

Instructions for Building a Kepler Paper Model

Version 2.0 Jan 5, 2005

You need the following files:

<u>File</u>	<u>Sheet #</u>	<u>Printer Paper</u>	<u>Color</u>
Kepler_model_instructions.pdf		plain	b/w
Photometer.pdf	1	Photo stock	color
Photometer_parts.pdf	2	Photo stock	color
Spacecraft_Base.pdf	3	Photo stock	color
Spacecraft_parts.pdf	4	Photo stock	color

Other materials:

One soda straw. Three toothpicks. Heavy flat transparent plastic from store packaging, about 2 inches square. About 2 in square of aluminum foil. Paper glue (glue stick). Glue gun or plastic cement (just because it is faster drying). Black spray paint. Scotch tape. A few feet of thread.

Tools:

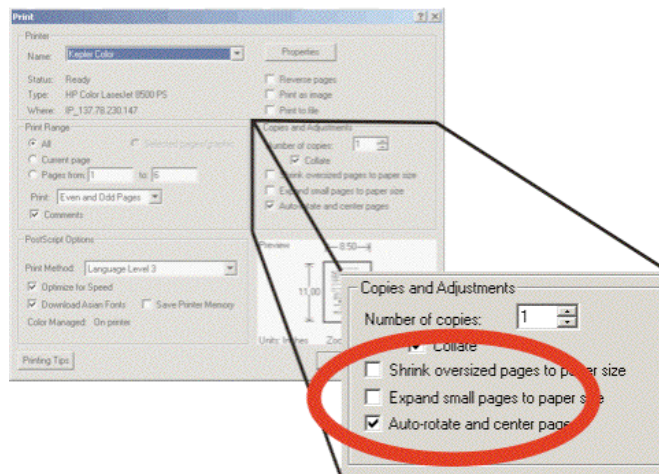
Scissors, hand held single-hole punch, metal ruler or other good straight-edge, sharp knife or Exacto-knife.

Tip: It is helpful to have a copy of the 4 sheets of uncut parts to refer to orientation and other reference marks, while assembling the cut parts.

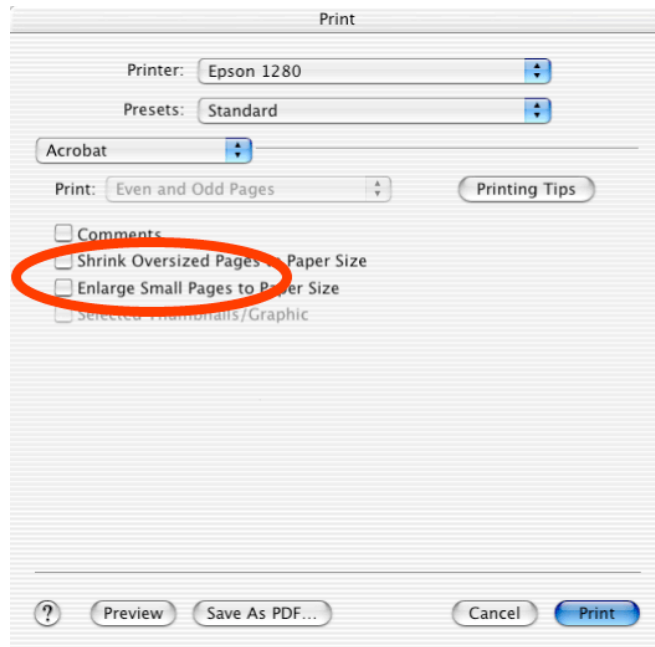
Steps:

1. Print the files indicated above on photo stock or other heavy weight paper. **IMPORTANT** After printing, **measure** the 6 inch scales on the sheets to make sure they are six inches. If not check your postscript printing options to see if the printer is resizing to fit the page. If you can't use photo stock or card stock, glue the plain paper to card stock or manila folders and then cut out. Costco sells 100 sheets of photo paper for about \$12.

Adobe Acrobat Print Settings



These are the settings to check for on a PC.




These are the settings to check for on a Mac.

Preparation:

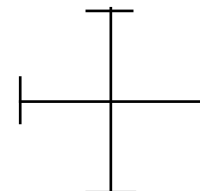
2. Spray the back of sheet 1 with flat black paint. Let Dry.

Photometer Construction:

3. Cut out the sunshade (part 1) and photometer tube (part 2) from sheet 1.
4. Glue the ends of the Sunshade part 1 together. The black goes on the inside. The narrow end should sit flat against a flat surface. (The wide end will also form a flat circle.) Use a small piece of tape to secure the ends until the glue sets.
5. Cut the 4 slits into the side of (part 2) as indicated by the special marks. Make a conical-cylinder out of the photometer tube with the black on the inside. Fold the tabs into the center of the tube. Cut out Ring-2 (part 5).
Tip: Cut out the center first and then cut around the outside. Glue the ring (part 5) onto the tabs on part 2.
6. Cut out the radiator (part 3). Curve the radiator by dragging it over the edge of a table. Fold the tabs so a cross section of the part looks like

this... . Put glue on the inside ends of the tabs and slip the 4 tabs half way into the slits in the side of the photometer tube. Fold the ends of the tabs onto the inside of the photometer tube. A little piece of Scotch tape on each tab will keep them in place until the glue hardens.

7. Create the focal plane spider. Cut out the two focal plane spider pieces (parts 6). Cut on solid line to centers and 1/4 in from right edge. Fold on horizontal dotted line. **TIP:** Use a good straight edge like a metal ruler to make crisp folds. Then unfold. Apply glue only along region K, but not



the last 1/4 inch. Fold back ends J to form a T. Apply glue to region J on both pieces, but not the last 1/4 inch. Glue the 2 Ts together to form a cross. Finally fold the last 1/4 inch back on each end to form the shape shown above.

8. Cut out part 7. Make cuts next to the tabs as indicated. Fold the tabs and the sides to form a box. Unfold the box, apply glue to the tabs and refold the box, securing the tabs on the inside of the box. The pointed ends should stick out. Let the glue harden. In the mean time cut out parts 8, 10 and 12 (do NOT cut out the center of part 10.)
9. After the glue for part 7 has set, slip the spider legs (part 6) into the box (the center of the cross is in the center of the box. (It only slides to the halfway point into the box.) Fold the pointy ends of the box down. Cut out part 8 and glue the focal plane onto the center of the spider-box. Let the glue set.

Making the Mirror

10. There are four options for the mirror;
 - a. Use part 9 only,
 - b. Glue a piece of aluminum foil to the back of part 9. Then cut out part 9. Now call the foil side the front.
 - c. Make an aluminum mirror with the appropriate curvature by pressure forming. For this see the **Advanced version of the Mirror** at the very end of the instructions.
 - d. You can also chose to skip the mirror (Parts 9, 10, 11 and 12.).
11. Cut out part 10, if you have not already done so. Do **NOT** cut out the center of this part. Fold all the tabs down when looking at the letters L-M-N. Cut out part 12. Apply glue to all the tabs of part 10 and to one side of part 12. Wrap part 12 around the tabs on part 10. A piece of tape on the part 12 joint will hold it in place until the glue sets. Cut out parts 11, 3 pieces. Fold them into C's. Glue them to the three places on the back of the "mirror" at locations L-M-N. Place your "mirror" (part 9) face down on the table. Apply glue to the edge of the mirror rim part 12 and stick part 9-10 to the back of the mirror.
12. Cut out parts 13 and 14. Do **NOT** cut out the center of part 14. Note the orientation point A arrow on part 14. Cut the 4 slits in part 14. Form part 13 into a collar and insert 4 tabs on one side of the collar into the 4 slits on the shaded side of part 14. Apply glue to the 4 tabs. Fold them over and apply small pieces of tape to each one to make sure the glue sticks well. See Figure 3. **You don't want these to come loose later since there is no way to repair them.**
13. Install the spider into the photometer.. Apply glue to the feet on the 4 ends of the spider assembly. Insert it into the photometer tube from the wide end to the point where the circular seam is on the outside. The "CCDs" should face the "mirror", bottom. See Figure 1.

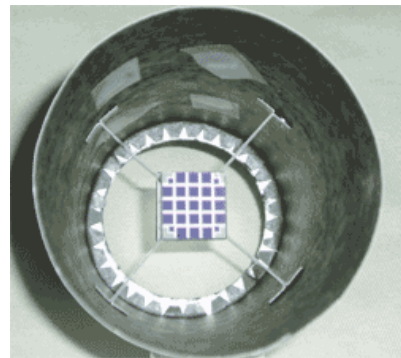


Figure 1

14. Apply glue to the 3 tabs L-M-N on the back of the mirror and glue the mirror to the inside of the photometer base, the side opposite part 13, the collar. Let the glue set, while cutting out parts 4 and 15. **Tip:** Cut out the inside of part 4 before cutting around the outside.
15. Fold the tabs on part 14 up, towards the mirror. See Figure 2. **Note** the location of the arrow on part 14, the photometer base. Apply glue to the tabs and to the inside of the wide end of the photometer tube. Align the arrow on part 14 with the seam on the photometer tube. Slide part 14 into the wide end of the photometer tube. See Figure 3.
16. Cut out parts 4 and 15, if you have not already done so. Use part 15 as a template to make the Schmidt corrector plate. That is, use part 15 to cut out a disk of stiff heavy-duty transparent plastic, usually used in packaging.



Figure 2

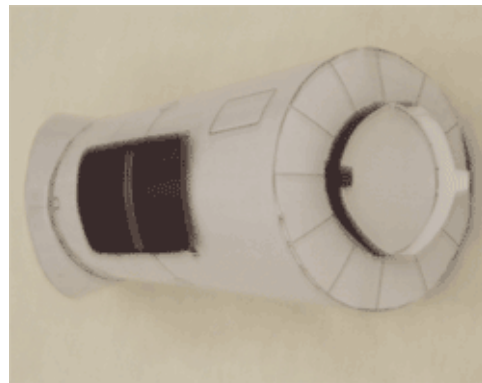


Figure 3

17. Fold the tabs of part 4. Apply glue to the ring inside of the folded tabs and place the "Schmidt corrector plate" on the ring inside the folded tabs. Apply glue to the outside of the tabs of part 4 and the inside of the narrow end of the sunshade part 1. With the narrow end of the sunshade on a flat surface, lower part 4 with the Schmidt corrector down into the inside of the sunshade all the way to the flat surface. Press the tabs of part 4 against the inside of the sunshade. Allow to set.
18. Carefully mark positions A, B and C on the back of part 16 for future reference. Then cut out part 16 on sheet 3. Do NOT cut out the center.
19. Apply glue to the top ring of the photometer, part 5, and the bottom of the sunshade part 4. Note the location of the seams on parts 1 and 2. These must be 180° apart, that is opposite each other, **NOT** aligned with each other. The low side of the sunshade should be on the same side of the photometer tube as the radiator, part 3. See Figure 3

You are finished with the Photometer.

Spacecraft Construction

20. (If you have not already done so, mark positions A, B and C on the back of part 16 for future reference. Cut out the part 16 from sheet 3. Cut around outside edges only. Do not cut out the center.)

21. Make 4 wide slits in the inner ring of part 16. Twist your knife to make the slits broad, since the photometer collar tabs and Payload attachment Fitting have to both go through the same slits, one from above and the other from below
22. As a fit check of the final assembly, try to slide the 4 tabs of the photometer collar into the 4 slits in the spacecraft base from the "unprinted" side of the spacecraft base so you can see how well the tabs and slits align. Make any adjustments in the slits now so it is an easy fit. Later you will have to do this "blindly" with the photometer base fitting down into the hexagonal spacecraft base.

23. **Tip:** Use a good straight edge like a metal ruler to make crisp folds on part 16. Fold the six side panels with gold colored equipment boxes on the outside to form a hexagonal (6-sided) base for the spacecraft with the gold boxes facing out. Glue the "Fold Tab In" to the inside of the adjacent side panel. See Figure 4.

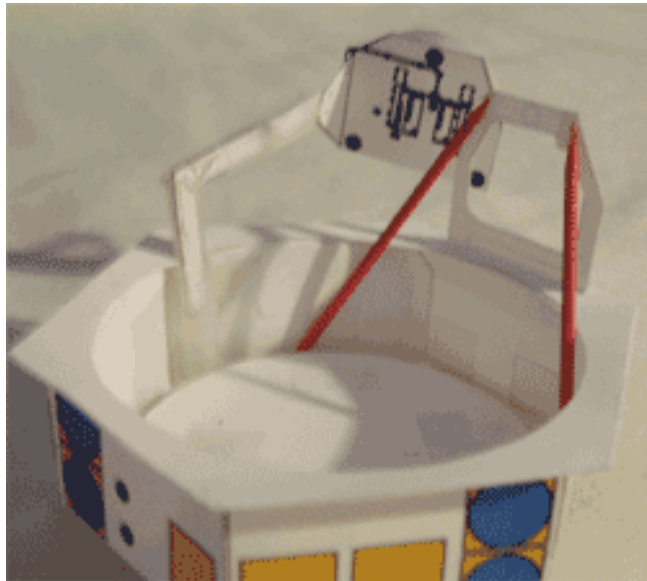
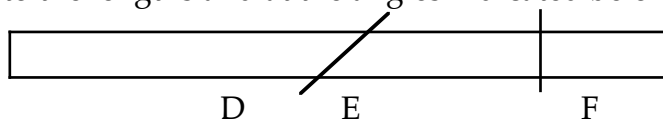


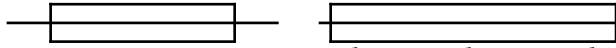
Figure 4

24. First note the positions of letters A, B, C, G and H on part 18 then cut out parts 17 and 18 from sheet 3. **Tip:** Cut out the insides of parts 17 & 18 before cutting around the outsides.
25. Slip the spacecraft base part 16 through part 17 and glue down the tabs. Glue part 18 to the top of the base, **aligning** the hole for the boom to position B on the spacecraft base.
26. Cut out part 21. Cut a slit in part 21 the antenna dish and carefully with a hole punch, punch out the center of the dish.
27. With part 21, overlap the ends of the dish to the point marked on the edge and glue to form a dish. Set this aside for later until the glue sets.
28. Cut part 22 the boom elbow from sheet 4. Fold part 22 in half.
29. Cut a straw to the lengths and at the angles indicated below.



Using a glue gun, fill the ends of the straw pieces at the angled cut with glue. (Plastic cement will not work for this!) Quickly insert the elbow part 22 into each end of the two parts so that the straw now forms a right angle.

30. Now cut two more pieces from the straw to the lengths shown below.



Split these each on one side only along the length. Slide the shorter piece over part D of the above elbow and the longer piece over the two parts E & F to join them. Do not use glue.

31. Slide the D end of the boom assembly through hole B in the spacecraft base and securely tape the sleeve on the D part of the boom to the inside walls of the spacecraft. The boom should be able to rotate freely inside the sleeve. See Figure 4.

32. Cut the sharp tips off a tooth pick. Cut the tooth pick into three equal length pieces about 1/2 inch long each. Using a glue gun or plastic cement (that dries quickly) glue the ends of the three tooth picks to the three dots on the antenna dish part 21 and then glue the three legs to a hole punch to form a tripod. Set aside for the cement to harden. See Figure 5.

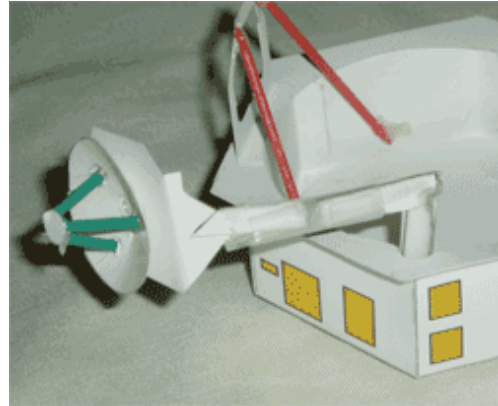


Figure 5

33. Cut the solar array part 24 from sheet 4. Cut the three slits in the bottom and fold the bottom. Fold the panels to match the shape of 4 sides of the spacecraft base.
34. If desired punch a tiny hole in the center of the solar array along the center fold and pull a thread through the hole. Tie the thread around a small piece of tooth pick so that the knot doesn't pull through the hole.
35. First note the points G & H for part 19 then cut out part 19, the HGA cradle. (HGA stands for High gain antenna). Fold the tab and glue to position C on the top of the spacecraft base. Using fast drying cement or a glue gun, glue one tooth pick from point G on part 4 to the G position along the inside of the spacecraft base. The end of the tooth pick should reach down to where the fold is in part 16 between the bottom and the side. See Figures 4 & 5. Likewise, glue one tooth pick from point H on part 19 to the H position along the inside of the spacecraft base. Let the glue harden.
36. Cut out part 20. Using a glue gun, glue the antenna dish part 21 to the front of the HGA back panel part 20, that is glue it to the side without any printing. See Figure 5.
37. Fill the end of the antenna boom F with glue from the glue gun and slip the folded tab on part 22 into the glue in the antenna boom end. See Figure 5.
38. Slide the long slit straw piece from step 24 over the E-end of the antenna boom elbow and then slip the F-end of the straw glued to the HGA into the slit straw on the antenna boom. See Figures 4 & 5.
39. The back of the HGA should now be able to be stowed against the HGA cradle, part 19. See Figure 6.

40. Cut out part 23 The payload attachment fitting.
41. Mount the photometer to the spacecraft. **This takes patience.** First note where position A should be on the spacecraft base, 2 panels over from the boom on one side and 2 panels over from the HGA on the other side. This is the location for the back seam on the photometer and high side of the sunshade. The arrow on the bottom of the photometer base should point to position A on the spacecraft base. If you haven't done the fit check in step 22, do it now from the bottom up into the spacecraft base so you can see the slits. Now insert the base of the photometer into the hexagonal spacecraft base. See Figure 6.

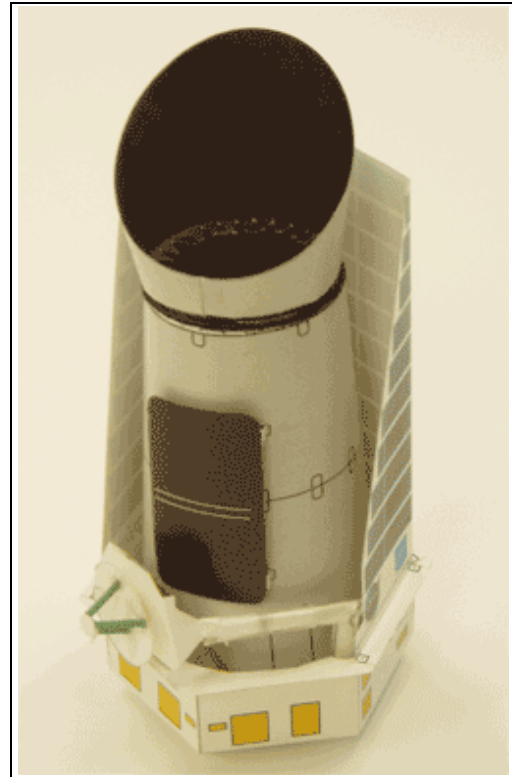


Figure 6.

- Patiently, jiggle it until all 4 tabs come out of the bottom of the base. Apply glue to the outer facing surface of these 4 tabs. Apply glue to the inner surface of part 23 at the 4 tab locations. Slip the 4 tabs of part 23 into the same 4 slits that the tabs from the collar are coming out of, with part 23 on the outside of the photometer collar tabs. Press the tabs against part 23 and make sure they are well glued. Finally add glue to the overlapping end of part 23 to form a ring. See Figure 7.
42. Glue the Solar array assembly to the spacecraft base assembly, noting the location of the orientation point A on the two assemblies. The fold in the center of the solar array should be aligned with the back seam on the photometer tube.

Congratulations. You have completed your paper model of the Kepler satellite.

The model was created by David Koch using data from Ball Aerospace. Comments about the model are welcome. Send to DKoch@mail.arc.nasa.gov

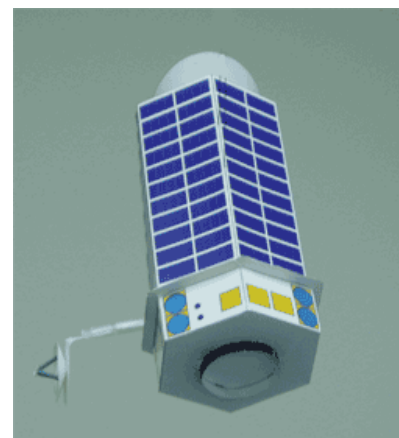


Figure 7.

Additional information about the *Kepler Mission* can be found on the Kepler web site at <http://Kepler.NASA.gov>

Advanced version of the Mirror

This involves pressure forming of the aluminum foil, requiring an air pump and shop skills to make the pressure forming components. The air pressure needed is under 20 psi.

1. Start with 2 pieces of plywood $3/8$ or $1/2$ inch thick and about 4x4 inches.
2. Use a $2\ 1/4$ inch diameter hole saw to cut a hole in one board.
3. Drill a hole in the center of the other board for the pressure hose connection. I drilled a hole somewhat smaller than the thread diameter on the brass fitting on the end of the pressure hose and just screwed it into the plywood. It "self-threaded" into the wood.
4. Now place 4 squares of foil between the two pieces of plywood and clamp at all four corners. I actually clamped one side in my workbench vise and used C-clamps on the other 2 corners. The foil needs to be clamped tight, so it stretches and not slips when the pressure is applied.
5. Now apply a small amount of air pressure to make the foil curve out by only $1/8$ inch.
6. I used Heavy Duty aluminum foil and found that a single sheet "pops" at about 15 psi. Also, with 15 psi the curvature is too much. So I tried 4 sheets and at 20 psi got about $1/8$ depth. This is about correct for the diameter of the mirror and the radius of curvature. The radius of curvature is the distance from the mirror to the Schmidt corrector. It seems that you need about 5 psi per number of sheets of foil used at once.
7. After forming the "mirror", lay the untrimmed foil on a flat surface with the "front" of the mirror toward the flat surface. Apply glue around the edge of the mirror rim (step 11 above), not to the foil. Stick the mirror rim to the "back" of the foil. After the glue sets, trim the foil.