Assembly of a Passive Slat System for a CH-701 Kit Aircraft

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Assembly of a passive slat system for a CH-701 Kit Aircraft

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This report presents the background and process involved in the assembly of a passive slat system for the Zenith Air CH-701 kit aircraft. This report details the application and theory behind passive slat system. As well it lays out the tools and materials required for the job. Finally, the assembly and installation process of the slats is presented step by step. By the end of the report, the reader should have a thorough understanding of the steps involved in the assembly and installation of passive slats.

Nomenclature

b	=	wing span, ft
c	=	wing chord, ft
C_{Lmax}	=	Maximum Lift Coefficient
S	=	wing Area, ft
STOL	=	short takeoff and landing
W	=	weight, lbs

I. Introduction

The Zenith Air CH-701 is a short take off and landing sport kit aircraft. A standard CH-701 is shown in Figure 1. The aircraft was designed as an "off-airport" plane, meaning it was meant to be used off of short dirt runways or even normal fields. The kit was first introduced in 1986 and was designed by engineer Chris Heintz. The original goal was to combine a normal flying aircraft with short field capabilities. Some unique features that allow the CH-701 these capabilities is the full span leading edge slats, the full span 'flaperons', all moving rudder, and a very low takeoff weight. The CH-701 kit used in this project was owned by Professor Kurt Colvin and students had the opportunity to take part in the assembly process.

Figure 1. A standard Zenith Air CH-701

The particular wings used on the CH-701 being built were not from Zenith Air but were instead the Dedalius Aviation Pega-STOL wings. The main difference between the Pega-STOL wings and the wings from Zenith Air is the deployment and operation of the leading edge slats. The Zenith Air slats are fixed in their position, while the Pega-STOL slats are retracted through a passive system during cruise. The retraction of the slats in cruise helps to reduce drag and increase cruise speed, which is discussed further in the background section. Both the Pega-STOL and Zenith Air wings use full span flaperons and multiple strut supports.

The Pega-STOL wing using the trailing edge flaperons and the leading edge slats to achieve a maximum lift coefficient of 3.6, which pilots claim can let them fly less than 20 miles per hour at takeoff weight. This is a higher level of performance over the Zenith Air wings which claim a maximum lift coefficient of 3.1 and a stall speed of 28 miles per hour at takeoff weight[1]. The Pega-STOL wings used on this particular CH-701 are just less than 23 feet in

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span, have a chord of 4 ft which gives a wing area of 107 ft. Table 1 is a summary of the general characteristics of the Pega-STOL wing

Table 1. General characteristics of Pega-STOL wings.

	LE Device	T.E. Device	Chord	Wingspan	Wing Area
Pega-STOL Wing	Slat	Flaperon	4 ft	27 ft	107 ft

II. Background

The CH-701 was designed to be used in “off-airport” situations, where the area to takeoff an aircraft is limited[1]. One of the most influential factors in takeoff and landing distance of an aircraft is the stall speed of the vehicle, since stall speed determines the takeoff and landing speeds. Short takeoff and landing vehicles with low stall speeds require less distance to accelerate the aircraft to takeoff speed and require less distance to decelerate the vehicle from landing speed. Accordingly, when designing an aircraft to have STOL capabilities, the designers will typically add features to lower the stall speed of the vehicle. Equation 1 is the equation for the stall speed of an aircraft under a normal 1-g load.

$$V_{stall} = \sqrt{\frac{2*W}{\rho*C_{L,max}*S}} \quad (1)$$

From Equation 1, it is seen that the designers have control over the weight, C_{Lmax} and wing area of the aircraft. While the CH-701 doesn’t have a particularly large wing for its size, it is a relatively light aircraft with a low wing loading. The other way aircraft designers can decrease the stall speed is by increasing the maximum lift coefficient. This is done using many different types of high lift systems. The CH-701 uses both trailing edge and leading edge devices. On the trailing edge, the CH-701 uses flaperons, or a combination flaps and ailerons. On the leading edge, the CH-701 uses a passively deployed slat. Slats are leading edge devices that increase the maximum lift coefficient by allowing the wing to be flown at a higher angle of attack before stalling. The lift coefficient will typically increase as the angle of attack of the wing increases until the wing is stalled and lift is lost. Figure 2 shows a plot of lift coefficient versus angle of attack for a plain airfoil, one with a flap, and one with a flap and a slat.

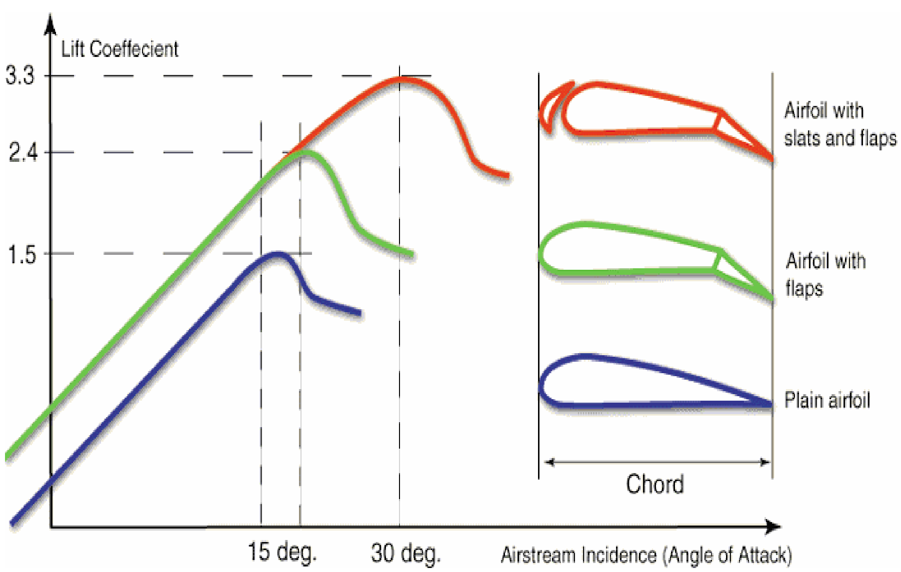

Figure 2. Lift Coefficients versus angle of attack for high lift devices.

It can be seen from Figure 2 the slats do not increase the lift coefficient for any given angle of attack, but allow the wing to be flown at higher angles which increases the lift coefficient. This happens because of the gap between the slat and the main airfoil. The gap is larger near the bottom of the airfoil picking up more air. As the air flows to the top surface of the wing the gap decreases in size and the air is accelerated due to the venturi effect. This leads to accelerated air across the top of the wing. The accelerated air is more energized, and fights the adverse pressure gradient of the boundary layer. This energized air can keep the flow attached to the wing up to higher angles of attack[2]. While the exact stall angles are dependent on airfoil and slat design, most stall aircraft with slats can fly at angles of attack in excess of twenty degrees.

Some STOL aircraft use fixed slats, usually just referred to as slots, while others use mechanically deployable slats. The Pega-STOL wing uses a mechanically deployable passive slat system. There are many advantages of a deployable slat system. During normal cruise flight slat systems add drag to the aircraft. The amount of drag is a function of the mass of air flowing through the gap and increases with velocity. Deployable slats that can be retracted during cruise do not have this drag increase; however they generally add complexity to the wing. Deployable slats can be done through passive systems or active systems. Active systems require the pilot or flight computer to deploy the slat, increasing pilot work load and complexity. Passive systems deploy on their own, once the aircraft approaches its stall speed. The Pega-STOL wings use a passive system that deploys the slat using air pressure. As the aircraft slows down and the angle of attack increases, the stagnation point moves aft on the lower surface of the wing. Once it reaches the gap in the slat, the pressure opens the gap, deploying the slat. Figure 3 shows streamlines around an airfoil with a leading edge slat. From the figure it is clear how the air pressure can deploy the slat.

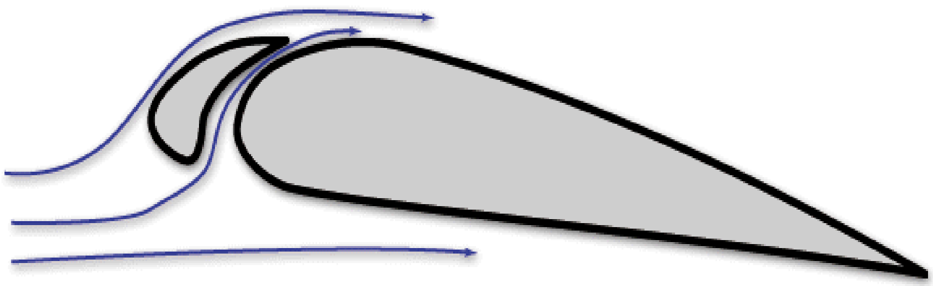

Figure 3. Streamlines over an airfoil with a leading edge slat.

While the passively deployed slat systems are advantageous, there are some disadvantages. The main concern with the slats is if one wing slats deployed and the other side didn't. A number of things can result from this. If the pilot did not realize the deployment failure, he could take the plane to an angle of attack that will stall the wing with the undeployed slat. This would result in a rather large rolling moment that would need to be corrected immediately, and at extremely low altitudes could result in a crash. If the failure is realized and the angle of attack is kept below the stall angle of the wing with slats undeployed, theoretically, there would be no rolling moment produced by the wing, as the slats do not increase lift coefficients for a wing. However, it is likely that because of the slight shape change of the nose, a rolling moment would be produced that would need to be corrected with aileron input.

III. Tools

Table 2 contains all of the main tools used in the construction of the slat system. Some of the tools are specific to aircraft construction, while others commonly available tools.

Table 2. Various tools used in the construction of the slat system.

Pull Rivets	Solid Rivets	Pneumatic Rivet Puller
Pneumatic Drill	Standard Drill Bits	Grinder
Center Punch	Files	Deburring Tools
Zinc Chromate	Jig Assembly	Safety Equipment

The connection of the main parts of the slat system was done using both pull and solid rivets. On the trailing edge of the slat where the shop head of the rivet is exposed to the flow, a solid flat rivet is used to help reduce parasitic drag. Everywhere else, standard pull rivets were used. The rivets were done almost entirely with a pneumatic rivet puller. In some cases where the pneumatic tool could not fit, a hand puller was used to pull the rivet. To drill the holes for the rivets, a standard pneumatic drill was used. The majority of the holes that needed to be drilled were predrilled with a water jet (done at the factory). However, most holes had to be drilled twice to get to a sufficient size to rivet. In some cases filing had to be done for a better part fit. All of the holes drilled were deburred before rivet, which is essentially to a clean flat surface between the rivets. All surfaces were treated with Zinc Chromate prior to mating. Zinc Chromate is a chemical that is used in metal aircraft construction since the 1940s (ref). Its primary purpose is to prevent corrosion of the metal surfaces that are mated together. Figure 4 shows the inside of one of the slats. The zinc chromate can be seen easily between the two surfaces with its bright yellow color. For the final assembly of the slats a jig was used. The purpose of the jig was to help form the skin over the top surface of the slat cleanly. The jig assembly also helped to apply even tension as the skin was pressed tight over the skin. The pieces of the jig were made of wood and came with the wing kit precut. The jig was easily assembled and ended up saving a lot of time on the construction. Figure 5 shows the jig being used to help assemble one of the slats.

Figure 4. The inside of a slat, showing the Zinc Chromate (yellow) between the two surfaces.

Figure 5. One of the slats sitting in the jig.

IV. Required Materials

The materials required to build the leading edge passive-slats on the Pega-STOL wing are included in the kit along with the assembly jig discussed in section 3.The pieces required to build one slat include: slat ribs, a slat angle doubler, slat skin, and the slat trailing edge doubler. A list of these parts, the corresponding part number, and the number of pieces to assemble one slat is shown in Table 3[3]. There are four slats total included in the kit, and the totals in the right column are multiplied by four to obtain the total part count.

Table 3. Slat assembly parts.

Part Number	Name	Quantity per Slat
B-101	Slat ribs	3 Left + 5 Right
B-102	Slat angle doubler	1
B-103	Slat skin	1
B-104	Slat trailing edge doubler	1

As seen in Table 3, there are a total of eight ribs where five face left and three face right from a top view with the leading edge pointing down. This can be seen in Figure 6. There is a subtle difference between the ribs in Figure 6, and to further illustrate the correct orientation Figure 7. shows which side is used as a reference. This is important to ensure that the correct ribs are used in the correct locations and more specifically that there are enough ribs to close the tips of the slats. It is beneficial to place all 32 ribs in their correct locations on the four slats and mark them before beginning assembly.

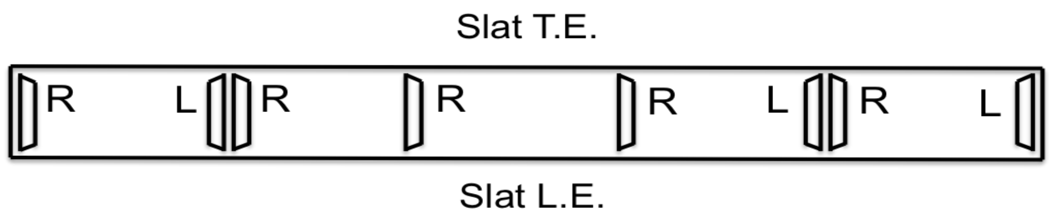

Figure 6. Top view of one right slat.

The next important piece required to begin assembly is the slat skin. The slat skin is the largest piece, and on a finished slat is directly connected to all other pieces included in Table 3. This can be seen in Figure 8.

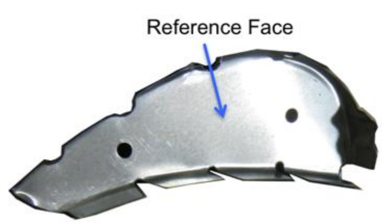

Figure 7. Rib reference face.

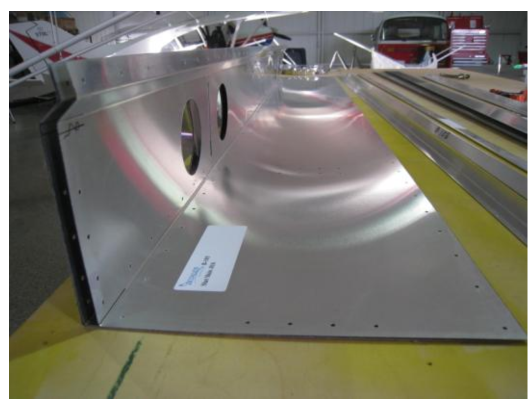

Figure 8. Slat skin.

Finally, the last two pieces to be discussed are before assembly can begin are the slat angle doubler and the trailing edge doubler. First, the slat angle doubler is secured to the inside leading edge of each slat to ensure rigidity and to maintain the shape necessary to complete the airfoil cross-section when mated with the rest of the Pega-STOL wing. The trailing edge doubler also goes on each slat at the rear of the slat airfoil shape. Both of these pieces can be seen in Figure 9.

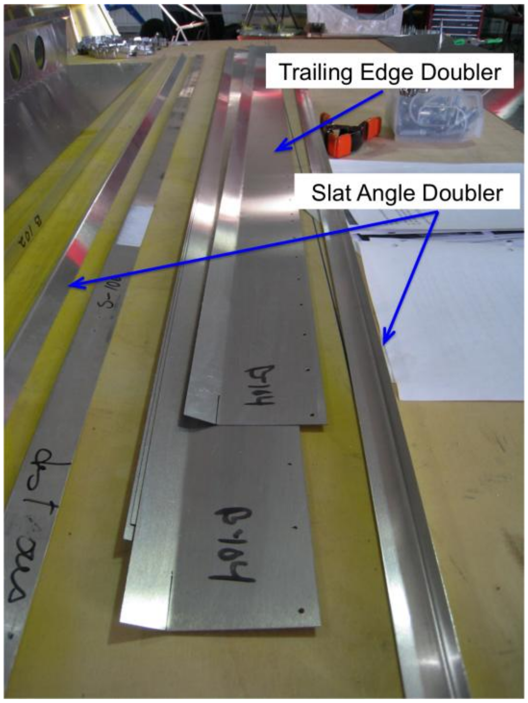

Figure 9. Leading and trailing edge angle doublers.

V. Assembly Procedure

With the required materials and the necessary tools, the assembly process can begin.

Slat Angle Doubler and Slat Skin Assembly

1. Starting with the slat skin and using a size 40 drill bit, the precut water-jet holes must be drilled. This is one of two drilling passes on the skin where the second pass comes in Step 3.

2. With the initial holes drilled in the slat skin, the slat angle doubler (B-101) is then mated to the inner corner of the skin (B-103) and clamped down for drilling. The angle doubler does not have any precut holes, and the holes on the skin are left at size 40 to serve as a guide in this step. With the skin and angle doubler secured as shown in Figure 10, drill size 40 holes in the top placing a silver cleco in every other hole to maintain proper fitment. Repeat this on the horizontal face. Make the second pass on the top and horizontal faces with the size 30 drill bit, now using copper clecos in every other hole to ensure proper fitment.

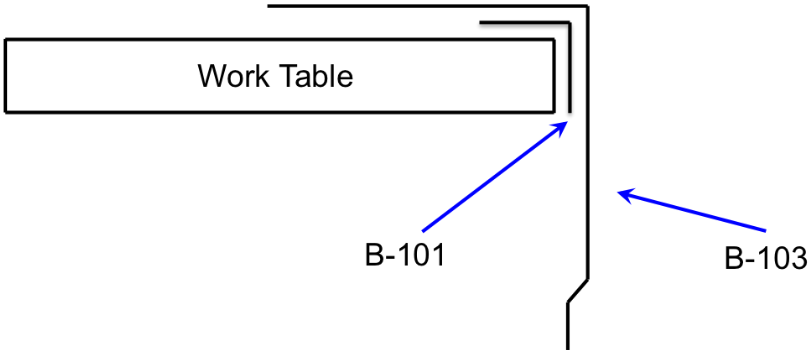

Figure 10. Side view of angle doubler and skin drilling alignment.

3. Next, remove all clecos and mark the orientation of the angle doubler relative to the slat skin so it can be easily replaced. Set the angle doubler to the side. Make the final drill pass on the skin using the size 30 drill bit for the remaining holes.

4. Deburr both sides of all drilled holes on the skin and the angle doubler.

5. Spray surfaces of the angle doubler and skin previously mated with zinc chromate in preparation for riveting as shown in Figure 11. The surfaces in Figure 11 have not been adequately coated, but this illustrates the proper location of the zinc chromate.

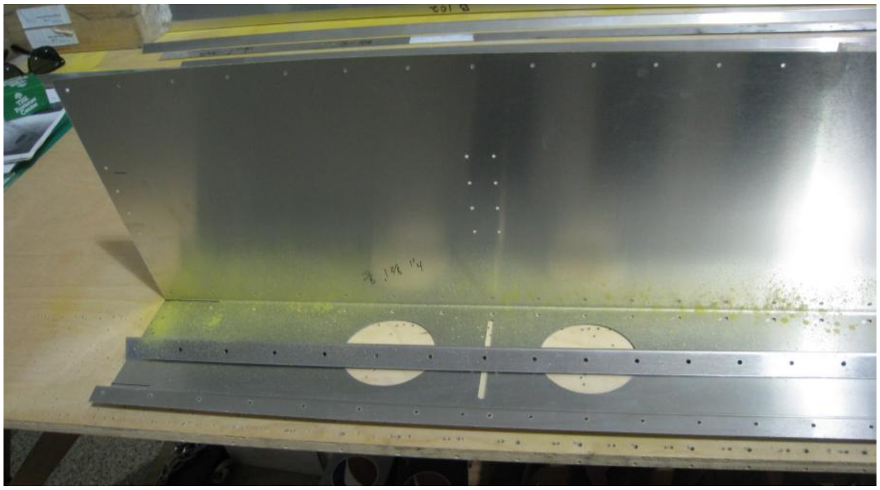

Figure 11. Zinc chromate anti-corrosion coating.

6. Place the angle doubler and skin back together in the proper orientation according to the markings noted in Step 3. Place copper clecos back into every other hole in preparation for riveting and clamp the pieces to the worktable as shown in Figure 12.

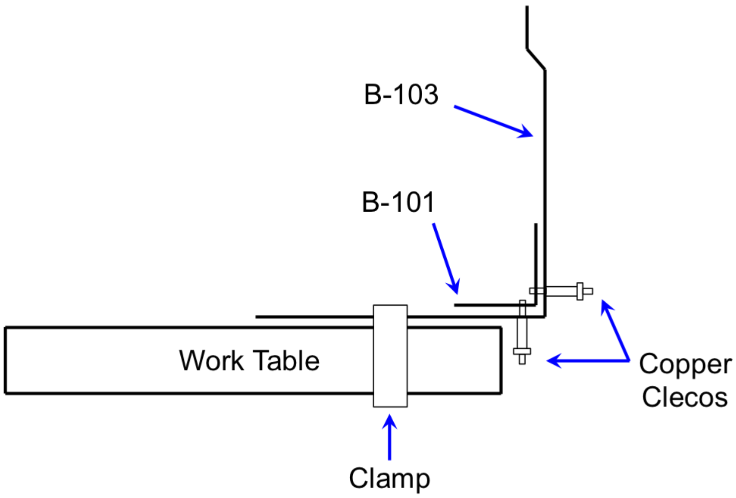

Figure 12. Skin and angle doubler clamped for riveting.

7. Rivet all holes mating the angle doubler to the slat skin **except** for holes lined up with rib positions. These rivets will be added later. The rivets used here are A-4 rivets and a pneumatic rivet gun is best suited for the job.

Rib Alignment and Assembly

The ribs require great care for initial positioning and drilling to ensure final rivets pass through the center of the intended flanges. This process is best suited for a two-person crew.

8. At the double-rib positions shown in Figure 6 a spacer is needed to replicate the rib spacing when the slat is attached to the wing in order to ensure proper placement. The reference faces should be facing away from each other, and the spacer should be bolted in between the two ribs for a total of two pairs. These pairs are bolted together with the spacer using two AN3-4A bolts, AN960-10 washers, and AN356-1032A stop nuts also included in the kit. The rib pair bolted together can be seen in Figure 13.

Figure 13. Bolted rib pair.

9. The process for marking and drilling the holes to secure both the rib pairs and the single ribs to the skin is the same. This process should be done one rib (or rib pair) at a time. First mark a line down the center of the rib flange for a reference line. Position the rib with the leading edge towards the bend in the skin. This orientation can be seen in Figure 14. Clamp or use the additional help to hold the rib in place making sure the line on each flange is visible through holes in the skin. Mark one hole, remove the rib, center punch the marked spot, and drill with a size 40 drill bit. Replace the rib securing it with a silver cleco and mark the next hole and repeat punching and drilling. Repeat these steps until all holes on each rib have been drilled. With the ribs in place on the skin, make a second pass on all the ribs with a size 30 drill bit and use copper clecos in preparation for riveting. Remove ribs and deburr all holes. Prepare contact areas by spraying zinc chromate, replace ribs, and place copper clecos back in each hole.

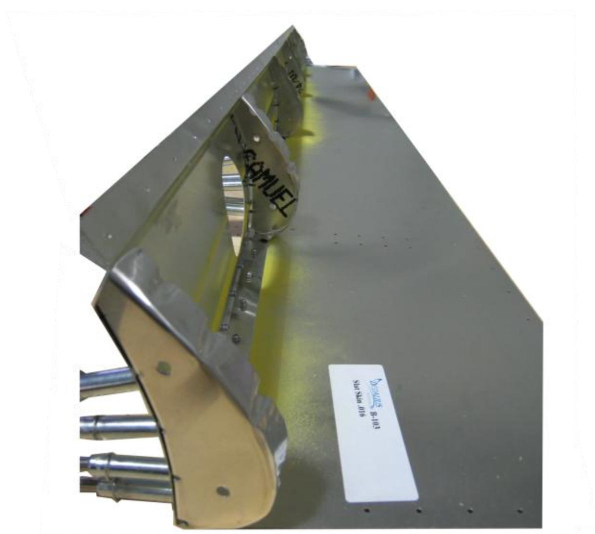

Figure 14. Proper rib orientation.

10. With the ribs secured to the skin using copper clecos, the skin clamped to the worktable, and the clecos facing the worker, riveting can take place. Use A-4 rivets. At this time, the rivets omitted from the rib positions in Step 7 can be installed. An illustration of a finished skin, angle doubler, and rib set can be seen in Figure 15.

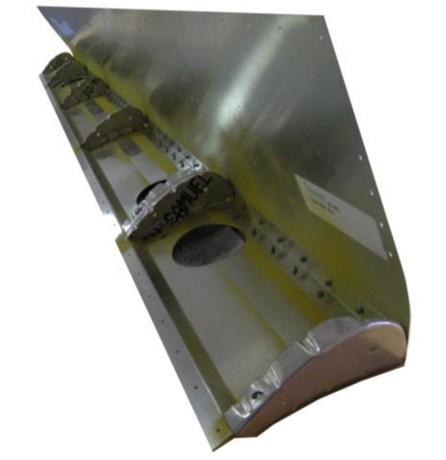

Figure 15. Installed ribs.

Jig Assembly

The slat is now ready to be close by riveting the skin to the ribs. In order to perform this step the jig included with the kit must first be assembled. A part list for the jig can be seen in Table 4. A top view can be seen in Figure 16 and a cross sectional view of the assembled jib can be seen in Figure 17[3]. Using a drill and clamps or additional assistance the jig assembly is straightforward.

Table 4. Slat jig assembly parts.

Part Number	Name	Quantity
S-101	Top slat plywood form	6
S-102	Bottom slat plywood form	6
S-103	Extruded aluminum angle	8
S-104	Piano hinge	1
S-105	Wood srews (3/4" x 8 flat HD socket)	48
S-106	Stopper aluminum strip	1
S-107	A5 aluminum rivet for S-104	40

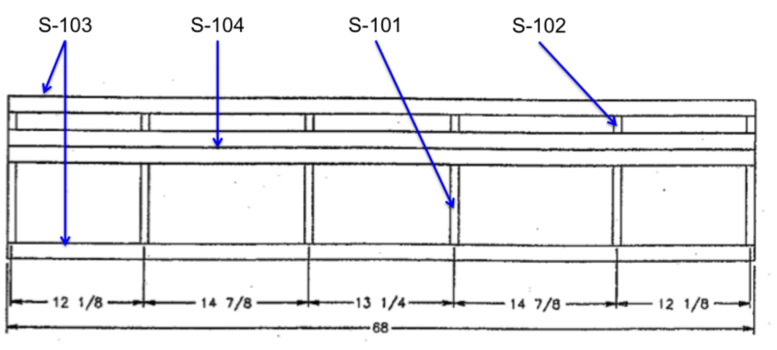

Figure 16. Jig top view.

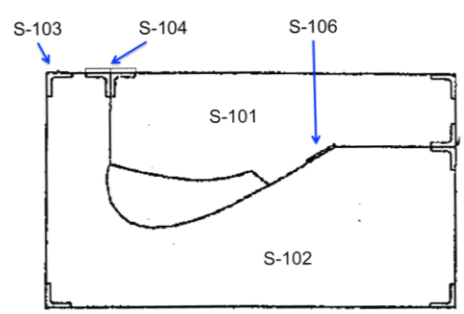

Figure 17. Jig side view.

The assembled jig will look like the jig pictured in Figure 18.

11. With the jig assembled the next step is to place the skin and ribs into the jig to wrap the skin over the open portion of the ribs. Begin by ensuring that the slat is centered in the jig and all the drilled holes are accessible. Place the trailing edge of the slat into the jig under the aluminum stopper strip at located at point A in Figure 19. The trailing edge will require some finesse and will have to bend slightly to fit in the jig. Next, carefully but firmly press the slat into the fixture so that the leading edge sits nicely against point B. Close the jig, clamp the jig shut and place on the leading edge side of the jig.

Figure 18. Finished jig assembly.

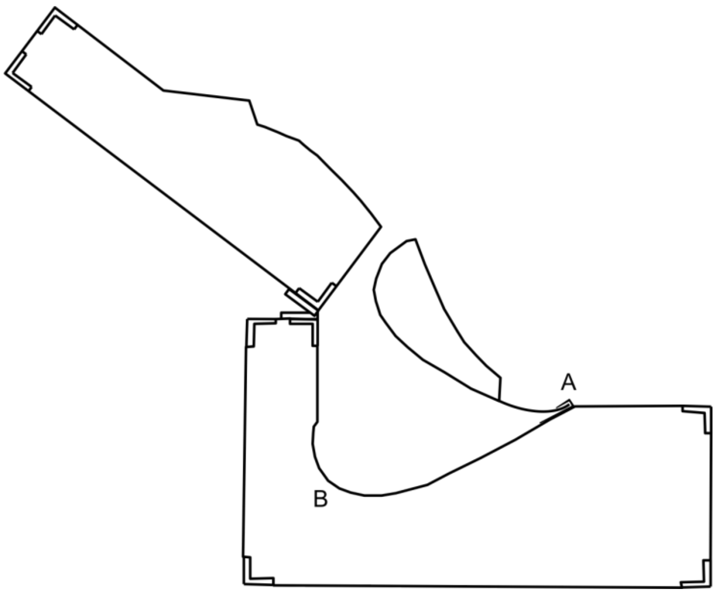

Figure 19. Slat being placed into the jig.

12. Place the jig so the leading edge is pointing down and the rib holes are visible. Drill all holes with a size 40 drill bit while being cautious not to puncture the other side of the slat once the drill has broken through each rib flange. Note that the end ribs should be aligned carefully for a proper fit. Place a silver cleco in each hole as progress is made.

13. Repeat the drilling process with a size 30 drill bit using copper clecos to secure each newly drilled hole.

14. Remove clecos, remove slat from jig, deburr all holes, and replace slat back in jig including copper clecos in preparation for riveting.

15. Use A-4 rivets to secure the wing skin to each rib.

16. Remove the slat from the jig assembly and place it upside down on its top surface. Line the trailing edge up with the worktable's edge and clamp it down including the bottom skin of the slat. This can be seen in Figure 20 where the line of holes to be drilled is denoted as the "Work Location". Drill with a size 40 drill bit, followed by a second pass with a size 30 drill bit using the appropriate clecos through the process. Remove clamps and deburr top and bottom sides of the slat.

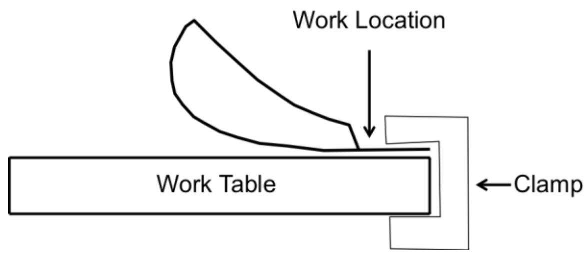

Figure 20. Bottom surface of slat positioned to be drilled.

17. Replace copper clecos and place slat on its bottom, again at the edge of the worktable as shown in Figure 21.

18. Use A-4 rivets along this line to secure the bottom of the skin to the top of the skin. Make sure the rivet from the top so the rounded head of the rivet is on the top of the slat.

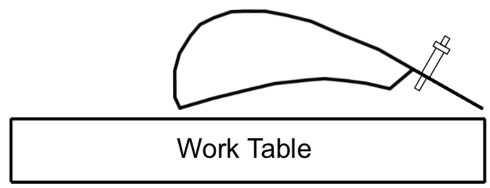

Figure 21. Orientation for riveting bottom skin to top skin.

19. The last piece to be assembled is the trailing edge angle doubler (B-104). Place the slat on its top surface; align the B-104 and the slat trailing edge with the edge of the worktable. Clamp the pieces down and make a pass at point A in Figure 22 with a size 40 drill. Follow this with the size 30 drill bit using the appropriate clecos for added support on each pass. Deburr the holes and rivet using A-4 rivets.

20. With the rivets in place at point A in Figure 22, drill size 40 holes at point B along the span of the slat. Use silver clecos to hold the pieces together in addition to using clamps. **Do not make a second pass with a size 30 drill bit**.

21. Remove all clecos to deburr the top and bottom surfaces. Place copper clecos back every other hole to begin riveting at point B in Figure 22.

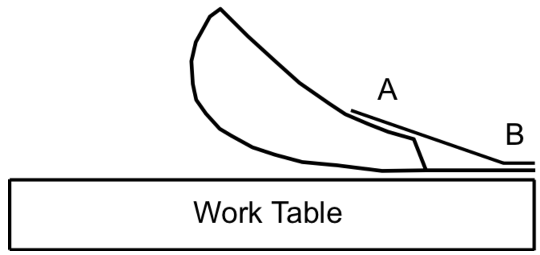

Figure 22. Trailing edge angle doubler installation.

22. AN47A-3-3 solid rivets are used for the trailing edge of each slat and a pneumatic rivet press is ideal for proper installation. Ensure that the round rivet head is on the top surface of the slat and rivet the B-104 to the slat skin.

VI. Slat Installation

The assembly of the passive slat system is not complete until the slats have been installed on their tracks on the Pega-STOL wings. The wing itself including the track system was previously built and the final step was to properly install each slat. This process began by bolting the slats to the track attachment points seen on the left side of Figure 23. The circular holes seen must be filed to and increased diameter and in some cased to an oval shape. This is to allow rotation of the slat relative to the blunt leading edge of the main wing. It is important that the bottom of the slat and the blunt leading edge of the main wing are parallel with each other as to avoid a situation in which the slat cannot move freely. With each slat adjusted properly and the tracks well greased for ease of deployment, the slats should slide back out after being pushed up to be flush with the wing.

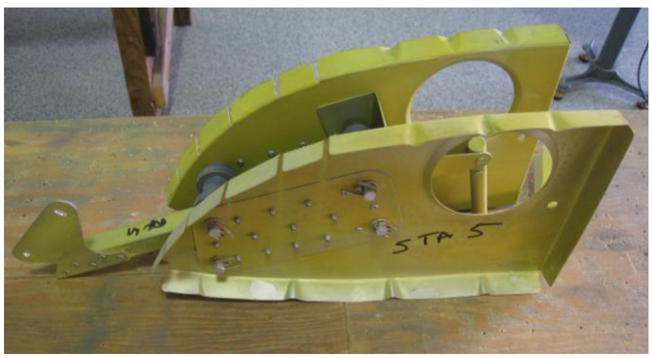

Figure 23. Passive slat track.

VII. Conclusion

This report presented an overview of the passive slat system used on the Pega-STOL wings for the Zenith Air CH-701 kit aircraft. A background on the theory of passive slats and their advantages to short take off aircraft was given. The tools required to install the slats was reviewed. Finally complete step by step process of the assembly and installation of the slats to the zenith CH-701 aircraft is given. It is hoped that this document can be used by future builders of this aircraft to assist them in the assembly process. Further improvements suggested are to the track system that deploys the slats. Proper alignment of the slat relative to the leading edge of the wing is crucial. As well, an extension of the track can me be made to improve the fit between the airfoil and the slat.

VIII. References

[1]Heintz, Chris. "Anatomy of a STOL Aircraft." *Anatomy of a STOL Aircraft*. Zenith Air, 2009. Web. 06 June 2012. <http://zenithair.com/stolch801/design/design.html>.

[2]Raymer, Daniel P. *Aircraft Design: A Conceptual Approach*. Washington, D.C.: American Institute of Aeronautics and Astronautics, 1989. Print.

[3]Dedalius Aviation. *How to Assemble the Slats Using the Jig*. 31 July 2000. Sherbrooke, PQ. Canada.