Development and Certification of Composite Propellers

Weight reduction and increased performance are probably the two most sought after traits in aviation. Having just returned from the Alaska Airmans convention, the hottest topic of discussion was the ability to reduce weight on aircraft and increase performance. It only makes sense since we're limited by our gross weight and every weight reduction adds to our useful load. This also translates to a safer aircraft as a lighter plane will out perform a heavy plane in every case. Shorter takeoff distances, greater rates of climb and safer landings are a few of the benefits of light and powerful aircraft. Weight reduction may be accomplished in many ways, although changing a metal propeller for a composite prop is one of the easiest and most effective. Normally a composite propeller will weigh 25% to 30% less than an aluminum prop and this translates to a weight savings of 15 to 50 pounds on GA single engine aircraft. Most pilots I know are really happy to save 5 pounds by changing the alternator or moving the battery and a propeller change may equal as much as 10 times this savings. Adding performance is the factor in the equation and this is not always as easy to accomplish. We're seeing more and more pilots having their cylinders "ported & polished" and changing their pistons to high compression to gain significant horsepower compared to their stock engines. This is very effective, but not always possible within STC and engineering parameters, and it's also not cheap.

Often an easier way to add performance is to change the propeller to a blade design more modern and suited to a particular aircraft. Using the Aviat Husky as an example, the original Hartzell 76" propeller is compatible with not only the Husky, but the Mooney, Cessna 172 and RV. This "combination" propeller works satisfactorily on all these aircraft, but excels on none. The Husky is a Utility aircraft and will benefit from a long, lightweight propeller, compared to the short 76" Hartzell. Replacing the Hartzell with a long, lightweight MT on this aircraft results in much shorter takeoffs, better climb, faster cruise and steeper descents. It's almost 20 pounds lighter and has no rpm restriction due to the non-vibrating composite material. This is only one example, but there is almost always an advantage to change to a propeller specifically designed for a particular type of aircraft.

So where did all the interest in composite propellers begin? Actually some of the very first composite designs were developed before and during the Second World War. Allied and Axis aircraft manufacturers were looking for the best combination of performance and light weight, their aircraft needing to fly long distances and carry large loads. The most notable propeller in this era was the composite propeller of the FockeWulfe 190 fighter. It was a combination of wood, epoxy, aluminum and a type of fiberglass that exceeded all performance of a standard aluminum propeller and was 30% lighter. It proved to be one of the most durable and was even repairable if the aircraft encountered a ground strike or had battle damage.

Modern designs of composite propellers descend directly from these earlier designs. The materials used today are remarkably similar to the originals, just with more development and variation in chemical make-up. Current composite propellers will fall into one of two categories, those made by molding and those made by CNC machining. In all cases the propeller hubs are made from aluminum (or rarely steel) and the following description of composite props will deal with blade design and manufacturing.

Propellers made by molding can also be separated into two categories, those with solid blades (like the Warp Drive Propeller) and those with foam center blades (ie. Hartzell). In both cases the propeller engineer calculates his blade design and then makes a blueprint for a mold to cast the blades. The mold is normally CNC machined and made in two parts that bolt together. When the mold is finished, the halves are bolted together, the proper materials are inserted into the mold (foam core, fiberglass or carbon cloth) and a liquid resin is injected into the mold and left until it has set. Then the halves are separated and the blade is removed.

The molding method is very efficient and consistent and produces a high quality blade, with or without a foam core. The biggest drawback is that the molds are very expensive will produce only one shape and size of blade per mold. Changing the design requires a complete new mold, which can cost in excess of $100,000. The blade length can be changed by inserting a “plug” in the mold, but the only change will be the length, nothing else. This technology leads to using the same blade for many applications as most manufacturers can’t invest in a shelf full of $100,000 molds. Hartzell has developed an excellent blade for aerobatic purposes and has had much success with this propeller. Unfortunately the high cost of production and the limited application for this design haven’t allowed application for many other aircraft.

Propellers made by CNC machining are produced in a very different manner. The blade is designed in the same way as a molded blade would be, but with one big difference, CNC machining allows an infinite number of changes at any time during manufacturing. Only the computer code must be changed and an entire new design will result. This allows the engineer to tailor the design to a specific aircraft with no cost or time penalty.

Once the design has been finalized, a blade “blank” is secured in the CNC milling machine. The cutters follow the code programmed by the designer and the result is a blade exactly to the specs of the aircraft. This method allows quick and effective test flying as the designer can order several blades with slight differences and test all of them without having to commit to a very expensive and time consuming mold production. If a design that should have worked proved to be less than expected, it’s a quick change to a new design and another test flight. This is particularly advantageous when developing a new aircraft with a new and untested power plant (similar to the Diamond Twin Star with the Thielert Diesel). MT Propeller Germany worked directly with Diamond & Thielert to develop a propeller that would accept the strong firing impulses of the diesel, produce the maximum performance with the power developed and reduce the weight of the heavier diesel engines. This effort took many different designs and was two years in testing before everyone was happy with final performance. If they'd been testing a molded composite propeller it would have taken years longer and cost millions more.

So how does this all begin? First, the designer must determine the desired characteristics of the new propeller. High speed aircraft want short and thin blades to minimize high speed drag and produce the best speed. Utility aircraft want longer, thicker blades to produce excellent take-off and climb while still allowing good cruise speeds. The number of blades a propeller has is also very important. If the propeller can't absorb all the engine horsepower and convert it to thrust then nothing will be accomplished. There are many considerations to the propeller diameter and blade count. One of the most important of these is blade tip speed. Long, high rpm blades create high blade tip speeds. If a blade tip approaches Mach .9 then the efficiency will begin to drop. A tip speed of more than .92 will begin to produce more noise than thrust and anything approaching 1.0 will have little or no performance at all. Noise also being an extremely important issue now, the slower the tip speed, the quieter and the better. This may lead to multiple blades in shorted length to absorb all the hp available from the engine while allowing for a quiet, efficient (high ground clearance) propeller. The designer must take all the parameters of the aircraft design into account and determine which blade will produce the most performance, give adequate ground clearance and pass all necessary noise and vibration tests required by the agency in charge of certification (FAA, EASA, LBA, etc.).

The actual testing process begins with a need from a manufacturer of airframes or a specific group of customers wanting to improve a new or existing design. Using the example of our recent MT Cessna 185 STC, you may get a good insight to the standard process of propeller development and STC certification.

The Cessna 185 is an excellent utility aircraft (some think the best in the world) and it performs it's role extremely well. It's used for everything from sport flying on paved strips to glacier flying in the Southern Alps of New Zealand, in wheel, ski and float configuration. The continental 300hp engine produces lots of reliable power and the original McCauley propeller has served everyone very well. However, the 185 has a few drawbacks that we thought we could eliminate. First, it's quite nose heavy when lightly loaded. This leads to the inability to three point the plane on landing and many pilots agree that this is the best and safest approach. The 185 is also one of the noisiest planes anywhere and this doesn't make for good relations with the neighbors or efficient use of the Continentals hp. The original 86" propeller qt 2850rpm is nearly supersonic in tip speed and a normal takeoff can be heard for many miles if conditions are right. This tips speed also lead to a great reduction in applied thrust, the only thing that makes the aircraft move.

Our objective was to develop a propeller that would first, be lighter, second, produce more thrust with a lower rpm and reduced diameter, third, produce much less noise and fourth, give better off airport durability.
The first step in the STC process is to see if what you develop for a propeller will really make the difference you expect. With this in mind, I worked with the engineers at MT and we decided on 5 different blade designs for both two and three blade test props. One standard straight blade with square tips, another with straight blades and round tips and a third, fourth and fifth in various shapes of a scimitar blades with square tips. We put my 1982 185 into experimental and began preliminary testing. Our first test was for static thrust. This would indicate the "0" airspeed thrust produced by each individual propeller with the same horsepower and under the same conditions. This is done by attaching the aircraft directly to a digital scale which is in turn, attached to a fixed object such as a tie down. We tested all the MT's and also the standard McCauley 86" 2 blade as well as the new 86" 3 blade "401". The static thrust was tested from 2400rpm to max static rpm possible. We left the propeller governor at 2850 for the tests, started at full throttle at 2400 and leaned for max thrust. We then increased the rpm in hundred rpm increments to the max the engine would produce. The long McCauley props produced good thrust up to 25500rpm and then started to fall off, producing about 12% less at 2800 than the high reading at 2550. The MT propellers were all from 82 to 84" and the produced similar thrust as the McCauleys up to 2550 but then increased to 2700 and leveled off at 2750. All propellers had reduced thrust at 2800. We then tested all propellers in climb to 5000 feet from sea level. We took off at 2700rpm, but reduced the rpm to 2500 for the climb. We were happy with the results and found the wide chord Scymitar MT to be the best of all propellers and exceeded the McCauleys by a good margin. We also were surprised that the 2 blade MT's produced almost the same results as the 3 blade MT's. We continued testing, checking the cruise speeds at both 5000 and 10,000, descent characteristics and landing ability. Naturally, the light MT's allowed full 3 point landings and more elevator control throughout the descent. The stall speed was also reduced due to the added elevator authority.

After two days of testing and determining the best of the MT's we decided to start the STC process with the two and three blade scimitar props. We also decided to apply for STC's for the Cessna 180, 182, 185, 206 T206, 210 & T210. We'd use similar propellers for all the models, the two bladders for hp's under 285, both two and three bladders for normally aspirated models of 285 or more and the three bladders for the turbo models. The STC process itself is quite involved and consists of several phases.
First a Project DER (FAA Designated Engineering Representative) will need to start with a call to the local ACO (Aircraft Certification Office of the FAA) to schedule a preliminary discussion or board meeting to discuss the potential of the modification. This meeting will determine the basis for the modification and if in fact the FAA will recommend the standard STC procedure or invoke the "change of product rule". If this rule is invoked it will mean virtually a total recertification of the aircraft. Naturally this is to be avoided if

at all possible. If they determine the change may proceed under normal STC rules, the normal process is as follows:

1. Submit a compliance checklist stating all the appropriate FAR's that will apply to the change. These changes will be complied with by testing, analysis, or combination of both. Analysis is always cheaper and normally quicker as well.
2. Develop a certification plan for complying with the FAR's. This will outline how the certification will be addressed. Flight tests, noise compliance, product durability, engine/airframe compatibility, and manufactures Type Certification for the propeller itself will be included.
3. A design data package will be also be necessary. This includes the part numbers of all items to be installed such as propeller, spinner, hardware, tachometer or other instrument changes, motor mount and may even include propeller governor changes if necessary.
4. Installation instructions for the new propeller combination will be written. This will list everything from uncrating to the final torque of the attach bolts.
5. Instructions for continued airworthiness must be included and these will note anything that must be accomplished during the life of the propeller. This will not only list what to do and any limitations that may exist but also where these instructions may be found, ie. Manufacturers website, S.B.'s, etc. (this portion of the STC will be approved by the maintenance division of the ACO which is separate from the Engineering division).
6. The POH or AFM must be supplemented to show the modification and any changes to the operation or weight and balance.
7. Upon acceptance of the checklist, cert plan and data package, a flight test plan will be developed and sent to the ACO for approval.
8. Upon approval of all these items, the ACO will issue a TIA (Type Inspection Authorization) which will allow the DER to proceed in the flight test process. The aircraft must have certified instruments, a current and actual weight & balance, recent pitot & static check, and be loaded to gross weight with most forward CG.
9. The actual flight test must be conducted by a Flight Test DER or an FAA test pilot. The testing procedure will include :
   Takeoff performance
   Climb performance
   Cruise speed
   Cooling compliance
   Vibration testing in flight
   V Dive test
   Balked landing
   Glide test
   Stall testing
   Ground clearance
   Noise testing if not available by engineering
   Icing compliance if required

10. Upon completion of flight testing, the flight test DER must complete a TIR (type inspection report). This report will indicate all the data compiled during the flight tests and show the compliance with the checklist and FAR's.
11. Lastly, the project DER will compile all the information and submit it as a finished package to the ACO for approval. This will include all the aspects of both flight testing and any analysis of compliance of performance, noise, or other requirements set forth by the ACO.
12. The ACO (divisions of: engineering, structural, propulsion, noise, flight test & systems) must agree to approve the application. They may approve it as submitted, return it for modification or reject it out of hand. Once approved, the ACO will issue the proper authorization for the installation of the propeller with the STC, Installation instructions, and continued airworthiness requirements.