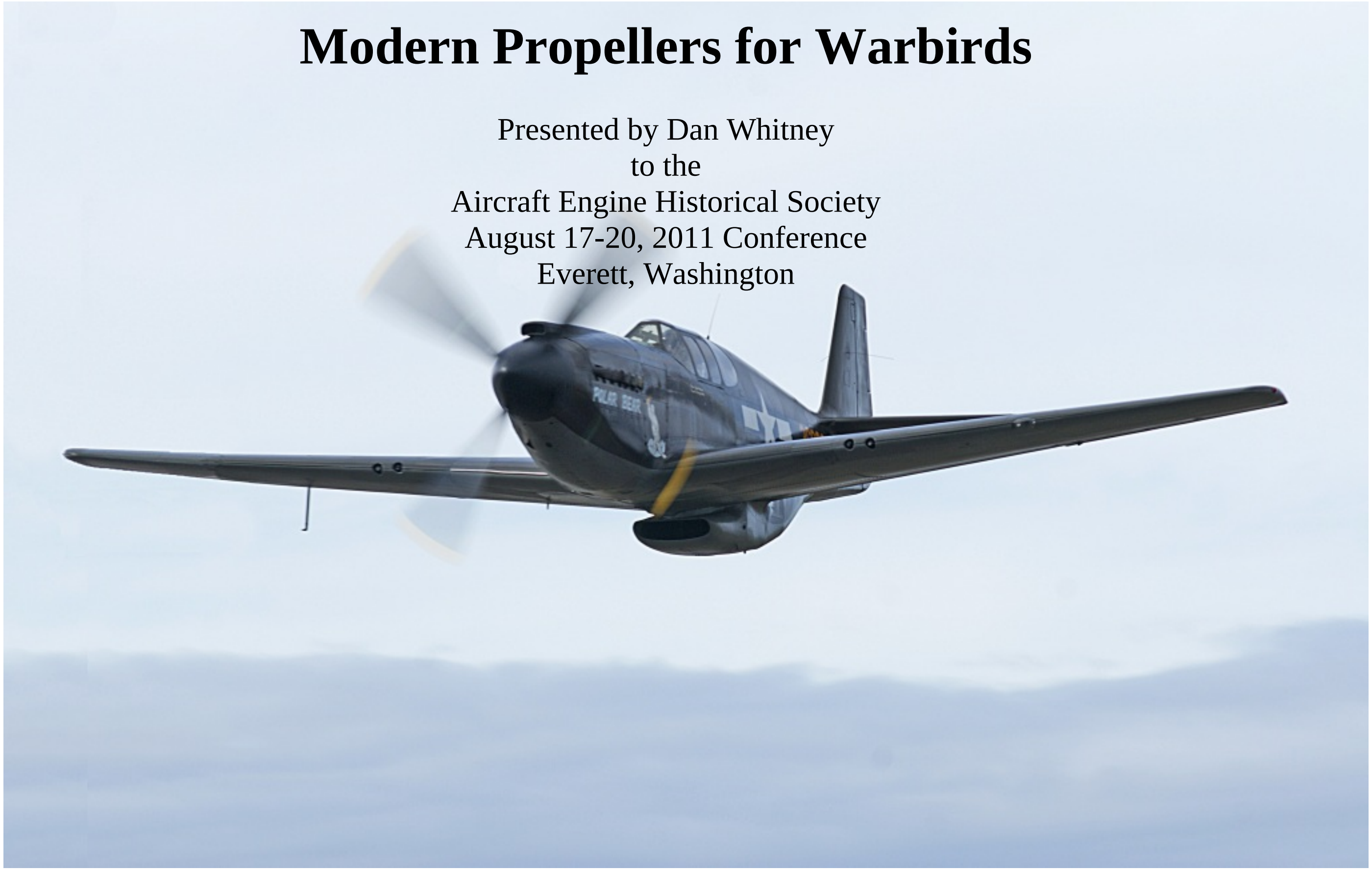
Modern Propellers for Warbirds

Presented by Dan Whitney
to the
Aircraft Engine Historical Society
August 17-20, 2011 Conference
Everett, Washington



Here we are, some 66 years after World War II and there is a vibrant industry supporting the interest in the aircraft of that conflict. The airplanes are categorically known as Warbirds. Their purpose is as a living monument to the sacrifices and achievements of the people of that period, and to maintain the sights, sounds and smells that are uniquely airplanes and engines of that time. They also serve as historic yardsticks of technology at a time when slide rules and pencils were the computers of choice, and were all that was available. At the time it was hoped that the aircraft would last a few hundred hours, and bring their crews home safely before being replaced by a newer model. Many aircraft received little or no corrosion treatments that would have prolonged their life, so when a restorer or operator today wishes to have one of the few examples that managed to escape the post-war smelter, it is often necessary to scrounge the world for critical parts. Sometimes the result is to find that the critical parts simply do not exist. At this point a reasonable person might quit, but for every one who does another steps forward and takes up the challenge.

This presentation is of one such quest. An extremely rare P-82E *Twin Mustang* was obtained by Pat Harker of C & P Aviation, Minneapolis, Minnesota, for a series of private owners who saw the value of the project, but chose to not pursue to a flight worthy conclusion. The scope of Pat's undertaking is breathtaking; the aircraft was one of the most technologically complex produced in the US during the war, and every component needed to be repaired or renewed. As it turned out the most significant roadblock, the lack of airworthy propellers, could not be resolved via conventional sources of supply or remanufacture, and began to look like a show stopper. At that time Pat and his team determined to think outside the box and look for a non-traditional solution to the dilemma. He took on the challenge of having new propellers designed and manufactured, as the original manufacture was no longer in existence, and the original technology used had been lost. The project is not yet complete, but the prototype propeller has flown and performed to the satisfaction of the team. The following provides perspective on how and what has been done, and details many of the requirements and methods used to provide a new generation of propellers for Warbirds.

Story of the P/F-82 Twin-Mustang

This twin fuselage, twin-engine fighter was originally designed by North American as a Very Long Range (VLR) fighter to escort B-29s from the Philippines to Tokyo. It utilized much of the developing aerodynamics and technology that came from the P-51 *Mustang* program, but only a very few *Mustang* parts. Only one was delivered prior to the end of WWII.

Two *Merlin* powered XP-82s were built, along with one Allison V-1710-119 powered XP-82A. These were followed by a small production run of *Merlin* powered P-82B airplanes. Following the end of the war the new Strategic Air Command needed a VLR fighter and 100 Allison powered P-82E's were ordered. This order was expanded to include 150 P-82F radar equipped interceptors/night-fighters. In support of the P-82E/F program Allison was contracted to deliver 750 V-1710-143/145(G6R/L) engines.

A *Merlin* powered P-82B *Betty Jo* set a non-stop, un-refueled record of 5,051 miles on December 27, 1947 when it flew from Hawaii to New York City.

The aircraft did not enjoy a long service life as very few spare parts were procured while the demands of the Korean War rapidly eroded their operational capability. The first air-to-air victory of that war was made by an F-82. The F-82F air defense interceptor version was phased out of front line service in 1951. The use of the F-82 in Korea ended in April 1952, but they continued in Alaska until June 1953 when all had been removed from operational military service.

For the most part the withdrawn aircraft were simply scrapped as jets were replacing them. The engines fared a little better as many were obtained from salvage by the first generation of hydroplane racers. As a two-stage supercharged engine these were capable of phenomenal performance when overboosted for racing. Unfortunately, the engines were considered expendable and many were literally blown up and irreparably damaged. Today there are very few complete engines available, even including museum examples.

Surviving P-82s

Four aircraft were acquired by NACA for research work.

XP-82 #44-83886 was ultimately salvaged.

XP-82 #44-83887 was damaged and parts of it sold to Walter Soplata. In March 2008 it was sold to Tom Riley and moved to Georgia for restoration using additional parts acquired from around the world.

P-82B #44-65168, *Betty Jo,* was used for Ram Jet research and then turned over to the National Museum of the Air Force.

P-82E #46-256 was complete and sold to Walter Soplata for $1600, following use by NACA in March 1954. Doug Arnold purchased it from Soplata in 1997, which in turn sold it to Wally Fisk of Minneapolis, MN, who started its restoration. This is the aircraft now being restored by Pat Harker of C & P Aviation, also located in Minneapolis, MN.

Ex-NACA P-82E #46-256 on Walter Soplata's Ohio farm during the 1980s.

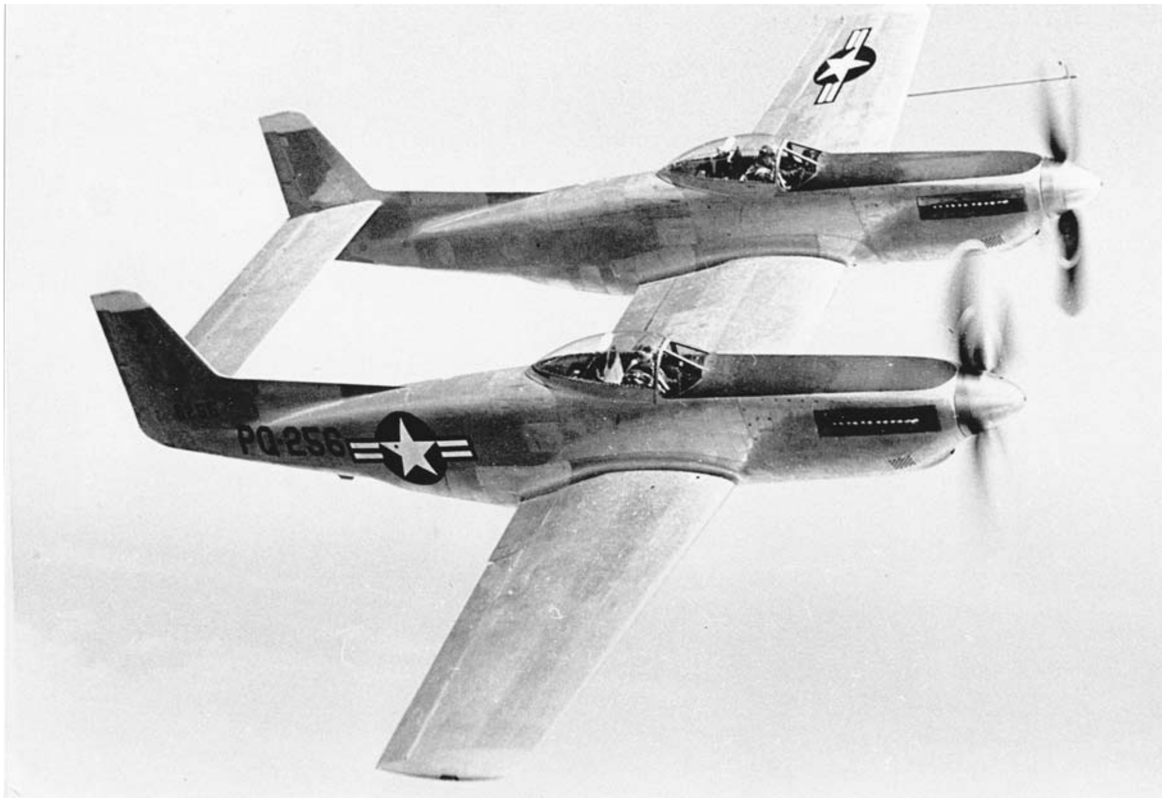
In addition P-82B #44-65162 was obtained from Lackland AFB, TX by the CAF in 1966, and restored to flight. It crashed during landing in October 1987 in Harlingen, TX, damaging the propellers. The lack of replacement propellers has kept it grounded. It has now been recovered by the National Museum of the Air Force.

The USAF has another P-82E #46-262, which is displayed on the parade ground at Lackland AFB, Texas.

So in total there are five remaining P-82s, of which two are being prepared to return to flight, two in the National Museum of the Air Force, and one on the parade ground at Lackland AFB.

Restoration of P-82E #46-256

This is a comprehensive restoration of a complete aircraft being done by Pat Harker. It is arduous as there are so many one of a kind components, complex systems and sophisticated engines.



Pat Harkers F-82E #46-256 when in service with the NACA prior to 1954.

C & P Aviation has acquired a complete set of drawings, all digitized from microfilm. This certainly helps, but the supporting database of design documents is largely missing. Even so, they intend to have all systems operational, including heating, anti-icing, fire detection and suppression along with the two-stage engine superchargers.

Scope of work has been huge, including complete disassembly of the airframe, comprehensive cleaning, repair and refinishing of all components. All system tubing for hydraulic, oil, fuel and coolant lines has been remanufactured. All wiring replaced and made functional. All accessories overhauled and some of the aircraft reskinned. Where necessary replacement components have been milled from billet. The aircraft is now up on its gear, fully wired and system plumbing installed. Accessories and components needed by the various systems are now being fitted.

Current Status of P-82E #46-256. It's up on its wheels, wired and plumbed, and having system active components installed, including buildup of the engine nacelles.

Restoration of the Engines

The engine used on the P-82E/F is most powerful of the Allison V-1710 series. It features two-stage supercharging and ADI/Water Injection, along with the unique Bendix SD-400D3 Speed Density "Carburetor".

Bud Wheeler of Allison Competition Engines, Latrobe, PA, is building the engines. They will incorporate the many engine improvements that his *ACE Allisons* has developed and for which they have either received FAA approvals, with several pending approvals included; such as, new pistons, new ring pack, new cylinder liners and new valve springs, along with numerous enhancements to engine support systems.

The final major components to be provided for the P-82 are the Propellers

Propellers that came with the project suffered from corrosion and could not be made airworthy.

The world was turned up side down looking for these unique Aeroproducts A-542F left and right turning propellers.

With no original propellers available at any price, consideration was given to remanufacturing the original Aeroproducts units. Considerable effort was put into this project, however no manufacturing drawings, or production process description was found with sufficient detail to be useful. Reverse engineering was impractical because of the scope and complexity of the unique manufacturing processes, coupled with the subsequent necessity to receive FAA Certification and Airworthiness certificate.

An effort was then launched to find alternate propellers that would be of the correct size and available in both left and right-handed models. The P-51H uses a very similar Aeroproducts A542-B1 propeller with H20-162-29M5 or H20-156-23M blades as the original, however it is only available for right-handed engines, and does not incorporate the necessary feathering capability. Going to a Hamilton-Standard hydromatic, full feathering propeller was also considered, but there were no four bladed units with the left-handed blades. Hamilton-Standard type solid aluminum blades are still being made for right-hand P-51s, however the forging dies are not available for a left-hand unit, and Alcoa was not interested in building them at any price.

Fortunately, when discussing the Hamilton-Standard issues with Avia, the licensee for their replacement blades, they mentioned that their sister company, MT-Propeller, of Atting, Germany, fabricates propellers in the desired power range for a very wide range of engines and aircraft, that they may be interested. Again fortune prevailed as Avia and MT were in adjacent booths at Oshkosh *Airventure*, and Gerd Mühlbauer primary designer and General Manager was in attendance.

Gerd became very interested in the project, not only for the use on the P-82, but to meet the developing needs of a wider audience of Warbirds. MT-Propeller has the capability to build replacement propellers for any of these old aircraft. What makes a project such as this affordable and timely is the fact that MT constructs their blades from a natural composite material, wood. This allows them the freedom to shape the propeller without the expense and complexity of forging. This project would be a highly visible opportunity to demonstrate their capability, and so it was not long before the necessary contracts were put in place and technical information exchanged so that detailed design could begin.

The Propeller

The original propellers were 11'-0" diameter full feathering, hydraulic, Aeroproducts A-542F-D1(RH) and AL-542F-D1(LH). The blades were H20-162-30M2 (RH) and H20-162L-30M2(LH), with low pitch settings of 26 degrees and high pitch settings of 63 degrees, and 89 degrees when feathered.

These original Aeroproducts blades are what the C & P Aviation team had to start with for propellers. The idea of finding serviceable propellers was attractive, and nearly became a showstopper for the restoration.

Propellers turn inboard at the top on the P-82. However on the prototype XP-82 they were opposite, turning outboard at the top, as is the case in the P-38, which was intended to allow better single-engine control. This did not work, as the aircraft could not takeoff. After a lot of engineering review it was determined that there was so much drag caused by the propellers that the lift of the center wing section was being canceled. The engines were then exchanged, right for left, and the aircraft flew very well. It is interesting that the XP-38, with inboard turning props, had similar issues and could barely fly until its engines were swapped so that the propellers turned outboard. The aerodynamics of the specific aircraft plays a significant roll in selection of optimum direction of rotation.

MT-Propeller has patents and designs for many propeller types and configurations, depending upon whether it is counterweight operated, hydraulic operated, feathering, etc.

The resulting MT Model MTV-4-1-T/50-C-F/335-14 propeller is full feathering, hydraulically operated, and uses counterweights on the blades and a spring in the hub to feather the propeller any time governing oil pressure is lost. A small "un-feather" pump using engine oil until the engine returns to speed and the governor is back on-line accomplishes unfeathering. Propeller diameter is 11'-0", equivalent to 335 cm.

An Interview with MT-Propeller Designer and patent holder, Gerd Mühlbauer

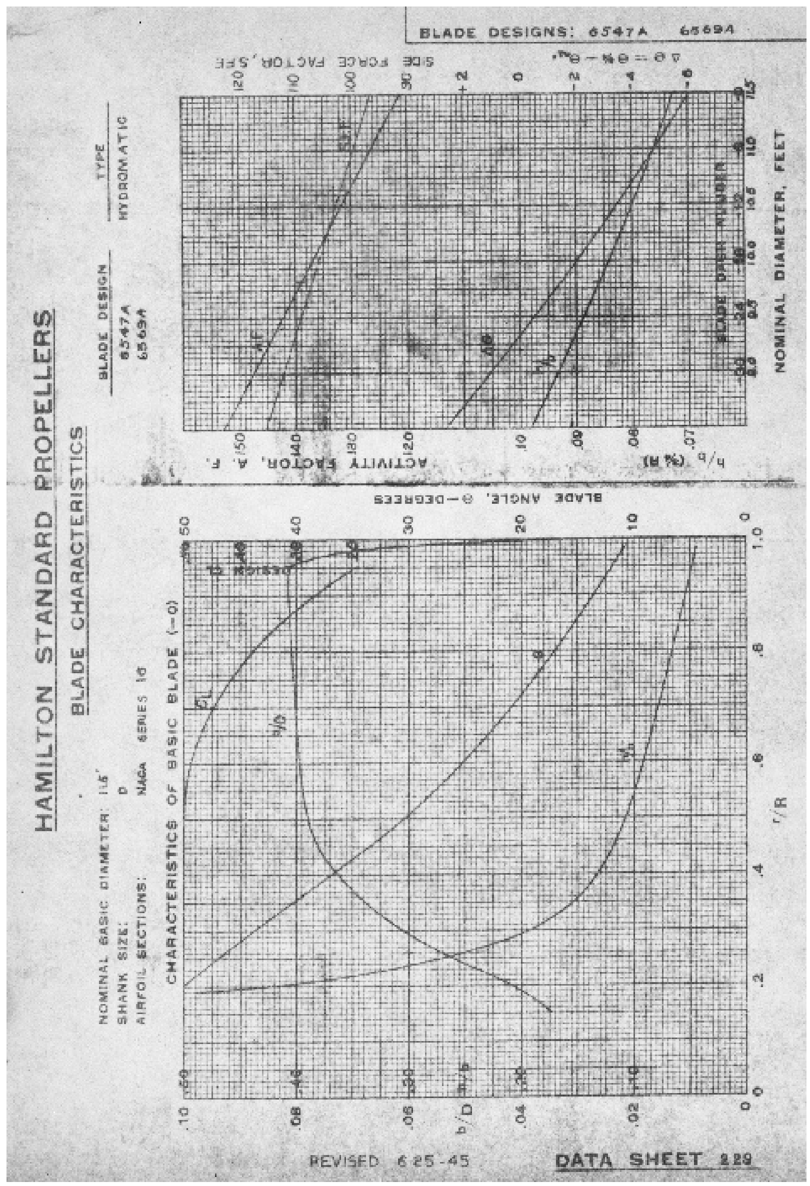
So Gerd, can you take us through the process you use when challenged by a new design as needed for the P-82?

Answer: We start with a questionnaire, looking at the fundamentals, such as maximum diameter, horsepower, propeller speed, number of blades and the performance envelope of the aircraft.

What role do computers play in the design process?

Answer: Computers do not design our propellers. We start with the Hamilton Standard Performance Charts, looking for optimum efficiency as appropriate to the design fundamentals for the propeller. We then refine the resulting propeller blade using computers to optimize the blade pitch distribution, or twist, we need. This is largely determined by the strength and performance of the materials of blade construction.

Often, as was the case for the P-82 propeller, we are not able to fully optimize the design as there are other considerations, such as matching the silhouette of the blade, as we did here when a nearly square tipped blade was required. An elliptical tipped blade will be the quietest, as it has minimal tip vortices, and we are

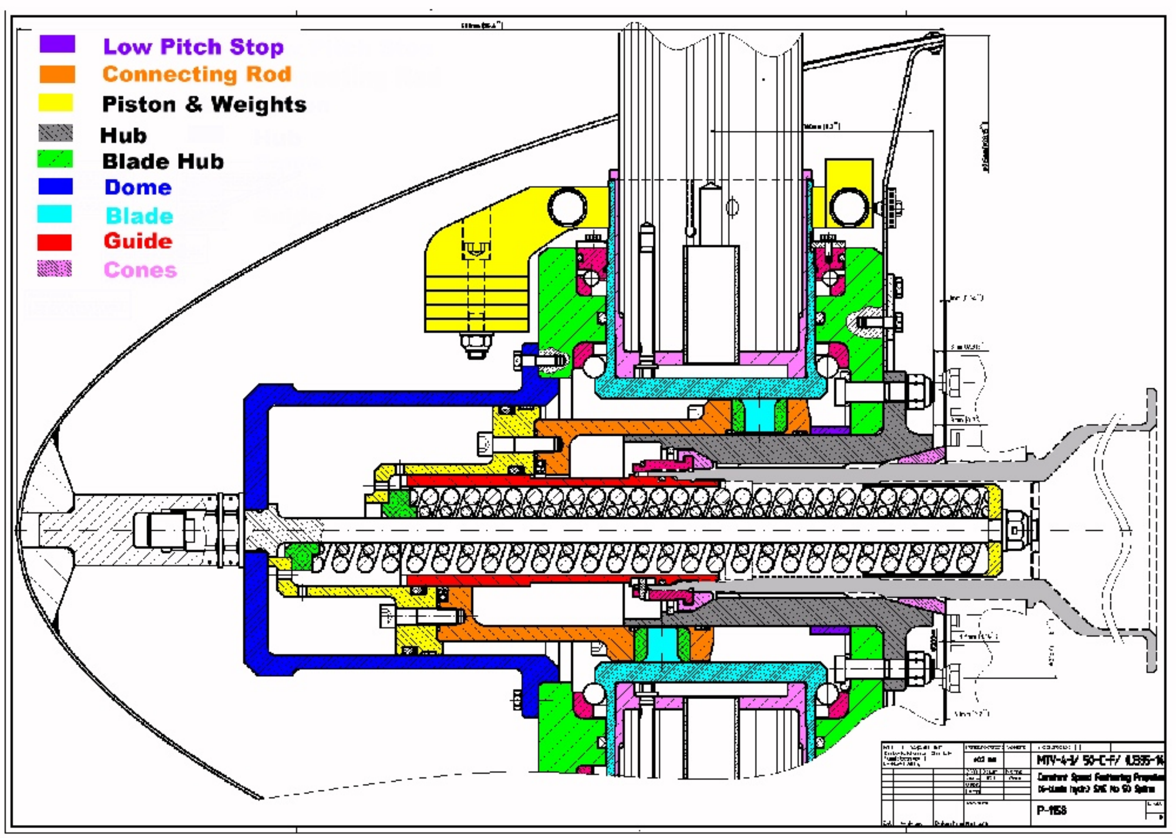


A page from the Hamilton Standard Method of Propeller Performance Calculation, 1941, with supplements, detailing blade designs 6547A and 6549A as used on the P-51D airplane.

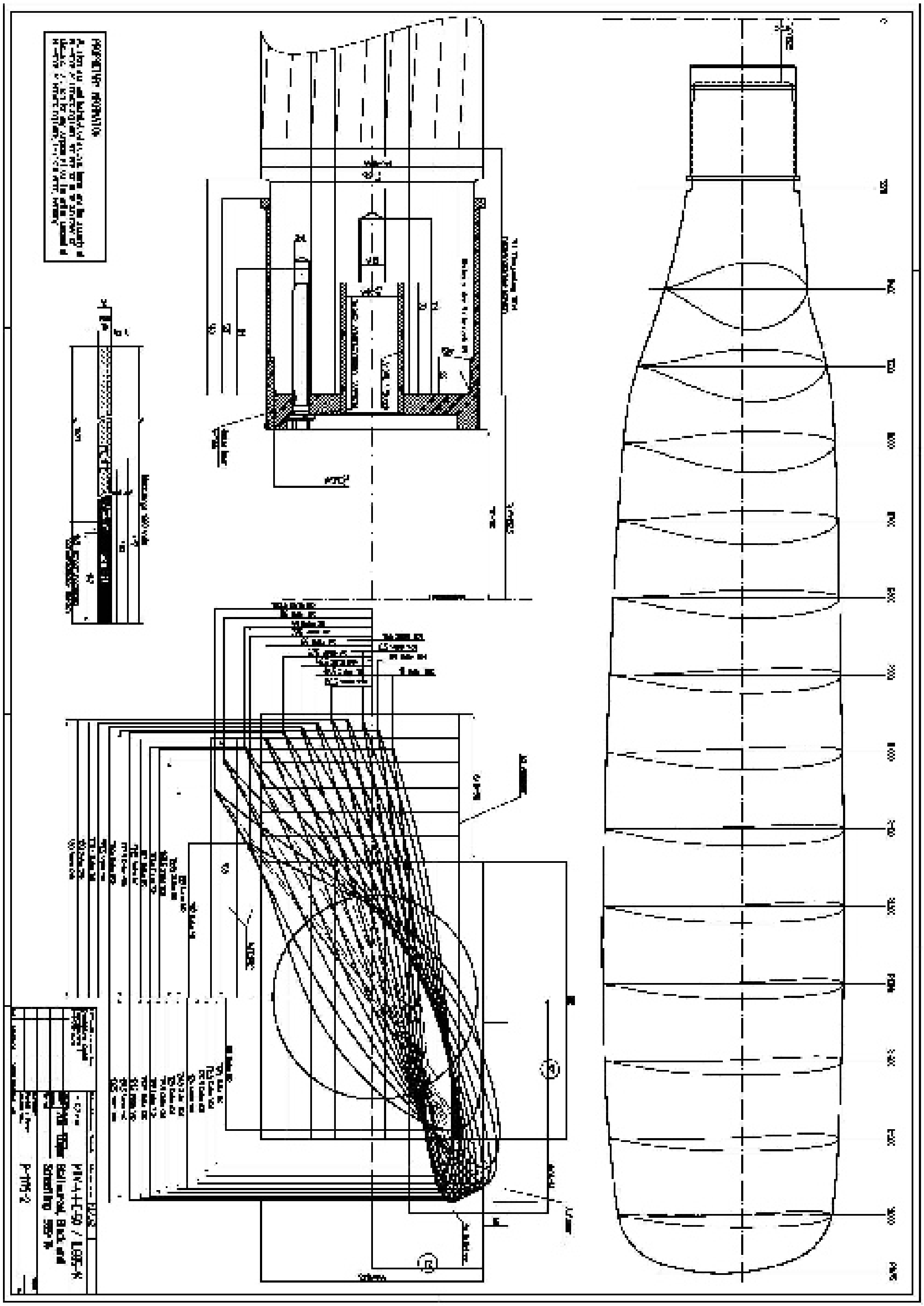
able to tailor the pitch distribution so as to unload the tips, thereby producing a quieter propeller. This is very important in a turboprop airliner, not so important for a piston engined fighter.

What about the details of the blades?

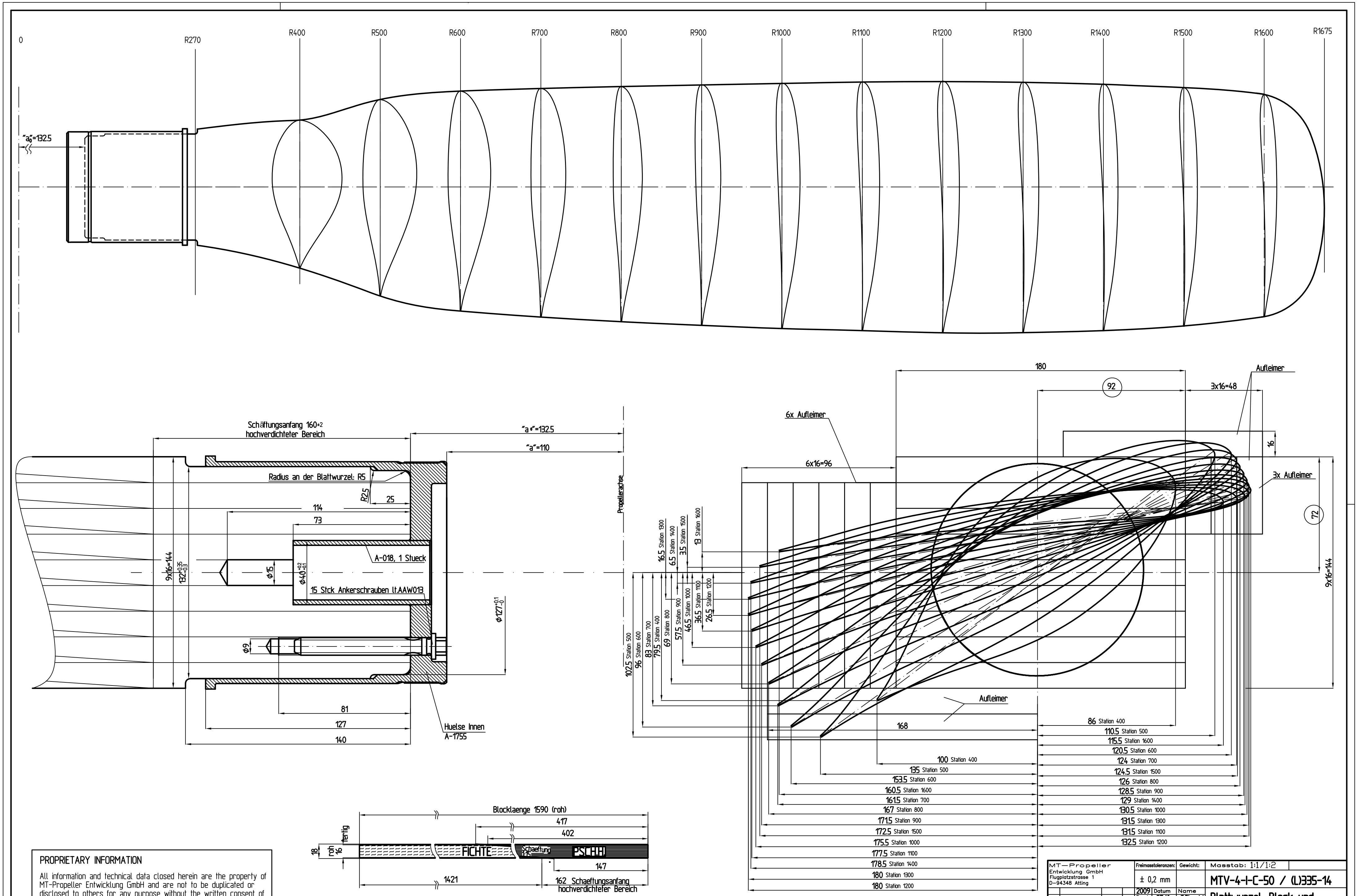
Answer: We use our own MT airfoils and the requirements of wood construction to shape the blade and blade profile. Our composite material is wood, not everyday wood, but specially treated wood (Beech, compressed to a density of 1.38-1.40, about double un-treated wood) for the outer portion of the blade and European Spruce for the inner portion. This natural composite material was invented by Hoffman in Germany in 1928 and is still being produced. We laminate it with spruce and get a very stiff blade that has an infinite fatigue life. For weather protection and torsional stiffness we wrap the blade in glass and carbon fibers cloth, which is then epoxied. A metal erosion sheath of stainless steel or nickel is then bonded to the leading edge of the blade to further protect it from damage. This is followed by 6-7 coats of paint, and then the blade root is drilled for special steel lag screws that hold it in the hub. The entire process takes about three weeks for each blade.



MT-Propeller Hub for the P-82 showing structural and operational elements along with attachment of the wooden blades.



Shape of the blades being used on the MT designed P-82 propeller.



PROPRIETARY INFORMATION

MT—Propeller
Entwicklung GmbH
Flugplatzstrasse 1
D-94348 Atting

Freimasstoleranzen: ± 0,2 mm

Gewicht:

Masstab: 1:1/1:2

	Datum	Name
2009	Datum	Name
Bearb.	27.10.	C.Dippold
Gepr.		
Norm		

Werkstoff: Psch.H + Fichte, Aerodux 185A

Rohteil:

MTV-4-I-C-50 / (L)335-14

Blattwurzel, Block und Schaeftling 335-14

P-1175-2

Blatt

Bl.

Zust. | Aenderung | Datum | Name

So what about the Hub, it is really different than a Hamilton Standard or Aeroproducts.

Answer: The hub for the P-82 is made from forged aluminum alloy. First the desired allow is cast and then hand forged into a suitably shaped billet, which is then heat treated at 480-510 ^{o}C and quenched in water. This billet is then machined as required to affect the features of the design. Since the propeller has to fit onto an existing SAE #50 propeller shaft we have to fabricate a matching internal spline to interface with and drive the propeller. We call this a splined spacer flange and it is the most important piece in the project. Since we are not making thousands of these we cannot afford the luxury of an expensive broach as was done during the war. Rather we are able to use Electric Erosion machining, which is accurate to 0.010 inch, to shape the splines that mate with the shaft. For the bolt pattern connecting the flange to the aluminum propeller hub we chose the one we use for the PW127 turboprop. No need to invent something different.

Blade trailing edge cutout needed to clear the intake scoop on the P-51A. The data tag on the blade is shown as is the new carbon fiber spinner that fits tightly onto the prop hub, The blades are retained in the hub by the counter-weight clamps. The hub is positioned and retained on the shaft using the original US military cones and retaining nut. No need to invent something different.

What about Flight Testing and Operation?

Answer: It was important that we flight test the prototype propeller before committing to the actual articles. Having a similar airplane with a similar engine was important for many reasons and I was very happy with the results we obtained.

During the flight-testing we were most interested in the governor oil pressure[1] under different conditions, including climbing, cruise, diving and maneuvering. This tells us whether or not there governor is developing sufficient pressure to provide the force necessary to position the blades as needed to control engine speed. If changes are needed we can adjust the mass of the counterweights, governor capacity, and the stiffness of the internal spring. For the P-82 the numbers confirming operation came in very nicely.

Pilot Dave Morss makes the first takeoff with *Polar Bear* fitted with the new 4-blade MT Propeller.

[1] Interestingly, the governor oil pressure control on this counterweighted propeller is the opposite that of a Hamilton Standard Hydromatic, and the same as Hamilton uses on their counterweighted propellers. Higher pressure flattens pitch on this MT propeller.

Flight Testing

To achieve the goal of FAA Certification a 110-hour ground test is required prior to flight certification. Because of the cost and complexity of such a program it was felt that a prototype propeller should be built and flown on an Allison V-1710 powered aircraft prior to the certification testing of the actual propellers. A way to accomplish this was provided when AEHS member Jerry Gabe, Hollister, California, offered the use of his P-51A Allison powered Mustang, *Polar Bear*.

Another fortunate occurrence came in at this point because *Polar Bear's* Reno race pilot, Dave Morss has considerable experience working with MT Propellers and Gerd from having performed first flight on a number of their propellers.

MT immediately began fabrication of the prototype propeller and it was delivered to Hollister in November 2011. Their crew chief Steve Lamb worked with Dave to revise the propeller systems for the new 4-bladed propeller and fit it in place of the 3-bladed Curtiss Electric. An interesting finding was that the new propellers total weight was only ten pounds different from the Curtiss Electric, although the blades are considerably lighter.

Dave Morss inspecting the propeller installation prior to first flight. Here the billet aluminum hub is very easy to see, as are the counterweights that assist in positioning the blades.

All was in readiness on December 3 in anticipation of Pat Harker and others arriving to witness the first flight. As the aircraft was being cowled it became abundantly clear that the unique forward engine air inlet would interfere with the trailing edge of the blades near the hub. No matter how many people had looked at the components and design, this had slipped by, for it is not an issue on other Mustangs, including the Twin-Mustang with their streamlined cowling behind the propeller hub.

So some mid-night oil was burned effecting Gerd's recommendation that the offending cuff area simply be cut away with a saw! This is easy to do on a wooden propeller, so after one blade was cleared a template was made and the other three cut to match. A little clear varnish to seal the wood and the aircraft was ready for flight the next day.

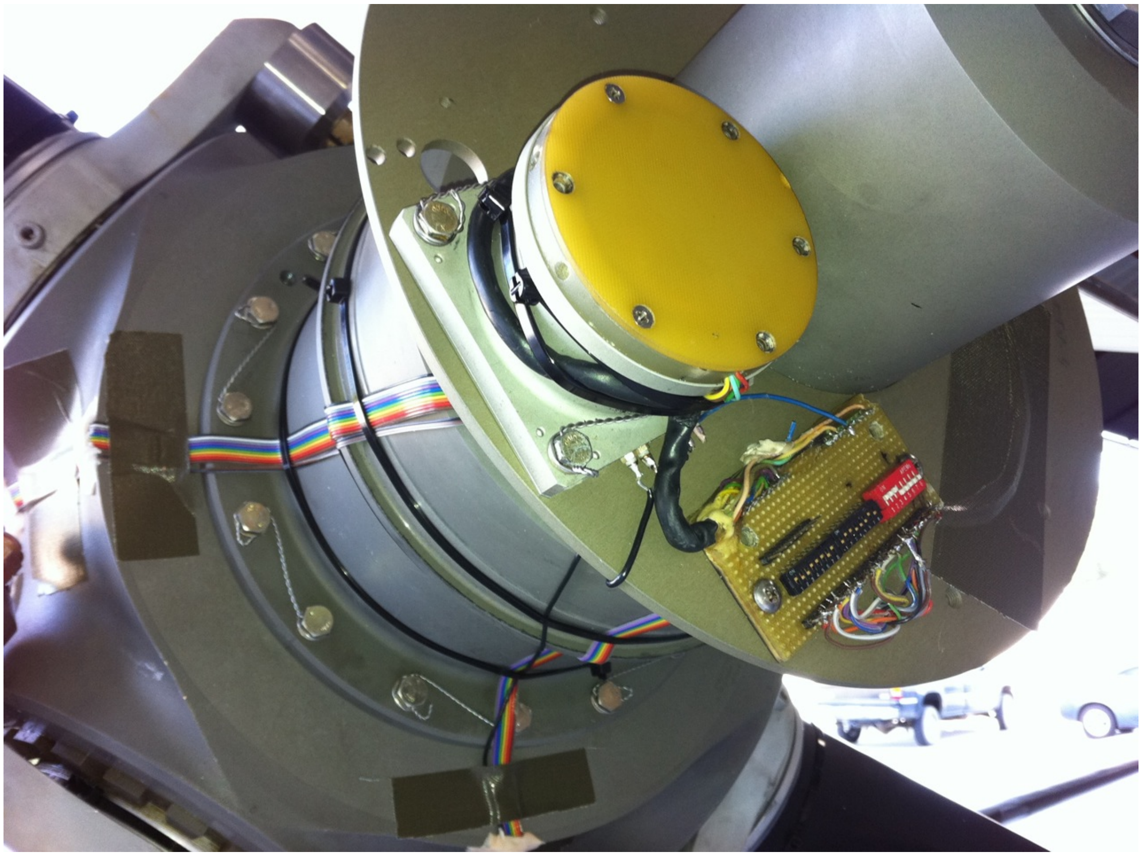
Interview with Dave Morss, *Polar Bear's* Test Pilot

Dave Morss is a highly accomplished test pilot having made first flights of more than 40 aircraft, flown more than 300 types of aircraft including pistons, jets, rockets and electric powered, and has flown more than 200 heat races at Reno flying in almost all of the racing classes including Sport, Jet and Unlimited. In addition he has performed component flight-testing on many new and/or modified accessories, including several new propellers.

Another view of the propeller detailing the hub, blade attachment, counterweights and backing plate for the spinner. The profile of the trailing edge cutouts is clear as well.

As he approached this ambitious project of first flight of a prototype design of a new propeller on a heavy and high performance military fighter, he relied upon his previous work with MT Propellers that included flight testing new propellers and MT's record and engineering experience in the field. Tempering the process was a first flight test he had performed on another manufacturer's first attempt at a constant speed propeller, a flight that included losing a blade.

In preparing for the flight Dave relates that he discussed the design and scope of the testing with MT's engineers, focusing on the mechanical aspects of the design, the blade retention system, and the operation of the governor in the various flight regimes. From this MT developed a detail Test Plan, identifying the required data to be obtained in the various flight conditions during the ten hours of flight required for the prototype propeller testing, all designed to minimize stress and risk while safely obtaining the needed data.



Here the wireless transmitter and stress measuring instruments are shown mounted on the hub before the spinner is installed.

Following are some of the key issues and parameters he focused on during the program.

- Engine Start – was potentially difficult because the prototype propeller had been configured for the P-51A and not the P-82, meaning that it did not initially have full feathering capability, nor did it have "pitch locks". Since the MT design automatically feathers when the engine is shut down the P-82 will have "pitch locks" to prevent a high blade angle (and high load on the engine at low rpm) during starts. Because of the experimental nature of the prototype propeller this feature was not incorporated in the name of risk reduction. The result was that the blades were resting against their high pitch stop at the time of engine start. Fortunately the V-1710 was able to handle this and immediately upon starting the governor was able to position the blades at the desired low pitch stop.

- Vibration and Balance – The combination of manufacturing accuracy and stiffness of the blades resulted in a very smooth running propeller, however P-Force and aerodynamic interactions between the propeller and airframe required awareness and monitoring throughout the entire flight process.
- Acceleration during Takeoff – Several high speed runs down the runway were made to determine when the governor would start controlling propeller speed, all prior to the first flight. Satisfied that propeller speed was being satisfactorily controlled the first flight was attempted.
- First Flight – Goal was to immediately go to a safe altitude and begin a check of aircraft handling characteristics. There was significantly less pull to the left on takeoff, due to the much lower P Factor, a measure of the reduced inertia of the considerably lighter wooden blades. Dave says it reminded him of takeoff in a wooden bladed Spitfire.
- In-Flight Observations – Compared to the original 3-blade propeller, the wide chord 4-blade MT-Propeller climbs better, the greater thrust requiring a steeper climb so the limiting gear door speed of 150 mph would not be exceeded. A result of the larger prop on the P-51A was that the aircraft was aerodynamically destabilized, that is, it did not want to fly straight (this was also a problem on the early P-51B/C aircraft with 4-blade propellers, resolved by adding a dorsal fin ahead of the tail). Also, from the ground, the airplane sounds different when flying, more like the 4-bladed *Merlin* powered P-51s.
- In-Flight Vibration Survey – MT installed stress sensors at critical points on one of the blades and hub. These were transmitted wirelessly to a receiver on the airframe and recorded while the aircraft performed various maneuvers. In this was it was determined that there were no adverse harmonics, stresses or vibrations in the propeller when driven by the 12 cylinder V-1710.
- In-Flight Findings – The aircraft accelerated and decelerated better, the result of reduced propeller moment of inertia. To improve the responsiveness of the propeller to changing loads in flight the mass of the counterweights was slightly increased, as was governor pressure. In normal cruise the aircraft flew 5 to 7 knots faster at the same power settings and altitude, no attempt at a maximum level speed was attempted.

- In-Flight Feathering Test – This test was the final step in testing of the prototype. In August 2011, after successfully achieving all of the test objectives the high pitch stop was reset for full feathering and an “unfeathering” pump installed. The test plan was to climb to a suitable altitude over the airport, put the hydraulically operated gear and flaps down as needed for landing, and then cut the mixture to the engine. After reaching the full feather position, actuate the unfeather pump and see how long it would take for the engine to reach idle speed, at which point the mixture would be restored and normal flight resumed. A preflight ground test found that it could take up to 14 seconds to unfeather enough so that it was assured that the pitch was adequate to windmill the propeller and start the engine. While this was longer than desired, it was deemed acceptable. As such the test flight was made on August 8, and found that the propeller feathered in seven seconds, and took only two seconds to get windmilling.

Next Steps

With the prototype propeller proving the viability of the design the 110-hour Certification can begin. *ACE Allisons* is preparing one of the P-82E's V-1710-143(G6R) engines to perform the test. This engine will be first run on their dynometer so that its performance can be calibrated, enabling the use of rpm and manifold pressure to be correlated to propeller torque and horsepower, parameters required by the certification process. The engine and propeller will then be mounted on their test truck and the testing begun in the fall of 2011.

Certification and the 110-Hour Test Program

The P-82 is a "non-certificated" aircraft and is suitable for operation in the FAA's "Experimental/Exibition" category. At first blush one might think that no certification would be required since it is "Experimental", but that would only allow occasional flight for specific purposes. A feathering propeller is a major component on the aircraft and since this is a new design it is critical that it be vetted and fully qualified. Furthermore, once certified for the P-82 it becomes feasible to qualify similar propellers for other warbird aircraft, a benefit for the manufacturer.

Since MT Propellers is a German company they desired to seek certification through EASA, the European counterpart to the FAA in the US. Fortunately, the two agencies have agreed to each other's propeller certification requirements, in fact, the requirements are identical, word for word. An outline of the test requirements follows:

Ground Testing:

- 5 Hours at Takeoff Power
- 5 Hours of 10 minute Transients - Idle to Takeoff Power
- 50-Hours of Maximum Continuous Power and Rotational Speed
- 50-Hours of five-hour Idle-Takeoff-Cruise Cycles
- Functional Test for Governing Propeller, 1500 cycles across the full range of Pitch and RPM
- 50 Feather-Unfeather Cycles from Max Continuous Power

Flight Testing:

- Overspeed Test, at overspeed dive condition
- Vibration and Aero-elastic effects
- Flight Functional Tests

It is not necessary to demonstrate the "overspeed" capability of the P-82 propeller during the ground testing as this was accomplished during the prototype flight-testing on *Polar Bear*. Its V-1710 engine has a 2.00:1 reduction gear while the P-82E has a 2.36:1 gear. Even though *Polar Bear's* engine only runs to 3000 rpm, and the P-82E's to 3200 rpm, the prototype testing routinely operated the new propeller at 1500 rpm, well above the normal maximum of 1356.

Summary

While the program is still some months from conclusion, results to this point suggest that it is feasible to aggressively pursue difficult programs focused on maintaining, or returning to flight, important historic aircraft that are unique in today's world. Such projects are not for the faint pocketbook, but offer a great deal of satisfaction and the reward of seeing rare and important aircraft in their natural environment. Safety of flight for the people involved, the public on the ground, and the rare artifacts is paramount. Requirements and regulations may be daunting, but there are ways to work with them and carry on from the day when our fathers and grandfathers accomplished impressive engineering feats using only slide rules and pencils. When working with these old engineering artworks one can only marvel at their insights, knowledge and skills in creating such masterpieces in an analog and empirical world.

The modern MT-Propeller being readied for the P-82 will look and perform as the original, but yet be entirely different. Yet it is using WWII technology blades, manufactured on CAD/CAM milling machines, as are thousands of other modern turboprop aircraft. We have to appreciate the contribution to keeping Warbirds flying that offered by companies such as MT-Propeller, who are willing to use their unique expertise in support of these beautiful aircraft.

Dan Whitney
August 14, 2011
Orangevale, California