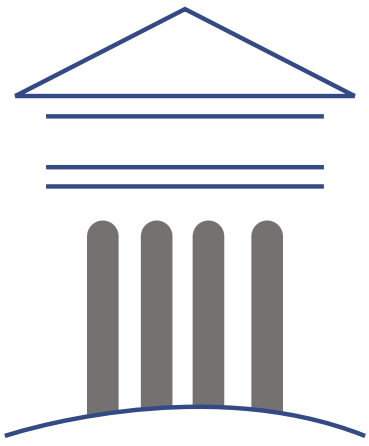
# Custom Fitting the Shotgun Lesson: 2182


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## Objectives

After completing this lesson, you should

1. Understand which corrections must be made if the shooter always shoots high.
2. Know how to correct a shotgun that is muzzle-heavy.
3. Be familiar with the tools used to fit a shotgun stock to the shooter.
4. Know how to correct the shell port on a Browning shotgun when converting it to shoot 2¾" shells.

## Introduction

Most gunsmiths require very exact dimensions when building a shotgun for an individual. To acquire these dimensions, a gunsmith measures the individual's body dimensions, like a tailor measures a customer for a suit. If a person cannot be measured on the premises, a form can be mailed to the customer who can fill in the necessary information (Figure 1). If these measurements are exact, the experienced gunsmith can supply a finished shotgun that fits the shooter precisely. A well-fitting shotgun not only pleases the customer, but also provides good business publicity for the gunsmith.

Why a custom-fitted shotgun? With the large variety of new and used guns available, it seems that a custom fit is not necessary. It is not absolutely necessary for the average hunter or skeet/trap shooter to have a custom-fitted shotgun. However, there are competitive shooters who make a living with their guns, just like professional athletes make a living from their athletic talent and abilities. In competition, one miss could mean the difference between winning a $25,000 or $50,000 prize. Professional shooters want their guns fitted exactly to achieve the highest performance possible when in competition.

There are some shooters who need modified firearms due to a physical handicap. For example, a right-handed shooter with a dysfunctional right eye has special needs. The gun must be modified so the shooter can shoot left-handed using the left eye or shoot right-handed using the left eye.

There are also individuals who prefer to purchase custom-made guns. They might collect and display firearms as a hobby. A fine custom-made gun is prized in any collection.

There are no hard rules for fitting a shotgun to the shooter. Since each individual is different in stature and/or shooting style, proper measurements will vary for each person. In many cases, a slight modification of one or more of the following factors helps improve the shooter's ability:

- Trigger pull
- Pitch
- Drop at comb and heel
- Cast-off and cast-on

With so many different reasons why people want to have a custom-made gun, there is a large demand for gunsmiths who can provide this service. As a result, custom fitting shotguns is a lucrative branch of gunsmithing.

# Custom Fitting the Shotgun Stock

Custom fitting a shotgun can involve several different tasks. The work can consist of merely reworking the existing stock, smoothing the action, or adding elaborate wood checkering and carving. But the work can also be more complex, requiring a complete overhaul of the entire shotgun, including both stock and metal work. In other words, a custom-fitted shotgun could cost from only a few dollars to $10,000, depending upon the amount of work involved.

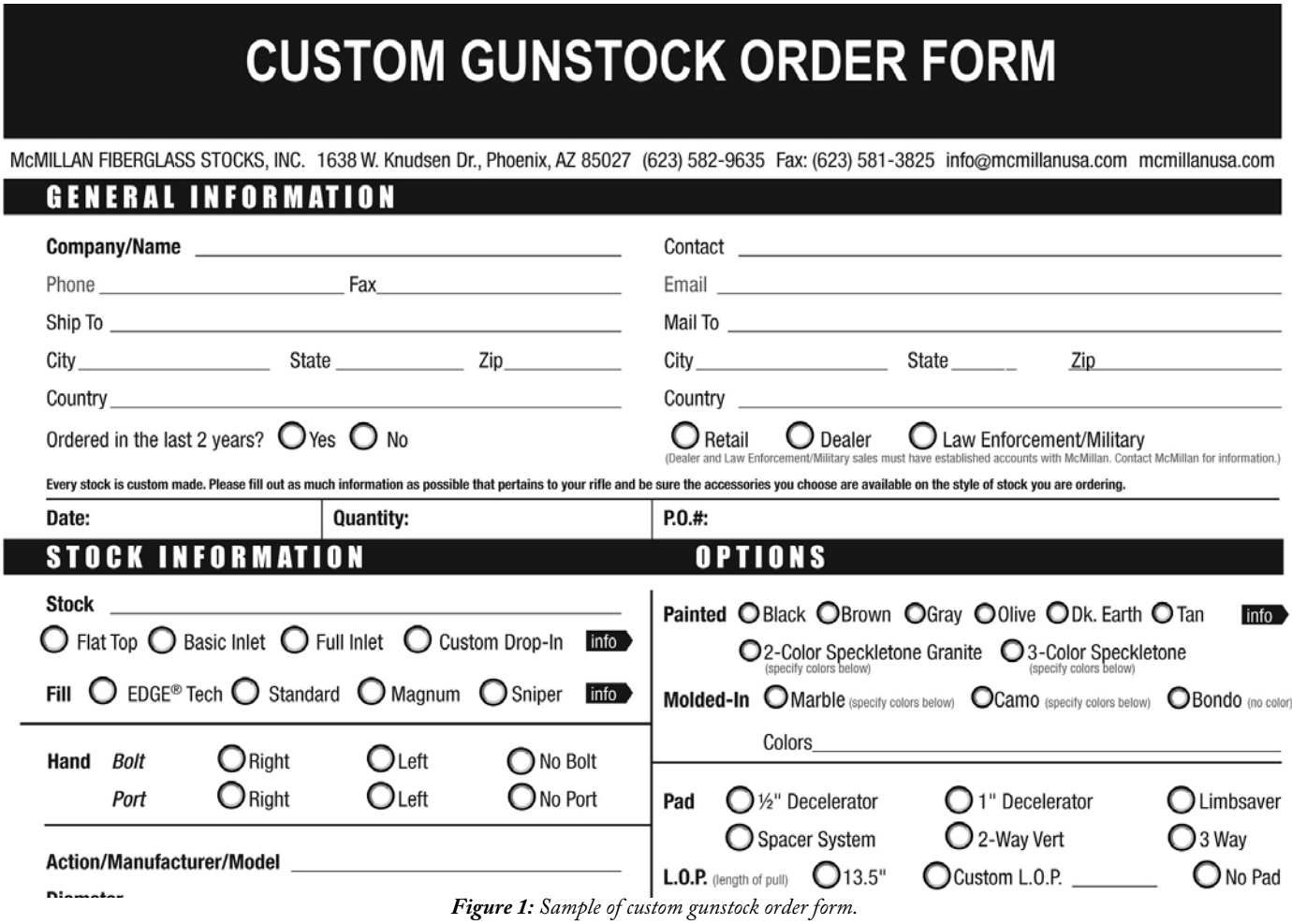
## LENGTH OF PULL

One of the most important areas to consider when custom fitting a shotgun to a customer is the length of pull. There are several easy ways to correct this problem.

The best way to get an exact fit is to use a shotgun equipped with a try stock. With a try stock, the recoil pad or buttplate can be adjusted and actually tried on the range until an exact fit is obtained. A stock can then be custom built to these dimensions, or a recoil pad of the proper thickness can be installed. However, unless the gunsmith has considerable stock work, it is hard to justify the cost of a try stock. An alternative to a try stock is to use a pull-and-drop gauge to approximate the distance the stock should be lengthened.

Another way to get an exact fit is to keep building the recoil pad with temporary pads until the correct length is found. When the shooter obtains the right sight picture and begins to hit consistently, then this will be the distance the buttstock should be lengthened. Some shooters do not like a thick recoil pad on their shotgun. If you have a customer that requests a thin recoil pad and the stock needs to be lengthened ¾" or more, a new stock is the only answer. On the other hand, if the shooter does not mind a thick recoil pad, pads are available on the market with varying thicknesses so you can get an exact fit easily.

One good way of testing the fit of a shooter to a gun is to pattern the shots on a target 30–35 yards away. Using large sheets of white paper, mark a black square or circle about 4" across in the center of each target. Have the customer aim directly at the



CUSTOM GUNSTOCK ORDER FORM

McMILLAN FIBERGLASS STOCKS, INC. 1638 W. Knudsen Dr., Phoenix, AZ 85027 (623) 582-9635 Fax: (623) 581-3825 info@mcmillanusa.com mcmillanusa.com

GENERAL INFORMATION

Company/Name _____ Contact _____

Phone _____ Fax _____ Email _____

Ship To _____ Mail To _____

City _____ State _____ Zip _____ City _____ State _____ Zip _____

Country _____ Country _____

Ordered in the last 2 years? Yes No

Retail Dealer Law Enforcement/Military

(Dealer and Law Enforcement/Military sales must have established accounts with McMillan. Contact McMillan for information.)

Every stock is custom made. Please fill out as much information as possible that pertains to your rifle and be sure the accessories you choose are available on the style of stock you are ordering.

Date: Quantity: P.O.#:

STOCK INFORMATION

Stock _____

Flat Top Basic Inlet Full Inlet Custom Drop-In info

Fill EDGE® Tech Standard Magnum Sniper info

Hand *Bolt* Right Left No Bolt

*Port* Right Left No Port

Action/Manufacturer/Model _____

OPTIONS

Painted Black Brown Gray Olive Dk. Earth Tan info

2-Color Speckletone Granite (specify colors below) 3-Color Speckletone (specify colors below)

Molded-In Marble (specify colors below) Camo (specify colors below) Bondo (no color)

Colors _____

Pad ½" Decelerator 1" Decelerator Limbsaver

Spacer System 2-Way Vert 3 Way

L.O.P. (length of pull) 13.5" Custom L.O.P. _____ No Pad

***Figure 1:*** *Sample of custom gunstock order form.*

center of the black mark. If the shot pattern is high, as shown in Figure 2, the buttstock is too short. If the shot pattern is low, as in Figure 3, the stock is probably too long.

When the shot pattern centers around the target, as in Figure 4, the stock is the correct fit and size.

A common off-the-shelf shotgun would fit the average size male shooter (5'9" – 6' in height). However, taller shooters with longer arms will tend to place their cheek forward on the stock. Consequently, they will see more of the barrel. A tall shooter will be looking down on the barrel rather than looking along the barrel to the front sight, which will invariably cause the shots to be high. A shooter who is shorter in stature with shorter arms will probably hold low on the target if the shotgun stock is too long. As a result, the shots will fall under the target. While your first inclination would be to give the shorter individual a shorter stock, a long stock is usually better than one that is too short. Both lengths will cause the shooter to aim off target, but the margin of error is less on stocks that are a little too long.

The obvious solution to fixing a shotgun stock that is too long is to cut off the required amount. However, you should be aware that just a very small amount of wood taken off will make a big difference in "feel." You should not take off more than ¼" at one time, and measure in increments of $^1/_8$ inches. First, use a gauge to mark the area of the wood that must be removed. Be sure to keep the same angles as the original buttplate. Use masking tape on this area to protect the finish that will remain, and also to help prevent the stock from splintering. The pattern or guidelines should be plainly marked on the tape. Use a coping or a band saw to carefully cut off the end of the buttstock, as shown in Figure 5. If you are sure of the dimensions, next use a wood rasp to smooth the area and finish with varying  s of sandpaper.

Before removing the tape, reinstall the original buttplate or recoil pad (if the original is being reused). Use the existing screw holes, cutting them to a depth to match the thickness of the wood removed. Once the existing buttplate is secure, note any high spots on the butt that will need dressing to make the buttplate fit precisely. Also be aware that the original buttplate is going to hang slightly over the sides since removing the wood decreases the size of the stock towards the receiver. With the buttplate in place, take a scratch awl and mark on the bottom of the buttplate using the buttstock as a guide. This will show the amount of material that must be removed from the buttplate to make it fit flush with the buttstock.

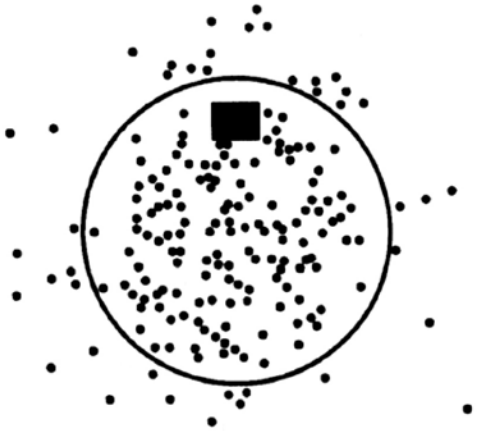


***Figure 3**: A low shot pattern indicates that the shooter's stock is too long.*

Once again, remove the buttplate from the stock and remove any excess material from around the buttplate. This can be done with either a metal file, wood rasp, or sanding disk, depending upon what material is used in the buttplate. Some experienced gunsmiths are able to get the buttplate to fit precisely with the plate off the stock. However, most will trim the plate down to almost perfect, refit the buttplate on the buttstock, and then do the final finishing with the plate on the stock. This is the reason for leaving the masking tape on the buttstock: to protect the stock's finish. If you should slip and damage the stock's finish, this means a lot of additional work. Therefore, be extremely careful in these final stages of refitting the buttplate or recoil pad.

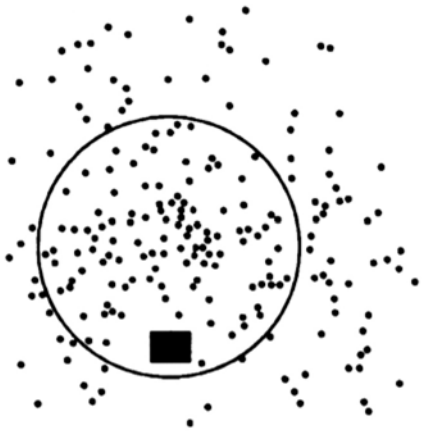


***Figure 2**: A high shot pattern indicates that the shooter's stock is too short.*

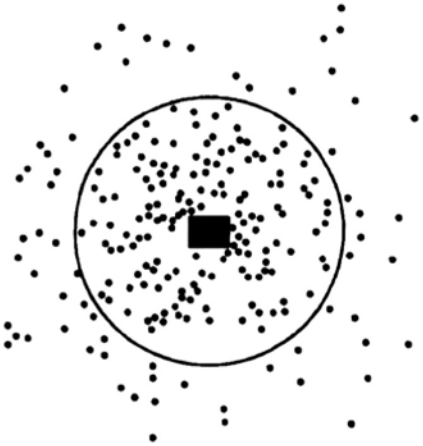


***Figure 4**: When the shot pattern centers around the target, the stock is properly fitted.*

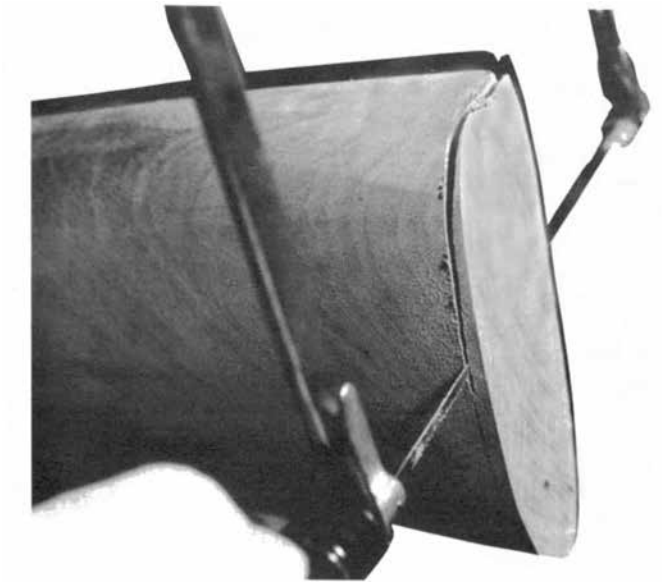


***Figure 5**: To shorten the buttstock, use a coping saw to carefully cut it off.*

Shotgun balance is very important to enable shooters to do their best work. A muzzle-heavy shotgun is especially awkward and will contribute to misses. The type of shotguns that usually have problems with balance are the heavy "duck guns:" 3" 12-gauge magnums with 32" barrels. Winchester compensated for the long, heavy barrels by installing a counter weight lead slug in the buttstock on their famous Model 12 Duck Gun.

If you work a shotgun that is unbalanced, there are a few ways to correct the problem. If the shotgun is muzzle-heavy, drill holes into the buttstock behind the buttplate or recoil pad and melt lead into these holes to act as a counter balance for the heavy muzzle. Shortening the barrel is another solution. However, if you shorten the barrel, the entire choke will be removed, requiring a new choke to be installed. Chokes can be installed as discussed in an earlier lesson. A new choke can be cut directly into the muzzle of the barrel.

If the gun is butt-heavy, the wood can be removed from the inside of the buttstock to lighten it. Remove the buttplate and drill a series of ¾" holes parallel to the stock-bolt hole starting from the rear of the stock. Be careful not to get too close to the edges which may weaken or split the stock.

Out of the many possibilities for fixing a stock, the final decision will usually depend on what your customer wants. Then, you will be in a position to make further recommendations and also decide if you want to handle the job. The average dimensions for shotgun stocks are shown in Figure 6 on next page.

## SPECIALTY STOCKS

As mentioned earlier, some shooters are handicapped and cannot shoot with conventional firearms. To accommodate a right-handed shooter with blindness in the right eye, the traditional solution is to offset or bend the buttstock so that the gun is fired right-handed with the buttplate against the right shoulder and the sighting plain of the barrel aligns with the shooter's left eye. Refer to Figure 7.

Reinhart Fajen, Inc. offers a crossover stock for shooters who must shoot from the right shoulder using the left eye. With this type of stock, the comb of the buttstock is cut down, rounded, and fitted with a cheek rest on top of the stock, rather than on the side. When firing, the shooter holds the butt firmly against the shoulder with the head tilted across the stock so the left eye lines up with the sights. The forward part of the comb must be cut down and must move freely so the recoil will not jolt the comb into the shooter's face.

Another way to supply a crossover stock is to use a piece of flat steel with two ivory bead sights attached that runs from the muzzle of the shotgun to the back about 20 inches. This "rib" is fastened to the left side of the barrels by two brackets—one at the muzzle and the other about 18" back. The sights on this rib are set at over 2½" at the rear and 2½" at the muzzle. A detailed drawing of the apparatus is shown in Figure 8, on page 8. This is probably the less expensive way of adjusting a gun for a right-handed shooter who must use his or her left eye.

## SELF-TEST QUESTIONS

Please check your answers on page 14.

1. ***True or False*. A shotgun stock that is too short for the shooter will cause the shooter to place the shots high.**
2. **Although there are many areas to consider when custom fitting a shotgun stock, what is one of the most important?**
3. **If a shotgun buttstock is too short, what is the easiest way to correct this problem?**
4. **What is the purpose of using masking tape on a buttstock when cutting off a portion of the stock to make it shorter?**

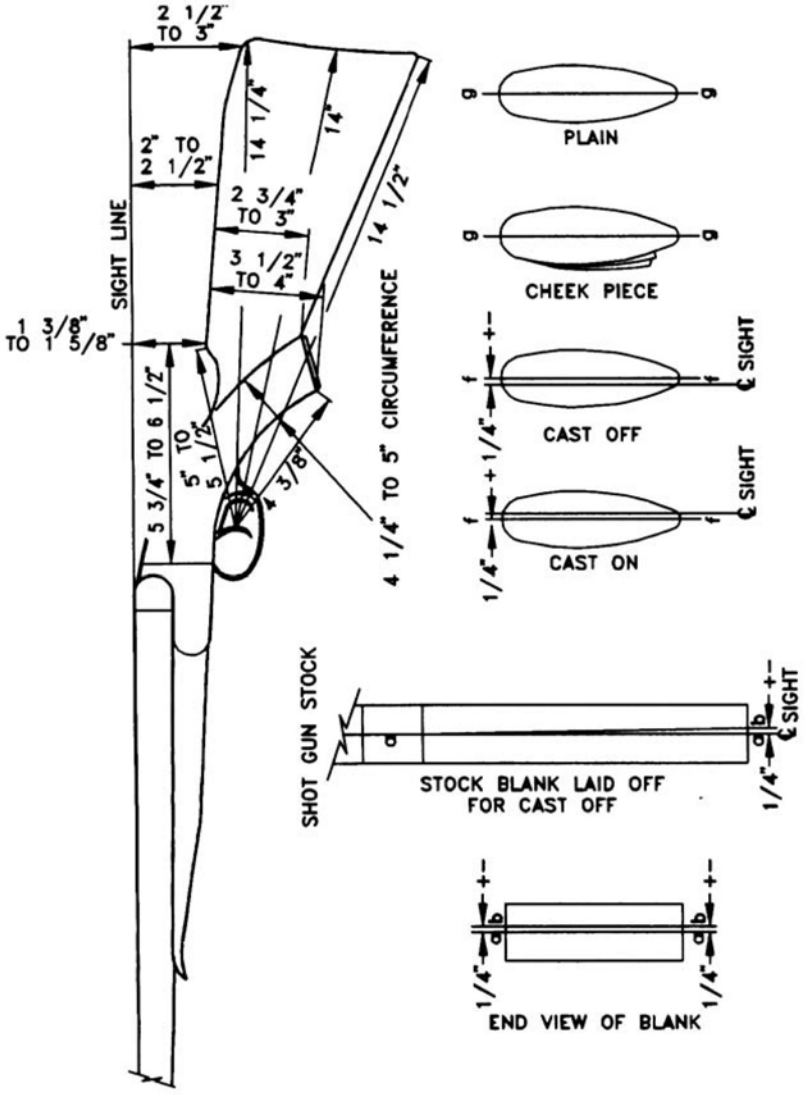



***Figure 6:*** *The average dimensions of shotgun stocks.*

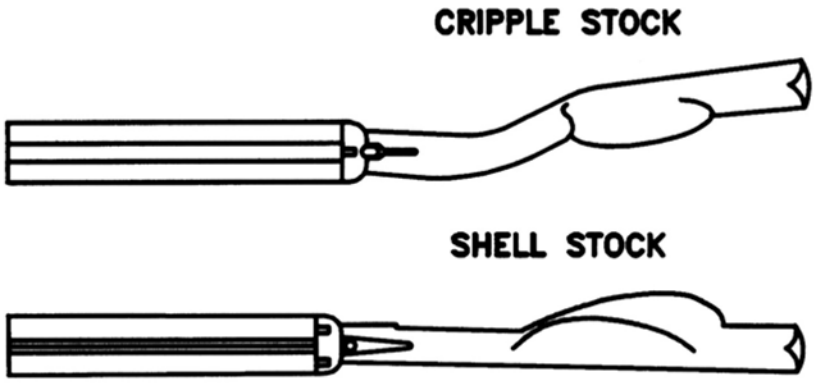



***Figure 7:*** *Two types of stocks used for shooting from the right shoulder using the left eye. Bent or cripple-stocks (top) are very expensive, not only because of their difficult shape, but because they require a specific piece of walnut that has a natural bend. The shell or cross-over, stock allows the shooter to place his or her cheek further to the right on the stock so the left eye can be used for sighting.*

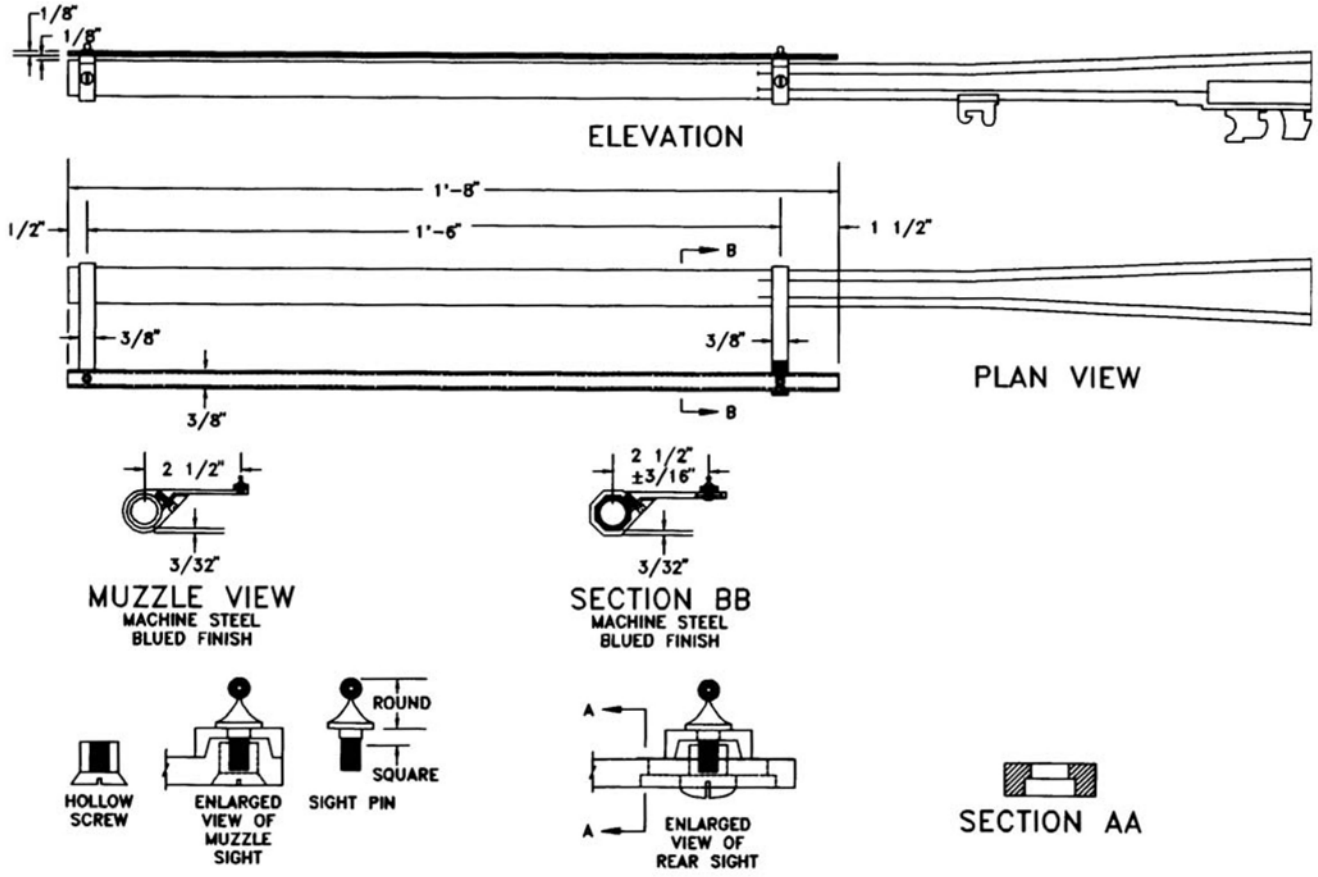



***Figure 8:*** *Offset rib used on shotgun barrel for monocular vision.*

# Shotgun Conversions

Several models of 16-gauge shotguns manufactured during the first half of this century were chambered for 2 ” shells, as opposed to the 2¾” chambers used for modern 16-gauge shotshells. Single-shot and double-barrel shotguns are easily converted to the longer shells by using the Walker long forcing cone reamer as discussed earlier in this course. However, repeating shotguns, such as the Winchester Model 12 slide-action shotgun and the Browning Auto-5 semi-automatic shotgun (Figure 9), will require additional work on the action to properly feed the longer shells. The following instructions outline the method of converting short chambers in the Browning Auto-5 shotgun to permit use of standard 2¾” 16-gauge shotshells. However, the method will also suffice for other models, with a few modifications.

**Disassembly**. To disassemble, use the enlarged view in Figure 10, on page 11, as a reference. Completely disassemble the gun, removing all drift pins, screws, and parts. This is essential in most altering jobs in order to determine if there are any worn or broken parts that might be in the gun.

Remove the buttstock by first removing the tang screw (B83) held in place by a lock screw (B53). These screws are located on the under-side of the stock to the rear of the grip. There is another screw (B66) between these two screws and the trigger guard. Do not remove this screw since it holds the mainspring in place. After removing the tang screw, the buttstock can be removed. Secure the shotgun in a carefully padded vise with the buttstock free. Grip the underside of the buttstock with the left hand and use the palm of your right hand to strike the comb of the buttstock lightly, which will move it rearward. This should loosen the buttstock from the receiver tangs so it may be removed without damage. Remove the trigger plate screws (B87 and B88) and lift out the trigger plate (B86).

Next, remove the carrier spring (B24) by forcing it from under the pin at the front and then sliding it off the one at the rear. Then, remove the carrier (B13) by taking out the carrier screws (B23) and lock screws (B53) from the right and left side of the receiver. When replacing the carrier screws, be sure to put them back in the same side from which they were removed. You will be able to identify the one on the right side because it is marked on the point.

Draw the breechbolt (B7) back with the operating slide (B67) so that the action spring is compressed. This spring may be held back by inserting a small nail or drift punch in the tang screw hole so that it will not force the breechbolt closed again. Continue by drawing the breechbolt back until the locking block latch pin (B34), which is the first pin at the front of the breechbolt, lines up with the small hole on the left side. The locking block latch pin can then be driven out and the locking block latch and spring (B50 and B52) removed. Lift the rear end of the link (B47)—the long piece of metal cut out in the center and extending to the rear of the receiver—up as far as it will go. Then move the operating slide backward while simultaneously pushing the breechbolt forward and out of the receiver. Reassemble it in the reverse order.



***Figure 9:*** *The Browning A-5 semi-automatic shotgun. Those made in 16-gauge prior to World War II had short chambers, requiring a minor alteration for the guns to fire modern 16-gauge shotshells.*

**NOTE**: When replacing the trigger plate, pull the operating slide back a little or you will be unable to get it in place. This is one of the most important things you should remember about reassembling the Browning Auto-5 semi-automatic shotgun.

**Clean**. Clean all parts, assemblies, receivers and barrels thoroughly.

**Check All Parts.** All parts should be carefully checked for wear, cracks, and deformities. These parts must be in perfect condition for the altered shotgun to function properly. Any part that has a defect or is worn should be replaced with a new or replacement part.

## ALTER ASSEMBLIES OF THE GUN RECEIVER

The shell port of the receiver, shown in Figure 11, must be lengthened to the forward part of the gun. The distance between the front of the port to the front of the receiver is $^{17}/_{32}$ inches. Three types of tools can be used to perform this job. A hand file or a Moto-Tool grinder can be used to lengthen the port. If you have the facilities and enough of this type of work, a jig can be set up on the milling machine with a $^{3}/_{8}$" end mill as a cutter to remove the metal necessary to lengthen the port.

**Link**. The link must be altered to prevent the rear portion of the link from overriding the safety sear. It should be milled or filed $^{3}/_{32}$" to the rear, maintaining the same angle (Figure 12). Tools required for this operation would be an extra narrow pillar file or a staggered tooth side mill. The size of mill required is $^{3}/_{16}$ x 3 inches.

**Carrier**. To accept the longer shell from the magazine, the carrier must be altered at the shell stop portion by grinding $^{1}/_{16}$" rearward. This is shown in Figure 13, on page 12.

A Moto-Tool grinder with a soft stone about $^{7}/_{8}$" x ¼" is needed. Some of the 16-gauge Browning Automatic parts are carburized, which makes them glass hard. Using a soft stone will make the cutting much easier. For the larger shops, a carbide end mill is designed to fit a special fixture which can alter the carrier.

**Locking Block Latch**. The shell stop portion of the locking block latch must be cut toward the rear of the gun. This is done to prevent the shell from overriding the locking block latch when loading shells into the magazine and from lodging between the carrier and the breechbolt. The recommended amount of metal to be removed is $^{3}/_{32}$" as shown in Figure 14, on page 13. A bastard file is used to rough the initial cut and a mill file is used to finish.

**Ejector**. The ejector must be altered to a movable sliding ejector that slides free, but must not have excessive play. File an oval hole where the ejector rivet goes through this part. The hole is ¼" long, taking up the complete area between the two rails of the ejector to maintain a web in the front portion of the ejector $^{5}/_{64}$ inches (Figure 15, on page 13). Use a drill to fit between the rails of the ejector and a round bastard file to enlarge and lengthen the hole.

**Barrel**. The barrel extension is one of the items of the 16-gauge Browning Automatic that is carburized. You need to use a Moto-Tool 1" x ¼" soft stone. The barrel and barrel extension must be ground to clear the front end of the longer shell. The line of the outside edge of the barrel extension should be maintained, as well as the inside lower rim of the headspace of the barrel. The barrel and the barrel extension should be ground on an angle from the lowest point of the headspacing to the outer edge of the barrel extension. This is only done at the point from where the extracted shell is ejected (See Figure 16. The barrel chamber must be rebored (reamed) to accept the 2¾" shell.

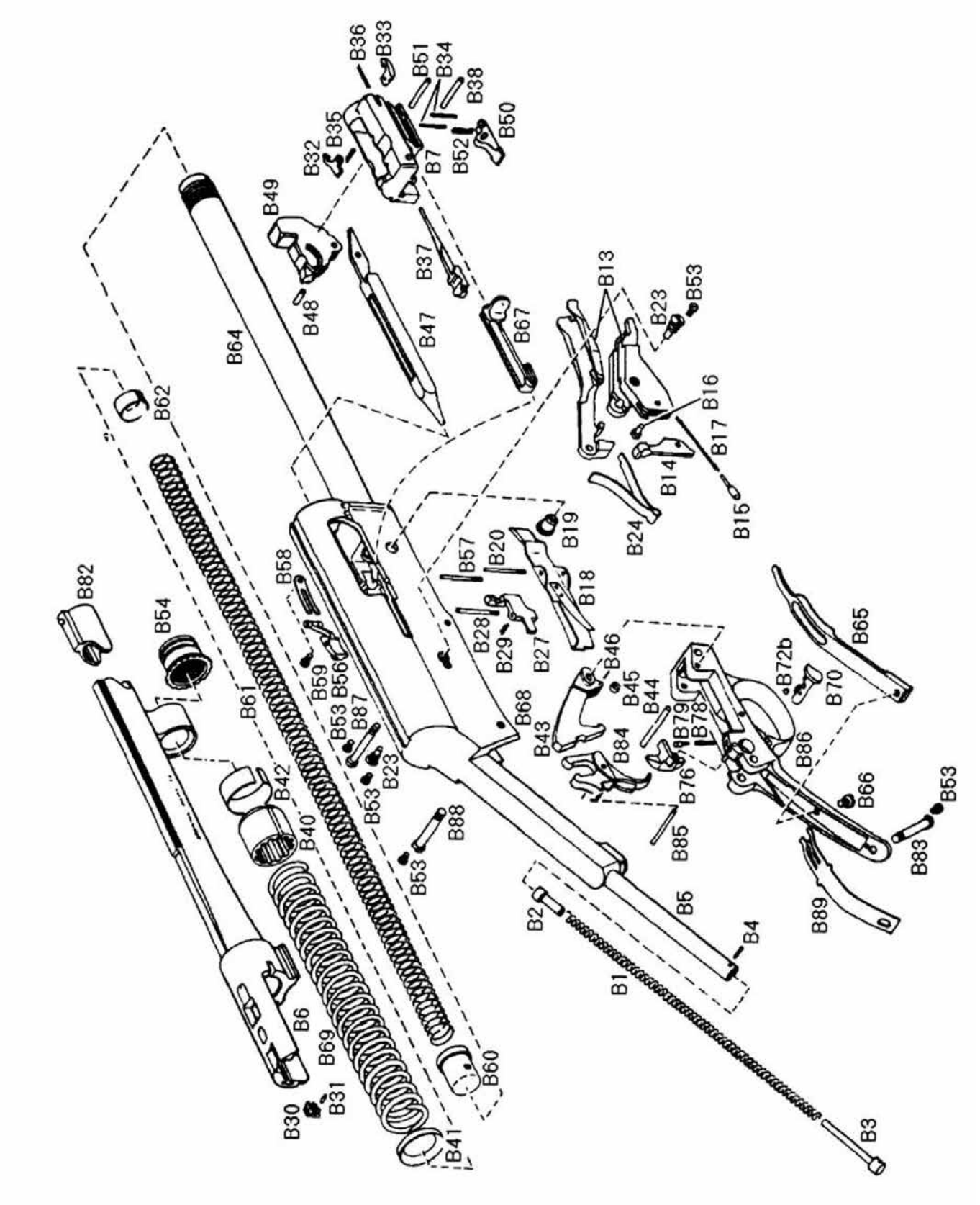



***Figure 10:*** *An exploded view of a Browning A-5 semi-automatic shotgun. This will help you during disassembly and assembly.*

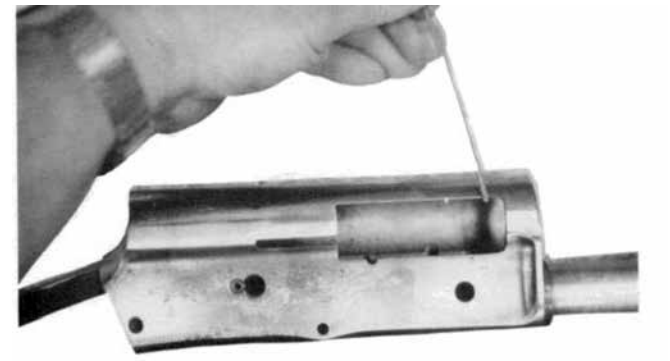


***Figure 11**: The shell port of the receiver must be lengthened to the forward part of the gun. The distance from the front of the port to the front of the receiver is $^{17}/_{32}$ inches.*

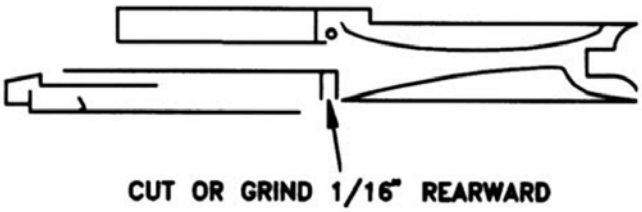



***Figure 13**: The carrier must be altered at the shell stop portion.*

**Fore-end**. The fore-end must be altered to let the barrel slide forward in the receiver. This is done by cutting on the inside of fore-end where the barrel guide ring strikes the fore-end. The amount of wood removed will be $^{3}/_{32}$ inches. Wood will have to be removed from the rear portion of the fore-end to allow the barrel extension and the barrel-extension guide to come into the fore-end. Where the barrel-extension portion fits into the fore-end, a woodcarving chisel may be used to remove necessary wood as shown in Figure 17.

**Reassembling Component Parts Into Assemblies, and** Adjusting. At this point, the gun is clean and ready for assembly. Replace the cartridge stop and spring, the carrier latch and carrier latch button, and the magazine cut-off and spring— in that order. Reassemble the magazine, magazine spring follower, spring, and magazine spring retainer. This completes the receiver assembly.

**Reassemble the trigger guard**. Replace in the following order: the safety, the trigger, the trigger spring, the mainspring, the hammer safety sear, and the safety sear spring.

Make all necessary checks, and adjust the safety, the amount of play between trigger and safety sear, and the trigger pull, which should be approximately five pounds.

The breechbolt assembly is next. Assemble the component parts in the following order: fasten the link to the locking block; inspect the rim on the locking block rim for cracks or burrs; and inspect the link to see if it is bent. Install this assembly in the breechbolt. Replace the firing pin and the firing pin retaining pin. Check the sharpness of the right-hand extractor and the tension of both extractor springs. Install these in the breechbolt assembly.

For the barrel assembly, install the ejector and ejector stop rivet in the barrel extension. Make sure that the ejector slides freely.

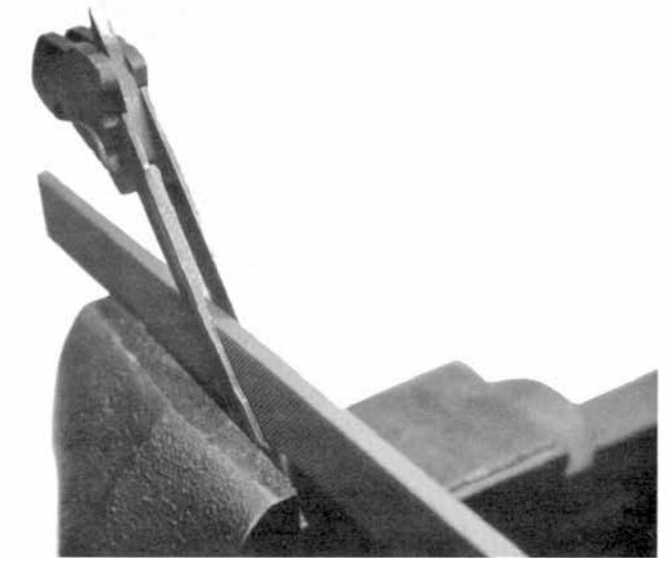


***Figure 12**: The link must be altered to prevent the rear portion of the link from overriding the safety gear. It should be filed $^{3}/_{32}$ from the rear, maintaining the same angle.*

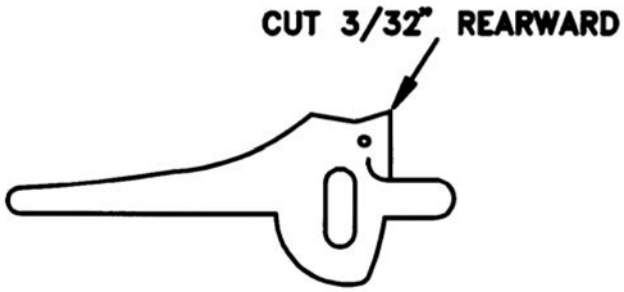



***Figure 14**: The shell stop portion of the locking-block latch must be cut to the rear as shown.*

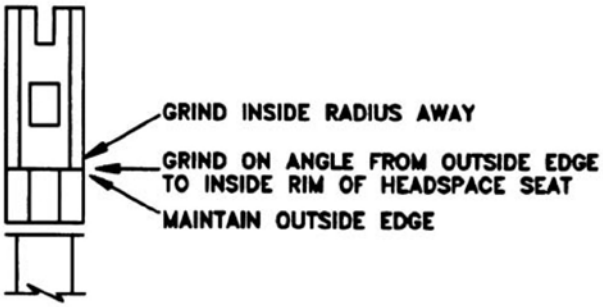



***Figure 16**: The barrel and barrel extension must be ground to clear the front end of the longer shell.*

**Reassemble Gun and Test.** Reassemble the assemblies and component parts in the receiver. Inspect all assemblies for burrs, and make certain that all movable parts move properly and do not bind around pins or screws. After the action has been assembled and the stock replaced, remove any burrs from the friction ring and the barrel guide ring with a honing stone. Check the tension and length of the recoil spring. Assemble the barrel to the action of the gun and test for proper functioning. Testing should be done with 2¾" light loads first. Then test with heavy loads.

## SELF-TEST QUESTIONS

Please check your answers on page 14.

5. **When converting short chambers to longer chambers in a Browning A-5 shotgun, what is the first step?**
6. **If using a milling machine to lengthen the shell port in a Browning A-5 conversion, what size end mill should be used?**
7. **What is the purpose of altering the link of the Browning A-5 shotgun when converting it to accept modern 16-gauge shotshells?**
8. **What is the purpose of grinding the barrel and barrel extension during the Browning A-5 conversion?**

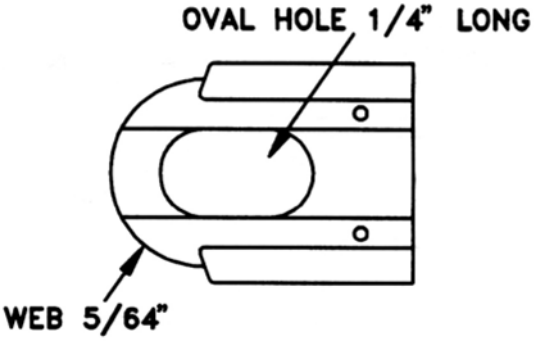



***Figure 15**: The fixed ejector must be altered to a moving sliding type that should slide free, but without excessive play.*

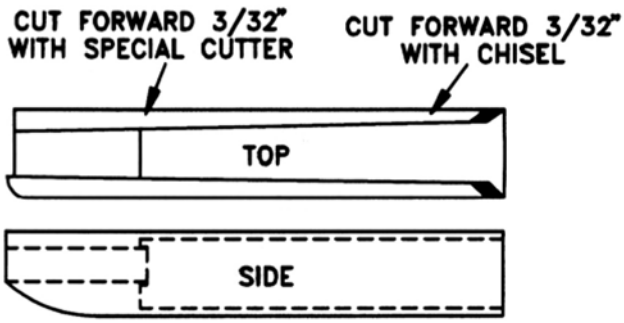



***Figure 17**: The fore-end must be altered to let the barrel forward in the receiver.*

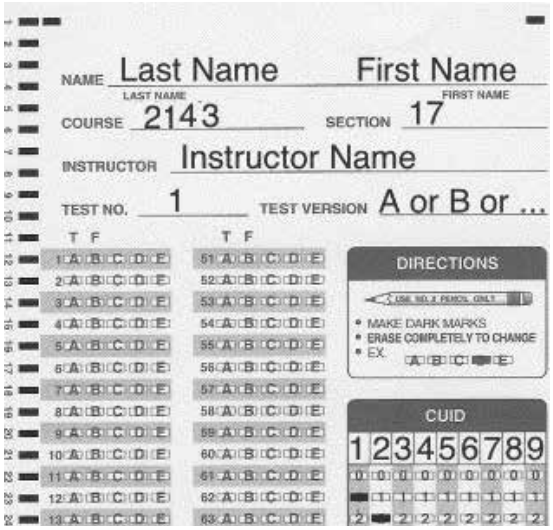
# Answers to Self-Test Questions

1. True.
2. Trigger pull.
3. Install a thicker buttplate or recoil pad.
4. To protect the stock's finish and to keep it from splintering.
5. Completely disassemble the shotgun.
6. $^{3}/_{8}$ inches.
7. To prevent the rear portion of the link from overriding the safety sear.
8. To clear the front end of the longer shell.

# Lesson Questions

**THIS IS LESSON NUMBER 2182.**

Make sure you print your name, student number, and lesson number in the space provided on the Lesson Answer Form. Be sure to fill in the circles beneath your student number. Code the lesson number as shown.




**REMINDER**: A properly completed Lesson Answer Form allows us to evaluate your answers and send the results and additional study material to you. Do not hold your Lesson Answer Forms to send several at one time. You may run out of study material if you do not send your answers for evaluation promptly.

You may also complete your exam online at www.sdi.edu, click on the *online exams* tab.

1. **Which of the following groups of shooters would usually request a custom-fitted shotgun?**
   a. Law enforcement agencies.
   b. Competitive trap shooters.
   c. Military personnel.
   d. The occasional quail hunter.

2. **When testing for shotgun fit, if a shooter constantly shoots high on the target, what is the most likely cause?**
   a. Buttstock is too short.
   b. Buttstock is too long.
   c. Buttstock needs cast-on.
   d. Buttstock needs cast-off.

3. **What type of gauge is be used to measure the shooter's correct length of pull?**
   a. Ting gauge.
   b. Pull-and-drop gauge.
   c. Trigger pull gauge.
   d. Thickness gauge.

4. **If a shooter constantly shoots low on a target, what is the most likely cause?**
   a. Buttstock is too short.
   b. Buttstock is too long.
   c. Buttstock needs cast-off.
   d. Buttstock needs cast-on.

5. **Which of the following types of shotguns will most likely be muzzle heavy if the balance is not corrected?**
   a. Riot shotguns with 20" barrels.
   b. Light 20-gauge, double-barrel shotguns with 26" barrels.
   c. 12-gauge magnum shotguns with 32" barrels.
   d. Single-shot, break-open .410 shotguns with 24" barrels.

6. **What is one way to correct a muzzle-heavy gun?**
   a. Lighten the buttstock.
   b. Add a magazine extension under the barrel.
   c. Install a Poly-Choke tube on the muzzle.
   d. Add weight to the buttstock.

7. **What is one way to correct a butt-heavy shotgun?**
   a. Install a Poly-Choke choke tube on the muzzle.
   b. Add weight to the buttstock.
   c. Shorten and rechoke the barrel.
   d. Add a thicker recoil pad.

8. **What is the standard chamber length for modern 16-gauge shotshells?**
   a. 2½ inches.
   b. $2^{9}/_{16}$ inches.
   c. 2¾ inches.
   d. 3 inches.

**9. What was the length of many 16-gauge shotgun chambers prior to World War II?**

a. 2½ inches.

b. $2^{9}/_{16}$ inches.

c. 2¾ inches.

d. 3 inches.

**10. When converting the Browning Auto-5 shotgun to accept longer 16-gauge shotshells, what should the distance be between the front of the shell port and the front of the receiver?**

a. ¾ inches.

b. ½ inches.

c. $^{17}/_{32}$ inches.

d. $^{9}/_{16}$ inches.