Speed with Economy by Kent Paser

An Introduction and Review by Scot Stambaugh
EAA Chapter 393
April 26, 2006

Chapter 1 Building my Mustang II

- When Kent started to build the Mustang, he was also working on the NASA Skylab Program at the Johnson Space Center in Houston.
- Aircraft was entirely flush riveted.
- Important construction features:
    1. It is very important that the wing leading edge radius on both wings is identical to prevent a wing drop during stall. Leading edge radius templates is a good way to compare and adjust.
    2. Engine cooling baffles must be held tight to the cylinder fins on the bottom of the cylinders.
    3. Toe-out causes squirrelly steering characteristics. Slight toe-in is desirable.
    4. Make sure that if the exhaust impinges on the belly of the airplane that you add an insulator plate of steel/insulator.
    5. If you use a cross-over exhaust pipe, use a shield to reduce overheating the alternator, starter and oil pan.
    6. Line cowl with steel and insulator to protect it from exhaust heat.
    7. Use white paint on inside of cowl to reflect heat.
    8. Protect spark plug wires from exhaust heat (talk about Bill's Velocity crash).
    9. Spinner shell cut-outs should fit closely within 3/16") to the front of each propeller blade. Make sure the 3/16" clearance is maintained through the entire travel of the blades on a constant-speed propeller.
    10. Exact centering of the spinner on the forward bulkhead support is critical to prevent fatigue and cracking as well as to maximize aerodynamic performance.

Chapter 2 Engine Exhaust System Modifications

- An engine's hot exhaust gases still have a lot of energy; harness that energy and put it to work.
- The initial exhaust system was a 4 into 2 were each cylinder flows into a common tube the feeds a Piper muffler on each side.
- Make sure all cylinders are feeding through equal diameter pipes. This will help with even power production from each cylinder.
- Exp #1 – Remove muffler and add 90 degree elbow. Small speed increase.
- Exp #2 – Reduce angle of elbow to reduce drag and benefit from exhaust as thrust. Additional speed improvement. Be careful of hot exhaust impingement on belly of airframe.
- Exp #3 – Individual exhaust tube per cylinder, also aligning for maximum exhaust thrust. More speed improvement.
- Exp #4 - Constrict the end of each exhaust tube to accelerate the exhaust flow to realize even more jet thrust. Kent performed a flight test at 1/8" reduction steps from 1 ¾" to 1". Optimum performance was achieved at 1 ¼" for this aircraft/engine (see figure 2-2 on page 36). Optimum nozzle diameter is altitude dependant thus necessitating the need for a variable exhaust nozzle device to optimize for all regimes of flight. A compromise could be achieved for your mission requirements.
- Exp #5 – Adding a cross-over tube demonstrated a 100rpm increase in climb and even more in cruise (fixed-pitch prop). This required going back to the 4 into 2 exhaust system.
- Exp #6 – Added anti-reversion cones (Figure 2-4 on page 40) helps to prevent hot exhaust gases from flowing backwards into the combustion chamber during the period of intake and exhaust being open at the same time (commonly called valve overlap). This experiment was first tried on the straight pipes and resulted in spectacular flight results. While there was no appreciable speed increase nor drop in exhaust temperature, fuel consumption , in cruise mode dropped a full gallon per hour! The mods were then made to the cross-over exhaust system and the additional performance of that system was maintained with the fuel economy of the anti-reversion mod remained intact at a 1 gph improvement. Fantastic!!
- Further experimentation showed that the crossover system made more power but it was uneven power with cylinders 1 &4 making more than 2 & 3 but economy fell. The 4 individual stacks made less power but more economy. You make the choice.
- Summary of final exhaust system:
  1. Stainless steel crossover exhaust system
  2. 1 ¼" diameter jet nozzles
  3. anti-reversion cones

Chapter 3 Engine Intake System Modifications

- An efficient air intake system lets the engine really breathe and allows hidden horsepower to express itself.
- Kents initial thoughts:
    - Don’t impede inlet air (air filter efficiency).
    - Don’t redirect inlet air anymore than necessary (change of direction).
    - Keep inlet air as cool as possible (maximum fuel charge density).
    - Maximize ram air (forward velocity/propeller augmentation).
    - Improve plenum chamber utilization if air direction change is necessary.
- Exp #1 – Remove air filter to determine the performance hit from the air filter. This resulted in slightly more than 1” of MAP increase and approximately a 3 mph increase in cruise speed at 7000 ft. Since no filter element could do as well as not having any filter at all, Kent chose to design an air box that would allow filtered air for takeoff and landing, heated air for icing conditions, and unfiltered ram air for enroute activities. Additionally, Kent found a better flowing air filter to improve takeoff performance.
- Exp #2 – Ram airflow augmentation from propeller pressure pulses by moving the ram air intake forward to within 5/8” behind the propeller.
- Exp #3 – Reduce the size of the ram air intake to slightly more than is necessary to feed the maximum required CFM at maximum power (approximately 1 ½ times the necessary air flow). An oversized intake allows excess air to spill back out of the scoop, causing a lot of unnecessary aero-dynamic drag. The smaller size also reduced aero drag. Kent’s discussions with John Swearingen suggest that final scoop size should be 1.1 times the size of the carburetor/ fuel injector intake.
    - Implementation features:
        - The scoop inlet is cut at a 10 degree angle into the advancing blade. This is because the air coming off the blade has a rotational component.
        - The scoop has a slight bell-mouthed opening.
        - The scoop has an inner liner that transitions the small round scoop inlet to the larger, rectangular front opening of the carburetor air box. The sides of the liner must not exceed 11 degrees of total angle else the air will go turbulent.
        - The timing of the pressure pulse must be timed with the opening of an engine cylinder intake valve.
    - Performance improvement:
        - Surprisingly, there was no MAP increase.
        - 300 FPM increase at 7000 feet.
- Exp #4 – Insulate the intake runners to keep the intake charge as cool as possible. Performance improvement – EGT was able to go up 50 to 75 degrees before engine roughness occurs during leaning.

Chapter 4 Engine Cooling System Modifications

- A cool running engine and accessories promotes safety, reliability, and long life.
- Add full pressure plenum to the top of the engine for efficient and equal pressurization of cooling air to all cylinders. The plenum also removes the problem of the cowl rising off of the traditional baffles at higher speeds.
- The smooth outflow of air at the cowl exit is just as important as a smooth inflow of air at the cowl inlets (figure 4-1).
- Exhaust “jet-pump” helps pull air out of cowl (figure 4-1). Resulted in significantly cooler cylinder head and oil temperatures. If the cooling is more than is needed then the cowl inlet size can be reduced, resulting in significant Aero-dynamic improvements.
- Exp #1 – Reduced cowl inlet size 4 square inches at a time until CHT’s hit the bottom of the temperature range. Initial size was 60 square inches. Final size was 30 square inches!! This experiment cannot be optimized until a CHT/EGT is placed on each cylinder and the under cylinder baffles must be optimized to get equal CHT’s on all cylinders. At this point reducing the inlet size until temperatures begin to go up means that all of the air going into the intakes is being used and none is spilling out as excess, thus reducing drag.
- Check for cooling fin flashing on the cylinder heads that might be impeding air flow.
- Don’t forget the maintain cooling on magnetos, accessories and battery. Kent likes to cool the insides of the mags.

Chapter 5 Aerodynamic Cleanup and Drag Reduction

- Air has mass; it takes energy to change the direction of mass in motion. Aerodynamic drag reduction is simply a matter of minimizing the redirection of air.
- **Landing Gear**
    - Gear leg fairing
    - Reshaped wheel pants to cover and fair the brakes and axle interface as well as have a tight tire opening with minimal tire exposure to the slipstream.
    - Wing to gear leg interface fairings.
    - Wing to fuselage interface fairings.
    - Horizontal and vertical stabilizer to fuselage interface fairings.
    - Performance improvement was 19 mph.
- **In-flight Experimentation with tufts of yarn and air-to-air photos.**
    - Even though the yarn didn't show a problem with the rather square jowls of the cowl, Kent decided to smooth the forward cowl area and reduce the blunt impact area.
        - Fix – Smooth and taper the cowl jowls, reshape cooling inlets to be flush with the edge of the spinner.
    - Tufts indicated complete airflow separation and significant turbulence aft of the canopy. At times the tufts were pointing forward. Kent reasoned that the canopy surface was receding at a greater angle (referenced to the relative wind) than the airflow could stay attached; thus, creating a low pressure region and large amounts of turbulence on the aft portion of the canopy. In addition to slowing the aircraft, the turbulence also caused "shadowing of the empennage control surfaces. This required that the surfaces be larger to be affective.
        - Fix – Raise the turtle deck 11" and lower the canopy to get a smooth line from the top of the canopy to the empennage. Kent also changed the bubble windscreen to a flat wrapped sloping windscreen. To smooth the frontal transition of the oncoming air stream and to create a seamless transition from the windscreen to the canopy. Raising the turtle deck resulted in a speed increase of 12 mph.
        - Kent also fabricated a canopy side skirt capture to prevent high pressure cockpit air from pushing out the skirts and dumping plumbs of slow air into the high speed slip stream, eliminating another source of significant drag. Other sources of high pressure cockpit air leakage were also eliminated to keep it from escaping into the slip stream and causing plumb drag. Cockpit air is exhausted through a ½" slot between the cockpit belly and the flap and is directed aft to streamline the air release and reduce plumb drag.
    - The tufts on the side of the fuselage, for 3 feet aft of the trailing edge of the wing, were pointing up instead of aft! Explanation? Low pressure being created by the wing's airfoil sloping down (in relation to the relative wind) and the side of the fuselage is sloping in to form the fuselage tail cone.
        - Fix – Add an extended wing root fairing/fence that extends a full 3 feet aft of the trailing edge of the wing along the side of the fuselage.
    - Cowl and wing root fairing modifications resulted in a 7 to 8 mph speed improvement.

- **A host of smaller improvements**
    - Removed external antennas.
        - Result – 5 mph.
    - Tailwheel streamlining included:
        - Reducing tailwheel size from 6” to 4”.
        - Added fairing to cover tailwheel leaf spring.
        - Added a tailwheel pant.
    - Added a clear plastic fairing over the flashing beacon.
    - Moved the Outside Air Temp probe out of the slipstream.
    - Added a molded fairing to fair in the Pitot/Static port.
    - Added Fairings over the aileron hinges and counter weights.
    - Added a molded fairing around the fuel tank vent tube.
    - Faired in a row of protruding head rivets using polyester fill.
    - Fabricated fairings to close in the root end of each elevator.
    - Minimized the gap between the spinner and the propeller blades at the cutout. Also the spinner the cowl clearance is minimized.
    - All cowl seams, between the cowl upper and lower half and also between the cowl and the firewall are sealed to eliminate any plumb air from escaping.
    - When racing, Kent would tape off the oil door seams and any control surface gaps at the hinge lines.
    - All external flush head rivets and seams were filled with polyester body filler.
    - Improvement after instating all of these small fairings and fillets, adverse airflow correction and surface friction drag reduction resulted in another 6 to 7 mph increase in top speed.
    - Additionally, Kent noticed that the speed difference between a dirty exterior and a cleaned and polished airplane is a good 5 mph!! He uses Star-Brite aircraft polish.

- **Miscellaneous Performance Modifications**
    - To improve slow speed performance (i.e. – lower the stall) Kent experimented with drooped ailerons. This effectively increased the size of the flaps and increased the camber of the entire wing.
        - This mod resulted in a 2 mph drop in stall speed.
    - Added more travel to the flap mechanism to get a full 60 degrees of flaps.
        - This mod resulted in a 2 mph drop in stall speed. The extra drag allowed Kent to carry more engine power and RPM for augmented air flow over the wings and tail surfaces. This further reduced stall. The extra notch of flaps also steepens the approach for landing.
    - Advanced timing on mags to 30 degrees. This mod requires great care or engine damage could occur.
    - Alternator Cutoff Switch – By removing any field voltage the field inside the alternator is removed and rotational resistance normally applied to the ameture stops. Kent says this mod contributes about 3 to 4 HP in engine performance that is applied to the propellor and not the alternator. This mod is for racing only and for short flights only as the alternator is no longer generating power to the electrical system, forcing the battery to provide all the necessary operating current.
    - Engine Additive – Kent tried a product called Microlon, a Teflon product. He claims he saw a 6 mph improvement in top speed and an improvement in rate of climb. Wow!!
    - Higher Compression Pistons – 7:1 compression was increased to 8.5:1.
    - Removable tiedown rings – Kent added threaded bosses inside the wings so that tiedown rings could be easily screwed in after landing and removed before flight. Another small speed improvement.
- **Performance Improvement Results**
    - The performance improvement results are measured in terms of:
        - Increased Top Speed
        - Increased Rate of Climb
        - Decreased Fuel Consumption
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