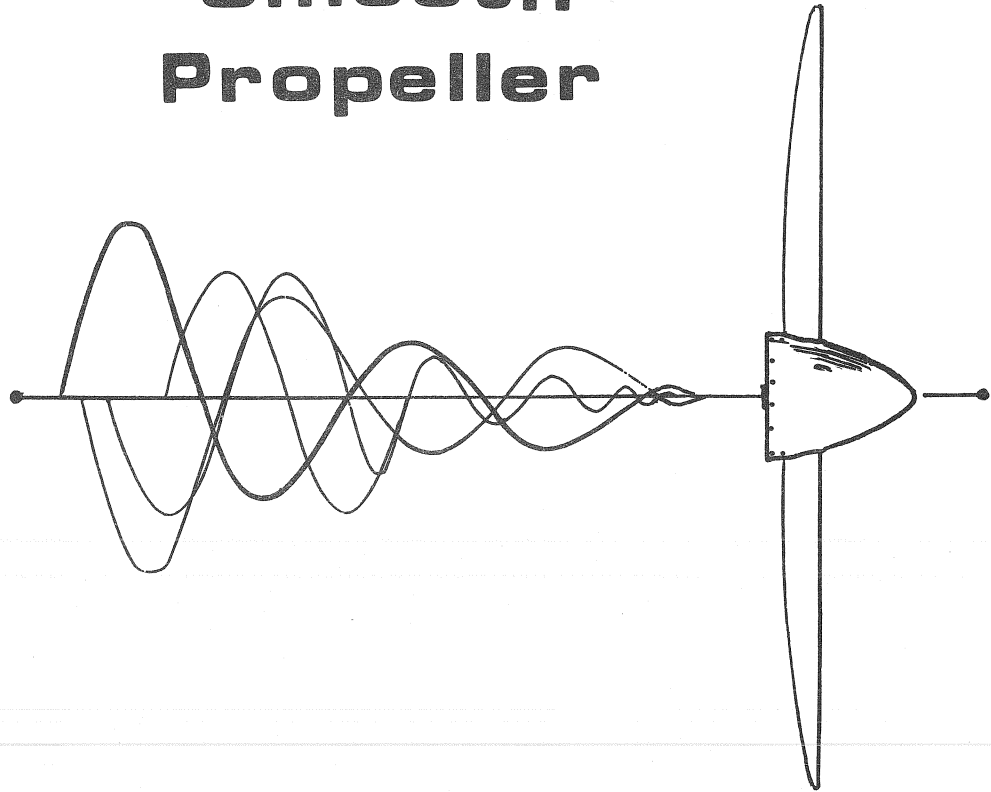




The Smooth Propeller



by James E Fackler

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INTRODUCTION

Propellers, spinners, crankshafts and other dynamic components are manufactured to strict tolerances. However, due to centrifugal force, aerodynamic loading and individual component tolerances some residual "out-of-balance" can be present. It has been determined that dynamic trim balance can correct such "out-of-balance" and results in significantly lower vibration levels.

Because the vibration caused by an out of balance propeller is low to medium frequency, typically in the 15-45 Hz range, it is often felt throughout the airframe, usually at a lower amplitude than at the engine.

All propellers can benefit from dynamic balance. When properly executed the balance has both short and long term benefits. In the short term, there is usually an immediate reduction in the noise and vibration "feel" in the cabin. Long term benefits are a reduction in the cycle fatigue of airboxes, exhaust stacks, radio equipment, sheet metal and cowling cracking and a reduction in wear of controls linking fixed portions of the airframe to the engine (ie. prop control, carburetor, and mixture linkages)

The process consists of mounting a sensor to the engine and converting the motion produced by out of balance to angular and amount values. These values are converted to a weight and azimuth solution. Trial weights are then added to the propeller assembly as an experimental condition. These weights are fine tuned until the balance levels are acceptable whereupon a permanent installation is then made.

This balance is generally good until the combination of components is upset via overhaul, or other major PTRC (Power Train Rotating Component) change.

Dynamic trim balance relies on proper working condition of the PTRC. If deficiencies exist in the PTRC it is not possible to affect a dynamic balance. Such items as bent or broken crankshafts, bent blades, or mechanically faulty propeller assemblies are not balanceable by virtue of the physical dynamic properties of components with any freedom of migration. In short, dynamic balance uncovers faults, it does not mask or hide faults.

INTRO cont.

Other vibration sources may still be present after dynamic balance of the PTRC. Dynamic balance of the PTRC does not mask other vibration sources. These vibrations are in most cases produced by the engine as a result of combustion or engine accessories. Dynamic balance at the propeller RPM is not affected by these vibration sources since they occur at frequencies other than the PTRC. It should be understood that the vibration complexion of the aircraft will be improved after balance of the PTRC but in no way is the balance a panacea for the entire vibration character of the aircraft.

In summary, balance of the PTRC will not adversely affect any operation of the engine or related components. Impending failures due to other sources of vibration such as firing order, detuned counterweights, and out of balance or misaligned components will continue to take their toll. Since failure due to vibration is additive, any reduction will relieve stress to all the affected parts. Parts will continue to break, but at reduced intervals.

PRE BALANCE INSPECTIONS

Ensure that all Airworthiness Directives are complied with for the particular propeller in question.

Inspect the blades for nicks, scratches and gouges. Dress out as specified per the appropriate propeller manufacturer.

Painting, boot replacement, and dressing should be done prior to dynamic balance.

Perform a visual inspection of the propeller and hub assembly checking for security, and proper installation.

Inspect the spinner and spinner bulkhead for cracks, stopdrills, and weldments. Dynamic balance weights may not be applied to spinners with any of these conditions present.

Remove any existing dynamic balance weights. Record the number and position of static weights if so equipped.

EQUIPMENT CALIBRATION

Ensure that the balance equipment has been function checked with equipment traceable to NBS Standards within the preceding 6 months.

The Chadwick-Helmuth Calibrator Model 11, 11A, or 11/11PS is acceptable for this function test. See manufacturers instructions for calibration procedures.

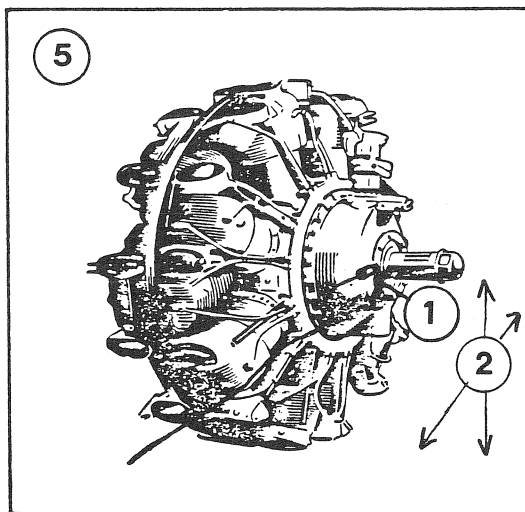
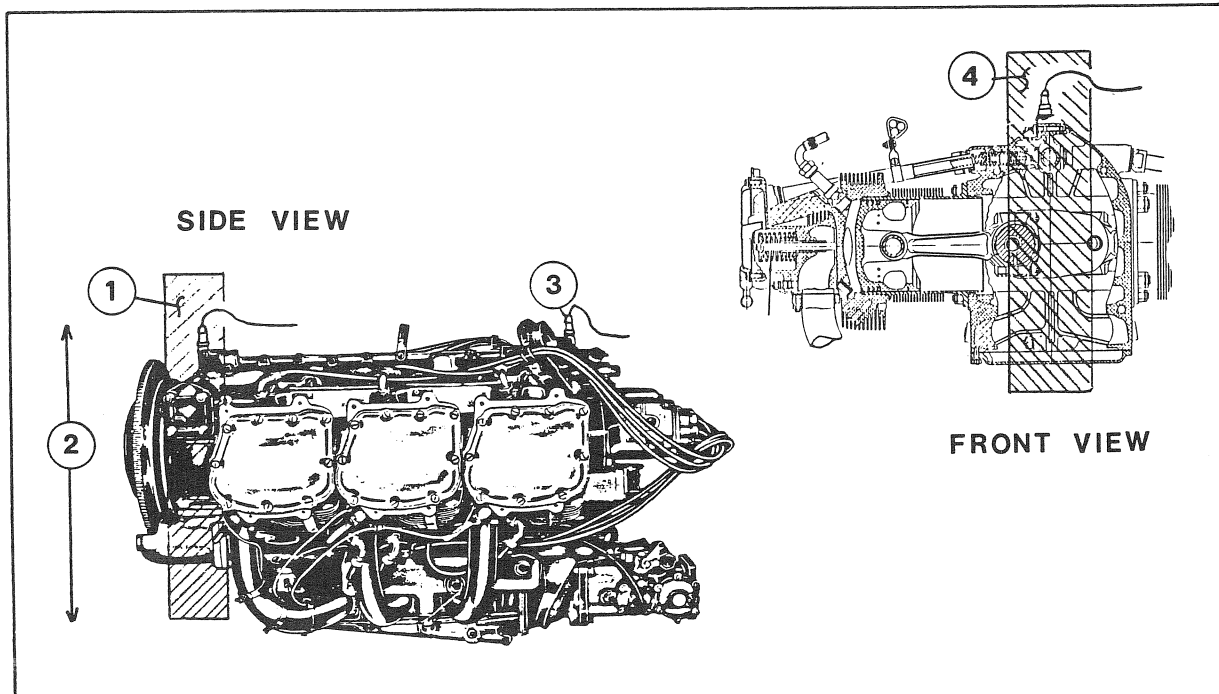
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INSTALLATION OF EQUIPMENT

Sensor attachment

Attach Sensor P/N 7310 within 4 inches of the power output end of the engine crankcase so its long axis is vertical and its connector is up. Alternately the connector may point down, the trial weight installation will change per instructions found in TRIAL WEIGHT ADDITION section. On most engines the forward most case half bolt is an excellent location.

On radial engines, the preferred installation is horizontal slightly aft of the output shaft.



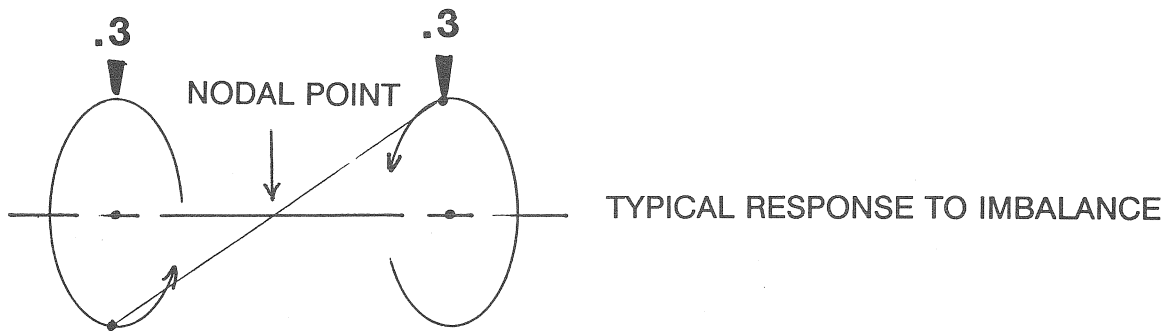
LEGEND

1. Area balance velometer should be located
2. Propeller plane of rotation
3. Nodal survey velometer
4. Area in which balance velometer should be located
5. Radial engine installation.

Usually when a propeller is out of balance, it causes the entire engine to oscillate about its C.G. (Center of Gravity). As the heavy point of the propeller is going up the rear of the engine is going down. During a routine balance, the amplitude (amount) of vibration produced by the propeller orbit is about the same at the front and rear of the engine, and as the balance is improved both the front and rear of the engine decrease in amplitude AND THE ENGINE FEELS NOTICEABLY BETTER.

If there is a problem elsewhere in the engine or there is a problem in the propeller assembly, it will be evident as the rear velometer reading will remain the same or increase in intensity. If this is the case, the propeller track should be checked as outlined under propeller track. The nature of the problem should be determined before attempting to balance.

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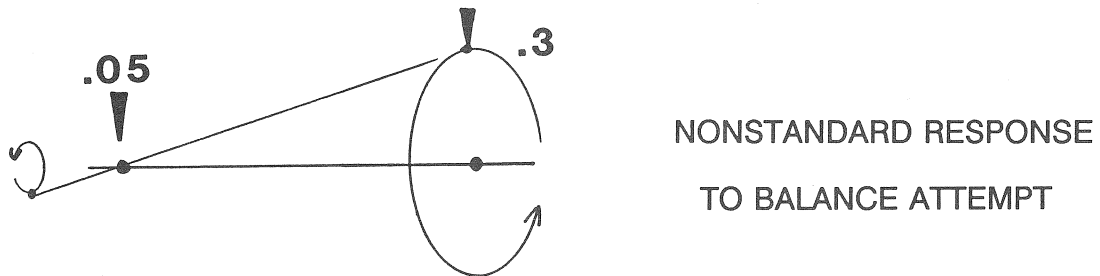


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PROP END ACCESSORY END

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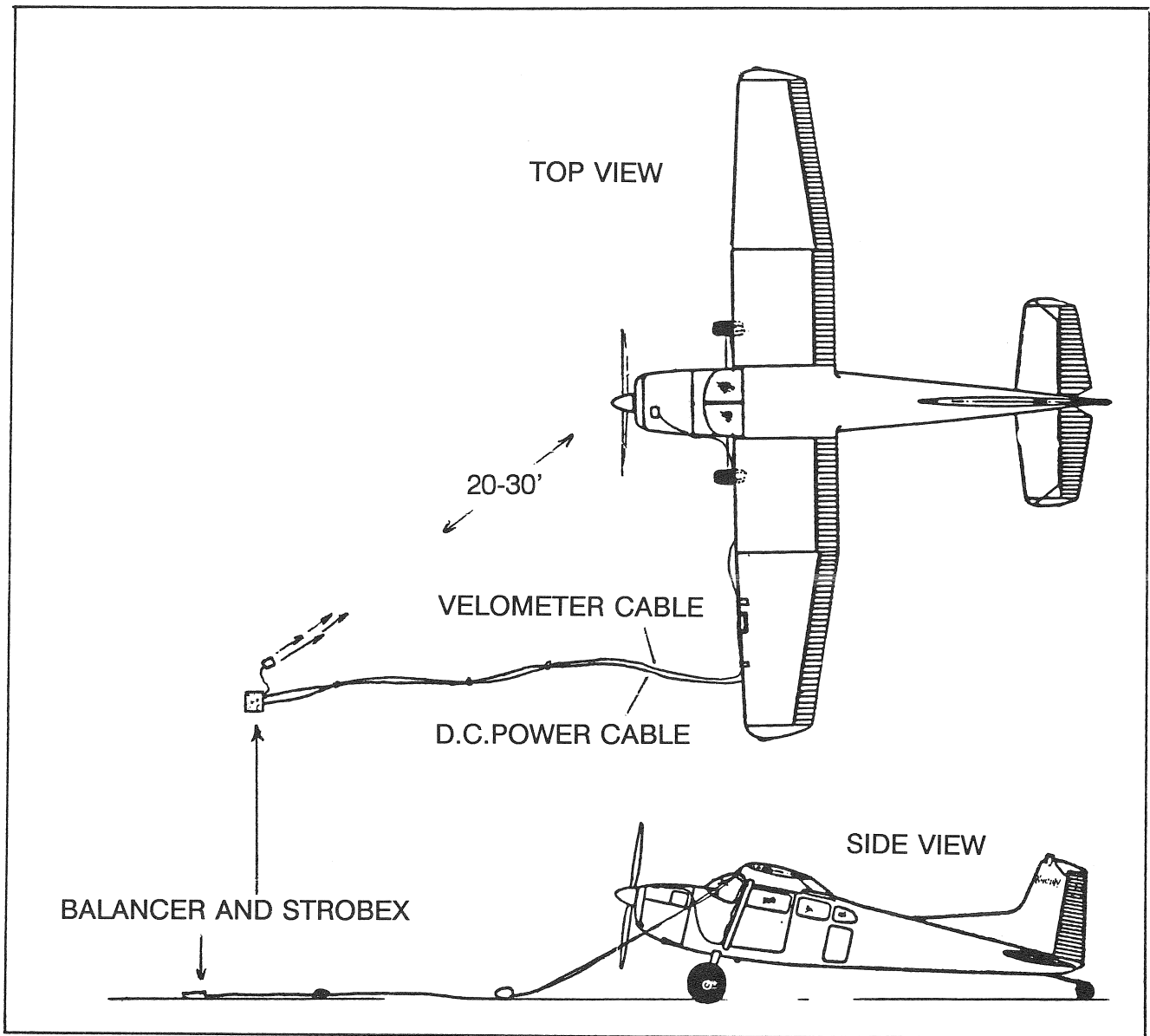


TARGET ATTACHMENT AND CABLE ROUTING

1. Outside viewing

Attach a reflective target #3300 to the root of a single blade. The target will be observed from the front of the aircraft.

Position the cables clear of moving parts to a convenient viewing position ahead and slightly off center line, 20 to 30 feet away from the aircraft.

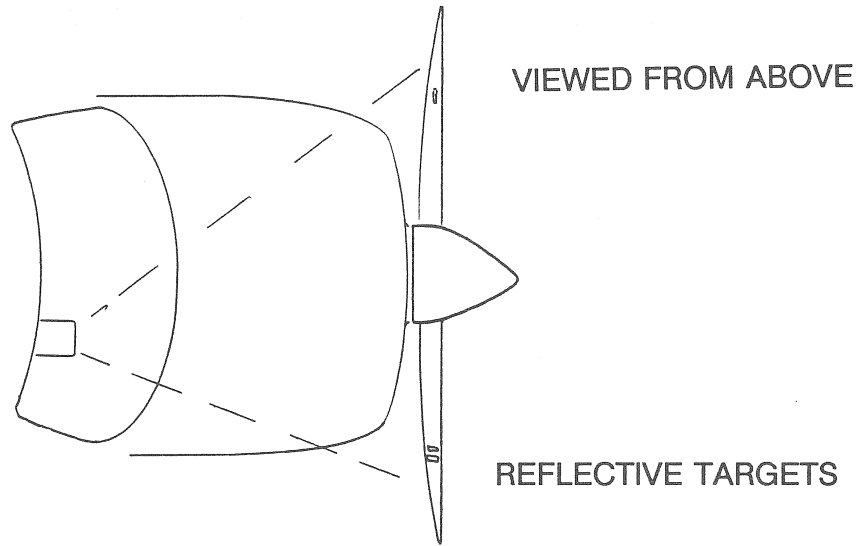


2. Inside viewing

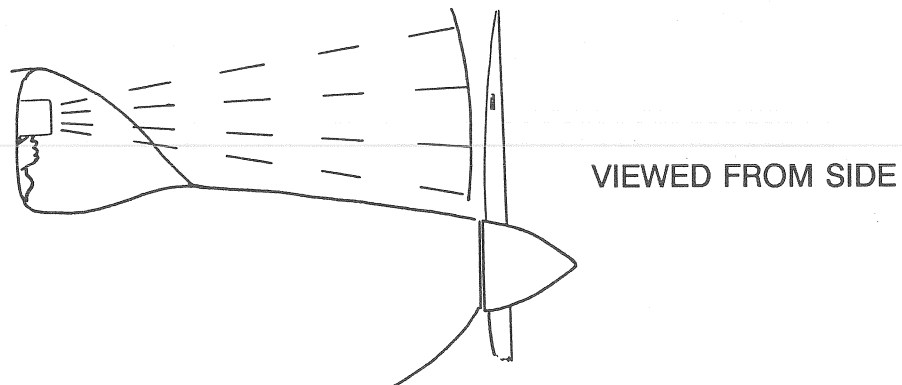
Attach a reflective target P/N 3300 to the face of a blade where it will be visible from inside the aircraft. Attach two targets on another blade if it is a two bladed prop, and three targets on the third blade of a three bladed prop, etc.

Because the visible arc of the propeller is limited when viewed from inside it is necessary to mark all the blades so angle of the master blade(#1) can always be determined. Each blade is marked individually so there is no confusion in identity.

FIG 61



STROBEX BEAM



BALANCE/VIBRATION CHECK

CAUTION

Observe engine operating limits. Airflow to the engine is generally limited during ground operation and may result in reaching temperature limits rapidly.

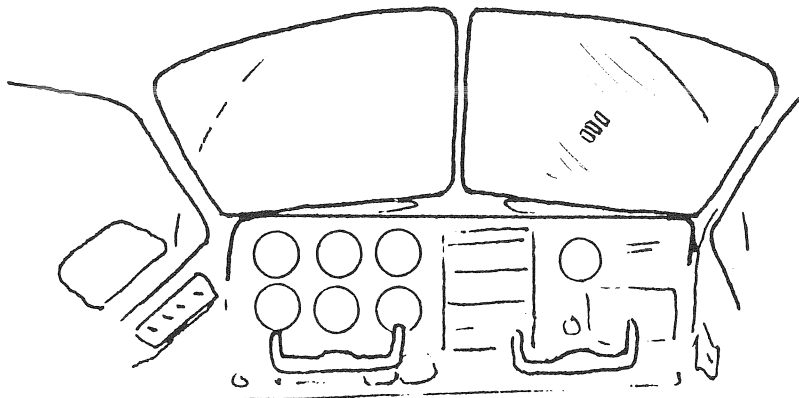
The balance reading may be taken at any RPM. Low cruise RPM on most opposed engines up to 300 HP is a good ballpark figure.

Observe propeller in arc circumscribed by reflective target(s) using Strobex. Observe the angle of the target and the amount of vibration as shown on the balancer and record.

WARNING - If IPS(Inches per Second Velocity) exceeds 1.2 at propeller RPM do not attempt balance. Remove propeller and re static balance assembly or rephase propeller on crankshaft if permitted by manufacturer.

For complete instructions on equipment use consult the particular operating manual for that equipment.

In the illustration, the third of three blades appears at 1:00 o'clock. Normally the first target seen is used as a reference or master blade whose position is plotted on the polar coordinate chart. The IPS appears on the balancers plotting card.



TRIAL WEIGHT ADDITION

1. With the engine shut down, rotate the propeller to the angular position at which it was observed while running.
2. Place a trial weight on the propeller, **OPPOSITE THE DIRECTION THE SENSOR POINTS** on the engine. See example on pages 32.

WARNING / WARNING / WARNING

Trial weights may be added to the spinner retention screws using large area washers (with longer screws if necessary) for purposes of test. These are TRIAL weights only and are prohibited as a permanent installation. Do not exceed a stack of six washers on any screw.

CAUTION / CAUTION / CAUTION

Trial balance weights may not be added to the spinner retention screws if they are smaller than #10 (10-32) size.

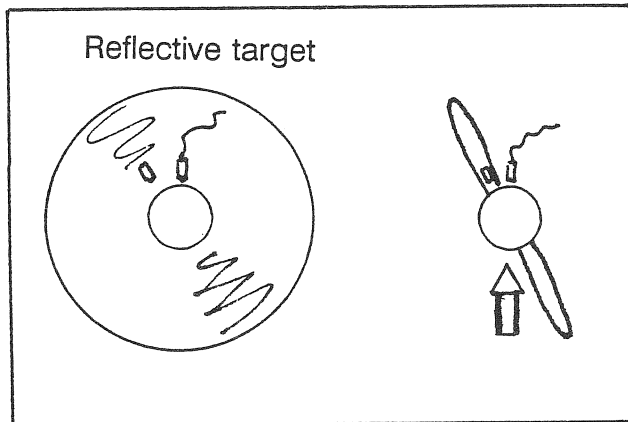
3. How much weight to use depends on the propeller, but as a rule the following should provide adequate guidance for a first run.

Rated takeoff horsepower / Grams per .1 IPS at spinner radius

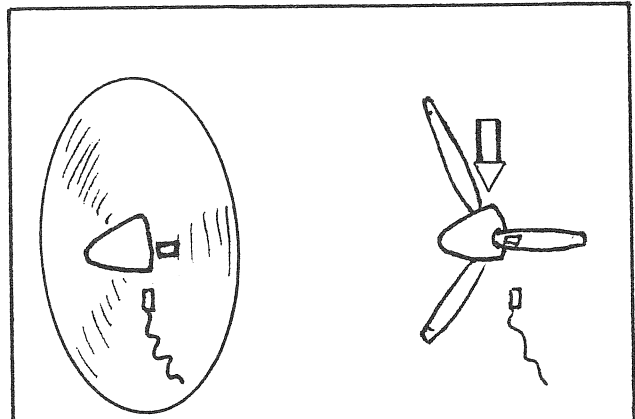
100-300	/	5.0-6.0
300-800	/	10.0-12.0
800+	/	Consult Chadwick-Helmuth Co.

TRIAL WEIGHT ADDITION EXAMPLES

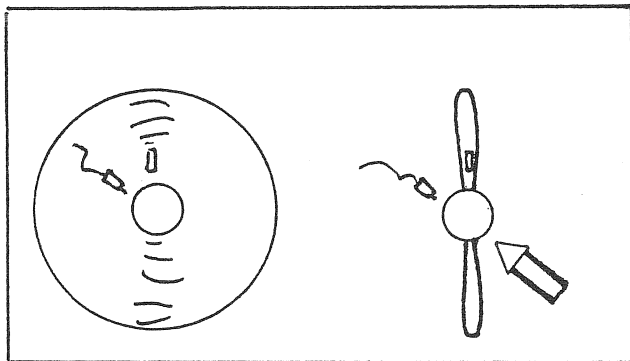
1. When engine is shut down, rotate propeller target blade to angle at which it was observed while running.
2. Place weight on propeller OPPOSITE DIRECTION SENSOR POINTS on the engine.



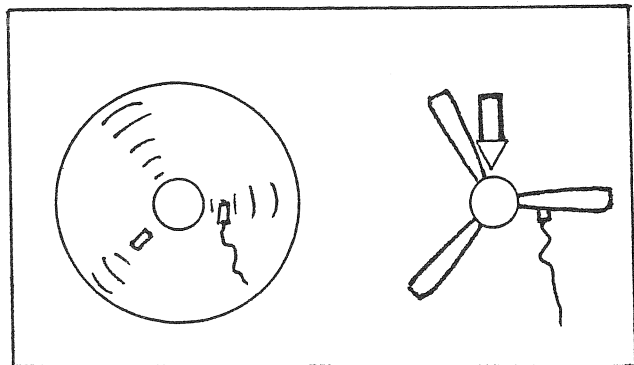
Sensor pointing up.
Add weight at 6:00 o'clock



Sensor pointing down.
Add at 12:00 o'clock position



Sensor pointing toward 10:30.
Add weight at 4:30



Sensor pointing down.
Add at 12:00 o'clock position

PLOTTING BALANCE POINTS

1. Run the engine again at the same power setting and repeat the readings.

Second reading below .2 IPS:

2. If on the second run the reading was below .2 IPS proceed to permanent installation instructions.

Second reading above .2 IPS:

Using balance chart worksheet #3659 plot the first and second points at their respective intersections of angle and IPS. Label them point #1 and point #2.

Connect the two points with an arrow so the arrow points at the second point.

Draw a line between the first point and the center of the chart.

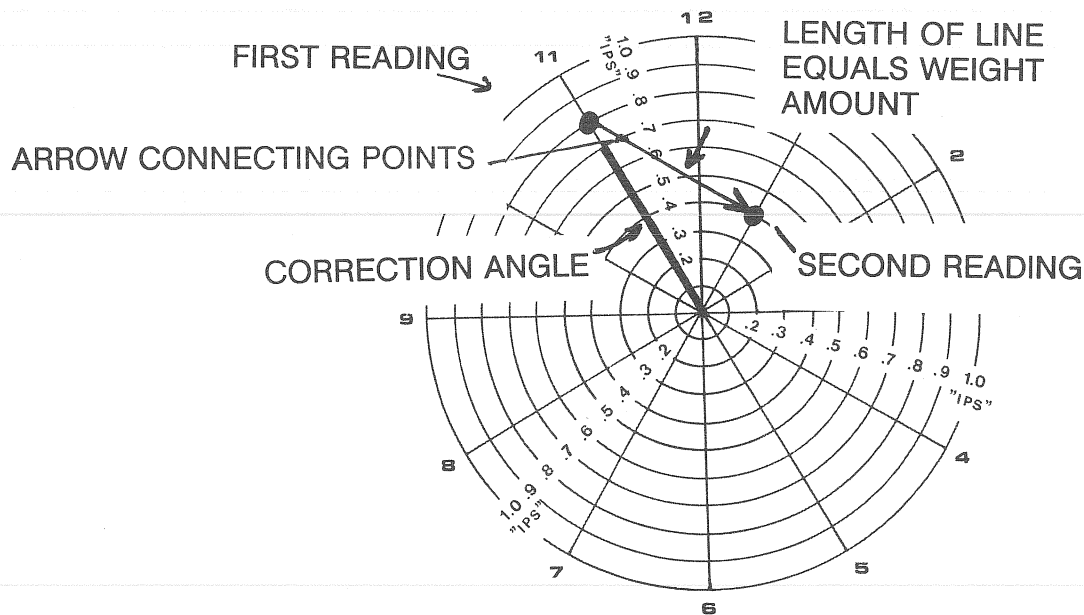
If the arrow is longer than the line, proportionally less weight is required.

If the arrow is shorter than the line, proportionally more weight is required.

Measure the angle between the line and the arrow.

If the target was viewed in a clockwise direction from the first point the weight must be moved the angular amount counterclockwise on the propeller.

If the target was viewed in a counterclockwise direction from the first reading the weight must be moved the angular distance clockwise on the propeller.



VERIFICATION RUN

Run the aircraft again at the RPM of the first two readings. Continue to adjust the balance weights until the IPS level is less than 0.20 .

The weight should not be spread over more than 3 retention screws, or farther than 40 degrees of azimuth unless it is necessary due to the angular spacing of the spinner screws.

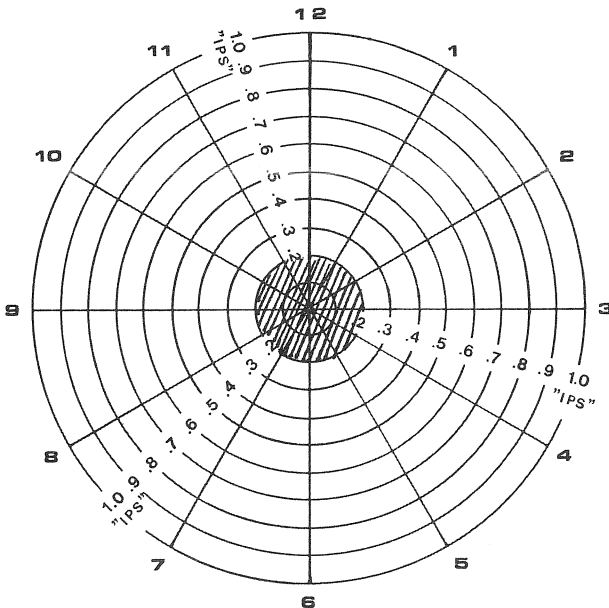
CAUTION/CAUTION/CAUTION

Trial weights must not be added to spinner screws smaller than #10 (10-32) size.

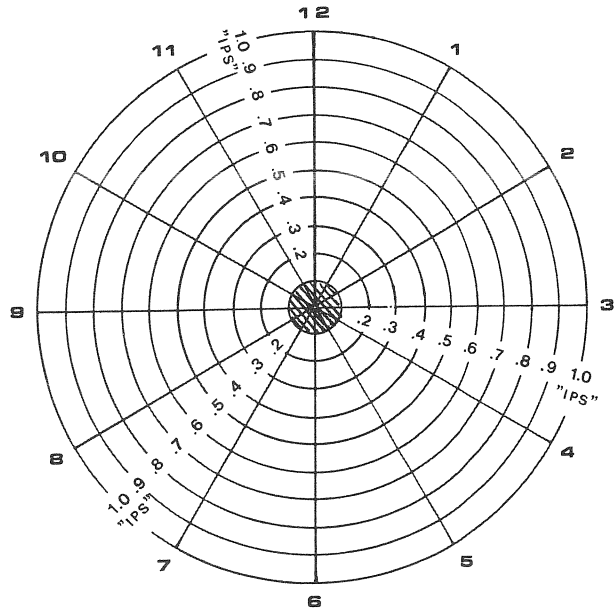
Once the balance is reduced to acceptable levels, record final IPS and Clocking information for inclusion in maintenance records.

If the balance cannot be reduced to acceptable levels within 4-5 runs and/or the readings are not repeatable or predictable it is evidence there is a problem with the PTRC that is making balance unlikely. Loose or worn components, out of track, etc., are often the cause. Balance weights may not be applied to the PTRC that exhibits these readings. Proceed to section on blade track and section on troubleshooting.

ACCEPTABLE BALANCE LEVEL



DESIREABLE BALANCE LEVEL



GENERAL PRECAUTIONARY NOTES

Be absolutely certain the applied balance weights do not interfere with the operation of the propeller. Propeller cuffs, counterbalances, deice assemblies, etc. must all operate in a normal manner with balance weights installed.

Rotate the propeller through by hand after weight addition. Look as well as listen for clearance conflicts. Bear in mind as the propeller produces thrust it will force the propeller and spinner forward. Also remember the transient vibration on startup and shut down will require more than just positive clearance.

DO NOT USE STICK ON SELF ADHESIVE WEIGHTS. This is prohibited unless specified by the propeller manufacturer.

Do not file or paint the blades to affect balance. Filing of the blades has an aerodynamic as well as mass balance effect.

Before turning any propeller, ensure the magneto switches are off and in proper working condition (i.e. grounded mags).

WEIGHT INSTALLATIONS

There are four basic acceptable methods of weight attachment to the PTRC. Variations of each addition method are listed as subtypes.

Note: Reference to axial and radial are from the crankshaft longitudinal axis. Axial is parrallel to the crankshaft long axis, radial is 90 degrees to the crankshaft centerline.

1. Inside periphery of spinner bulkhead
 - A) Type 1 Radial bolt, doubler washer
 - B) Type 2 Countersunk machine screw, aft facing flange
 - C) Type 3 Countersunk machine screw, forward facing flange

2. Spinner backing plate
 - A) Type 4 Axial bolt, doubler washer

3. Starter ring gear (Lycoming installations)

4. Static balance locations

INSIDE PERIPHERY OF SPINNER BULKHEAD

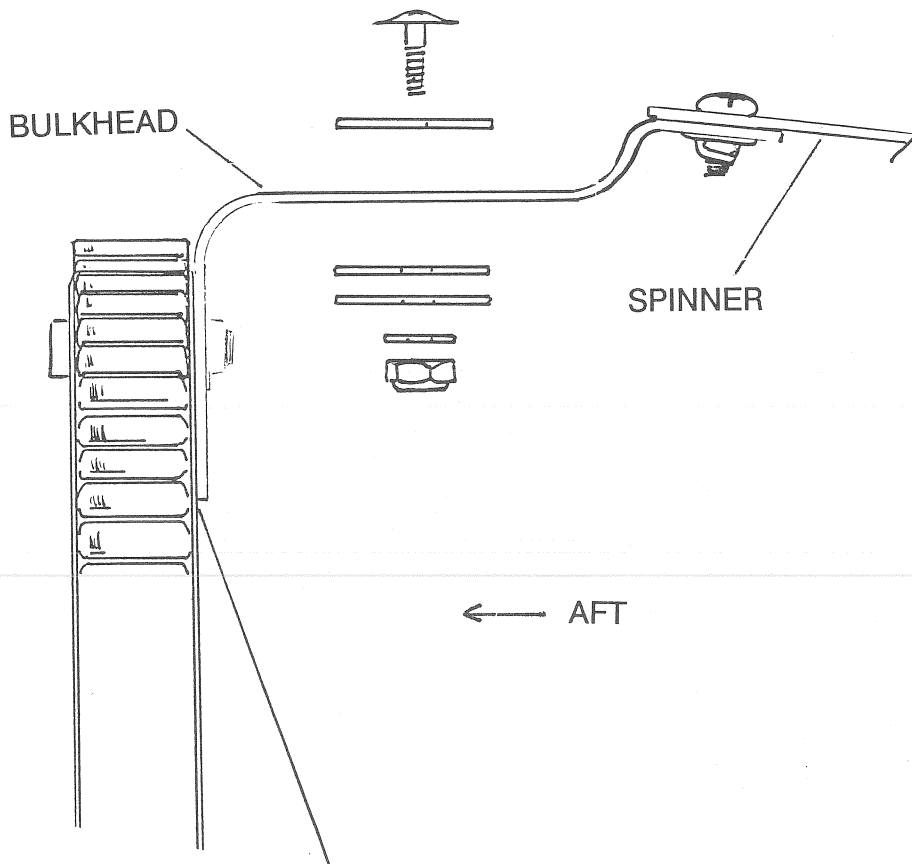
Type 1 Radial bolt, doubler washer

Minimum bulkhead thickness: .030 inch
Maximum radius: 6.75 inch
Maximum rotational velocity: 2850 RPM
Maximum moment: 350 inch grams

Hardware requirement: AN 970-3 washer
AN 960-316 washer
AN 365-1032A nut
AN 525-10R"X" screw

Note: A maximum of two holes may be used for attachment of balance weight.

Note: Weight and attachment hardware must clear stationary portions of the cowl and engine by at least .25 inch.



INSIDE PERIFERY OF SPINNER BULKHEAD

Type 2 Countersunk machine screw, aft facing flange

Minimum bulkhead thickness: .040 inch
Maximum radius: 6.75 inch
Maximum rotational velocity: 2850 RPM
Maximum moment: 400 inch grams

Note: Divide weight equally between two holes if moment exceeds 200 inch grams. A maximum of two holes may be used.

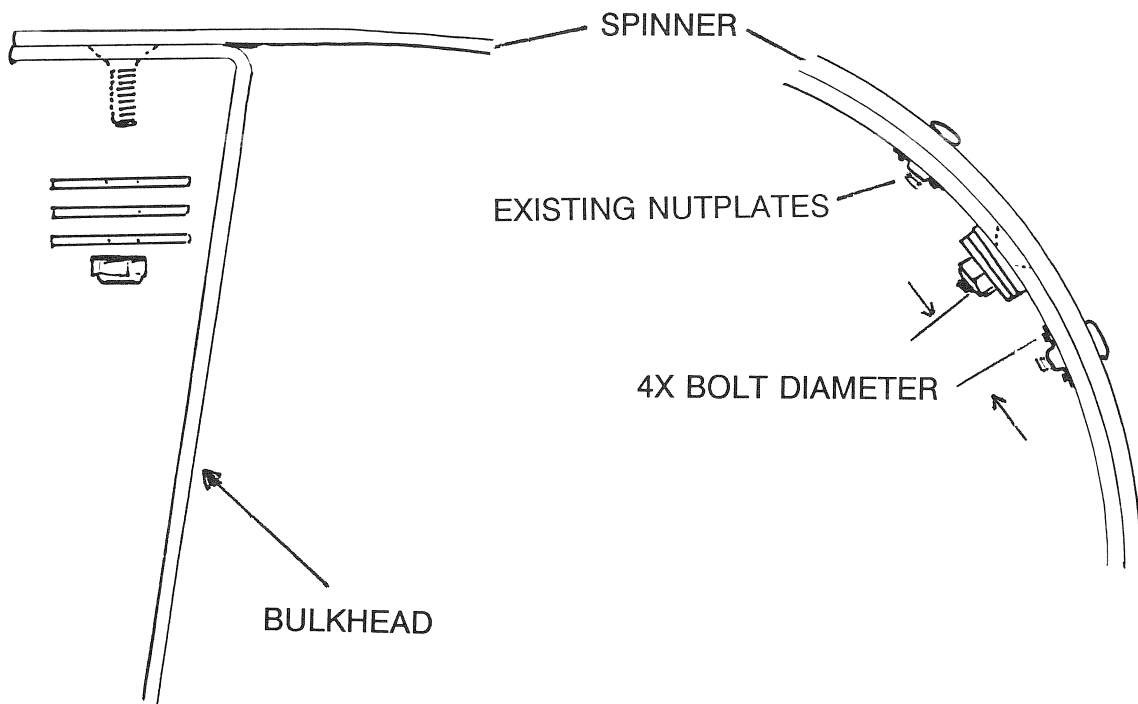
Hardware requirement: MS 24694-S"X" countersunk machine screw
AN 970-3 washers
MS 21042-L3 lock nut
AN 365-1032A lock nut (alternate)

Note: Weight and attachment hardware must clear stationary portions of the cowling an engine by at least .25 inch.

Installation note:

First washer against bulkhead may require trimming to accommodate radius of bulkhead flange.

First washer against bulkhead may require light countersinking to provide proper torque values. No more than two holes allowed to carry balance weights.



INSIDE PERIFERY OF SPINNER BULKHEAD

Type 3 Countersunk machine screw, weights inside bulkhead

Minimum bulkhead thickness: .040 inch
Maximum radius: 6.75 inch
Maximum rotational velocity: 2850 RPM
Maximum moment: 400 inch grams

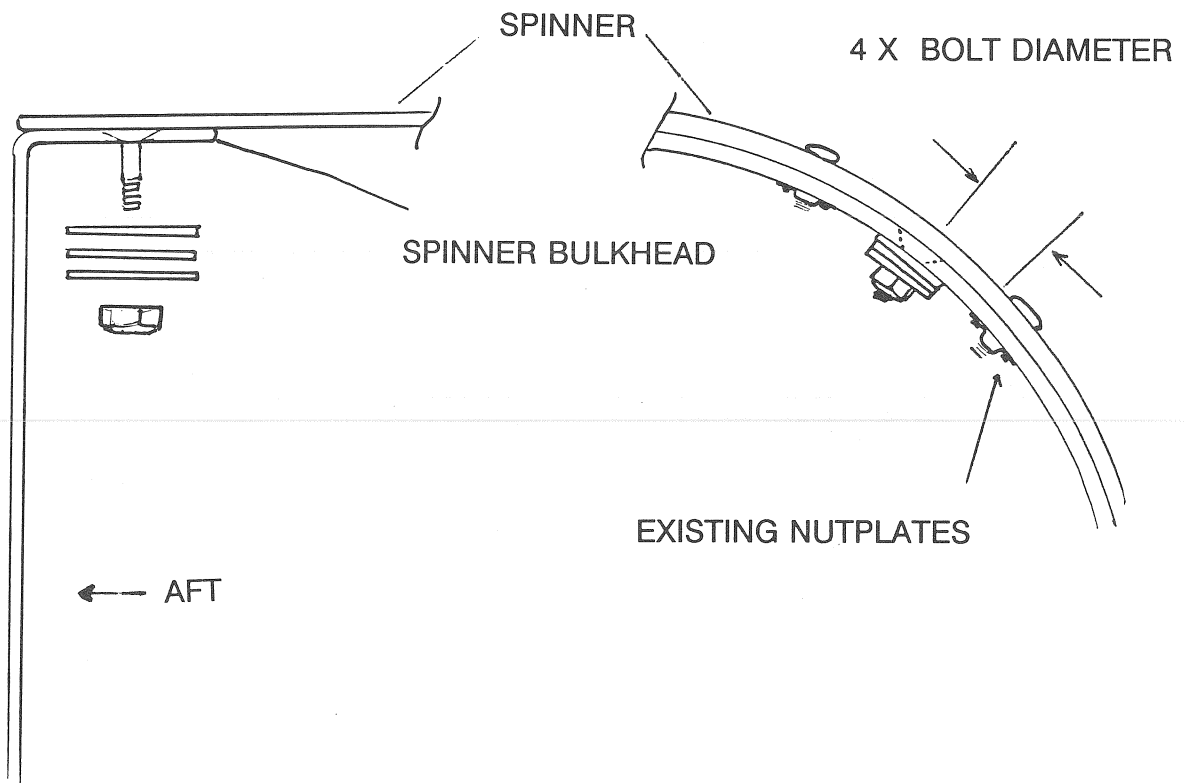
Note: If required weight exceeds 200 inch grams divide weight equally between two holes.
A maximum of two holes may be used.

Hardware requirement: MS 24694-S"X" countersunk machine screw
AN 970-3 washers
MS 21042-L3 lock nut
AN 365-1032A lock nut (alternate)

Installation note:

First washer against bulkhead may require trimming to accommodate radius of bulkhead flange.

First washer against bulkhead may require light countersinking to provide proper torque values. No more than two holes allowed to fit balance weights.



SPINNER BACKING PLATE

Type 4 Axial bolt, doubler washer

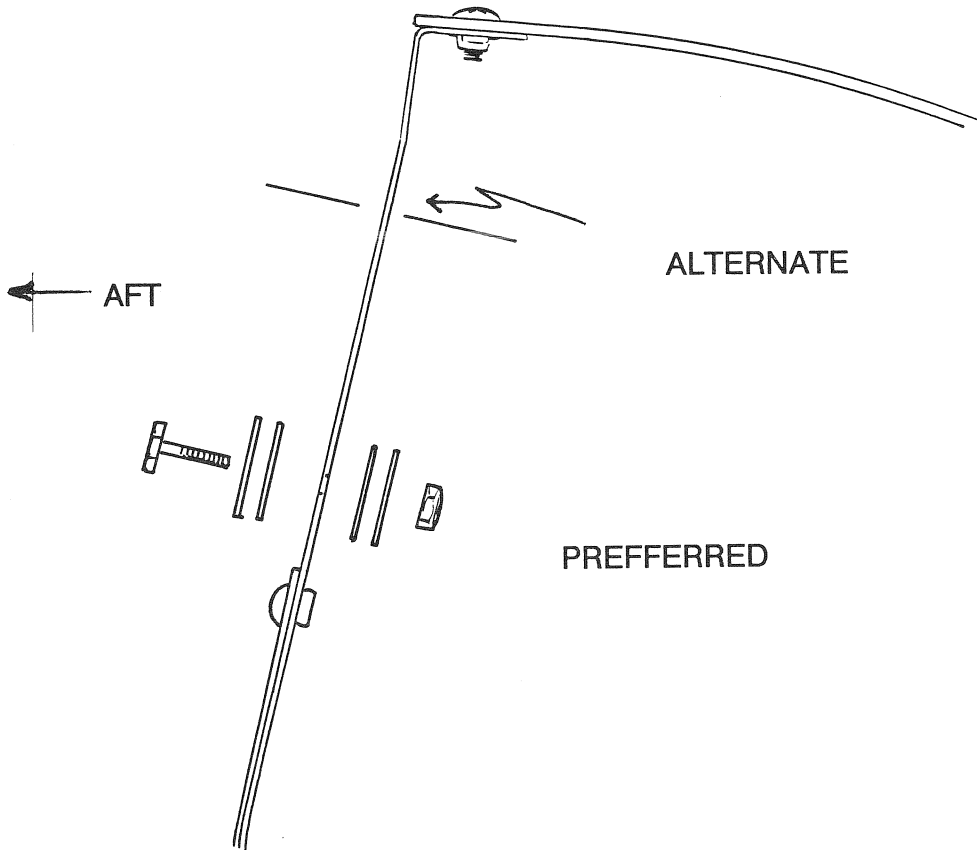
Minimum thickness:	.040	inch	.040	inch
Maximum radius:	3	inches	5	inches
Maximum rotational velocity:	2850	RPM	2850	RPM
Maximum moment:	180	inch grams	180	inch grams

Note: If weight required exceeds 90 inch grams, divide equally between two holes. A maximum of two holes may be used.

Note: Attachment hardware and weight must clear stationary portions of the cowling and engine by at least .25 inch.

- Hardware requirement:
- AN 3-"X"A bolt
 - AN 970 - 3 washer
 - AN 960 - 316 washer
 - AN 365 - 1032A nut

Note: Preferred location near reinforcing web. Alternate to be used to meet cowling clearance requirements. Washers must be placed on both sides of the bulkhead.



STARTER RING GEAR

WARNING/WARNING/WARNING

DO NOT install washer under head of bolt. Head of bolt must face engine side of ring gear.

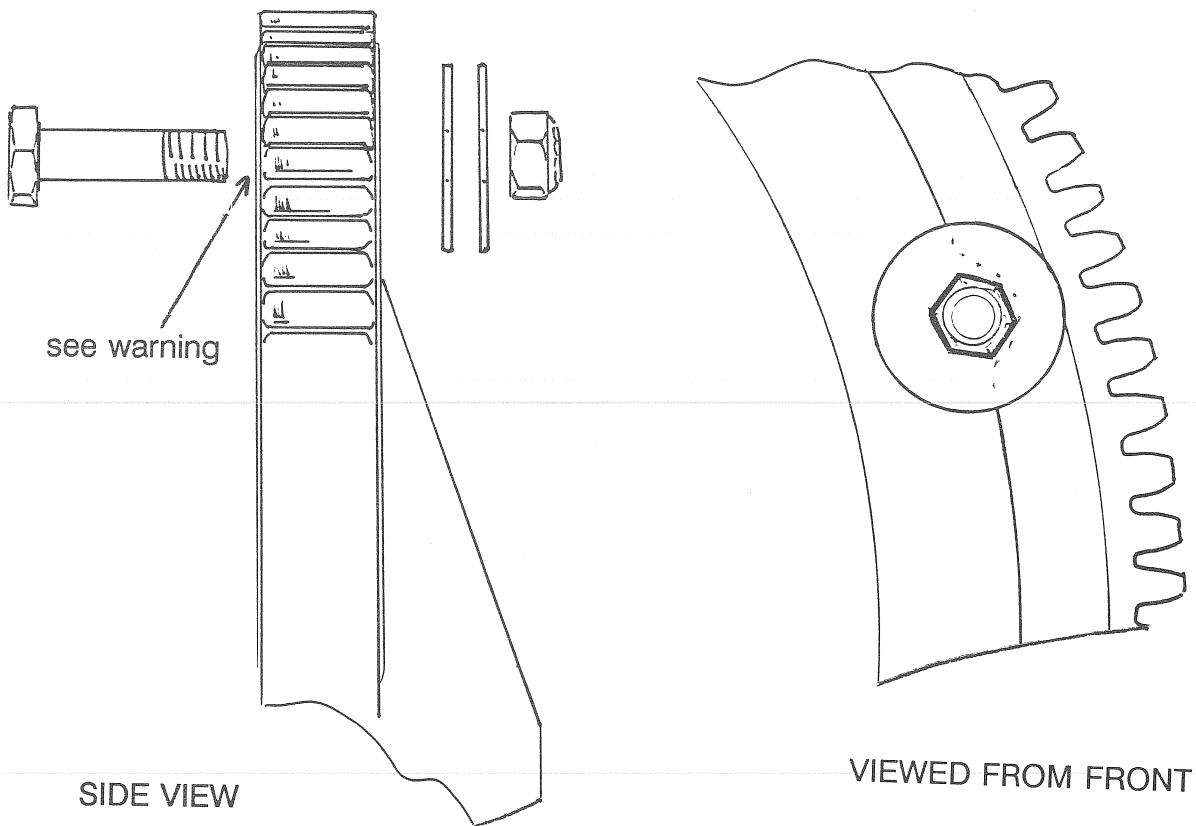
Hardware used: *AN4-"X"A bolt
 AN970-4 washer
 AN365-428 nut

* On some ring gears the weight attach holes are countersunk on the engine side of the ring gear. These ring gears necessitate the use of countersunk machine bolts on the engine side of the ring gear in lieu of the AN 4 bolt.

A maximum of two holes may be used. Bolt head must have positive clearance through starter bendix with crankshaft seated fully aft. This method is to be used only on ring gears without spinner bulkheads attached.

Note: Attachment hardware and weight must clear stationary portions of the cowling by at least .25 inch.

← AFT



SIDE VIEW

VIEWED FROM FRONT

STATIC BALANCE WEIGHT LOCATIONS

Use of the static weights is limited by some propeller manufacturers. Consult propeller overhaul instructions for applicable part numbers and number of weights that can be installed.

If the static weights are used for dynamic balance the P/N (or equivalent gram weight) and location of these weights must be recorded in the logbook so the propeller can be restored to its original static balance condition if placed on another aircraft.

It will be necessary to recompute the balance weight from the outside of the spinner to the static weight locations. This is essentially a weight and balance recomputation based on the formula $W \times A = \text{moment}$, where W = weight, A = arm (radius from center of rotation).

DOCUMENTATION/PLACARDS

The propeller hub must bear a placard notifying future maintenance personnel the propeller has been dynamically balanced and the assembly of the PTRC is an indexed assembly.

The maintenance entry should be made in the appropriate propeller and/or engine log book and should reference the amount of weight installed and its azimuth. Azimuth reference can be made to either top dead center or a clearly visible indelible mark on the PTRC. This indelible mark must be made on all accessible PTRC components.

Enter the engine time and date and the final IPS and azimuth readings.

The entry must be signed and the certificate number of the maintenance person entered.

If the balance was done using a hard copy vibration recorder include a copy of the before and after vibration record.

In normal service the balance will last approximately 400 hours of average use, on conventional geared airplanes (tail draggers) approximately 700 hours. Normal dressing of the propeller leading edges will not alter the balance enough to require a rebalance. Substantial nicks which are more than .25 inch in depth require removal of enough metal the balance should be checked and trimmed if required.

LIMITATIONS

No propeller may be balanced whose initial reading exceeds 1.2 Inches per second velocity.

No weights may be attached to spinners or spinner bulkheads which are cracked, stopdrilled, or welded.

Balance washers may be applied to the outside of the spinner for test purposes only. Washers on the outside of the spinner are not permitted as a permanent installation.

Self adhesive weights are not permitted except where outlined by the propeller manufacturer.

Acceptable balance level is .2 Inches per second velocity at the RPM of the propeller.

Clearance of attachment hardware and weight must be a minimum of .25 inch from fixed portions of the cowling and engine except the engine where outlined for starter ring gear attachments.

PROPELLER TRACKING

Installation of a Sensor is not required for blade tracking.

Attach a reflective tape overlapping the leading edge of a blade approximately 1 inc from the tip. Attach another reflective tape to the next blade in rotation overlapping the leading edge approximately 2 inches from the tip. Continue application to additional blades moving the target position a little farther in on each subsequent blade.

Operate aircraft at idle. Using the Strobex, adjust the oscillator to fire at the rate at which blades pass. (Ex. 3 blades at 1000 RPM = 3000 blade pass rate).

Observe the targets on the blade tips edge on to the propeller disc. Fine tune the oscillator until the targets come into view. The fore and aft relationship of the targets will be equal with a perfect track. If a target is ahead or behind the other target(s) the prop is out of track in the obvious sense.

Operate the aircraft at a medium power setting. Adjust the oscillator to the new blade pass rate. Fine tune to stop the target image. Observe and record the track relationship.

Repeat readings at a higher power setting.

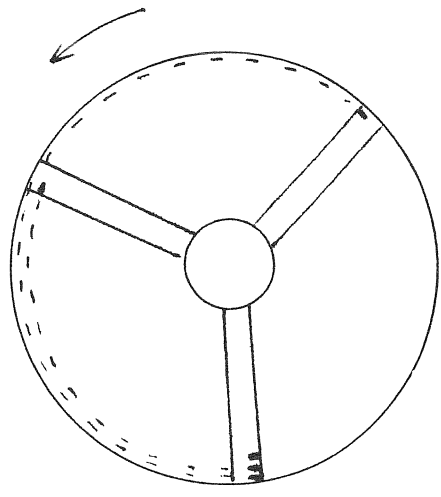
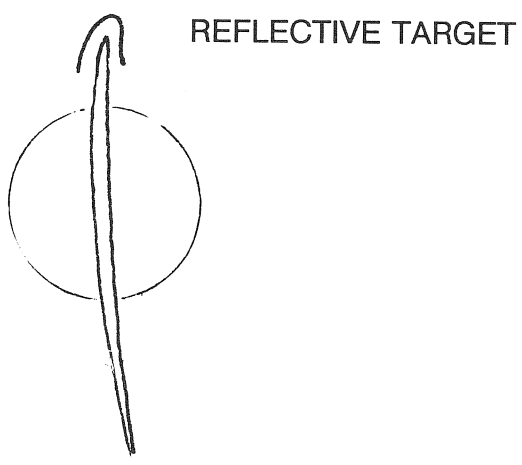
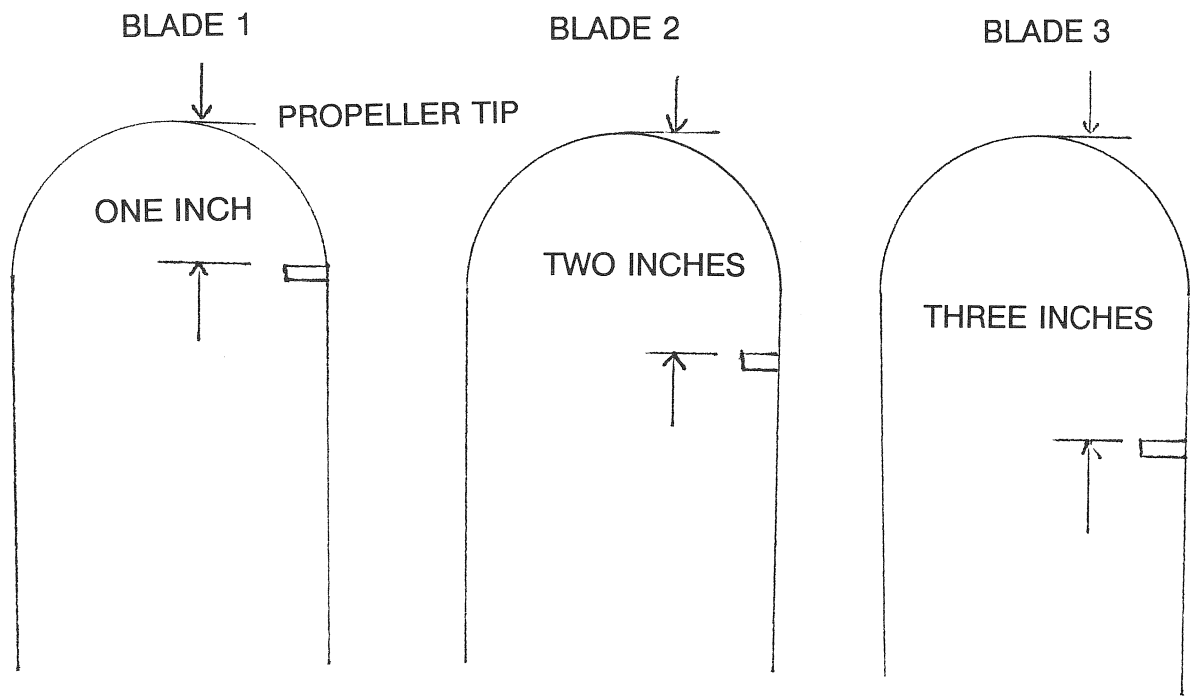
Differences of 3/16 inch or more are likely to create problems when attempting to balance. If the fore and aft relationship "floats" or changes during any of the settings there is likely a wear problem in the propeller hub or blade retention mechanism.

If the track picture changes between power settings it may indicate a "soft" blade or a blade whose lift characteristics change due to profile, incidence, or bending.

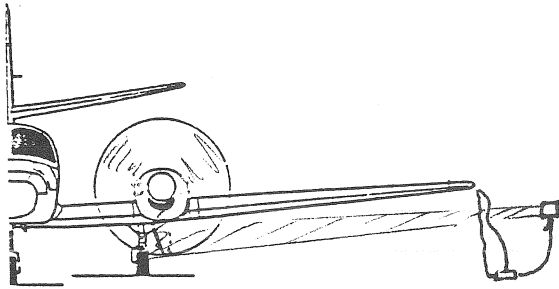
In any of the above cases it is recommended that the blade thickness, chord width and diameter be checked against propeller manufacturers limits and corrected if required.

Differences that are constant over all RPMs are usually caused by blade angle, microadjusting ring, or hub shimming differences.

Some looseness in the hub is noticeable in the static condition. This is a normal condition on most propellers and is acceptable. See propeller manufacturers limits for excessive amounts.

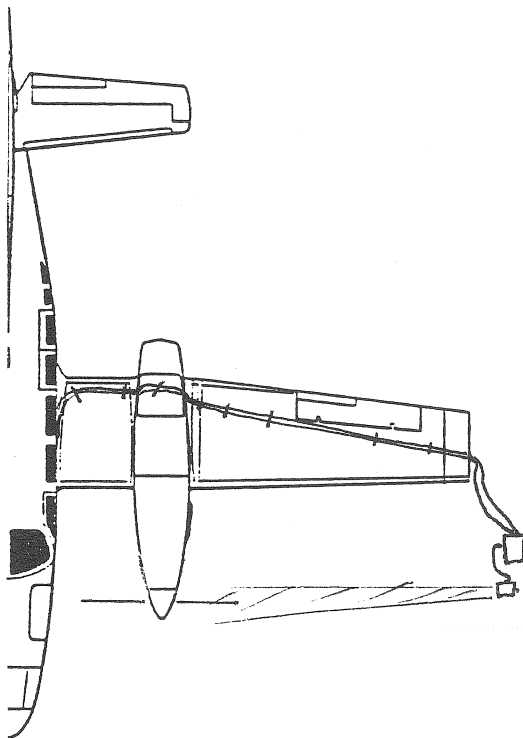


AS VIEWED FROM TIP
TOWARDS ROOT OF BLADE



AS VIEWED FROM FRONT

Set Strobex to flash at blade passage rate and view prop blades as they advance towards viewing position.

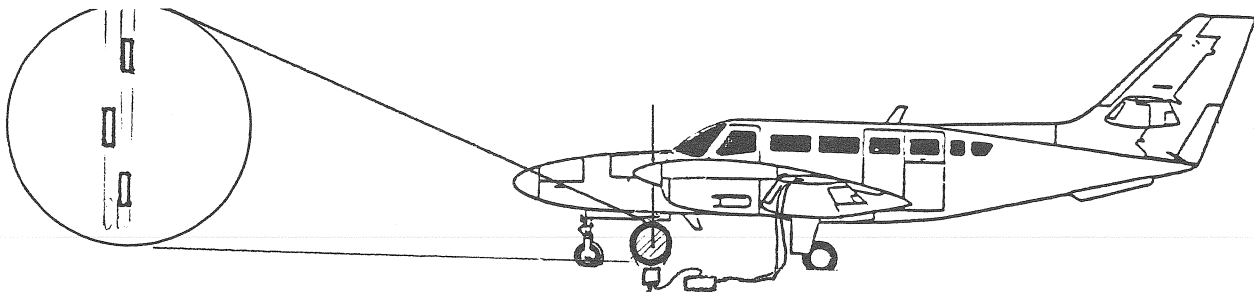


AS VIEWED FROM ABOVE

VIEWING POSITION NEAR WING TIP

If prop were in perfect track the blades would appear as a vertical line. In this example the blade with the target midway between the three is out of track.

AS VIEWED FROM SIDE



TROUBLESHOOTING GUIDE

The following chart may be used to isolate problems in balance.

I EQUIPMENT MALFUNCTION

A) Transducers / Cables

- 1) Accelerometer/Velometer inoperative
- 2) Magnetic pickup inoperative
- 3) Cable open or short

B) Balancer

- 1) Power supply
- 2) Filter (no IPS)
- 3) Phazor (no clock using mag pickup)
- 4) Mechanical damage (switches, knobs, etc.)

C) Strobex

- 1) Power supply
- 2) Flash tube or flash tube focus
- 3) Will not trigger due to lack of trigger pulse

II OPERATOR ERROR

- A) Balancer/Strobex controls incorrectly set
- B) Not tuning properly or tuned to wrong RPM
- C) Error in reading IPS or clock angle

III AIRCRAFT / INSTALLATION PROBLEM

- A) Poor transducer location
- B) Faulty PTRC components
- C) Loose cable or transducer mounts

TABLE 1

HARDWARE REQUIREMENTS

1. All balance hardware is to be aircraft grade or equivalent.
2. All hardware to be corrosion compatible per AC 43.13. Stainless hardware is preferred, cadmium plating is acceptable as a corrosion inhibitor on ferrous metals.
3. Any lead weights used must be supported between steel washers having at least 80% surface contact with the lead.
4. All nuts used to secure balance weights must be of the self locking type.
5. Minimum acceptable bolt diameter is 3/16 inch. Maximum bolt diameter not to exceed 1/4 inch.
6. All holes in the bulkhead are to be drilled undersize and reamed to final dimensions.

APPROXIMATE WEIGHT OF AN HARDWARE

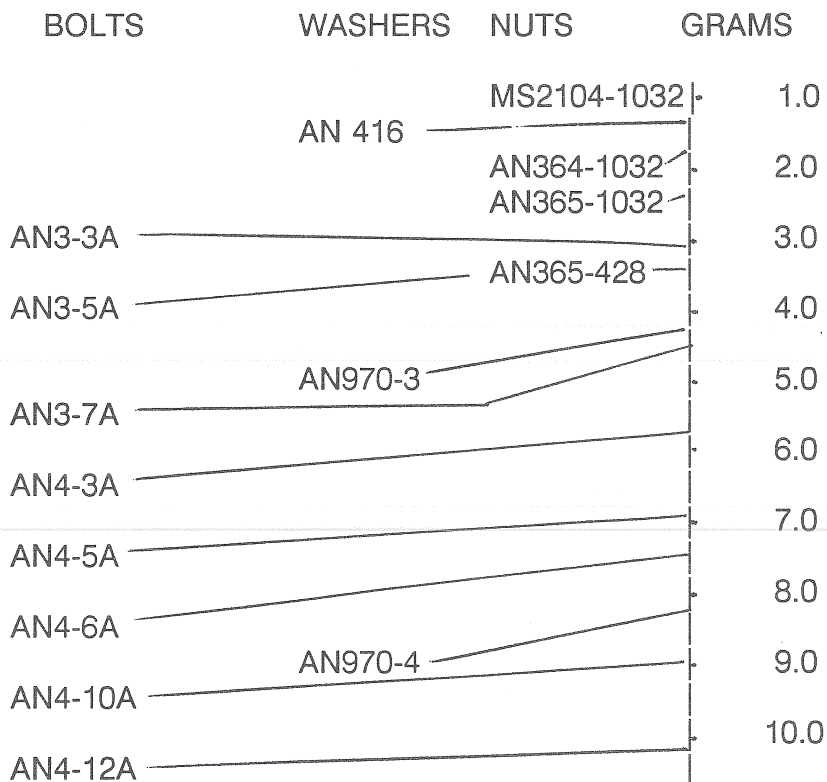


TABLE 2

WEIGHT / MOMENT CALCULATIONS

If the weight is moved inboard or out board from its trial location, it will be necessary to recompute the required weight based on the formula $W \times A = M$. W equals the weight. A equals the arm usually expressed as a station from the center of rotation. M equals the moment, or the calculated force the weight produces, and is expressed as both a weight unit and distance measure (ex 47 inch grams).

The following chart will aid in computing weight changes due to arm changes.

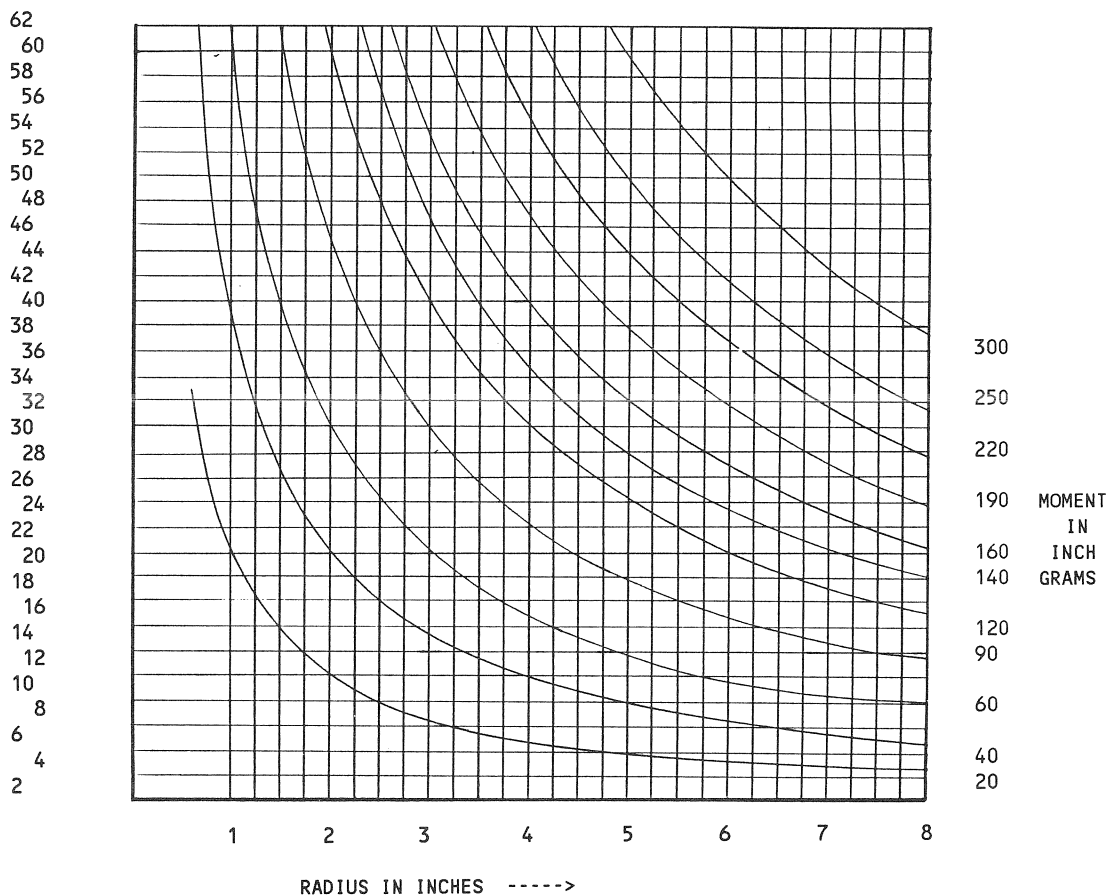


TABLE 3

INITIAL WEIGHT CALCULATION

The initial weight calculation is dependent on the total weight of the propeller and the radius at which the weight is placed. If the weight of the propeller is known a trial weight roughly equivalent to 0.1% of the propeller weight applied to the spinner periphery would be adequate to produce enough change on which to base further calculations. In any case the record of the balance change as plotted on the polar coordinate chart is the best guide as to the effect of any weight.

Numerous other factors can alter the purely mathematic determination of the required weight such as mount stiffness, freedom of movement, transducer location, RPM, and sympathetic resonance to name only a few. This is why identical installations can result in different weight requirements for a given imbalance.

DO NOT EXTRAPOLATE BEYOND GRAPH LIMITS

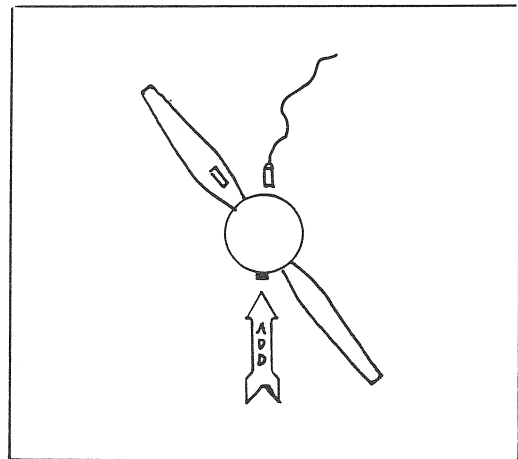
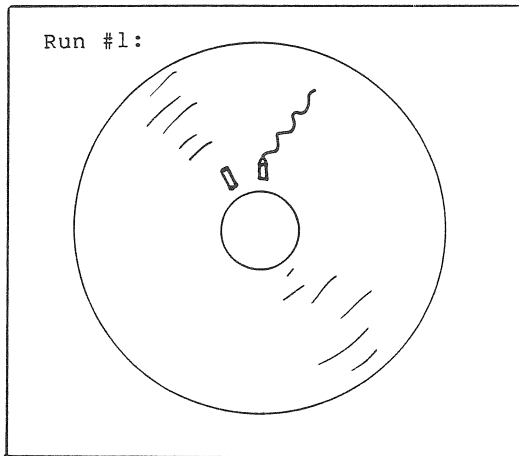
65 - 100 HP	0	8	16	24	32	40	GRAMS
	----- ----- ----- ----- -----						
	0	.2	.4	.6	.8	1.0	IPS

100 - 300 HP	0	10	20	30	40	50	GRAMS
	----- ----- ----- ----- -----						
	0	.2	.4	.6	.8	1.0	IPS

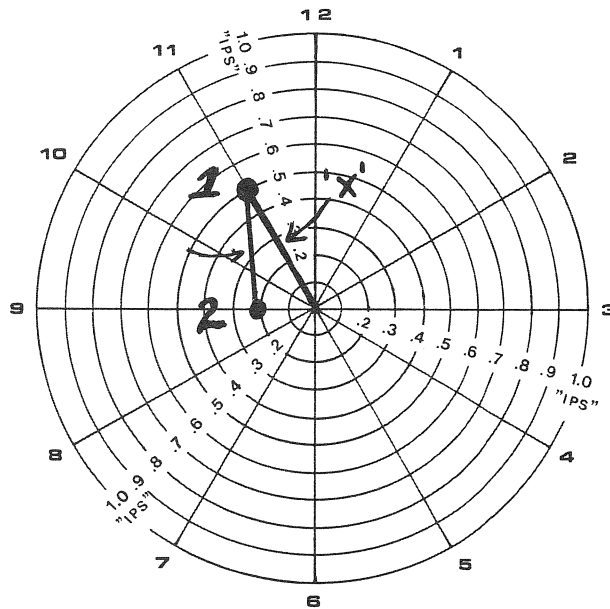
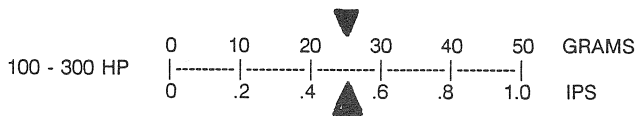
300 - 1000 HP	0	24	48	72	96	120	GRAMS
	----- ----- ----- ----- -----						
	0	.2	.4	.6	.8	1.0	IPS

EXAMPLE TRIAL WEIGHT ADDITION AND CORRECTION

Suppose an initial reading of 11:00 o'clock and 0.5 IPS. This point is plotted on the graph at the intersection of the IPS and angle and labeled point #1. From the trial weight graph it can be determined the required weight will be approximately 25 grams.

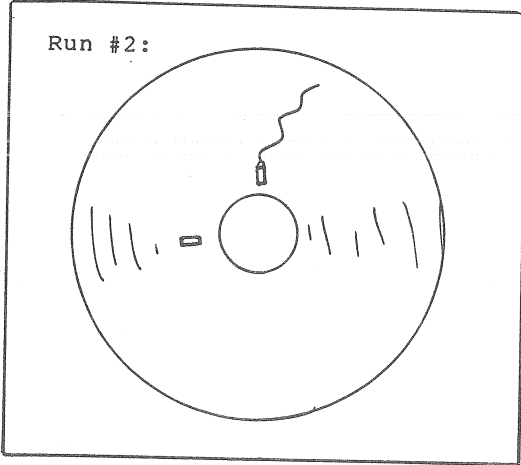


The velometer is pointing up so the target is positioned where it was seen and the weight added opposite the sensor at 6:00 o'clock.

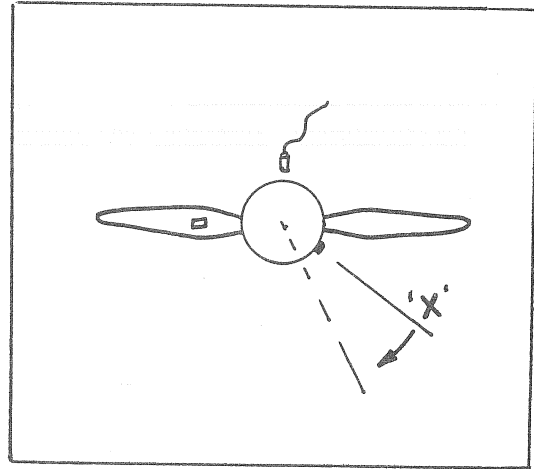


The second run yielded a reading of 9:00 o'clock and .21 IPS. This point is plotted on the graph and a line drawn from the first to second points, and from the first point to the center of the chart.

FIG 11



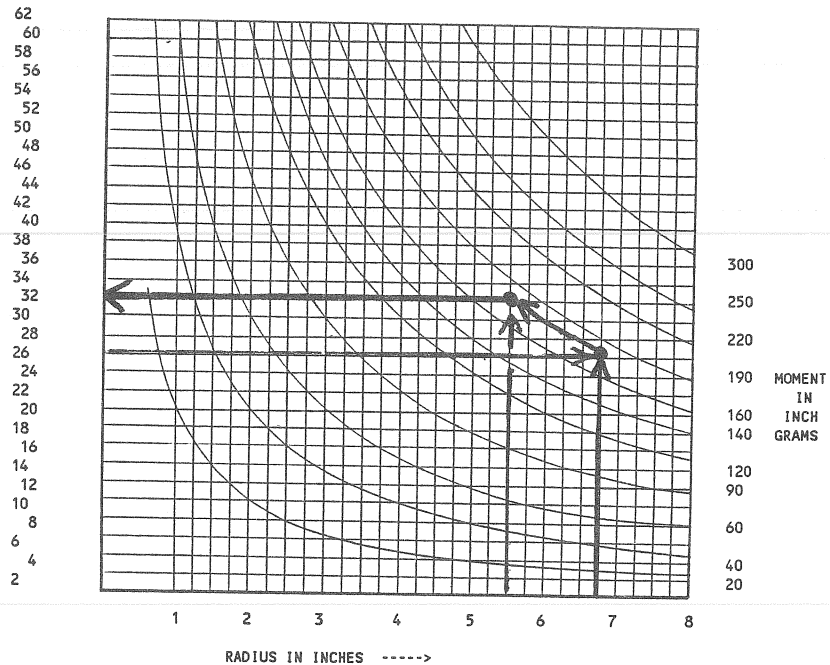
12



Position the propeller target where it was seen on the second run. Move the weight TOWARDS the original 6:00 o'clock position the same number of degrees it missed the center of the chart. More weight will also be required since the length of the line between the first and second points is shorter than the line between the first point and the center.

When a good balance level is reached, determine the final weight installation point. By using the weight moment graph, find the moment of the existing trial weight by plotting at the intersection of weight and radius. Follow the curved moment line to the line that intersects the permanent radius. Read to the left to determine the weight requirement at the permanent location.

FIG 13



For Aircraft Make _____

BALANCE CHART WORKSHEET

Date: _____

Model _____

#3659

S/N: _____

Rotor: Main Tail / Propeller; Left Right / Engine: Left Right

N: _____

RUN NO. →	1	2	3	4	5	6
VISUAL TRACK (if applicable)						
CLOCK ANGLE						
READINGS "IPS"						
CHANGES MADE - WEIGHT - P/C LINK - TRIM TAB - SWEEP						
CLOCK ANGLE						
READINGS "IPS"						

