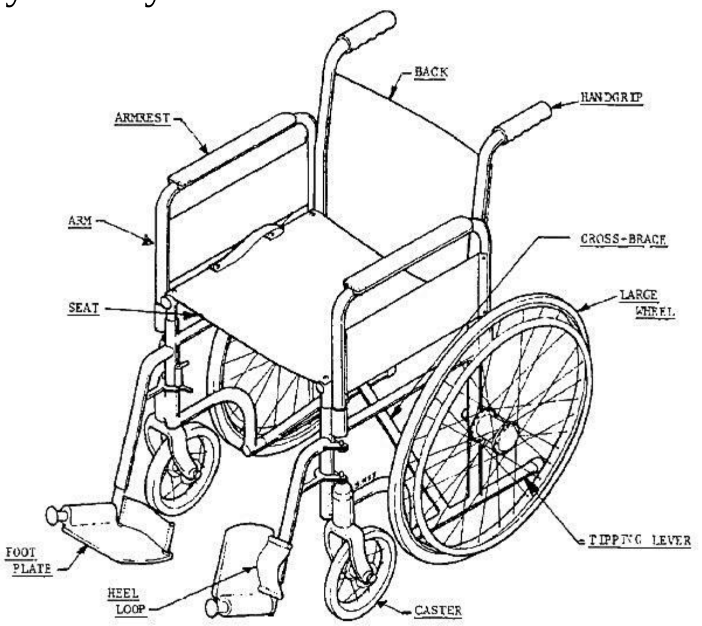
MANUAL WHEELCHAIR DESIGN

4.1. Introduction: - Wheelchairs were designed to provide the veteran some mobility within the hospital and home, and not to optimize ergonomic variables. Wheelchairs remained virtually unchanged until the disability rights movement began in the 1970s.

Due to the development of this new class of manual wheelchair, the ultralight wheelchair, there has come some confusion. Ultralight wheelchairs require more knowledge to specify properly than do standard wheelchairs. This is because more variables can be specified for ultralight wheelchairs. Some of this difficulty can be overcome by specifying an ultralight wheelchair that allows adjustment of many key features.

4.2. Classes of Manual Wheelchairs

Manual wheelchairs have developed rapidly in recent years-fifty years ago there was only one style of wheelchair and it came in one color: chrome (figure).



Now, there are numerous types of wheelchairs to choose from and they come in a wide range of colors. Wheelchairs have moved from being chairs with wheels designed to provide some minimal mobility to advanced orthoses designed to meet the mobility demands of the user. The proper selection and design of a wheelchair depends upon the abilities of the user and on the intended use.

4.2.1. Depot (institutional) wheelchair

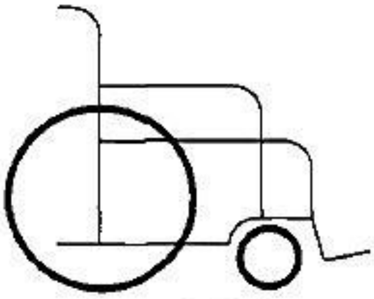
The depot or institutional wheelchair is essentially the same wheelchair that was issued to veterans in the 1940s. The wheelchairs may be a bit lighter, but the basic frame is unchanged. Depot wheelchairs are intended for institutional use where several people may use the same wheelchair. These wheelchairs are typically used in airports, hospitals, and nursing care facilities. Generally, they are inappropriate for active people who use wheelchairs for personal mobility.

Depot wheelchairs are designed to be inexpensive, accommodate large variations in body size, to be low-maintenance, and to be attendant-propelled. Hence, they are generally heavier and their performance is limited. A typical depot wheelchair will have swing-away footrests, removable armrests, a single cross-brace frame and solid tires. The swing away footrests add weight to the wheelchair; however, they make transferring into and out of the wheelchair easier. Armrests provide some comfort and stability to the depot wheelchair user and they can aid in keeping clothing off the wheels. Depot chairs typically fold to reduce required storage area and so that the chair will fit into the automobile of the borrower. Solid tires are used to reduce maintenance. However, solid tires typically dramatically reduce ride comfort. Pneumatic tires are recommended for outdoor usage. There is typically very little if anything that can be adjusted to fit the user on a depot chair.

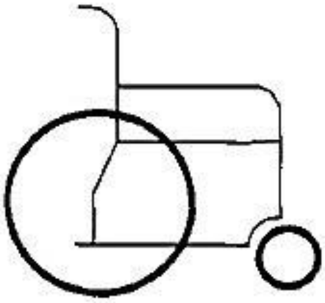
4.2.2. Amputee wheelchair

People with lower-limb amputations typically have a different center of gravity location than do people who have their lower limbs. When seated in a wheelchair the center of gravity of the person with lower limb amputations may be close enough to the rear axles of the wheelchair to require some modification to the wheelchair axle position. The amputee wheelchair came about because wheelchairs were originally designed for people who were anatomically intact.

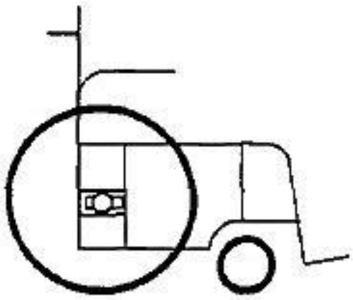
Thus the center of gravity of the wheelchair and an amputee was too close to the rear axles. This caused the wheelchair to have too great a tendency to do a 'wheelie'.



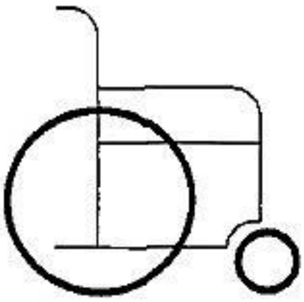
Depot wheelchair



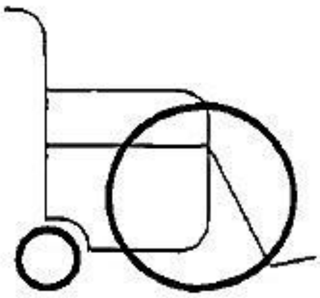
Amputee wheelchair



Ultralight wheelchair



Foot-drive wheelchair

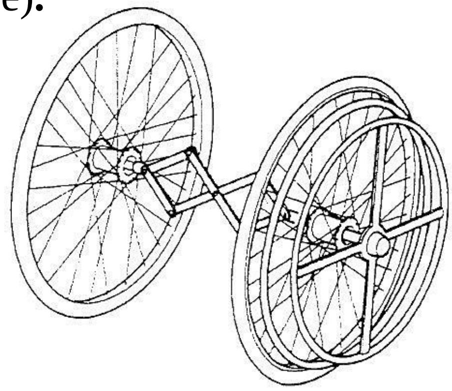


Indoor (rear caster) wheelchair

Hence, amputee wheelchairs had the rear axle positions extended rearwards on the frame. The frame of an amputee wheelchair has to be designed to accommodate the offset between the back of the seat and the rear axle housings. Not all people with lower limb amputations require the more stable axle mountings and the abilities of the user must be evaluated before the wheelchair is specified or designed

4.2.3. Hemiplegic (one-arm drive) wheelchair

People who have brain related motor impairments often require specialized wheelchairs which permit the optimum application of their motor abilities. Typically a one-arm drive wheelchair consists of a linkage connecting the rear wheels (figure).



This allows the user to push upon the pushrim of one wheel and to propel both wheels. To effectively turn the wheelchair, the user must have the ability to disengage the drive mechanism and to propel each rear wheel independently. One-arm drive wheelchairs are modified versions of standard wheelchairs. Most types of wheelchairs can be modified to accommodate one-arm drive mechanisms. The proper fit of the wheelchair to the user is most critical with one-arm drive wheelchairs, because of the user's reduced physical strength. The wheelchair must fit such that the user can get maximal leverage for pushing the wheelchair and to control the wheelchair

4.2.4. Foot-drive wheelchair

Some people have weakness of the upper and lower extremities and can gain maximal benefit from wheelchair propulsion by combining the use of their arms and legs or by using their legs. The design and selection of a foot-drive wheelchair depends greatly upon how the user can take greatest advantage of their motor abilities. The strength of the user's legs must be determined to decide whether it is best to pull or to push with the legs. The design of the chair is affected by whether the user pushes or pulls. If the person pushes the wheelchair, then modifications to the design of standard wheelchairs are required. It may be best to design the chair so that the seat faces opposite the direction it would face in a typical wheelchair. The casters should lead the rear wheels for the most common direction of travel This will help to reduce the possibility of the user flipping over when hitting an obstacle and will make the chair more directionally stable. The wheelchair should be set-up so that the used wheelchair center of gravity is well within the footprint of the wheelchair. This may require some consideration of where the larger wheels are mounted

4.2.5. Indoor (rear caster) wheelchair

Wheelchairs have been and can be designed to be used indoors. Commonly, indoor wheelchairs use rear casters because of the maneuvrability of these designs. However, rear caster designs make the wheelchair less stable in lateral directions. Indoor wheelchairs typically have shorter wheelbases. This makes them less stable and they are not recommended for outdoor use. Some indoor wheelchairs have the ability to elevate the user to the standing position. Most manual wheelchairs cannot be propelled in the stand-up setting in order to ensure safe and stable operation. Standing gives the user the ability to reach cabinet and counter space which would otherwise be inaccessible. Some wheelchairs are made to operate in the standing position.

4.2.6. Ultralight wheelchair

Active users often prefer highly maneuverable and responsive wheelchairs which fit their physical and psychosocial character. The ultralight wheelchair evolved from the desire of wheelchair users to develop functional ergonomic designs for wheelchairs. Ultralight wheelchairs are made of such materials as aluminum, alloy steel, titanium, or composites. The design of ultralight wheelchairs allows a number of features to be customized by the user or to be specified for manufacture.

Wheelbase, wheel size and type, axle position, camber, wheel alignment, caster type and size, seat angle and a number of other variables affect the performance of wheelchairs. Many of these characteristics can be adjusted or specified with ultralight wheelchairs. Ultralight wheelchairs are designed for active users and are made more durable with less weight than a typical wheelchair. There are a wide variety of ultralight wheelchair designs. The most common features of all are the low weight, the high-quality of materials used in their construction and their functional design. Many people can benefit from ultralight wheelchair designs.

4.2.7. Sports wheelchair

Sports wheelchairs are an outgrowth of the popular wheelchair sports movement. The desire to achieve better performances has lead wheelchair users, inventors and manufacturers to constantly develop specialized wheelchairs for sports. There is no real typical sports wheelchair, as the design depends heavily on the sport. Basketball and tennis wheelchairs are often thought to typify sports wheelchair design (figure). However, racing, field events or shooting wheelchairs have little in common with the former. Sports wheelchairs are designed to meet the demands of particular sports. Some people may use an ultralight wheelchair to compete in sports.

4.3. Frame Design

Several factors must be considered when designing a wheelchair frame: what are the intended uses; what are the abilities of the user; what the resources available are; and what are the existing products available. These factors determine if and how the frame will be designed and built. Successful designs of sports wheelchairs can only be accomplished with continuous input from and interaction with wheelchair users. The durability, aesthetics, function, ride comfort and cost of the frame are dependent on the materials for construction, frame geometry, and fabrication methods. One of the issues that makes wheelchair design more complicated is the fact that the user is dependent upon wheeled mobility every day, nearly all day.

Presently all common wheelchair frames center around tubular construction. In other words wheelchairs are generally made out of some lightweight tubing. The tubing can either be welded together or bolted together using lugs. There are two basic frame types, folding and rigid and two common frame styles, the box frame and the cantilever frame.

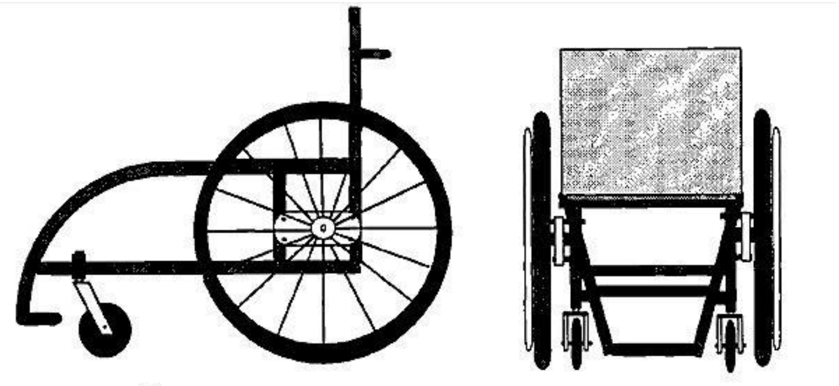


Figure *Example illustration of a box frame wheelchair.*

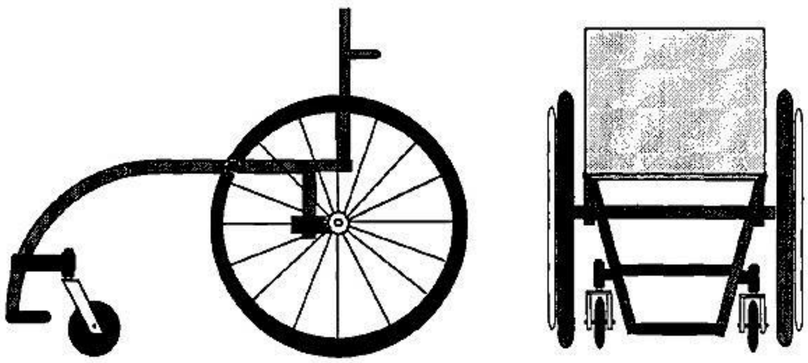


Figure *Example illustration of a cantilever frame wheelchair.*

4.3.1. Frame styles

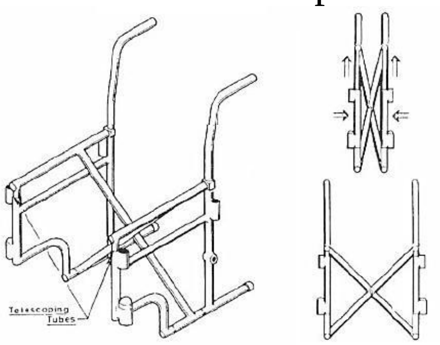
The box frame is named such because of its rectangular shape and because of the tubes outlining the edges of the 'box' (left figure). **Box** frames can be very strong and very durable. **A** cantilever frame is so named because the front and rear wheels, when viewing the chair from the side, appear to be connected by only one tube; this is similar to having the front wheels attached to a cantilever beam fixed at the rear wheels (right figure**).**

Both frame types require cross-bracing to provide adequate strength and stiffness. These frame types stem from slightly different design philosophies. The box frame provides great strength and rigidity. Thus the wheels are mounted to a fairly rigid framework. If designed and constructed properly the frame only deflects minimally during normal loading and most of the suspension is provided by the seat cushion, the wheels and the wheel mounting hardware. Many manufacturers do not triangulate, i.e., have tubes criss-crossing the frame; their box frame design allows some flexibility in the frame.

The cantilever frame is based upon a few basic principles: (1) the frame can act as suspension and there is some flexibility purposely built into the frame; (2) there are fewer tubes and they are closer to the body which may make the chair less conspicuous; and (3) there are fewer parts and fewer welds which makes the frame easier to construct. Both basic frame types are very functional and have their merits. Some users prefer the lines and the feel of the box frame while others prefer the cantilever frame.

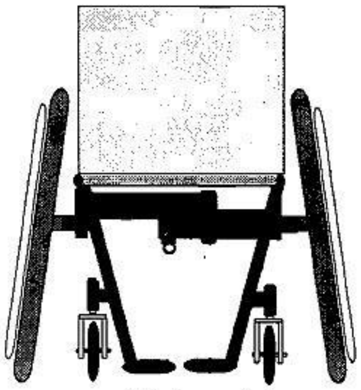
4.3.2. Folding mechanisms

There are three commonly used folding mechanisms used with wheelchair frames: (1) cross-brace; (2) parallel-brace; and (3) forward folding. Most common folding wheelchairs use variations on the cross-brace design. Each of these folding mechanism designs have their relative advantages and their application depends upon the user's preferences. Wheelchairs are designed with either single or double cross-brace mechanisms. Double cross-brace designs add some stiffness to the frame. A cross-brace folding mechanism consists of two frame members connected in the middle attached to the bottom of a side frame member on one side of the chair and to the seat fabric above the top side frame member on the opposite side.

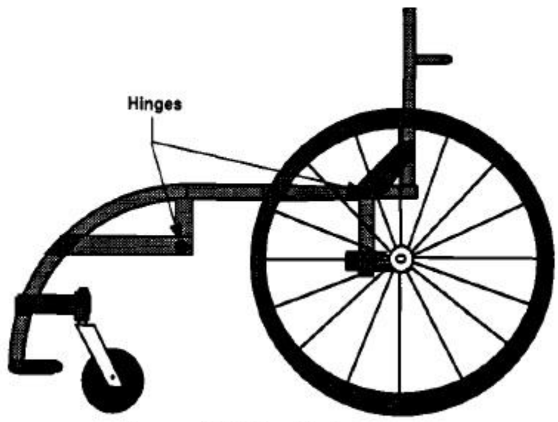


The cross members are hinged at the bottom and are pinned together in the middle. When viewed from the back of the frames, the cross members form an X. The chair is folded by pulling upwards on the seat upholstery. When the seat is lifted the cross-members move upwards pulling the frame together. The user's weight keeps the frame from folding when the wheelchair frame is extended. Cross-member folding mechanisms are simple and easy to use. However, the wheelchair may collapse when tilted sideways and the frame gets taller when folded. Some chairs incorporate snaps or over-center locking mechanisms to reduce the problems of tilting. The parallel brace folding mechanism lets the frame fold sideways by having the frame cross member hinge forward. Each cross member is hinged in the center and at each end. When in the extended position the center hinge is locked. The user releases the lock and pulls forward. The chair folds as the user pulls forward. The cross members can be locked with a pin or cam mechanism. The advantages of this design are that the frame behaves like a rigid frame in the extended position and the chair can be partially folded with the user in it. This could permit negotiation of some narrow entrances. Parallel brace mechanisms are more difficult to operate and maintain.

Forward-folding wheelchairs are not very popular, but have some nice features. Many ultralight wheelchairs incorporate forward folding backrests. The concept of a forward-folding wheelchair involves hinging the front end of the wheelchair and the backrest. The backrest folds onto the seat and the front end folds under the seat. Forward-folding wheelchairs can be made very compact if the rear wheels are quick release. However, forward-folding wheelchairs require more operations to fold them.



parallel-brace design



forward-folding design

4.4. Materials

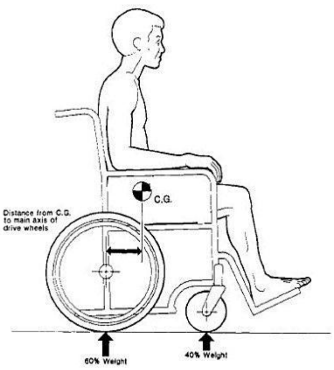
Most wheelchairs are made of aluminum, steel, or titanium. Some chairs have been made of advanced composite materials, primarily carbon fiber and in the future carbon fiber frames will probably begin to become more available. All of these materials have their strengths and weaknesses.

4.5. The Wheelchair and Rider

Simplicity of form and function are the key guidelines to the design of a desirable wheelchair. The handling of a wheelchair is primarily dependent upon a few factors: the location of the center of gravity of the person and chair, the stiffness of the frame, wheels, and components and how well the pilot and chair mesh together.

4.5.1. Center of gravity (COG) location

The COG is typically located along the midline of the person and chair, and generally bilateral symmetry is assumed. The COG in the sagittal plane (fore and aft) should be located slightly forward of the rear axles. This depends on the user, as having the COG located near the rear axles makes the person and chair more likely to flip backwards (wheelie).



However, having the COG near the rear axles has certain advantages: the downhill turning moment due to crown (slope for drainage on roadways and sidewalks) is minimized as the turning torque is related to the mass of the individual and the wheelchair and its location relative to the pivot point (the rear axles); the tendency for caster flutter is also reduced; the rolling resistance is reduced as most of the weight is born by the larger rear wheels; and the user-initiated turning ability is increased. The further the COG gets from the midpoint between the front and rear wheels and the closer it gets to the rear axles the greater the control effort and ability required to maintain balance. Thus in general the greater the functional ability of the user the closer the COG can be to the rear axles. Thus the COG can be adjusted by adjusting the position of either the rear wheels with respect to the seat or vice versa. Generally this is an option left to the user. However, if the desired location of the COG is known, then the frame can be made lighter by designing fixed axle and seating structures.

4.5.2. Ride comfort and durability

Ride comfort is primarily a function of the following: frame, wheel and component stiffness, frame geometry, seat and cushion design and compliance. Fide comfort is an important issue because people must sit in the chair from 12 to 18 hours per day every day. Because some chairs are used by active users they may be used nearly ten miles per day over a variety of grounds (i.e., grass, carpet, gravel, concrete, asphalt, etc.). The frame design must be durable but should have sufficient flexibility to withstand dropping off curbs and also not to break after several thousand miles of road vibration. Most wheelchair suspension comes from the cushion and the tires.

4.5.3. The user-wheelchair interface

The user-wheelchair interface is the most critical design factor, and is the least understood. The chair must become an extension of the user's body, much like an orthosis. This requires carefully matching critical chair dimensions to body dimensions, user ability, and intended use. There are several critical seat dimensions to be considered during wheelchair design: seat height, seat angle, seat depth, seat width, back height and backrest angle. The seat base should be made of some stiff material to provide a rigid base of support for the cushion. Either a pliable material stretched tightly across the side frames or a rigid base (e.g., plastic, aluminum, composite) works well.

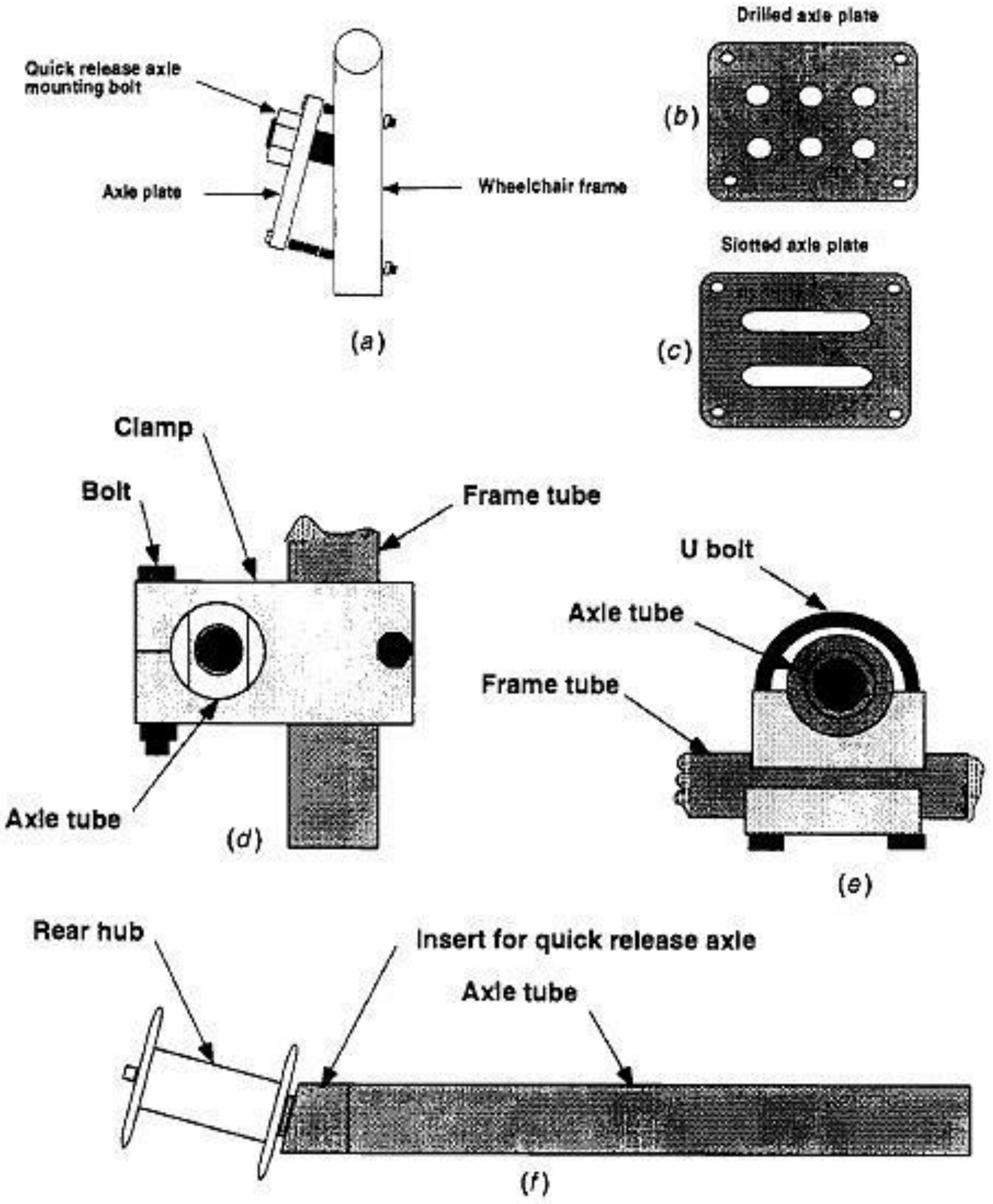
4.6. Wheels and Casters

Wheels and casters are available in a wide range of styles and sizes. The front casters can range from 50 to 200 mm in diameter for manual wheelchairs designed for daily use. Casters are either pneumatic or polyurethane. Pneumatic casters offer a smoother ride at the cost of durability, whereas polyurethane casters are very durable. Caster foot clearance is maximized with 50 mm 'Roller Blade' casters often used for court sports (e.g., basketball, tennis and racquetball. Rear tires can be of two types; pneumatic or puncture proof. Pneumatic tires can either use a separate tube and tire or a combined tube or tire.

4.7. Components

Several components can be added to the basic chair design to provide riders with customized features. Some of the more common additional components are wheel locks, armrests, anti-tip casters, footrest rollers, side-guards and quick-release axles. Wheel locks act as parking brakes and assist when transferring to other seats and when the rider wishes to remain in a particular spot.

They help to allow the rider to push things and to be more stable when desired. Armrests provide a form of support and are convenient handles when the rider leans to one side or the other. Anti-tip casters are small wheels mounted at the back of the wheelchair which help to prevent the wheelchair and rider from tipping backwards. They are used by many neophyte wheelchair users and by some basketball players. Footrest rollers are used in court games where the rider and wheelchair may tip forwards onto the footrests. The rollers help to prevent the wheelchair from flipping forwards. Side-guards are supports which come up the side of the wheelchair frame and help to prevent the hips and clothing from rubbing against the wheels. Quick release axles allow the rear wheels (and sometimes the front casters) to be removed by simply pushing a button



Common rear-wheel mounting mechanisms.