Fan failure analysis and repair

by Russell E. Baetke ©
Seattle, Washington

Introduction

For some owners, the original Model A fan has been a real problem and for the rest of Model A owners the fan is a problem waiting to happen. Many a hood and radiator has been damaged as a fan blade ripped from the hub. These failures have been mostly unexpected. When they come, they come with great inconvenience and expense. They could even hurt someone! Possibly you have already replaced your Model A fan with another of unknown character in hopes of avoiding the catastrophe.

If you have any doubts about the serious consequences of a fan failure, just ask the man who has had one! The catastrophic nature of this failure results in such significant damage that it is wise to make frequent checks for impending failures. That applies to all originals without exception and probably most replacements too. The failure mode of the fan is unique to the Model A. It was designed in an era when fatigue analysis and stress risers were not understood.

Just how early these failures started showing up on Model A's is something not easily established, but the fan was redesigned in the '31 model year suggesting an early fix was needed to satisfy an already known problem. But, that did not correct the fundamental problem.

The construction of this fan is different from others. It is not designed like modern fans, or like previous fans on the Model T or other Ford products. It is a box section using two skins to form the front and rear of the blade surfaces. These form a complex aerodynamic surface blended aerodynamically into the stream-lined hub. Structurally this design has been causing failures over the years. They can be quite catastrophic. To avoid the failure, many have already substituted after-market fans and lost original-ity. Others have clipped the tips with hopes of avoiding the problem. My reasoned attempt to explain the cause and offer a solution will preserve the original with an almost invisible repair. It gets directly to the cause of failure. It's not what you think.

Current philosophy leans toward replacement of originals. I offer this study to help you decide if there is a better alternative to avoid a failure, correct the problem and make the original service-able. Should you use an original with or without the proposed safety strap or seek the alternative of a non authentic after-market solution? Judge for yourself. A procedure for repairing the original two blade fan is offered but, you the reader, should have the comfort of an explanation of the rationale and experience behind it.

General description of fan construction

Compared to any other car fan I have seen, this is a piece of sculpture. It is beautiful; it is exotic; it is complicated and it is flawed. Its two dimensional airfoils blending into a streamlined hub are a work of aerodynamic art and uniquely Model A. It is worth preserving as a part of the character that makes up our unique automobile. That is not to say the design was without serious problems. The problem simply comes with the heritage of the Model A. The design and construction consists basically of two separate layers of 20 gauge metal contoured to form the hub and front and rear surfaces of the airfoil. This is in marked contrast to the single layer configuration that was the standard for Model T and again became the standard for later metal fan blades. This tells you something about a Model A fan. It needs help to preserve it!

Welding along the edges and at the hub core ties all these parts to form the aerodynamic blades and hub. It is the contours and the proximity where the welding stops near the hub that we must concern ourselves. Here the sheet metal pieces are notched to overlap and form the hub contour at a point inboard of the weld. This is the primary point of concern, and is usually where the trouble starts. There is a small area near the hub where the two sheet metal pieces are not welded. This allows the two metal sheets to work independently and the loads are the highest. There is a stress riser (it is hard to see) in the design where the metal is wrapped to form the double layer at the center. Initially one of these sheets at the leading edge fails, then the overlapping sheet fails on the leading edge. After the leading edge fails the load transfers into the trailing edge which has less load carrying capacity and finally the blade separates from the hub.

With the aid of friends (Ken Wall, Jack Eichman and Jerry McCullough) I have collected together a number of fans in various conditions of failure. It seems remarkable to me that some of them are still in one piece. These represent, what I believe is an appropriate restructure of, the failure sequence. Most of the samples show that the blades exhibit unequal blade angle and that the leading edge of the blade is bent out of the plane of rotation at a point just outboard of the center where the seam weld stops. The blade angle is generally greater than original. More about this later.

Before it fails

Experience indicates that an unmodified original fan will eventually fail. Age and past usage work against all fans. Since we can't identify how far and how fast the fans were driven or how abused, all we can do is look for symptoms of impending failure and hope to spot them before a major failure occurs.

You can avoid the catastrophic affect of loosing a fan blade by removing the fan before failure occurs. But, how can you tell if failure is about to happen?

Learn where to look. You must look very closely for the critical failure spots. If you look at the hub when the fan is in the car, you have a fair to poor chance of catching the failure before a blade rips off and damages your hood and radiator. Once you see any crack or separation of the sheet metal, the failure is close at hand. Remove the fan immediately!

In the beginning this initial crack is hard to see, especially when the fan is in the car. It is best to have it out on the bench in good light. The problem is that the starting crack is so small it is sometimes hard to see even on the bench. Look closely at both blades because, one blade or both may be failing simultaneously. The trick is to know exactly where to look and **look closely**.

The cracks are so hard to see, especially if the fan is painted, that there is a good chance you will not see them unless the light is just right and the surfaces are cleaned. In the early time of this study, we shopped for a fan and bought one with no apparent crack. It looked good. Only 3,500 miles later it failed. I mention this because it gives you an idea how close you must watch to assure catching an impending failure before it creates a catastrophe.

A very small crack starts on the side about 5/8" out from the shaft center and progresses on to the forward flat face where the shaft nut is installed. The cracking areas are identified on the drawing. This is a spot where the fan blade leading edge forms into the hub. From here the crack expands across the front face at the same location. Sometimes the progressing crack jumps about 5/8" further outboard to the location where the blade leading edge seam welding terminates. In this area the blades may also have a visible bend backward (sweep back) due to fatigue.

There is another possible impending failure caused by the abusive practice of cranking the engine with the fan. This action causes a separation of the two sheets of metal forming the hub in this same area. This causes the blades to bend forward in the fan plane.

Background

Some people say they solved the fan failure problem by trimming the tips and making a smaller fan. You know that as the "bobbed" fan. This may have reduced the cyclic aerodynamic loading and reduced the blade weight which is the centrifugal loading. However, this modification works only if the fan is not already fatigued in the first place.

In the 1931 model year a redesign using a single surface on the outboard end of the blade was introduced. That reduced the blade weight without changing the cyclic aerodynamic fatigue loading. This fan was looked upon as a solution to our problems. Now, there are reports that this redesigned fan is failing. The Model A fans, all of them, are subject to fatigue failure. Without attention they will eventually fail.

A repair of this weak area can be made. But first I must say that a simple weld of the crack is not satisfactory. Many, with the cracks welded, are offered as good fans at swap meets. They are a catastrophe waiting for an unsuspecting customer. The load path is not corrected and little strength is returned to the fatigued part. Also, it is unlikely that the blades were straightened. *Bent blades are a preview of failure.* During this early period before blade separation, the blade position changes and each blade shifts back from its original position. If welded in this bent position, the fan can no longer be balanced!

The repair that I developed has been driven since 1983. The difficulty with making an early claim to a satisfactory repair in those days was that it was hard to get courageous testers to run a fan with unknown repair characteristics. This one has been running under constant observation for 30,000 miles. When I started this, there was only one person courageous enough to try running with a "yellow" fan, the color they were painted to be sure they were visibly experimental. On the first trip with one of these repairs, we went in caravan from Seattle to the meet at Calgary. That trip I had two failures! They were very visible to the group and at the time it seemed to be the end of the test. Neither of the failures, however, had anything to do with the blades. Both occurred in the pulley flanges. Being such strange failures they were assumed to somehow have been caused by the repair. Later I found that a flat spot in my fan belt had fatigued the pulley flanges. The test fan on the other car continued to work, but a few months later, it came back with what appeared to be a crack developing. It turned out to be the plastic body putty and paint coming loose from the vibration! That too was an early learning experience directing attention to the severity of the vibration environment in which the fan operates. I have come to believe that the fan is the most cyclically fatigued part on a Model A.

Environment problem

The fan operates in an environment something less than ideal. The blades are subject to both centrifugal loading and aerodynamic loading which pulls on and bends the blades at the same time. The centrifugal loading is a function of rotation speed and is fairly uniform. The air loading on the other hand is very erratic. The flow of air behind the radiator is distorted as the blade tips rotate past the radiator hose, the generator pulley and timing gear cover. A cyclic air pulse is introduced each time the fan tips pass one of these objects causing three fatigue cycles for each revolution of a blade.

Looking at the failure mode of many failing fans focuses attention to the design in the hub area. All fans exhibit similar failure conditions. The blades are bent aft from their normal position in the propeller plane. This bend starts at the leading edge about 1-1/4" out from the center. The blades are also out of the fore and aft plane. That is they tend to bend forward and the pitch is increased. Cracks begin showing at the leading edge about 5/8" from this center where metal is tearing apart. It indicates that the local material is stressed beyond fatigue limits in this area. This small area in the hub is formed by two overlapping sheet metal pieces that are not welded and therefore working separately since the weld stops 1-1/4" from the center. Therefore one is stressed higher than the other.

There must be a tension member to react to the blade centrifugal loading, and that is the design flaw. The hub contour causes much of the sheet metal to be curved, causing the metal to be at an angle to the loading path allowing only a small part of the fibers to react to the loading. The load carrying fibers are a small section only along the leading edge. The sheet metal is 20 Ga. (.0375") and approximately 1.00 inch of material is working out of a possible 5.0 inches devoted to the hub contour. This is also essentially the same spot where the loading happens to be maximum.

Straightening

Balancing a fan requires careful straightening of the blades to achieve both mass and aerodynamic balance. This is a consideration of merit for propellers in general that an unbalanced loading of the bearings supporting the shaft are affected by both air loads and mass unbalance. If the blades are not exactly opposite each other (even if they both weigh the same) the fan is out of balance and lastly, if the pitch of the two blades are not equal, one blade will pull harder than another causing abnormal blade loading.

When I started looking into balancing a fan I didn't realize how much was involved. Some of what I learned is probably beyond what a Model A'er will want to do in restoring a fan. But, on the other hand the information is useful in terms of the relative magnitudes and may give some insight into how good was the original balance. If you are going to try to restore an original you must know what almost 70 years of time and thousands of miles of use have done. When the two blade fan was new the blades were exactly opposite each other and the angles were exactly equal. Even as they get older the weight of the blades does not change appreciably. The unbalance develops primarily from the bending of the blades which results in them being no longer opposite. Now, in this condition the blade weights result in an unbalance 90 degrees to the blades. It is therefore necessary to straighten the blades by removing the sweep back caused by loading on the blades. This can be checked by placing a straight edge on the leading edge of the two blades and checking that they are parallel. Normally one blade bends more than the other. Also the leading edge appears out of plane in the side view. All this bending results in the blade angle changing. Working at the end of the blade, check that the angles are equal.

A fan cannot be balanced unless it is first straightened. I learned a lot about straightening fans to get them into correct shape and how to balance them. I also learned that the commercially available reproductions are not well balanced. There is much to say about the construction details and their effect on balance techniques. There are two kinds of balance to be considered on a propeller. There is the obvious mechanical balance and the not so obvious aerodynamic balance. Both of these must be considered. Mechanical balance requires that both blades be the same weight and that they are exactly opposite each other. Because the fan blades bend in use, the blades are no longer opposite to each other. Therefore a fan will not balance if the sweep back resulting from bending is not removed. The blades must be exactly in line on the diameter.

Aerodynamic unbalance is more subtle and is caused by unequal blade angles. This causes one blade to pull more or less than the other. This too can cause increased bearing torque applied to the shaft bearings. What is more important is that poor cooling performance can result at idle. This is because once the blade angle increases beyond a certain value, the blade airfoil will lift less (not more) and therefore stop pulling air as required during idle.

The primary unbalance is due to the blades no longer being on the same diameter. The blade weights are still fairly near equal. There is, however, a check you should make. Since the blades are hollow there may be rust or other debris in the cavity. If this gets bad enough the concave side of the blade may bulge.

To check that the blades are in line, stretch a string from tip to tip and observe if the tight string crosses the shaft hole at the exact center. Straighten the leading edges as required. Then make the pitch of both blades equal. The angle at the tip is 18-20 degrees.

Preliminary balance

Modify an old water pump shaft by turning the threads off the end for about 1/8-3/16". Build a simple stand as shown to provide two metal "knife" edges for the shaft. Put the fan on the shaft and using modeling clay as a temporary weight try to get it to balance with the blades horizontal. Then rotate 90 degrees and balance with the blades in a vertical position. This is the test to tell if the sweep error is corrected. Place the temporary clay weights on the hub flanges. Adjust the sweep until the weights are minimal. This test is four positions. If it balances in only one, the sweep is not corrected.

Repair

Only after the blades are properly straightened, cracks welded and the fan balanced, should the safety overlay be installed.

The repair I developed is a sheet metal overlay made in one piece which when formed will fit over the front and rear surfaces of the crack effected area to make the two fan sheet metal pieces work as one. The part forms quite well with relatively little stretching. When the part is shaped, recheck the blade alignment with the string. It is then wire feed welded or surface brazed onto the fan. All edges are ground to a smooth edge and lead filled to taper it into the contours. This avoids stress concentration and makes the overly near invisible when installed. The template of the overlay is drawn to scale shape. I did start with a simpler shape, and that simpler shape is the one that has been running in my car. This shape is more suitable since tears propagate onto both front and rear surfaces which are the places of origin for the failure. As to the complexity of doing this, it is necessary to operate a gas torch if you braze or job out the TIG welding as required. Other than that, normal body tools are all that are needed. The overlay bends down to the fan contour with minimum stretching.

Commercial TIG welding along the perimeter of the overlay is under observation and appears to be simpler than brazing.

Summary process for straightening fan blades

1. Install fan on a water pump shaft.
2. Make sure the taper is in good condition in the hub. It sometimes wears hour glass shape. If the taper is damaged, stop here.
3. Bend blades to remove sweep back.
4. Place string from tip to tip and observe crossing at center.
5. Using rear pulley as base, check fore and aft of fan blades.
6. With flat surface, check that the front face of the fan is flat.
7. Check that the pitch angle on both blades are equal.
8. Repeat the steps 3 through 7 until all check.
9. Now go to the preliminary balance section and check.
10. Cut out the overlay and clamp with a bolt and two clamps.
11. Hammer form the overlay to the contour of the fan. Remove overlay.
12. Check straightness of fan as before and if still straight have the hub seams and cracks TIG welded.
13. Grind and file welds to smooth and return overlay to position.
14. Final form the overlay and clamp with bolt and four clamps.
15. Return to welder with instructions to start welding at the clamps and hammer the overlay tight to the surface as welding progresses.
16. Grind and file the weld bead to the surface of the overlay.
17. Blend the overlay step into the original fan surface using lead or silver solder.
18. When the contours appear satisfactory, check the balance.
19. Add or remove solder as required to final contour and balance.
20. Paint.

Final balance

1. Use modified old pump shaft in preliminary balance process.
2. Make a stand from 2 by 4 and metal edges.
3. Make metal edges level.
4. Place shaft in fan.
5. Place on knife edges.

6. Let fan roll on edges and place a small weight like clay on the high blade to get a balance.

7. Turn the fan over and try again; if it doesn't balance from both sides the fan is not straight. After welding the final overlay I checked the balance with modeling clay as a weight. On the tip of the fan a piece the size of a small marble for horizontal balance translates to 20 grains at 8 inches or 0.37 inch-ounce. At right angle to this for the vertical balance check, a weight of 41 grains on the pulley flange translates to .19 inch-ounce.

8. Lead solder on the concave side equal to the test weight. Body putty does not work. Braze or solder only. Polish it up and paint.

Stress analysis

For this analysis consider the fan as rotating 3,743 R.P.M. at 60 M.P.H.. The engine revolutions per mile can be determined from the speedometer gear ratio and knowing that the speedometer shaft rotates 1,000 times per mile. 19/7*1,000=2,714 revolutions. Using 60 M.P.H. as a design criterion for the purpose of analysis the engine would be running at 2,714 R.P.M.. The fan runs faster because of the pulley size and is: 2,714*5.00/3.625=3,743 R.P.M..

Therefore if each blade experiences 3 pulses per revolution and the fan rotates 3,743 times per mile, each blade is flexed 11,229 times per mile.

The fan assembly weighs 1 lb. 11 oz. and the hub itself is 11 oz. So each blade weighs slightly less than half a pound. Say 0.4 lb. then:

Centrifugal F = W*R*N^2/2,933.9 =
.4*4*3,743^2 / (12*2,933.9) =
637 lb.

Elementary stress = 637 / (.0375*1.00) = 16,987 psi

Stress concentration factor K estimated range 2 to 3 (Ref. 1) therefore:

Stress at notches in probable range 34,000 to 51,000 psi.

The endurance limit of this material is probably about 30,000 - 55,000 psi. (Ref. 2) In general parts with 10,000,000 cycles are subject to this kind of stress failure. It takes a bit less than 1,000 miles to get that. Of course in the real world the car is not going 60 M.P.H. for all that time but I hope you see that we are in the range of proper explanation. Slower speeds will yield longer operating times which are the real experience for the car.

Blade angle calculation assumed at the tip radius, 60 M.P.H. and 3,743 R.P.M..

Tip speed = 3743*16*3.1416/12 = 15,679 fpm

Angle at tip = arctan (5,280/15,679) = 19 degrees

Performance at idle

When the engine is running it requires air movement through the radiator for cooling. At any time the car is moving in high gear, the forward motion of the car produces sufficient air movement through the radiator for cooling. When the car is stopped and the engine is idling, no air is moved as a result of forward motion. This is the reason for the fan. The fan draws air through the radiator when the car is parked with the engine idling.

Basic laws of fan performance from Ref. 3

Capacity varies as fan speed
Pressure varies as square of fan speed
Power varies as cube of fan speed

Derivation of formulas for the car radiator and fan:

The air flow through the radiator (1930-31) = (speed M.P.H.*5,280*17*22)/(60*144) = cu ft/min of air = 228.8*speed M.P.H. (where the * means multiply)

The air flow through the fan (1928-31) = speed M.P.H.*5,280*16^2*pi)/(60*4*144) = cu ft/min of air = 122.9*speed M.P.H.

Minimum engine speed is about 250 R.P.M. therefore minimum fan speed is 345 R.P.M.

Engine R.P.M. = (2,714/60)*M.P.H. = 45*M.P.H. therefore the theoretical minimum high gear speed is 250/45 = 5.6 M.P.H. but it bucks and you shift into low gear to not slip the clutch and now the engine speed is 250*3.12 = 780 R.P.M. and the fan speed is 1,076 R.P.M. (Ref. 4)

The air needed is 122.9*5.6 = 688 CFM but it must all come from the fan so the ratio of areas suggests the fan must pump 688*228.8/122.9 = 1,280 CFM

Commercial fan for reference performance

Performance data for a commercial fan of similar design:
Capacity table for American Blower Co fan Model 20A; (Ref. 3)
16 inch diameter three blade with venturi
2,000 cfm free air
1,150 R.P.M.
1/12 HP
Calculating the air velocity from this data: V = 2,000 / (16^2*pi/(4*144) = 1,432.39 fpm
Correcting for speed and number of blades:
CFM = 2,000/1,150*1,076*2/3 = 1,248 CFM. This is substantially equal to the 1,280 CFM flow required and agrees with known operating conditions.

Tools

String about 3 feet
Hammer
4 - C clamps
Pump shaft (modified)
Soldering iron
Protractor
Level
Rotary cutters/stones
Welding Torch/TIG
Pick hammer
Vise
Balance stand
Files
Measuring scale
Tin shears
Drill motor

Materials

.0375 (20 Ga.) x 2 in x 6 in steel sheet
Braze metal and flux or commercial wire feed welding
Clay
Solder
Sandpaper
Paint

Friends who contributed fans

Jack Eichman (the courageous one)
Jerry McCullough
Ken Wall
Vaughn Miller

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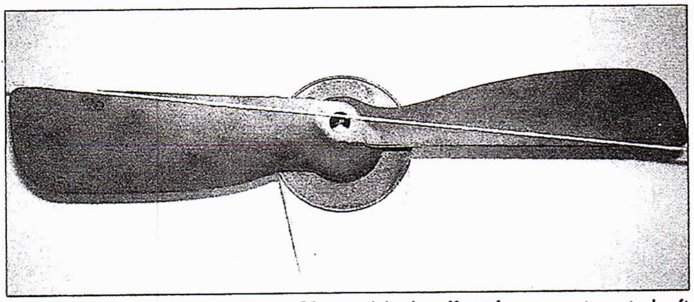
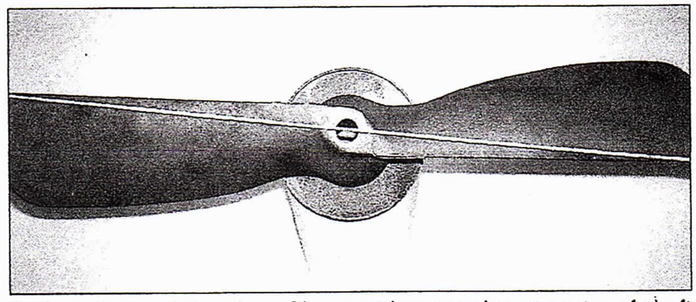
3. Kent's Mechanical Engineer's Handbook; 12th Edition, Power, 1950 pp 1-65 - 1-90

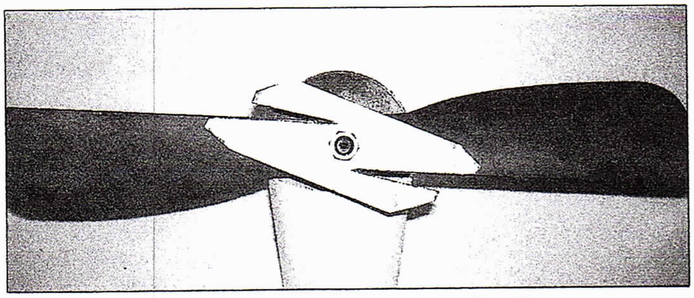
4. Restorer's Model A Shop Manual, Jim Schild, Motorbooks Intl pp 103



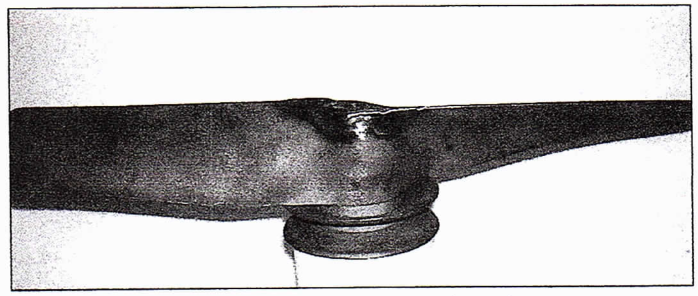
1. Fan before straightening. Shows blade offset from center at shaft hole.



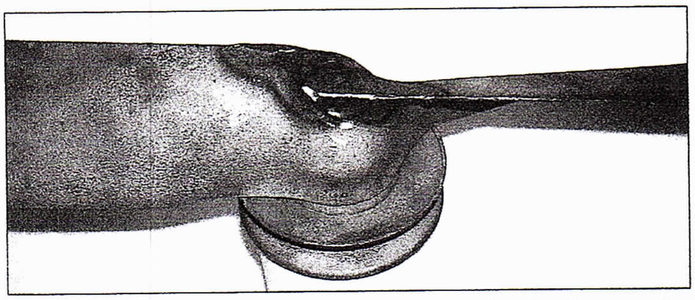
2. Fan after straightening. Shows string crossing at center of shaft hole. Ready for preliminary welding.



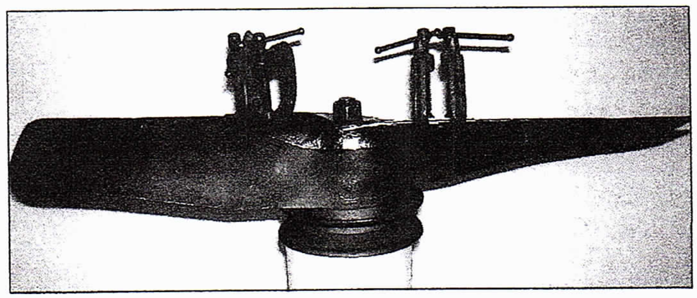
3. Overlay bolted in place before preliminary forming.



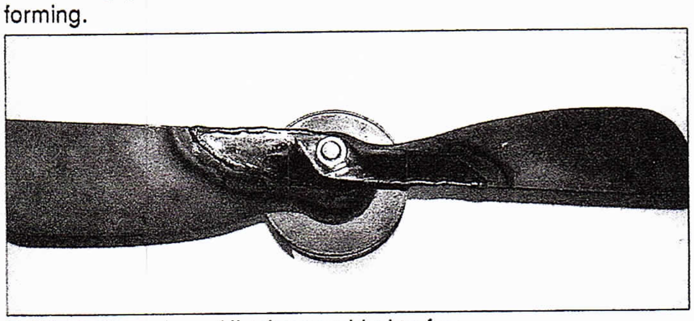
4. First welding of all unwelded seams and cracks.



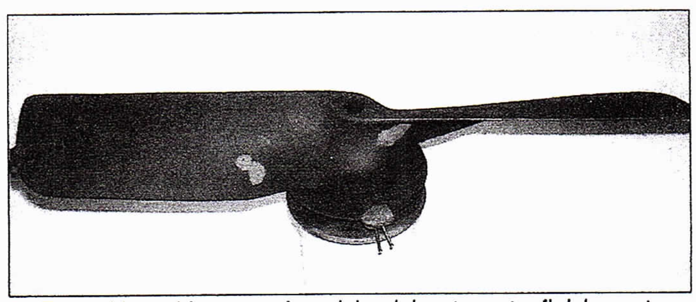
5. Welding ground flat to surfaces in preparation for final overlay forming.



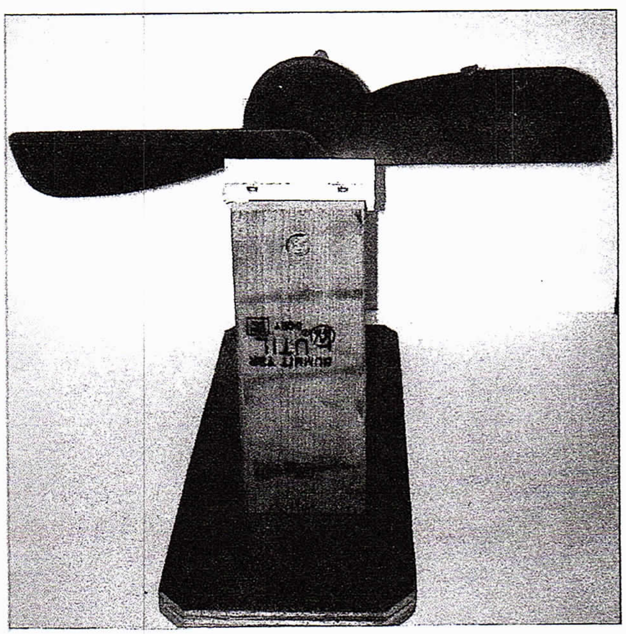
6. Overlay final form. Clamped at ends and ready for welding.



7. Welded overlay. All edges welded to fan.

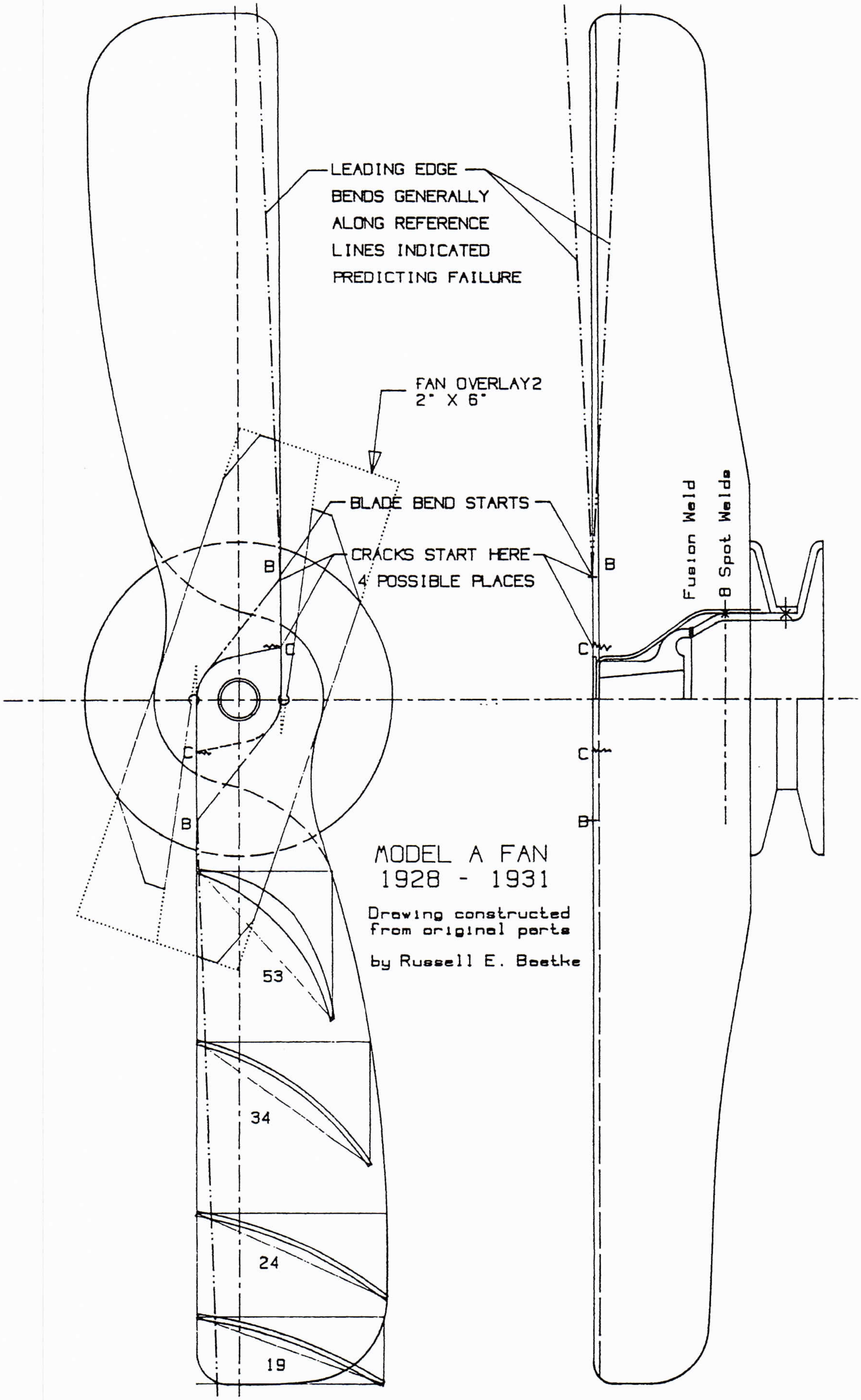


8. Fan with welds ground and lead in steps to finish contour. Primered and balance weights.

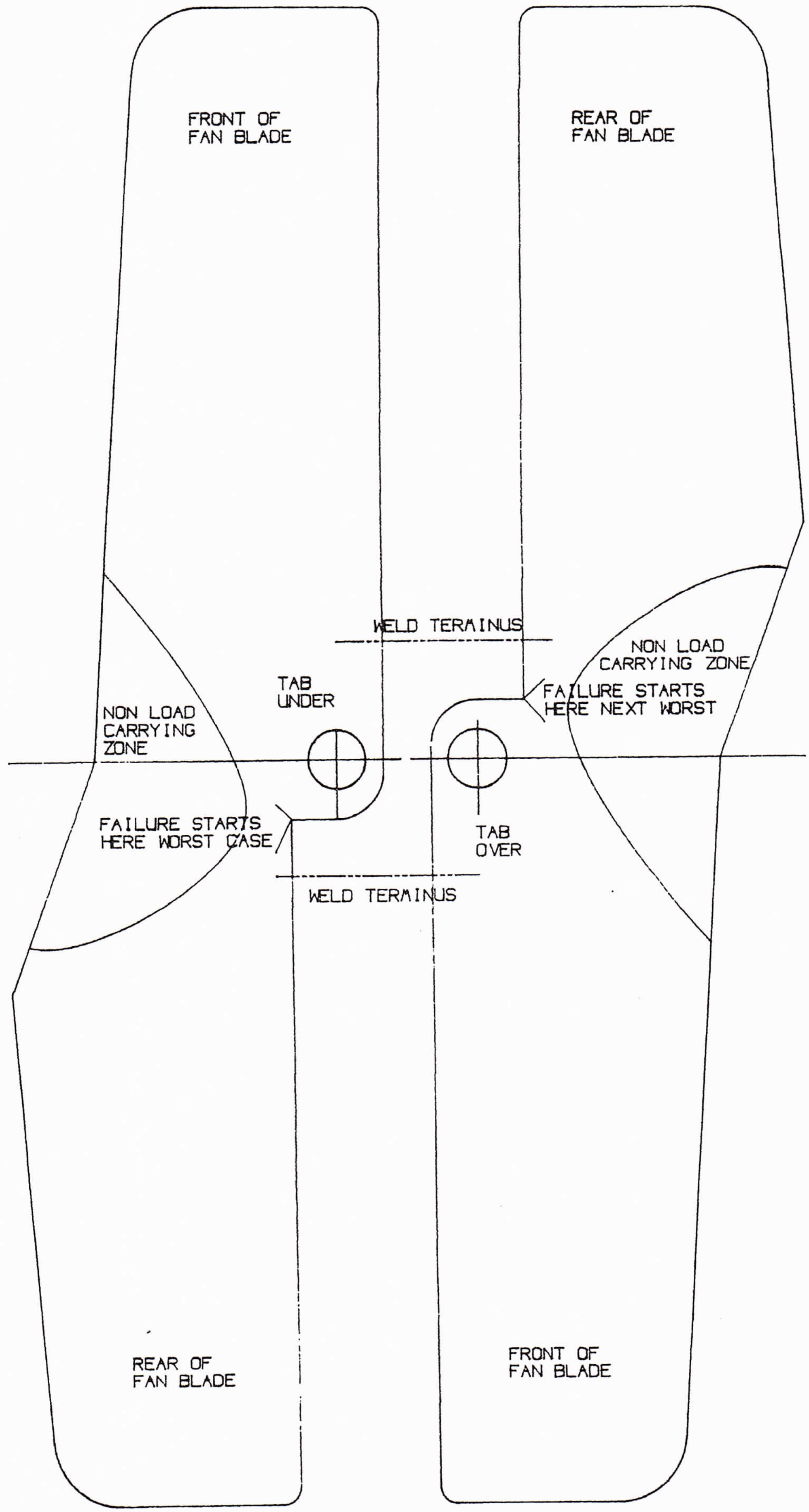


9. Balance weights reduced and ready for final finish.

About the author: Russell E. Baetke is a mechanical engineer by profession and has been a member of MAFCA since 1975. He writes, "My purchase of a junk Model A was not made because of a love for the car. That came later. I bought it for the challenge - to see if I could accomplish something I had never experienced. Five years later I had a running car - I accomplished my goal. Only then did the real rewards of having a bright restored antique car become apparent. Well you know the rest - you get out of the shop and share with people interested in your project. The nostalgic joy of those who owned one, touring with folk of like interest. Tours, parades, seminars and shows provided a conduit for the rewards not perceived during the restoration. It does become a love affair." Now retired, Russell indicates, "I made my living teaching at two different universities and designing airplanes at the Boeing Co." He is currently volunteering at Boeing Co., helping restore one of only 10 Boeing S-307 planes made. This was the first pressurized airliner ever built and it was developed in parallel with the B-17 in 1939. The S-307 is being restored by Boeing for the Smithsonian.



Drawings by Russell E. Baetke (reduced to 65% of original size)


FRONT OF
FAN BLADE
REAR OF
FAN BLADE
WELD TERMINUS
NON LOAD
CARRYING ZONE
TAB
UNDER
FAILURE STARTS
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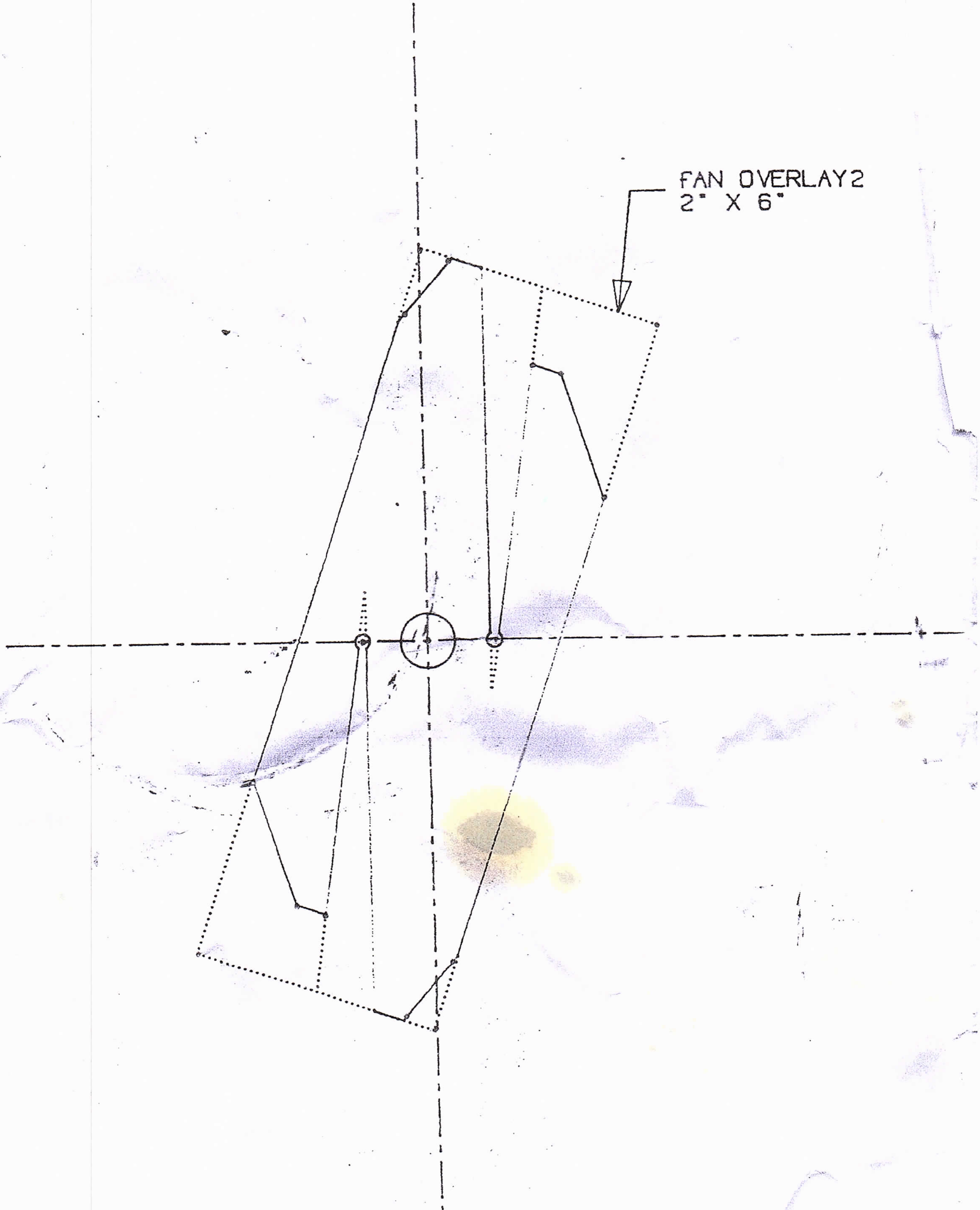

Drawing of fan overlay by Russell E. Baetke (actual size).