the forearm, the "X" and "Y" adjustments. These control gravity forces acting on trough pivot rotation about the Z axis.
2. Two adjustments to control the tilt of the work-plane, the "pitch" and "roll" adjustments. These control gravity forces affecting pivot translational movement over the XZ plane. They also affect rotation about the Y axis.

In the Michigan feeder, these four adjustments are provided by screw-type precision mechanisms as follows:

1. Adjustment of the pivot relative to the balance point.—As shown in Figs. 9 and 10, the pivot (p) is attached to the trough by means of two threaded shafts (x and y) which parallel the X and Y axes when the forearm is horizontal. Knurled nuts (a) and (b) control the pivot position on the x and y shafts respectively. Alignment of the trough with respect to the adjusting screws is maintained by arm (f) which carries the weight of the trough at nylon buttons (g) and (h); and also by key (d) which prevents rotation of the trough about the vertical threaded shaft (y). Lock screw (c), the end of which bears against the bottom of the keyway, is used to prevent the small amount of angular motion permitted by keyway clearance. An extension of the key vertically reduces the tendency of the nut (b) to

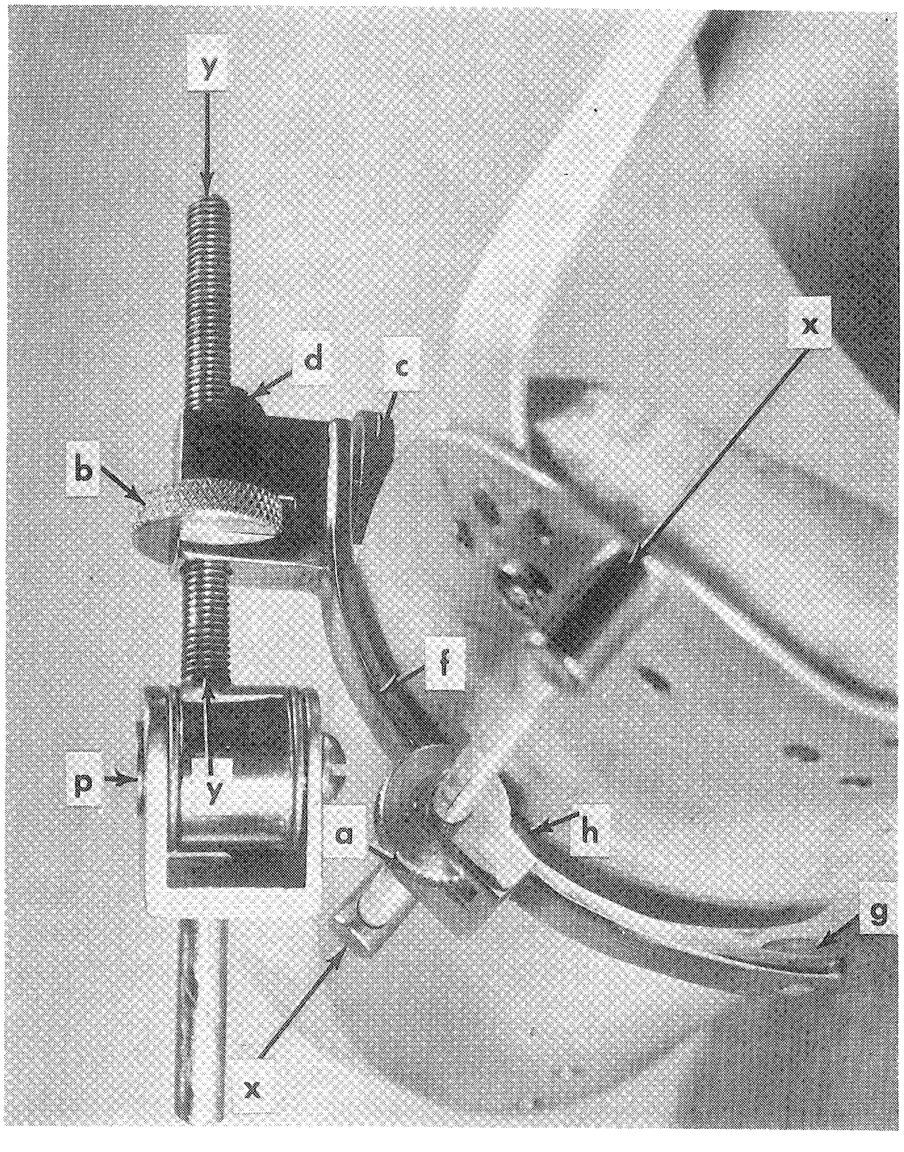



Fig. 9. Michigan feeder trough pivot adjustment assembly.

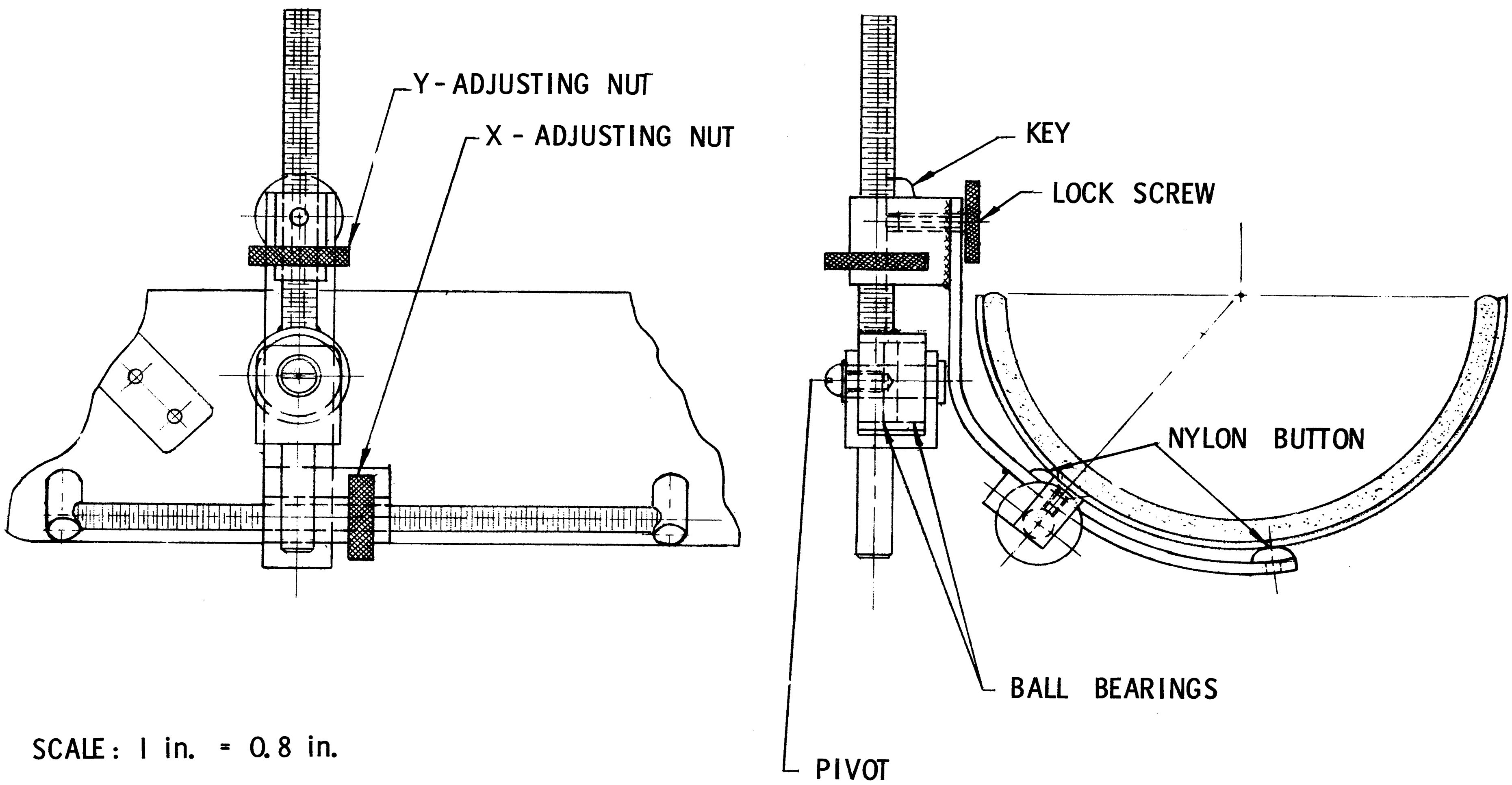



Fig. 10. Trough pivot adjustment assembly.

bind when the trough is bearing the full weight of the arm; however, for ease of adjustment of this control, the weight of the trough should be supported with one hand while the adjustment is made with the other.

The combination of these two adjustments permits fine control of gravity forces acting on hand up-and-down movement throughout the patient's usable range. Either negative or positive gravity forces can be applied to the hand, and the extent of these forces can be made to vary with the degree of elevation of the hand. If desired, gravity forces can be completely balanced out throughout a useful range of up-and-down hand excursion. The rationale for use of these adjustments is developed in Tech. Report No. 4—Section VII-A, B and C.

As a side effect of these adjustments, it is often possible to eliminate the "stops" used in the conventional feeder to restrict extremes of trough inclination. When balanced for optimum function, excessive gravity forces at the extremes of up-and-down movement are generally not present, making stops unnecessary. Also, use of screw-type adjustments with knurled nuts has simplified the procedure for making the settings.

With patients unable to limit humeral external rotation or elbow flexion adequately, however, it may be necessary to add an adjustable vertical inclination stop to prevent the vertical forearm from flipping backward out of the trough as the weight is transferred to the elbow-supporting member. The forces producing this effect are analyzed in Appendix I.

2. Adjustment of work-plane tilt.—Any direction and degree of tilt desired can be obtained by controlling tilt in two directions: anteroposterior (pitch) and mediolateral (roll). If the link joints remain parallel to each other, the work-plane will be perpendicular to the axis of the proximal link joint which, in turn, is attached to the wheel chair frame. Thus, change in the angle of inclination of this joint causes a corresponding change in the tilt of the work-plane.

To provide precision control of tilt, a chair-clamp unit has been designed incorporating two screw-type, adjustments which set the angle of inclination of the proximal joint. This unit is shown in Figs. 11 and 12. With reference to Fig. 11, rotation of screw (m) (pitch adjustment) varies the tilt of the work-plane in the anteroposterior direction, and rotation of screw (n) (roll adjustment) varies the tilt in the mediolateral direction. The two adjustments can be made independently. The unit itself can be used on either the right or left side of the wheel chair.

When the forearm is horizontal, gravity forces power horizontal hand movement in the direction of tilt, and when the forearm is vertical, hand movement about the face is affected. Tilt adjustment influences, also, the

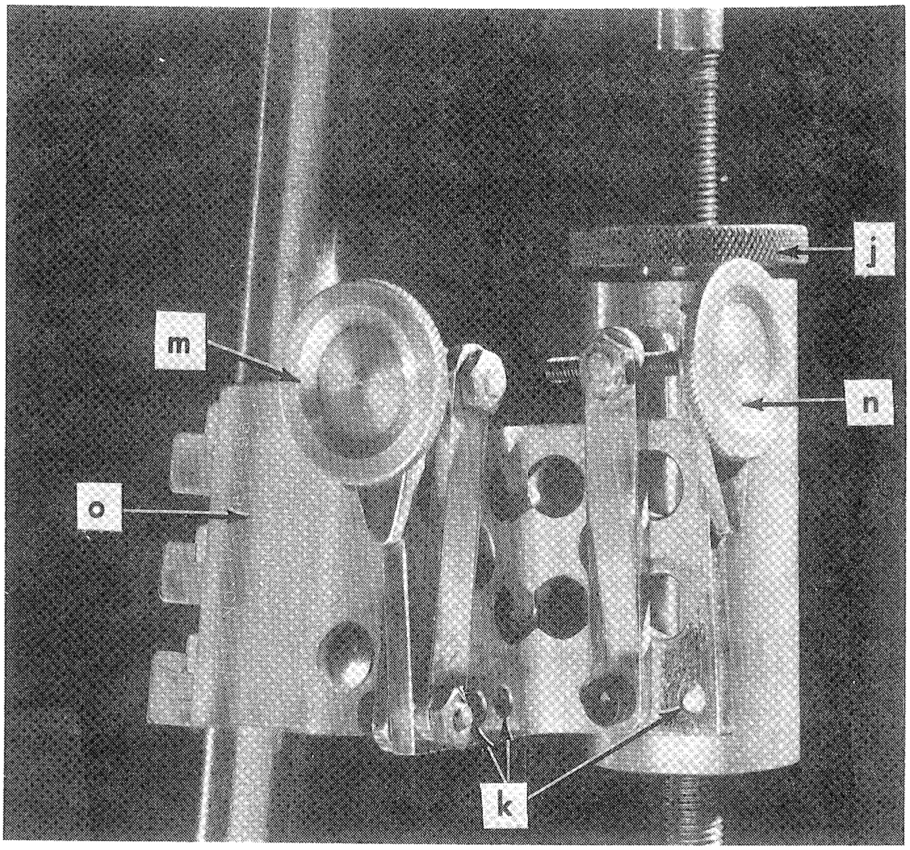


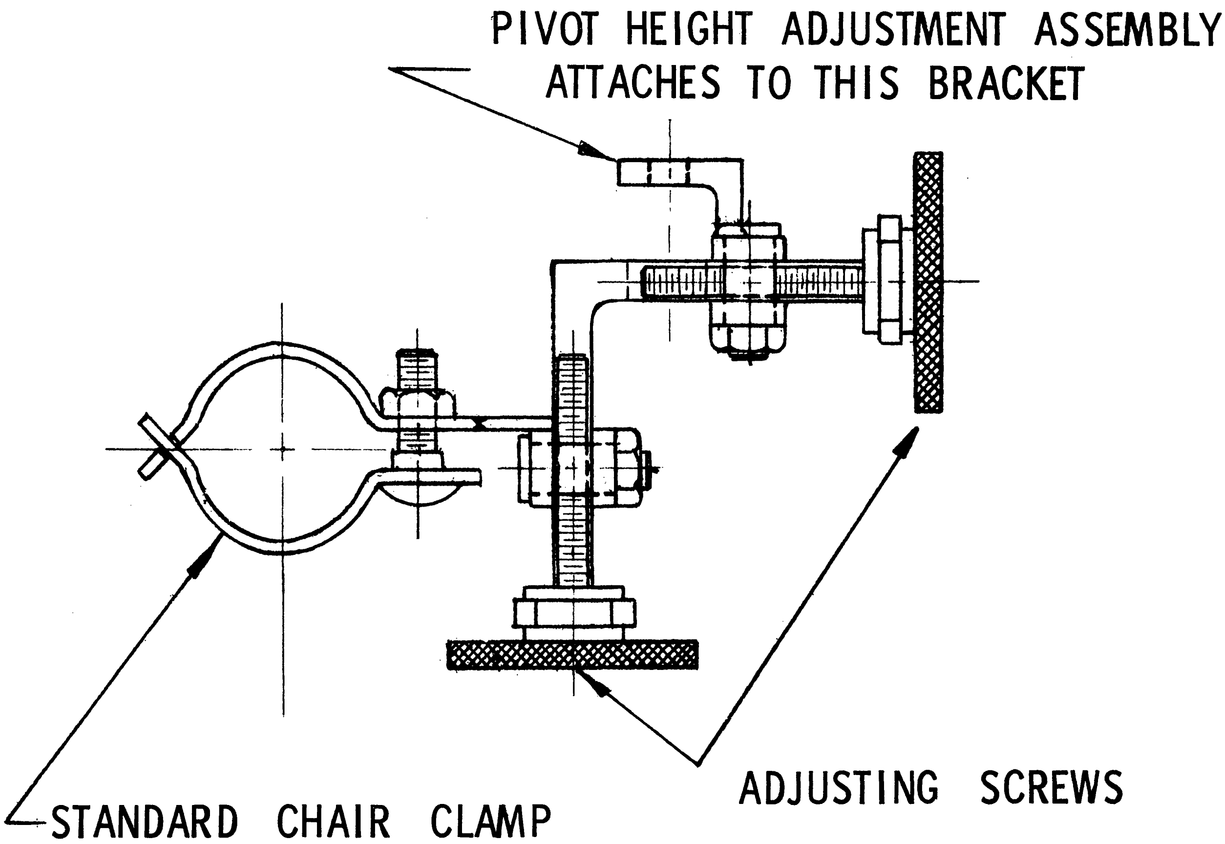

Fig. 11. Michigan feeder, pitch, roll, and pivot height adjustment assembly.

location of the hand rest-zone both about the face (forearm vertically inclined) and over the work surface (forearm horizontal). The rationale for use of pitch and roll adjustments is developed in Section VII-D of Tech. Report No. 4.

In order that the work-plane remain flat throughout its entirety, the feeder links have been constructed of 1/2-in. outside-diameter steel tubing having .125-in. wall thickness. This provides enough link rigidity to maintain a high degree of parallelism between the joints without adding excessively to the mass of the system or cost of construction.

## B. DESIGN CHANGES AFFECTING CONTROL OF PIVOT HEIGHT RELATIVE TO THE TRUNK

A mechanism has been added to the Michigan feeder to provide fine control of the height of the pivot relative to the body. This is shown in Figs. 11 and 13. The mechanism consists of a vertical screw with large knurled head (j, Fig. 11) added to the chair clamp unit, which serves to alter the height of the entire link assembly relative to the chair (and thus to the patient).



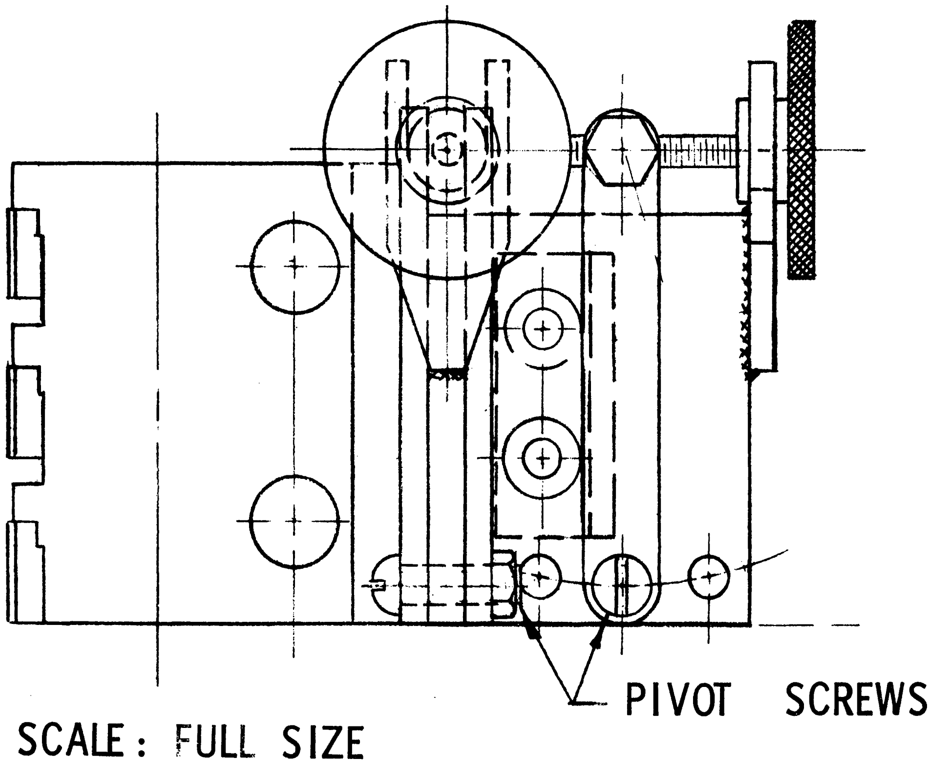




Fig. 12. Pitch and roll adjustment assembly.

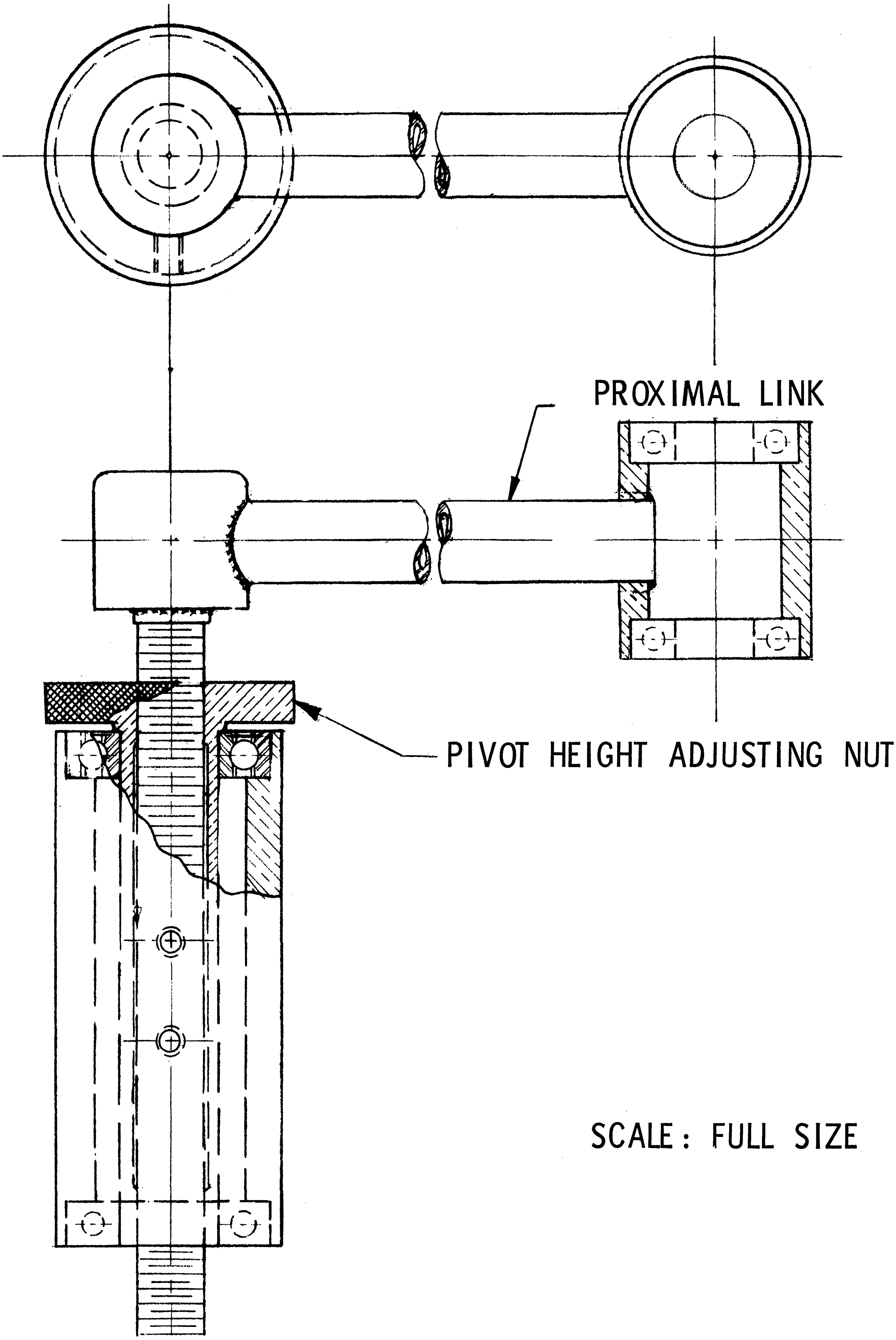



Fig. 13. Pivot height adjustment and proximal link assembly.

This adjustment mechanism may not be necessary on all feeder models, but should be particularly helpful on a "fitting" model used to establish the proper pivot height for an individual patient. Without the special height adjustment assembly, height changes must be made by loosening the main clamp and sliding it vertically on the wheel chair frame. The rationale for use of this adjustment is discussed in Section VII-E of Tech. Report No. 4.

## C. DESIGN CHANGES LESSENING PROTRUSION OF FEEDER PARTS

In the Michigan feeder, the zone of space usurped by the system has been reduced in two areas, inferiorly and laterally, by decreasing the protrusion of parts in these directions.

1. Reduction in protrusion inferiorly.—For a given degree of forearm inclination, the extent of elbow protrusion inferiorly depends on the location of the pivot relative to the elbow, and cannot be altered without rearranging the mass distribution of the system or changing the pivot position relative to the balance point. Both of these changes would presumably affect function adversely. However, by substituting a triceps strap for the conventional "donut" (see Section D below), the inferior projection of the elbow can be reduced as much as 1—1-1/2 in. when the forearm is inclined. This, of course, permits a work surface to be placed closer to the trough pivot.

Similarly, clearance between the trough undercarriage and objects on a work surface has been increased by locating the pivot adjustment unit on the side of the trough instead of underneath (Figs. 1 and 2 vs. Figs. 9 and 10). This has reduced inferior protrusion of the trough undercarriage during horizontal hand movement from approximately 2 in. to less than 1/2 in.

2. Reduction in protrusion laterally.—Lateral protrusion can be limited, of course, by permitting the middle joint to "buckle" inward instead of outward, but this has the disadvantages of interfering with objects on a work surface and, probably of requiring additional links if full horizontal hand excursion is to be achieved. When it is elected to avoid inward buckling, lateral protrusion can be minimized by ascertaining the proper ratio of proximal and distal link lengths, and by keeping the proximal attachment of the assembly as medial as possible. In the Michigan feeder, the latter has been accomplished by attaching the link-to-chair clamp behind, and slightly lateral to, the chair back, where it is as medially as can be without interfering with the patient's trunk or arm, or perimitting the proximal link to strike the chair frame. The total length of the linkage should be long enough to permit full horizontal hand excursion without the component links becoming co-linear and allowing inward buckling.

Through analysis of the geometry of the system (see Appendix II), the optimum ratio of length of proximal to distal links has been established as approximately 1:2 (with link length being defined as the straight line distance between the pivot axes). This will vary slightly among different persons, or when wheel chair back-boards are used. Whenever minimum lateral link protrusion is desired for a particular patient, optimum link length can be calculated quickly by using the principles described in Appendix II. If a set of standard feeder sizes is desired (e.g., "small," "medium," and "large"), the optimum ratio of link lengths for each set can be taken as 1:2.

In order that the elbow not strike the linkage assembly during movement, the distal link should be bent. Clearance should be adequate in nearly all cases if a right angle bend is incorporated as described in Appendix II.

## D. DESIGN CHANGES AFFECTING FOREARM SUPPORT BY THE TROUGH

1. Trough support, forearm horizontal.--The trough structure should serve to minimize resistance to voluntary forearm supination-pronation while maintaining adequate forearm support and constraint. Free supination-pronation, however, would require rotation between the proximal and distal ends of the trough. Although several schemes for approximating this were investigated, none proved entirely satisfactory because of problems with bulk, cost, function, durability, etc. However, resistance to forearm supination-pronation in the standard feeder trough can be minimized by keeping it as nearly flat and as short axially as possible. Empirical observation has indicated that, to provide adequate support, the trough should extend distally to a point approximately 85% of the distance from olecranon to ulnar styloid. If an allowance is made for a 1-1/2-in. gap between olecranon and the proximal trough end,optimum length can be quickly calculated. For example, if it is assumed that olecranon to ulnar styloid distance rarely exceeds 11 in., an 8-in. trough should be long enough for virtually all forearms. A longer trough may be necessary, however, if no vertical inclination stop has been employed, and there is a tendency for the forearm to flip out when maximally inclined (Appendix I).

The trough margins have also been raised (Fig. 14) to improve forearm retention, particularly when inclined. The constant radius construction has been maintained, however, because of its ease of fabrication, and because it provides a reasonable compromise between shapes minimizing supination-pronation resistance and maximizing forearm constraint. A trough diameter of 3-3/4 in. has proven satisfactory for a majority of adults, but if constraint is inadequate, the margins can easily be bent inward. The proximal medial margin is notched (Fig. 14) to prevent impingement on the forearm during inward hand movement. The trough is also padded with a thin layer of a durable resilient material having a high coefficient of friction, e.g., foam rubber or polyurethane foam.

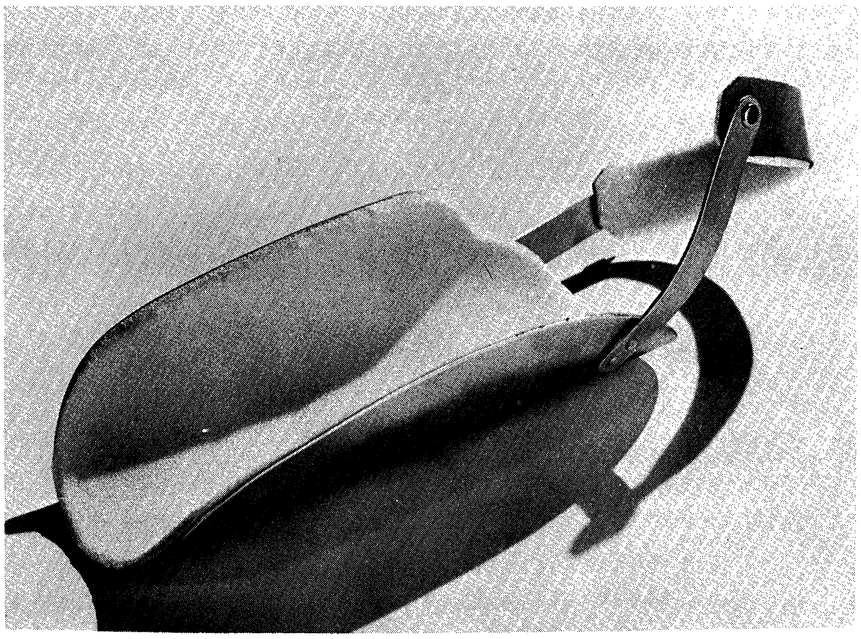


Fig. 14. Michigan feeder trough and triceps strap assembly.

2. Trough support, forearm vertical.—For the structure supporting the vertical elbow, design objectives have been to retain the advantages of the triceps strap while overcoming its disadvantages, i.e., its tendency to limit elbow extension and its failure to prevent outward hand drift. The strap acts to limit elbow extension when: (a) the axis of strap rotation fails to coincide with the axis of elbow flexion-extension, or (b) the humerus rotates axially (during elbow flexion-extension) and the elbow axis becomes displaced from the strap axis. Several mechanisms designed to keep these two axes roughly coinciding throughout elbow rotation were tried but were discarded for various reasons.

The design selected as best is illustrated in Figs. 14 and 15. A pad lined with material having a high coefficient of friction, such as foam rubber, is connected by straps to trough outriggers at pinned joints (c). With the forearm in a horizontal rest position, the strap axis is placed as close as possible to the axis of elbow flexion-extension without losing the support function of the pad. A compromise is necessary, however, since the closer the weight-bearing portion of the strap is to the olecranon, the more likely is the elbow to slip out of the strap, and the more proximal the strap, the more binding and limitation of extension it causes.

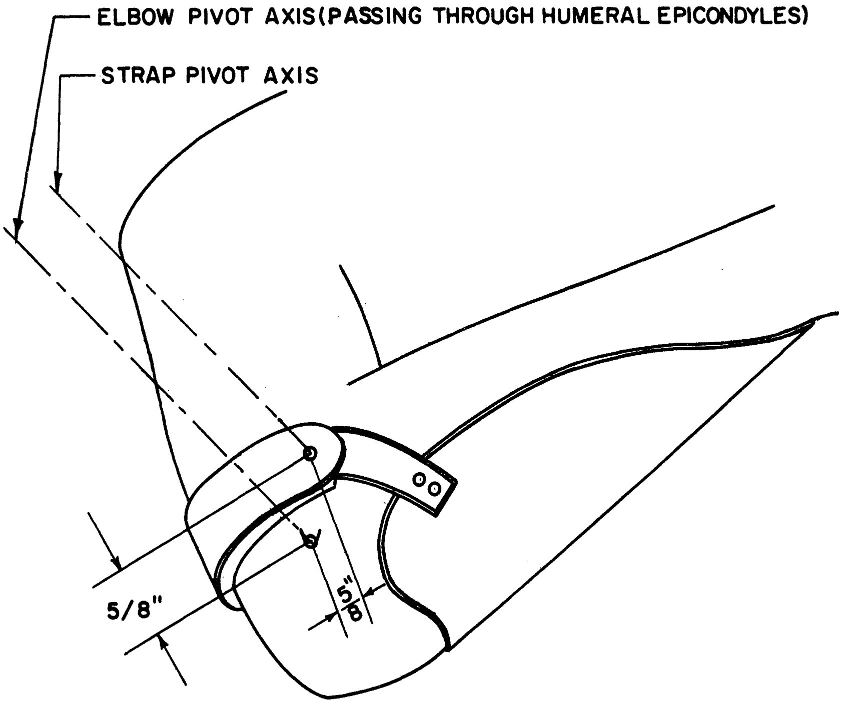



Fig. 15. Relation of the axis of rotation of the redesigned triceps strap to the anatomical axis of elbow flexion-extension.

The compromise selected empirically locates the strap axis about 1/2-3/4 in. proximally and anteriorly to the elbow axis (which is considered to pass through the tips of the humeral epicondyles). This relationship prevents significant binding until the elbow has extended to about 135°. Since maximum horizontal hand excursion requires no more than 150-160° of elbow extension (Section V of Technical Report No. 4), loss of function is minimized. Also, the binding effect of displacing the strap and elbow axes is reduced by establishing the strap-axis location when humeral rotation is nearly neutral (Appendix III).

As shown in Fig. 15, the padded inner surface of the lateral pin joint touches the upper arm lightly. This contact serves both to hold the humerus snugly into the triceps strap, and to prevent the vertically inclined forearm from drifting outward and into pronation. The mechanism of the latter effect is depicted in Fig. 16. As the vertical forearm pronates, the lateral outrigger is pressed against the humerus. Since outward hand drift (which presumably is the result of elastic forces limiting elbow flexion) cannot occur unless accompanied by forearm pronation, the "pronator stop" effect of the lateral outrigger serves to keep the hand in front of the face. Forearm supination is not restricted, however, since in this position, neither outrigger contacts the arm. A procedure for fitting the outrigger and the triceps strap is presented in Appendix III.

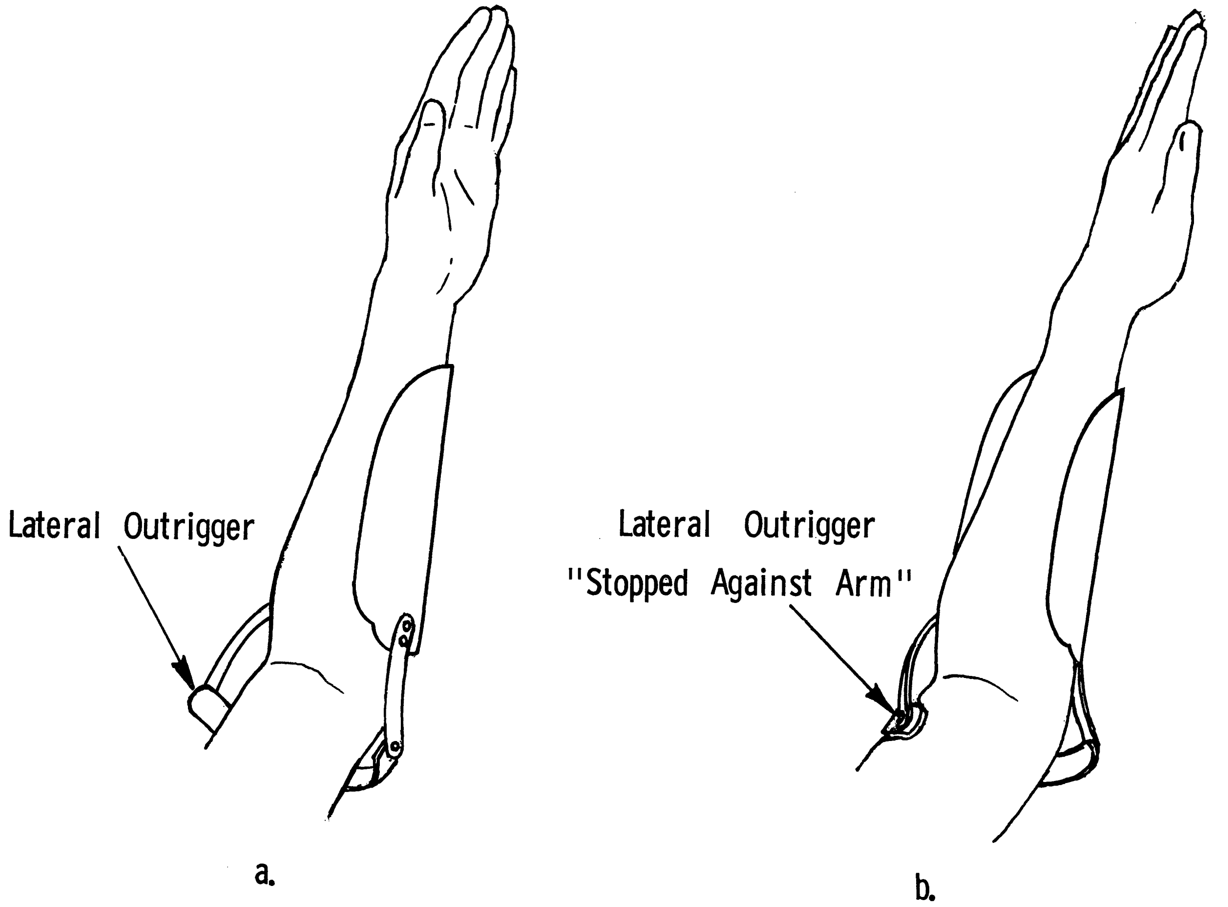



Fig. 16. Pronator "stop" function of lateral outrigger.

## VI. SUMMARY

The Michigan feeder incorporates design changes which could be made without altering the basic principles of the device. Since the purpose of the feeder is to control gravity forces acting on the severely weakened upper extremity, the major design effort has been to provide new, and refine old, mechanisms for optimizing control of these forces.

The new feeder, therefore, includes independent adjustments (X and Y) for precision control of the gravity forces acting on vertical hand movement during all angles of forearm inclination. Other adjustments (pitch and roll) permit fine control of gravity forces acting on hand excursion over a nominally horizontal plane. The rest position of the hand at the beginning and end of vertical hand movement can thus be established to suit individual requirements. Another adjustment (pivot height) provides precise control of certain geometrical configurations of the system, particularly the angle of forearm inclination with hand at mouth, and angle of humeral elevation with forearm horizontal.

In addition, design changes have been incorporated to reduce the protrusion of feeder parts, and to overcome several disadvantages of the conventional trough mechanism. Accepted mechanical design practices have been followed throughout to minimize mechanical failures.

Obviously, further refinements are possible, and will undoubtedly be made as the result of clinical testing of the unit. It is believed, however, that the present model has the following advantages over conventional units:

1. Advantages associated with improved control of gravity forces:
    a. Undesired gravity forces, and thus the work required of available muscles in overcoming these forces, can be minimized during feeder activities.
    b. Gravity forces can be matched to available muscle forces with greater versatility.
    c. The forearm can be balanced over a functional range of inclination as opposed to the "two position" operation of conventional feeders.
    d. The adjustments can be made with greater ease and precision.
    e. The need for trough-pivot "stops," and their associated drawbacks, is eliminated (except for a vertical inclination stop in some cases).

2. Advantages associated with control of pivot height relative to the trunk:
    a. Adjustment is easier.
    b. Adjustment is more precise.

3. Advantages resulting from reduced protrusion of feeder parts:
    a. The work surface, and objects on it, can be positioned closer under the trough.
    b. The space usurped by the feeder laterally is reduced.

4. Advantages resulting from better support of the forearm by the trough:
    a. Positive positioning of the forearm in the trough is improved.
    b. The likelihood of ulnar nerve pressure is diminished.
    c. Restriction of elbow extension is reduced.
    d. Outward drift of the vertically inclined forearm is controlled.

5. Miscellaneous advantages resulting from design improvement:
    a. Mechanical failure of parts is reduced.
    b. Cosmesis of the unit is improved.

# APPENDIX I

## FOREARM INSTABILITY IN THE VERTICAL TROUGH

In patients lacking restraints to extremes of humeral external rotation or elbow flexion, there is a tendency for the vertical forearm to "flip" out of the trough. The following is an explanation for this occurrence.

Fig. I-1 shows that, when the forearm is vertical, weight W carried by the elbow strap produces a torque about the pivot axis tending to flex the elbow further. In Fig. I-2, the elbow is flexed sufficiently to bring weight W directly below the pivot, so that a gravity torque is no longer produced.

Fig. I-3 illustrates the forces acting on the feeder trough assembly if elbow anatomical restrictions to flexion exactly balance the gravity torque when the forearm is vertical. The anatomical constraint gives rise to two horizontal forces, F, which are of such magnitude that torque F•a is equal to torque W•b. Fig. I-4 shows the equal and opposite forces which act on the arm.

Whenever the magnitude of force F necessary to produce the required torque F•a exceeds the available friction force on the elbow strap, i.e., when the required F exceeds W times coefficient of friction, the arm will slide on the strap and "flip out" of the feeder. Two design modifications are available for controlling "flip-out": (1) increasing trough length, thereby increasing dimension "a" so that a given product F•a is attainable with a smaller force F, or (2) providing an adjustable mechanical stop to limit trough vertical inclination to a value safely below that at which slippage occurs.

Because trough length is often limited by supination-pronation requirements (Section V-D), "flip-out" is probably best prevented by limiting vertical inclination to safe values. In the absence of sufficient anatomical restraint to humeral external rotation or elbow flexion (either of which serve to limit trough inclination), a mechanical stop is advised.

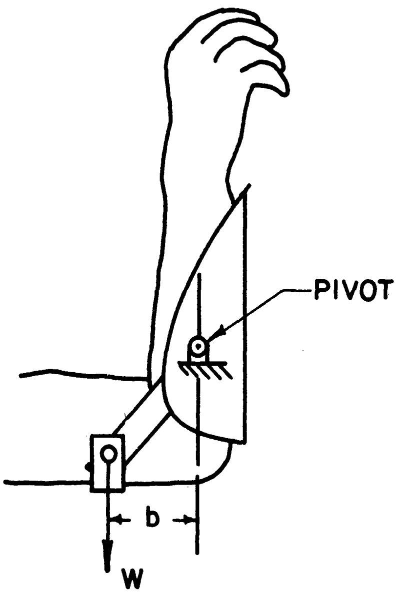



Fig. I-1. Trough pivoting torque developed by weight transfer to triceps strap (assuming negligible flexion restraints).

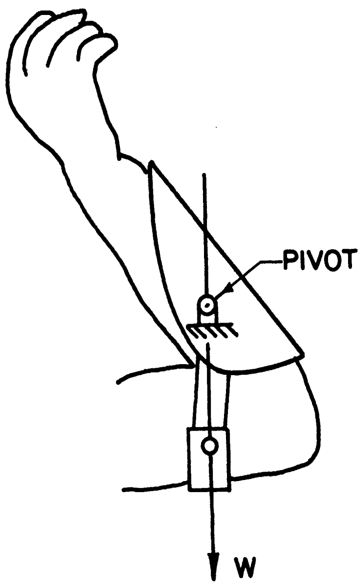



Fig. I-2. Stable forearm position with weight on triceps strap (assuming negligible flexion restraints).

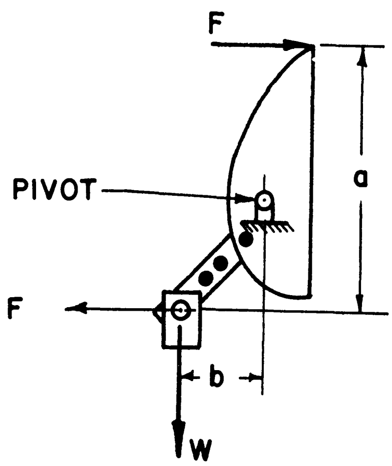



Fig. I-3. Forces acting on trough assembly when flexion restraints cause vertical forearm to be in equilibrium.

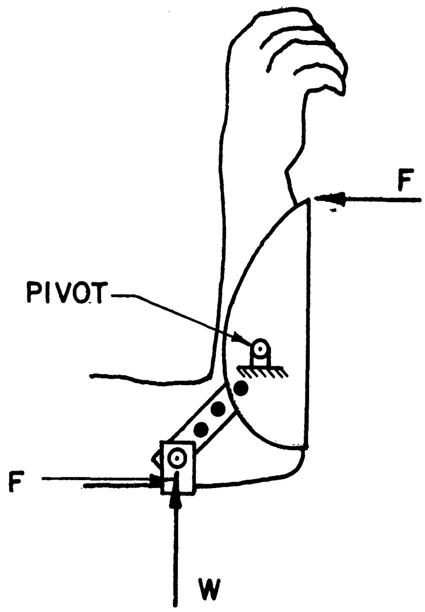



Fig. I-4. Forces acting on arm when flexion restraints cause vertical forearm to be in equilibrium.

## APPENDIX II

## LINKAGE GEOMETRY STUDY

It is assumed that the linkage involves three nominally vertical pivots separated by two nominally horizontal links (see Section V, C, 2) of lengths designated herein as $L_1$ and $L_2$. Optimum values for $L_1$ and $L_2$ may be determined as follows:

1. The sum $L_1 + L_2$ is determined on the basis of maximum hand excursion. This is illustrated in Fig. II-1 where the proximal and distal pivots $p_1$ and $p_3$ are separated as far as anatomical restrictions permit. The distance between the pivots is measured as dimension A. Then, to permit full range without buckling of the linkage, $L_1 + L_2$ must slightly exceed A, or:

$$L_1 + L_2 = 1.1A \text{ - - - - - - - - - } (1)$$

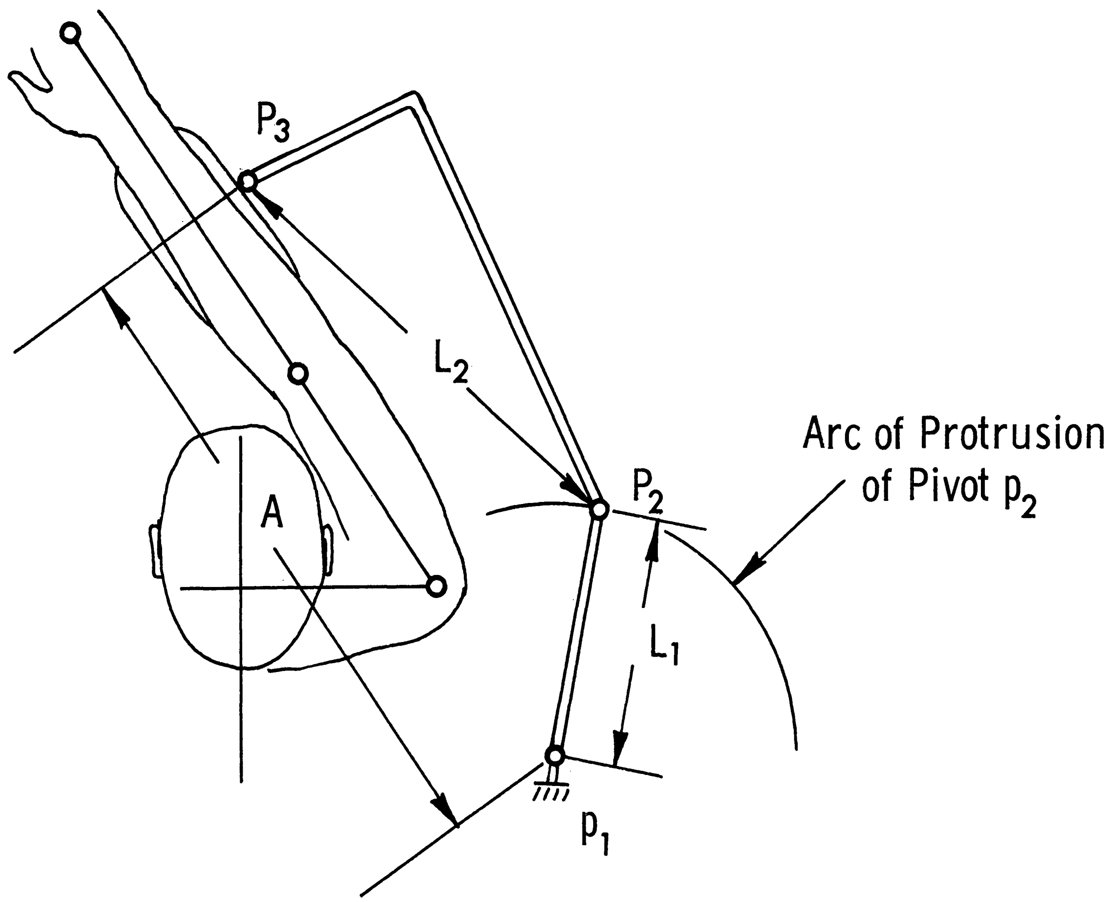



Fig. II-1. Measurement of "A" in Eq. (1).

2. So that the intermediate pivot, $p_2$, protrude as little as possible, length $L_2$ should be held to a minimum. The extent to which the proximal link can be shortened is limited because hand placements close to the trunk require that distal pivot $p_3$ be allowed to come close to proximal pivot $p_1$. If it were required that $p_3$ be able to come immediately adjacent to $p_1$, distances $L_1$ and $L_2$ would have to be equal. Figure II-2 illustrates that if B is the minimum required distance between $p_1$ and $p_3$, then $L_2 - L_1$ must be no greater than B. To avoid the possibility of buckling, a 10% margin is again suggested, or:

$$L_2 - L_1 = 1.1B \quad \text{- - - - - - - - - -} \quad (2)$$

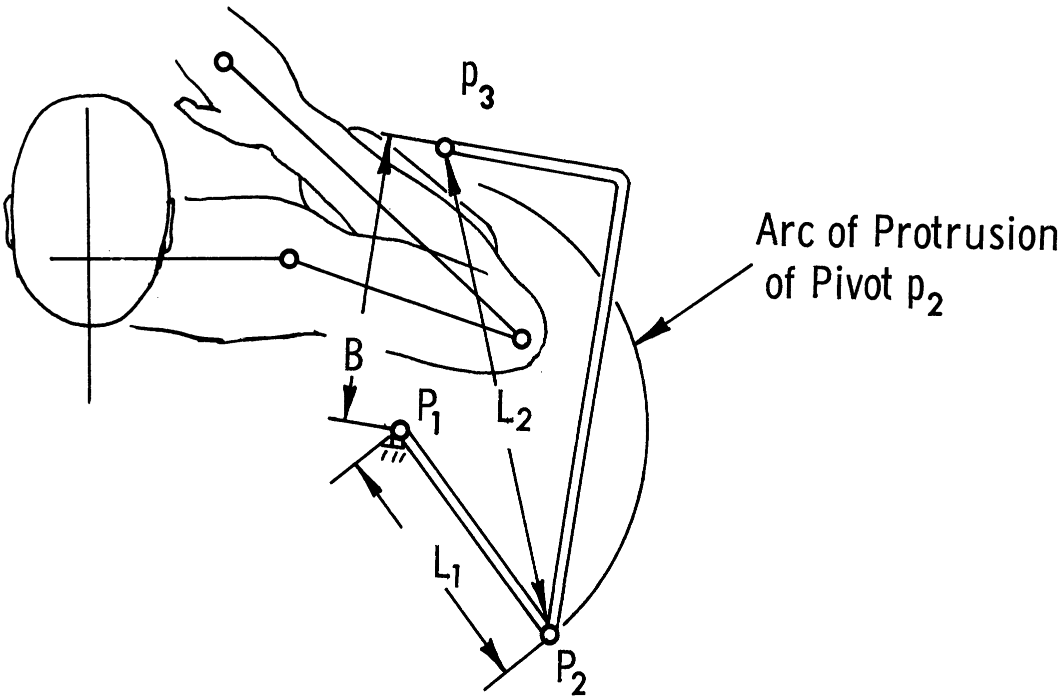



Fig. II-2. Measurement of "B" in Eq. (2).

Simultaneous solution of Eqs. (1) and (2) yields the desired values of $L_1$ and $L_2$. As mentioned in Section V, C, 2, such an analysis usually establishes values of $L_1$ and $L_2$ in the approximate ratio of 1:2.

A study has been made also of the amount of distal link bend which is required to provide elbow clearance. This resulted in the proportions given in Fig. II-3. In a typical linkage for an adult feeder patient, distance $L_1$ is approximately 8 in.

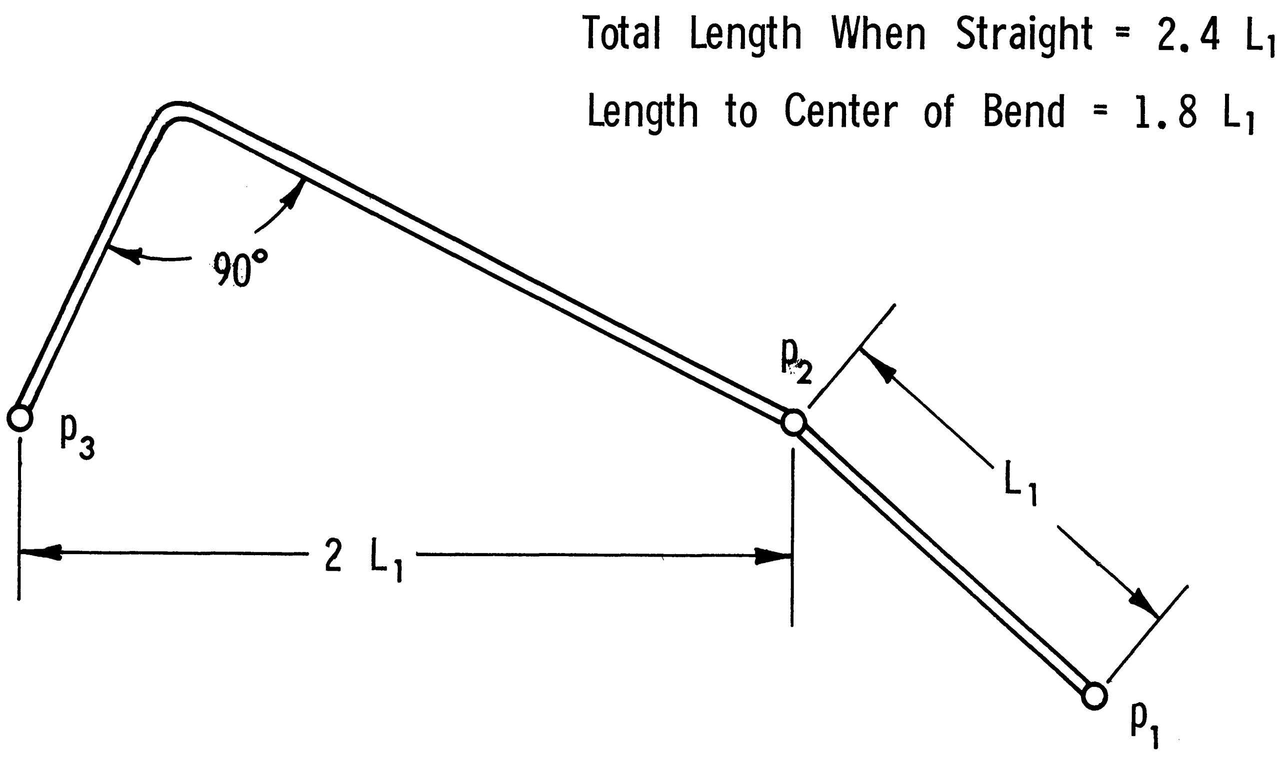



Fig. II-3. Linkage detail.

## APPENDIX III

## SEQUENCE OF STEPS FOR FITTING THE TRICEPS STRAP

A. Determine strap length

1. Locate and mark the strap axis of rotation on the skin 1/2-3/4-in. proximally and anteriorly to the tips of the two humeral epicondyles (while the forearm is inclined about 45-55° beyond horizontal, and thumb tip is at mouth level).
2. Measure the distance between these two points posteriorly. The strap length should equal this distance plus 1 in. to compensate for clearance of the medial outrigger and strap padding.

These dimensions should be adhered to rather rigorously since incorrect length will cause binding during elbow extension and may reduce the support offered the elbow during vertical forearm inclination.

B. Determine the location of the strap axis of rotation relative to the feeder trough.

1. Attach the trough to the linkage system fastened to the patient's wheel chair.
2. Position the forearm in the trough so that the hand is palm down and the posterior trough margin is about 1-1/2 in. from the tip of the olecranon. The X and Y adjustments should be roughly in balance.
3. While holding the forearm securely in its position in the trough, raise the pivot height until the forearm is inclined approximately 45-55° from horizontal when the thumb is at mouth level.
4. Fasten medial and lateral outriggers to the trough so that the location of the joint at their ends lines up with the strap axis as marked on the elbow. The end of the lateral outrigger should be adjusted to make gentle contact with the arm, while the end of the medial outrigger should be permitted about 1/2-in. clearance.

This last procedure can be expedited by fastening the outrigger stock to the trough by single rivets initially to permit free pivoting. The pieces can then be rotated and bent until some part near their ends coincides with the desired strap axis. The outrigger-trough junction can then be stabilized, and the strap axis pivots can be fabricated after excess outrigger length has been discarded. The strap padding can then be extended to cover the inside of the joints.