GENERAL AVIATION TURBINE ENGINE (GATE) OVERVIEW

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Previous papers have mentioned various alternative powerplants that could be considered for future aviation use; among these, the turboprop (TP). While turboprops should not be the major part of this workshop, for completeness I will summarize the content of the GATE turboprop studies that were completed two years ago. Those studies were initiated not with the intent of supplanting some of the reciprocating powerplants that we have today but rather of defining the best opportunity for small turbine power plants. The GATE studies suggested that the 300-600 horsepower range was best for small turboprop engines.

As everyone knows, turbine powerplants are conventional in the large aircraft arena and, unlike the other engine candidates, the challenge is to develop fuel-efficient small ones at reciprocating engine prices. While some advantages (e.g., reliability, low maintenance, vibration-free operation, jet fuel) are relatively easily realized, engine cost and fuel inefficiency are problems. The main theme, then, of the GATE studies was one of reducing the manufacturing costs of small turbine engines without sacrificing the advantages.

Figure 1 shows the approaches that were investigated by the four study teams involved. Mainly they chose to simplify the engine: one rather than two centrifugal compressors, and one radial turbine rather than three turbine stages.

Another approach involved new manufacturing technology; ways of manufacturing small parts that are reasonably accurate and yield reasonable performance (not ultimate performance) but are substantially lower in cost. An example is making almost finished parts in one piece using powder metal techniques. The compressor might be manufactured that way. Another example is making small, cooled radial turbines with laminated sheets of super-alloy, powdered material, that have the cooling holes photo-etched into them.

When all the technology studies were done and the accompanying market analyses were complete, the conclusion was that it is indeed possible to reduce the cost of turbine engines by a factor of 3 using low-cost manufacturing techniques and increased production rates. In the interest of reducing engine cost, some performance was sacrificed. Yet we ended up with about a 20 percent predicted improvement in SFC over current technology turboprops. However, even this level of improvement does not match the low SFC of reciprocating powerplants--particularly those advanced concepts described earlier. The 20 percent better SFC and much lower weight of a turboprop does mean that if such a powerplant were installed in a resized small airplane, one could save between 10 and 30 percent fuel relative to existing recip engines, depending on different mission and airplane combinations. This is shown in Figure 2. The price of the aircraft would go down about 15 percent in the case of a high powered single, or 25 percent in the case of a normal size twin. The operating costs would decrease about 10 percent in the case of the single, and as much as 35 percent in the case of the twin. The turbine was not judged to be competitive in very small sizes such as the 140 SHP required for a turboprop version of a Cessna 172. It just simply could not achieve the performance required in that size category. So the advanced turboprop would only be a candidate for the higher end of the singles market and the multi-engine twins. These results, comparing advanced turboprops with current recip engines, are only part of the story of course. Comparison with the various hypothetical advanced internal combustion engines is equally important and such comparisons were made in a NASA in-house analysis.* Results showed the turboprop to be competitive only above 300 SHP. Above 300 SHP, all of these candidates are worthy of pursuit.

If eventually it turned out that the turboprop was the only viable solution, one might then ask "What would that do to the fuel situation?" I think that is a legitimate "what if" type question. The shaded portion of Figure 3 shows the number of engines that are subject to turbinization. In 1979, turboprops accounted for about 1/20th of the production of all aviation engines. Most of the piston engines, of course, were produced around the 200-300 horsepower size. The potential of a hypothetical GATE-technology turbine engine is such that it could replace about 30 percent of piston engine production. One can conclude, therefore, that the alternative IC engines are complementary in nature to the advanced turboprop. However, the question is "What will happen in the absence of alternative IC engines?" Figure 4 shows our projections. The current G/A turbine engines, although very small in number, actually consume more fuel than avgas-powered aircraft do. Even without a GATE Program, that trend is continuing such that in several years we expect that avgas will represent only about 35 percent of the total general aviation fuel consumption. If there were a GATE turboprop in the future, it would occupy some of the marketplace and eventually would reduce the avgas portion of the total market to something on the order of 25 percent. Of course, these estimates are very rough.

We heard previous comments concerning flying piston airplanes into airports where they do not have avgas. The other side of the coin is "What happens if you take a turbine-powered aircraft into one of the small, general aviation airports and you don't find turbine fuel?" That would become an even more interesting question if the GATE Program were actually to be implemented and become successful. The problems encountered are summarized in Figure 5 and arise from the lead in the gasoline. Lead forms deposits in the combustor. These are severe with extensive and continuous use of leaded avgas in turbine engines. Tests have also shown intergranular metal attack of the hot turbine parts, which is detrimental to the life of those parts. Also, because of the volatility, low boiling point, and flammability limits of avgas, turbine engines are likely to suffer some flight envelope and starting envelope restrictions. These restrictions are not judged to be serious if one were to just use this fuel on an emergency basis. And lastly, if an aircraft does not have an onboard fuel boost pump it would likely suffer vapor lock or fuel pump cavitation problems. But most of the turbine-powered aircraft, of course, do have boost pumps.

The real show-stopper is the lead. If you got the lead out, there's no reason you couldn't use avgas in turbine engines today. The current status, then, is that turbine engines can use avgas on an emergency basis. They are certified to do so, in fact, for between 6 and 150 hours per TBO. You can sometimes even use avgas on a semi-continuous basis. For example, to cold start the Allison 250 small engine when Jet B is not available, avgas is allowed in a one-to-two mixture with Jet A. In fact, that procedure

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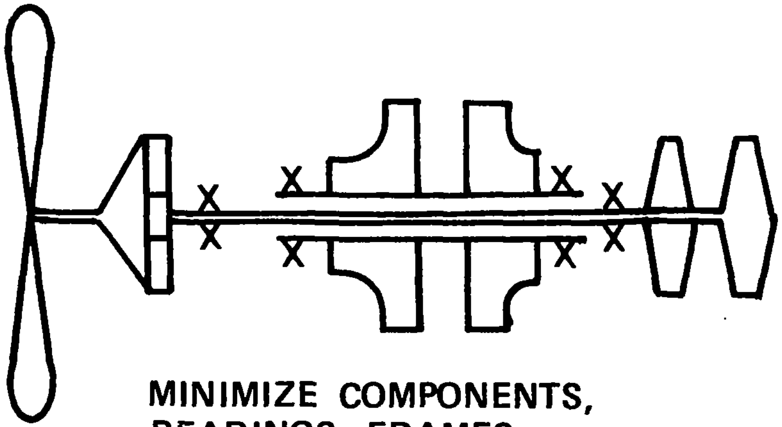
*Wickenheiser, T. J., et. al: Comparisons of Four Alternative Powerplant Types for Future General Aviation Aircraft. NASA TM 81584, Oct. 1980.

is recommended below 40^{o}F. Avgas use usually requires an adjustment of the fuel control. For example, the pilot may open a cowl access door and reset a fuel density knob. In most cases it's not a difficult task. In days past, the fuel control systems have been limited in their capability to tolerate avgas when starting engines or for accommodating throttle bursts. The modern electronic systems can tolerate the acceleration schedule of turbine engines using avgas considerably better than the past systems. So the real show-stopper, to say it again, happens to be lead.

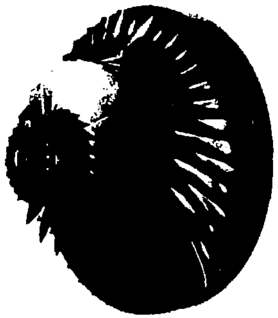
Finally, NASA has recently initiated combustor research for small turbine engines that addresses the capability to use the broad specification fuels we anticipate in the future. And I would add a recommendation that those studies be broadened into consideration of the possible use of avgas as well.

DESIGN SIMPLICITY



MINIMIZE COMPONENTS, BEARINGS, FRAMES

NET SHAPE INTEGRAL COMPONENTS



LOW-COST COOLED TURBINE

Figure 1. - GATE approaches to low cost.

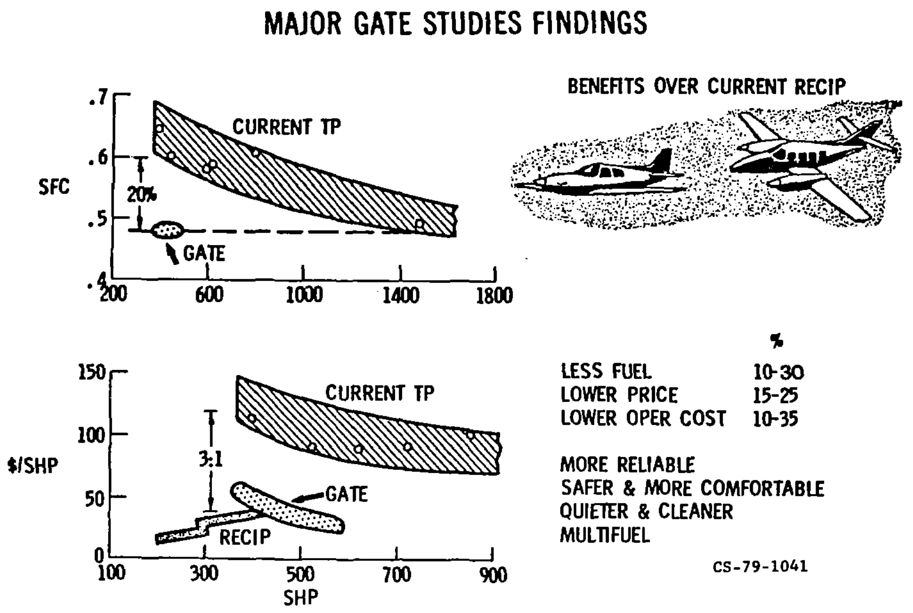


Figure 2.

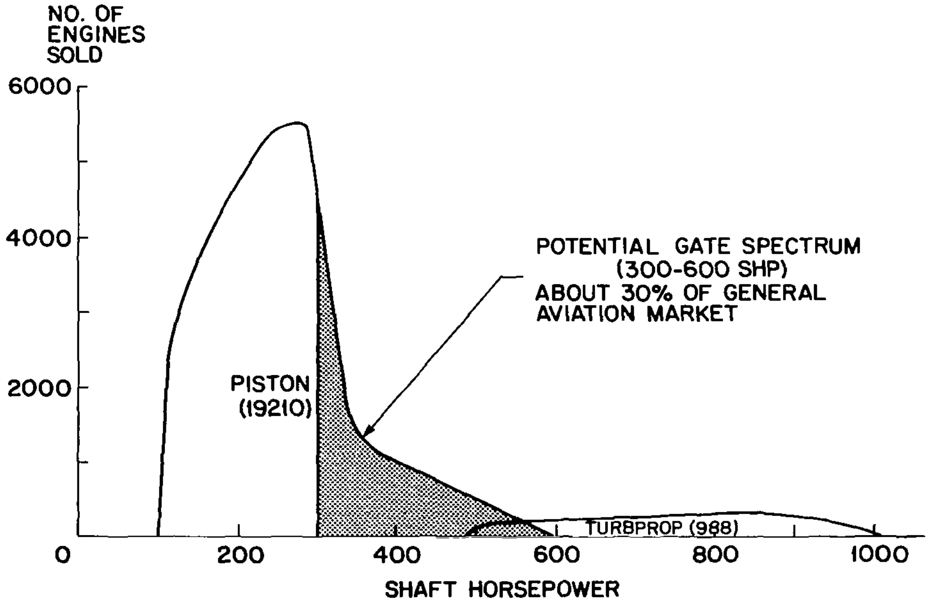


Figure 3. - Approximate engine sales in General Aviation, 1979. Data for U.S. manufacturers only, spares excluded.

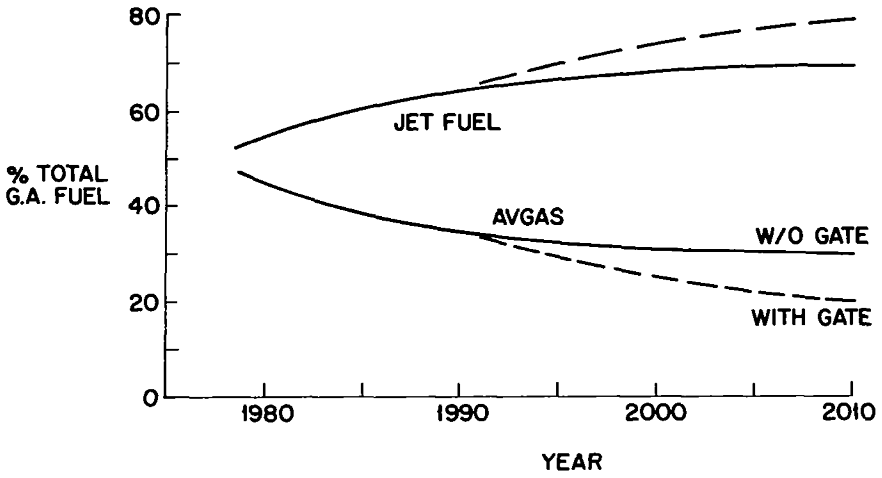


Figure 4. - Potential impact on General Aviation fuel.

TURBINE ENGINE TOLERANCE TO AVGAS

PROBLEM

- Forms lead deposits in combustor
- Intergranular metal attack of combustor and turbine by lead
- Shrinks flight and ignition envelopes (boiling/flammability)
- Requires fuel boost pump to prevent cavitation (usually onboard)

CURRENT STATUS

- Acceptable for emergency use (6-150 hr per TBO period)
- Sometimes permitted for semi-continuous use, e.g.,:
  - 250 gal. per 100 hr
  - Mixed with Jet A (1:2) for cold weather
- Usually requires density adjustment on fuel control
- Modern electronic fuel control systems accommodate AVGAS

FUTURE DIRECTIONS

- Combustor research aimed at heavy end of broad-spec fuels
- Recommend consideration of AVGAS as well

Figure 5.