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NASA PROPELLER TECHNOLOGY PROGRAM

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The vast majority of general-aviation aircraft manufactured in the United States are propeller powered (approximately 98 percent in 1978). Most of these aircraft use propeller designs based on technology that has not changed significantly since the 1940's and early 1950's. This older technology has been adequate; however, with the current world energy shortage and the possibility of more stringent noise regulations, improved technology is needed. Studies conducted by NASA and industry indicate that there are a number of improvements in the technology of general-aviation propellers that could lead to significant energy savings. New concepts like blade sweep, proplets, and composite materials, along with advanced analysis techniques have the potential for improving the performance and lowering the noise of future propeller-powered aircraft that cruise at low speeds. Current propeller-powered general-aviation aircraft are limited by propeller compressibility losses to maximum cruise speeds near Mach 0.5. The technology being developed as part of NASA's Advanced Turboprop Project offers the potential of extending this limit to at least Mach 0.8. At these higher cruise speeds, advanced turboprop propulsion has the potential of large energy savings compared with aircraft powered by advanced turbofan systems.

This paper summarizes NASA's program on propeller technology applicable to both low and high speed general-aviation aircraft, and outlines the overall program objectives and approach.

EFFICIENCY TRENDS

The free-air propeller is the propulsive device that has the highest level of inherent efficiency for subsonic aircraft. A comparison of the installed cruise efficiency of propeller-powered and turbofan-powered propulsion systems is shown in figure 1 for a range of cruise speeds. The installation losses included with the propeller-powered systems are nacelle drag and internal cooling airflow losses. For the turbofan-powered systems the losses include fan cowling external drag and the internal fan airflow losses associated with inlet recovery and nozzle efficiency. The installed efficiency available with current technology propeller-powered general-aviation (GA) aircraft ranges from about 70 to 75 percent for reciprocating powered applications to slightly over 80 percent for turboprops. The reciprocating system performance is slightly lower due to higher nacelle drag and large internal cooling airflow losses (ref. 1). The installed performance of the current lower speed turboprop systems remains high to about Mach 0.5; about this speed, efficiency falls off significantly because of large propeller compressibility losses. These propellers are generally designed with blades of thickness to chord ratios (at 75 percent radius) that range from about 5 to 7 percent. These rather thick blades, when operated at relatively high tip helical Mach numbers, are the main cause of these losses.

The advanced, high-speed turboprop shown in figure 1 is a new propulsion concept that has the potential of eliminating or minimizing compressibility losses at flight speeds to Mach 0.8. The level of potential installed efficiency projected for the advanced turboprop is considerably higher than that available with comparable technology high-bypass turbofan systems. At Mach 0.8 the installed efficiency of turbofan systems would be approximately 65 percent compared with about 75 percent for the advanced turboprop. This large performance advantage for the advanced turboprop may offer the potential for some attractive energy savings for future high performance business aircraft.

ADVANCED, HIGH-SPEED TURBOPROP

To achieve the performance potential of the advanced, high-speed turboprop, several new concepts and advanced technologies are required. (See fig. 2.) These new concepts and advanced technologies are discussed in references 2 and 3. The advanced propeller would be powered by a large, modern turboshaft engine and gearbox to provide the maximum power to the propeller with a minimum engine fuel consumption. Propeller efficiency would be kept high by minimizing compressibility losses. In the outboard part of the propeller blading, these losses would be minimized by using sweep and thin blade sections (2.4 percent thickness to chord ratio at 75 percent radius). Blade sweep would also reduce propeller source noise both during takeoff and landing and during high-speed cruise. In the inboard region an area-ruled spinner, in combination with an integrated nacelle shape, would be used to reduce the local velocities through the propeller to minimize losses in this region. A power loading (shaft horsepower divided by propeller diameter squared) about five times higher than that in current GA turboprops would be used to minimize propeller diameter and weight. Eight or ten blades would be required to maximize ideal efficiency during high-altitude, high-speed cruise. In addition to these advanced concepts a modern blade fabrication technique would be used to construct the thin, highly swept and twisted blades.

The program that NASA has underway to address the technology requirements of the advanced turboprop is shown in figure 3. The advanced turboprop project, part of NASA's Aircraft Energy Efficiency (ACEE) program, has the goals of a 15 to 30 percent fuel saving relative to turbofan-powered aircraft, a significant reduction in turboprop propulsion-system-related operating costs, and a cabin ride quality equivalent to the best turbofan-powered aircraft. The four major elements of the advanced turboprop project are shown in figure 3.

In the first, propeller and nacelle, technology work is currently underway in propeller aerodynamics, acoustics, and blade structures. The use of advanced aerodynamics concepts in the design of high-speed propellers is discussed in reference 2, and some recent wind tunnel results are presented in reference 4. A photograph of an advanced high-speed propeller model is shown in figure 4. This model, along with three others, was tested in the Lewis 8- by 6-foot wind tunnel. High performance and some significant noise reductions were obtained during high-speed cruise testing of these models. Some design study results on advanced propeller acoustics and blade structures are contained in references 5 and 6.

The second major project element, cabin environment (fig. 3), concerns the aircraft fuselage, which may be in the direct noise path of the propeller. The fuselage will have to adequately attenuate this noise source if the cabin environmental goals are to be achieved. Some recent analytical studies on fuselage interior noise control for high-speed turboprops are presented in references 7 and 8. Fuselage vibration is also an important cabin environmental consideration, and future advanced turboprop aircraft will have to be designed to minimize or control any undesirable vibrations.

The third major element, installation aerodynamics, is concerned with the accelerating, swirling, propeller slipstream passing over a wing. The technology challenge here is to design the overall aircraft to achieve the best combination of propulsion system performance and airplane lift-to-drag ratio, while maintaining adequate aircraft stability and control. Results from a recent experimental investigation of propeller slipstream wing interactions at cruise speeds near Mach 0.8 are presented in reference 9.

The final major element is the key mechanical components. Advanced design and packaging technology for the core engine, gearbox, and propeller will be required if an advanced turboprop is to reduce maintenance costs and improve reliability. A study of current-generation turboprop reliability and maintenance costs is presented in reference 10 along with an estimate of the potential improvements available from advanced technology.

Because the four major elements of the advanced turboprop project are highly interrelated, aircraft trade-off studies are being made to insure that these technologies are properly integrated and that progress is being made toward achieving the overall project goals. A summary of the progress made under NASA's advanced turboprop project is contained in reference 3. Also, papers that were presented at this conference by Gatzen, Jeracki, and Bober show the potential and some of the recent aerodynamic advances made as part of this project.

LOW-SPEED PROPELLERS

Current-generation propeller-powered GA aircraft operate at cruise speeds of Mach 0.5 and below. The technology trends that are projected for the propellers of these lower speed aircraft are shown in figure 5. The sketch in the lower left of this figure depicts current-technology propellers. These propellers are designed based on a trade-off of the four factors enclosed in the center circle. For many applications performance is traded off to meet noise and cost goals. Solid aluminum blade construction is used in most designs, and this can result in a potential weight penalty when compared with some of the future advanced materials which are being studied. The design trade-off on future advanced technology low-speed propellers may be altered because of two key factors - outside drivers and technology opportunities. The outside drivers are the high cost and fuel availability problems due to the energy shortage, the possibility of more stringent government noise regulations, and the need to retain or improve aircraft safety. In the technology opportunity area several new concepts are currently under study that show considerable performance and noise benefits. Advanced analysis techniques will make it possible to better understand propeller and nacelle aerodynamics and acoustics for additional benefits. Also, lightweight high-strength composites show considerable promise. When these outside drivers and technology opportunities are applied to future advanced technology propellers, the design may be altered to optimize performance to a lower noise goal using lightweight composite blades of advanced shape. This may result in a small propeller cost increase; however, this penalty should be more than overcome by the large potential performance and weight advantages. An advanced technology low-speed propeller may resemble the design depicted in the sketch on the upper right of figure 5. Some of the advanced features incorporated in this design are blade sweep, proplets (propeller tip device), advanced airfoils, composite blades, and improved integration of the propeller and nacelle.

The NASA research program that addresses the projected technology trends of low-speed GA propellers is summarized in figure 6. A cost-benefit study that evaluates the effect of advanced technologies on low-speed propellers is being conducted by the McCauley Accessory Division of the Cessna Aircraft Company. The NASA Langley Research Center is sponsoring two grant programs on reducing propeller source noise. MIT is evaluating several approaches for reducing noise while optimizing performance (refs. 11 and 12). In a complementary program Ohio State University is evaluating an alternative noise reduction approach in a flight test program. In the propeller performance area, Purdue University, under a NASA grant, is involved in a program to investigate several advanced concepts that show considerable potential for improving propeller performance. In addition, the current low-speed propeller aeroacoustic design methodology is being evaluated and enhanced through a cooperative program between Ohio State University and Lewis.

General-aviation propellers are usually designed as separate propulsion components without properly accounting for the aerodynamic interaction between the nacelle (or fuselage) and the propeller. A program is underway at Mississippi State University to develop technology that will allow the propeller and nacelle to be designed in a more unified approach. This program should lead to improved overall propulsion system performance for general-aviation aircraft.

Propeller dynamics and aeroelastics can be serious design limitations for both current and future advanced low-speed propellers. To better understand this important area, NASA is sponsoring a research program at Pennsylvania State University (ref. 13). More detailed information on NASA's low-speed propeller research is contained in individual papers given by Keiter, Green, Korkan, and McCormick at this conference. A summary of the Purdue University research program on advanced performance concepts is shown in figure 7. This program, under the direction of Dr. John Sullivan, includes analytical and experimental research on such new concepts as proplets (tip devices) and swept blades (ref. 14). A new swept lifting line analysis program is being developed at Purdue, and they are verifying this analysis and determining the performance potential of advanced concepts through subscale propeller wind-tunnel tests using some improved test techniques. These new techniques include the laser velocimeter system shown in figure 7.

The approach being used by Mississippi State University to develop improved propeller-nacelle integration technology is shown in figure 8. They have conducted an extensive search of the propeller literature to assist in evaluating potential loss mechanisms and to see which of the results apply to modern GA propeller-nacelle geometries. Mississippi State also plans to conduct full-scale propeller wind-tunnel tests (in the Langley full-scale tunnel) in combination with analytical studies to develop the improved propeller-nacelle integration technology. This research should lead to better overall propulsion system performance for general-aviation propeller-powered aircraft.

In addition, to the advanced, high-speed propeller wind-tunnel test program discussed earlier, NASA is also testing lower speed GA propellers. A 5-foot-diameter model of one of these low-speed propellers is shown in figure 9. This propeller, along the with three other designs, was tested in the Lewis 10- by 10-foot wind tunnel to compare measured performance with analytical predictions. Results from this comparison will be used to develop enhanced analytical prediction procedures for this category of propeller.

CONCLUDING REMARKS

The world energy shortage has led to the need for more fuel efficient GA aircraft. Propeller-powered propulsion, with its inherent high level of efficiency, remains an attractive propulsion concept. Current GA aircraft are limited to maximum cruise speeds near Mach 0.5 because of propeller compressibility losses. The NASA research program on these lower speed propellers offers the potential of significant performance improvements and noise reductions through the development of advanced concepts and new analytical design procedures. Extending the current cruise speed limitation to at least Mach 0.8, with a large potential fuel saving compared with turbofan powered aircraft, may be possible with the technologies that are being developed under NASA's Advanced Turboprop Project.

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INSTALLED CRUISE EFFICIENCY TRENDS

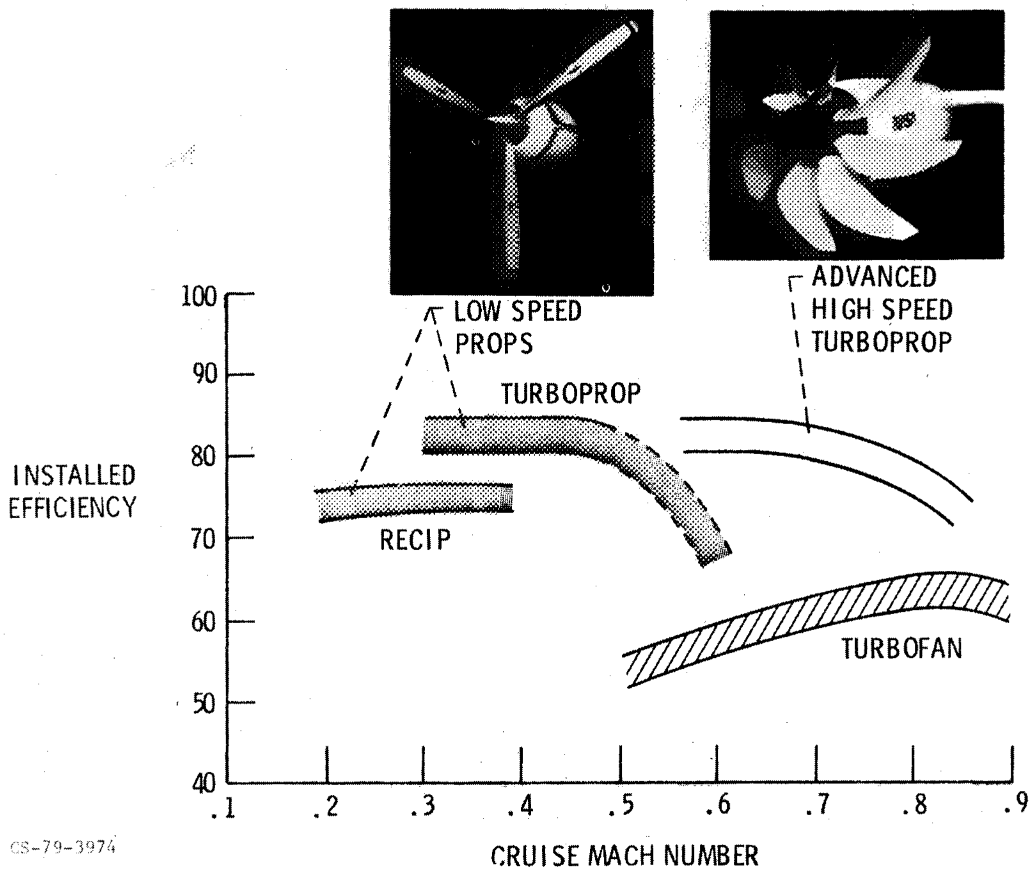


Figure 1

ADVANCED TURBOPROP PROPULSION SYSTEM

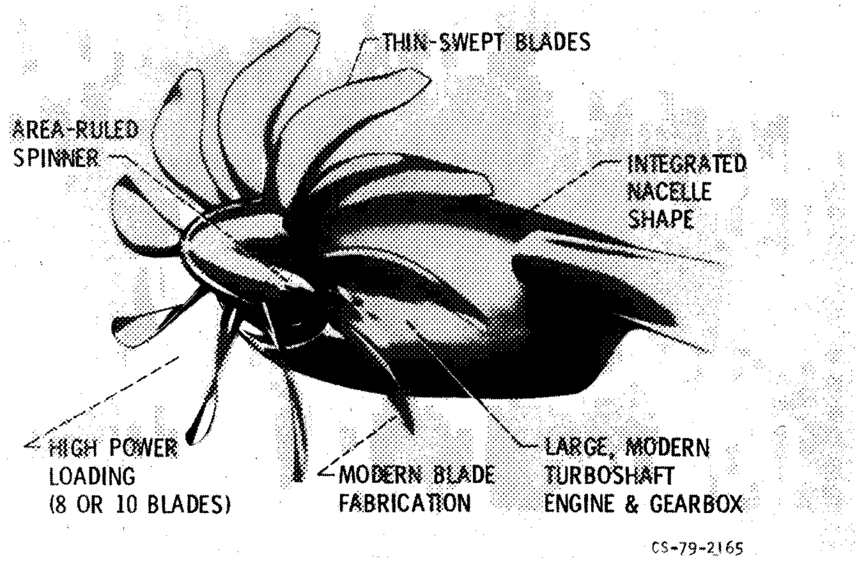


Figure 2

ADVANCED TURBOPROP PROJECT

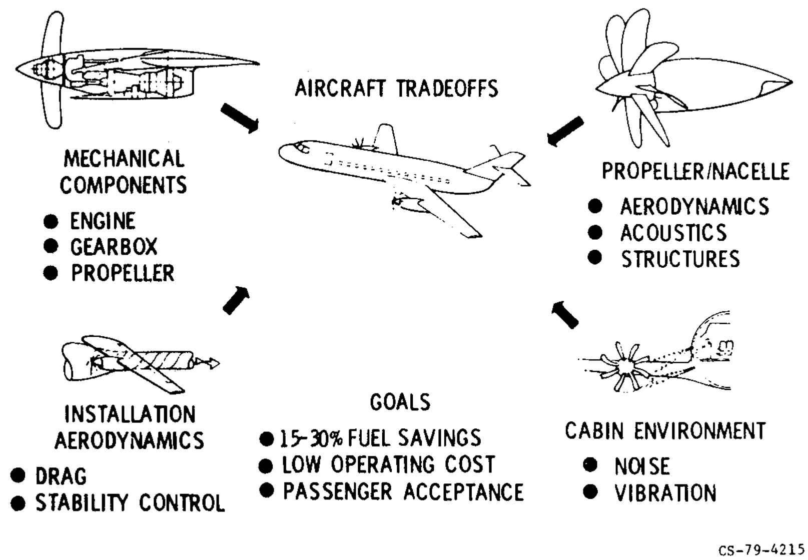


Figure 3

HIGH SPEED PROPELLER WIND TUNNEL MODEL

Figure 4

LOW SPEED PROPELLER TECHNOLOGY TRENDS

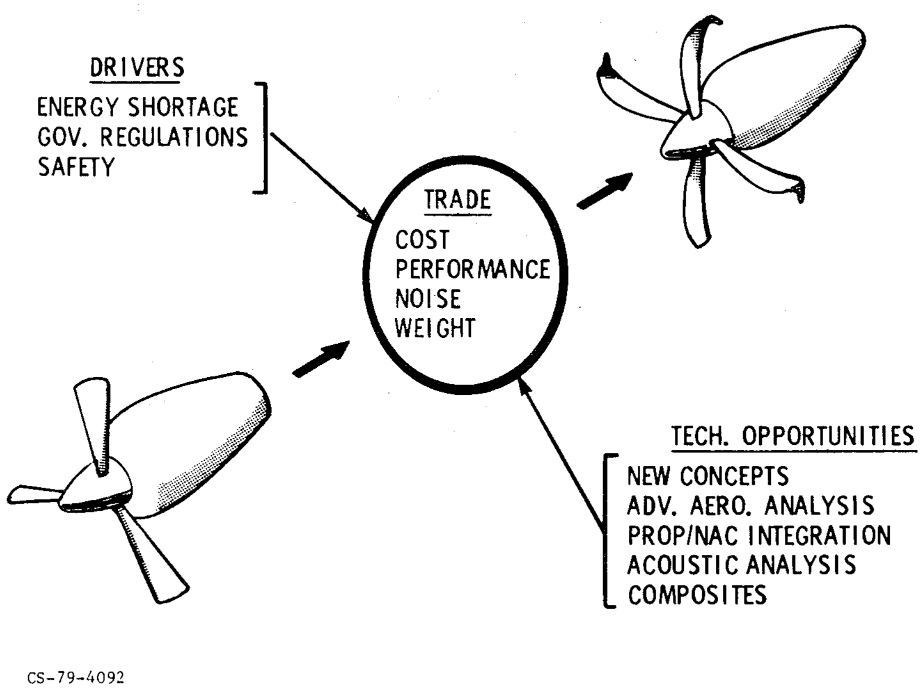


Figure 5

LOW SPEED PROPELLER RESEARCH PROGRAM

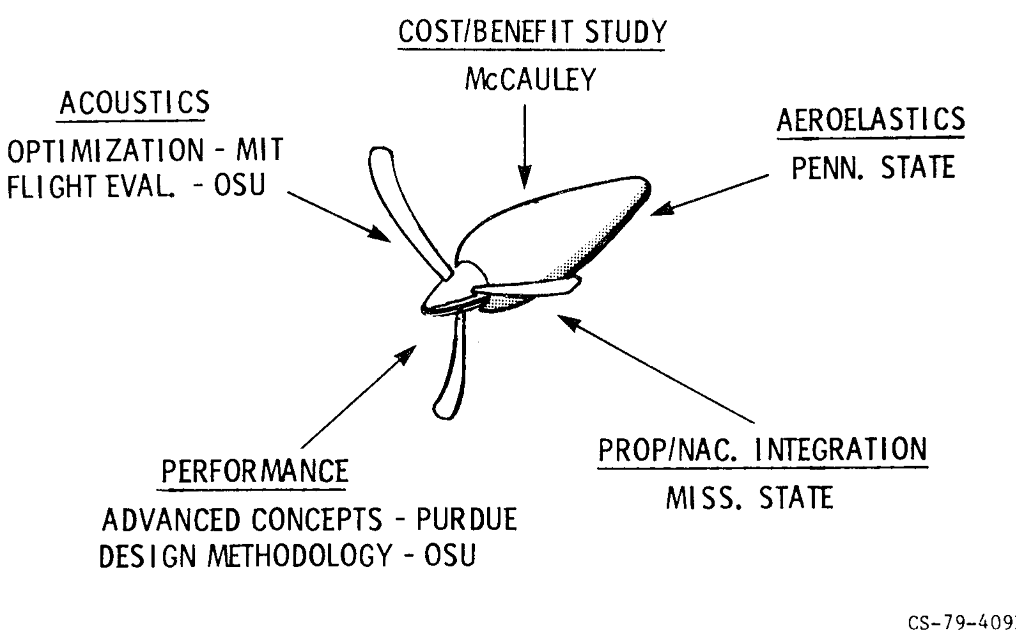
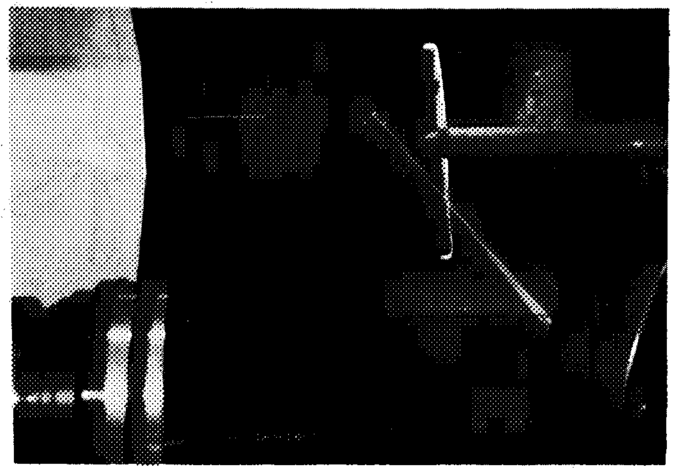


Figure 6

ADVANCED PERFORMANCE CONCEPTS



PURDUE UNIVERSITY

- NEW CONCEPTS
  - PROPLETS
  - SWEPT BLADES
- SWEPT LIFTING LINE ANALYSIS
- IMPROVED TEST TECHNIQUES

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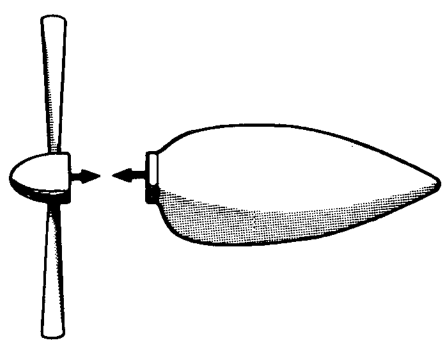
Figure 7

PROPELLER NACELLE INTEGRATION



MISS. STATE

- EVALUATE LOSS MECHANISMS
  - LITERATURE SEARCH
  - WIND TUNNEL TESTS
- DEV. ADVANCED INTEGRATION TECH.

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Figure 8

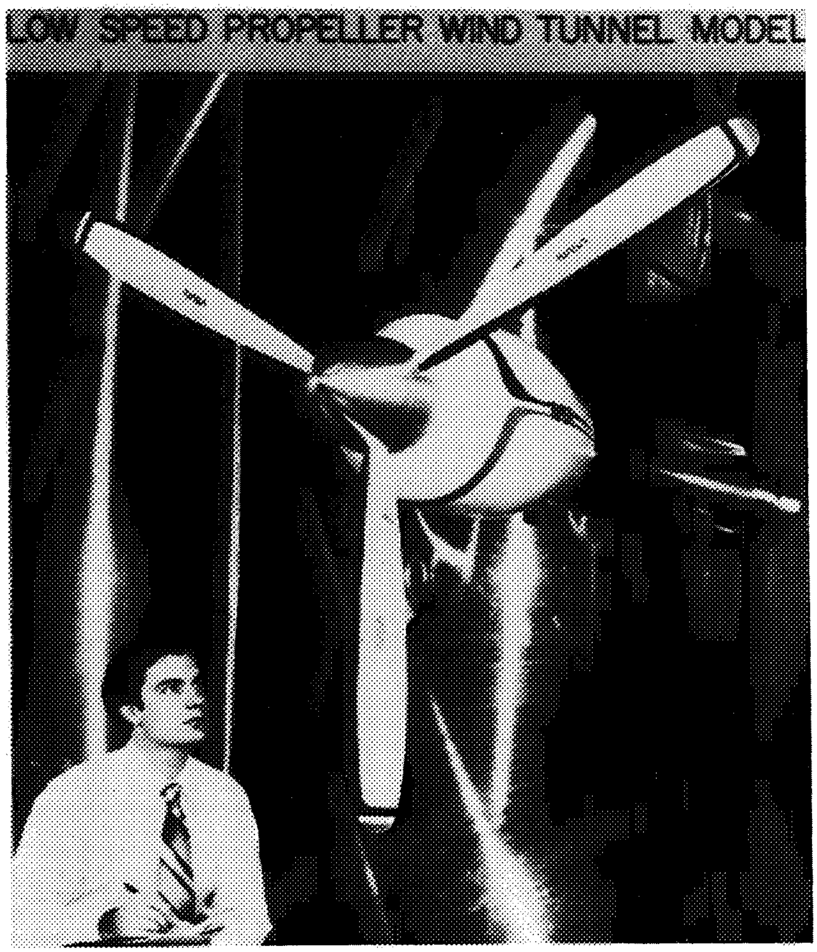

Figure 9