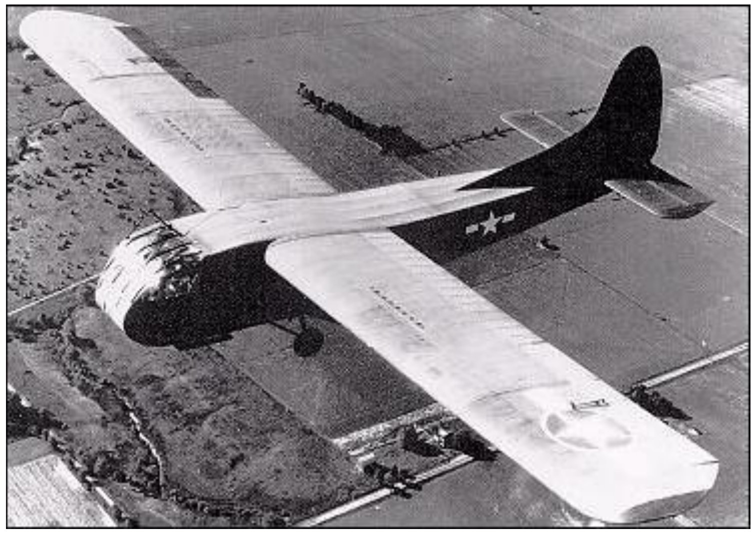
The Trailing Edge

September 2024

What Was It Like To Fly Cargo Gliders? Modern Sailplanes vs Waco CG-4A



Waco CG-4A Cargo Glider

Students of World War II aviation will eventually learn about the use of cargo gliders to deliver troops and equipment into small fields behind enemy lines.

During my many years on staff at the USAF Test Pilot School, I learned to fly gliders and became a glider flight instructor. The oldest glider design that we fly is the Schweizer SGS 2-33, which first flew in 1965. Being a glider pilot, one day I started wondering what it would be like to fly a cargo glider and would it have similarities to the modern gliders that we fly. Through the TPS qualitative evaluation program, I have had the chance to fly World War II era aircraft, such as the Douglas C-53 (DC-3), North American T-6 Texan, Beech 18, Lockheed C-60, Stearman biplane, Boeing B-17G Flying Fortress, and Luscombe 8E. However, there was no chance that I would get to fly a Waco CG-4A glider because of the minor detail that there are no airworthy examples available to fly.

Modern Sailplanes Used By TPS

Given this minor setback, I decided to do the best I could to determine the performance and flying qualities of the Waco CG-4A by studying any reference material that I could find. To support this effort, my Dad provided me with Waco CG-4A *Pilot's Flight Operating Instructions* (Ref 1) and a *Pilot Training Manual for the CG-4A Glider* (Ref 2). Armed with these documents and my own glider experience, I assembled a presentation comparing the Waco CG-4A to the modern sailplanes flown by TPS. This presentation was presented to the glider pilots of TPS, and on 17 March 2009 to EAA Chapter 1000. This article is written to capture and expand on that presentation so that it might be preserved and made available to a wider audience. Unfortunately, over the span of 15 years I have forgotten the source of some of the information provided here, but have been able to rediscover most of the sources.

Combat Glider Background

With the coming of World War II, militaries looked for ways to use aircraft to increase their advantage. Planners looked for a way to use aircraft to rapidly deploy men and materials to the front lines or even behind enemy lines. Cargo aircraft were no larger than a Douglas DC-3 or Junkers Ju 52. These had limited capacity and required several thousand feet of runway for landing. Intended drop zones tended to be much smaller, typically farmer's fields surrounded by hedgerows. One option was to use parachutes, but these had very limited availability. Parachutes required fabric that was strong, thin, and able to be folded into a small package. Silk was suitable, but was very expensive and in limited supply due to its dependence on biological production by armies of silkworms. Nylon was suitable, but was very new, having only been announced in 1938. During World War II almost all nylon production was diverted to the military for use in parachutes and parachute cord (Ref 3). Even then, parachutes were produced in sizes suitable for personnel drops, not large enough for heavy equipment.

Another possible solution was to use gliders towed to the landing zone and released. The biggest perceived advantage of gliders was that an entire squad would all land in the same spot. Parachute drops resulted in squads being spread over large areas, requiring valuable time to reconstitute a fighting force. Another perceived advantage was that after the enemy had been driven back, the gliders could be picked up and used again. In practice, this would be proven to be nearly impossible. Gliders required trained pilots to operate. After landing, provisions were required for the glider pilots to fight their way back to the rear to be available for further glider flights.

Germany was the first to use gliders for airborne assault. On 10 May 1940, they were quite successful at the Belgian fortress ofÉben-Émael, which was defended from all sides, but not the top. A year later they were less successful at the Battle of Crete. In fact, the Battle of Crete was such a pyrrhic victory that Hitler declared that there would be no further use of airborne troops, either by parachute or by glider. However, that last bit of information never made it to the Allies, who only saw the successes and decided "we gotta get us some of those!".

The US Army Air Forces (USAAF) now had an idea, but they were basically starting from zero. In 1942 there was a grand total of 160 licensed civilian glider pilots in all of the United States. Of those, only 25 were considered sufficiently experienced to be instructors (Ref 2). While not much, this is where they started.

Another use for gliders would evolve, being used as cargo aircraft in friendly territory. Prior to World War II, the idea of large cargo aircraft had not arisen. As the need to quickly move supplies from here to there evolved, there was a rush for "large" cargo aircraft. There were some smaller aircraft available, such as the Beech 18 or Lockheed 10, but these were rather small. The largest aircraft in terms of cargo capacity at the beginning of the war was the Douglas DC-3, which would be modified into the C-47. However, the DC-3 first flew on 17 December 1935, so there hadn't been that many of them built by the beginning of the war. The first C-47 flew 16 days *after* the attack on Pearl Harbor. The Curtiss C-46 Commando first flew in 1940, but far fewer of them were built compared to the C-47. The larger C-54 Skymaster first flew in 1942, and was just starting to become readily available by the end of the war. As such, the availability of aircraft capable of carrying supplies was very limited. Gliders were seen like "trailers" for cars that could be used to carry supplies. Some squadrons were equipped with aircraft, such as a B-17 or B-25, which were not very suitable for carrying supplies, but those aircraft could be used as tugs towing gliders carrying the supplies. Thus, gliders served as cargo airplanes until larger, purpose-built cargo aircraft were available.

CG-4A Description

In the original presentation, I showed a video to introduce the audience to cargo gliders and how they were used. That video can be seen on YouTube at https://youtu.be/XNT61IipahQ?si=eWmCxl_etfKotUGi (Ref 4).

To try to get a feel for the size of a Waco CG-4A, let us first compare its characteristics to a couple of gliders that TPS regularly uses. First is the ubiquitous training glider, the Schweizer SGS 2-33.

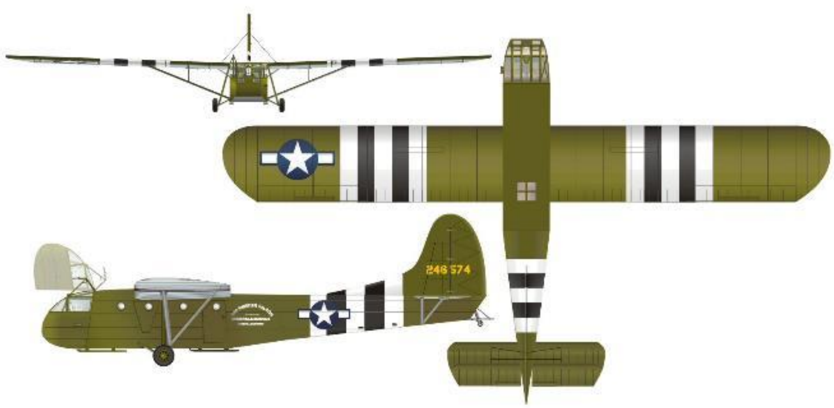
Schweizer SGS 2-33

Second is a popular, medium performance training glider, the Schleicher ASK-21.

Schleicher ASK-21

Here is a comparison of the Waco CG-4A to these gliders for some significant geometric properties.

	CG-4A	SGS 2-33	ASK-21
Wing Span	83.7 feet	51 feet	56 feet
Wing Area	851.5 square feet	219.5 square feet	193 square feet
Aspect Ratio	8.23	11.85	16
Max Gross Weight	7500 pounds	1040 pounds	1320 pounds

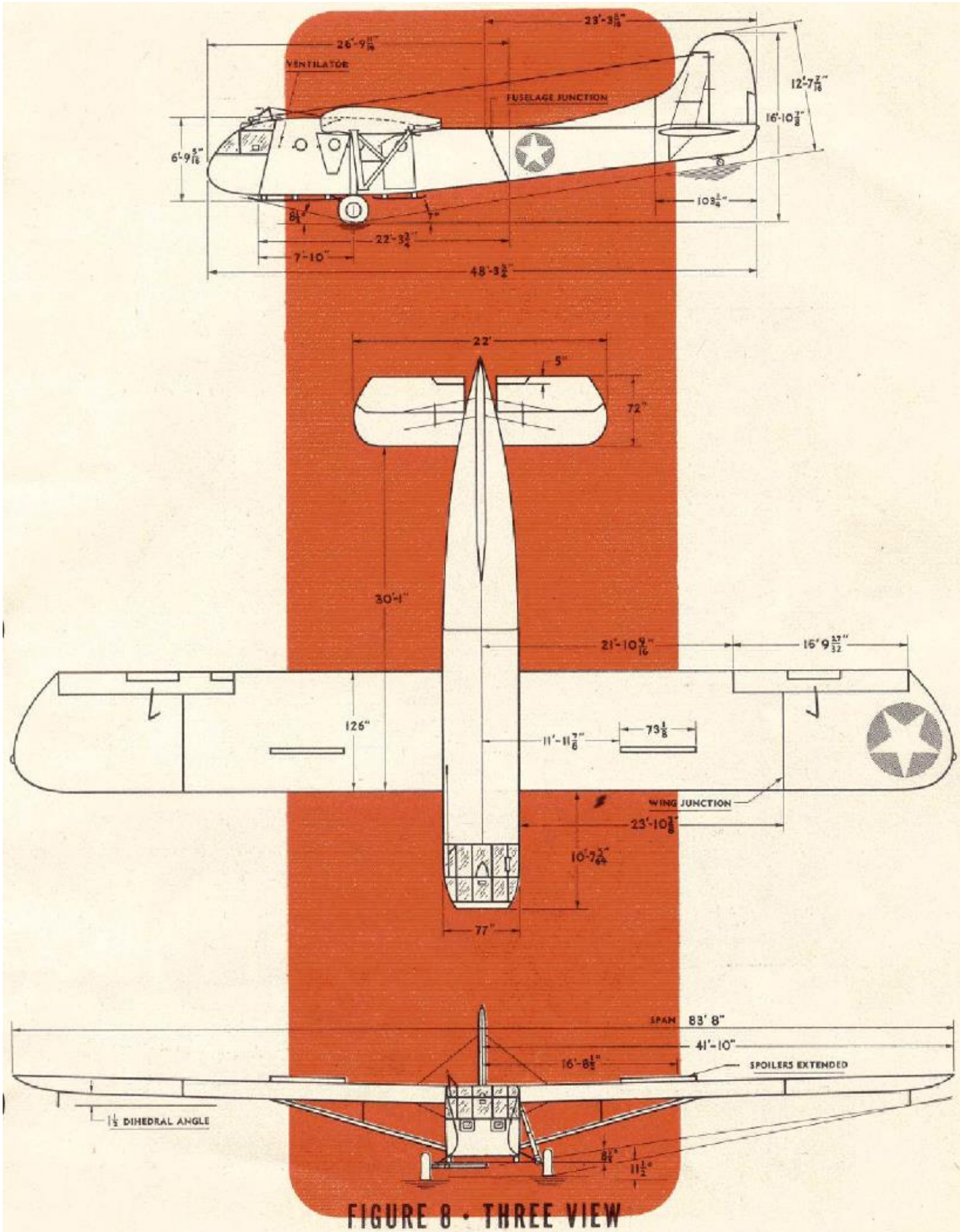


As can be seen from the numbers, the Waco CG-4A glider was significantly bigger than the other two gliders. The wing span was about 30 feet more, and the wing area was about four times as much. Of course, the maximum gross weight was significantly more, since the mission was to carry payload. In fact, about the only thing that the CG-4A had in common with the other gliders was the lack of a powerplant. Reference 2 described it as "The CG-4A was not designed as a sailplane. It is simply a cargo-carrying airplane without engines, and falls in the same category as other troop-carrier type aircraft." The relatively low aspect ratio supports the idea that this was not a sailplane.

The CG-4A had a cargo useful load about half that of the C-47, but was almost the same size as the C-47, with a wingspan only 12 feet shorter than the C-47. Much like a Piper Cub, because of limitations in power available, the CG-4A lifted a large payload through the use of large wing area rather than high speed.

Fuselage Construction

Construction techniques used in the CG-4A had much more in common with light airplanes than with other airplanes of similar size. This was presumably to keep costs down (given the somewhat disposable nature of combat gliders) and to avoid use of "strategic materials" such as aluminum, which was being used to build fighters, bombers, and other combat aircraft. Given the amount of wood used in the construction, it is possible that the overall weight



Waco CG-4A Three View Drawing (Ref 5)

was actually greater than an equivalent aircraft made of aluminum. The majority of the steel tubes were SAE 1020 or 1025 carbon steel with the exception of several tubes which were X4130. Wood parts were mainly spruce or yellow poplar (Ref 5).

The fuselage frame was built of welded steel tubing, covered with fabric and using wooden fairings. This picture shows the steel tube cage, the wood stringers, and the fabric covering. I'm guessing that the covering on this glider is not the historic Grade A Cotton, since that fabric is essentially unavailable today. It is probably polyester (Dacron/Ceconite/Poly Fiber), and to be historically accurate would be finished in dope (such as Ceconite). If it is Poly Fiber, they used the untinted Poly Brush instead of the usual pink Poly Brush.

The CG-4A was shipped in wooden boxes, and to keep the size of the packing boxes manageable, the fuselage frame was made in three sections, the nose, the main cargo area, and the tail. This diagonal splice was where the tail section was bolted on to the main cargo section. Per Reference 5, this gap should have a fabric tape doped

Fuselage Structure, Tail Section

Tail Section Attachment Joint

over this gap and painted to match, but I would not be surprised if in the rush to get gliders assembled for combat that this step would have been skipped.

The doors were constructed of a wood frame with what appears to be a thin plywood skin. This is one of the normal crew entry doors.

Right Side Main Entry Door

Inside the main cargo area, the door like the one shown to the right is at the left side of the lower photo. In the center, the similarly constructed, sort of triangle shaped, structure was an emergency exit door. Because of its smaller size, it was more difficult to use than the main door, but fit in the steel tube structure. If you want to get out quick because people are shooting at you or the main door is stuck, the emergency door will work just fine.

Immediately above the triangle shaped emergency exit door is the brake cylinder for the left side brake. The hydraulic line to the brake cylinder is not currently installed.

Personnel seating was on wooden boxes with slightly curved tops. These boxes also served as storage areas for things like tie down ropes. When transporting items other than people, the boxes could be easily picked up and removed from the glider.

A parachute is shown on the seat. It appears to be a seat type personnel parachute.

Left Side Interior Structure

Because the nose was hinged at the top, all of the flight controls and other controls ran along the ceiling of the glider. The main cables down the centerline with the large pulleys are for the elevator. Running next to the elevator cables are the trim cables for elevator and rudder. The cable at the far edge of the roof is the left rudder cable. The cables near the top of the picture are for the parachute release and jettison. The bellcrank transfers control inputs to the ailerons. The rear cable to the right aileron is not tensioned. The bellcrank has an odd shape because it is mounted off-center in the fuselage, probably so as to not interfere with the elevator and rudder cables. The pulley at the right center of the picture is a double pulley, carrying the cables to the spoilers. The cable to the left wing spoilers is not attached. Spoiler opening was accomplished through cable action with a spring-return system (Ref 5).

Control Cables, Fuselage Ceiling

This picture looks forward from the right main door toward the cockpit. On the personnel bench you can see examples of the seat belts provided.

Fuselage Forward Section Interior

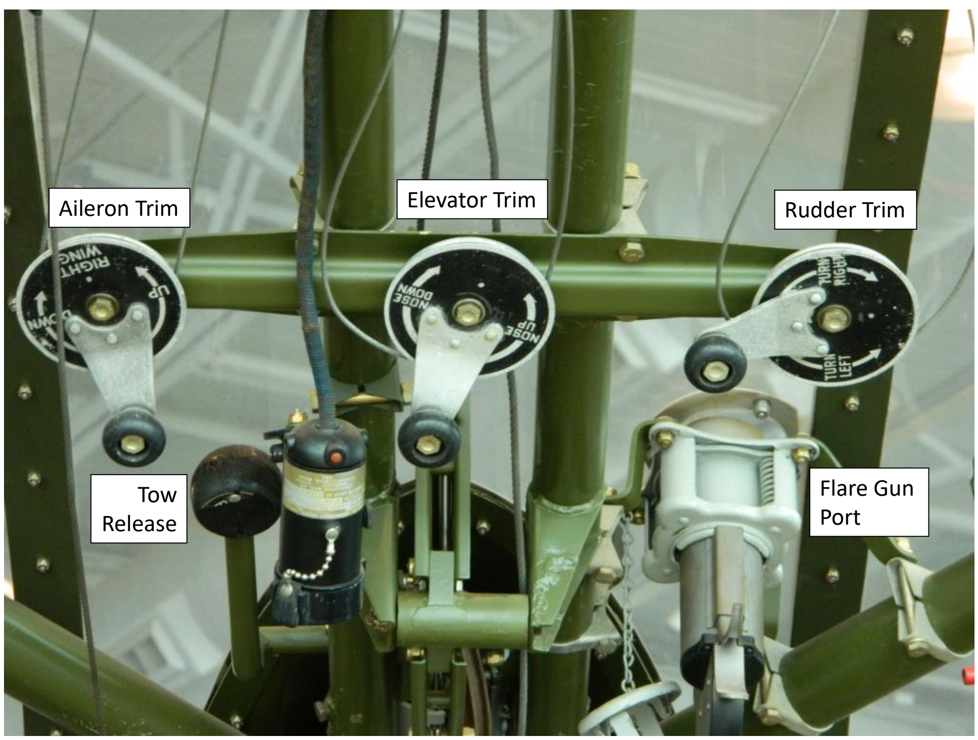
The top of the flight controls. The V-shaped structure was hinged above the 3 pulleys, moving the elevator bellcrank. The three pulleys routed the aileron control cable, from the left side down the left arm to the pilot control wheel, back up the left arm then down the right arm to the copilot control wheel, then back up the right arm and off to the right side.

The yellow and red pull handles on the right side controlled the drag parachute. The red handle deployed the parachute, and the yellow handle jettisoned the opened parachute (Ref 6).

Above the flight control assembly were three trim cranks for (left to right) aileron, elevator, and rudder. The pulleys attached to the cranks moved cables that turned another pulley near the tab. This pulley turned a screw thread on the pushrod to the tab horn. Between the aileron and elevator trim cranks, the black knob is the tow release, with a light fixture to the right. On the right side is a mount for a flare pistol.

One of the drawbacks of the Waco CG-4A was that the nose section, which contains the cockpit area, did not

Top of Flight Control Yoke and Trim Wheels



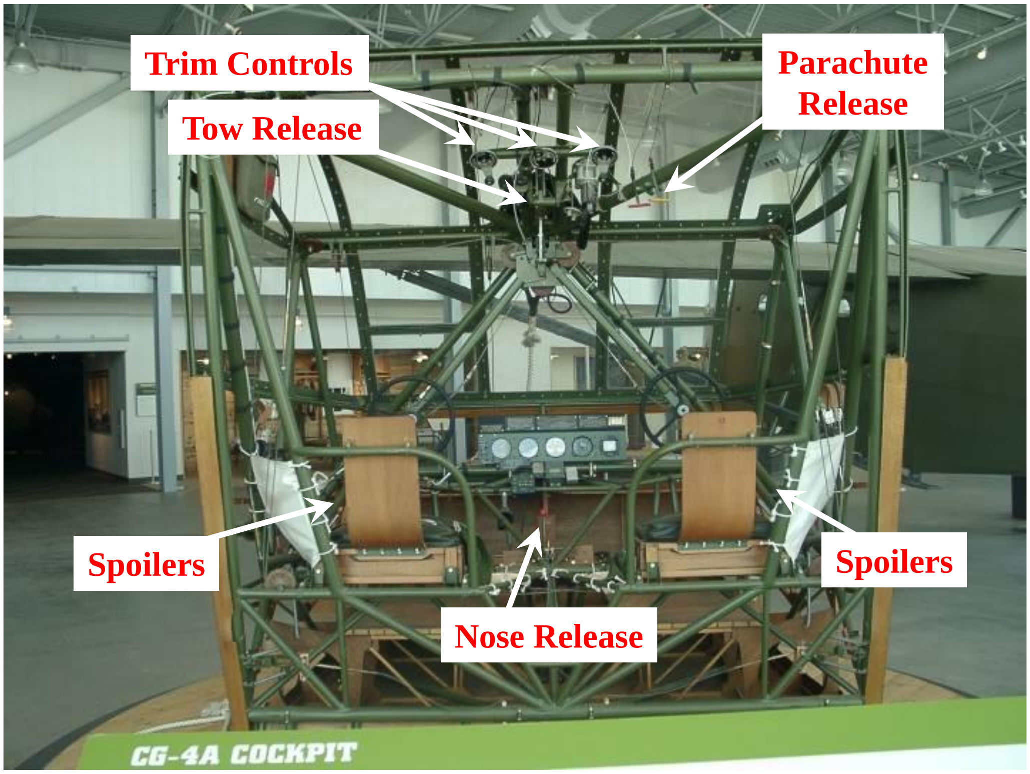
Trim Wheels, Tow Release, and Flare Gun Port

have a lot of structural strength, probably because structural strength comes from structural material and more structural material means more weight. The standard nose of the Waco CG-4A gave very little crash protection to the pilots. As we will see later, in a combat operation, running into something was not only probable, it was inevitable. The Ludington-Griswold Co. of Saybrook CT came up with a different design of the nose section which provided more crash protection. This was known simply as the "Griswold Nose" (Ref 7). I'm pretty sure that this had nothing to do with National Lampoon's Vacation series of movies.

The Griswold Nose also moved the towline attachment point down lower from the top of the windshield to the point where the crash protection structure came to a point. This was reported to improve stability during towing operations (Ref 7). The original tow location pulled mostly through the hinge of the nose section. The lower location of the Griswold tow hitch presumably required some modification of the latches that held the nose section closed, since those latches would now take more loading.

Griswold Nose

The following is a labeled picture of the nose section cockpit area of a Waco CG-4A. All of the controls were connected to the rest of the glider by cables. Because the nose was hinged at the top to swing up for loading and unloading the glider, all of the cables must exit the cockpit over the top hinge tube. This made for some rather interesting cable runs. Lots of fairleads and pulleys, and probably a goodly amount of friction. It must have been fun adjusting and safetying all of the turnbuckles necessary to properly tension all of those cables.



All pictures shown in this article show the dual control wheels. “The right-hand column may be removed if desired in which case the left-hand column may be swung over from the pilot to the copilot” (Ref 1). Full aileron deflection was available with 135 degrees of wheel rotation from center (Ref 5).

The rudder pedals were adjustable fore and aft. Toe brakes were provided only on the left-hand set of rudder pedals. Brakes were only available on the training landing gear.

The instrument panel was very simple, as shown in this graphic from Reference 1. The airspeed indicator was marked in miles per hour, as was common for the time. Knots did not become mostly standard for airspeed until years later. The Turn and Bank Indicator was driven by vacuum supplied by a venturi on the left side of the nose section.

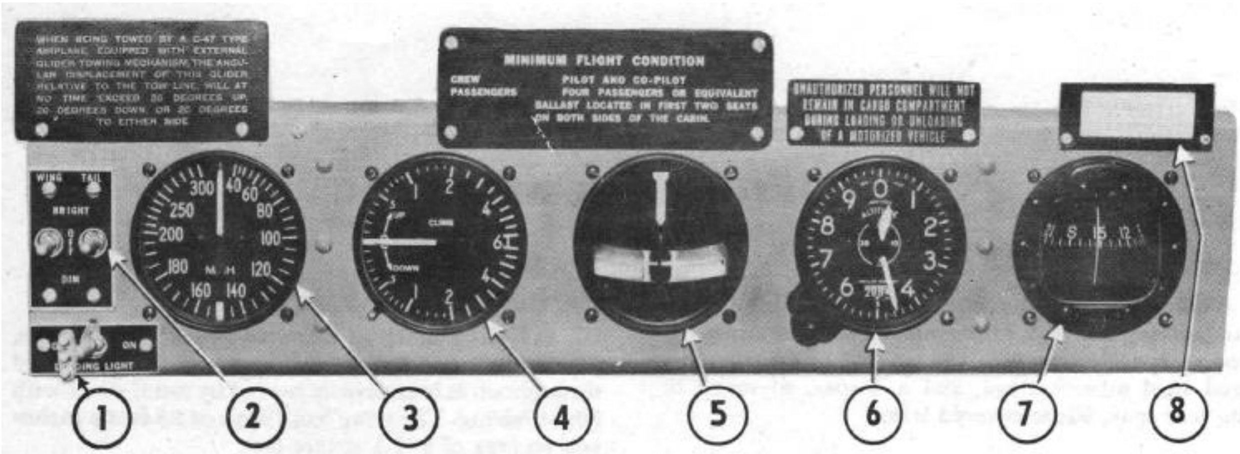


Figure 3—Instrument Panel

1. Landing Light Switch
2. Navigation Light Switch
3. Airspeed Indicator
4. Rate of Climb Indicator
5. Bank and Turn Indicator
6. Altimeter
7. Compass
8. Compass Compensation Card

The instrument panel as shown in the nose section mockup.

Instrument Panel

Above the nose section on the right side was a tripod. This tripod was connected to a cable that ran inside the glider which was used to hold the nose open while loading. If carrying a Jeep, this cable could be connected to the trailer hitch to pull the nose open simply by driving the Jeep out the front.

Mounted on this tripod is an AN5816 Pitot-static tube, just like I have on the Bearhawk. This installation does not appear to be heated as there are no wires running to it, not to mention the only power source in the glider was a 12 volt battery, mostly used to power navigation lights.

One of the challenges with a fabric covered fuselage is how to get access to the interior pieces that need adjusting or servicing. Many fabric airplanes glue rings into the fabric and cover them with metal disks. For larger openings, it was common to sew zippers into the fabric such that areas could be opened up and closed again. The open hole in the picture is access for the elevator torque tube. The zipper in front (to the left) is for access to the elevator horn.

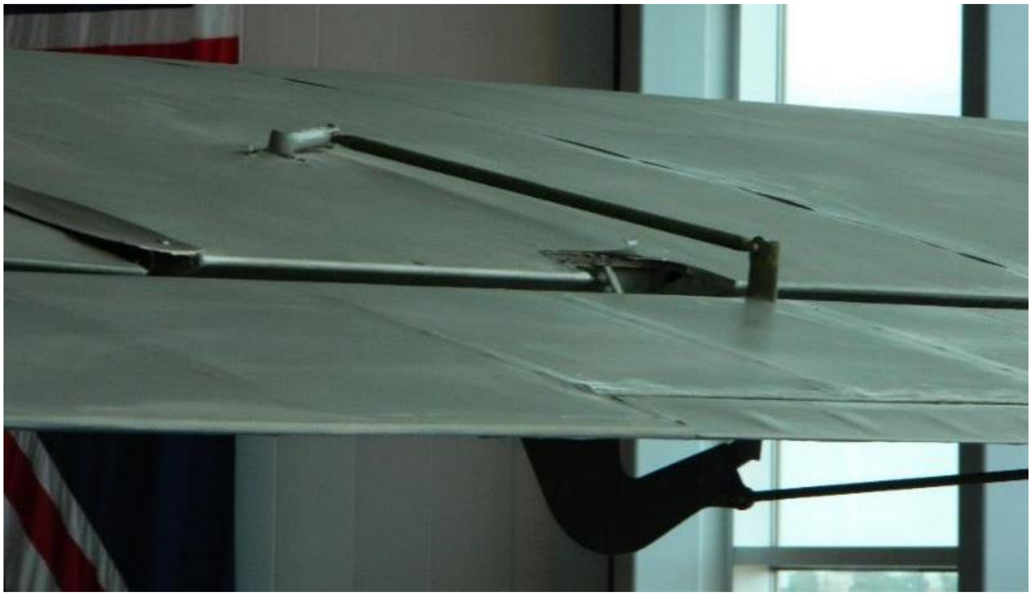
Nose Raising Tripod and Pitot-Static Tube

Zippers for Fabric Access

Wing Construction

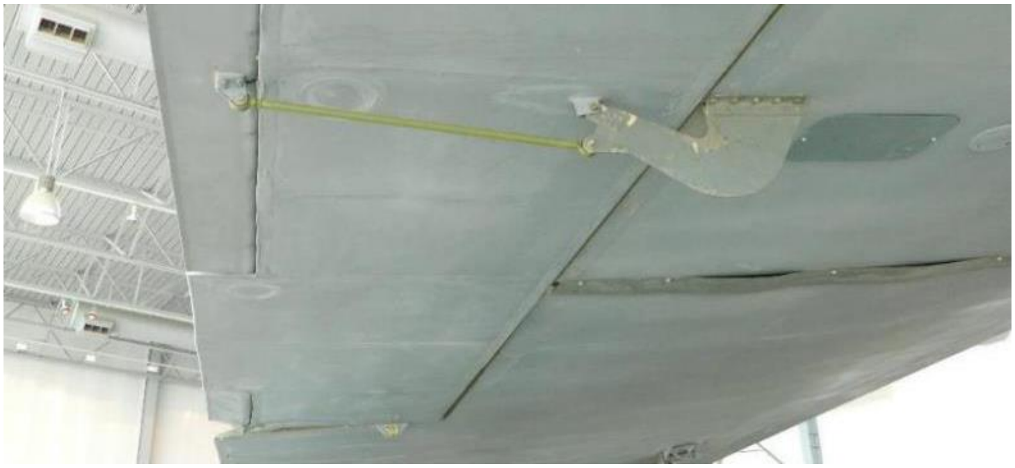
The wings were of wooden construction, using a box beam main spar at 27 percent of the chord and an "I" beam rear spar at about 74 percent of the chord (Ref 5). Plywood covered the leading edge D-section (from the top of the spar around the leading edge and back to the bottom of the spar), with plywood top and bottom skins from the main spar back to the rear spar. The plywood grain was at 45 degrees to the spanwise axis of the wing. The forward spar and the plywood skin around the leading edge formed a closed cell. The top and bottom skins with the forward and aft spar also formed a closed cell. A closed cell has good resistance to torsion, as it is hard to twist a paper towel tube, but cut the tube down one side making it an open cell and it becomes very easy to twist. Thus, these plywood skins provided torsional stiffness, which was augmented by the use of two wing struts per side. The trailing edge (no flaps) and ailerons were fabric covered. The wing struts were round steel tube, covered with a fabric fairing (Ref 1). Reference 8 states that the strut fairing structure had aluminum ribs, but this would seem odd because aluminum was a strategic material. These ribs may have been wood like so much of the rest of the construction.

The aileron control was by an external horn on the top of the wing that actuated a pushrod to the aileron.



Aileron Horn and Push Rod

Because of the size of the ailerons, the control force was reduced by a servo tab, driven by this pushrod connected to the aileron hinge bracket. The aileron trim tab can be seen at the root of the aileron. A contoured lead counterweight is located externally on the leading edge of the aileron providing complete static balance (Ref 5).



Aileron Servo Tab. Note the large setback of the hinge line, well behind the leading edge of the aileron. The aileron stop was provided by the aileron contacting this external hinge support (Ref 5).

This is not a great picture, but it barely shows the spoiler installed on top of the wing.

Right Wing Spoiler

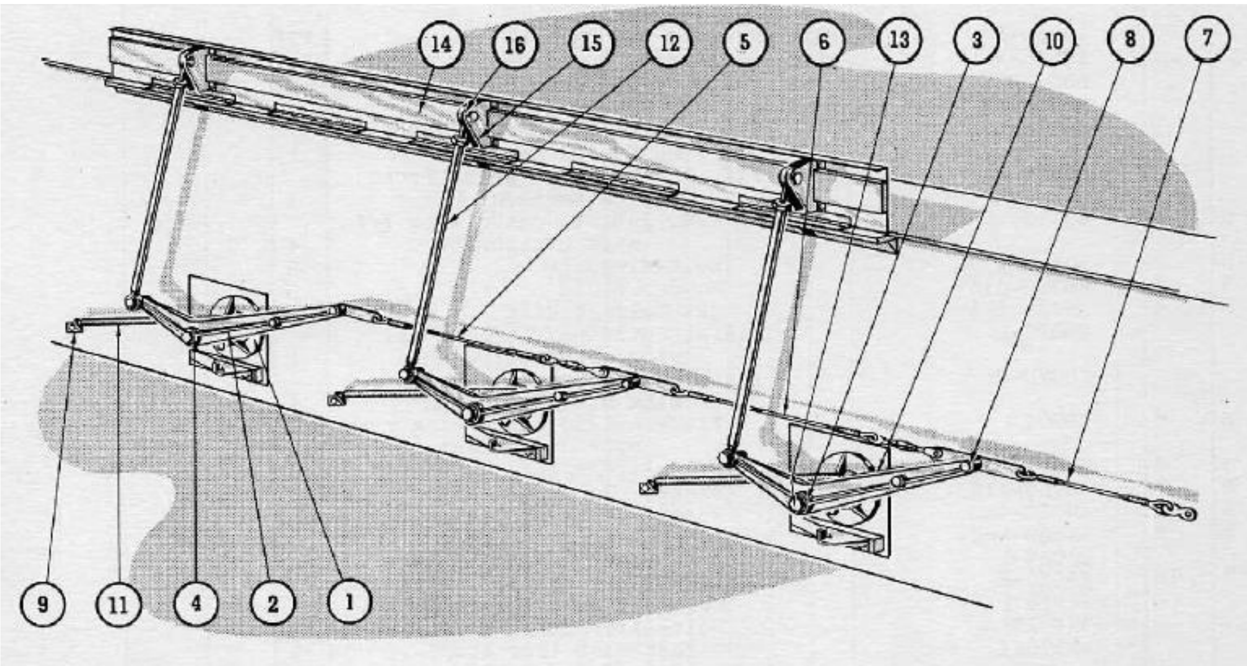


FIGURE 4 SPOILER AND BELLCRANK

Tail Construction

The tail group had a wooden structure, a wooden leading edge, and was covered with fabric. The horizontal stabilizer was held in place with a V-strut on each side. Wires from the horizontal stabilizer up to the vertical stabilizer helped stiffen the vertical stabilizer.

Tail Group

Tail Group

A trim tab was located at the bottom of the rudder.

Rudder Trim Tab

As an additional drag device, some Waco CG-4A gliders were equipped with a tail drag parachute. The tail end of the fuselage was originally rounded, but sometime during 1943 a change order was issued by Wright Field to clip the tail at a 45 degree angle to provide a flat surface on which to mount the parachute (Ref 6).

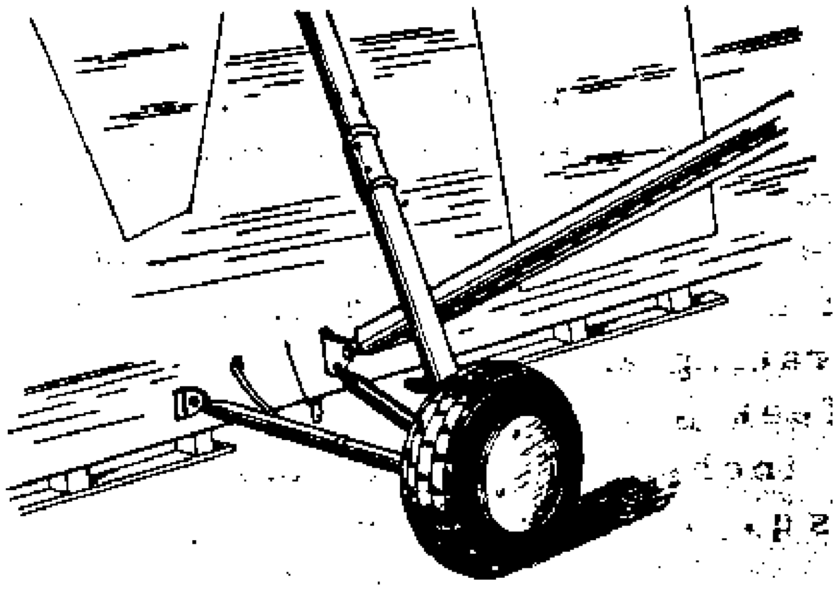
Tail Drag Parachute

This release mechanism was provided to jettison the drag chute after deployment if required. The operation of this release mechanism can be seen in https://youtu.be/ND_MPBwO6UU?si=MRIBbbdDP4A3OE9W starting at 1:08 (Ref 9). Pulling the cable on the top pulled the lever, which slid the tube forward, releasing the catches on the hitch. The wire shown here from hitch jaw to release lever is a museum lock to prevent patrons pushing the release lever and opening the jaws. Such a wire would not be present for flight.

Tail Drag Parachute Release

Landing Gear

The Waco CG-4A could be equipped with two different types of landing gear. Both were of the conventional gear (taildragger) type. The training gear was intended for use during training, and could be used multiple times and was equipped with brakes. The wheels were mounted on a tripod of struts just in front of the wing strut. The tripod provided a greater width (tread) for the landing gear for better lateral stability on the ground.



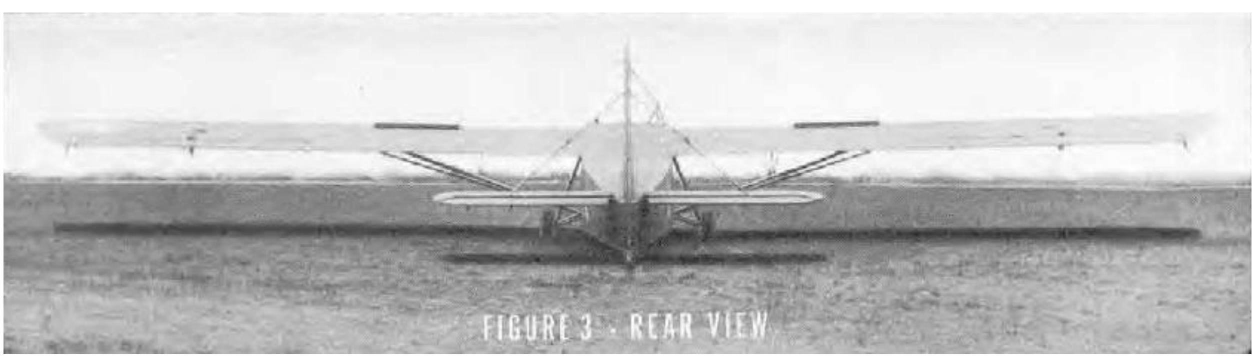
Training Landing Gear

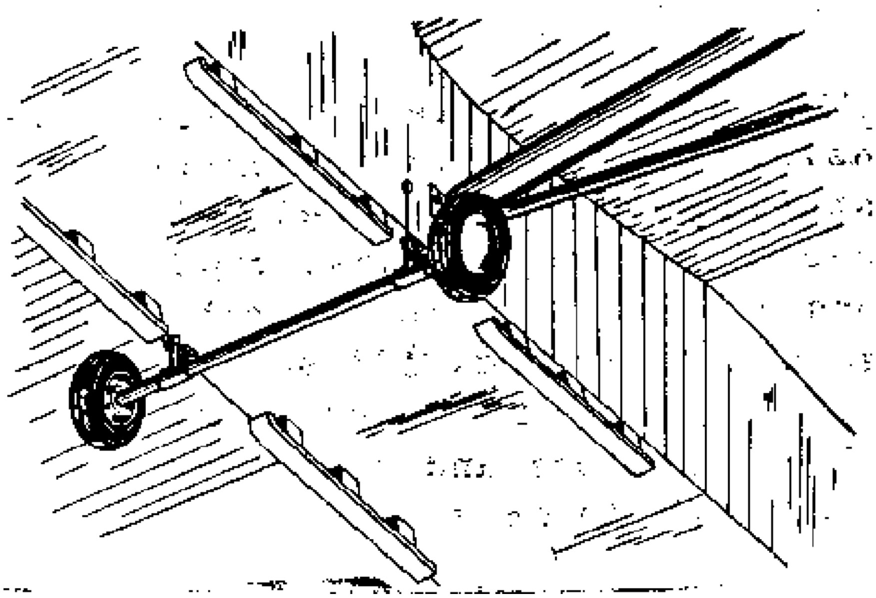
Fuselage Showing Training Gear

Closer view of Training Landing Gear Tripod attachment

As originally conceived, a tactical landing gear would be fitted to the gliders when being deployed into combat. This landing gear was a simple tube across the bottom of the fuselage with wheels and tires on each end. This landing gear was intended to be jettisoned after takeoff, reducing weight and drag. The subsequent landing would be made on the four skids mounted under the fuselage. However, the skids provided essentially no directional control, being just as happy to slide sideways as they were to slide in the intended direction. Thus, in operation, crews found that they could make better landings under better control if the gear was left in place (Ref 8). This was because with the wheels in place, the glider could be steered to some degree on the ground.

If the tactical landing gear was jettisoned, the useful load was increased by 277 pounds, the weight of the training gear which would not be installed. The tactical landing gear weighed 168 pounds, so if the tactical landing gear was retained, the useful load increase (compared to training gear) was 109 pounds (Ref 5).





Tactical Landing Gear

For an emergency stop, the guidance was to touch down, apply the brakes evenly, then ease the controls forward until the nose skids contacted the ground. The combined action of the brakes and skids maximized the deceleration (Ref 2). "On sod terrain a stop can be made in approximately 50 yards" (Ref 1).

In addition, a part of the glider concept of operations would grow to include the idea of recovering the gliders for reuse after the front lines had moved away from the gliders. Techniques were developed (discussed later) to fly relatively undamaged gliders out of the fields back to friendly bases for reuse. To manage the takeoff in the field, the gliders really needed some sort of wheeled landing gear. Review of videos of gliders being retrieved show that the tactical gear was still in place, having not been jettisoned. Other gliders were shown with the "training gear" as they were being recovered. Thus, we can conclude that in practice, the gliders flew into combat with whatever wheel set was originally installed during assembly. Remember that the training gear was heavier and had more drag, but it provided brakes.

Manufacturers

At the beginning of World War II, there was a rush to create combat glider designs. The major aircraft manufacturers were at full capacity designing and building traditional military aircraft, such as fighters, bombers, and cargo aircraft. Thus, glider design was limited to smaller aircraft manufacturers and companies who had never designed or built an aircraft before (Ref 10). Many designs were proposed, but the only reasonably successful design came from the Waco Aircraft Company of Troy Ohio. This was designated the CG-4A by the US Army Air Forces, and called Hadrian by the British.

The demand for combat gliders was so great that Waco Aircraft Company could not build sufficient numbers. The USAAF contracted with 15 other companies to build the design under license. Some of these companies were experienced aircraft builders, and others were not, such as Gibson Refrigerator, which built wooden refrigerators and caskets. None of these companies were major aircraft manufacturers. The success rate varied at the different contractors, as well as the cost. The design was relatively complex, with no less than 70,000 individual parts per glider. National Aircraft Corporation, despite their name, didn't seem up to the task.

Waco CG-4A Manufacturers (Ref 11)

Manufacturer	Location	Number Built	Cost Each
Babcock Aircraft Company	DeLand FL	60	$51,000
Cessna Aircraft Company (subcontracted to Boeing Wichita)	Wichita KS	750	-
Commonwealth Aircraft	Kansas City KS	1470	-
Ford Motor Company	Kingsford MI	4190	$14,891
G&A Aircraft	Willow Grove PA	627	-
General Aircraft Corporation	Astoria, Queens, NY	1,112	-
Gibson Refrigerator	Greenville MI	1,078	-
Laister-Kauffman Corporation	St. Louis MO	310	-
National Aircraft Corporation	Elwood IN	1	$1,741,809
Northwestern Aeronautical Corporation	Minneapolis MN	1,510	-
Pratt-Read Tools	Deep River CT	956	-
Ridgefield Manufacturing Company	Ridgefield NJ	156	-
Robertson Aircraft Corporation	St. Louis MO	170	-
Timm Aircraft Company	Van Nuys CA	434	-
Waco Aircraft Company	Troy OH	1074	$19,367
Ward Furniture Company	Fort Smith AR	7	$380,000
Total		13,905	

Speed and Load Limitations

The normal tow speed for the CG-4A was around 120 mph (104 knots) (Ref 8). While not stated explicitly, based on context and other clues from other sources, it is assumed that this was calibrated airspeed. Then again, since the gliders were generally towed at low altitude, probably under 2000 feet AGL, it really doesn't matter if this is calibrated or true airspeed.

The normal cruise speed for a C-47 or C-53 was around 161 mph (140 KCAS) (Ref 12). It is quite reasonable to think that a C-47 towing a glider would be slowed down from 161 mph to 120 mph.

The Maximum Design Speed was 150 mph (130 KCAS). This airspeed would never be reached while on tow, but was possible if diving at the landing zone. Reference 11 states that you should not exceed 150 mph "due to the possibility that windshield panels may blow in and other failures may occur".

The nominal Empty Weight of the glider was 3600 pounds. With a Design Gross Weight of 7500 pounds, that would mean a maximum payload of 3900 pounds. The Willys quarter-ton Jeep weighed about 2200 pounds, leaving 1700 pounds for the pilots and Jeep crew, which at 250 pounds apiece would be 6.8 men and equipment. There are no documented cases of a crew including 0.8 men, so they probably went with an integer amount.

The Emergency Maximum Gross Weight was 9000 pounds, which left 5400 pounds for payload. The Clarkair Crawler Model CA-1 Tractor was small bulldozer/tractor that would fit in the CG-4A. This tractor only weighed 5000 pounds (Ref 13), meaning that with two pilots (about 400 pounds), a CG-4A carrying a CA-1 tractor would be at Emergency Gross Weight.

For center of gravity considerations, in order to carry large payloads up front, the empty center of gravity was fairly far aft. Per the flight manual documents (Ref 1 and 2) and placards on the instrument panel, the minimum load for flight was a pilot, a copilot, and 600 pounds of ballast (consisting of 300 pounds behind each cockpit seat) (Ref 2). Reference 1 states a minimum load of a pilot, a copilot, and four passengers on the forwardmost two seats on each side.

Types of Cargo

Of course, the Waco CG-4A could be loaded with anything needed in the field, such as C-Rations and ammunition, as long as there was space and payload weight available. Following is a list of some of the larger items that could be carried. Remember that there was nominally 3900 pounds of payload available, of which about 200 pounds was reserved for the pilot. Emergency payload available was 5400 pounds, minus 200 pounds for the pilot.

13 Fully Equipped Troops

***Operation Rubidoux Sundown VI*, 21 February 1998 (http://eaa1000.org/9803nltr.pdf#page=2)**

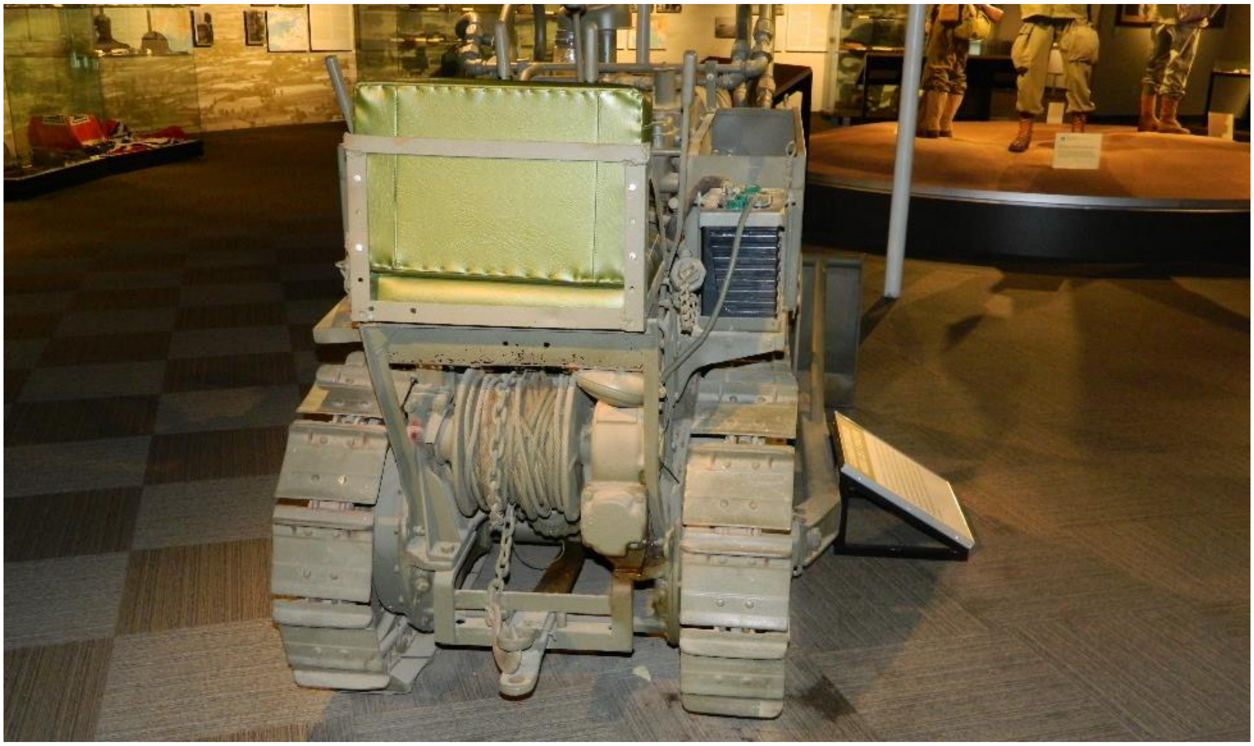
Here we see a collection of 12 ***Project Police* Officers** plus one captured EAA Chapter 1 President. While these ***PPOs*** do not appear to be "fully equipped", they could be. Estimating 200 pounds per ***PPO*** plus 50 pounds each of equipment, this motley collection would weigh in at 3250 pounds. The limiting factor preventing adding another ***PPO*** was most likely lack of additional seats, and we don't play "musical chairs" in combat gliders. Three troops would sit on each of the four wooden benches. The thirteenth troop sat on a fold down chair in front of the left main crew entry door.

The count of 13 troops does not include the pilot and copilot.

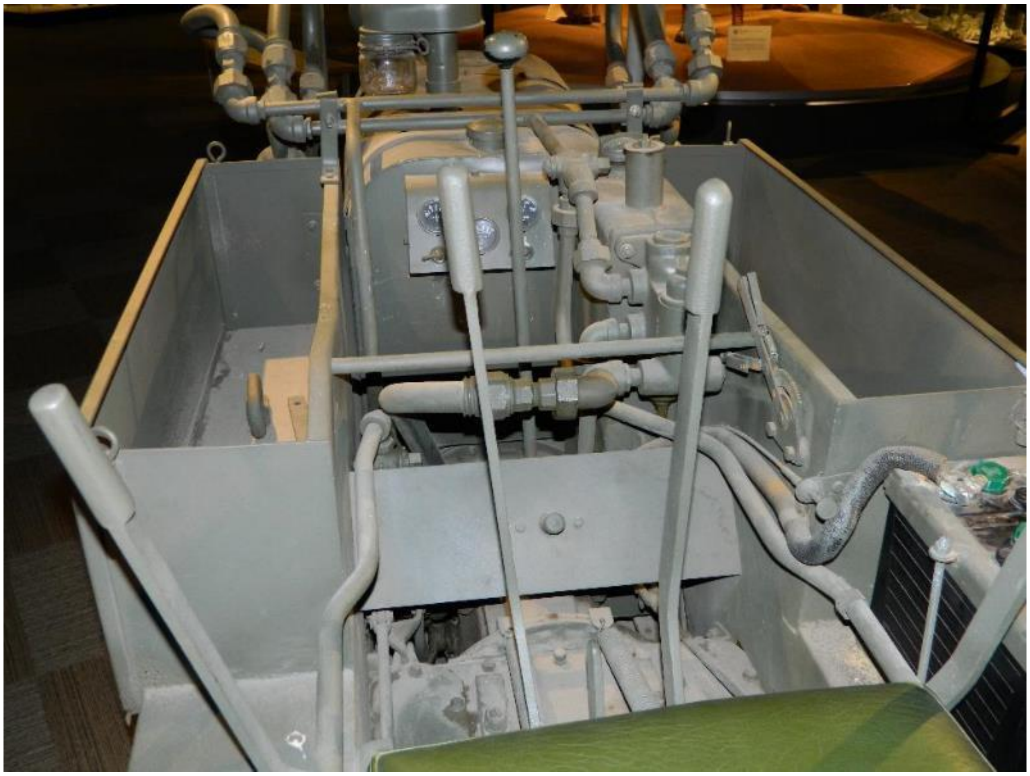
Clarkair Crawler Model CA-1 Tractor

As mentioned before, this airborne bulldozer would fit in a CG-4A, but it put the glider right at its Emergency Gross Weight. The tractor nominally weighed 5000 pounds.

From the Silent Wings Museum placard "Used primarily as a bulldozer, this rugged tractor was small enough to be carried in a CG-4A glider. Due to its weight, the CA-1 was not the glider pilots' favorite cargo. However, it was an essential piece of equipment that allowed airborne engineers to clear landing strips for larger aircraft. The CA-1 was developed by the Clark Equipment Company, which produced a prototype and 13 production units. The Cleveland Tractor Company produced approximately 145 more of the vehicles for the Army." (Ref 7)



The tractor also came with a large winch on the back.

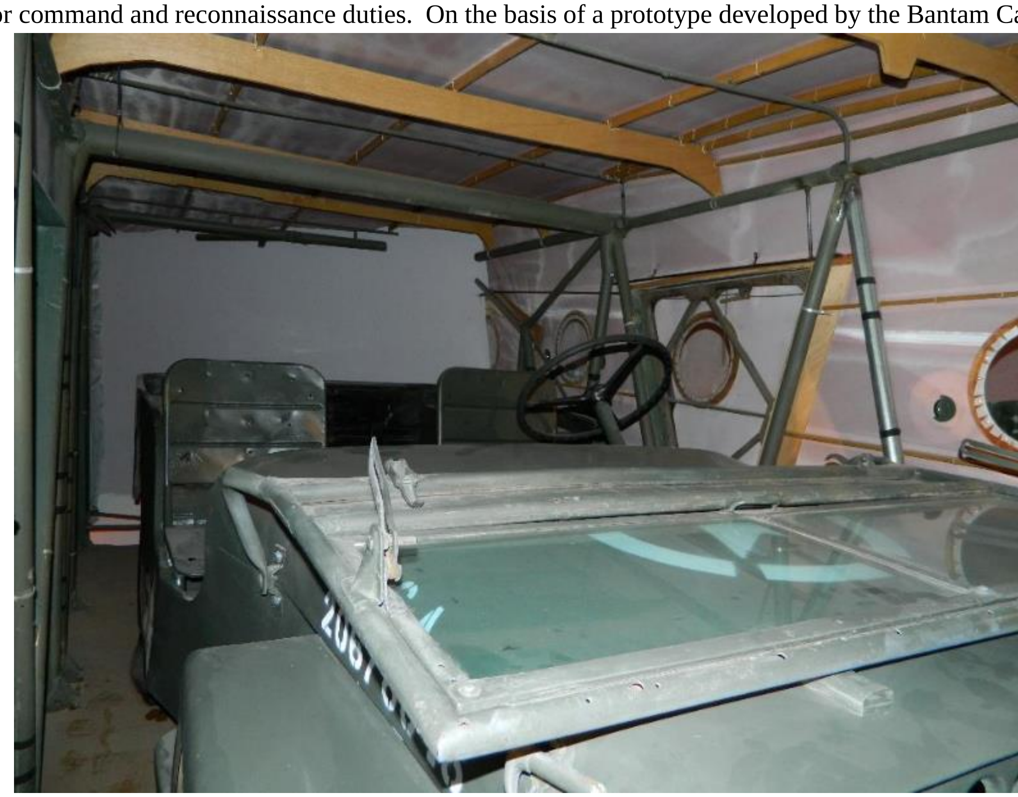


No fancy creature comforts here or any fancy cockpit. To keep the weight down, anything not absolutely necessary was left off.

Quarter-Ton 4x4 Truck (Jeep)

The Quarter-Ton 4x4 Truck, commonly called the "Jeep", whether built by Ford or Willys, seems to be the primary payload that the Waco CG-4A was designed around. In any promotional material or newsreels, the cargo is either a Jeep or 13 troops. The glider was specifically designed so that the Jeep would open the nose as it drove out (more on that later). A typical Jeep weighed about 2200 pounds, which left some payload weight for the crew and other equipment.

From the Silent Wings Museum placard "The Jeep was developed in response to the Army's call for a fast, light, all-terrain vehicle for command and reconnaissance duties. On the basis of a prototype developed by the Bantam Car Company, the Army established design criteria for the new vehicle. An accelerated development program was initiated, resulting in the approval of a design submitted by Willys Overland. Production contracts were awarded to Willys Overland and the Ford Motor Company. From 1941 to 1945, the two companies manufactured more than one million of the all-terrain, all-purpose vehicles." (Ref 7)



The Jeep above is shown in a forward fuselage mockup (note the lack of a tail section). The windshield had to be in the lowered position for loading and unloading.

The Waco CG-4A glider came with these built-in ramps for the Jeep. These ramps also worked for other wheeled vehicles, such as the trailer or 75mm howitzer. These ramps pivot up to allow the nose to close.

There is reason to believe that the Waco CG-4A was specifically sized to carry the Jeep, with just enough clearance for crew members to move around the Jeep to secure it. This table shows the clearance around the Jeep in the cargo compartment.

	Cargo Compartment (Ref 5)	Willys MB Jeep (Ref 14)	Clearance
Length	159 inches	132 inches	27 inches
Width	72 inches	62 inches	10 inches
Height	65 inches	69.75 inches/52 inches	13 inches

FIGURE 4 · THREE-QUARTER FRONT · LEFT

Quarter Ton Trailer

From the Silent Wings Museum placard "Manufactured by the Bantam Car Company and Willys Overland, the 1/4 Ton Trailer was designed to carry a wide variety of loads over almost any terrain. Pulled by a Jeep, the 1/4 Ton Trailer carried food, ammunition, gasoline, fuel, medical supplies, and practically anything else that was needed in combat." (Ref 7) Empty weight of the trailer was 572 pounds. Trailer payload was 1000 pounds.

M8 75mm Howitzer

From the Silent Wings Museum placard "The M1 Pack Howitzer, which was introduced into service in the 1920s, was modified for use by airborne forces in World War II and re-designated as the M8 75mm Howitzer. The M8 could fire a wide variety of shells including high explosive, anti-tank and smoke. Small enough to be carried in a glider, and light enough to be towed by a jeep, the M8 was an ideal artillery piece for the highly mobile airborne infantry units." (Ref 7)

The M8 75mm Howitzer weighed 1440 pounds. This left plenty of payload capacity to also carry 27 rounds of ammunition and six troops as the gun crew.

37mm Anti-Tank Gun

The 37 mm gun M3 was a dedicated anti-tank gun introduced in 1940. At a weight of 912 pounds, it was small enough and light enough to be carried in a Waco CG-4A and be towed by a Jeep. Initially effective, the inability of the 37mm round to penetrate the frontal armor of mid-war tanks severely restricted the anti-armor capabilities of units armed with them. (Ref 15)

Loading the Waco CG-4A

An Army training film from WWII called *Basic Training of Glider Borne Troops* is available on YouTube at https://youtu.be/JenPV5HtFfU?si=MwT70t24zeNc0Drv (Ref 16). This wonderful film shows how to load the 1/4 ton trailer, the 1/4 ton truck (Jeep), the M8 75mm Howitzer, and the 37 mm Anti-Tank Gun.

You'll also learn wonderful things, such as the ring on the trailer that goes on the pintle hook of the Jeep is called a "Lunette", which is from the French, literally meaning "small moon". Also check out the knot called a "Baker Bowline" which looks incredibly useful but was not in the list of knots in my Boy Scout Handbook.

Raising the Nose

As shown in Reference 16, the nose was released by moving a lever between the pilots to the forward position. This pulled cables that pull the over-center releases on both sides at the bottom of the nose. A minimum of two soldiers grabbed the outside of the nose and lifted it up. Another soldier inside the glider moved the nose lock as the nose came up. The lock was a simple flat plate around a tube with a hole slightly bigger than the tube. As the lock moved rearward, it pulled a cable connected to the tripod on top of the nose. With tension on the cable, the lock twisted around the tube, jamming into place and holding the nose up by the cable. For additional safety, a shackle on the end of the cable was clipped around a fuselage tube to hold the nose up if the lock should slip.

Diorama showing the nose being lifted. White arrow shows where the museum has replicated the common occurrence of impacting a tree upon landing

After lowering the nose, the release lever between the pilots was moved back to its original position, but this only put slack in the cables that released the latches. The latches on each side were manually re-engaged.

If the cargo load was a Jeep, an alternate method could be used to unload the Jeep. The shackle on the end of the cable to the tripod on the nose was attached to the pintle hook on the back of the Jeep. The lashings on the Jeep were removed. The nose release lever between the pilots was pushed forward, releasing the latches. The Jeep drove forward, pulling the cable, which pulled the nose up, as shown in the following illustrations.

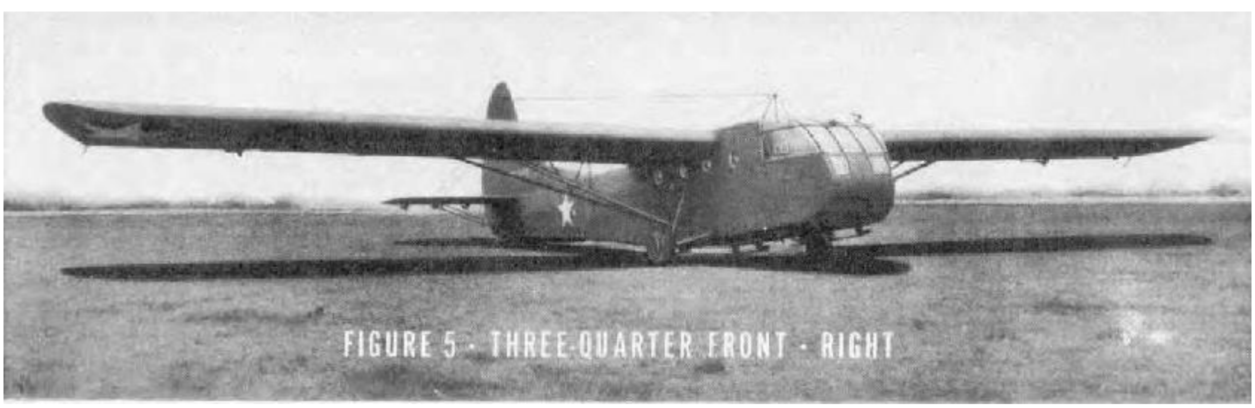


FIGURE 5 · THREE-QUARTER FRONT · RIGHT

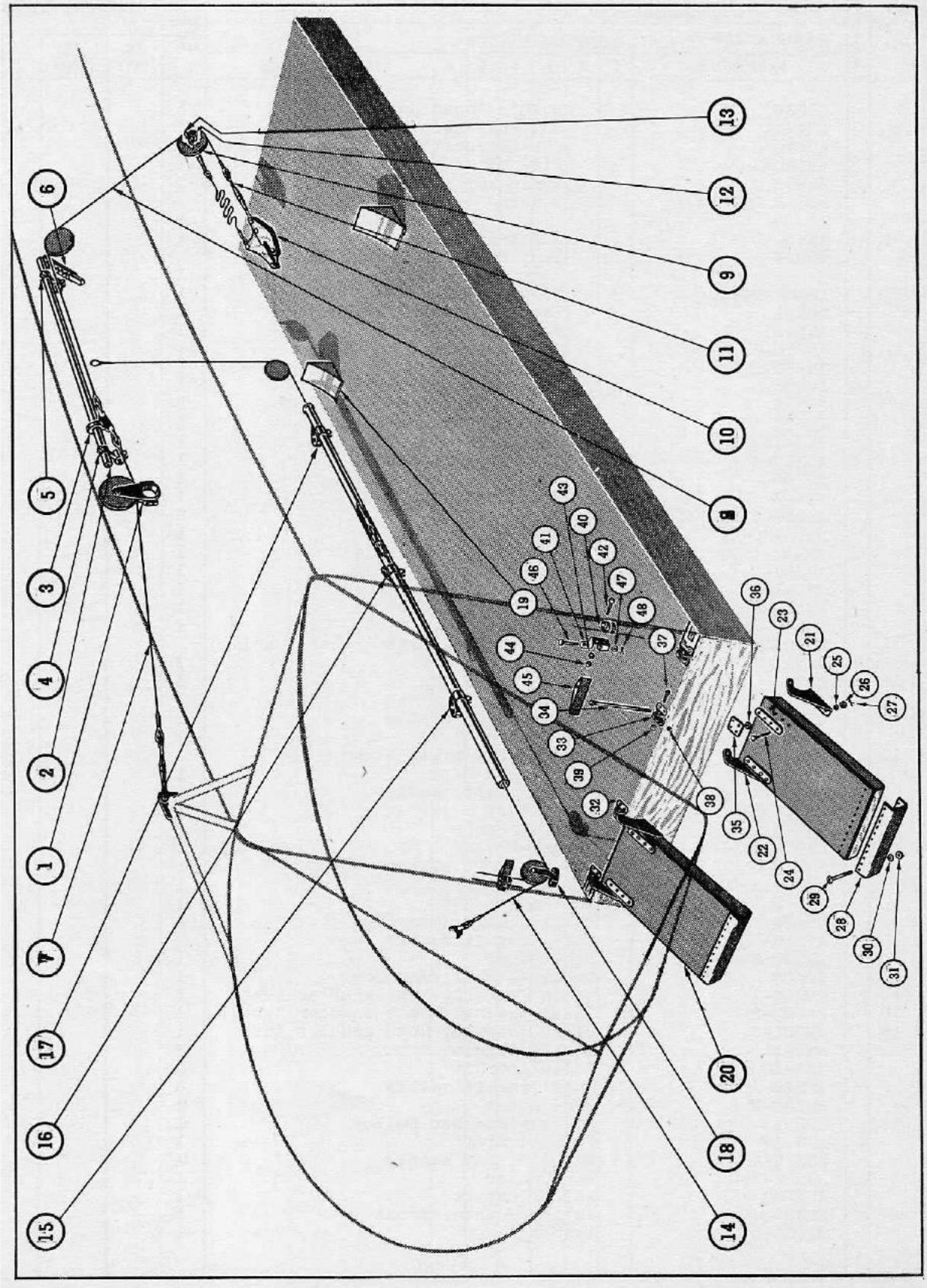
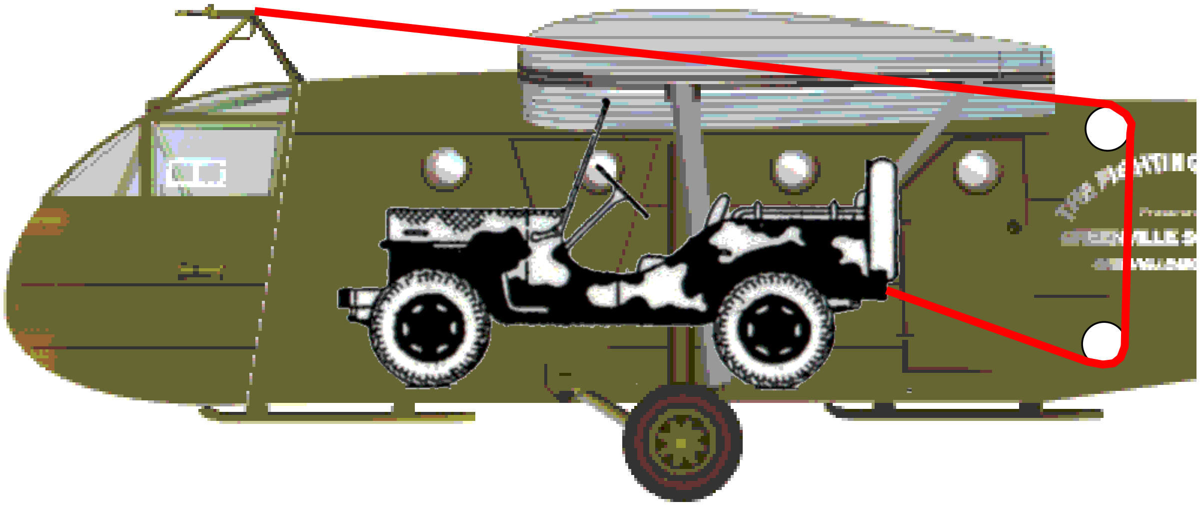
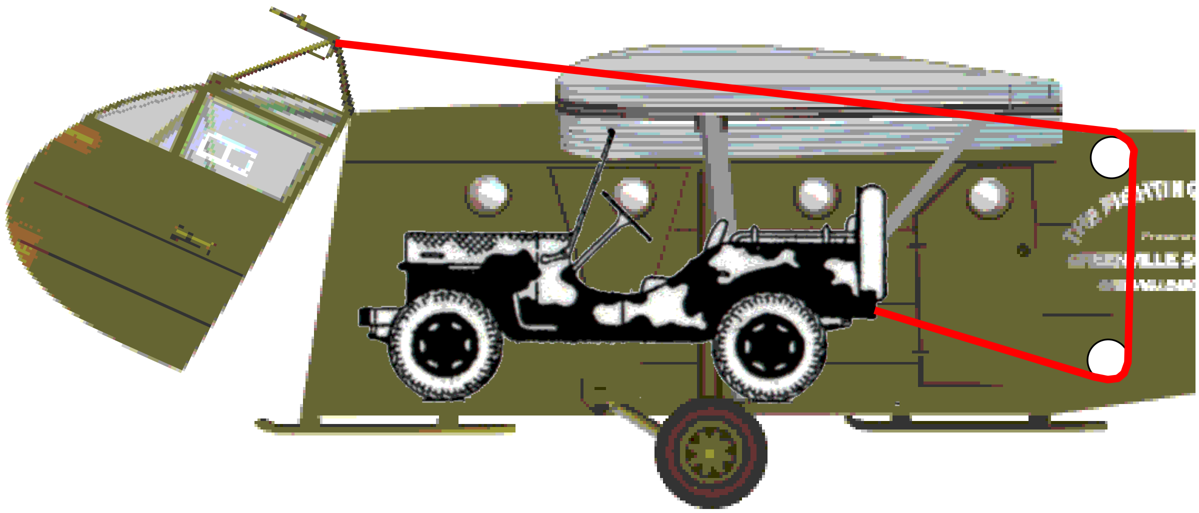
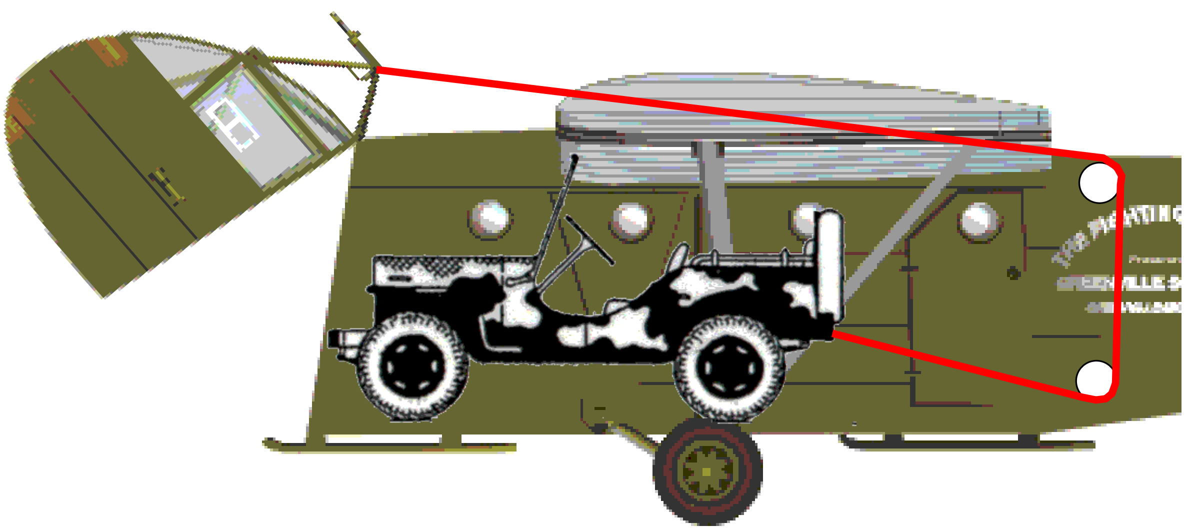
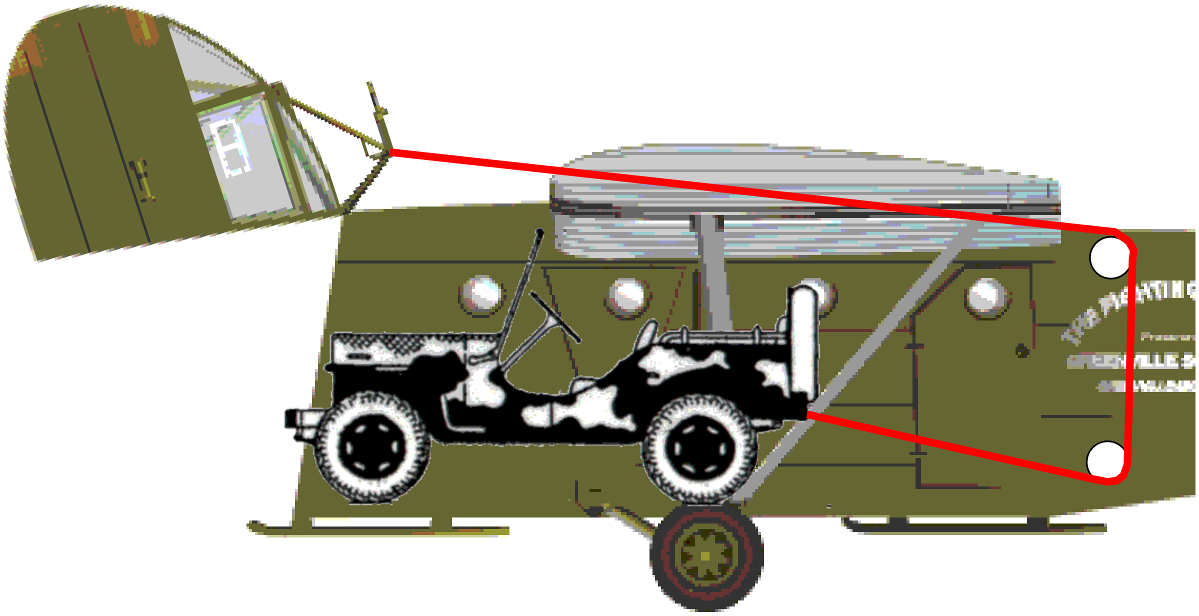


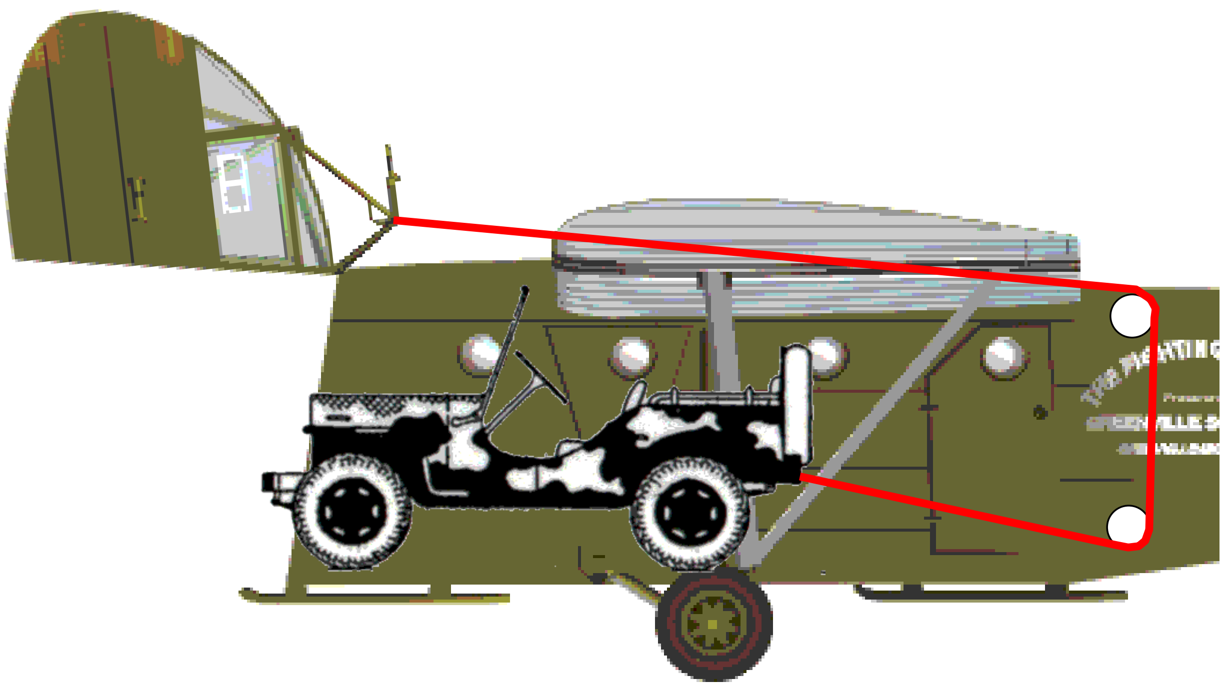
FIGURE 27 NOSE LIFTING DEVICE AND RAMP











When the nose was fully open, a cable connected to the shackle release went taught and released the shackle. The cable lock locked the nose open and the Jeep drove down the ramps and away from the glider. This can be seen in Ref 16 starting at 18:11.

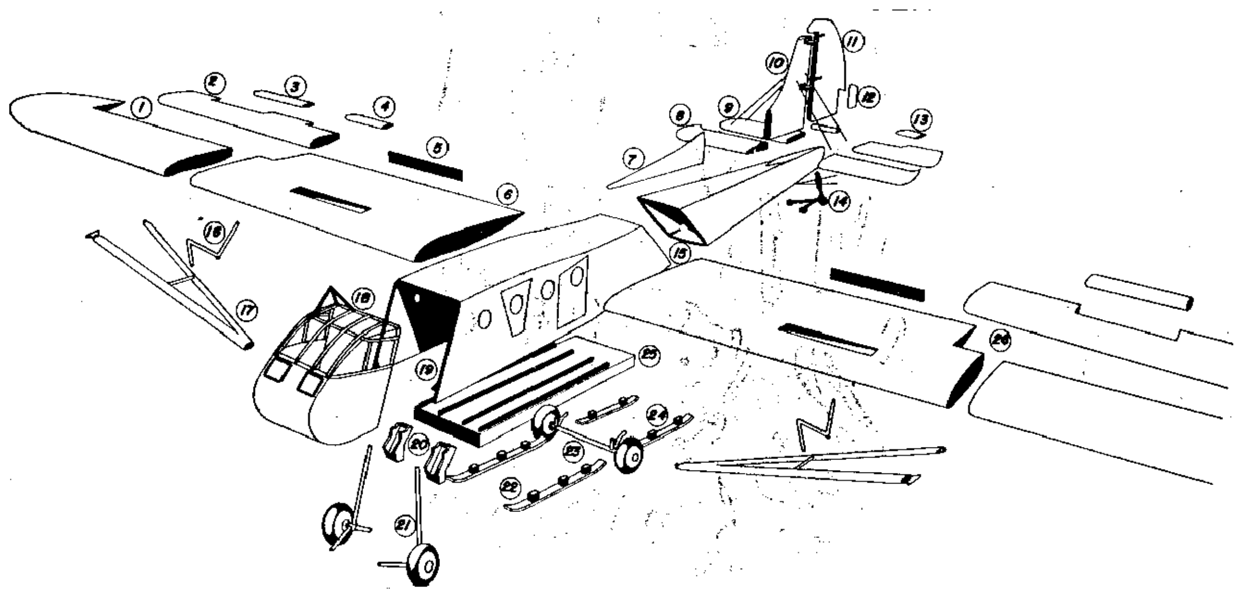
Of course, the center of gravity location after loading was just as critical for the Waco CG-4A as for any other aircraft. Information was provided for calculating the cg location, and for common loads instructions were given for where to locate men and equipment. As a final check, Reference 2 gives the following guidance: “A rough method of checking the CG position of the loaded glider is to see whether it balances on the landing gear. The gear is centered at Station 206.6, near the middle of the CG range. To test this, have two men lift the tail of the glider after it is loaded. If the aircraft is tail-heavy, they will have difficulty in lifting it. If it is nose-heavy, the tail will have a tendency to fly up.”

Waco CG-4A on display overhead with a C-47 at the National Museum of the US Air Force

Ground Transport

Given the large size difference between the TPS gliders and the Waco CG-4A, it is not surprising that they would have very different ways of moving them around on the ground. While the TPS gliders typically just stay assembled on the flight line, it is possible to disassemble each one and load it on a trailer, assuming such a trailer was available. Such a trailer, while rather long, can easily be pulled by a pickup truck such as a Ford F-150 or larger.

The Waco CG-4A was big enough that to be moved by ground transportation it was disassembled and packed into five separate large crates. Each wing panel breaks into two parts. Each tail surface is removeable. The fuselage disassembles into three parts.



Waco CG-4A Parts Breakdown for Packing

World War II Glider Troop trying to figure out how to assemble all of the various components

These shipping crates, or boxes, were built with the finest wood available to U.S. Army Specification No. 23-78-A, dated October 5, 1942. Clearly somebody's job during the war was to write specifications on how to build shipping containers. This table shows the size and weight of each box, along with what was packed in each box.

Box	Length	Width	Height	Contents	Weight (pounds)
1	8'10"	7'2"	5'9"	Fuselage nose section	1800
2	24'3"	7'5"	8'3"	Fuselage midsection (with landing skids attached) Training gear, Loading ramps, Benches (installed) All equipment installed, Batteries (radio and storage) Fairing strips	5200
3	24'3"	6'10"	6'11"	Fuselage tail section, Dorsal fin, Fin and rudder assemblies Stabilizer and elevator assemblies (two) Wing struts (two), Wing jury struts (two), Tail brace wires Tactical landing gear	4400
4	17'2"	4'10"	11'7"	Outboard wind panels and ailerons	3750
5	25'5"	4'4"	11'7"	Inboard wing panels with spoilers installed	5375

Each glider had an empty weight of approximately 3600 pounds. The total shipping weight based on the table above was 20,525 pounds. That means that each 3600 pound glider was delivered in 16,925 pounds of shipping material.

The following pictures from Reference 5 show how the inside of each box would have looked when packed.

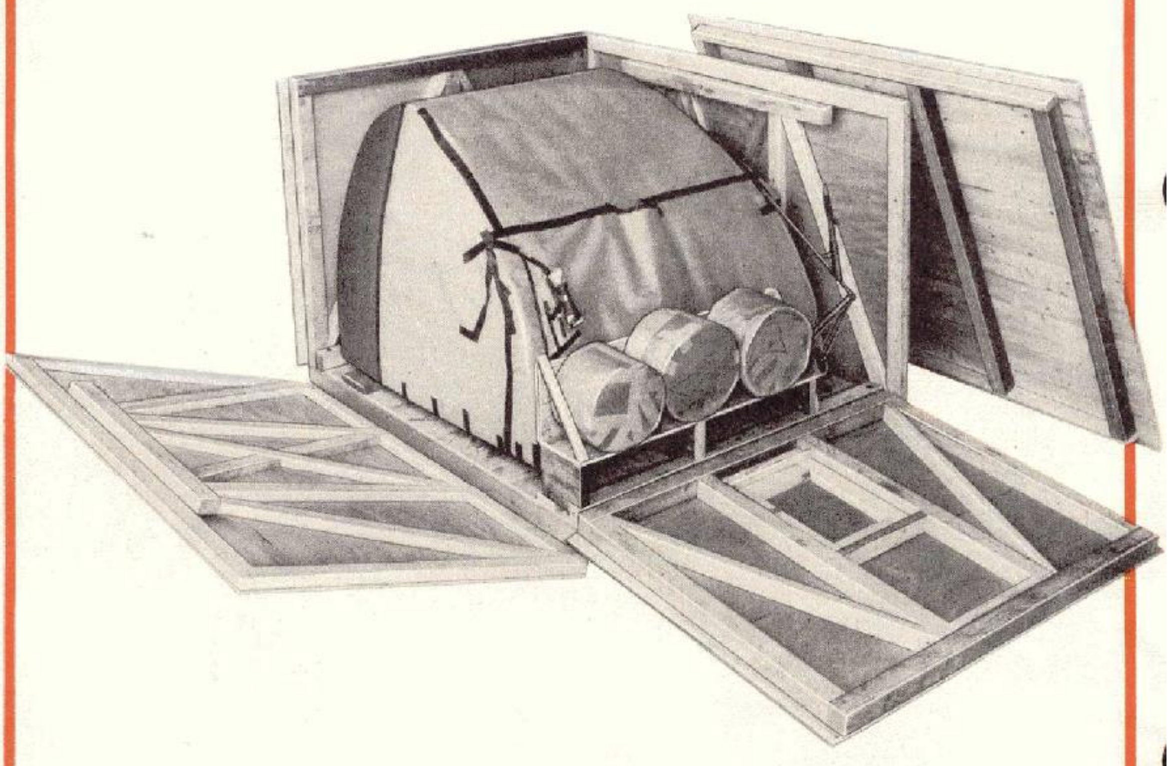


FIGURE 10 - FUSELAGE NOSE SECTION

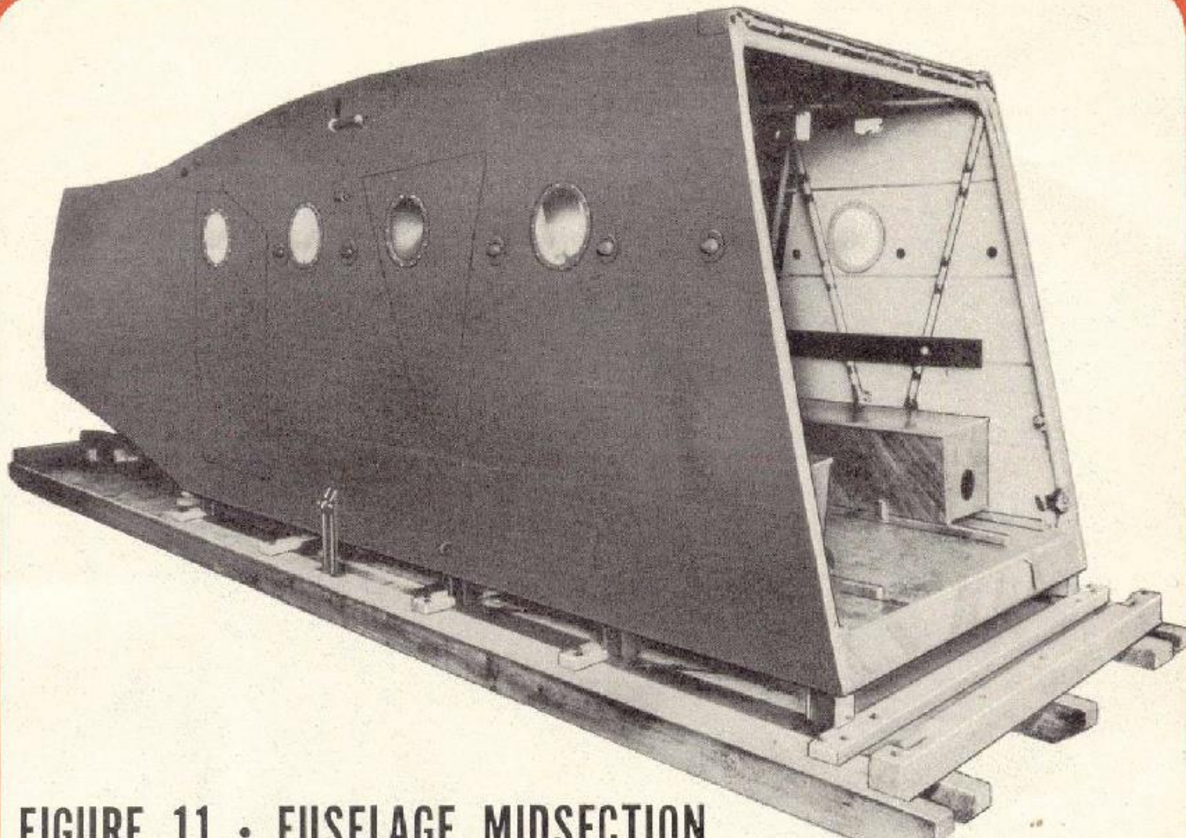


FIGURE 11 · FUSELAGE MIDSECTION

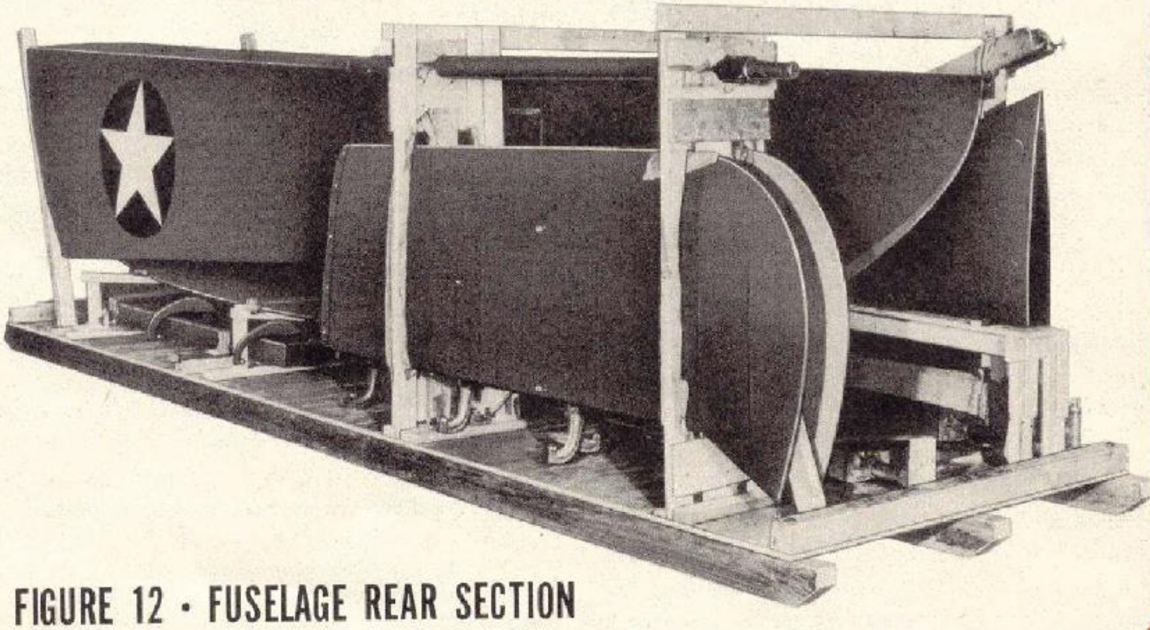


FIGURE 12 · FUSELAGE REAR SECTION

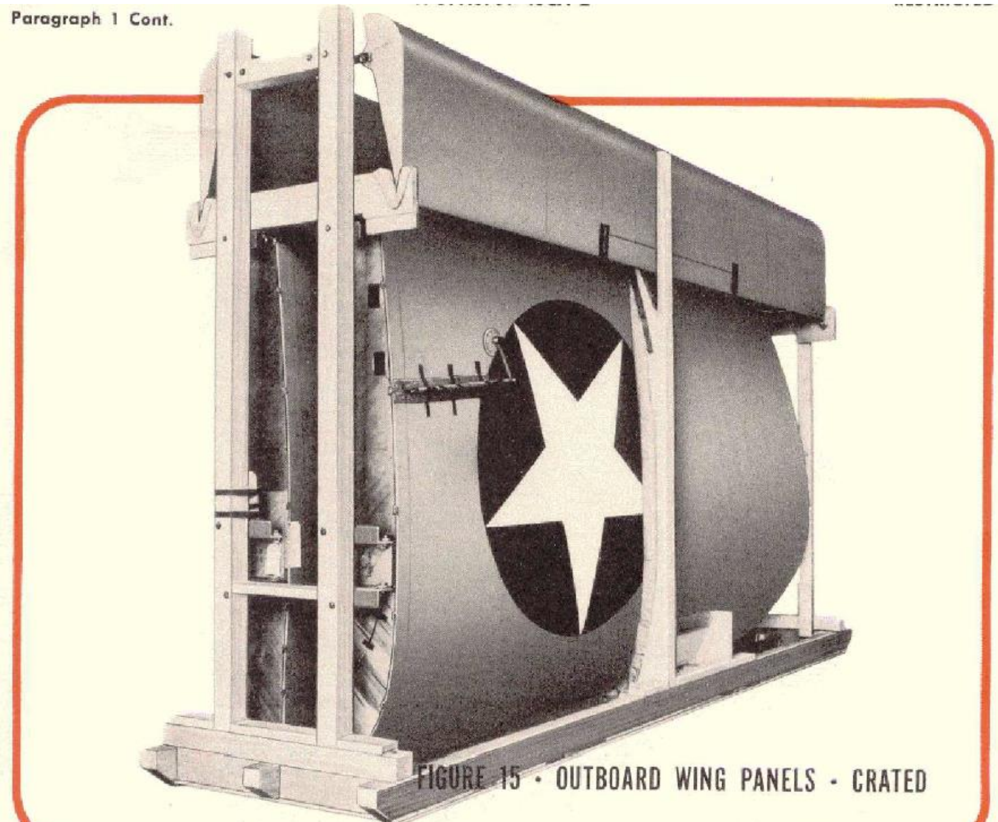


FIGURE 15 · OUTBOARD WING PANELS · CRATED

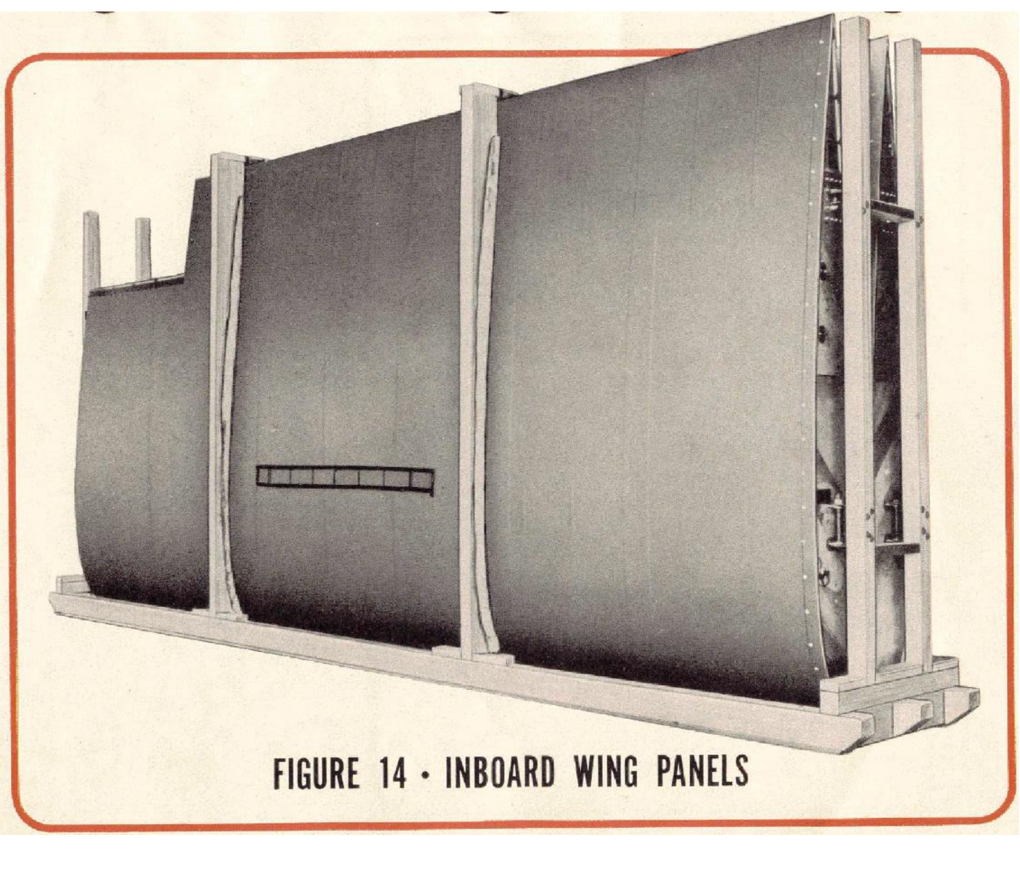
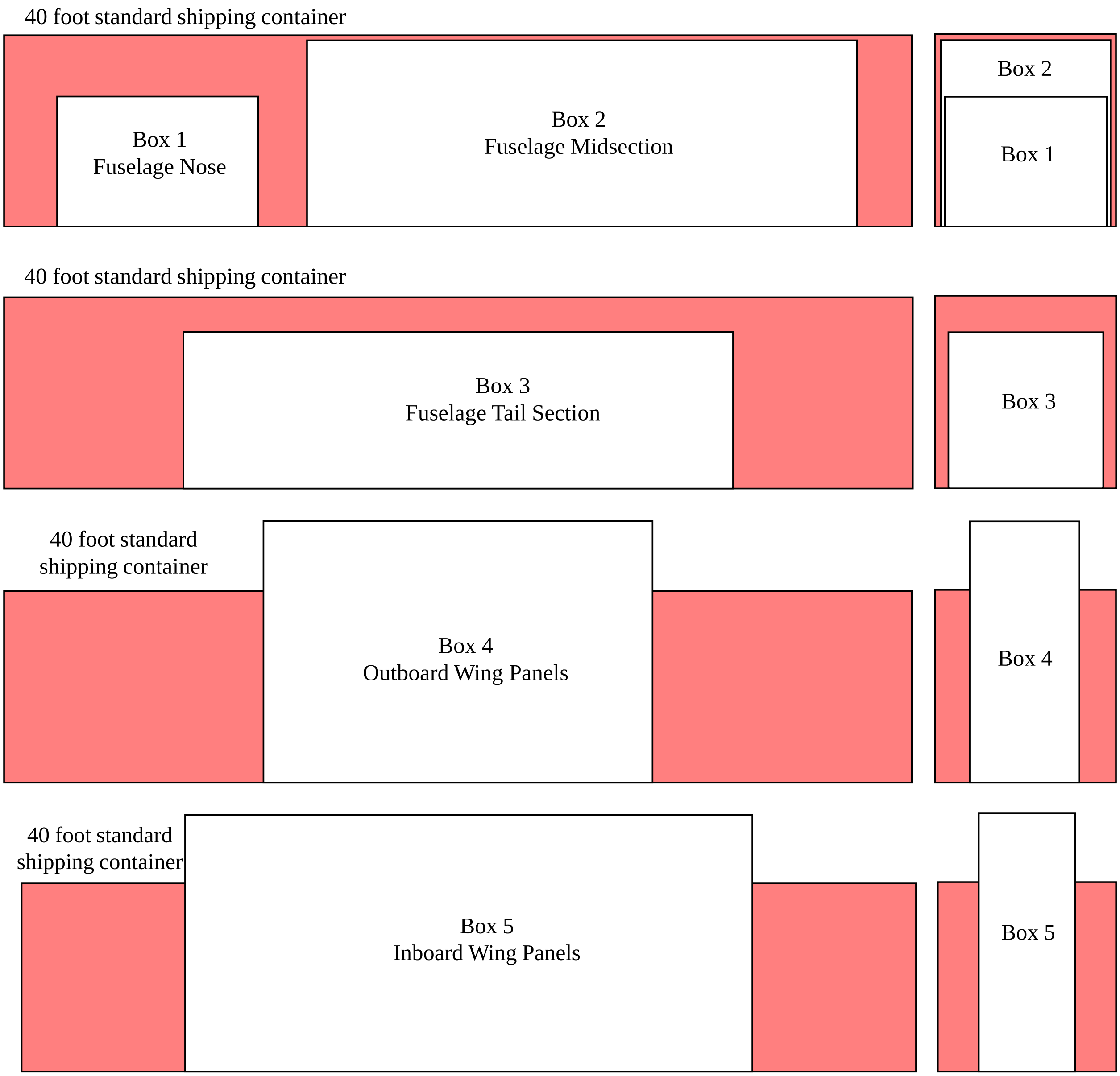


FIGURE 14 · INBOARD WING PANELS

Trying to get a feeling for just how big these boxes were, I imagined loading them into standard 40 foot shipping containers like we see on trucks or trains. Granted, there were no intermodal containers during World War II – they were invented well after that. This is just an exercise in visualizing size. Of note, boxes 4 and 5 with the wing panels were too tall to fit in a shipping container. I'm surprised the Army didn't try to get these boxes closer to a standard size or in some shape that they would pack neatly together on the cargo ship.



Thus, it would have taken four semi-trucks to move one glider, or they would have looked something like this in four containers on a train.

Tow Plane

The TPS gliders can be towed by many types of relatively high-powered single engine light planes. TPS generally uses the Piper PA-25 Pawnee, powered by a Lycoming O-540 engine of 235 horsepower. A former crop duster with all of the spray equipment and chemical payload removed, it operates at 1400 pounds below its maximum gross weight (flying weight is 52 per cent of maximum gross weight), and thus has a large amount of excess power available for glider towing.

Piper PA-25 Pawnee

The Waco CG-4A, being around seven times heavier than the TPS gliders, needed a significantly larger tow plane. About every type of large airplane seemed to have been pressed into service as a tow plane, including the P-38 Lightning. The most common types of airplanes to be used as tow planes were the Douglas DC-3 derivatives, including the C-47 and C-53. These were so common that they were called out as the de facto tow plane in training documents (Ref 2). The typical powerplants for the C-47 and C-53 were two engines of about 1200 horsepower each.

Douglas C-47

Much like the PA-25, the C-47 was typically flown mostly empty when operating as a tow plane. In most cases, the C-47 had sufficient excess power to tow two CG-4A gliders, especially if they were not excessively overloaded.

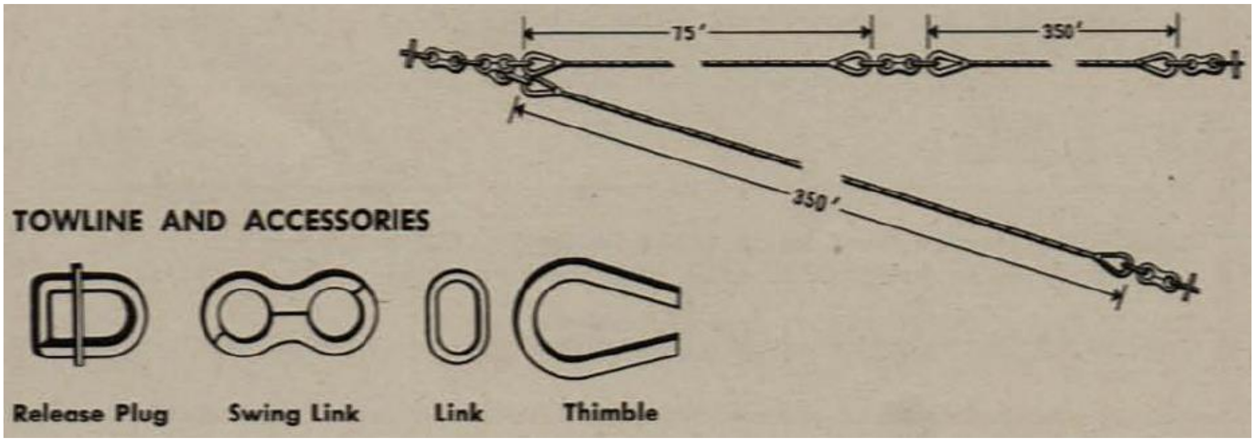
Towline

The towline used to tow gliders must be strong enough, but not too strong. Of course, the towline should be strong enough to tow the glider without a significant likelihood of breaking. However, if the towline is too strong, excessive loads in the towline would cause structural damage to the tow plane or glider. The towline should break before causing structural damage to the tow plane or glider.

According to 14 Code of Federal Regulations §91.309, the breaking strength of the towline must be greater than 80 per cent the maximum gross weight of the glider. The breaking strength of the towline must be less than twice the maximum gross weight of the glider. If the main towline has excessive breaking strength, then weak links must be provided that meet these requirements.

The towline used for TPS gliders is 200 feet of 5/16 inch Polypropylene, with a breaking strength of 2,050 pounds. This is 197 per cent of the SGS 2-33 maximum gross weight. All of the other gliders are slightly heavier, so this towline works with all of them. A hollow rope braid is used, and the loop at the end is formed by feeding the end of the rope into the hollow center. Tension on the rope clamps the end similar to a Chinese finger trap. This method preserves rope strength by avoiding the sharp bends of a knot.

The towline used for the Waco CG-4A was 350 feet of 11/16 inch Nylon. This towline had a breaking strength of 12,000 pounds, which was 160 per cent of the CG-4A Design Gross Weight. For double tows, one towline was extended by adding a 75 feet extension. This put one glider 75 feet behind the other glider rather than right next to it, reducing the likelihood of collisions. Note that if the tow plane released the double towline in an emergency, both gliders were still connected to each other until at least one glider released the towline. Reference 2 explains the material choice as “Nylon is used for two reasons: not only because it is strong, but because its elastic quality permits it to stretch readily under shock, yet contract slowly when tension is reduced, absorbing all stresses.” Studying the pictures, the tow line used a three strand twist structure. The loops at the ends are formed using a three strand splice.



CG-4A Double Towline and Accessories

CG-4A Towline display at the National Museum of the USAF

Tow Attachment

To attach the towline to the Piper PA-25 Pawnee tow plane, the towline is formed with a metal ring on the end. This ring is slipped onto a Schweizer-type hitch, with the hook held in place with a catch. A tow release lever in the cockpit pulls a cable to pull the catch off of the end of the hook. A rubber block preloads the hook up against the catch to prevent unintentional releases with no load on the towline.

Piper PA-25 Pawnee glider tow hitch

To install the tow hitch in the C-47, the tail cone was removed. The tow hitch was designed to be easily attached to the C-47 fuselage structure with no modification of the airframe structure required.

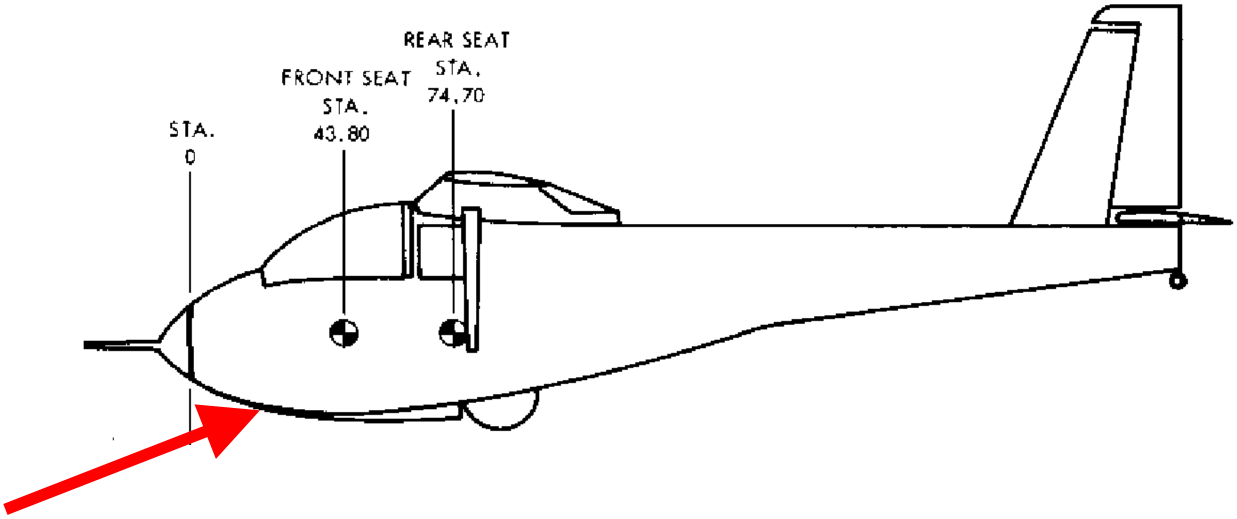
C-47 with tail cone removed for glider tow hitch

The fitting at the end of the towline had a rod shaped as a rectangular "U". This rod was clamped between two jaws in the tow hitch.

Attaching towline to C-47 tow hitch

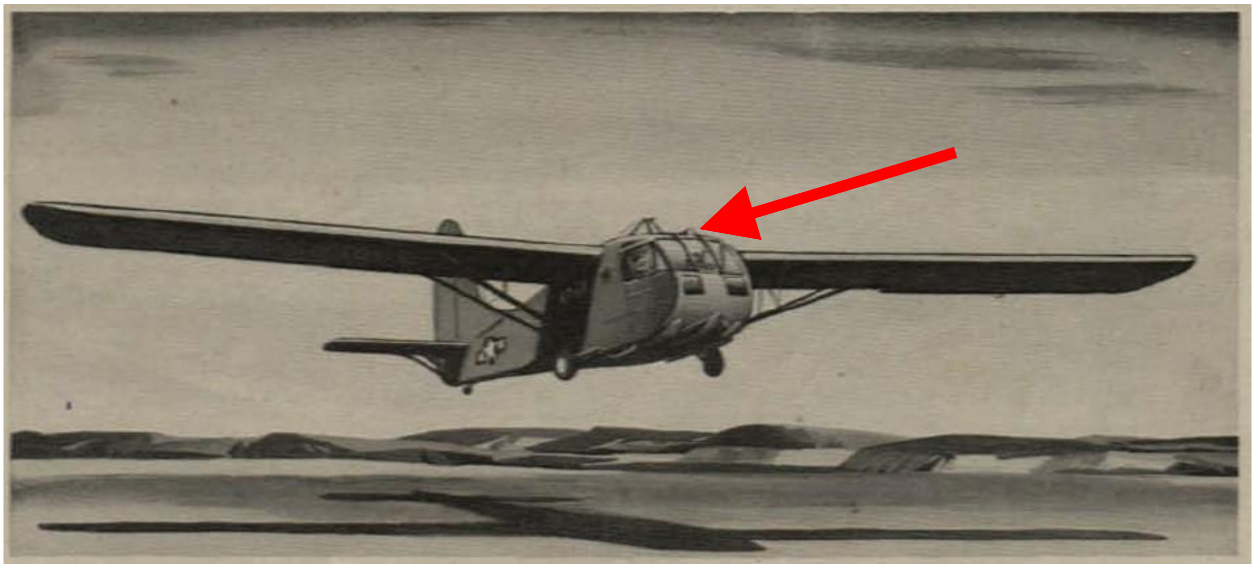
Tow Hook Position

The tow hook on the TPS gliders is mounted at the extreme nose of the glider or underneath the nose forward of the skid or nosewheel.



Red Arrow showing tow hook position on the Schweizer SGS 2-33

The standard location for the tow hook on the Waco CG-4A was centered on the fuselage above the cockpit windows. It was located on the nose section, and its high location meant that most of the tow force went directly through the hinge at the top of the fuselage and into the fuselage. The tow force thus created relatively little moment against the latches holding the nose section closed.



Red Arrow showing tow hook position on the Waco CG-4A

Towline attached to tow hook at top of nose section of Waco CG-4A

Many pictures show soldiers attaching the towline to the Waco CG-4A. Some soldiers were standing on a short ladder to attach the towline. If a ladder was not available, one soldier would hold his hands together for another soldier to stand on, giving the soldier a "boost" to connect the towline.

Uninstalled tow hook and towline as displayed at Silent Wings Museum

Inter-Cockpit Communication

Communications between TPS gliders and the tow plane are generally limited to standard visual signals, such as leveling the wings, wagging the rudder, or rocking wings. Any desires differing from normal operations are discussed with the tow pilot on the ground before launching. If more communication is desired, aircraft VHF radios can be used.

For the Waco CG-4A, all of the above methods of communication were available. However, use of radios in a war time environment could result in undesirable signal interception. From Reference 2, "The CG-4A has a type A1A-1 interphone system for communication between glider and towplane. The unit consists of a microphone for the pilot, and three headsets, one each for pilot, copilot, and crew chief. A 3-conductor insulated wire, either woven in or attached to the towline, forms the connection between the glider and the interphone system of the towplane. Operation of the equipment is simple. To talk from the glider, simply press the large thumb button on the hand-held microphone."

Takeoff

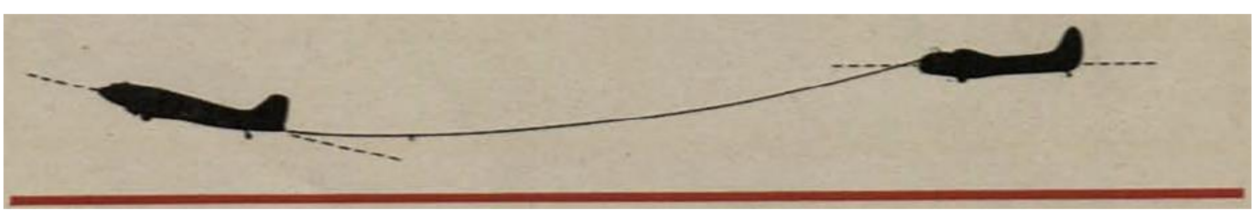
For TPS gliders, the glider is lined up on the runway behind the tow plane. The towline is connected to the tow plane and to the glider. A wing runner lifts the wing tip to level the wings, since the main landing gear is only a single centerline wheel. The glider pilot signals the tow pilot to begin the takeoff by wagging the rudder stop to stop.

Initially the glider is rolling on the ground. The glider pilot keeps the wings level with the ailerons, steers with the rudder, and after gaining some speed, uses the pitch stick to "raise what's dragging". The glider pilot then maintains a level pitch attitude. If the pitch attitude is high enough, upon reaching flying speed, the glider will lift off the ground. If the pitch attitude is not high enough, after reaching flying airspeed, the glider pilot pulls back on the stick until the glider lifts off the ground. The glider pilot then keeps the glider low (2-5 feet) over the runway. Eventually the tow plane reaches flying speed and lifts off. After reaching climb speed, the tow plane begins its climb. The glider climbs with the tow plane. For the "high tow" position, the glider pilot maneuvers the glider to keep the tow plane on the horizon in front of the glider.

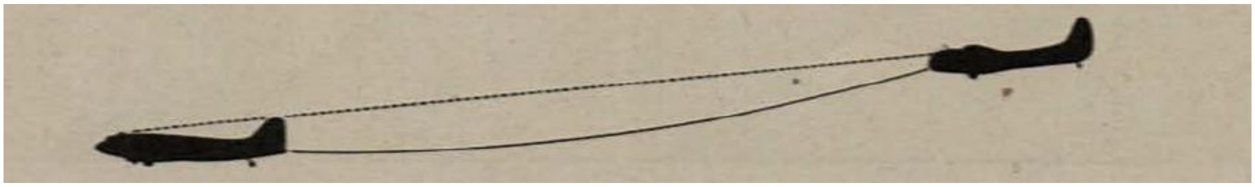
The takeoff procedure for the Waco CG-4A was quite similar. For a single tow takeoff, Reference 2 gives the following directions: "The glider has a tendency to nose over onto the skids when slack is taken up and the towplane moves off." (Not surprising, considering how high the tow hitch is on the glider.) "If the tail is lifted off the runway by the initial surge of the towline, hold back pressure on the wheel until the nose has reached a level flight position, then neutralize the elevators. Maintain this attitude through the takeoff run. Use rudder to control your direction during the run, because the drag of the brakes tends to throw the glider onto its nose skids."

"Take off when your airspeed is 15 mph higher than stalling speed, as estimated for your glider at its particular gross weight. If you allow the glider to float off the runway with insufficient airspeed, you do not have safe control. Yet if you hold the glider on the runway longer than necessary, you delay the acceleration of the glider train, because of the heavy drag of the glider's tires at high speed. Climb smoothly and rapidly, and level off just above the disturbed air created by the towplane (approximately 20 feet above the runway). This is necessary because disturbed air makes glider control difficult and places extra drag on the towplane. Your glider has a tendency to climb as you gain speed. A too-rapid pull-up also creates excessive drag on the towplane, making it difficult for the pilot to take off."

"Continue a level course in this position until the towplane is airborne."



"When the towplane is airborne, move into the tow position shown in the illustration."



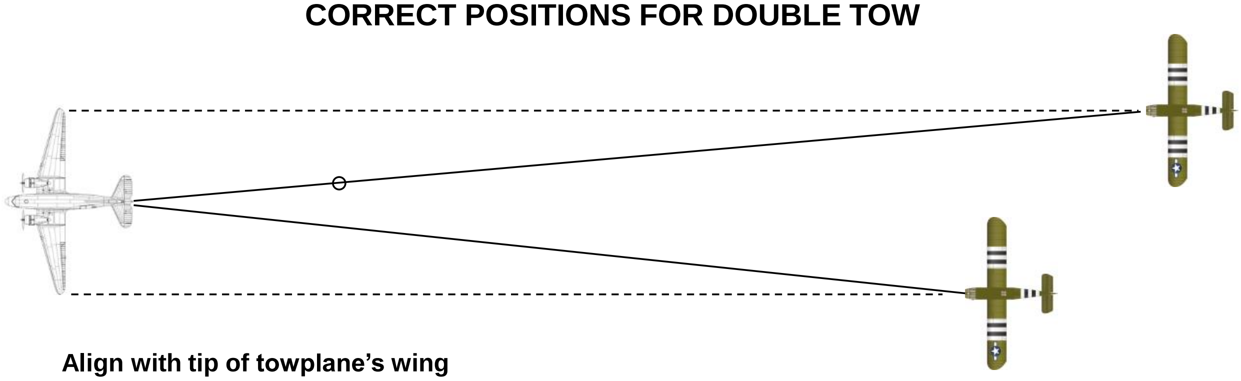
The C-47/C-53 towplane had sufficient power to tow two Waco CG-4A gliders at once, especially if the gliders were not loaded above their Design Gross Weight. As mentioned earlier, one glider used a standard towline length. The other glider used a towline with a 75 feet extension. From Reference 2 "As the gliders start the takeoff, the towlines tend to pull them together toward the center of the runway.

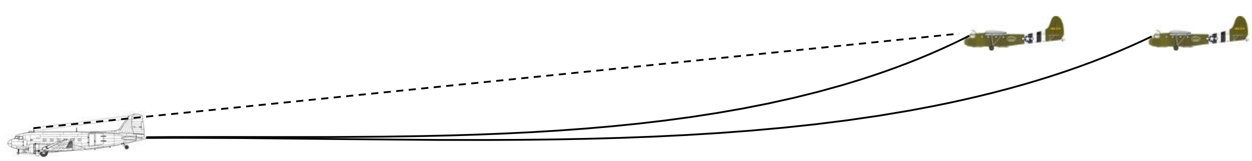
At this point, there is not enough speed to make rudder control effective, so use brakes to correct for the inside pull of the towline. When your glider has sufficient speed, use rudder instead of brakes to hold a straight roll.

The takeoff is made in the same manner as for single tow, except that you now align your glider on the wingtip of the towplane. Hold this tow position as closely as possible. If you swing out too far from the towplane, you increase the drag on it. If you swing toward a position directly behind the towplane, you endanger the glider on tow with you. Fly at the same altitude above the towplane as in single tow.

CAUTION: The pilot on long tow has an unobstructed view of the glider in the short-tow position, but the short-tow pilot cannot see the glider on his right. For this reason, the pilot on long tow is responsible for avoiding a collision in any emergency."

CORRECT POSITIONS FOR DOUBLE TOW



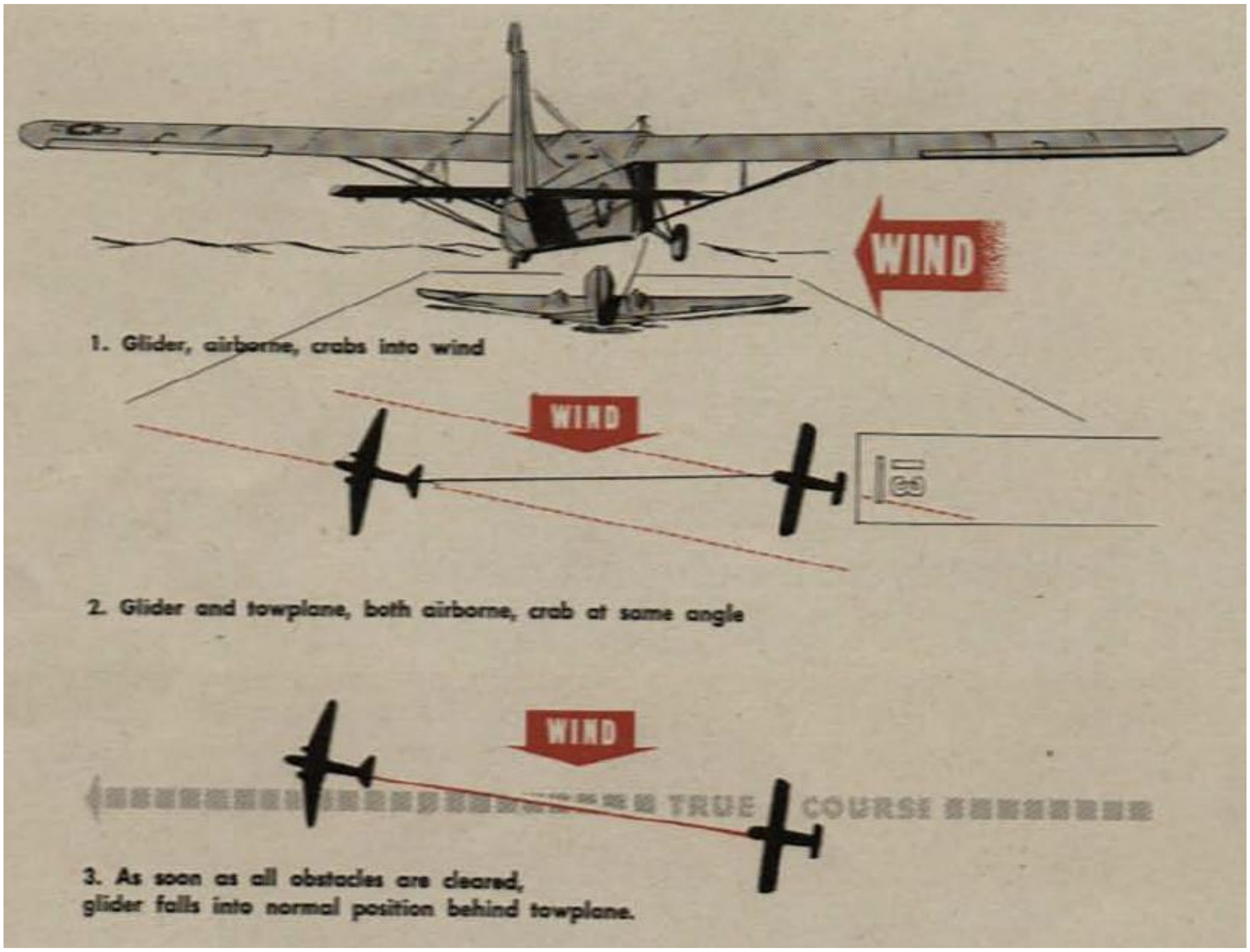


Crosswind Takeoff

When taking off with a crosswind, the takeoff procedure is modified slightly. When the glider lifts off the runway, the pilot uses the rudder to yaw the glider into the wind. The resulting sideslip causes a side force to keep the glider over the runway. This keeps the towline directly behind the tow plane. If the glider were to drift downwind, the towline could pull sideways on the towplane, overpowering the tow pilot's ability to maintain directional control, causing the tow plane to depart the runway (which is generally considered "bad").

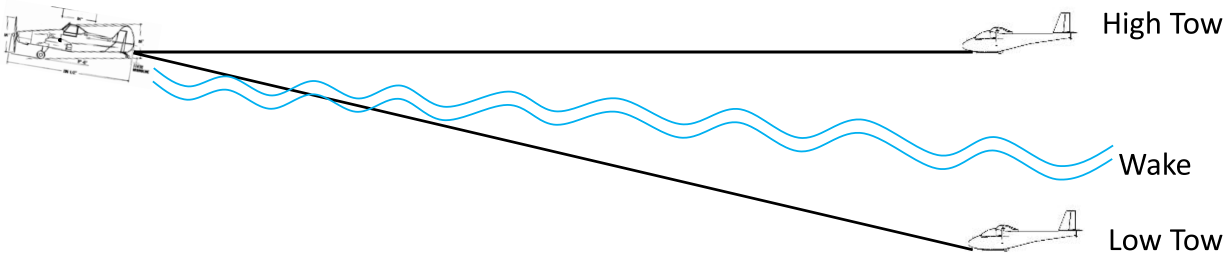
After obstacles are cleared, the glider moves sideways into its normal tow position.

The crosswind takeoff procedures are the same for TPS gliders and for the Waco CG-4A, as shown in the following figure from Reference 2.

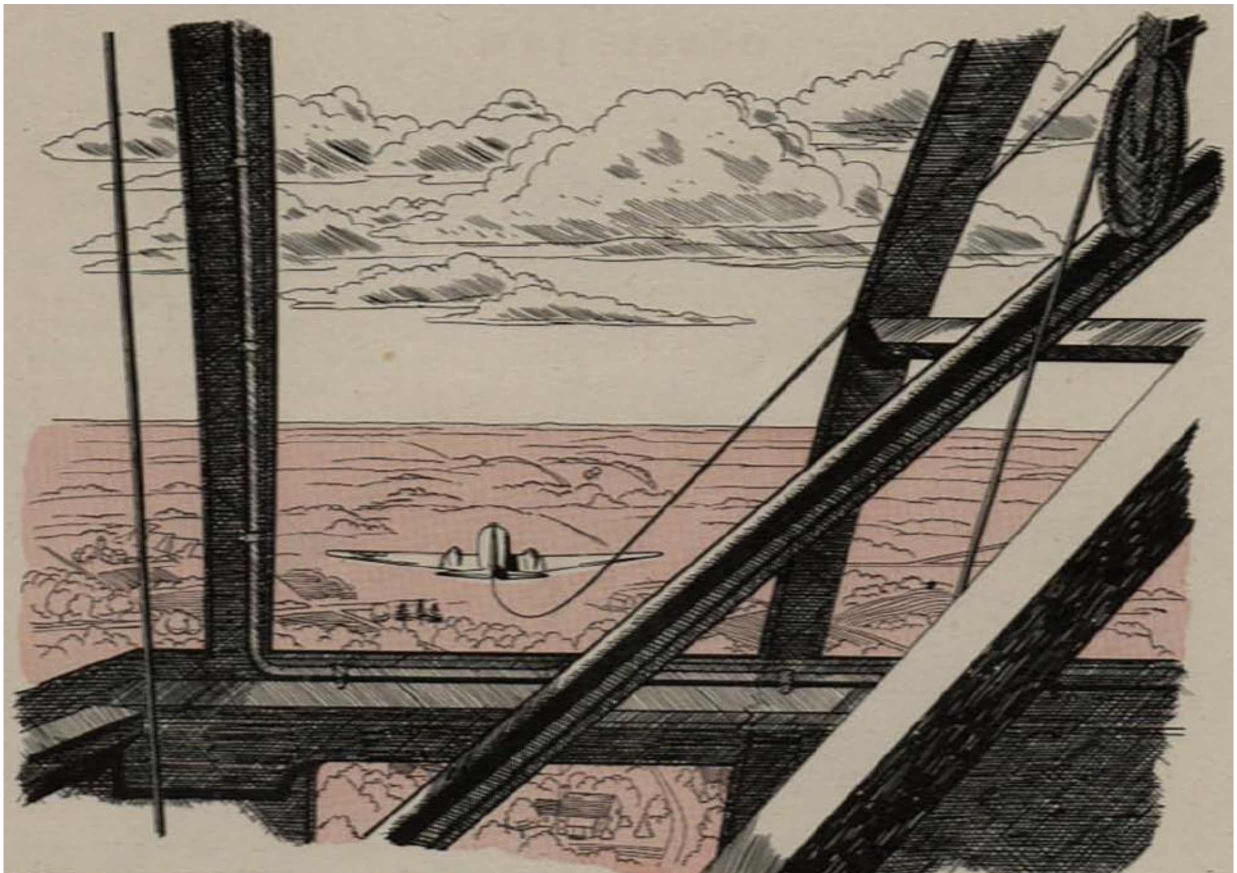


Tow Position

TPS gliders normally fly in the "High Tow" position, which is directly behind the tow plane, coaltitude with the tow plane (towplane on the horizon as viewed from the glider). This places the glider above the turbulent downwash/propwash of the tow plane. An alternate tow position is the "Low Tow" position, which is directly behind the tow plane, below the turbulent downwash/propwash.

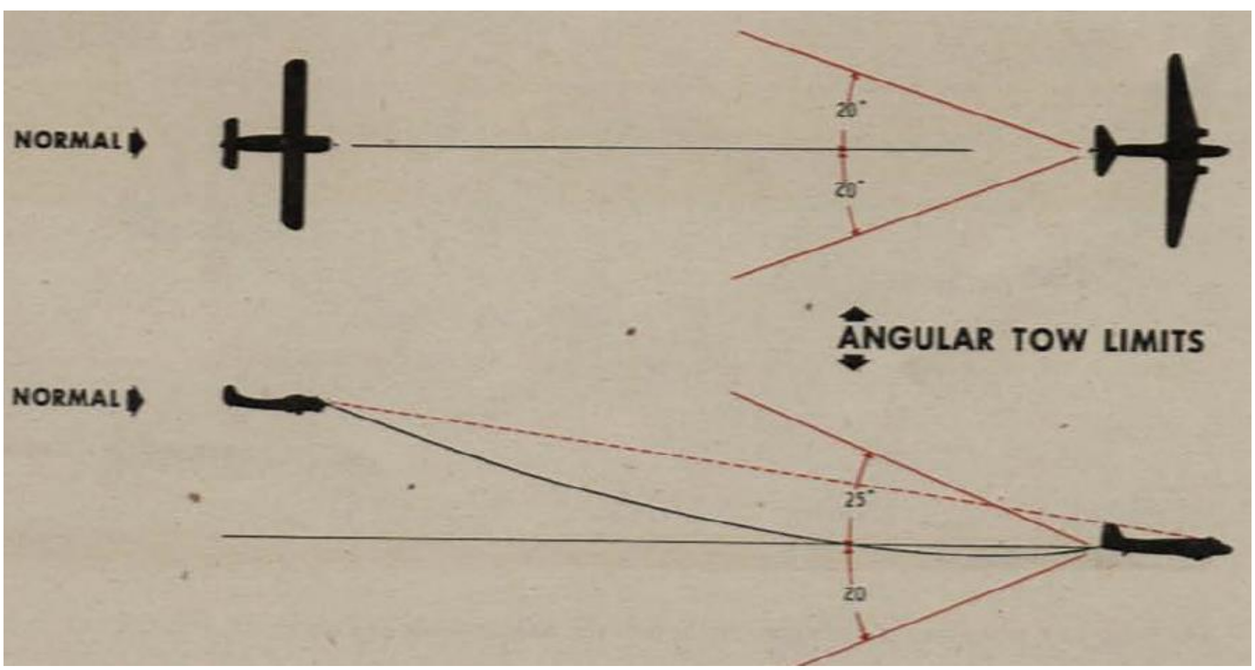


According to Reference 2, the Waco CG-4A normal tow position was higher than High Tow as used at TPS. For single tow operations, the Waco CG-4A flew directly behind the tow plane. The vertical position was defined by aligning the top of the vertical fin with the navigator's astrodome just behind the cockpit. This resulted in a position nine degrees above horizontal.



NORMAL SINGLE TOW POSITION
Align tip of towplane rudder on astrodome

The limits of vertical position were 25 degrees above and 20 degrees below horizontal. Lateral limits were 20 degrees to either side of the tow plane. Compared to the tow position limits used for TPS gliders, the Waco CG-4A tow limits were quite generous.



Airborne Pickup

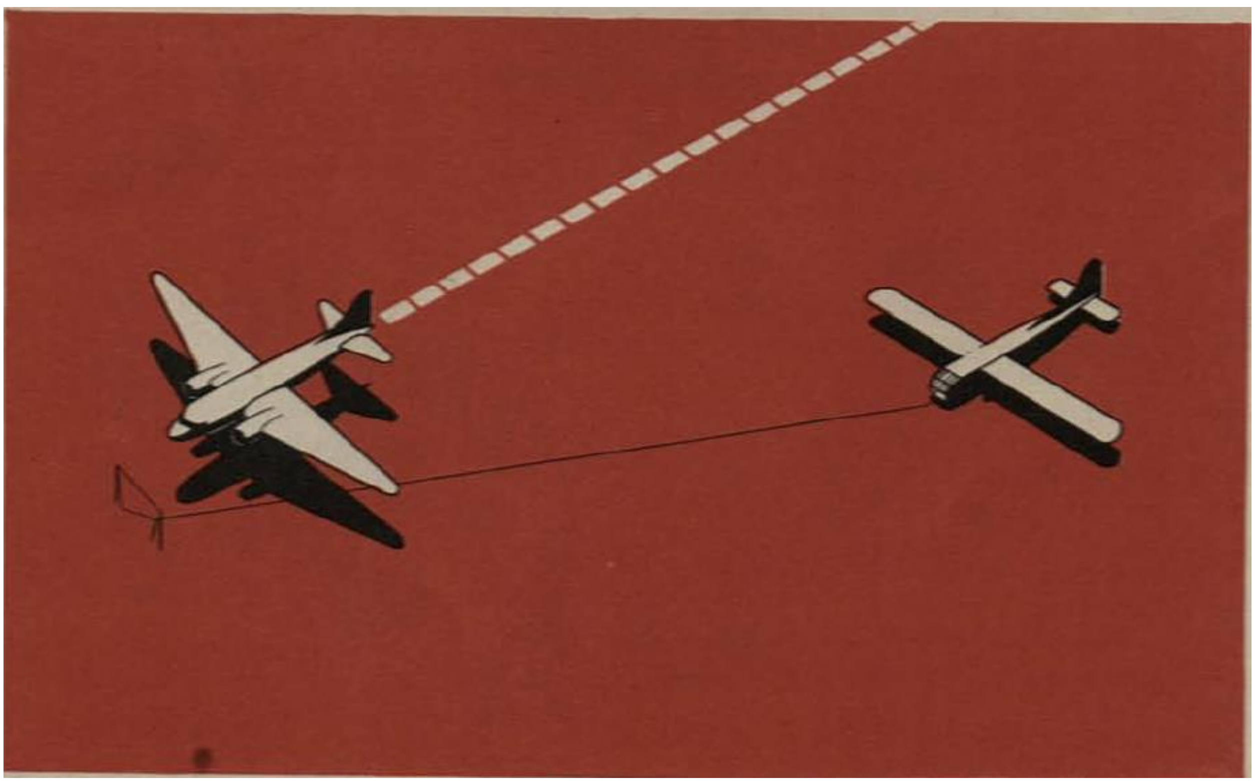
Most of what has been written about the use of cargo gliders focuses on delivery of men and equipment behind enemy lines. However, cargo gliders could also be used for delivery to relatively inaccessible areas in friendly territory, such as jungle clearings too small to land power planes. There was also the possibility of launching gliders from such fields without landing the tow plane. Much like mail pickup by moving trains, the towplane would fly low over the glider, snagging a suspended towline with a hook suspended from the towplane.

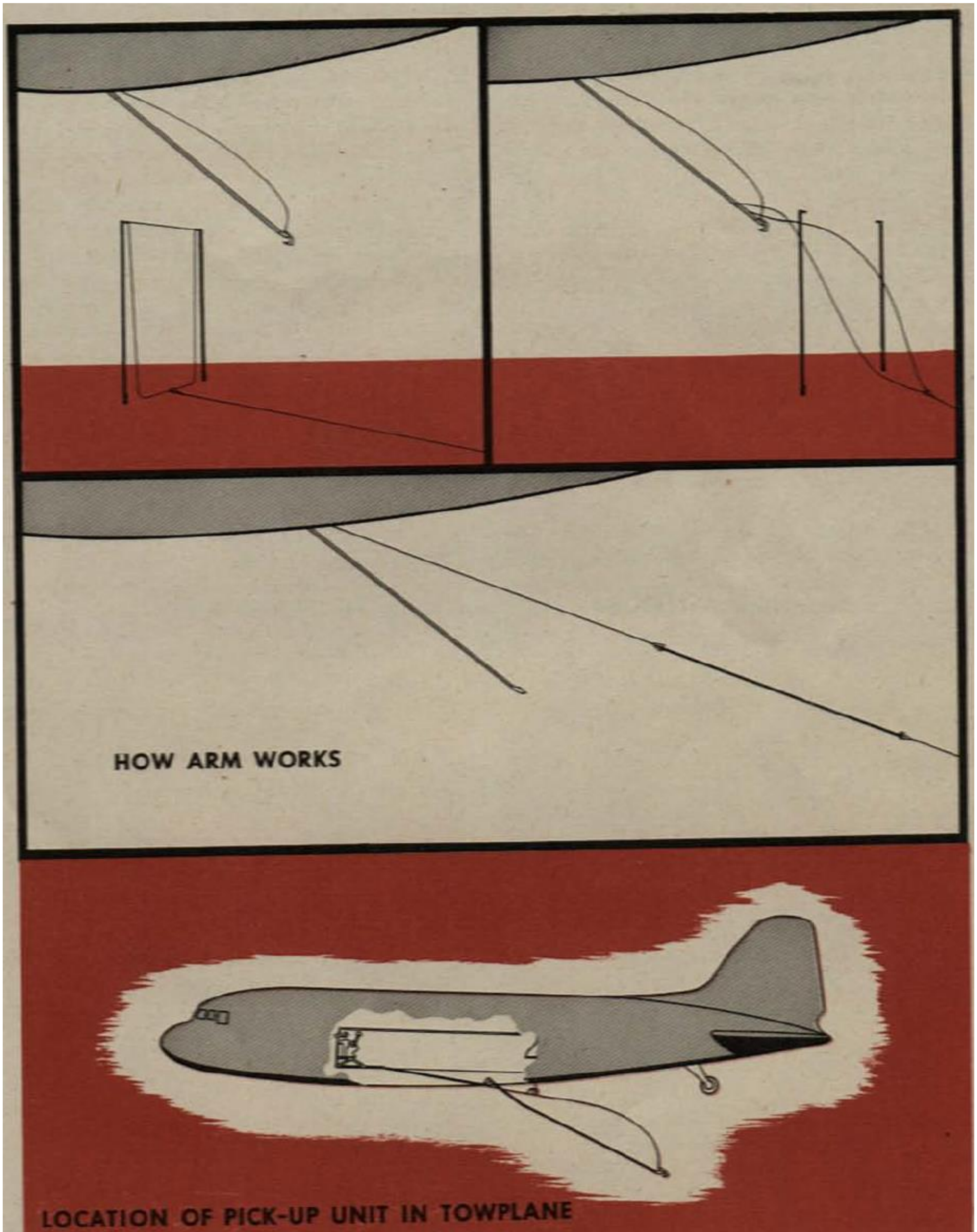
The hook was located at the end of a rigid pole trailing below the towplane. When the hook captured the towline, it was pulled through a spring detent, releasing it from the pole and pulling out the tow cable. The tow cable paid out from a device in the tow plane cleverly named the “Model 80”. You’d think it would have some cool name like “Glider Retrieval Cable Brake Device Thingee”, but every reference I have found simply refers to it as the “Model 80”. The Model 80 was fitted with 1057 feet of cable and a multiple disk brake. After hooking the glider towline, the brake engages gradually as the cable pays out. Typically, around 600 feet of cable would pay out during a glider pickup. The longitudinal acceleration during the pickup was around 0.7g for about 6.5 seconds. This was less than seen during modern fighter takeoff rolls. A contemporary Navy catapult launch, such as a seaplane from a battleship catapult, accelerated at 2.5g (Ref 2).

The towplane made its approach at 130 to 145 mph with engine RPM set to high. Upon hook engagement the throttles were advanced to climb power, and the towplane pitched up to capture an airspeed of 105 mph for the initial climbout.

For an airborne pickup, the Waco CG-4A was limited to a gross weight of 8000 pounds.

A wartime training film describing the entire process of an airborne pickup in detail is available at https://youtu.be/aYHzkT-Hkig?si=aaQnJxqPqwM0f4fn (Ref 17). This film, a product of the First Motion Picture Unit, Army Air Force, was produced and narrated by Captain Ronald Reagan, who would go on to have a reasonably successful career after the war.




HOW ARM WORKS
LOCATION OF PICK-UP UNIT IN TOWPLANE

Aerotow

For TPS gliders, most of the flight time is spent in gliding flight. The purpose of the aerotow is to "launch" the glider in favorable lift conditions or at some altitude near the takeoff airfield to enter gliding flight.

For the Waco CG-4A, the only part of the flight flown in gliding flight was the approach and landing. The purpose of the aerotow was to "deliver" the glider from the takeoff field to the vicinity of the landing field. Thus, the cruise portion of the flight was on tow. Generally, the flight was conducted at low altitude, no higher than the intended release altitude. Thus, the flights were generally flown no higher than maybe a couple of thousand feet.

Since a large part of the flight was in level flight on tow, Reference 2 gives this guidance to glider pilots: "On tow the glider responds with little control pressure if the air is smooth and stable. Use aileron rather than rudder to hold your position. Slight aileron movements do not require compensating rudder pressure, because the towline exerts a steadying influence, tending to hold the glider in a straight path." This statement would seem to indicate low adverse yaw and strong directional stability, beyond that provided by the towline. The position of the aileron hinge line shown earlier indicates that the ailerons were of the Frise type, where the upward deflected aileron projects its leading edge below the wing's lower surface, creating form drag to offset the reduced induced drag, thus minimizing adverse yaw. Additionally, the deflections of the ailerons were not equal (25 degrees up, 20 degrees down (Ref 5)), which also helped to reduce adverse yaw. Following the stated guidance from Reference 2 in TPS gliders will result in the adverse yaw causing the nose to yaw opposite of the stick input, with little directional stability to offset the yaw. Continued use of ailerons on tow without coordinating rudder will generally lead to a bounded pilot induced oscillation (PIO) in yaw, along with a rather annoyed instructor pilot telling you to wake up your feet.

Reference 2 continues "Practice flying with your feet off the rudder pedals while on tow. This enables you to relax, especially on long cross-country flights."

"As soon as the glider moves toward the normal position, begin neutralizing the controls. This slows the speed of the movement and permits you to stop the swing when the glider reaches the correct position." This matches the training given to TPS glider pilots for correcting position on tow.

Tow Release

For release from tow, TPS gliders follow the Soaring Society of America procedure. On release, the glider makes a level right turn. The tow plane turns left and descends.

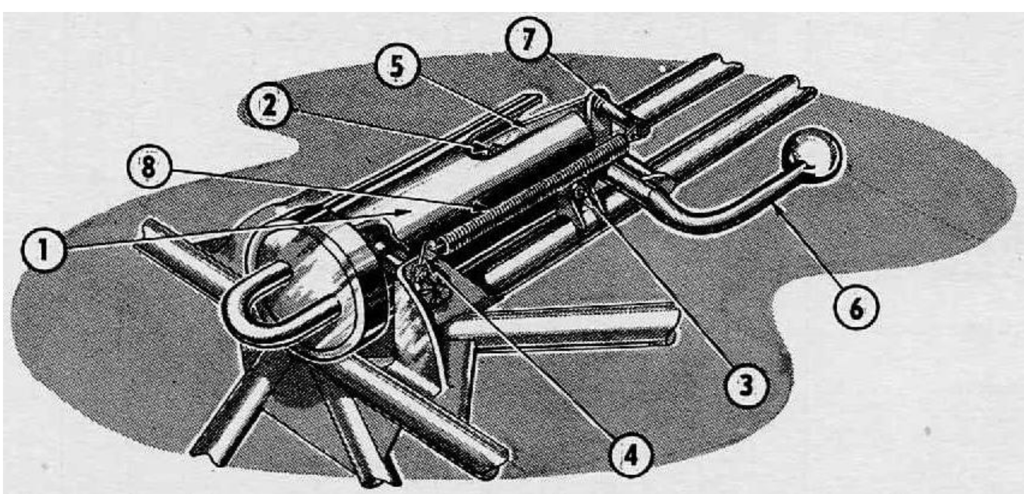
Reference 2 gives the following direction for tow release for the Waco CG-4A: "You are responsible for releasing from the towplane when your destination is reached. You may release beforehand only in an emergency.

The glider tends to climb as soon as released. The reason is that you trim the nose up during tow to counteract the downward force created by the towline.

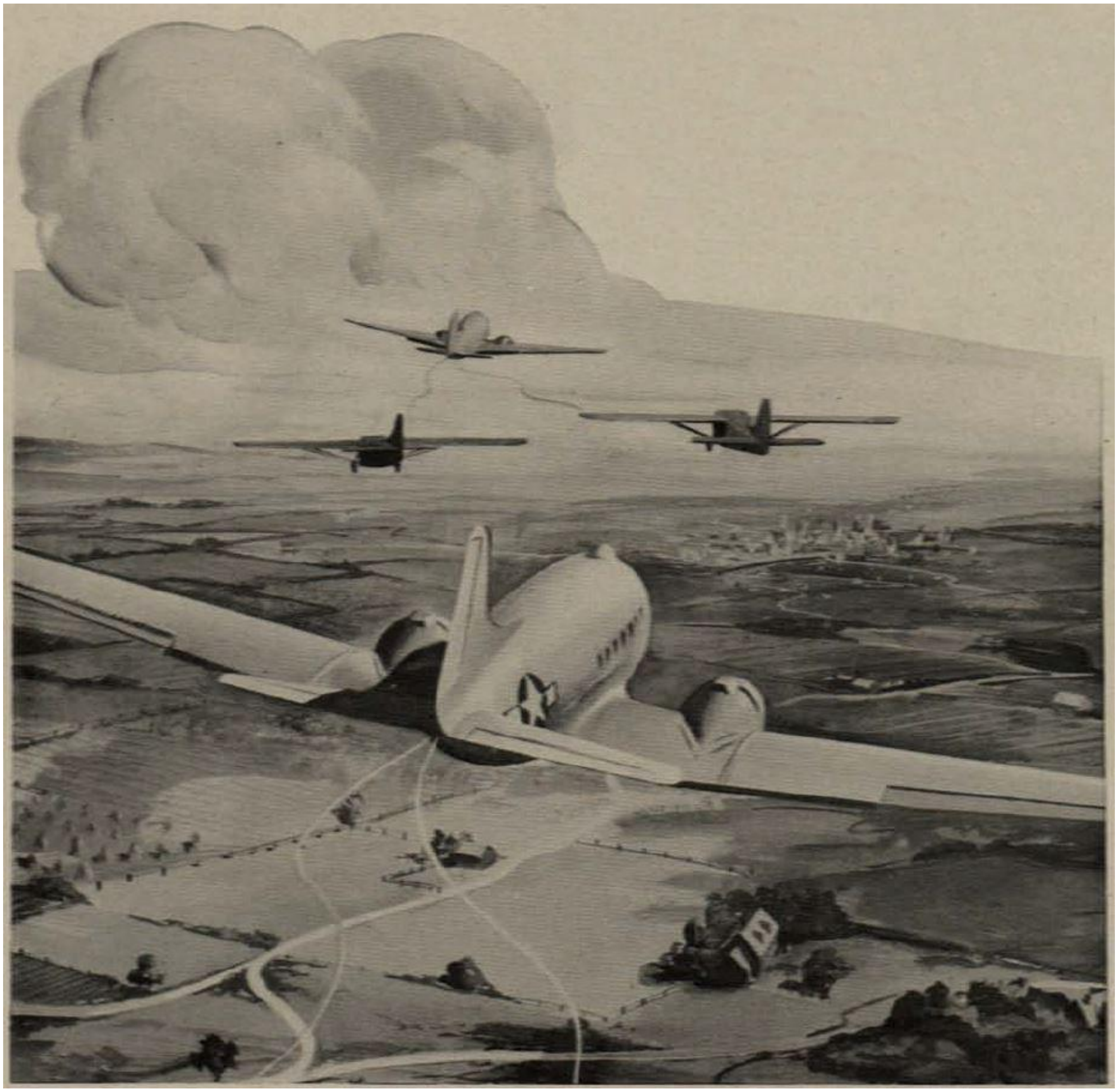
To correct, ease the control wheel forward and maintain straight and level flight until excess speed is dissipated. Then trim the glider to fly at the tactical glide speed.

The reason for emphasizing straight and level flight after release is that in formation flights the overtaking towplane clears you by climbing above and to your right. This hazard is particularly great on 90° and 180° approaches.

As you approach the release point, hold your normal double-tow position. If you drop below the other glider while flying on long tow, you have difficulty keeping track of it during the approach."



Glider Tow Release Mechanism



General Stall Characteristics

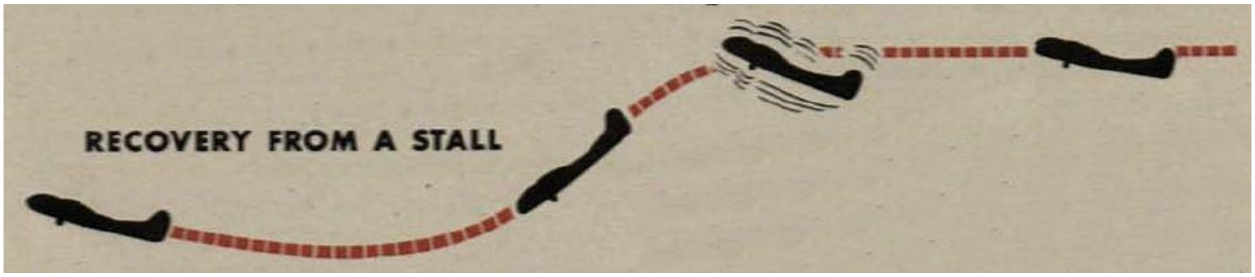
The stall characteristics of TPS gliders are generally benign. These gliders are usually elevator limited, meaning that the "stall" is usually characterized by reaching full aft stick. Alternatively, the stall may be marked by a slight wing drop or nose drop. In all cases, the recovery is made quickly and easily by simply putting the stick back in the neutral position.

For the CG-4A stall characteristics, according to some reference that I copied from years ago but can't find now, "The first warning of approaching stall is loss of aileron control. The glider has little tendency to drop either wing and mushes considerably before becoming completely stalled. Control is maintained throughout the stall by use of the rudder." Reference 2 states "Regardless of the airspeed at which you approach the stall (as in a steep bank), the ailerons begin to feel 'soft' as soon as the burble of the stall, creeping out over the wing, reaches them."

Reference 2 goes on "Since virtually all tactical glider flying is done at minimum altitudes, learn to make recovery from a stall with minimum loss of altitude.

The altitude lost after you detect a stall depends upon the wing-loading and how far you allow the stall to progress before you begin recovery. Therefore, you must recognize and react to the stall promptly. Because the stall is caused by the wing striking the air at too high an angle of attack, correct by reducing this angle. When you lower the angle of attack practically all lift is lost and the ship proceeds in a diving attitude until you gain sufficient airspeed to provide lift at the new angle of attack.

The large elevators of the CG-4A permit you to recover from the dive as soon as you regain tactical glide speed. Practice this quick recovery from the stall on a high-altitude tow, so that you will recognize the feel and sound of the glider when it may be leveled out of its dive."



Glide Performance

The glide performance of TPS gliders puts them well into the sailplane category. Glide ratio numbers range from 23:1 for the Schweizer SGS 2-33 up to 41.7:1 for the DG-1000. These glide ratios allow for reasonably long flights and the ability to stay aloft on weak vertical air currents.

By contrast, the glide ratio of the Waco CG-4A was much lower, estimated at a maximum of 12:1, even with the very large wing area provided. This was slightly better than the Space Shuttle or a rock. Reference 2 doesn't beat around the bush, saying "The CG-4A was not designed as a sailplane. It is simply a cargo-carrying airplane without engines." Emphasizing that the glider is similar to other airplanes, Reference 2 states "Any heavier-than-air pilot can step from the cockpit of one to the other and feel at home at the flight controls after normal transition training."

The significant difference with the Waco CG-4A was that upon tow release, you were committed to landing, and fairly soon. There have been reports of pilots managing to soar the CG-4A (gain or maintain altitude in gliding flight), but these were in gliders flying at minimum weight in strong updrafts, and not in combat conditions. Since the job of the glider pilot after release was to land quickly (to minimize vulnerability) and safely in the landing zone, any responsiveness to vertical air movement would interfere with that mission.

The rate of descent in gliding flight is a strong function of the glider's airspeed. For normal gliding flight, TPS glider pilots generally have two airspeeds to consider. Best Glide Speed, also commonly referred to as L/D max, is the usual go-to airspeed, as it gives the most distance flown for altitude lost. In strong headwinds, loss of range relative to the ground can be minimized by increasing airspeed. While not exact, the glider pilot's rule-of-thumb is to increase airspeed by half of the estimated headwind speed. While glide distance in a tailwind can be increased by reducing airspeed, the effect is much smaller, such that close to optimal glide range in a tailwind can be achieved by flying at the zero-wind Best Glide Speed. If the glider pilot's objective is to stay aloft for the maximum time or otherwise minimize the descent rate without respect to distance travelled, the glider pilot should fly at the Minimum Sink Speed.

While the aerodynamics of the cargo glider are the same as for TPS gliders, the cargo glider pilot's objectives were different. Reference 2 states "The normal glide speed is that which results in covering the greatest distance for a given loss of altitude...In following the standard approach patterns there is no advantage in flying the maximum distance over the ground. In planning your approach, figure on a glide much steeper, and therefore slower, than the normal glide." By this definition, "normal glide speed" was the same as what TPS glider pilots refer to as Best Glide Speed.

"The glide speed which is standard for combat gliders is called the tactical glide. It is a speed approximately halfway between the stall and normal glide speeds."

For reasons unknown to me, in Reference 1, billed as the "Pilot's Flight Operating Instructions", the USAAF published the next figure, showing the power required for the Waco CG-4A. This information unlocks the ability to determine the Waco CG-4A drag polar, and thus create other performance charts, answering many questions about how the Waco CG-4A performed in flight. The methods used for determining the drag polar and other performance charts are shown in Appendix A.

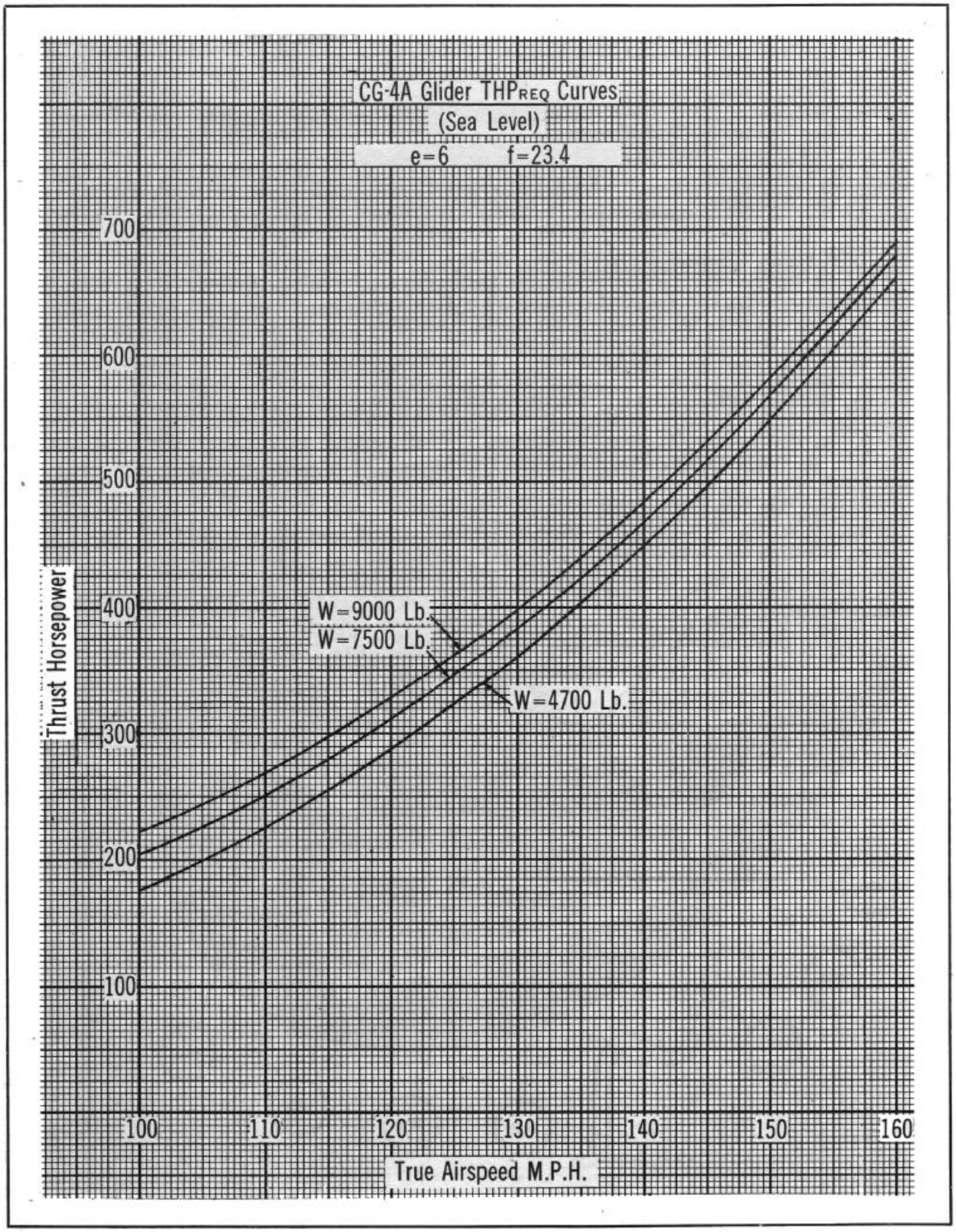
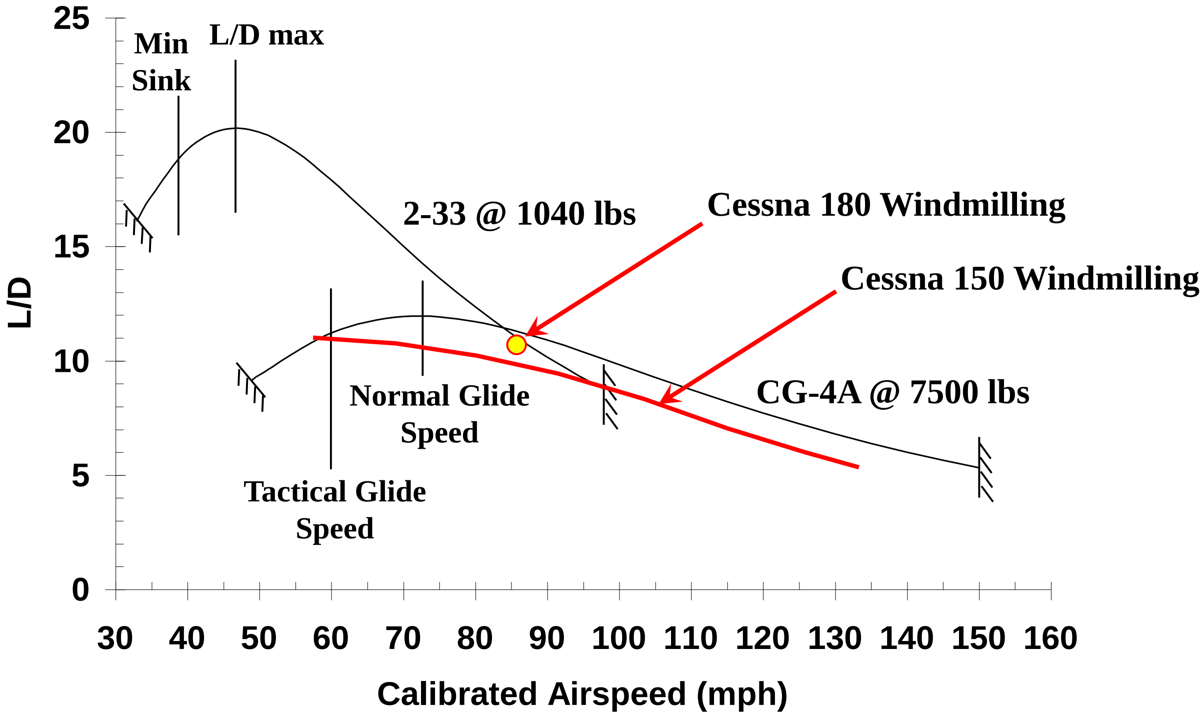


Figure 9—Power Required Curve

Following the methods of Appendix A, the glide ratio for the Waco CG-4A at Design Gross Weight is shown here. Normal glide speed (72.6 mph CAS, 85 mph IAS) and tactical glide speed (60 mph CAS, 70 mph IAS) (Ref 2) are marked on the curve. As mentioned earlier, we can see that the normal glide speed corresponds to maximum L/D. Likewise, the tactical glide speed is approximately halfway between the normal glide speed and stall speed. (Yes, Reference 2 calls out the normal glide speed as 72.6 mph CAS, surprising resolution when the airspeed indicator is marked in increments of 5 mph and the position correction is at least 10 knots.)



For comparison, glide ratio data for other aircraft are shown. The glide ratio data for the Schweizer SGS 2-33 is from flight test (Ref 18). The published maximum glide ratio for the SGS 2-33 is 23:1, but this flight test only measured a maximum of 20:1. This discrepancy is generally attributed to the glider not being in pristine condition and no incentive to interpret the data favorably to sell more gliders.

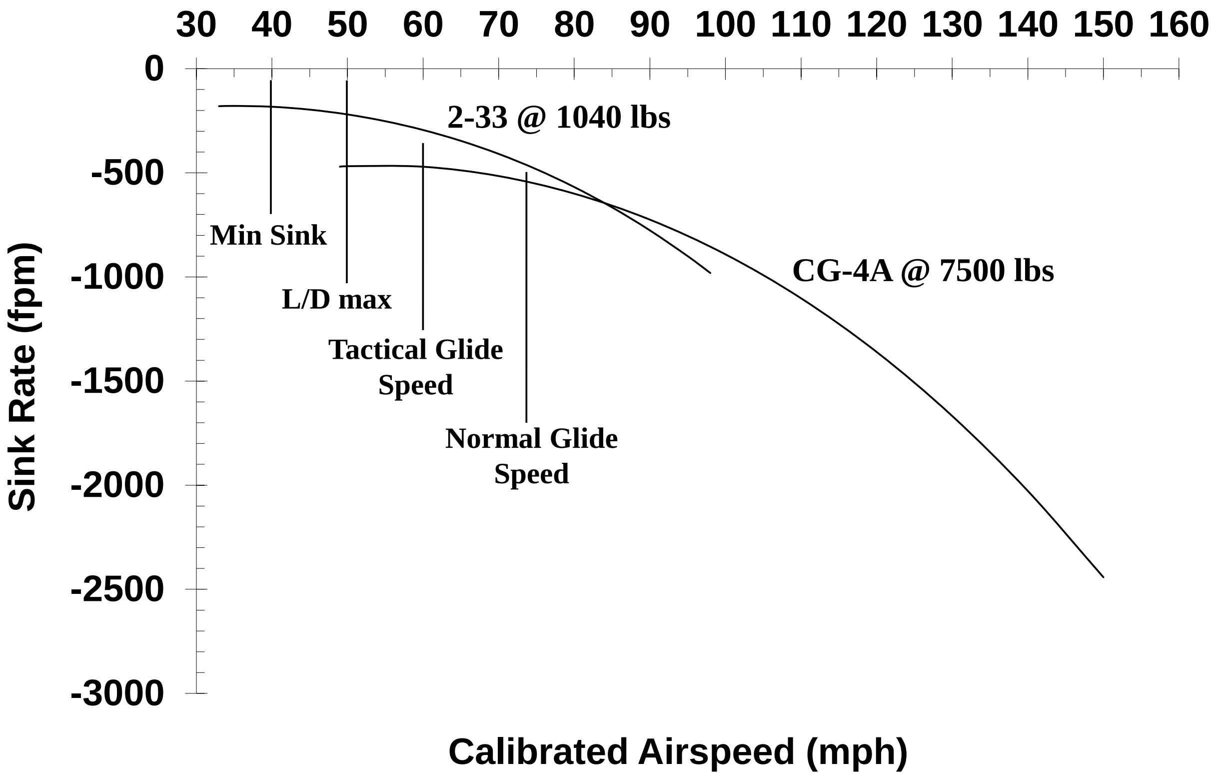
As expected, the performance curves for both gliders have similar shapes, but the sailplane has about twice the maximum glide ratio. This difference does not come from an improvement in technology, as the Schweizer SGS 2-8 (USAAF TG-2) was a glider contemporary with the CG-4A, and the SGS 2-8 had a maximum glide ratio of 24:1 at 42 mph (Ref 19). Thus, sailplanes do not provide a good analog for glide performance of the Waco CG-4A.

For a better analog for the glide performance of the Waco CG-4A, we turn to the power-off performance of general aviation airplanes. The windmilling best glide ratio and airspeed for a Cessna 180 are shown as given in the Pilot's Operating Handbook (Ref 20). Flight test data for a windmilling Cessna 150 are also shown (Ref 21). Thus, the glide performance of the Waco CG-4A is best simulated by general aviation airplanes with the power near idle.

The same data from above are also plotted as the glide polar, sink rate as a function of airspeed.

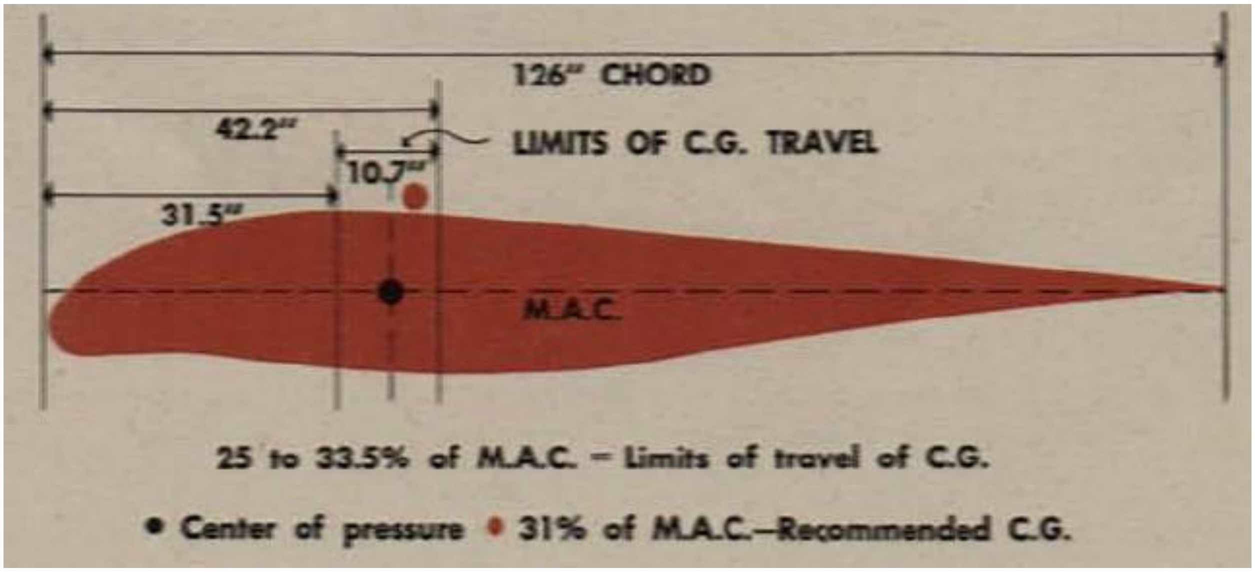
The glide polars for the Waco CG-4A and the Schweizer SGS 2-33 are plotted together for comparison. Reference 2 states that the rate of descent of the Waco CG-4A at design load and tactical glide speed was approximately 400 feet per minute at tactical glide speed. The chart below shows a rate of descent of 470 feet per minute, which is close enough to validate these curves as representative of the actual performance.

This figure also shows that the tactical glide speed just happens to correspond with minimum sink speed. I suspect this is just coincidence, since the tactical glide speed was chosen to give a steep approach and low energy landing, not to maximize time aloft.



Airfoil

The airfoil used for the wing of the Waco CG-4A is shown in the next figure taken from Reference 2. At first reaction, this airfoil looks unusual compared to typical cambered airfoils such as the Clark Y or the NACA 4412 airfoils.



Waco CG-4A Airfoil as shown in Reference 2

The design requirement for the airfoil was to have a high design lift coefficient for slow flight at minimal drag. Camber allows realization of the desired lift coefficient without a large angle of attack, which allows a relatively horizontal pitch attitude of the fuselage without a large angle of incidence, which simplifies integration of the wing with the fuselage. At the specified Normal Glide Speed for the Waco CG-4A (maximum L/D) at Design Gross Weight (7500 pounds), the required lift coefficient is about 0.6. While many similarly sized airplanes use a design lift coefficient of 0.2 or 0.4, gliders tend to operate at slower speeds, closer to stall speed, hence the higher design lift coefficient.

The selected airfoil for the Waco CG-4A was the NACA 43012 (Ref 22). The description of the numbering system for the NACA 5-digit airfoils given by Abbott and Von Doenhoff (Ref 23) states that the first digit (4) multiplied by 0.15 gives the design lift coefficient, which matches the 0.6 lift coefficient for Normal Glide Speed at Design Gross Weight. The second and third digits (30) multiplied by 0.5 give the position in per cent chord behind the leading edge (15%) of the maximum camber. The fourth and fifth digits (12) gives the maximum thickness in per cent chord (12%).

Because of the rather far forward position of the maximum camber, the airfoil has the appearance of a drooped leading edge. This is beneficial for preventing flow separation at higher angles of attack, such as approaches at Tactical Glide Speed.

The following figure shows the 2-dimensional lift and drag curves for the NACA 43012 (Ref 24). These curves show a section angle of attack of about 3.5 degrees for a lift coefficient of 0.6, and a stall angle of attack around 16 degrees. The actual angle of attack for the 3-dimensional wing would be slightly higher, but still in a reasonable range.

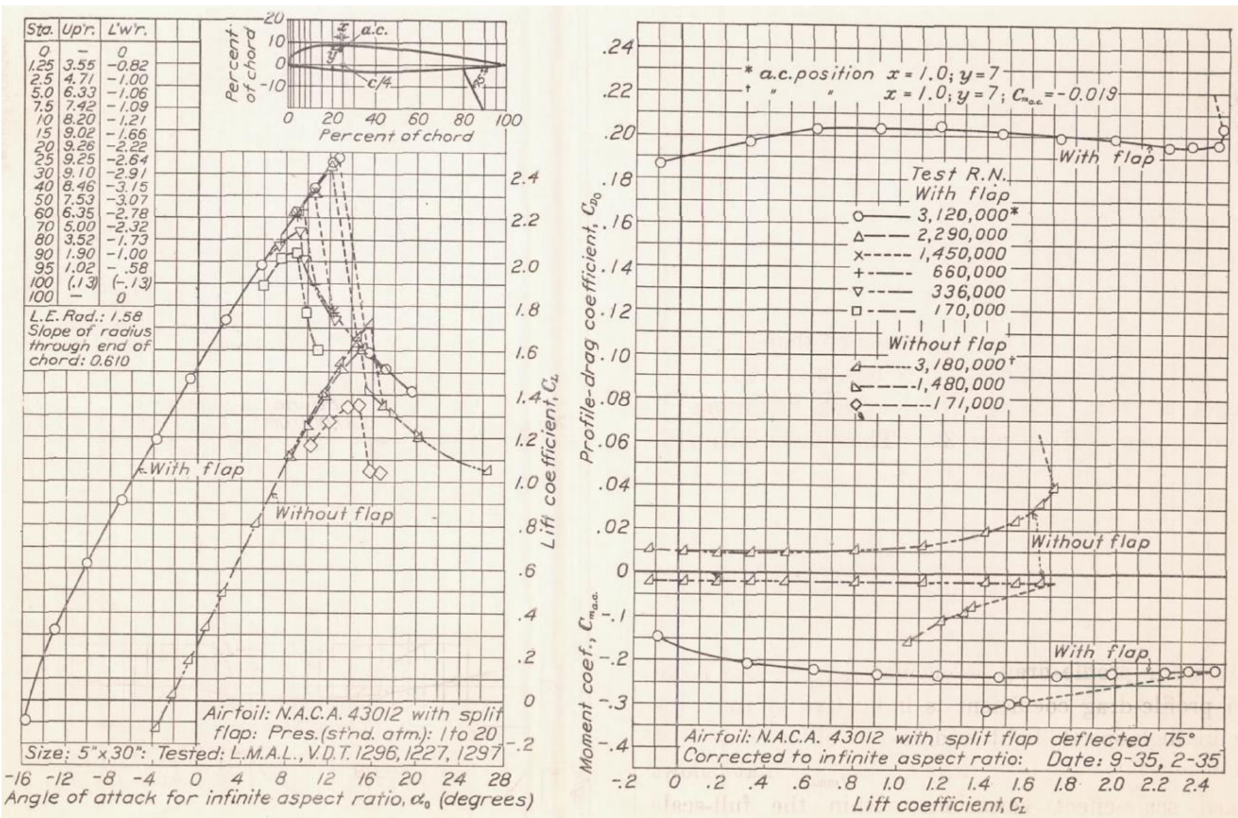
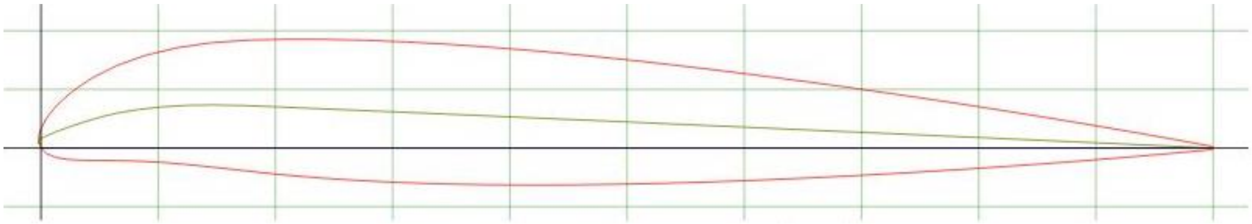


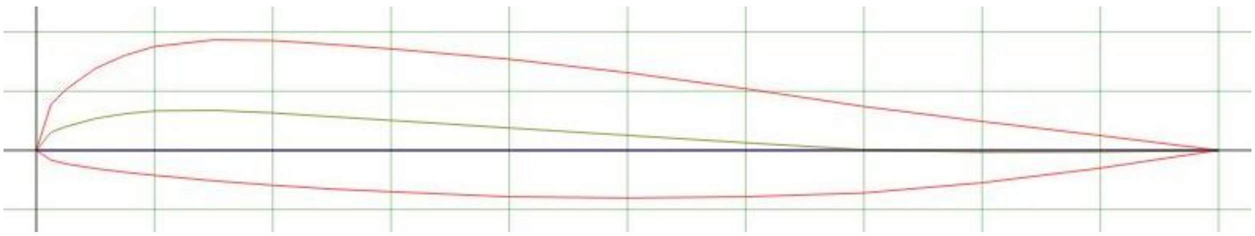
FIGURE 21.—N. A. C. A. 43012 with split flap deflected 75°.

NACA 43012 2-Dimensional Lift and Drag Curves (Ref 24)

Circumstantial evidence supports that this somewhat odd-looking airfoil was a good selection for this application. According to *The Incomplete Guide to Airfoil Usage* (Ref 22), the Schweizer SGU 2-22 glider, designed four years after the Waco CG-4A, used the NACA 43012A airfoil. This airfoil continued to be used on the Schweizer 1-26 glider (designed 12 years after the CG-4A) and the Schweizer SGS 2-33 glider (designed 23 years after the CG-4A). The NACA 43012A airfoil was similar to the NACA 43012, with the difference being described as “filling out the concave portion of the lower surface near the nose of the N. A. C. A. 43012 airfoil and thickening the upper surfaces so that the mean line is unchanged” (Ref 25). The differences can be seen in the following figures.



NACA 43012 Airfoil (Ref 26)



NACA 43012A Airfoil (Ref 26)

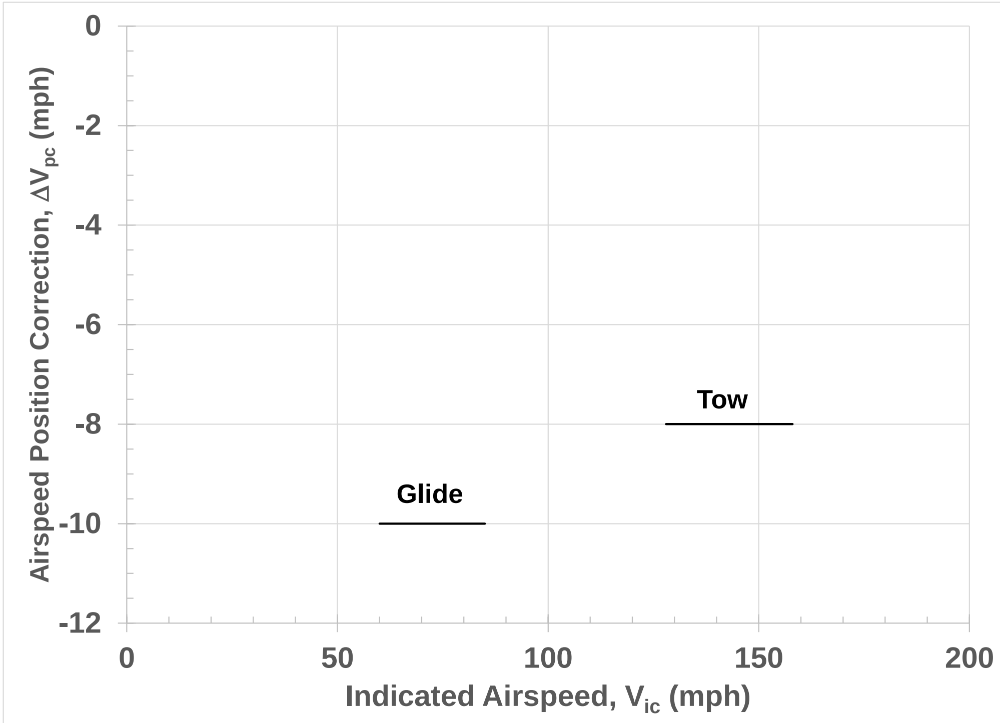
Position Error

As shown earlier, the AN5816 Pitot-static tube was mounted on the nose-raising tripod. This was a convenient place to mount it, as it was part of the nose section, as were the Pitot-static instruments. Thus, the entire air data system was a part of the nose section and didn't require making connections between the nose and other parts of the glider. Additionally, there was no requirement to bridge the hinge line in a way that would allow the nose to be opened.

Unfortunately, the location of the static ports was poor, as they were in the influence of the fuselage where the air was accelerating over the top of the nose (like going over the top of a wing), which lowered the local air pressure well below the ambient air pressure of the freestream.

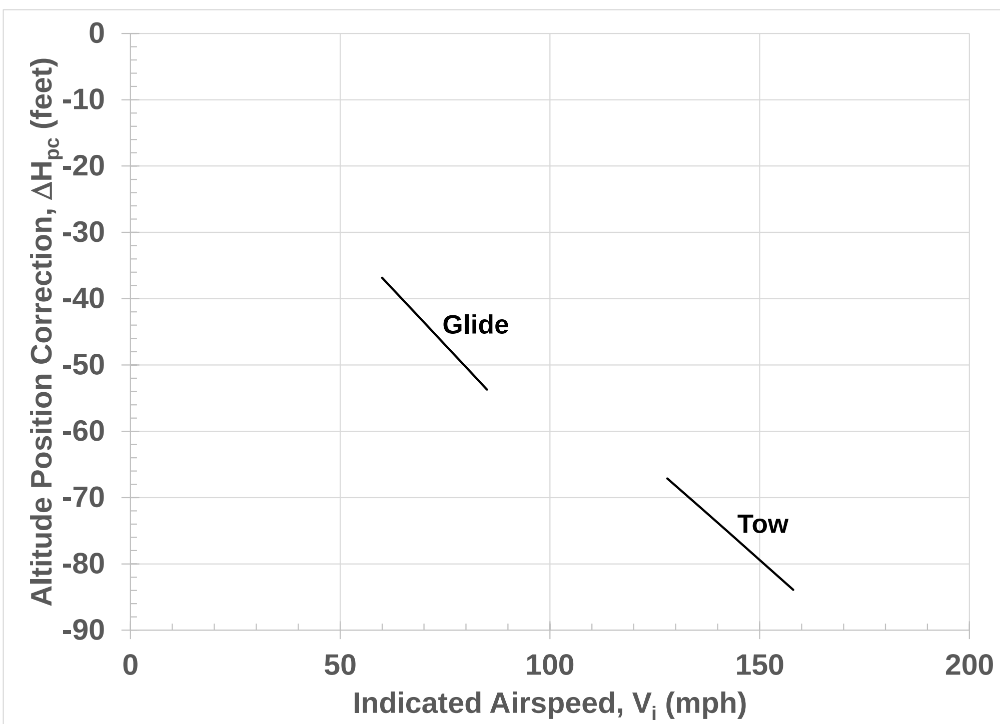
This was acknowledged in Reference 2, stating "The location of the pitot-static tube causes an error in readings for both the airspeed indicator and the altimeter. The reason for this error is that the pitot-static head is in a low-pressure, high-velocity area in the airstream which sweeps over the nose section. The high velocity of air in this area accounts for an exaggerated reading of 128 mph in indicated airspeed (IAS) when calibrated airspeed (CAS) is 120 mph."

Various locations in Reference 2 show an airspeed correction of -8 mph at airspeeds seen on tow. Reference 2 goes on to state "As your airspeed drops, the error of reading on your airspeed indicator increases slightly. The error throughout the range of glide speeds (60 to 85 mph IAS) averages 10 mph." No information is given in between these ranges, but that airspeed range would only be seen immediately after tow release while slowing to glide speed, and this short time period was not operationally significant.



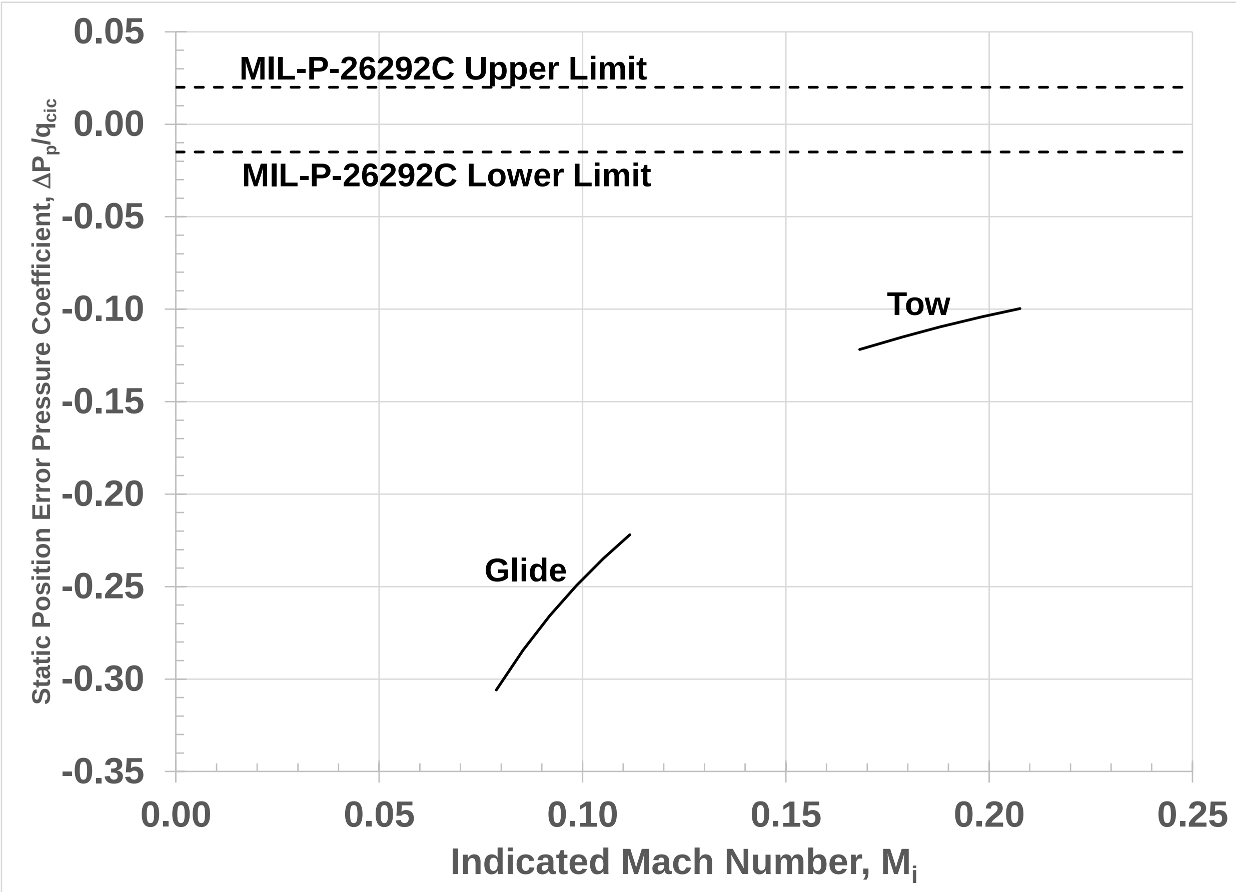
Waco CG-4A Airspeed Position Correction

Reference 2 also states "The location of the pitot-static tube also causes an error in the reading of the altimeter. The lower air pressure in the area of the static opening causes the altimeter—when CAS is 120 mph—to indicate an altitude 200 feet higher than you are actually flying." Using standard Pitot-static relationships (assuming total pressure error is zero) calculates an altitude position correction of about half that magnitude.



Waco CG-4A Altitude Position Correction

These airspeed and altitude corrections are actually quite excessive, especially for such a low-speed aircraft. Calculating the Static Position Error Pressure Coefficient allows comparison against the requirements of MIL-P-26292C (Ref 27), as shown in the next figure. The position corrections are well outside the limits called for in the Mil Spec. To be fair, this specification only calls out limits to a minimum Mach number of 0.3, and this figure extrapolates the requirement down to a Mach number of zero.



Waco CG-4A Static Position Error Pressure Coefficient Comparison to MIL-P-26292C Limits

Even though the air data corrections were excessively large, considering the mission of the cargo glider, this was acceptable for the mission. First of all, glider pilots were not trying to collect accurate flight test data. For most of the flight, the airspeed and altitude were set by the tow aircraft and the glider pilot had no control over them. The only time that the airspeed and altitude instrument readings were important was between tow release and landing, which was very short in duration. Glider pilots were not trying to navigate by airspeed. They simply needed to know what indicated airspeed they should maintain. Since training was focused on indicated airspeed, it really didn't matter that the indicated number was 10 mph faster than the actual airspeed. Once in the landing flare, the instrument reading was no longer consulted. As for altitude, during the landing phase altitude was mostly judged by looking out the window, not by looking at the altimeter. The altimeter reading had even less significance since the elevation of the landing zone was usually not known exactly.

Forensic Flying Qualities Investigation

Evaluating the performance of the Waco CG-4A is fairly straightforward, especially since Reference 1 published a power required chart. Evaluating flying qualities, however, is far more tricky, as there are no flying examples available to evaluate. Thus, in the USAF TPS mantra of Predict-Test-Validate, we can only Predict. There is no Test-Validate. Even so, we can come up with meaningful, defensible predictions. I have titled this "Forensic Flying Qualities" as it can only be determined from evidence, not from direct evaluation.

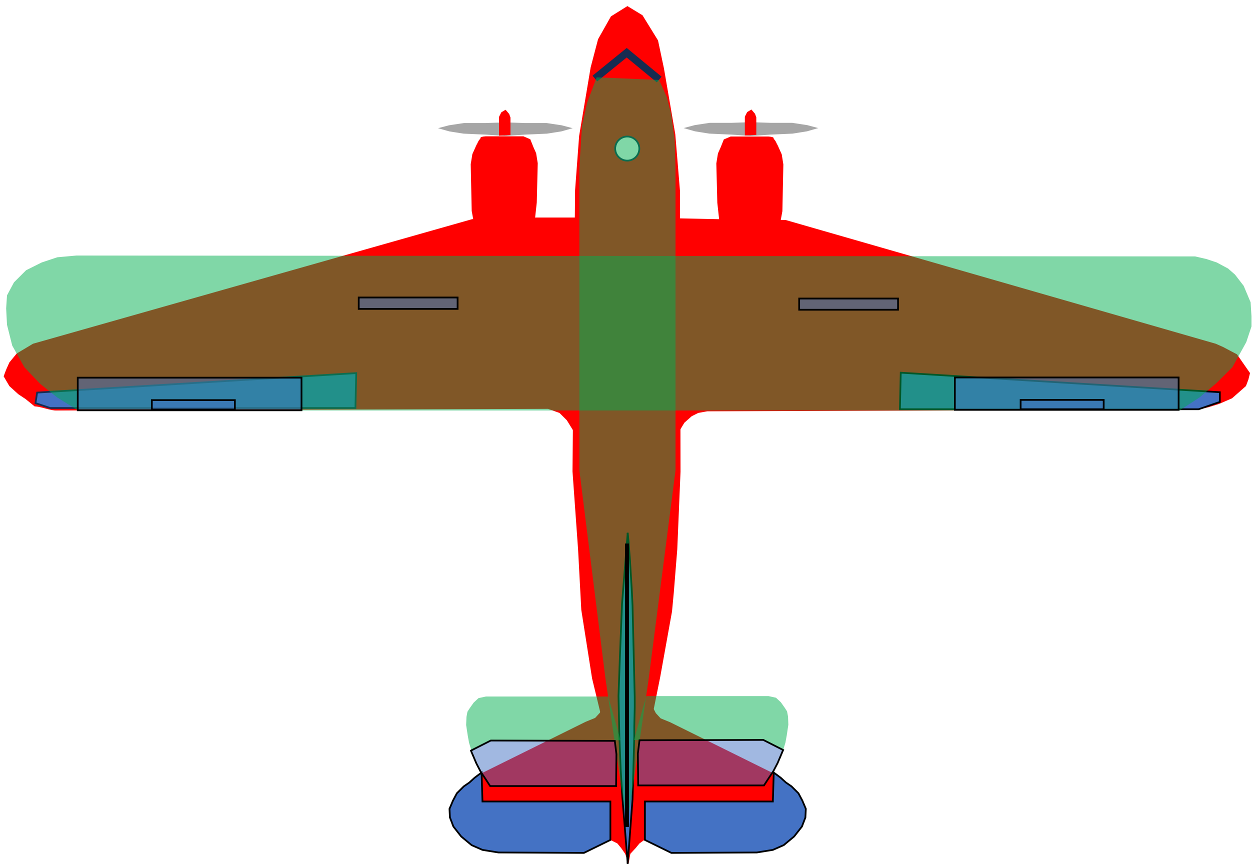
Some evaluations can be calculated directly from data available. Other data can be estimated using widely accepted linear approximations. Some evaluations can be interpreted from comments in manuals and reports.

Assumptions will be made. Finally, some evaluations will be made by comparing the glider with similar aircraft with known flying qualities. Some results will be evaluated against MIL-STD-1797B, Flying Qualities of Piloted Aircraft (Ref 28). Since MIL-STD-1797B was published in 2006, it might seem like applying today's morals to yesterday's decisions, but this is still reasonable as MIL-STD-1797B contains the Air Force's best description of what are considered "good flying qualities".

Aircraft Comparison

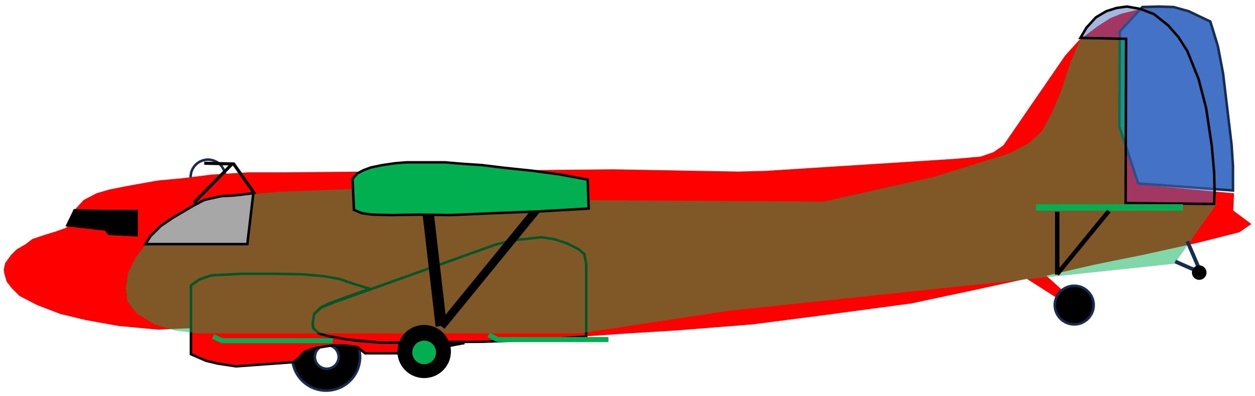
The Waco CG-4A will be compared to a C-53D, an aircraft of similar size and era for which we have flying qualities data (Ref 12). The C-53D was a Douglas DC-3 wearing a USAAF uniform. (The C-47 was a DC-3 built with a strengthened cargo floor and widened cargo door. The C-53D did not have these modifications.)

The wing span of the Waco CG-4A was 88% of the wing span of the C-53D. For easier comparison, in the following figure, the silhouette of the Waco CG-4A has been scaled up so that its wingspan is equal to that of the C-53D.



CG-4A overlayed on C-53D for comparison. The CG-4A has been scaled up such that its wingspan matches the C-53D wingspan.

Likewise, in the following figure, the side silhouette of the Waco CG-4A was upscaled the same amount and overlayed on the C-53D.



CG-4A overlayed on C-53D for comparison. The CG-4A has been scaled up such that its wingspan matches the C-53D wingspan.

Pitch Stability

The longitudinal pitch force ("stick force") and pitch stability, like any airplane or glider, was dependent on the location of the center of gravity. We will assume that the center of gravity was within limits. Looking at the top view of the CG-4A and the C-53D above, the wing areas are roughly the same. The areas of the horizontal tail are roughly the same, and the moment arm to the horizontal tail is a little shorter for the CG-4A, but we can consider the pitch tail volumes as comparable. These are the primary factors that affect pitch stability, so it is reasonable to assume that the pitch stability of the Waco CG-4A was similar to that of the C-53D. From Reference 12, the C-53D was tested at 120 KIAS. This is about 15 per cent faster than the normal CG-4A tow speed of 120 mph CAS (104 KCAS). "The short period was heavily damped, so pitch captures were easily done with no significant overshoots. The pitch control forces were not light, but were easily manageable." It is expected that the CG-4A was similar.

At high speed, the control forces of the C-53D increased. Reference 1 states that for the CG-4A "As elevator and rudder loads become quite heavy at high speeds, use trim tabs wherever possible."

To evaluate the phugoid (long period) dynamics, the frequency and period were calculated using linear approximations. The phugoid is not an issue while on tow, as the airspeed is controlled by the tow aircraft. It is suspected that the phugoid would be more of an issue at normal glide speed than when on the backside at tactical glide speed. Thus, we will assume a glide speed of 72.6 mph CAS. We will assume the analysis is at sea level, since it makes the math easier and typical WWII CG-4A missions were at low altitude. At sea level, our glide speed would be 72.6 mph true airspeed.

$$V_t = 72.6\frac{\text{miles}}{\text{hour}}\frac{88\frac{\text{ft}}{\text{sec}}}{60\frac{\text{miles}}{\text{hour}}}$$

$$V_t = 106.5\frac{\text{ft}}{\text{sec}}$$

The natural frequency of the phugoid is approximated by the true airspeed.

$$\omega_n \approx \frac{\sqrt{2}g}{V_t}$$

$$\omega_n \approx \frac{\sqrt{2}(32.2\ \text{ft/sec}^2)}{106.5\ \text{ft/sec}}$$

$$\omega_n \approx 0.428/\text{sec}$$

With the natural frequency calculated, the period can be calculated.

$$T \approx \frac{2\pi}{\omega_n}$$

$$T \approx \frac{2\pi}{0.428/\text{sec}}$$

$$T \approx 14.7 \text{ sec}$$

The phugoid damping ratio can be approximated based on the aircraft glide ratio. As shown earlier, at normal glide speed, the glide ratio of the CG-4A was 12.

$$\zeta \approx \frac{1}{\sqrt{2}}\frac{C_D}{C_L} = \frac{1}{\sqrt{2}\left(\frac{L}{D}\right)}$$

$$\zeta \approx \frac{1}{\sqrt{2}(12)}$$

$$\zeta \approx 0.0589$$

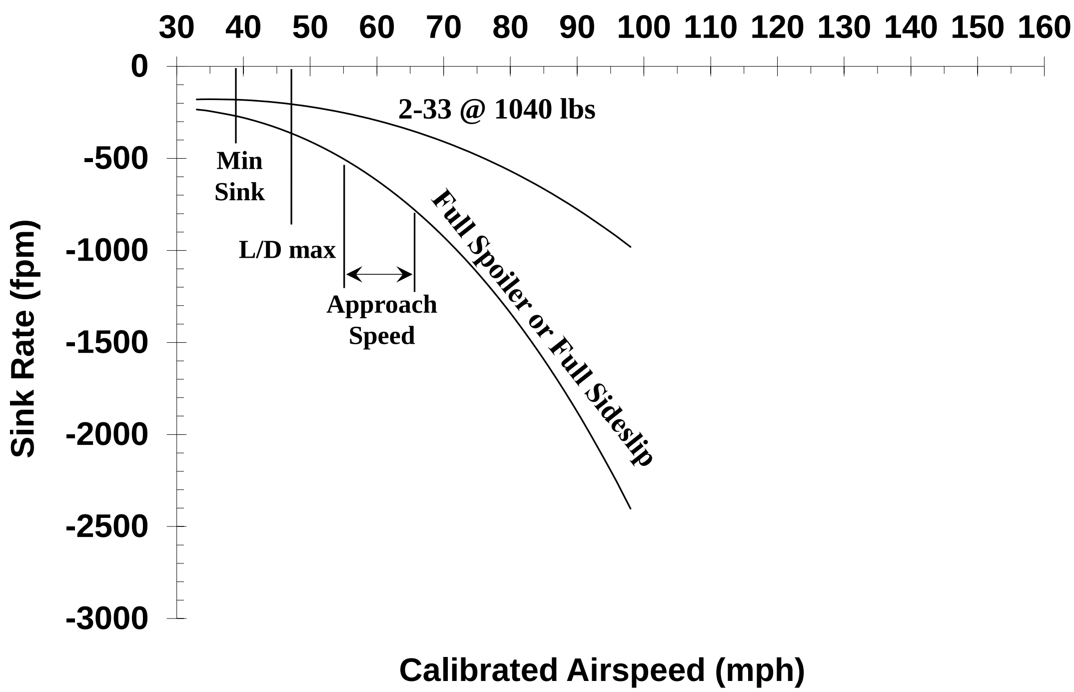
The MIL-STD-1797B (Ref 28) requirements for the phugoid mode are given in paragraph 5.2.2.1.2.1 Long-term longitudinal response. This paragraph defines the phugoid mode as “any oscillation with a period of 15 sec or longer”. Even though our phugoid period is predicted to by slightly shorter at 14.7 sec, we will consider this within the intended spirit of the standard. For Level 1, the damping ratio should be greater than 0.04. The predicted damping ratio is slightly greater at 0.0589. Therefore, we expect that the phugoid mode of the CG-4A was acceptable for the mission. Given the low altitudes that the CG-4A released at and the tight longitudinal control exercised by the pilot, it is unlikely that the phugoid mode ever had any chance to express itself.

Spoiler Effectiveness

During landing approach, powered airplanes modulate pitch angle and thrust to maintain the desired airspeed and flight path angle. Gliders can modulate pitch angle, but instead of modulating thrust, gliders must modulate drag. The drag devices on TPS gliders can appear very large in comparison to the size of the glider. By contrast, the spoilers on the Waco CG-4A appear quite small compared to the size of the glider, which raises the question of just how effective were they?

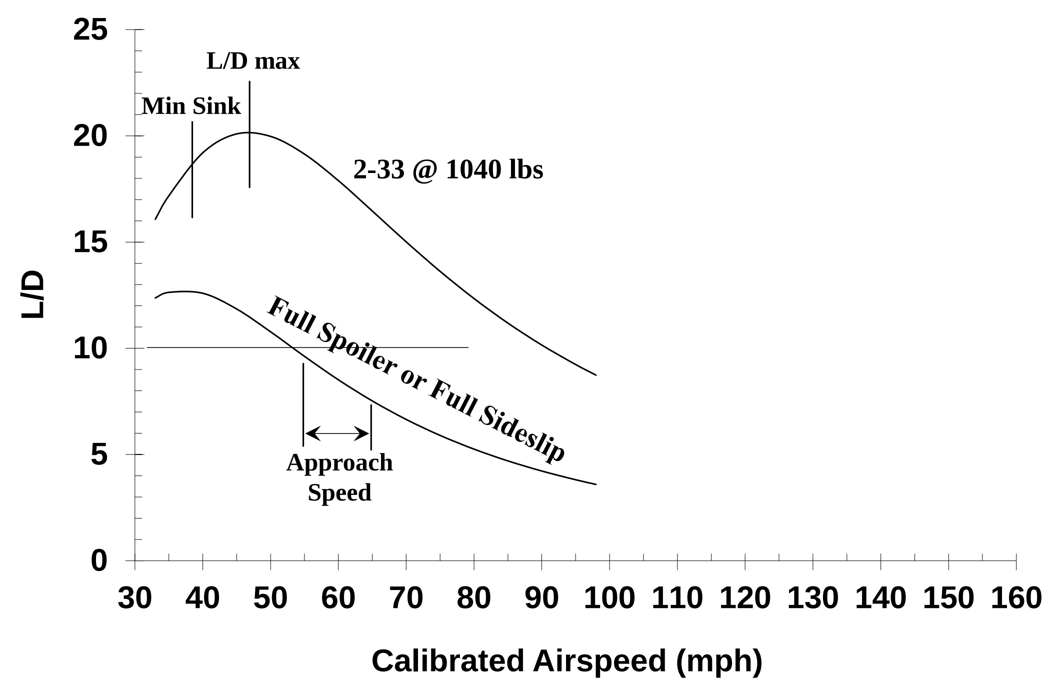
To gain information on how to model spoiler effectiveness, a flight test was accomplished with a Grob G-103 glider and a Schweizer SGS 2-33 glider. The results of these tests are documented in Appendix B. Descents without and with spoilers were made at the Best Glide airspeed, because data could be compared to published data (spoilers closed) and it was reasonably close to the approach speed.

The change in drag with spoilers was calculated, and a corresponding incremental drag coefficient was calculated. Assuming that this incremental drag coefficient stayed constant with changes in airspeed, the following figure shows the change in descent rate with airspeed for the SGS 2-33.



We can see that the spoilers on the SGS 2-33 roughly double the descent rate available at any airspeed. The spoilers on the Grob G-103 showed an even greater effect. However, the G-103 spoilers were operated at a higher airspeed (57 KIAS instead of 50 mph IAS (43 KIAS)) where they could take advantage of the square of velocity to create more drag. This analysis will continue with the SGS 2-33 data considered as the lower limit of spoiler effectiveness.

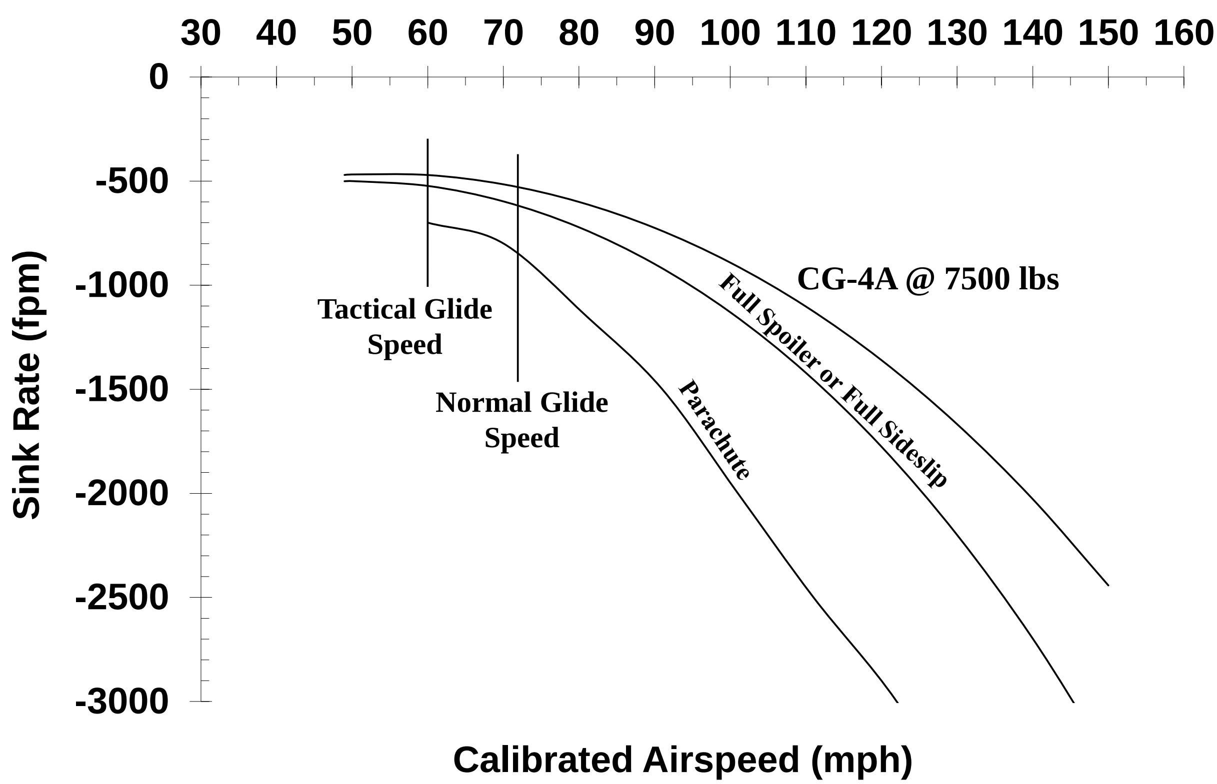
The same data were used to calculate the L/D for the SGS 2-33 with deployed spoilers as a function of airspeed, shown in the next figure.



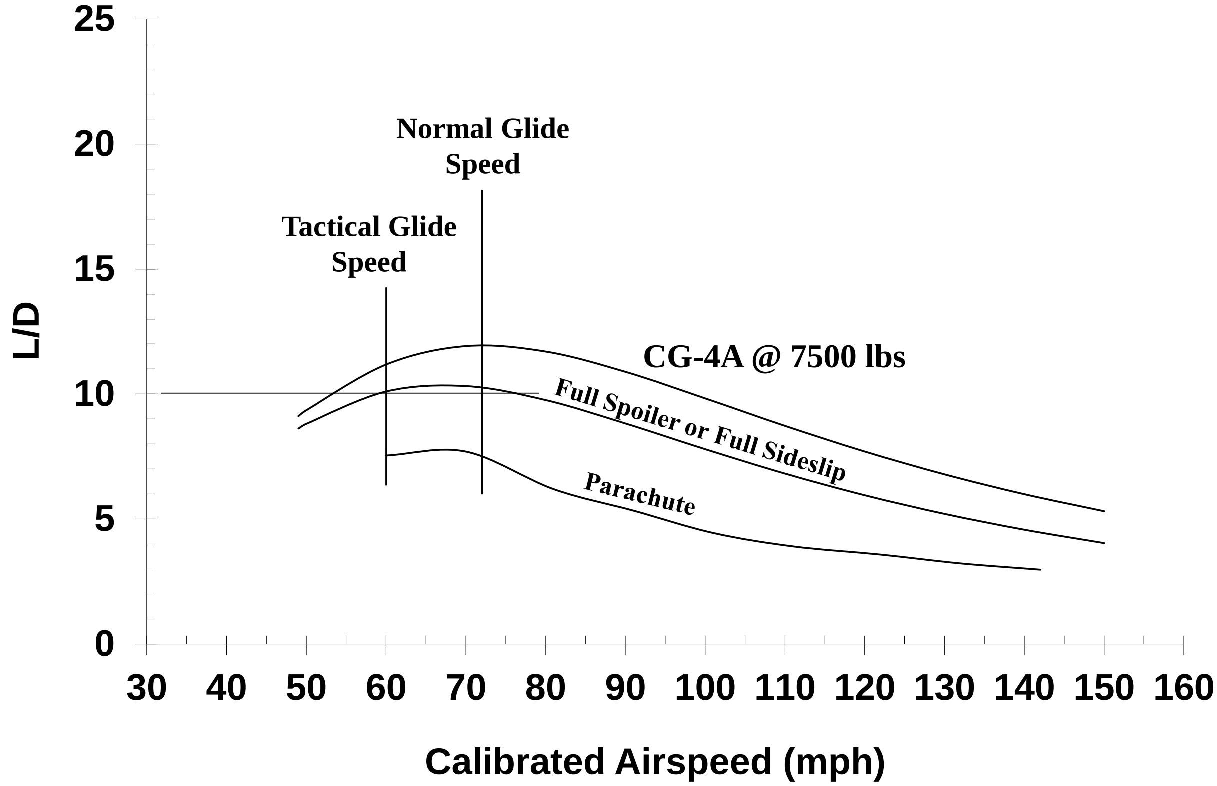
The landing pattern used for TPS gliders is a constant descent angle corresponding to an L/D = 10. This figure shows that using spoilers on the SGS 2-33 in the normal approach speed range, it is possible to decrease the L/D to the desired value of 10. Therefore, the SGS 2-33 has sufficient drag available from the spoilers to fly the desired approach angle.

As mentioned before, the G-103 spoilers were even more effective, which is reasonable. The G-103 with spoilers closed has a maximum L/D of 36, so more effective spoilers are required to reduce the L/D to 10 to fly the approach.

The Waco CG-4A spoilers were each 73.125 inches in span and 5.125 inches in height. With one spoiler on each wing, these two spoilers added up to a total spoiler area of 5.2 square feet. As a ratio of spoiler area to wing area, this was tiny. However, that is not the appropriate measure to compare the spoilers. Assuming that the CG-4A spoilers had the same drag coefficient (relative to spoiler area) as those for the SGS 2-33, the following descent rate chart was calculated.



Note that at Tactical Glide Speed or Normal Glide Speed the spoilers don't immediately seem very effective. Unlike the SGS 2-33 where the spoilers doubled the descent rate, the spoilers on the CG-4A only seem to increase the descent rate by maybe ten percent. To properly evaluate if the spoilers are sufficient, we need to look at this plot of L/D by airspeed.



The key difference to see is that while on the SGS 2-33 the spoilers needed to reduce the L/D from 20 to 10, on the CG-4A the spoilers only need to reduce the L/D from 12 to 10. Since the CG-4A started almost at the required L/D for landing approach, it didn't need any bigger spoilers. Therefore, what seemed to be undersized spoilers at first glance were actually sufficient.

As for pilot actions required to actuate the spoilers, the following notes come from Reference 2:

"Most glider spoiler controls operate like the handbrake on an automobile, except that you cannot set them. It requires considerable pressure to pull the spoiler stick back, and then you must hold it in the desired position.

Because spoilers decrease the over-all lift of the wing, the nose tends to drop, causing the glider to pick up speed. Use considerable back pressure on the control wheel to compensate for this, and hold constant airspeed.

Caution: Don't release the spoiler control lever suddenly. Ease it back to closed position. A sudden release causes the glider to balloon.

Use spoilers at any time to dissipate altitude. If necessary, you may use a combination of slip with spoilers."

Sideslip Effectiveness

The effectiveness of full pedal sideslip to increase drag and thus increase descent rate was also tested on the SGS 2-33. By coincidence, a full pedal sideslip (spoilers closed) produced the same descent rate as full spoilers. Thus, the earlier SGS 2-33 figures showed the same curve marked for descent rate with full spoilers OR with full pedal sideslip.

The SGS 2-33 was chosen as the analog for sideslip in the CG-4A because both have rather flat fuselage sides, and thus could be considered to be equally effective in increasing descent rates. Thus, the full spoiler curves in the CG-4A figures are also marked for full pedal sideslip. Thus, we can conclude that the sideslip effectiveness was sufficient for getting the desired approach angle. Since sideslip was allowed with spoilers deployed, the combined effect is expected to be roughly twice that of either spoilers or sideslip alone (linearity assumed), which would really be able to increase the descent angle.

Drag Parachute Effectiveness

The Drag Parachute, if installed, had a diameter of 10 feet (Ref 6). The maximum deployment airspeed for the parachute was 140 mph IAS. "With a moderate pull up to level flying position the glider can be decelerated from 150 to 75 mph glider indicated air speed in 30 seconds with a loss in altitude of approximately 500 feet" (Ref 1). Reference 1 gives the following rate of descent data:

Waco CG-4A Descent Rate with Drag Parachute (Ref 1)

Miles per Hour Indicated Air Speed	Feet per Minute With Parachute Open
150	4200
140	3600
130	3000
120	2500
110	2000
100	1500
90	1150
80	800
70	700

These data are plotted on the previous CG-4A descent rate and L/D figures. These figures show that the parachute was very effective in increasing descent rate and decreasing L/D. As shown in Appendix B, the frontal area of the parachute was estimated at 31.8 square feet, which was six times larger than the spoilers. Thus, it is reasonable that the parachute would create a large reduction in L/D. The problem with the drag parachute was that it was all or nothing—you got all of the drag or none of the drag. The amount of drag could not be modulated. Also, it was a one time use. Deploy the parachute and get all of the drag. Jettison it and you can't use it anymore.

Roll Performance

To investigate the roll performance of the Waco CG-4A, consider the previous overlay of the CG-4A on the C-53D. With the spans matched, the wing areas appear to be similar, and the ailerons have similar areas and location on the span, so it is reasonable to assume that the roll performance of the CG-4A would be similar to that of the C-53D. Reference 12 only states that for the C-53D "Roll forces were significant". Wheel deflection for full aileron in the C-53D was 180 degrees. Wheel deflection for full aileron in the CG-4A was 135 degrees. Aileron force in the CG-4A was reduced by comparison because of the much slower airspeed (lower dynamic pressure) and the large servo tabs on the ailerons.

The upper bound of the roll inertia (I_{xx}) for the CG-4A was the roll inertia of the C-53D. The CG-4A did not have the mass of the engines and nacelles, but the wood construction of the CG-4A wing is suspected to be heavier than the aluminum construction of the C-53D wing, so the roll inertias may have been similar. Reference 2, discussing crabbing to a crosswind landing, states "The long, heavy wings make it difficult for the pilot to swing the glider into position at the last minute." While this quote refers to yaw inertia (I_{zz}), the heavy wings would also affect roll inertia.

The roll performance of the C-53D was sufficient for the mission, so it is suspected that the roll performance of the CG-4A was also sufficient.

In the video (Ref 29) at 2:38, a CG-4A glider is seen rolling out from a base to final turn at an estimated roll rate of 28 degrees/second. Roll rate tests (Appendix B) of the Grob G-103 gave roll rates of 25 to 30 degrees/second. Roll rate tests of the Schweizer SGS 2-33 gave roll rates of 16 to 23 degrees/second. These roll rates are sufficient for the mission for the G-103 and the SGS 2-33, so it is inferred that the roll rate available in the CG-4A was sufficient for its mission.

Lateral-Directional Stability

The lateral stability (dihedral effect C_{l_β}) is suspected to be sufficient for the mission. The wing was built with 1.5 degrees of geometric dihedral (Ref 5). Additionally, the high wing position adds to the dihedral effect. The Bearhawk has sufficient lateral stability with 1 degree of geometric dihedral and a high wing. Reference 2 discusses that it is possible while slipping for a crosswind landing to touch the wing tip to the ground. Large bank angles in sideslip are indicative of a reasonably strong dihedral effect.

Looking at the previous side view overlay of the CG-4A and the C-53D, the proportions of the vertical tail area to side area are relatively similar. This implies that the directional stability (C_{n_β}) of the CG-4A was sufficient. The C-53D vertical stabilizer and rudder were sufficient for the mission. The CG-4A rudder did not have to counter engine-out yaw. The CG-4A rudder would be needed to counter adverse yaw. However, with the Frise aileron design and the comment during aerotow to "practice flying with your feet off the rudder pedals while on tow" (Ref 2), it is implied that adverse yaw was minimal. Study of various videos shows that lateral position on double tows was held primarily by bank angle rather than sideslip.

MIL-STD-1797B paragraph 5.2.3.8.4 Yaw control forces in rolls states "In the rolling maneuvers described in 5.2.3.5, but with coordination allowed, directional control effectiveness shall be adequate to maintain zero sideslip with pedal forces not greater than" 100 pounds (Ref 28). Based on the suspected minimal adverse yaw, it is suspected that the CG-4A had sufficient rudder effectiveness and would have been Level 1.

Reference 2 discusses crosswind landing techniques, with no mention of being rudder limited.

Reference 2 also states for sideslips "lower the wing 20° to 30° on the side to which you plan to slip as you apply full opposite rudder." Thus, full rudder could be used for sideslips. Reference 2 goes on to say "Use aileron to control the direction of flight." MIL-STD-1797B paragraph 5.2.3.9.4 Roll control power in steady sideslips states "For Levels 1 and 2, positive effective dihedral shall never be so great that more than 75% of roll control power available to the pilot, and no more than 20 lbs of roll control force, are required for sideslip angles which might be experienced in service employment" (Ref 28). It is suspected that this paragraph would be met as the statement in Reference 2 implies there would be no trouble having enough aileron to stabilize the sideslip.

~~Crashing~~ Landing

While both TPS gliders and Waco CG-4A cargo gliders land in gliding flight, the piloting methods used are very different, as the objectives for the landing are very different. For TPS gliders executing a normal landing, the approach is made to a prepared airport with a clear runway, with the objective of coming to a stop at a particular point. TPS gliders use an approach speed of 55 + half the expected headwind (good for whatever units the airspeed is presented in), which results in an airspeed greater than best glide speed, as shown in the next figure. This puts the glider on the "front side" where the flight path response to pitch is "normal", which is to say pitching up reduces the rate of descent, and pitching down increases the rate of descent.

Even though the approach is made on the front side, pilots are taught to use a "back side" technique. In this technique, the pitch stick is used to control airspeed, pitching down to increase airspeed, or pitching up to decrease airspeed. Drag devices, such as spoilers or flaps, are used to control the flight path (rate of descent). These drag devices are typically large enough to make substantial changes to the flight path. If additional drag is needed for a steeper approach, a sideslip may be used. Drag devices are actuated with the left hand, pulling for more drag and pushing for less drag. In this respect, the control motions are similar to operating a throttle on a powered aircraft. Using these techniques, it is possible to repeatedly land the glider at the same location each time.

The additional airspeed used with headwinds gives better penetration into the headwind, allowing better control and keeping the ground speed up. Higher winds may be accompanied by low level wind shear, causing a sudden decrease of airspeed on short final. The additional airspeed gives more cushion for dealing with wind shear. The glider lands with more speed than necessary, which provides extra energy to roll to the desired stopping point.

TPS gliders always land on the runway back at the airport. Similar gliders, while flying cross country, may be required to land on an unprepared field. In this case, the objective is to land as slow as possible, so as to have the minimum amount of energy to dissipate by braking after landing. This generally results in slowing during the final approach to just above stall speed.

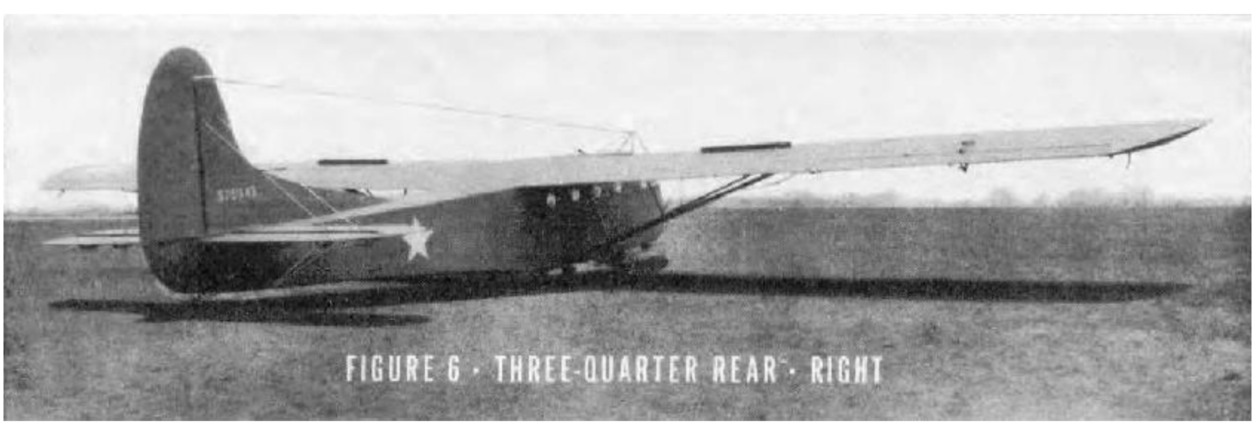
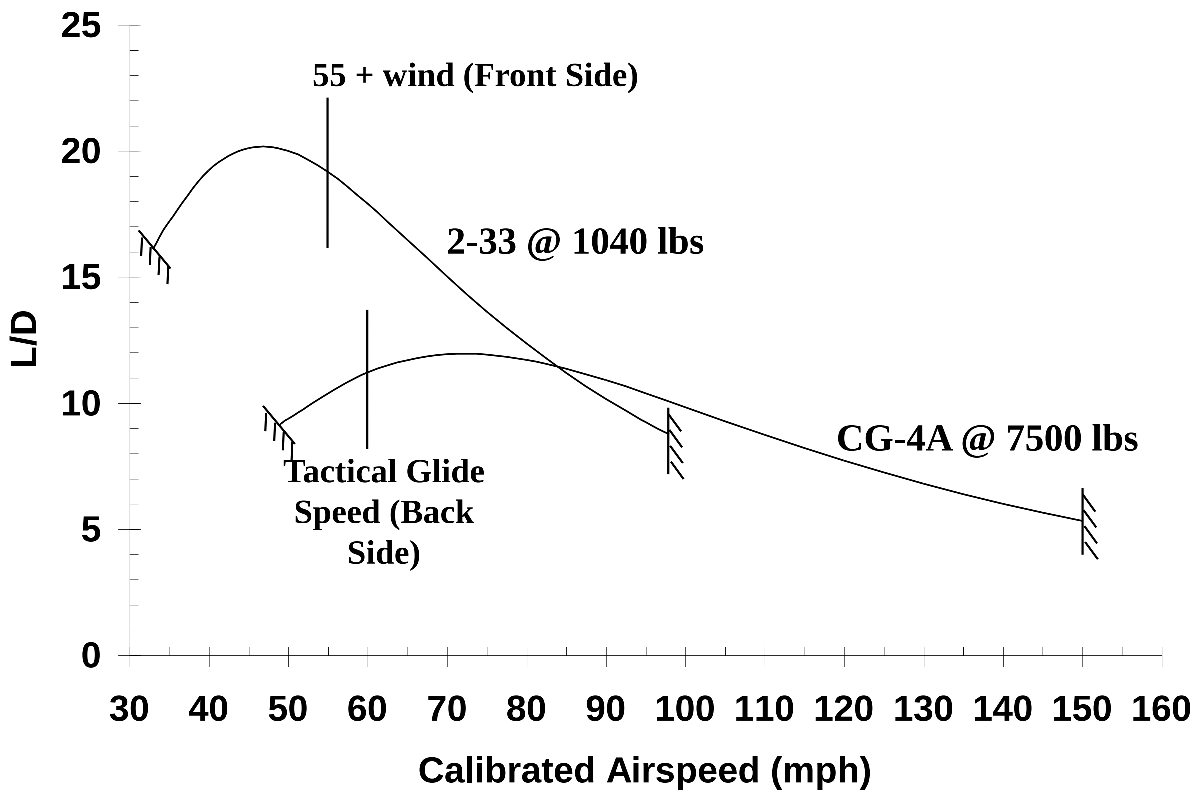


FIGURE 6 · THREE-QUARTER REAR · RIGHT



Typical Approach Speeds

Combat gliders had very different objectives for landing. The landing zone was nothing like a well prepared airport. Landing zones in France were typically farmer's fields, which were bounded by hedgerows, with only a few hundred feet between them. Multiple gliders were generally trying to land in the same field, so with each glider landing there was even less space for the next glider. The enemy suspected that gliders would be used, so they erected wooden poles like telephone poles throughout many of the most likely landing fields. These poles were commonly referred to as "Rommel's Asparagus". The earlier picture from the Silent Wings museum of a CG-4A unloading a Jeep shows the leading edge of the wing impaled on such a tree or pole. To add to the fun, there may be people shooting at you because they would rather you not be there. Unlike the TPS glider landings, it may not be nice weather during the day. You may be landing in bad weather or at night.

All of these considerations added up to the desire to be able to land as slow as possible in as short of a distance as possible. This minimized the energy to dissipate after landing. Since it was almost inevitable that you would run into something upon landing, it was best to hit that something as slow as possible to minimize damage. Hence the reason for approaching at tactical glide speed, about as slow as possible without stalling. This resulted in an approach very much on the "back side". In this case, the flight path response to pitch input was reversed. Pitching down increased airspeed, which decreased drag and the descent rate was reduced. Conversely, pitching up reduced airspeed, which increased drag and the descent rate was increased. As stated in Reference 2, "The use of the tactical glide gives maximum control over your glide angle, as follows: 1. To steepen your glide path, raise the nose a few degrees, decreasing the airspeed. 2. To flatten the glide path, lower the nose, increasing the airspeed."

Sometimes it was necessary to fly at a higher airspeed for better penetration into a head wind, where flying at tactical glide speed might cause the glider to land short.

Landing With A Headwind

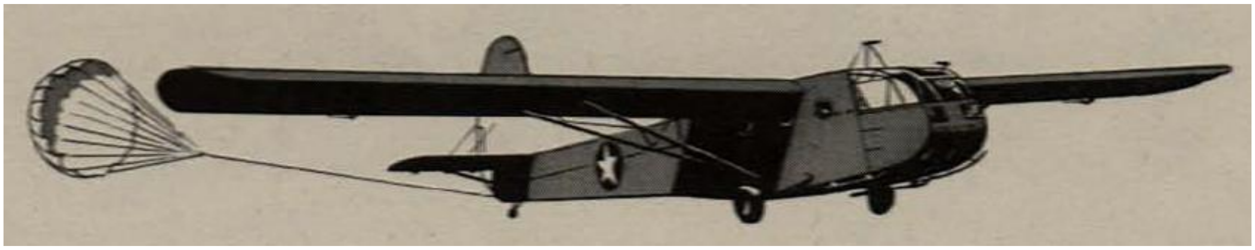
This example of a landing aimpoint, taken from Reference 2, looks like the glider is about to run into that building ahead. Maybe he should have pointed a little more to the left.

If additional drag was required to steepen the glide path, either pilot could deploy spoilers, which were on the top of the wings.

Top surface spoilers

Slips were also available as a means to increase drag and thus increase the descent rate. One can imagine that slips would be very effective with the large, flat sides of the fuselage. Reference 2 warns to “Be *Cautious* about using the slipping turn under emergency gross weight conditions.” While no explanation was given for this caution, the suspicion is that if the glider was very heavy, then it was probably flying very close to stall speed. If the airspeed was allowed to decrease during the slip (likely since this was a high drag maneuver), there was a strong likelihood that the glider would stall in the slip and fall into an incipient spin without recovery altitude available.

Some CG-4A gliders were equipped with a tail parachute. This parachute could be used to create drag to increase descent rate if too high on the approach, or to reduce airspeed if too fast on a low approach. However, this parachute was a one-time use item. If the parachute was in use but creating too much drag for continued use, it could be jettisoned.



Flight Path Stability

As mentioned before, the Waco CG-4A flying an approach at tactical glide speed was very much on the back side. Because the long term reactions of the glider to changes in airspeed were different from those normally expected, it could be easy for the pilot to get confused. Pilots could be trained to fly this way, but it took a lot of effort to get them to think this way. Reference 2 recognized this problem with the following advice:

"In playing the glide speed to control the glide angle, the desired results do not occur immediately. For example, when you raise the nose of your glider to decrease the airspeed, and so steepen the glide angle, the first result is an abrupt leveling off, or even climbing, as the excess airspeed is dissipated.

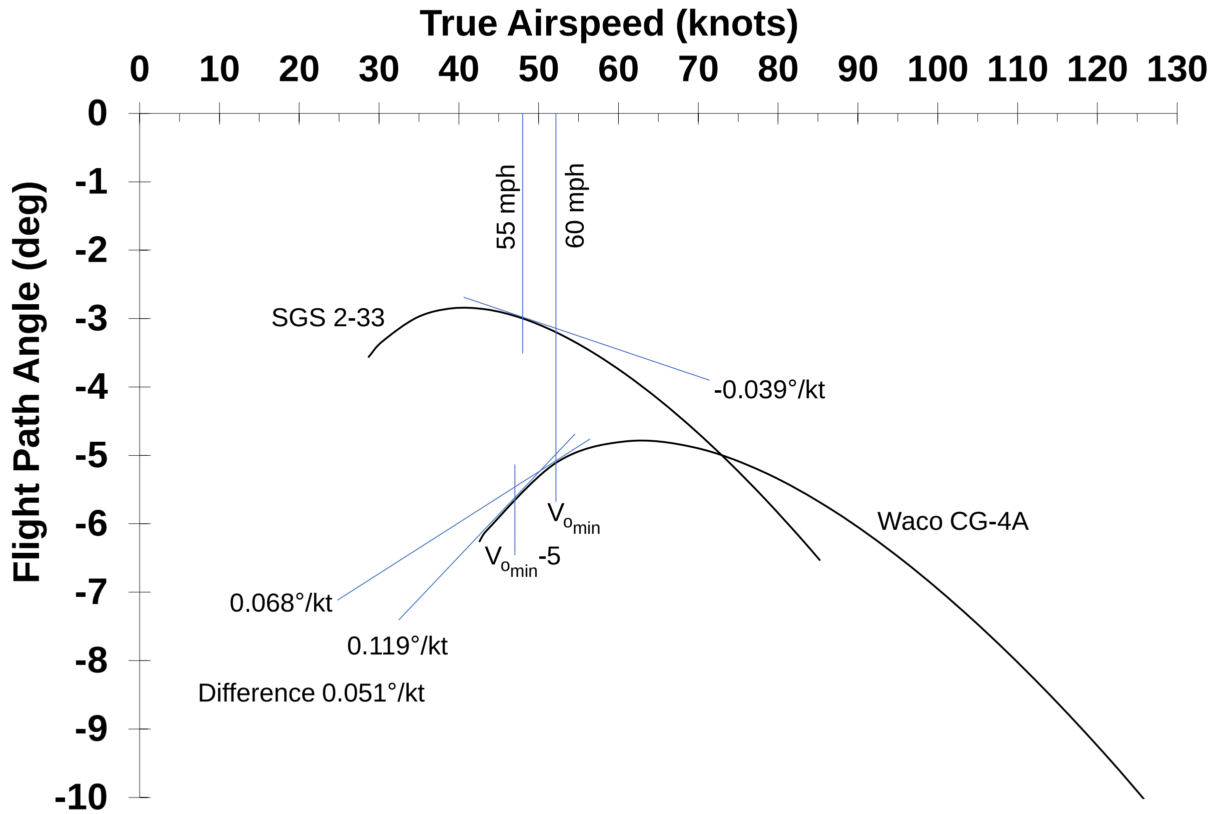
Likewise, when you lower the nose to increase the airspeed and so lengthen the glide, the most noticeable immediate effect is a loss in altitude. These reactions are confusing and, unless anticipated, may make you think you have applied the wrong technique. When in danger of undershooting and the trees look close, you need plenty of will power and great faith in your own knowledge of aerodynamics to make the only correction possible and lower your glider's nose."

Years later, MIL-STD-1797B (Ref 28) would recognize this behaviour, acknowledging that a pilot could successfully fly a back side approach like this as long as the aircraft wasn't "too far" on the backside. In paragraph 5.2.2.1.2.3 Steady-state flight path response to pitch controller, MIL-STD-1797B gives the following recommendation on how far on the back side is too far:

"For flight control modes in which flight path is controlled primarily through the pitch controller, with thrust at the setting required for the normal approach glide path at $V_{o_{min}}$, the curve of flight path angle versus true airspeed shall have a local slope at $V_{o_{min}}$ which is negative or less positive than 0.06°/kt (Level 1). The slope of the curve of flight path angle versus airspeed at 5 kts slower than $V_{o_{min}}$ shall not be more than 0.05°/kt more positive than the slope at $V_{o_{min}}$."

In the next figure, the previous L/D versus true airspeed data have been manipulated to show the flight path angle versus true airspeed. The true airspeed unit has been converted to knots since that is how MIL-STD-1797B is written. The slope of flight path angle versus true airspeed for the SGS 2-33 at approach speed (here 55 mph) is negative, and thus satisfies this requirement at Level 1. The glider is on the front side, so raising the nose decreases the flight path angle, and lowering the nose increases the flight path angle, which is intuitive for the pilot.

For the Waco CG-4A, the slope of flight path angle versus true airspeed at approach speed (tactical glide speed) has a positive slope of 0.068°/kt, which is slightly more positive than the Level 1 requirement of 0.06°/kt. The slope of flight path angle versus true airspeed at 5 knots slower than approach speed (tactical glide speed – 5kt) has a positive slope of 0.119°/kt, for a difference of 0.051°/kt. Again, this is slightly more than allowed for Level 1. Thus, the flight path stability of the Waco CG-4A was slightly into Level 2. This meant that flying the approach was a little more challenging than ideal, but still manageable.



Landing Patterns

TPS gliders normally will enter the landing pattern on a downwind leg, followed by base and final. This allows multiple ways to adjust the approach through use of spoilers or modifying the length of each leg so as to end up on the desired approach path on final.

There was no single landing pattern defined for the Waco CG-4A. Reference 2 shows at least five options to choose from, depending on the release heading and the desired landing heading. It is interesting that the 360° pattern is not a rectangle but a triangle. What is notable by its absence is any sort of straight in approach. A straight in approach leaves very few options for adjusting the flight path, and no options if the glider is low on energy. All of the approach paths shown have a base leg, which can be turned slightly left or right to intercept the final approach at the right glide path.

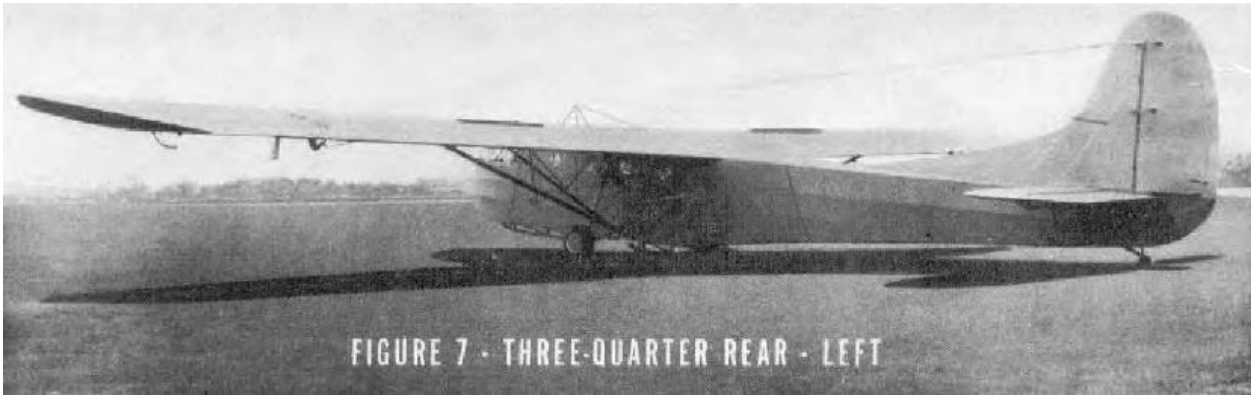
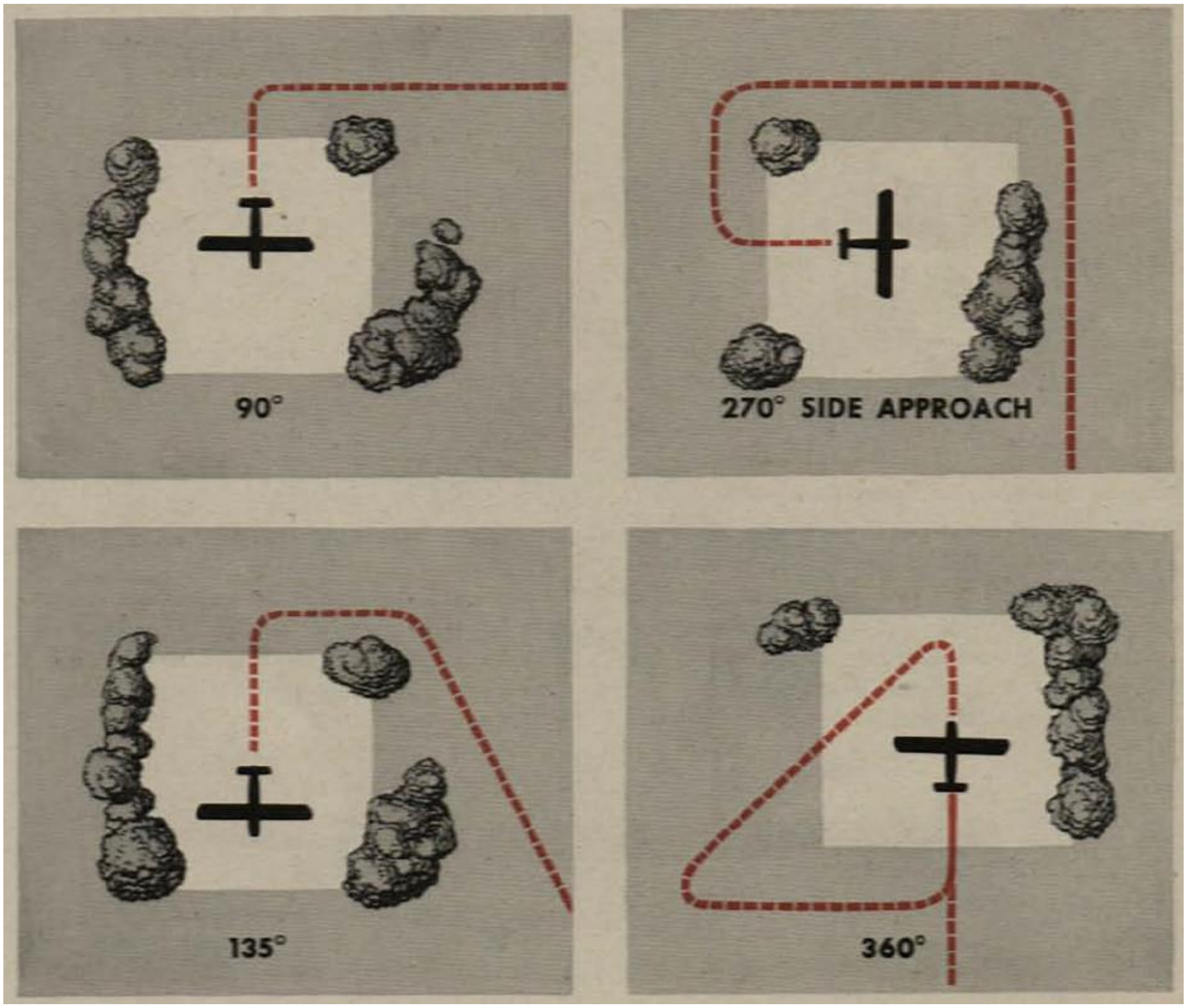
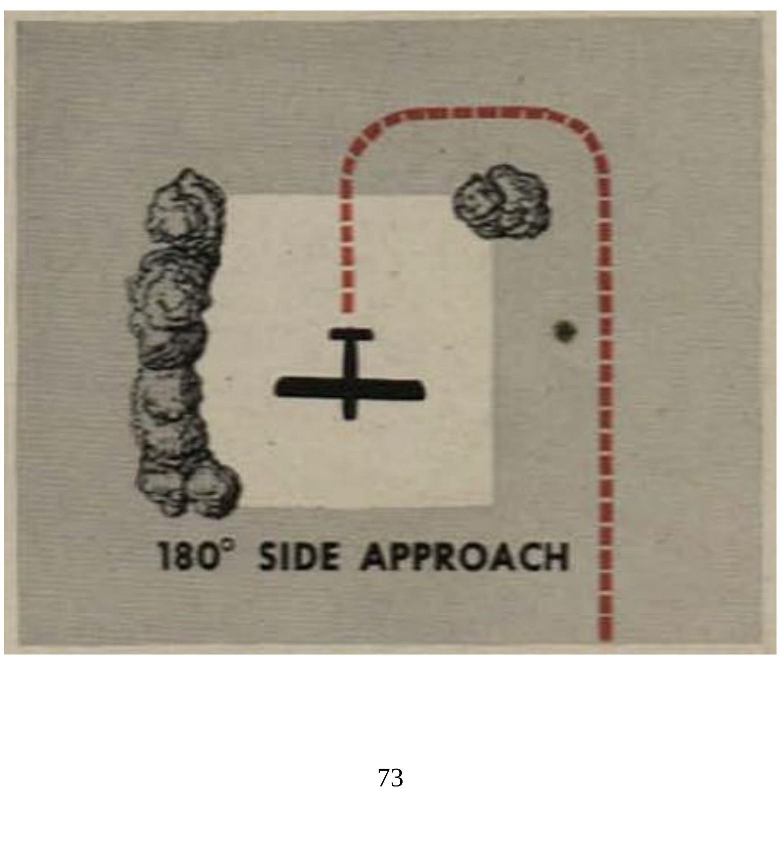


FIGURE 7 - THREE-QUARTER REAR - LEFT

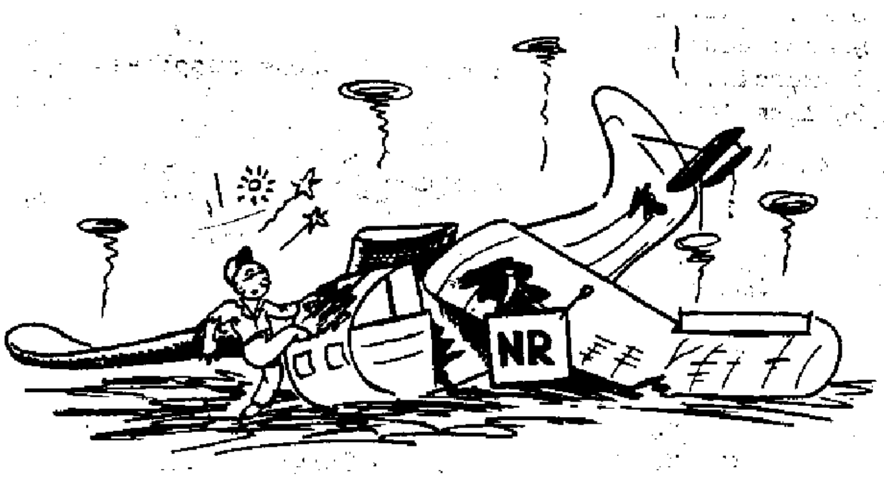

90°
270° SIDE APPROACH
135°
360°


180° SIDE APPROACH

Normal Landing Outcome

For TPS gliders, the normal outcome after landing is that the glider is undamaged and ready to fly again. If properly managed, the glider is probably perfectly positioned to hook up the towline and take off again.

For the Waco CG-4A, after landing in the combat zone, if you were lucky, no one was injured and the cargo could be unloaded and used. It was highly likely that the glider was damaged and could not be used again. One story goes that after the Normandy landings, a group was sent to recover as many gliders as they could for reuse. After all, gliders were expensive and in limited supply. Of all the hundreds of gliders sent over the Normandy beaches, they found like 13 gliders that were undamaged. It didn't help that the troops who had just landed regarded the gliders as a source of materials for other uses and would start "parting them out". Some gliders were repaired sufficiently using pieces of other gliders to be flown out for reuse.



Training Aircraft

The Waco CG-4A and other allied cargo gliders were a response to Germany's use of gliders in combat. The CG-4A first flight was in 1942, after the German glider attack on FortÉben-Émael in May 1940. Because this was a quick reaction design, there was little time for development. Also lacking in this development was a suitable training system other than flying the large cargo glider, which was not a good introduction for *ab initio* pilots.

Prior to the war, any gliders commercially available were built as sailplanes. The most readily available two place glider was the Schweizer SGS 2-8, also known as the "Schweizer Two-Place". There were 57 gliders in existence at the beginning of World War II, and the US Army Air Force tracked down all of them and bought them all for military training from their civilian owners. These gliders were given the designation TG-2A. The USAAF ordered production models as the TG-2, and the US Navy and US Marines ordered production models as the LNS-1.

Schweizer SGS 2-8 (TG-2)

The TG-2 had aluminum wings with a steel tube fuselage and tail covered in fabric. As aluminum was considered a "strategic material", the military requested Schweizer to redesign the glider using a wood frame with fabric covering. This model was the Schweizer SGS 2-12, designated the TG-3A by the USAAF. This model also included some improvements, such as changing the wing to a cantilever low wing to improve instructor visibility from the rear cockpit.

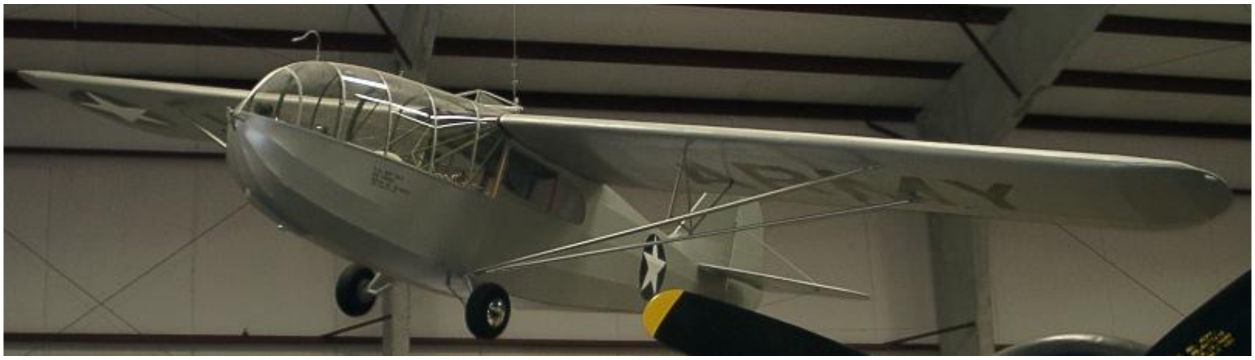
Schweizer SGS 2-12 (TG-3) at the National Museum of the United States Air Force

However, because “the CG-4A was not designed as a sailplane” (Ref 2), these sailplanes had such different glide performance from the CG-4A that they did not provide good training analogs. This was seen earlier in the comparison of the glide performance of the SGS 2-33 and the CG-4A. Also mentioned earlier was that the gliding performance of the CG-4A was similar to that of other light planes with their engine idling or shut down. As such, the USAAF turned to light plane manufacturers to provide converted light planes as training aircraft for cargo gliders. Because of the urgency of the war, the first prototype was developed in nine days. In each case, the engine was removed and the cockpit was extended. An additional pilot seat was added where the engine had been, avoiding the need for changing the rest of the airplane to achieve proper weight and balance. Assuming the other two seats remained in their original positions, the new seat was fairly far forward, as the weight of the pilot was similar to or slightly less than the weight of the engine the pilot replaced. Thus, all of these training gliders had three seats in tandem. The third seat could be used to carry an additional student pilot to observe and learn. These training aircraft provided a much better performance match with the Waco CG-4A gliders.

All of the conversions had their landing gear legs shortened to better replicate the ground attitude of the Waco CG-4A.

A Taylorcraft L-2. This example was actually originally built as a TG-6 and was converted back to the L-2 configuration after the war

Taylorcraft TG-6 (modified L-2)



Taylorcraft TG-6 (modified L-2) (Pima Air Museum)

Aeronca L-3

Aeronca TG-5 (modified L-3)

Piper L-4

Piper TG-8 (modified L-4)

Examples of these training gliders are extremely rare today, because most of them were sold off to civilian owners, who converted them back to their original powered airplane configuration. The training gliders had no value as sailplanes because of their low glide performance, which is what made them perfect as trainers for the Waco CG-4A.

The Pima Air & Space Museum in Tucson AZ has a TG-6 on display. The Western Antique Aeroplane & Automobile Museum of Hood River OR has a TG-8 and a TG-6 which are maintained in flyable condition. These gliders were on display and flown at Airventure 2018, as shown in the video *Gliding to Success World War II Training Gliders* (https://youtu.be/JTGJcNo2LU0?si=HRx94i8IuEhUOchb) (Ref 30).

Flight Training Common Student Errors

Reference 2 has a rather interesting section in it, aimed at young glider instructors. This section lists common student errors and other problems that an instructor should watch for in his students. To wit:

Common Errors in Attitude

1. Lack of military discipline
2. Being disinterested, listless
3. Disliking flying
4. Non-aggressiveness, lack of initiative
5. Not asking pertinent questions
6. Asking unnecessary questions
7. Being surly, resentful
8. Fearing glider, or a specific maneuver
9. Wasting solo time
10. Wasting spare ground time
11. Cockiness
12. Lacking self reliance
13. Polishing the apple

Common Errors in Technique

1. Not coordinating; no feel of glider
2. Varying speed in turn
3. Rough control movements (tense, jerky)
4. Making corrections too slowly
5. Carelessness about details

Common Errors in Judgement

1. Not thinking ahead of glider
2. Making dangerously low turns
3. Slow in making decisions
4. Recklessness
5. Poor judgment of speed and distance

Common Errors in Progress

1. Slow understanding
2. Poor retention of instruction
3. Lack of progress after adequate instruction

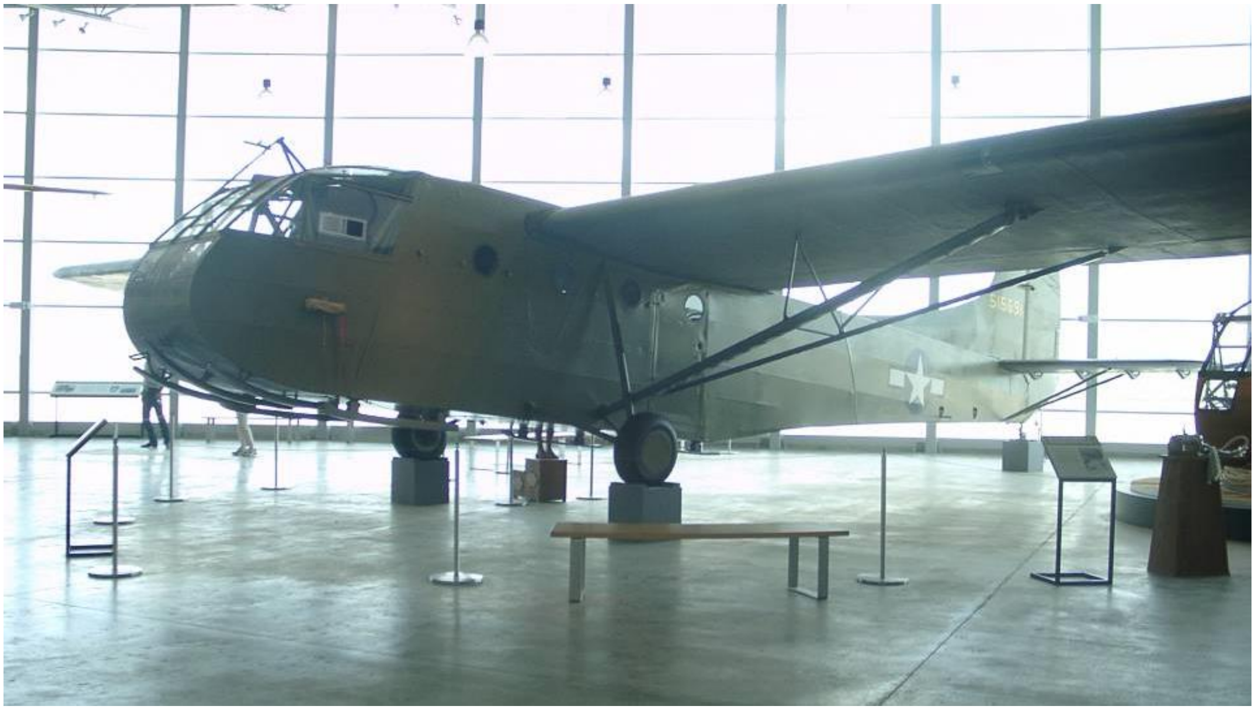
As a glider instructor for over 20 years, all I can say is **"Some things just never change!"**

Where'd They All Go?

There are a few Waco CG-4A gliders remaining on display. Reference 11 states that 13,905 gliders were built. Most were used during the war, and most of those were destroyed to some extent in action. Quite a few were built that were still waiting to be shipped when the war concluded. By the USAAF contract, each glider was shipped in five substantial large wooden crates. Since Oriented Strand Board (OSB) wasn't invented until 1963, the crates were constructed of 10,000 board feet of select lumber. After the war, these gliders were declared surplus and the USAAF was in a hurry to offload excess inventory. These undelivered gliders were sold to civilian buyers for pennies on the dollar. Most of these buyers were far more interested in the crate materials, which were worth more than the selling price. As for the gliders in the crates, these were generally disposed of by whatever means was convenient. Others were bought for conversion to towed camping homes with the wing and tail end cut off and being towed by the rear section. Others were used as hunting cabins and lake side vacation cabins (Ref 11).

Perhaps the most accessible completely restored Waco CG-4A is at the Silent Wings Museum in Lubbock TX (http://www.silentwingsmuseum.com). The museum is located in the former terminal building of the Lubbock airport (KLBB). The CG-4A is the centerpiece of the collection.

Silent Wings Museum, Lubbock International Airport (KLBB)



Silent Wings Museum Waco CG-4A 45-15691

This glider was manufactured by Ford Motor Company at its Iron Mountain Plant in Kingsford MI under a Fiscal Year 1945 contract (Ref 6, 11). The majority of this glider served as a unique advertising piece for nearly 30 years in Fresno CA. It was emblazoned with "Commercial Tire". The National World War II Glider Pilots Association removed this glider from its rooftop perch on 6 March 1976 (https://youtu.be/BklWWzyMV6Q?si=feiKRgcTosqr7uww) (Ref 31). They combined this CG-4A with other salvaged gliders to create the CG-4A on display.

Silent Wings Museum Waco CG-4A at its previous job in Fresno CA (Ref 32)

Another Waco CG-4A is on display, hanging from the ceiling of the National Museum of the Air Force at Wright-Patterson Air Force Base, Dayton OH. This glider on display was built by Gibson Refrigerator Company in Greenville MI and was accepted by the US Army Air Forces in July 1945.

National Museum of the US Air Force Waco CG-4A 45-27948

Several other examples are listed on display on the Wikipedia page "Waco CG-4" (Ref 11).

Why Don't We Use Combat Gliders Any More?

Prior to 1940, none of the Allied powers had even thought of a combat glider mission. The Axis powers surprised the world on 10 May 1940 by attacking the Belgian fortress of Ében-Émael using gliders. Within two years, the Waco CG-4A made its first flight in May 1942. At this time, combat gliders were the best practical solution for this mission set. Only about 10 years later, the last known use of the Waco CG-4A by the USAF was in the early 1950s (Ref 11). By this time, the role of delivering men and materials to small landing areas had been taken over by helicopters, which had been developed and were rapidly increasing in capability. By the early part of the Vietnam war, the Bell UH-1C Huey helicopter had a nominal useful load of 4673 pounds, greater than the useful load of 3900 pounds for a Waco CG-4A at design gross weight. The Bell UH-1D could carry two pilots and 13 troops, the same capacity as the CG-4A. While a Jeep wouldn't fit inside the helicopter, it could certainly be transported as a sling load below the helicopter. The helicopters had the obvious advantages of not requiring a tow plane and being able to land with a much lower likelihood of damage. Even better, the helicopters were not treated as expendable, being able to take off again and return to base, which was a much easier way for the pilots to get back to fly another mission. Other helicopters, such as the Boeing Vertol CH-47 Chinook would be developed with much higher useful loads than any of the World War II gliders.

Bell UH-1H Huey

Boeing Vertol CH-47 Chinook

The other mission of the cargo glider, transporting cargo to friendly bases, was picked up by airplanes as the US Air Force started to develop larger, purpose-built cargo aircraft. Even the USAAF experimented with eliminating the tow plane by mounting engines directly on cargo gliders. Several CG-4A gliders were equipped with two 200 HP engines, redesignated to the oxymoronic Powered Glider PG-2A. These did not have enough advantages to justify mass production. Purpose-built cargo aircraft included the C-82 Packet and C-119 Flying Boxcar. The C-123 Provider was a design derived by adding engines to the Chase XCG-20 assault glider. Later cargo aircraft included the C-124 Globemaster II, C-130 Hercules, and C-141 Starlifter. Current USAF cargo delivery is by the C-17 Globemaster III.

Boeing (nee McDonnell Douglas) C-17 Globemaster III

Thus, the cargo glider was a solution for its time, using the technology available at the time. Cargo gliders are now obsolete, having been replaced by other aircraft types with far less limitations.

Want to Know More?

The development of cargo gliders was not smooth, and was pretty much the poster child example of a military goat rope. Development was extremely rushed because of the needs of the war. Most of the companies who had any knowledge of aircraft design were busy designing and building airplanes. Thus, many contracts for glider design were let to companies with no experience in designing aircraft. The results were predictably disastrous. One company even tried to design a glider for the Navy that would take off and land on the water. It is not clear what the proposed mission for this glider was to be. It seems amazing that Waco (Weaver Aircraft Company) was able to create a useable design for a cargo glider. Then again, Waco was an aircraft company, having built many types of aircraft before the war. To better understand the mess that was the combat glider development program, I recommend *American Military Gliders of World War II* by Bill Norton (Ref 10).

- **Russ Erb**
USAF Flight Test Engineer
Glider Flight Instructor
Cargo Glider Afficianado

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Appendix A

Creation of Waco CG-4A Performance Charts

The performance charts started with the Power Required chart published in Reference 1, shown previously. Data points for Thrust Horsepower and True Airspeed (miles per hour) were pulled from the chart and entered in a spreadsheet. All three curves were used, including a gross weight of 4700 pounds (minimum operational weight), 7500 pounds (design gross weight), and 9000 pounds (emergency maximum gross weight).

Consider the following data.

True Airspeed	100 mph
Thrust Horsepower	205 HP
Gross Weight	7500 pounds
Altitude	0 feet
Wing Area	851.5 feet^2

The true airspeed and the power required were converted to consistent units.

$$\text{True Airspeed} = \frac{100 \text{ mile}}{\text{hour}}\left(\frac{5280 \text{ feet}}{\text{mile}}\right)\left(\frac{\text{hour}}{3600 \text{ sec}}\right) = 146.6 \ \frac{\text{feet}}{\text{sec}}$$

$$\text{Power Required} = 205 \text{ horsepower}\left(\frac{550 \ \frac{\text{feet-pound}}{\text{sec}}}{\text{horsepower}}\right) = 112750 \ \frac{\text{feet - pound}}{\text{sec}}$$

Assume that lift is equal to weight.

Lift = 7500 pound

Calculate drag from Power Required.

$$\text{Drag} = \frac{\text{Power Required}}{\text{True Airspeed}}$$

$$\text{Drag} = \frac{112750 \ \frac{\text{feet - pound}}{\text{sec}}}{146.6 \ \frac{\text{feet}}{\text{sec}}}$$

Drag = 769 pound

Since the chart is for sea level, the air density is 0.0023769 slug/feet^3. Thus, the lift and drag coefficients are given by

$$C_L = \frac{2 \text{ Lift}}{\rho V^2 S}$$

$$C_L = \frac{2 \text{ (7500 pound)}}{\left(0.0023769 \frac{\text{slug}}{\text{feet}^3}\right)\left(146.6 \ \frac{\text{feet}}{\text{sec}}\right)^2 (851.5 \text{ feet}^2)}$$

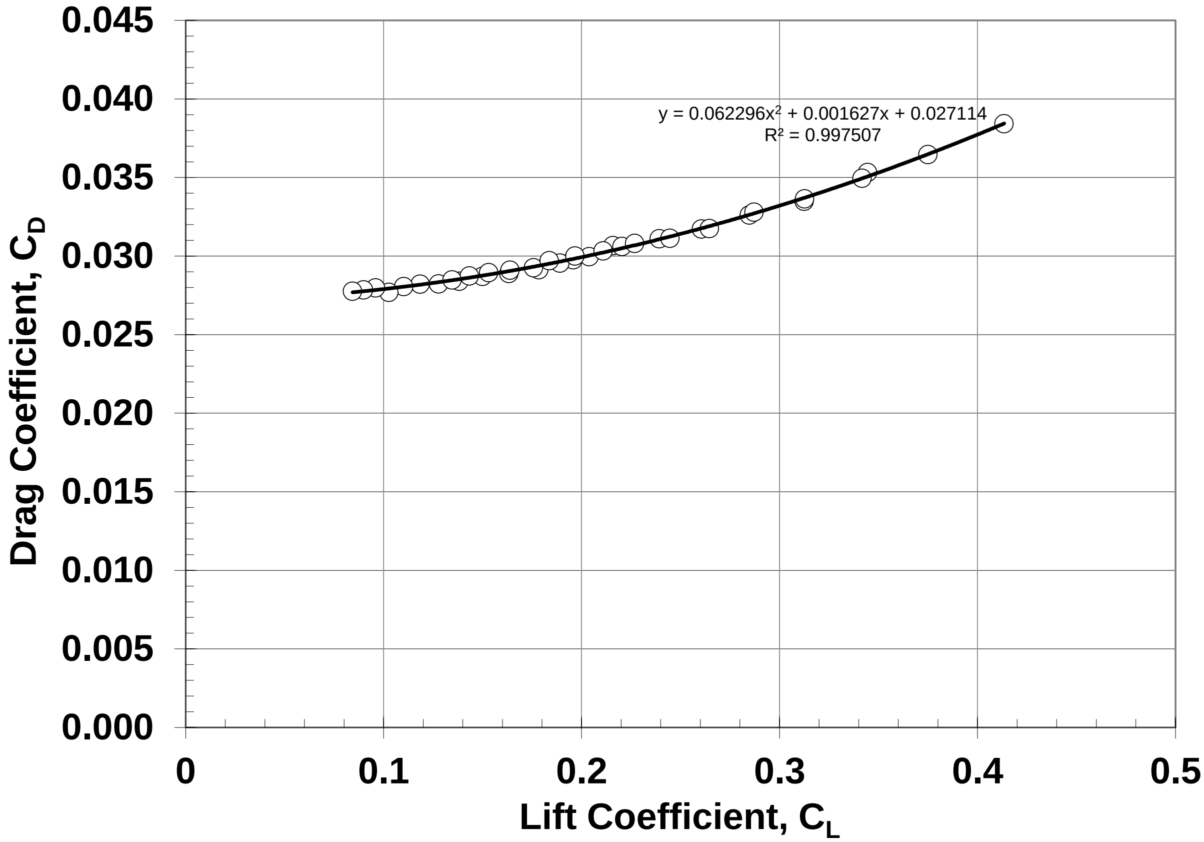
C_L = 0.344

$$C_D = \frac{2\ \text{Drag}}{\rho V^2 S}$$

$$C_D = \frac{2\ (769\ \text{pound})}{\left(0.0023769\,\frac{\text{slug}}{\text{feet}^3}\right)\left(146.6\ \frac{\text{feet}}{\text{sec}}\right)^2 (851.5\ \text{feet}^2)}$$

$$C_D = 0.0353$$

The values for lift and drag coefficient for all points derived from the Reference 1 Power Required curves, including all three gross weights, were plotted. A second order curve was fit to the data to derive a drag polar.



Waco CG-4A Drag Polar

The drag polar thus devised was

$$C_D = 0.02711 + 0.001721\ C_L + 0.062051\ C_L^2$$

(You may note that the coefficients given above vary slightly from the figure shown above. It has been over a decade since I created the original spreadsheet and pulled off the coefficients above, which were used to produce the charts shown in this article. The plot is what the spreadsheet shows as I create this article. Somewhere in that time some small change was probably made in the spreadsheet that changed the coefficients. This is not a large enough change to affect the conclusions, so I'm not wasting my time chasing this discrepancy.)

The Power Required chart from Reference 1 only covers airspeeds flown while on tow. The airspeeds flown in gliding flight are below the airspeeds shown on the chart. To analyze glide performance, we will assume that the derived drag polar is still valid at the higher lift coefficients found during gliding flight.

To create the L/D chart and sink rate chart, the following calculations were run across a range of airspeeds. Consider the following data.

Calibrated Airspeed	70 mph
Gross Weight	7500 pounds
Altitude	0 feet
Wing Area	851.5 feet^2

At Sea Level, the true airspeed is equal to the calibrated airspeed. The true airspeed was converted to consistent units.

$$\text{True Airspeed} = \frac{70\text{ mile}}{\text{hour}}\left(\frac{5280\text{ feet}}{\text{mile}}\right)\left(\frac{\text{hour}}{3600\text{ sec}}\right) = 102.6\ \frac{\text{feet}}{\text{sec}}$$

Assume that lift is equal to weight.

$$\text{Lift} = 7500\text{ pound}$$

Doing the calculations at sea level, the air density is 0.0023769 slug/feet^3. Thus, the lift and drag coefficients are given by

$$C_L = \frac{2\text{ Lift}}{\rho V^2 S}$$

$$C_L = \frac{2\,(7500\text{ pound})}{\left(0.0023769\,\frac{\text{slug}}{\text{feet}^3}\right)\left(102.6\ \frac{\text{feet}}{\text{sec}}\right)^2 (851.5\text{ feet}^2)}$$

$$C_L = 0.704$$

Calculate the drag coefficient from the drag polar.

$$C_D = 0.02711 + 0.001721(0.704) + 0.062051\,(0.704)^2$$

$$C_D = 0.0590$$

For L/D

$$\frac{L}{D} = \frac{C_L}{C_D} = \frac{0.704}{0.0590}$$

$$\frac{L}{D} = 11.9$$

The flight path angle is found by

$$\gamma = -\tan^{-1}\left(\frac{1}{\frac{L}{D}}\right)$$

$$\gamma = -4.8\text{ deg}$$

The sink rate in feet per minute is found by

$$V_s = V_t \sin\gamma \left(\frac{60\ \text{sec}}{\text{minute}}\right)$$

$$V_s = \left(102.6\ \frac{\text{feet}}{\text{sec}}\right)_t \sin(-4.8\ \text{deg}) \left(\frac{60\ \text{sec}}{\text{minute}}\right)$$

$$V_s = -515\,\frac{\text{feet}}{\text{minute}}$$

Appendix B

Estimating Roll Rate and Drag Device Effectiveness

To inform the estimations of roll rate and the effectiveness of drag devices, flight tests were flown on 24 and 26 July 2024. The test pilot was Tyler Sanders, and the Test Conductor/Flight Test Engineer was Russ Erb.

On 24 July 2024, the test aircraft was a Grob G-103 N4464P. This glider was selected for having similar spoilers to the Waco CG-4A. When fully extended, both glider's spoilers are a vertical flat plate. With a published maximum L/D of 36, the G-103 has much higher glide performance than the Waco CG-4A, which limits its usefulness as an analog for the CG-4A. Wing loading for the G-103 was 6.68 pound/square foot, compared to the Waco CG-4A at 8.81 pound/square foot.

On 26 July 2024, the test aircraft was a Schweizer SGS 2-33 N65824. This glider was selected because it was the oldest design available, thus the closest to the time of the Waco CG-4A. The SGS 2-33 also had flat sides like the CG-4A. The spoilers were above and below the wing. The published maximum L/D was 23, closer but certainly not equal to 12. Wing loading for the SGS 2-33 was 4.77 pound/square foot.

Roll Rate

Roll rate was measured for each glider in bank to bank rolls from 45 degrees of bank to 45 degrees of bank. No bank angle instrumentation was installed. Bank angle was estimated by aligning the instrument mounting screws with the horizon. Rolls were flown at best glide speed (G-103: 57 KIAS, SGS 2-33: 50 mph IAS). Rolls were coordinated, using full lateral stick and full coordinating rudder. Rolls were timed with a stopwatch.

Grob G-103

Direction of Roll	Time (sec)	Roll Rate (deg/sec)
Left	3.54	25.4
Left	3.56	25.3
Left	3.34	26.9
Right	2.97	30.3
Right	3.22	28.0
Right	3.38	26.6

Schweizer SGS 2-33

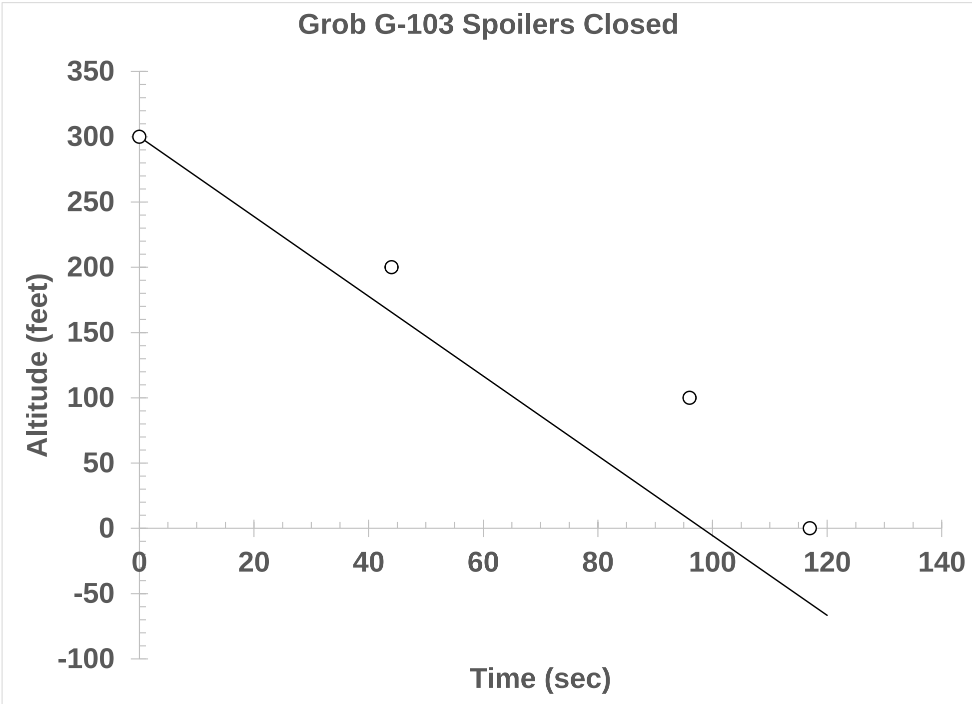
Direction of Roll	Time (sec)	Roll Rate (deg/sec)
Left	5.38	16.7
Left	4.13	21.8
Left	5.00	18.0
Right	3.97	22.7
Right	4.10	22.0
Right	4.29	21.0
Right	3.78	23.8

Spoiler and Sideslip Effectiveness

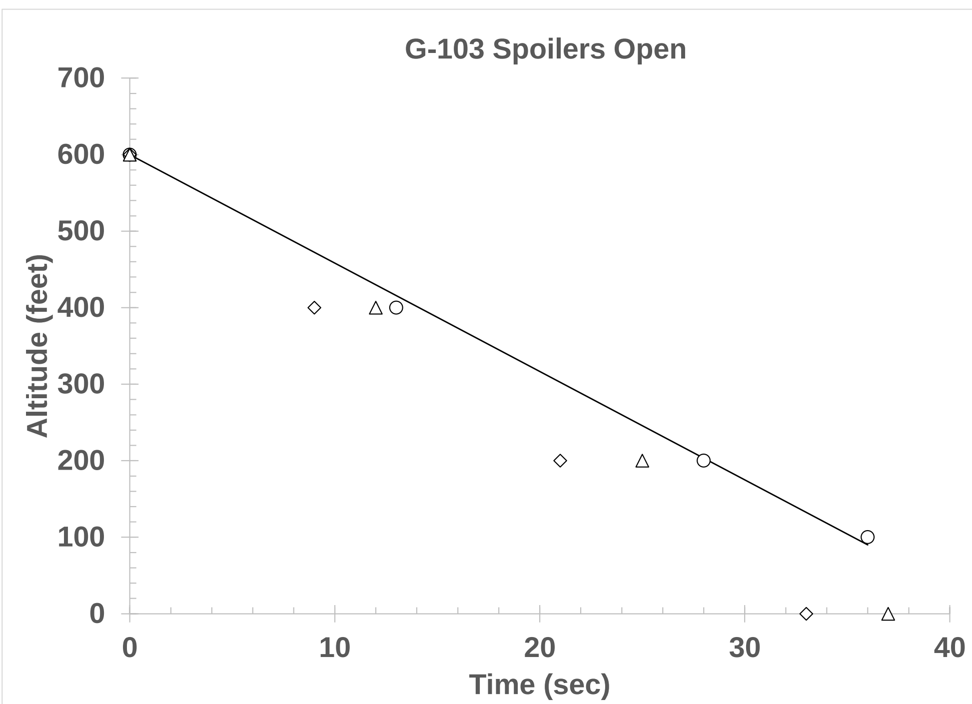
Spoiler effectiveness was measured by straight glides at best glide speed, recording time to descend, with spoilers closed and spoilers open. Sideslip effectiveness was measured similarly in a straight glide with full rudder sideslip.

Collecting rate of descent data in a straight glide seems like it would be simple and straightforward, but it turns out to be incredibly difficult to do, because any vertical movement of the air (up or down) can corrupt the data. Vertical air motion cannot be controlled and is difficult to detect real time. It can be mitigated by flying in the morning, but this is not guaranteed.

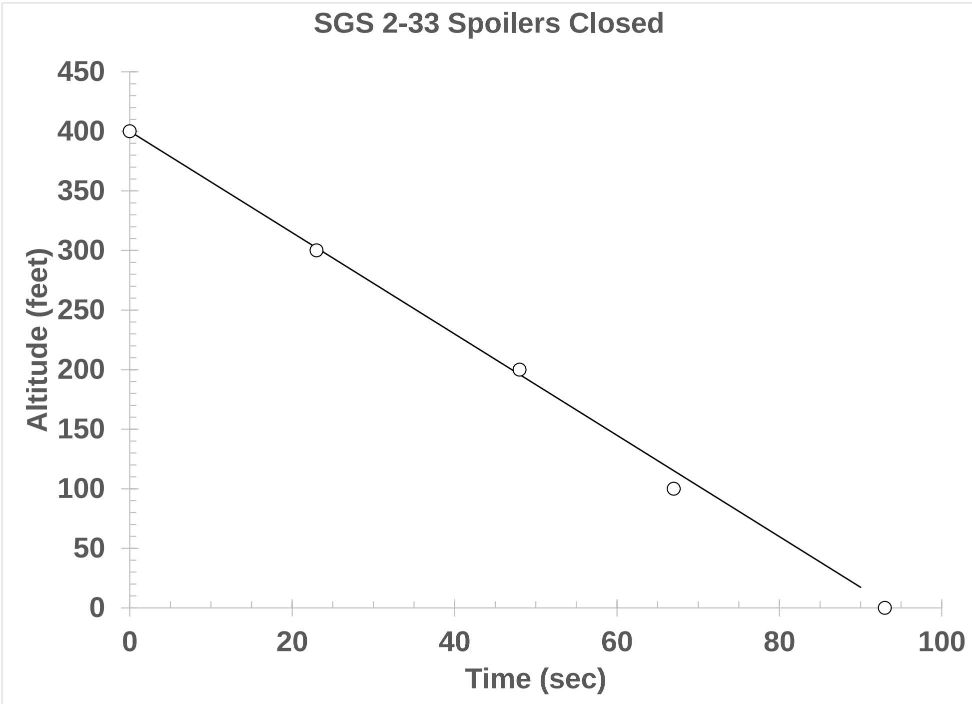
This plot shows the baseline data for the Grob G-103 with spoilers closed. Fitting a line closer to the data points results in a glide ratio of 44, which would be very questionable, since the published best glide ratio is 36. The line shown is for a glide ratio of 36, which gives a reasonable fit.



Three descents were flown in the Grob G-103 with spoilers full open, shown in the next plot. The run in circles was flown in the best conditions. Since the other runs show a faster descent rate, the circles show the minimum possible effectiveness of the spoilers and were thus chosen to be used for fitting. The line shown is a glide ratio of 7.69.



This plot shows the baseline data for the SGS 2-33 with spoilers closed. The line shown is for a glide ratio of 20, which matches the results from Reference 18.



The next plot shows the results of a straight glide in the SGS 2-33 with spoilers full open in circles. The line fit shown is a glide ratio of 10.8. Also shown in triangles are the results of a straight glide in the SGS 2-33 in a full pedal sideslip with spoilers closed. Quite by coincidence, the rate of descent with full spoilers and the rate of descent in a full pedal sideslip were essentially identical.

The rate of descent was determined by the slope of the line fit to the data. The glide ratio (L/D) was determined by dividing the true airspeed by the descent rate. Consider the SGS 2-33 Spoilers Closed data:

Airspeed	50 mph IAS
Altitude	7700 feet
Temperature	64 °F
Rate of Descent	255.15 feet per minute
Weight	1048 pounds

Find the true airspeed. The altimeter was set to local field setting. Assume minimal error in true airspeed by calling this altitude the pressure altitude.

$$\delta = (1\text{-}6.87559\text{x}10^{-6}\text{H}_c)^{5.2559}$$

$$\delta = (1\text{-}6.87559\text{x}10^{-6}(7700))^{5.2559}$$

$$\delta = 0.75134$$

$$\theta = \frac{\text{T} + 460}{519°\text{R}}$$

$$\theta = \frac{64°\text{F} + 460}{519°\text{R}}$$

$$\theta = 1.0096$$

$$\sigma = \frac{\delta}{\theta}$$

$$\sigma = \frac{0.75134}{1.0096}$$

$$\sigma = 0.74419$$

Assume Equivalent Airspeed is equal to Calibrated Airspeed because of very low speed. Assume no instrument error, so Calibrated Airspeed equals Indicated Airspeed.

$$\text{V}_t = \frac{\text{V}_e}{\sqrt{\sigma}}$$

$$\text{V}_t = \frac{50 \text{ mph}}{\sqrt{0.74419}}$$

$$\text{V}_t = 57.96 \text{ mph}\frac{88 \text{ fps}}{60 \text{ mph}} = 85.0 \ \frac{\text{feet}}{\text{sec}}$$

Calculate glide ratio

$$\text{V}_s = 255.15\frac{\text{feet}}{\text{min}}\frac{\text{min}}{60 \text{ sec}} = 4.252\frac{\text{feet}}{\text{sec}}$$

$$\text{L/D} = \frac{\text{V}_t}{\text{V}_s}$$

$$L/D = \frac{85.0 \text{ fps}}{4.252 \text{ fps}}$$

$$L/D = 20$$

Assume Lift equals Weight. Calculate Drag.

$$D = \frac{L}{\left(\frac{L}{D}\right)}$$

$$D = \frac{1048 \text{ pounds}}{20}$$

$$D = 52.4 \text{ pounds}$$

Following the same analysis for the SGS 2-33 with Spoilers Open yields a drag value of 96.8 pounds, for a delta drag due to the spoilers of 44.4 pounds.

The spoiler dimensions were measured at

Glider	Spoiler Span	Spoiler Height	Spoiler Area	Total Spoiler Area
	inches	inches	square feet	square feet
G-103	48	6.875	2.292	4.58
SGS 2-33	44.5	4.5 (top) 3 (bottom)	2.318	4.64

Calculating the drag coefficient of the spoilers referenced to the spoiler area (50 mph = 73.33 ft/sec)

$$C_D = \frac{2\Delta D}{\rho_{SL} V_e^2 S}$$

$$C_D = \frac{2(44.4)}{(0.0023769)(73.33)^2(4.64)}$$

$$C_D = 1.5$$

The accepted value for the drag coefficient of a flat plate perpendicular to the flow, referenced to the flat plate area, is 1.28. There are other effects not modeled here, such as the effect of separated flow over the wing behind the spoiler. The goal here is not to explain this discrepancy, but rather to get numbers to model the effects of the spoilers on increasing drag.

Similar analysis for the G-103 yielded a spoiler drag coefficient of 2.59.

Parachute Effective Area

The drag parachute for the Waco CG-4A had a diameter of 10 feet. If we assume the parachute forms a hemisphere, then the length of the curved portion of the cross section (half circle) is 10 feet. The diameter of this half circle would be 6.36 feet. Dividing this in half gives a radius of 3.18 feet. Calculating the frontal area of the parachute yields 31.8 square feet.