THE ROTARY DRIVER SYSTEM

By Harley Michaelis

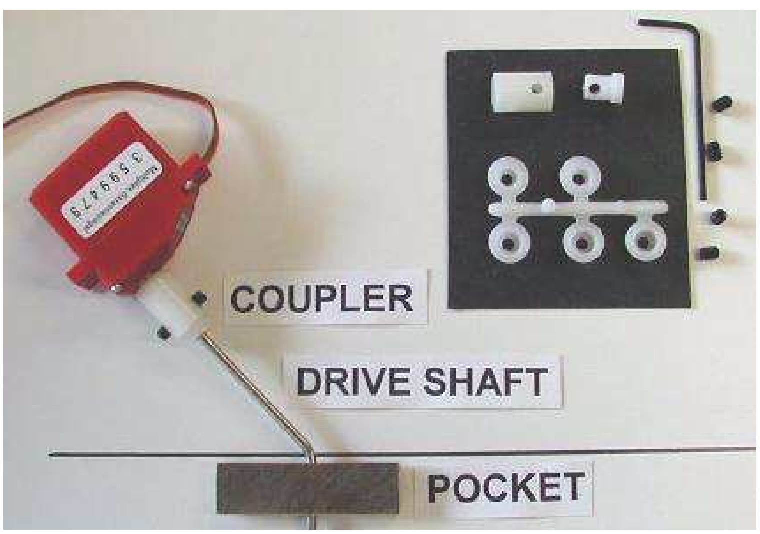
The RDS is an all-internal method of moving hinged surfaces on fixed wing R/C aircraft. The RDS section in Construction File #3 provides extensive installation details for the Genie line ships.

The RDS involves no output arms, horns, clevises, threaded rods, protruding well covers, etc. Surfaces are totally free of unsightly hardware to catch on things & cause drag & noise. Properly fabricated & installed, no slop or bind is contributed by the system. Full expected deflections are provided for positive control. It can be used to move flaps, ailerons, flaperons, elevator, rudder, etc. Servos commonly used for a particular application are fine here if they can be fully recessed in structure ahead of & near the hingeline.

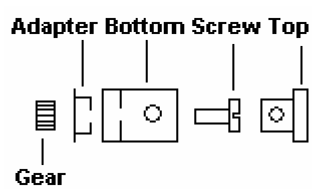
Installation is made practical using an adaptable, injection-molded servo accessory along with simple, inexpensive & easily made "drive shafts" & "pockets".

The servo accessory is Kimbrough Products (the R/C car gear people) item #500, a 3-part "coupler" shown in the picture below. It attaches to the output gear with the servo screw. It receives & secures a "drive shaft" that enters a hard "pocket" in the movable surface.

The coupler parts (white) are shown below on the black background. Top right is the coupler top that has a pilot hole. To enlarge the hole, drill a 15/64" hole in a board. With a tapered tool (1/4" round file, etc.) enlarge it slightly to press in with a snug fit. For a 1/16" shaft, open the hole with a #51 bit. For the most commonly used 3/32" shaft use a #41 or #40 bit. Top left is the splined coupler bottom. It receives a double-splined adapter from the 5 adapter tree. One or the other fits the output gear of most popular servos. Setscrews secure the top inside the bottom & seat to flats ground on the shaft to lock it in place. <u>The #500 package includes a pair of the molded parts shown, plus four setscrews & an Allen wrench</u>. Two pair are needed for a four servo wing.



This exploded view shows how parts go together. An adapter slips inside the coupler bottom, seating to its internal flange. These fasten to the output gear with the servo screw. The top is secured with setscrews that also secure the drive shaft. Flats on shafts avoid slippage.



Shafts & pockets vary with airframe size & application. No one size fits all, but 3/32" shown fits most. An aileron application is depicted. Particularly note that the elbow of the bend is at the hingeline & that the pocket front edge is a little behind the hingeline. 1/16" works well in practice. Pockets have a top & bottom, spaced in parallel planes for a "slightly snug" fit with the shaft.

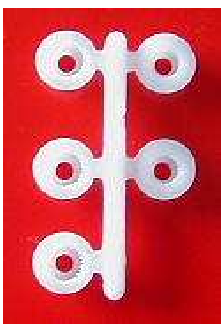
Pockets & shafts are easily fabricated from common materials as detailed further on. Shafts & pockets are optionally available with Genie packages. Shafts, pockets & tempered aluminum coupler tops are commercially available from modeler-machinist Walt Dimick. **See pg. 9.**

With servo oriented 45 degrees to the hingeline, as shown above, deflection available either way is similar to the bend angle. This orientation & a 90 degree bend will provide full down flap. For ailerons, with the shaft bent no more than 45 degrees, the servo & shaft may be squared to the hingeline as illustrated with the shaft segment on the right in the drawing on page 4.

Smaller bend angles equate to moving a clevis closer in on an output arm. An analysis by an engineer who designs guidance systems for rockets & space craft showed, for example, that a 32 degree bend allows 30 degrees deflection while doubling effective servo power & resolution. Go to page 9 for a link to an engineering discussion of the RDS.

"Pockets" slip over the bent end of the drive shaft. Hinging stabilizes the shaft in the vertical. If hinges fail, the surface can slip off undamaged, unlike when tethered by a horn, clevis & pushrod. Unlike a pushrod, the rotary action doesn't impart forces at right angles to the axis of the output gear & so is much easier on servo gear trains & pin sockets in servo cases.

<u>DOUBLE SPLINED ADAPTERS</u>: Which is known to fit which servos is shown below. To attach the coupler, usually seat an adapter first in the coupler bottom. Some fit very tightly. Then, using the servo output arm screw, fully seat the assembly on the servo output gear.



<u>LEFT TOP</u>: Hitec 60/80/85/101, etc. Volz Alu-Star

<u>LEFT CENTER</u>: Std. Airtronics including 94761Z, JR, Multiplex, Sanwa.

<u>LEFT BOTTOM</u>: Std. Futaba, FMA series 300, Critter bits, some larger ACE, Dymond.

<u>RIGHT TOP</u>: Std. VOLZ, Airt. 557 (very tight). See bordered paragraph below about using this on the JR 168 & Hitec 125 thin wing servos.
<u>RIGHT BOTTOM</u>: FMA 88/90/95/100 etc. ACE 8112, Cirrus CS20/21, MPI MX 30.

To prepare the Volz adapter to go on the JR or Hitec thin wing servos, drill a 5/16" hole in a board. Put the adapter in it. Using a sharp 3/16" bit in a drill press, gently widen a little of the adapter opening. Square up the adapter & gently press it over the output gear with a bench vise.

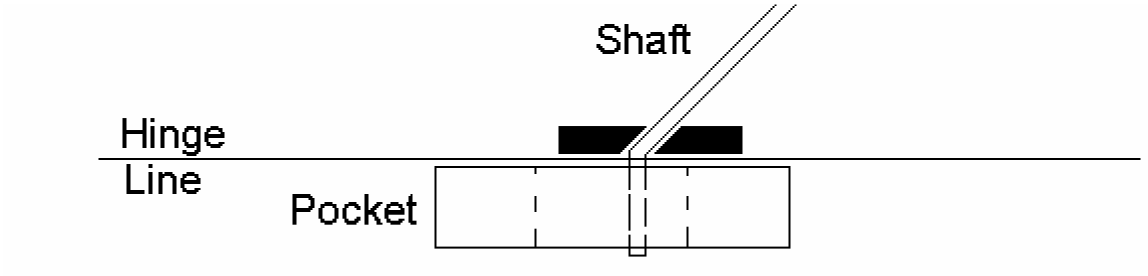
<u>CUSTOM SPLINING:</u> Any of the three standard adapters on the left can be fitted to a smaller output gear as follows: Plug the output gear screw hole with paste wax. Wax the gear & case or coat with PVA release agent. Put clear tape over the hole for the servo screw in the adapter. Almost fill the adapter with epoxy. Press it, visually centered, over the output gear. Let the epoxy cure well. Pry off the adapter. Clean off wax & excess epoxy. Open the servo screw hole.

The splined coupler bottom itself can be custom splined. From an adhesive backed paper, cut a disc to cover the screw hole at its bottom. With a pin, punch a hole in the center of the paper. Almost fill the splined bottom with epoxy. As closely as possible, center the bottom over the output gear. Run a waxed round toothpick into the pinhole & find the screw hole in the gear to finalize the centering. When cured, pull out the toothpick. Open the hole for the servo screw. For heavier duty applications a filled epoxy is recommended.

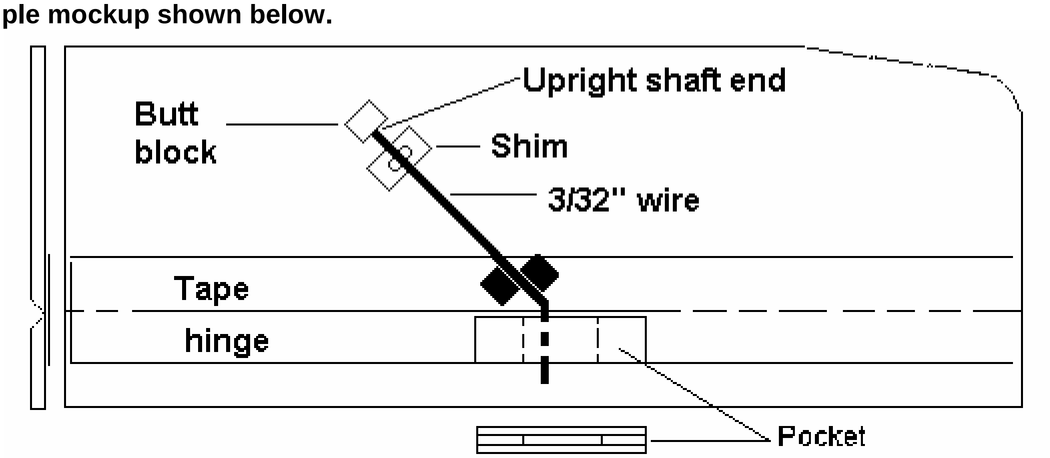
The #500 package sells for $5. Order from Augie McKibben, 7011 52nd Ave N. Crystal, MN 55428. Add a flat $5.00 for shipping any size order. Specify "pair" not "sets". Send cash, check or money order please. Inquire about non-USA orders at augie-mrcss@comcast.net. If ordering other things from Tower Hobbies or Walt Dimick (page 9), they also carry the couplers.

<u>RDS KINEMATICS</u>: During deflection, 3 motions take place. (1) The bent section of the shaft works in a fan pattern within the pocket. (2) The pocket moves slightly fore & aft on the fixed shaft. (3)

The shaft "floats" slightly up & down at the hingeline. These motions enable the RDS to work properly. The three motions take place simultaneously to avoid bind or pulling on hinges not in the same geometrical plane as the pockets. Snug fitting tubes by the hinge line should not be used as they interfere with the "float". Lateral movement is to be restrained. Actually a snug tunnel in a denser foam core works fine. Blocks either side of the shaft, as shown black in the drawing below, are another a simple solution. In a wing with a sub-spar just ahead of the hingeline, a vertical slot can be made in it in lieu of installing blocks. The pocket itself supports the end of the shaft.



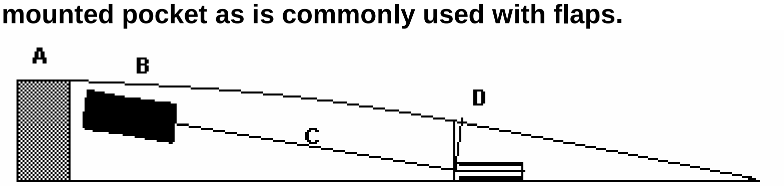
To see & feel what's happening during deflection & to dispel misconceptions, it's helpful to make the simple mockup shown below.



From 1/8" balsa sheet, make a "wing" & an "aileron". 12" span by 3" to 4" chord is fine. Bevel edges as shown on the left to allow down deflection. With aileron spaced slightly at the hinge line, apply a clear tape on top that sticks well. From 3/32" softer wire (coat hanger, etc.) make a low radius bend. Bend the front end to point vertically with the rear bend horizontal.

From harder balsa make a pocket to nicely fit the shaft, neither too tight nor sloppy. Cut away some of the hinge to glue the pocket to the top of the aileron, placed 1/16" behind the hingeline.

It's not uncommon for a servo to require tilting under the top skin to direct the bent end of the shaft into the pocket, as illustrated below. "A" represents the spar, "B" the servo, "C" the drive shaft & "D", a low mounted pocket as is commonly used with flaps.



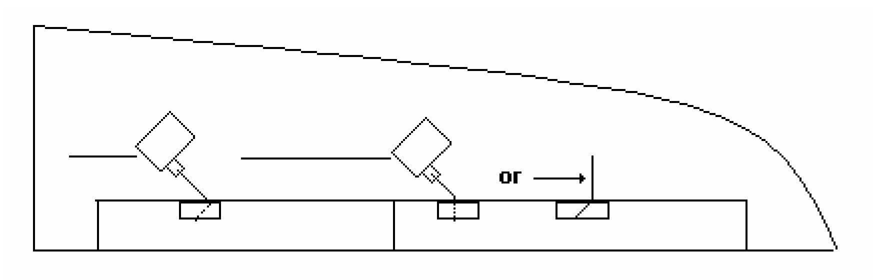
To simulate tilt on the mockup, raise the shaft 1/8" with a piece of ply glued in the "shim" spot. Glue the whole assembly to a block ¾" or so thick placed under the wing. Drive some small nails through the shim either side of the shaft to allow only rotary movement there. Glue blocks (shown in black) either side of the shaft to restrain lateral motion. Find the "sweet" spot for the elbow that allows smooth, easy deflection. Then glue a "butt block" to the wing that puts the elbow at that exact position. Operate the mockup with the upright shaft end against the block.

Note what makes the RDS work well. The servo must be firmly mounted, possibly with a tilt, to (1) direct the shaft into the pocket & (2) keep the elbow in the "sweet" spot. (3) The pocket needs to be located a little behind the hingeline, say 1/16". (4) It needs to fit the shaft without bind or slop. (5) Restraints are needed to prevent lateral play, but allow slight vertical "float". In a real installation, the intrinsic flex in the plastic coupler allows the "float" similarly as a universal joint does in an automotive drive train. This is independent of the torsional rigidity of the shaft.

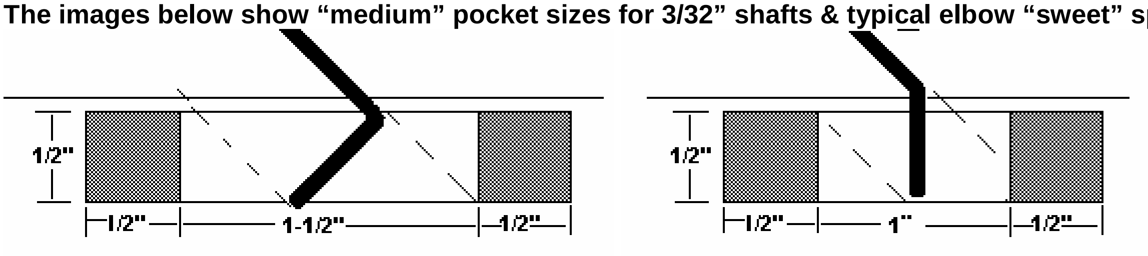
Particularly note that with the surface hinged, the pocket itself supports the rear end of the shaft. No other bearing is needed. In fact any close fitting bearing would interfere with the essential float and, if metal, can emit a spurious RF signal that can cause servo twitching.

SERVO ORIENTATION

The drawing immediately below illustrates 45 degree servo orientation for plug-in panels or a one-piece wing. If a panel has a foam core, tunnels go from the hingeline to the servo well. As shown in the larger individual drawings, the front edges of the pockets go a little behind the hingeline. The elbow of the bend for flaps goes a little behind the hingeline & for ailerons, a little ahead. The actual elbow locations are those manually found to be the "sweet" spots in a particular installation as the shafts are sized to length. See File 3 about sizing shafts to length.



The images below show "medium" pocket sizes for 3/32" shafts & typical elbow "sweet" spots.

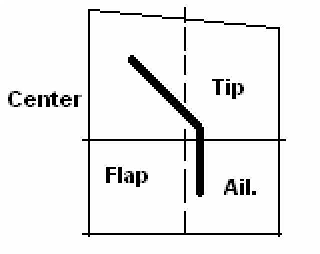


Keeping the servo, pocket & shaft near the thicker inboard end of tapered surfaces provides more vertical pocket space & keeps mass more centered for good roll response.

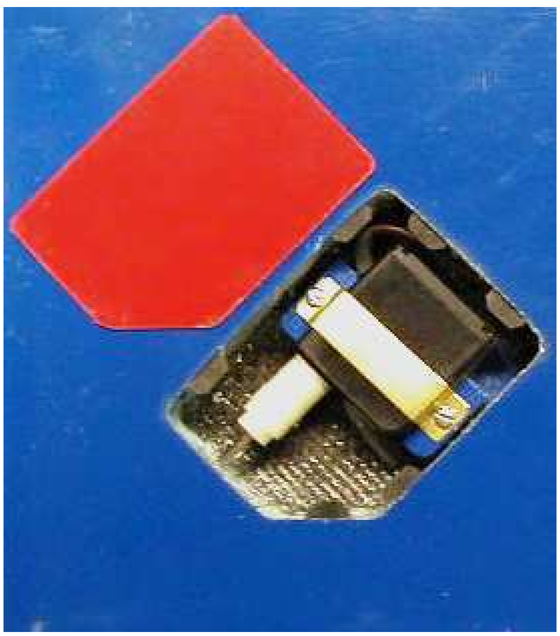
MOUNTING SERVOS

To keep it simple, the RDS requires easy attach/detach of servos & drive shafts during installation & after hinging. This is done by positioning a shaft in the pocket opening so the shaft itself it can be slid back into the opening, as illustrated by the dashed lines above. Fore-aft shiftability of a mounted servo is essential to disconnect the shaft from the coupler & if tilt is needed to direct shafts into pockets, the mounting system must also allow it. Harley's Easy Mounting System (HEMS), a dedicated one for RDS, provides these features in the simplest, least expensive way.

HEMS is fully detailed in file 3. The picture below shows the mount installed in a well with servo attached.



3-PIECE WINGS: Aileron servos can be mounted inside the ends of the center section. The shaft can protrude from the endcap to slip into a slot in the aileron. Center to tip wiring/connectors are eliminated. See File 3.



Using "HEMS", the servo fits snugly between rails on a base. The base mounts to the top skin which is reinforced inside with a layer of CF cloth to prevent "oil-canning". A bracket secures the servo, but allows it to be shifted on the mount.

With surface hinged, the bent end of a sized shaft is inside the pocket, not shown here. To get a mounted servo out, it must be detached from the shaft. ¼" well clearance by the case bottom allows the servo to be shifted rearward. With setscrews loosened from the shaft, needle-nosed pliers can be used to slide the shaft further into the pocket & fully out of the coupler.

Shifting also allows some leeway to cinch down the servo at the "sweet spot" for the elbow.

In a skinned composite wing, such as the Genie, bits of CF laminate under the skin (gray tabs) will support a cover flush with the skin. Clear tape secures it.

MOLDIES: Molded wings & others that come with tiny wells pre-made for use with traditional hardware may defeat or at least hamper doing a proper RDS installation. For example, if the Walt Dimick tempered aluminum coupler top is attached to the Kimbrough coupler bottom the combination protrudes an inch beyond the servo. Clearance beyond the coupler is still needed to grasp the shaft to seat it in the coupler during the installation procedure. For easy servo attach/detach, wells need to be long enough to accommodate servo, coupler and also allow the shifting mentioned above.

To easily get 90 degrees down flap for precision landings, angle the servos at a convenient 45 degrees, although something less may do. If the bend angle is then a simple 90, full deflection is possible if hinging or gap wiper geometry do not restrict it. Less bend, say 80 degrees, will likely be plenty.

Using the RDS, a smaller bend angle equates to using a closer in hole in an output arm. Deflection is decreased. Effective power and resolution are increased.

For ailerons, using the 45 deg. servo angle, a 45 bend angle allows more deflection than normally wanted. A 32 deg. bend allows 30 deg. deflection and doubles power and resolution.

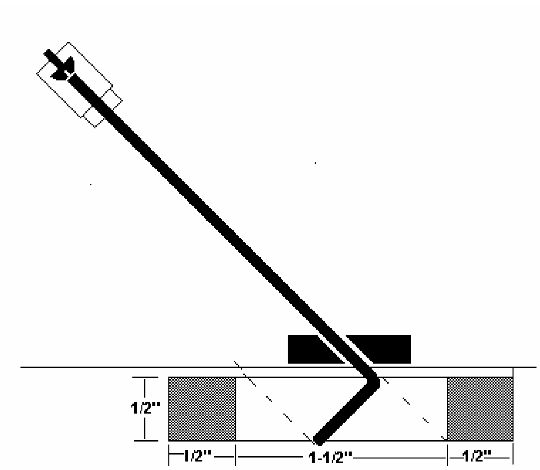
Aileron servos do not have to go in angled, but the same space considerations apply. If a moldie comes with wells in the tip section of 3 piece wings, then the servo must go out there along with wiring and connectors. File 3 details how, in 3-piece wings, no well, servo, wiring or connector need go into the tips at all.

If existing wells will allow the installation, here is how to go about it, illustrated with an installation for flaps:

The servo, not shown in the drawing, would be attached to the Kimbrough Coupler. A precise location for the mounted servo would have been determined. The shaft would be sized so when jammed to the servo screw (black), the elbow would be at the "sweet spot". If a sub-spar is in the structure ahead of the hingeline, open a hole in it so the shaft can go in and "float" vertically, but restrain lateral movement. The pocket itself provides support for the rear end of the shaft. Pocket dimensions and planform shown will allow a shaft with a 5/8" long bent end to be installed.

Lacking a hole in a sub-spar, lateral shaft movement can be controlled by blocks (black) between the skins. Wire shafts can be stiffened axially by bonding tubing on after sizing. Walt Dimick offers stiffer hardened and tempered solid shafts made from drill stock.

Follow the MECHANICS AND PROGRAMMING section in File 3. Study the section on sizing shafts to length. Position the coupler bottom with adapter on the servo so the opposing setscrews are properly oriented for easy access. Attach it with the servo screw. A longer screw may be needed. Finalize precise shaft length after the HEMS mount is attached and servo location set.



INSTALLING SHAFTS: (1) With the pocket for the drive shaft installed, make an opening for the shaft in any sub-spar ahead of the hingeline. (2) Manually lower the flap to run the bent shaft into the servo well and away from the hingeline. (3) Manually move the flap toward neutral so the bent end of the shaft can be backed into the pocket. (4) Coupler slipped on the servo, place servo in its mount and in the well. Run the shaft fully into the coupler. With the elbow correctly located by the hingeline, a flap can be manually dropped smoothly and easily. As needed, adjust shaft length to achieve that. (5) Grind the opposing flats as detailed in File 6. (6) Fully seat the setscrews. (7) Install the guide blocks, inboard one last.

With servos mounted under the top skin and with flap pockets mounted on the bottom skin, the servos are naturally tilted to direct shafts into pockets. If more tilt is needed, it's done with an epoxy putty mix between the HEMS base and skin.

In bagged wings, installation is easy if the modeler can locate and cut his own wells as detailed in File 3. Tunnels for leads to flap & aileron servos need to be located to enter the wells.

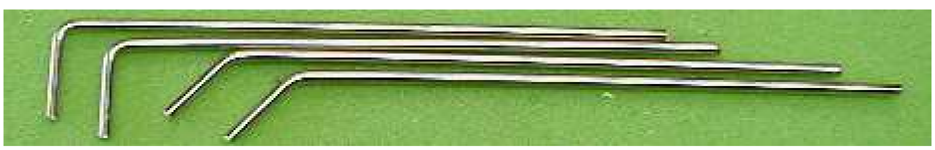
COMMERCIAL MOUNTS: Those that prevent shifting the servo to disconnect the shaft can't be used for flaps unless tape hinged and tape removed. They are okay for ailerons in 3-piece wings like the Genie with the servo oriented at 45 degrees inside the center endcap. The shaft is then easily slipped in and out through the endcap. Any needed tilting will still have to be dealt with.

SERVOS WITH SIDE MOUNTING LUGS: if the well is sized to allow shifting, then these, such as (Volz, Hitec 125, JR 168, Airt. 761, etc. can be shifted by removing the mounting screws. To keep the well opening small, a recess could be made under the skin to allow ample shifting.

MARK DRELA MOUNTS: For his lightweight designs Mark mounts servos in cantilever fashion to posts between the skins. He uses SS tubing to make stiff drive shafts & has his own, super light "coupler" system. These are intricate & take a delicate touch to install. See http://charlesriverrc.org/articles/supra/supra.htm about it. Page down to the Wing Plans files for FLAP & AILERON RDS. I used the well configuration & cantilever mounting on several airframes, but with the Kimbrough couplers & solid SS shafts and before developing the HEMS.

I grant that the use of telescoping SS tubing will be more torsionally stiff than solid wire. I do not deem the extra stiffness necessary for traditional thermal work. The stiff tubing setup also restrains the "float" needed at the hingeline to avoid binding. Shallow shaft orientation and shallow bend limit the flap deflection. In contrast, the solid shaft oriented at 45 degrees and with a 90 degree bend does not mechanically limit the flap deflection to something less than 90 degrees.

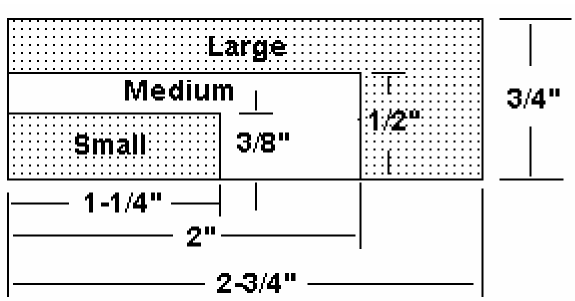
MAKING SHAFTS FROM STAINLESS STEEL(SS) WELDING RODS: This is a "no brainer" requiring a bench vise & hammer. SS is smooth, reasonably uniform in diameter, takes a sharp 90 degree bend without cracking & doesn't rust. Cut pieces long enough, say 5"-6". Round an end, Clamp 5/8" horizontally in a bench vise. To make needed low radius bends, pound near the jaws. Jaws do not mar areas that contact the pockets. Four shafts can quickly be made from the welding rod. Set aside for later sizing to length as detailed in File 3. After sizing, grind flats. See page 9 below.



MAKING SHAFTS STIFFER: after sizing a SS shaft to length to put the bend in the"sweet spot", it can be stiffened by bonding a brass tube over it with CA glue. Size the tube to length to not interfere with insertion of the shaft into either the coupler or the pocket.

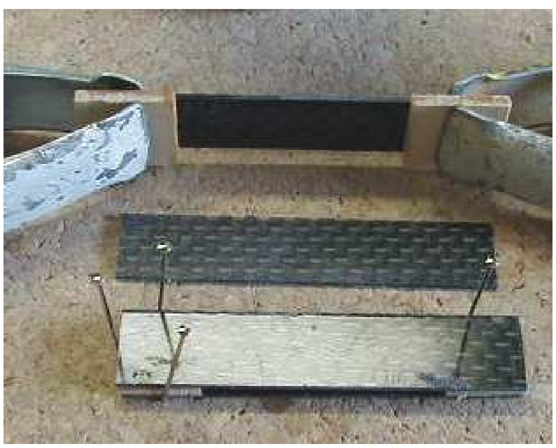
MAKING POCKETS; this is also a "no brainer". Typical sizes for ailerons are shown below for 1/16", 3/32" & 1/8" shafts. The "medium" for 3/32" shafts would be ½" x 2" with a 1" slot. For flaps, pockets need to be longer with a longer slot to allow the broad fan motion & to slide the shaft in & out of the coupler. Another ½" opening length usually works well.

Clearance is needed behind a pocket to back the shaft out of the Kimbrough coupler to disengage it from a mounted servo. I've used only the medium size with 3/32" shafts for all my sailplanes from spans from 6 to 12 feet. Larger pockets & shafts would be appropriate for thicker surfaces or heavier duty applications.



Pocket tops/bottoms of smooth Formica, CD or CF plate spaced to make a slightly snug fit with the shafts, work very well. Carbon plate is most rigid. See the Misc. pictures file how a rotary tool can be mounted to slice up rectangular pieces of carbon plate. .028-.032 thickness works well.

Carbon plate can be easily cut with a cut off wheel in a rotary tool. The next picture shows how the tool can be mounted to make a 1”cut & shims used for ¾” & ½” cuts. See more details in the Miscellaneous Pictures File.



For 3/32” shafts, 3/32” bass sheet works well for spacers. Clamp ¾” sq. pieces to a top or bottom. Wick join with thin CA. Trim excess spacers. Clamp on the other piece. Check for “slightly snug” fit with shaft. If loose, a few, even swipes with the sanding block will get a fine fit.

Over cork board, etc., place <u>four</u> pins as shown as guides to position the other piece. Coat fingers with paste wax to avoid bonding them. Dab CA on inside ends, flip over & press in place. The pockets here were intended for flaps with shafts oriented at 45 degrees so they have a 1-1/2” opening.

It’s okay to bevel & thin the assembled pockets on a belt or disc sander to get them between the skins. <u>Then wrap ends with Kevlar thread to prevent splitting</u>. When pockets are joined to the skins all becomes very rigid, based on the “bundle of sticks” principle. See File 3 for details about installing pockets. In 3 piece wings, aileron servos can go in the center section. See File 11 about installing hard slots in the ends of ailerons.

<u>CAVEATS APPLICABLE TO ALL INSTALLATIONS</u>

1. **Use servos & drive shafts suited to the application. In high speed, heavier duty applications, favor larger shafts if there is space for the pockets between the skins.**

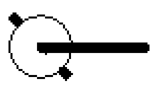
2. **Vertically position the pockets as close as practical to the plane of the hinges to prevent**

shafts from slipping out of a pocket in extreme deflection. This is not a concern in thin wings, but for example, if you had a top-hinged thick aileron & a low pocket, it could be.

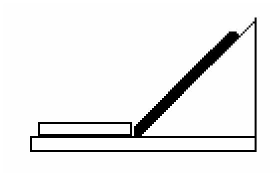
3. Where possible, keep shafts short by using thinner servos that can be mounted closer to the hinge line. Short shafts are less subject to axial flex. Axial flex may be a concern with high speed, heavy duty, high load applications. In contrast, flex would be advantageous in combat foamies.

4. Until shafts have been sized to precise length, flats ground & programming done, there is no need to seat setscrews. When a screw hits the shaft, go easy as too much torque will strip or break the plastic couplers.

5. SETSCREW & FLATS ORIENTATION: After shaft length is finalized, opposing flats can be ground on the long end with a bench grinder. Flats must be located so setscrews are readily accessible through the servo well. The drawing below illustrates proper location. (Thanks, David Stack, for this 45 degree flats orientation suggestion.)



Think of this drawing as the rear view of the coupler for the right flap servo with the wing inverted. The heavy line represents the end of the shaft pointing inboard in neutral. The outboard setscrew is then accessible. Upon CCW rotation to down flap, the inboard screw becomes accessible. Flats on the shaft must face the setscrews. This requires a suitable holder for grinding. The next drawing shows its cross section.



The heavy line represents the bent end. Triangular stock is glued to a base of ply. A ply strip is glued to the base to keep the shaft in position. A flat is made by running the vertical edge of the grinder wheel on the long (horizontal) end of the shaft. A holder as pictured below with cleat glued at the center stabilizes the shaft during grinding. Moved against the wheel, vertical flats can be ground on the protruding end of the shaft. A holder 4” to 5” long will do fine.

A 2nd & opposing flat is made by rotating the holder 180 degrees with the shaft left in its original position.

To get a RIGHT & LEFT set for both flaps & ailerons, point the long end of one shaft in the opposite direction to make the flats on it.

With opposing flats, the two setscrews can be seated through the stock plastic coupler top to secure the shafts for typical applications. Just don’t overdo the torque & risk stripping threads.

For heavy duty, demanding applications, or where time is a premium, check out the fine RDS accessories by modeler-machinist Walt Dimick at http://www.irfmachineworks.com/rds. The shafts, made from drill stock, have a long single flat, not oriented at 45 degrees as detailed above. They have a feel similar to Allen wrenches.

Walt's tempered aluminum coupler tops for heavier duty applications, used in place of the plastic ones, allow firm seating of four setscrews to shafts without danger of stripping.

If the fit between a shaft & pocket is good (slightly snug) but surface play is subsequently noted, one or more reasons may be found below.

1. There's slop in the servo gears. 2. The surface itself is flimsy or flexible. 3. The flat is convex. 4. Setscrews are not well seated. 5. The servo or its mount is loose. 6. The shaft used is too springy. 7. Hinging allows play between the fixed & moving surface. 8. The servo screw is not fully seated allowing the adapter to slip on the gear. 9. An adapter may seem to fit, but is the wrong one & allows slippage. 10. The pocket is wiggling around in the surface. 11. The pocket has split. 12. The shaft is not laterally restrained.

What I know about the RDS has been empirically determined. Technically oriented readers can go to http://www.hauninger.gmxhome.de/hobbies/modeling/RDS/RDS.html. Copy that link to the internet address line if it does not display from here. Use your pointer to slide the main screen to the right to access related graphs and formulas.

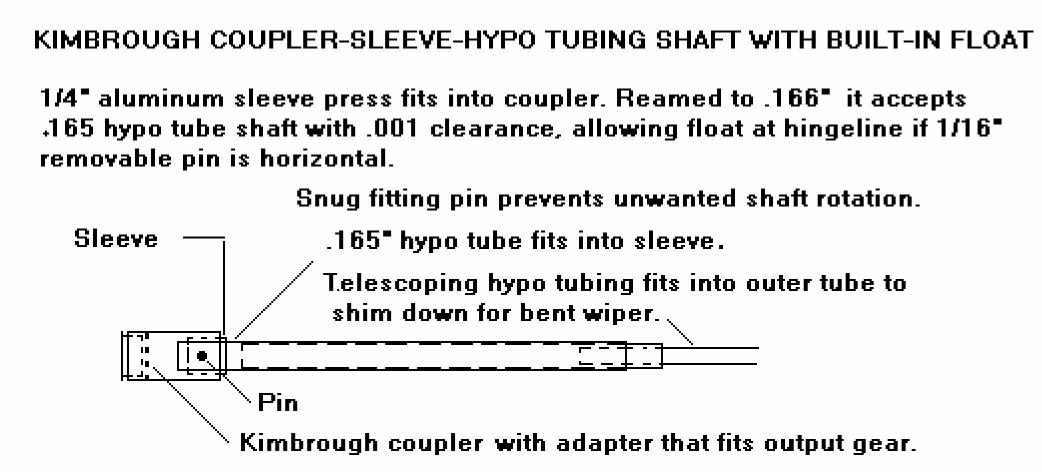
WINSTON OKERLUND'S RDS MODIFICATIONS

See http://genie.rchomepage.com/RDS%20MODIFICATIONS.pdf Winston details some additional ideas about coupling & about making tubular drive shafts for applications that require more stiffness than typical thermal sailplanes. There is also a section on DLG's.

In keeping with Winston's ideas, a ¼" diameter, ¼" long adapter sleeve made from aluminum rod or thick-walled aluminum tubing can be reamed to .166" and press fitted into the .242" inside diameter of the top of the bottom section of the Kimbrough coupler. Be sure to put the servo screw in the coupler before press fitting in the sleeve. You may need a longer screw than provided with the servo to bite into the output gear threads when the screw bears against the thicknesses of the coupler internal parts.

Here is a picture of precision-machined sleeves by Walt Dimick. If you are into F3B or extreme slope racing, etc. and must have the absolute best in RDS mechanics, send inquiries to wdimick@aol.com about pricing and availability. Do not confuse these with an unwanted hingeline sleeve that restricts the float of the shaft at that point.

The sleeves give .001" clearance with .165" hypo tubing from Small Parts, Inc. The essentials of this arrangement are illustrated in this drawing:



If you do not have a metal lathe, but want to make some of the sleeves, here's how:

From 1/4" aluminum rod or thicker walled tubing, cut a 1-1/2" piece. If rod, drill a hole in a board to support it upright. With telescoping pieces of tubing over it, shim down to start a centered and aligned pilot hole.

In a squared up drill press, progressively open it to 5/32" (.1562"). With .166" reamer, open to provide .001" clearance with the .165" hypo tubing. This provides the micro play to allow the float. Cut into 1/4" lengths. Place the servo screw into the coupler. With vise, press sleeve into the coupler. Slip outer hypo tube into the sleeve. 90 degrees to the coupler setscrew holes, drill through coupler, sleeve and hypo tube for a removable 1/16" pin.

Bend pin end at a right angle to easily grasp. Size outer tube to length. Size inner tube and wiper to length as usual. Bond with solder or adhesive. When securing coupler to the output gear, see that the pin is horizontal to allow easy float at the hingeline.