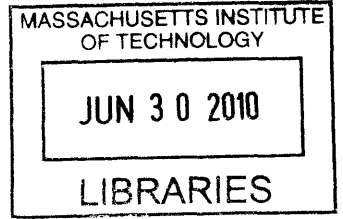


Unidirectional Inline Skates

by

Adam J. Goldstein



Submitted to the Department of Mechanical Engineering
in partial fulfillment of the requirements for the degree of

ARCHIVES

Bachelor of Science in Mechanical Engineering

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2010

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Abstract

In this thesis, I describe the design, manufacture, assembly, and testing of “1WSkates,” a pair of inline skates that prevent backwards motion. The defining element of 1WSkates is the use of a one-way bearing which, along with a fixed axle, prevents certain wheels from rolling backwards. The axle is custom-shaped to lock into an existing inline skate housing. The one-way bearing is attached to the wheel with a custom fitting. The complete 1WSkates allow a user to walk up an incline and roll down the other side, and to use a nordic skiing motion on flat terrain.

Thesis Supervisor: Sanjay Sarma

Title: Associate Professor of Mechanical Engineering

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Chapter 1

Introduction

Traditional inline skates (such as “Rollerblades”) have wheels that permit both forward and backward rotation. In this paper, I explore the design and manufacture of an alternative type of inline skates that only permits forward rotation¹.

1.1 Advantages of 1WSkates

One-way skates (I refer to them as “1WSkates”) have several advantages over normal inline skates. For one thing, 1WSkates prevent the skater from sliding backwards on uphill. With no fear of rolling backwards, the skater can “walk” up hills similarly to the way he would with shoes. Additionally, while climbing long hills, the user can take breaks; as he slows down, he will come to a stop rather than beginning to slide backwards. Stopping in such a position is far stabler than standing perpendicular to the incline, the more difficult alternative offered by regular inline skates.

Additionally, 1WSkates permit an entirely new propulsive motion on relatively flat terrain: skaters can “push off” of one foot and start rolling forward on the other foot, while keeping both feet oriented forward at all times. (This motion is reminiscent of

¹The motivation for this project came from my experience walking to work one summer in Sebastopol, California. The walk involved a long, shallow uphill, followed by a long, shallow downhill. One morning, it occurred to me that the commute would be easier if I had a pair of inline skates that allowed me to walk up the uphill and roll down the downhill.

the motion of cross-country skiing, and also resembles pushing off with one foot on a scooter.) A comparison of both methods is shown in Figure 1-1.

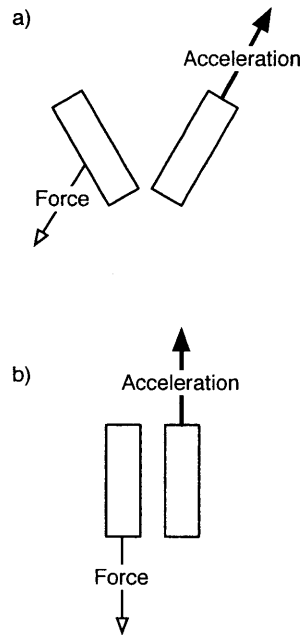


Figure 1-1: A top-down comparison of skating motions. a) Standard skating motion, permitted by both standard inline skates and 1WSkates. b) Cross-country skiing motion, only possible with 1WSkates.

1.2 Disadvantages of 1WSkates

1WSkates limit several sophisticated skating motions. In particular, 1WSkates do not allow the skater to do a 360° turn moving backwards (or, indeed, any turn while moving backwards). 1WSkates also preclude the skater from purposely sliding backwards on a hill.

Additionally, the bearings used in 1WSkates are not tuned for ultra-low frictional losses, making them a poor choice for speed skaters. Finally, the durability of the 1WSkate mechanisms have only been tested for a few hours.

1.3 Paper Overview

This paper is divided into several parts. In Chapter 2, I explore the design process of 1WSkates, highlighting the various design iterations as well as the ultimate design. In Chapter 3, I explain the manufacturing process used for 1WSkates and examine the skates' performance. In Chapter 4, I include possibilities for additional improvements and offer concluding remarks.

Chapter 2

Design

Early on in the design process, I decided it would be easier to modify an existing pair of inline skates than build a pair entirely from scratch. This decision greatly reduced the amount of work necessary to produce the prototype by allowing me to focus on the wheels and how they would be held in place, rather than how to build components like a rigid shoe.

2.1 Existing Skate Wheels

Regular inline skates are designed with replaceable bearings, axles, and wheels. Four wheels on each existing skate fit inside a “wheel holder”—an angled piece of aluminum that holds the axles (and thus the wheels) in place. Each existing wheel contains a pair of bearings fit into the wheels’ plastic.

In order to modify the wheels, therefore, I chose to replace the wheels’ existing bearings with bearings that only permitted unidirectional rotation.

Due to the labor involved in modifying wheels (see page 35), I decided to modify the minimal number of wheels necessary to get the desired performance: the front and back wheel on both skates. This would permit the skater to stop while facing uphill (where the weight is concentrated on the back wheel) as well as permitting the skater to “cross-country ski” to move forward (where the weight moves from being

concentrated on the back wheel to the front wheel as the skater kicks from heel to toe).

2.2 One-Way Bearings

Originally, I had envisioned using a ratchet in each wheel to prevent backwards motion. However, experience suggested ratchets are noisy and have an unacceptably high level of backlash—and it would be unpleasant for a skater to roll backwards for an inch before the ratchet mechanism engaged.

Prof. Sarma and Hunter suggested I look into 1-way roller bearings (Figure 2-1). When such a bearing is held still, it only permits an axle inside to turn in one direction. Similarly, when the axle is held still, the one-way bearing can only turn in one direction. I decided, then, that my design would be based on preventing the axle from rotating. Then the wheel, attached to a one-way bearing, would only be able to rotate forward.

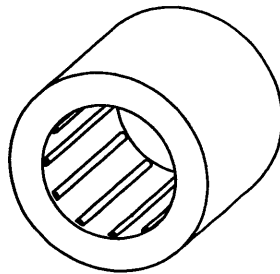


Figure 2-1: A one-way roller bearing.

The first requirement for the one-way bearing was that it be able to handle the torque applied by a skater pushing off his wheel. For comparison, I looked up the maximum force applied by a cross-country skier “kicking” himself forward¹. The maximum horizontal force on a ski was given as 50 N; assuming this force was borne entirely by a single existing Rollerblade wheel (radius 1.655”), the one-way bearing would have to handle a torque of approximately 2.1 Nm.

¹ASTM, Committee F-27 on Snow Skiing, Society for Skiing Safety International, and Symposium on Skiing Trauma and Skiing Safety International. Skiing Trauma and Safety: International Symposium. Philadelphia, PA: ASTM, 1985. No. 938. p. 107.

Secondly, I hoped to find a one-way bearing that was sized for the existing axles in the Rollerblades (0.308" diameter).

Unfortunately, I was unable to find a bearing of this exact size, so I settled for the closest one-way bearing I could find—one with an inside diameter of 0.315". Fortunately, this new bearing was also rated to a torque of 3.15 Nm, which was greater than the 2.1 Nm requirement I calculated.

The difference in diameters between the existing axle and the one-way bearing (only 0.007") was enough that the existing axle would not engage with the one-way bearing, which meant it would be necessary to either modify the existing axle or design a new one.

2.3 The Custom Axle

I considered several designs for the axle, outlined below.

2.3.1 Thickening the Existing Axle

The existing axles had the advantage of being shaped to fit precisely in the existing wheel holder. Additionally, the existing wheels had two-way bearings which bore some of the axial load. As such, my preference was to simply modify an existing axle to simultaneously accommodate the existing bearings and the new one-way bearing. In practice, this would mean having the outsides of the axle at the old thickness, with the center of the axle thickened slightly to accommodate the new one-way bearing.

As a proof of concept, I applied a layer of tape (approximately 0.004" thick) to the center of an existing axle, to make it large enough to fit well inside a one-way bearing. This worked at first, but after several minutes of playing with the assembly by hand, the tape started to peel into small sections, gumming up the bearing.

I next considered adding a small metal or plastic sheath to the existing axle to thicken it enough to fit well in the bearing. However, I was skeptical it would be possible to a) easily manufacture such a small sheath (0.004" thick) and b) affix it tightly enough to the existing axle to disallow rotation between the sleeve and the

axle under heavy load. I therefore concluded it made more sense to design a new axle from scratch.

2.3.2 Designing a New Axle

The first new axle design I tried had two thicknesses: the left and right sides were the thickness of the original axle (to accommodate the existing two-way bearings), while the center section was the thickness necessary to fit in a one-way bearing (Figure 2-2).

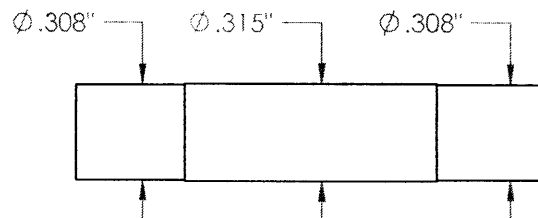


Figure 2-2: The two-thickness axis design. The outside sections accommodate the original two-way bearings, while the middle section accommodates the one-way bearing.

Unlike the original axle, this new axle did not lock itself into the wheel holder; it needed to be screwed in on both sides. Unfortunately, no matter how tightly I screwed the axle in, the torque applied by turning the one-way bearing was enough to make the axle rotate the screws against the wheel holder, rendering the skates useless at preventing backwards rotation.

2.3.3 Preventing Axle Rotation

Since screws alone were not enough to prevent the axle from rotating, I next focused on anchoring one end of the axle rigidly to the wheel holder. This turned out to be the portion of the design that required the most effort; it is very hard to prevent a small axle from rotating under large torques.

I first considered the idea of making a thicker version of the axle that came with the Rollerblades (Figure 2-3). However, it seemed like it would be extremely difficult to machine the small nubs that slide into slots in the wheel holder, so I rejected this approach.

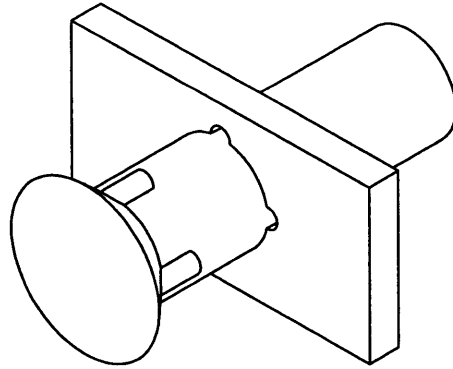


Figure 2-3: The design of the axle that came with the Rollerblades. 4 nubs on the axle fit into slots in the wall of the wheel holder.

Next, I considered using dowel pins to hold the axle in place. In particular, I considered making an axle with 4 slots on one end, sized so a pin could fit between each slot on the axle and its matching slot on the wheel holder (Figure 2-4). Ultimately I rejected this approach for several reasons. First, I was concerned that the dowels might slide out of their slots under large wheel torques, possibly causing damage to the aluminum wheel holder. Second, I was worried that the dowels would shear under large wheel torques. Finally, I was concerned that it would be necessary to expand the existing wheel holder slots (width 0.052”), since the smallest dowels I could find were 0.062”. If the process of expanding the existing slots had any errors, I might have been left with an unusable wheel holder, and it would have been very expensive to buy a new one.

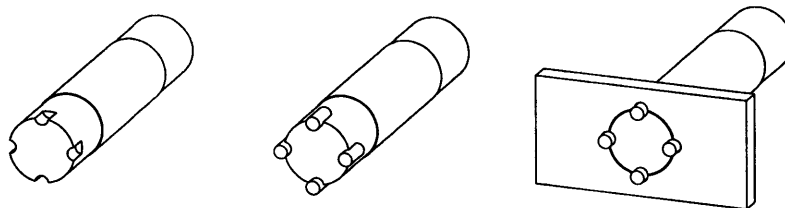


Figure 2-4: The dowel pin design for the axle. Left: the axle itself. Center: the axle with dowel pins in one end. Right: the full assembly in the wheel holder, with the dowel pins placed to resist the force of the axle’s rotation.

2.3.4 The Final Axle Design

The idea of drilling slots in the axle, however, inspired the design that ultimately proved successful. I decided to drill most of the material away from one end of a new axle, leaving four thin “flanges” that fit snugly in the existing slots in the wheel holder, as shown in Figure 2-5. (Appendix A contains computations of the flange geometry.)

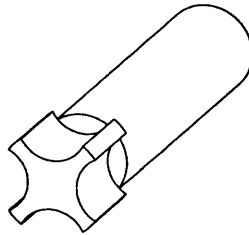


Figure 2-5: The final flanged axle design.

With the flanged side preventing the axle from rotating, I screwed the un-flanged end of the axle into the other side of the wheel holder to prevent lateral motion.

Unfortunately, having an axle with a large flanged end and a midsection thick enough to accommodate the one-way bearing made it impossible to fit one of the original two-way bearings on the axle. I therefore jettisoned the idea of re-using the existing two-way bearings on the new axle, and decided that if it became necessary to provide additional axial strength, I would simply use different bearings sized to fit on the new axle².

No longer bound by the requirement that the axle have two thicknesses, I decided to simplify the design by making the entire axle (except the flanges) a single thickness large enough to fit in the one-way bearing.

²Ultimately, there was no need to provide additional radial strength; the one-way bearing was able to bear the vertical load on its own

2.4 Coupling the Wheel to the Bearing

Any slippage between the bearing and the wheel would allow backward motion, defeating the purpose of the one-way bearing. Therefore, the next step was to devise a way to firmly attach the one-way bearing to the wheel.

The outer diameter of the one-way bearing was substantially smaller than the inner diameter of the wheel (Figure 2-6). It was therefore necessary to design a coupling that would transmit the torque applied to the wheel to the one-way bearing.

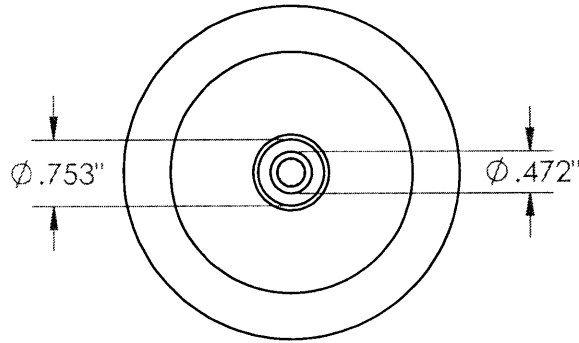


Figure 2-6: The outer diameter of the one-way bearing (0.472") was substantially smaller than the inner diameter of the wheel (0.753"), necessitating the addition of a coupling "sleeve" between the two.

I first tried the most straightforward approach I could think of: manufacturing a custom metal sleeve with an outer diameter to fit inside the wheel and an inner diameter to hold the one-way bearing.

For the metal-to-metal fit between the sleeve and the one-way bearing, I found that the Loctite in the shop was rated to handle a torque of 22 Nm after curing for one day—an order of magnitude more torque than I calculated would be transmitted by a strong cross-country skier. In practice, the Loctite lived up to this promise.

For the metal-to-plastic fit between the sleeve and the wheel, however, none of the epoxies in the Hobby Shop were rated to handle a specific torque; instead, they were all rated to handle a certain shear stress. I calculated the maximum shear stress experienced at the wheel/sleeve boundary by:

$$\tau_{max} = \frac{T_{max}}{R_o A_s} \quad (2.1)$$

Where T_{max} is the maximum torque applied by an aggressive skier, R_o is the outside radius of the sleeve, and A_s is the surface area of the outside of the sleeve. Plugging in for A_s yields the following, where w is the width of the sleeve:

$$\tau_{max} = \frac{T_{max}}{2\pi R_o^2 w} \quad (2.2)$$

Using $T_{max} = 2.1 \text{ Nm}$, $R_o = 0.753''$, $w = 0.400''$, I calculated the maximum shear stress at the sleeve/wheel boundary would be $90 \frac{\text{N}}{\text{m}^2}$. Unfortunately, none of the epoxies in the Hobby Shop were rated to this stress, so I purchased some Devcon Plastic Steel Epoxy. I applied the epoxy to the boundary, and ensured the outer radius of the sleeve was slightly larger than the inner radius of the wheel to provide a good interference fit as well.

2.4.1 Epoxy Failure and Repair

The first wheel I assembled in this way worked correctly. However, the second wheel I assembled this way loosened at the wheel/sleeve boundary after only half an hour of skating. Taking the assembly apart, it was clear the epoxy had sheared. I sanded down the sleeve, epoxied it again, and this time the epoxy sheared again after about 2 hours of use.

To fix this, I considered “keying” the sleeve to the wheel, but there were no tools in the Hobby Shop that would easily cut a groove in the inside of the wheel. I decided instead to improvise a “key” by milling ruts in the sleeve and filling them in with additional epoxy before attaching the sleeve to the wheel (Figure 2-7). This way, the rutted sections of the sleeve would not be in direct contact with the wheel, but instead would be held in place with virtual “pins” made of set epoxy. The rest of the wheel was interference-fit and epoxied as before.

So far, this new arrangement has worked for more than 5 hours. If it were to fail, I would find a shop with the ability to “key” a wheel.

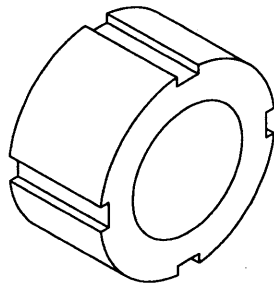


Figure 2-7: The final version of the sleeve for coupling the one-way bearing to the wheel. The grooves were filled with epoxy to make a stronger bond with the wheel.

Chapter 3

Manufacturing, Assembly, and Testing

As the previous chapter illustrated, the process of design was tightly linked to the manufacturing and testing processes. While the last chapter focused on high-level design decisions, this chapter focuses on the actual manufacturing processes used, and the performance of the resulting skates¹. Figure 3-1 is a guide to the coverage in this chapter.

3.1 The Axle

The final axle design, described on page 22, was labor-intensive to manufacture but easy to assemble with the rest of the skates. This section describes both processes.

3.1.1 Manufacturing the Axle

The process of manufacturing the final axle design involved three main steps:

1. Turning down the axle to the correct diameters.

¹Due to MIT's restrictions on using the various machine shops on campus, I was only able to do my machining in the Hobby Shop, which had none of the CNC machines found in, for example, the LMP shop. This meant that manufacturing processes described in this chapter were much more time- and labor-intensive than they might have otherwise been.

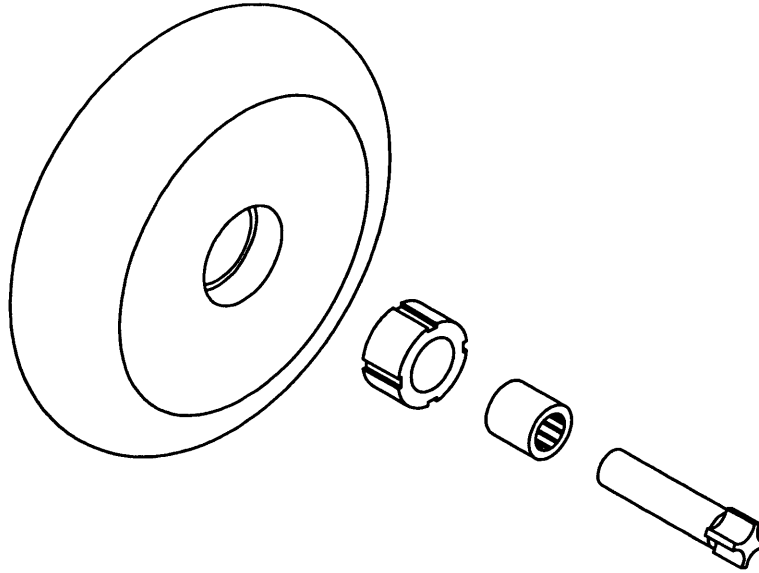


Figure 3-1: An exploded view of the whole wheel and axle assembly. From left to right: the wheel, the sleeve, the one-way bearing, and the axle.

2. Preparing one end of the axle to be screwed into the wheel holder.
3. Milling the flanges on the other end.

Obtaining the correct outer diameters

The axle, as described on page 22, needed sections of two diameters. Most of the axle was of a thickness to accommodate the one-way bearing (0.317" diameter). The remaining portion of the axle was thicker (0.382" diameter) so it could be milled to leave the flanges necessary to lock it in place in the wheel holder (Figure 3-2).

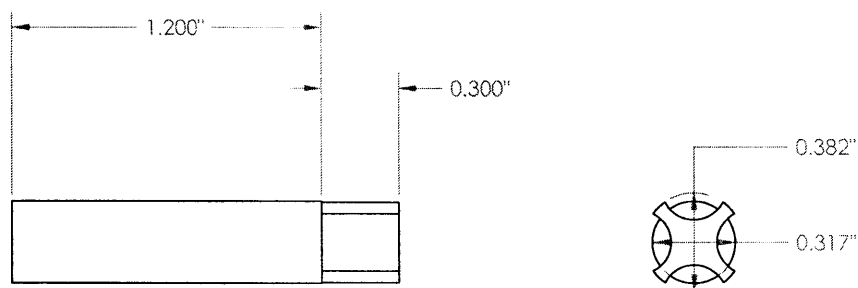


Figure 3-2: The dimensions of the flanged axle.

I started with a rod of 0.433" diameter O1 Tool Steel (chosen for its resistance to wear). I then turned a 1.5" section of the rod to a diameter of 0.382". I next turned 1.2" of this section to a diameter of approximately 0.317"².

Drilling and tapping

The thick end of the axle was to be milled into flanges later; in the meantime, I used the lathe to prepare the thin end of the axle to be screwed into the wheel holder. Since I had the screws that came with the Rollerblade's original axles, I decided to drill and tap my new axle to accommodate the same screws.

First, I center-drilled the thin end of the axle. Next, I used a #19 drill bit to drill a hole 0.7" deep in the axle, and used a M5 × 0.8 tap to thread the axle. This produced a hole that accommodated the original screws well.

Separating the axle from the rod

I next cut off the full 1.5" axle on the bandsaw and faced off any imperfections created by the bandsaw cut.

At this point, I had an axle with a 1.2"-long section that could accommodate the one-way bearing, as well as a thicker section to be milled into flanges.

Making the flanges

As described in Appendix A, I oriented the axle horizontally and used a 0.25" ball endmill at a depth of 0.102" to mill material from the axle. I kept the axle in a square collet holder so I could easily rotate it 90°. After milling four segments of the axle 90° apart, I was left with flanges of 0.064"—just the right size to fit in the wheel holder³.

²The precise diameter I produced depended on which one-way bearing I was using, but it varied by no more than 0.002" in either direction.

³Readers may note that this is wider than the wheel holder slot size listed on page 20. This discrepancy is due to the fact that I wanted the flanges to deform the wheel holder slightly when press-fit to ensure a good fit. I considered this far preferable to pre-drilling the wheel holder slots, since pre-drilling would risk incorrectly positioned slots. By contrast, press-fitting would automatically deform the slots to the right size.

To ease the assembly of the axle and the wheel holder, I filed the leading edges of the flanges (i.e. the edges closest to the center of the axle) to a sharp point. This meant that when I pressed the axle into the wheel holder, the flanges automatically guided themselves into the center of the slots.

3.1.2 Assembling the Axle with the Skates

To lock the axle into the wheel holder, I first slid the thin end of the axle into one side of the wheel holder. I then slipped the wheel onto the axle. Next, I lined the flanges up with the slots on the wheel holder, and press-fit the flanges into the wheel holder. Finally, I screwed the thin end of the axle into the opposite side of the wheel holder.

3.1.3 Axle Performance

The final axle design performed exactly as desired; even when other parts of the wheel assembly failed under heavy loading, the axle always remained locked in place.

A noteworthy anecdote, however, concerns one axle that had a particularly tight fit with its corresponding one-way bearing. When I first tried the skates, the bearing and axle made a “vroom” noise that increased in pitch as I gained speed. Additionally, after about half an hour of use, the axle had been polished to a mirror finish by the one-way bearing.

To reduce the friction or vibration that was causing this, I made a point of removing an extra 0.002” inches from the axle beyond what was strictly necessary to ensure it fit in the one-way bearing. No subsequent axles produced as much noise or got polished by the one-way bearing.

3.2 The Wheel Assembly

The wheel assembly consisted of the original wheel (with the original bearings removed), the sleeve, and the one-way bearing. This section describes the process of producing a fully functional wheel assembly.

3.2.1 Manufacturing the Sleeve

The sleeve started as a 1" diameter 12L14 carbon steel rod (I picked steel so it wouldn't wear or deform easily). To make the rod fit inside the wheel, I turned down a length of 2 inches to a diameter of 0.753".

Next, I center-drilled the rod, drilled it with a $\frac{1}{4}$ " bit, and then drilled it with a $\frac{29}{64}$ " bit. This produced an inner diameter of 0.453", which was barely large enough for me to fit a boring tool inside. I then bored out the inside of the sleeve to approximately 0.470" (plus or minus 0.003" depending on the one-way bearing I was trying to fit inside).

Next, I used a parting tool to cut off a sleeve 0.400" wide. Since the turned-down rod was 2 inches long, I was able to repeat this process to get several sleeves from a single rod.

Finally, to allow the "virtual key" to form (page 24), I milled four 0.04"-deep grooves with a $\frac{3}{16}$ " endmill at points 90° apart on the perimeter of the sleeve⁴.

3.2.2 Preparing the Wheel

As described on page 17, the original Rollerblade wheels had two bidirectional bearings which needed to be removed to make room for the one-way bearing. I achieved this using a hammer and a punch⁵.

⁴Since these grooves did not have to line up precisely with any corresponding grooves on the inside of the wheel, I spaced the grooves out by eye.

⁵It's worth noting that the casings of the two-way bearings are very thin and dent easily.

3.2.3 Assembling the Wheel

There were two steps to assembling the final wheel: attaching the one-way bearing to the sleeve, and attaching the sleeve to the wheel.

Attaching the one-way bearing to the sleeve

As described on page 18, I used a one-way bearing that was rated to handle the torque corresponding to the horizontal force of a cross-country skier (McMaster-Carr part #6392K42).

I scored the outside of the one-way bearing and the inside of the sleeve with rough sandpaper, applied a thin layer of Loctite 262 to the inside of sleeve, and lightly pressed the bearing into the sleeve until it was centered in the sleeve. After setting for one hour, the one-way bearing never came loose.

Attaching the sleeve to the wheel

I next applied a thin layer of Devcon High Strength Plastic Steel Epoxy to the outside of the sleeve, taking special care to fill in the grooves. Since I'd purposely sized the sleeve to interfere slightly with the inside of the wheel, I had to hammer the sleeve into the wheel to get it in place. After setting for 24 hours, this assembly never came loose, unlike the ungrooved sleeve.

3.2.4 Wheel Performance

Once I used the grooved-sleeve method, the wheels performed generally as expected. However, every single wheel experienced a slightly visible wobble when rotating forward on its axle. This could either have been caused by skew at the bearing/sleeve boundary or at the sleeve/wheel boundary. I suspect it was the latter, since my method for fitting the sleeve into the wheel (hammering) was fairly imprecise. In future revisions, it might make sense to make a looser fit that allows the sleeve to slide into the wheel more easily.

However, the wobble was not noticeable to anyone who used the skates.

3.3 Testing

I invited three of my friends to try the 1WSkates on various flat and sloped terrain.

Their observations are summarized below:

- It takes some time to trust the skates to behave properly on a hill.
- It is a pleasant surprise when the skates “catch” you before you begin rolling backwards down a hill.
- The cross-country skiing motion takes a lot of getting used to on skates; having “poles” like skiers have might make this motion more natural. (Figure 3-3 shows me performing this motion.)



Figure 3-3: Testing the skates. I have just pushed off my back foot using the “skiing” motion, and have shifted my weight slightly forward to glide on my front foot.

- It’s nice being able to skate normally, too. (And the 1WSkates permit this.)
- (Before I installed the mechanism on the skates’ front wheels:) It is awkward not being able to push off the front of the skate.

- Even when the epoxy sheared, the skates still resisted backwards motion greatly—they just didn't make it impossible. (One skater didn't even notice the difference.)
- Except for when the epoxy sheared, the skates felt very sturdy.

Chapter 4

Further Improvements

This chapter covers several classes of additional improvements that could be made to the design and manufacture of 1WSkates.

4.1 Mass-Production

The process of manufacturing and assembling 1WSkates was very time-intensive. Table 4.1 lists the time for performing each operation¹.

Table 4.1: Actual Process Time

Process	Time
Manufacturing one axle	3 hours
Manufacturing one sleeve	1.5 hours
Assembling the axle and wheel holder	0.5 hours
Assembling the sleeve, wheel, and one-way bearing	1 hour
Total for a single wheel/axle	6 hours

I decided to make 4 of each part, to make the front and back wheels of each skate only roll forward. The total work time to modify a complete pair of skates was therefore 24 hours.

¹These times are only count active work time; they do not include the setting time of the Loctite (1 hour) or the epoxy (24 hours)

On CNC machines, the manufacturing processes would probably have only taken 10% of the time, for a total manufacturing time of approximately 2 hours per wheel/axle or 8 hours per pair of skates.

This is still an unacceptably high time to assemble a pair of skates if the goal is true mass-production. Below I explore several improvements that would greatly accelerate the manufacturing and assembly time.

4.1.1 Die-Casting the Axle

The axle is currently the part that takes the longest to manufacture. While it would probably be impractical to die-cast the entire axle including the hole and screw threads, it would probably be possible to die-cast the axle in its pre-drilled state, and then use an automatic drill/tap process to complete the manufacturing of the axle. This could reduce the axle manufacturing time by several orders of magnitude.

4.1.2 Eliminating the Sleeve

The manufacturing of the sleeve is also quite labor-intensive, and introduces a point of failure and wobbling (see pages 24 and 32). One way to eliminate the sleeve would be to embed the one-way bearing directly in the wheel at manufacturing time. Alternatively, the inside diameter of the wheel could be made small enough that the one-way bearing could fit directly in the wheel.

The former approach could be achieved by injection-molding a new wheel over the one-way bearing. However, I don't know whether the wheel/bearing interface would be able to handle the necessary torque, since plastic/metal interfaces often require epoxy to adhere well.

Therefore, another method that would eliminate the need for a sleeve would be to injection-mold a wheel that had a small enough inner diameter to fit the one-way bearing directly. Then, using epoxy, it would be possible to bond the bearing to the wheel. Unfortunately, if I continued to make the wheel out of plastic, this approach would also create an epoxied metal/plastic interface—precisely the interface that

sheared under torque in my original design. One solution would be to make the wheel out of metal rather than plastic, but this might lead to a very uncomfortable ride. Another approach would be to use the epoxy but also mill grooves into the casing of the bearing to create the “virtual keys” described on (page 24).

4.1.3 Alternative Assembly Methods

If 1WSkates were being manufactured in very large quantities, it might be sensible to build a robotic system to unscrew the existing wheels and axles and replace them with the new wheels axles in place. (Alternatively, an inline skate manufacturer might modify its existing assembly line to incorporate 1WSkate axles and wheels directly.) Absent these methods, 1WSkates could still be sold as an aftermarket modifications for skaters to install at home.

4.2 Further Work

Work for future iterations could include:

- Adding electronics for measuring the speed of the device (e.g. an encoder), connected wirelessly to a cellphone to monitor speed.
- Adding a device for capturing the rotational energy of rotating downhill to charge a device like a cellphone or provide a boost when climbing hills.
- Measuring the speed and power output of a skater using 1WSkates vs. normal inline skates on various terrain.
- Adding stabilizers (like training wheels) on the sides of the skates to keep the skater from rolling his ankle.
- Performing similar one-way modifications on rollerskates, and comparing the resulting comfort and efficiency to the 1WSkates described in this document.

- Redesigning the shoes that come with normal inline skates to be more comfortable for the front-to-back motion encouraged by 1WSkates—perhaps like telemarking skis.

4.3 Conclusion

I achieved my fundamental goal for this thesis: manufacturing and assembling a pair of skates that prevent backward motion.

The current design, however, is time-consuming to manufacture and assemble. Further improvements to the manufacturing process could reduce the total manufacturing and assembly time from 24 hours to an hour or less. Shortening the manufacturing time would also allow quicker iterations on the design, enabling more rapid testing of additional features.

Test skaters found 1WSkates an improvement over existing inline skates for getting from one place to another. The current design, especially with additional improvements and testing, could provide a desirable new product—or an aftermarket modification—for the inline skating market.

Appendix A

Computation of Flange Geometry

To produce the flanged end of the axle, I used a ball endmill to remove all material but the flanges (Figure A-1).

Since I was moving the ball endmill parallel to the axle, the key question was this: how far should the tip of the endmill be positioned relative to the top of the axle? (Figure A-2 shows this geometrically.)

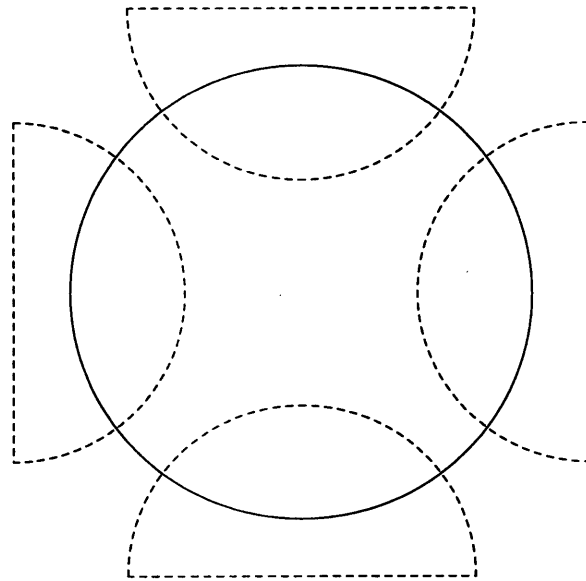


Figure A-1: The making of the flanges. The solid line represents a head-on view of the end of the axle. The dotted lines represent the tip of the ball endmill in the frame of reference of the axle. The area inside the solid line and outside the dotted lines is the material that's left: the flanges.

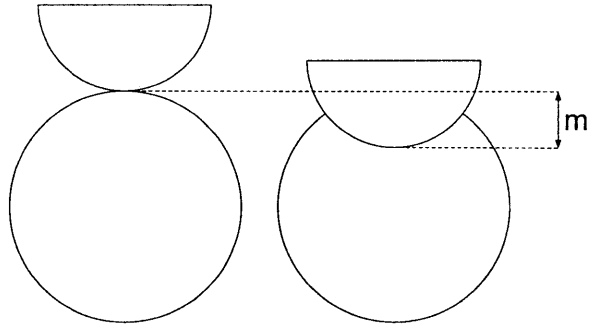


Figure A-2: The position of the tip of the endmill, m , as measured from the top of the axle.

To start, I defined the distance between the center of the axle and the end of the semicircular portion of the endmill as h . I then imagined a reference line that connected the furthest-apart points of intersection of the endmill and the axle. From this reference line, I defined the distance to the center of the axle as h_1 , and the distance to the end of the semicircular portion of the endmill as h_2 (Figure A-3). This yielded the first geometrical relation:

$$h = h_1 + h_2 \tag{A.1}$$

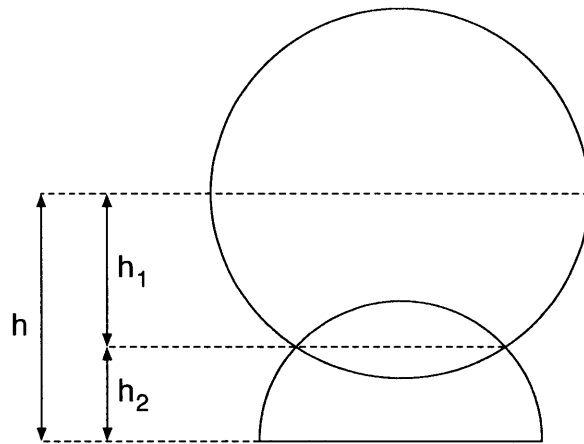


Figure A-3: The distances between the center of the axle, the center of the endmill, and the reference line.

Next I considered the triangles formed by the reference line and the midpoints of the two semicircles (Figure A-4). This yielded the following additional relations:

$$w = R_x \sin(\theta) \quad (\text{A.2})$$

$$h_1 = \sqrt{R_x^2 - w^2} \quad (\text{A.3})$$

$$h_2 = \sqrt{R_m^2 - w^2} \quad (\text{A.4})$$

Where R_x is the radius of the axle, R_m is the radius of the endmill, w is half the length of the reference line, and θ is the angle of the triangle at the center of the axle.

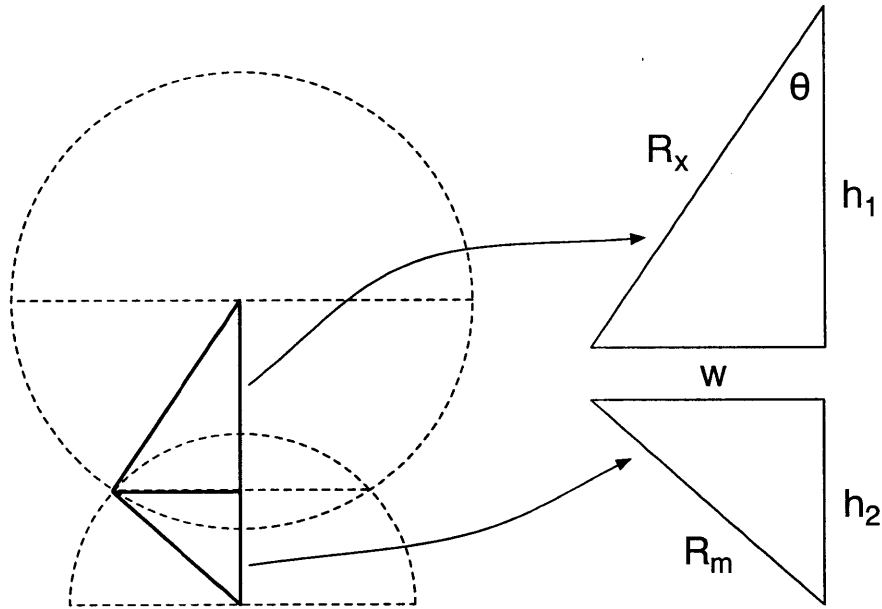


Figure A-4: The triangles formed by the reference line.

Combining Equations A.2 through A.4 yielded:

$$h_1 = \sqrt{R_x^2(1 - \sin^2(\theta))} \quad (\text{A.5})$$

$$h_2 = \sqrt{R_m^2 - R_x^2 \sin^2(\theta)} \quad (\text{A.6})$$

To find θ , I considered the geometry shown in Figure A-5, where ϕ is the angle subtended by a single flange. This yielded the following relation:

$$8\theta + 4\phi = 2\pi \quad (\text{A.7})$$

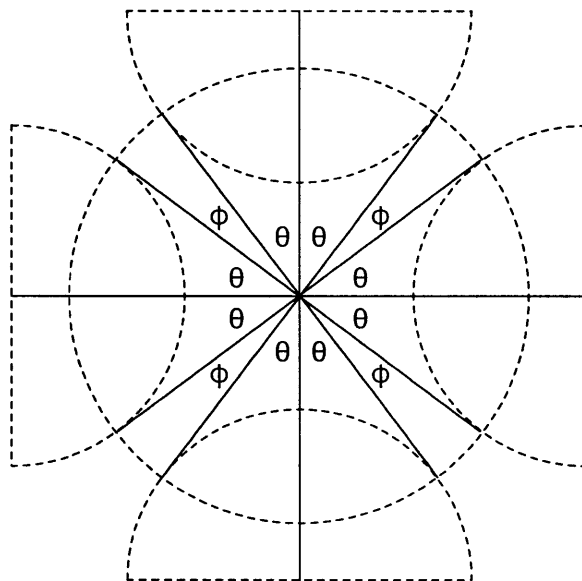


Figure A-5: The angles subtended by the flanges and the milled-out portions of the axle.

Or, in terms of θ :

$$\theta = \frac{\pi}{4} - \frac{\phi}{2} \quad (\text{A.8})$$

Next, as shown in Figure A-6, I obtained the relationship between ϕ , R_x , and L_f (the length of the flange measured along the perimeter¹):

$$\phi = \frac{L_f}{R_x} \quad (\text{A.9})$$

Plugging into equation A.8 yielded:

$$\theta = \frac{\pi}{4} - \frac{L_f}{2R_x} \quad (\text{A.10})$$

¹It might seem like the more relevant measurement would be the end-to-end length of the flange rather than its length measured along an arc. I assumed that since ϕ is small the two measurements would be approximately equal. This can be verified using the law of cosines: if \tilde{L}_f is the point-to-point length of the flange, $\tilde{L}_f = \sqrt{2R_x^2 - 2R_x^2 \cos(\frac{L_f}{R_x})} = 0.0637''$, as compared to the given L_f of $0.064''$

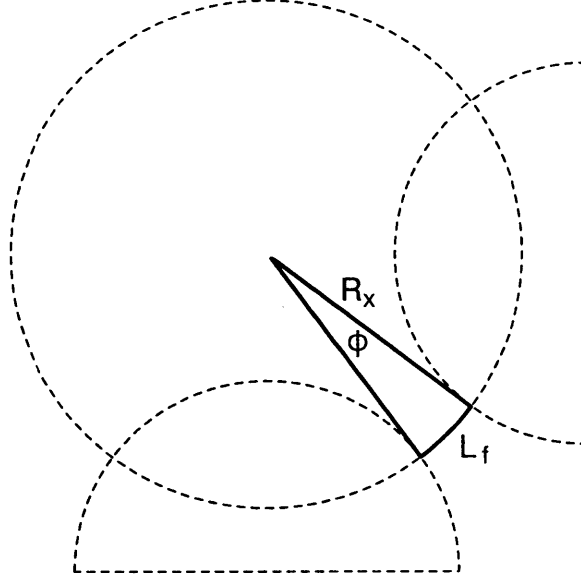


Figure A-6: The angle subtended by a flange.

Combining with Equation A.1 yielded:

$$h = \sqrt{R_x^2 \left(1 - \sin^2 \left(\frac{\pi}{4} - \frac{L_f}{2R_x}\right)\right)} + \sqrt{R_m^2 - R_x^2 \sin^2 \left(\frac{\pi}{4} - \frac{L_f}{2R_x}\right)} \quad (\text{A.11})$$

Next, I computed the value of m based on the value of h . The resulting relationship, as demonstrated in Figure A-7, was:

$$m = R_x + R_m - h \quad (\text{A.12})$$

Plugging in from A.11 yielded the final equation for m :

$$m = R_x + R_m - \sqrt{R_x^2 \left(1 - \sin^2 \left(\frac{\pi}{4} - \frac{L_f}{2R_x}\right)\right)} - \sqrt{R_m^2 - R_x^2 \sin^2 \left(\frac{\pi}{4} - \frac{L_f}{2R_x}\right)} \quad (\text{A.13})$$

A summary of the dimensions of the stock and equipment I used can be found in Table A.1.

Plugging in these values resulted in a value of $m = 0.102''$.

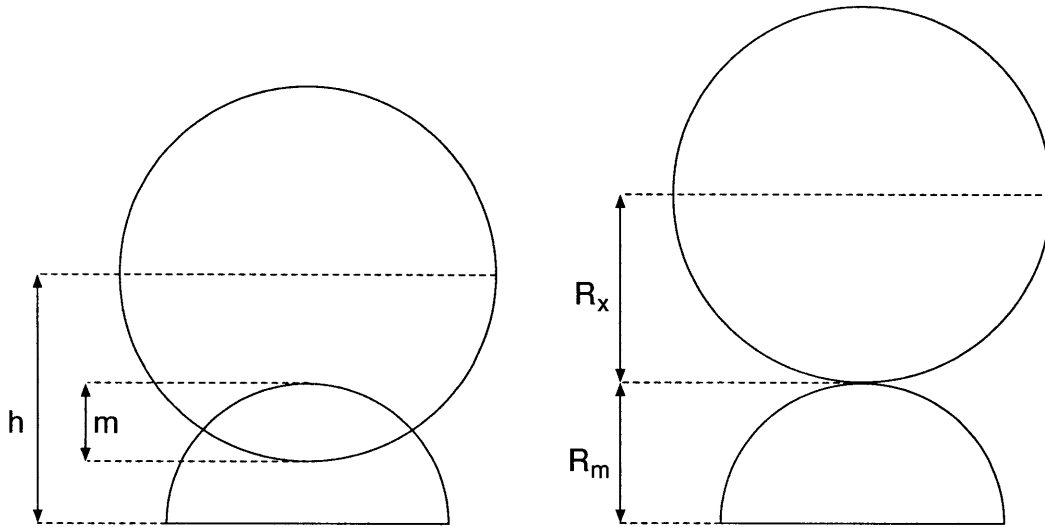


Figure A-7: The relationship between m and h .

Table A.1: Axle milling symbols, descriptions, figures, and values

Symbol	Description	Figure References	Value
R_x	Radius of the ball endmill	A-4, A-6, A-7	0.125 in
R_m	Radius of the axle	A-4, A-7	0.382 in
L_f	Desired flange size, measured along an arc	A-6	0.064 in
h	Distance from the center of the axle to the end of the circular portion of the endmill	A-3, A-7	0.214 in
h_1	Distance from the center of the axle to the reference line	A-3, A-4	0.156 in
h_2	Distance from the reference line to the end of the circular portion of the endmill	A-3, A-4	0.058 in
θ	Angle, measured from the center of the axle, between the closest and furthest points of axle contact with the endmill	A-4, A-5	0.618 rad
ϕ	Angle subtended by a flange	A-5, A-6	0.335 rad