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NASA Research in Aeropropulsion

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INTRODUCTION

The activities of NASA in the field of aeronautics are oriented around three broad objectives: seeking to maintain and improve a safe , economically viable, environmentally acceptable air transportation system including both commercial transports and general aviation; second, helping to strengthen U.S. industry in an era of challenging international competition; and third, contributing to the aviation capabilities of all three military services. NASA, of course, does not design or operate such aircraft; its role is to perform research and technology activities that will enable industry to build improved vehicles. Propulsion, as one of the key elements of an aircraft, is the subject of a major part of this research. The Lewis Research Center has the responsibility within NASA for advancing aeropropulsion technology, and the emphasis in this paper is, therefore, placed on Lewis activities. It should be noted, however, that other important propulsion-related work is also performed at other NASA centers (e.g., Langley is active in inlets and scramjets).

The first portion of the paper reviews representative R&T activities that are focused on various vehicle applications (Fig. 1). In each case one or more relevant propulsion programs is discussed as an example of a continuing effort to improve factors like efficiency, emissions, performance, cost, etc. A second section will discuss some interesting new technologies that have broad application.

COMMERCIAL AIRCRAFT

Subsonic Transports

Consider first the familiar subsonic airliner, such as the Boeing 707 shown in Fig. 2. This kind of vehicle, with the many more-modern models now in service, is the backbone of the commercial air transportation system. The availability of short travel times and comparatively modest fares has affected the way business is conducted and, indeed, influenced the shape of our entire contemporary society.

With the help of increasingly more-productive and more-efficient aircraft, the airline industry has experienced enormous growth. Nevertheless, at the present time, new urgent demands on airplane technology arise from two sources--environmental protection and energy.

In the environmental area exhaust emissions control has long been a major concern. However, there has been much progress and, at present, it is not considered a critical factor. In fact, emissions by aircraft are a very small factor in the context of the total pollution scene within the country. On the other hand, the noise generated by aircraft is not so easily dismissed.

The problem of aircraft noise has been with the commercial sector for quite awhile, and is aggravated by more frequent flights, more powerful jet engines, and more residences in the proximity of airports. Increasingly militant objections are being expressed by the affected citizens. These objections have, to some extent, limited the growth of the civil aviation sector and are expected to continue as a major influence. Some communities have set curfews on airports at night. Others have disallowed the building of new airports. Because of constraints such as these, the effective use of aircraft is inhibited and commercial investment in new aircraft that could emerge, such as dedicated airfreighters, has been discouraged.

In response to this problem, NASA has had numerous programs aimed at reducing the noise generated by airplane engines. Fortuitously, the problem has been mitigated in recent years by the successive development of low-bypass-ratio, and later, high-bypass-ratio turbofans. Although the principal motivation for these engines was better efficiency, they were also inherently quieter. By contrast, the older engines, which are still in widespread use, seem especially objectionable. Consequently, NASA several years ago conducted the so-called Refan program to show how an existing commercial engine (in this case it was the JT8D, which powers the 727, 737, and DC9 airplanes) could be quieted by modifying the fan and by incorporating sound-absorbing material within the flow ducts. Fig. 3 is a picture of the modified engine on a test stand. This program went through a flight activity with McDonnell Douglas, using a DC9 with refanned engines provided by Pratt & Whitney (Fig. 4). The results showed that the noise level could be reduced dramatically by this technique. In fact, this technology is now being applied commercially in the form of the DC9 Super 80 by McDonnell Douglas (Fig. 5). More than 100 orders have been received for this aircraft, which is substantially quieter than its predecessors. It uses a derivative of the Refan engine that is being produced by Pratt & Whitney.

Many other programs are underway as part of NASA's continuing effort to develop technology that will aid in further reducing the aircraft noise.

NASA recognized sometime back that the high cost and limited availability of fuel represent critical threats to the viability of the commercial air transportation industry. One approach being studied is to modify the engines so that they can utilize fuels whose properties are not so tightly specified. This would broaden the sources of supply, possibly even including nonpetroleum sources such as shale oil or coal. But the major thrust of the NASA program is to reduce the consumption of fuel by the engines. The principal activity in this area, known as the ACEE (Aircraft Energy Efficiency) program, was started about 4 years ago and is directed at possibly cutting the fuel use of these transports by a factor of two. There are three major propulsion parts of that program (as indicated in Fig. 6). The near-term activity is called the Engine Component Improvement program (ECI) and is directed at derivative versions of the present generation of engines. The Energy Efficient Engine is a mid-term program with perhaps as much as an 18 percent fuel saving. The long-term program promises a fuel saving as much as 30 percent or more with an Advanced Turboprop. The cited fuel savings are relative to current engines installed in subsonic aircraft and flying on a mid-range mission.

The near-term ECI program involves three engines manufactured by Pratt & Whitney and by General Electric, who provide the majority of the engines for subsonic transports. The engines are the JT8D, JT9D, and CF6, the latter two being the engines that power the large wide-bodied jets. The objective here is to make modifications within the engine that do not represent major changes in the design but that could reduce the fuel consumption by up to 5 percent (which is highly significant to the airline operators). Example techniques include tightening up the clearances within rotating parts, reducing the amount of cooling air, and modifying the design of some components to improve efficiency. This program is nearing completion and has been deemed by the total industry, including the airlines, the engine manufacturers, and the airframe manufacturers, to be highly successful. Many of the concepts that were identified and explored in this program already are being incorporated into the production engines.

The mid-term program is the Energy Efficient Engine (Fig. 7). These are major contract efforts with both Pratt & Whitney and General Electric. The total program is about $200 million. It involves laying out the technology for the next generation of engines that would be developed in the mid to late 1980's. The techniques that provide the potential of attaining the 18 percent fuel reduction as compared with present engines are multifold. They include higher cycle pressures (as high as 40 atmospheres, compared with 20 to 30 atmospheres in present engines), substantially improved components, higher temperature hot-end components, such additional components as mixers, ample use of composites throughout the engines, advanced control systems which will allow the engine to be tuned throughout its flight path, and the like. Fig. 8 shows the engine designs that have evolved. This five-year program is presently at its midpoint. Progress to date has been very satisfactory.

The third element, which is the long-term, high-risk program, is the Advanced Turboprop. The objective here is to explore what one might be able to do by going back to propeller systems which have a much-improved propulsive efficiency compared with turbofan systems. The principal challenge is to develop the technology that might allow such propeller systems to be utilized in an aircraft that could operate in the same altitude and speed range as present subsonic jets. The type of propeller required to provide this capability is quite different from those of the past (Fig. 9). Noteworthy is the large number of blades used so that the diameter is moderate, despite the low air density at high altitudes. The blades are very thin and are highly swept. This sweep is used to maintain a high efficiency in the tip region where local Mach numbers become supersonic. It also serves to lower the cabin noise level, as propellers are inherently noisy from a passenger standpoint.

The initial phases of this program have established that the aerodynamic performance of the blades is quite acceptable. However, there are still many problems of structures and aeroelasticity that must be addressed in larger sizes. The model shown in Fig. 9 is only 2 feet in diameter, whereas the full-scale propellers would be in the 10- to 15-foot range.

Supersonic Transports

Consider now a much higher-speed form of commercial transportation, the supersonic transport (Fig. 10). The appeal of this type of aircraft to a sizable portion of the traveling public has been demonstrated by the Anglo-French Concorde. However, it suffers from several problems that resulted in this country not undertaking the development of such an aircraft: noise and fuel economy. Also, overall airplane economics are questionable. Nevertheless, Congress has deemed it important for this country to continue research in the area of supersonic transports so that, should a decision ever be made to embark on its development, the technology will be there. Accordingly, NASA has a continuing program directed at technology for supersonic transports which includes materials, structures, aerodynamics, and propulsion. Propulsion is obviously the key ingredient for such a high-thrust vehicle as a supersonic airplane.

The diverse requirements of a civilian SST, such as low noise, good efficiency at subsonic conditions, and outstanding efficiency at supersonic conditions, force the designer to consider a variety of alternative engine systems. An approach that is presently receiving much attention is the variable cycle engine. The features of a variable cycle engine are as follows: during takeoff, subsonic flight, and landing, the engine would operate like a turbofan, because the jet velocity would be low and hence the noise would be low. During supersonic flight, it would operate like a turbojet to give the very high jet velocities needed for efficient operation under supersonic conditions. Hence, there is interest in devices that are capable of changing their modes of operation to best suit the needs of each part of the flight.

NASA has major analytical and experimental programs underway with both Pratt & Whitney and General Electric to study various concepts for variable cycle engines. Breadboard engines are being used to examine some of the unique components and technologies required.

Fig. 11 shows such an engine on the test stand. The features of this General Electric engine include internal valving, in order to shift the flow from one mode of operation to another, and multistream exit jets (at least two streams) with the velocities adjusted to minimize noise. (Incidentally, at the right of the picture may be seen a Laser Doppler Velocimeter (LDV) instrument which is used to measure the velocity in the jet plume emerging from the engine. This will be mentioned again later in the paper.)

COMMUTER AIRCRAFT

The final commercial transport category to be discussed is commuters. This term refers to smaller aircraft that can carry 20 to 50 passengers. They are almost entirely turboprop aircraft, such as the one shown in Fig. 12. The current increased interest in commuter aircraft has been the result of the recent deregulation of the airline industry. This has permitted the certified trunk carriers to withdraw from their less profitable routes, often leaving little or no service to many smaller cities. In their place, the commuter airlines have sprouted, offering frequent departures in smaller, more-economical aircraft. NASA is looking into what technologies might be useful to the newly important commuter aircraft industry. As a starting point, broad studies of airplanes and the associated propulsion systems are being performed for typical commuter missions. Fig. 13 shows some of the unusual configurations that have been evolving from NASA-sponsored studies with industry. Noteworthy is a general tendency to put the propulsion system toward the rear of the aircraft so that the noise and vibration of the propellers would not be transmitted into the cabin. One concept uses pusher propellers; others use the standard forward configurations. Unusual wing arrangements and the use of canards are also being contemplated.

The technology needs for this kind of aircraft are still being studied. If appropriate, NASA will initiate a major program in the future.

GENERAL AVIATION

The next part of this paper deals with the subject of general aviation, which is an extremely important part of civil aviation. In fact, aircraft sales and passenger carriage approach those of the commercial sector. There are many more aircraft on the general aviation scene, with about 85 percent of these being used for business. Despite the popular impression, recreational flying is only a small portion of the total. Thus, general aviation truly is a vital part of our total transportation system.

General aviation is faced with problems similar to those of commercial aircraft:

(1) Safety and reliability
(2) Environment
    (a) Community noise
    (b) Cabin noise and vibration
(3) Fuel
    (a) Aviation availability
    (b) Consumption

Safety and reliability head the list in recognition of the poorer record of general aviation as compared with the commercial transports. NASA is involved in several programs to try to improve that situation. The second and third items are repetitions of the same sort of problems affecting the commercial sector.

With regard to community noise, although these small airplanes tend to be relatively quiet, they also frequently operate from small airports in suburban or rural areas where the natural noise level is low and where this additional noise source is especially objectionable. In addition to the community noise, passengers and crew experience a lot of noise and vibration particularly in the smaller aircraft. (Any reader who has flown some of the small piston-engine aircraft is familiar with these defects.)

Fuel shortages are of particular concern to general aviation because its image of being a frivolous energy consumer makes it susceptible to diversion of fuel to supposedly higher-priority users. Furthermore, it relies heavily on aviation gasoline, which represents such a limited market to oil refiners that they can be tempted to drop production during crises situations; this did occur recently.

There are many types of aircraft that fall within the broad category of general aviation. For the purposes of this paper they can be conveniently categorized by engine type (Fig. 14). Many of these aircraft operate with intermittent combustion or IC engines (i.e., piston engines). Of the larger general aviation aircraft quite a few are turboprops. The fairly large number of high-speed, high-altitude aircraft known as executive jets are powered by turbojet or turbofan engines. NASA-Lewis is looking at the needs of each of these engine systems.

Fig. 15 shows one of the Lewis test cells with a piston engine installed. In general, the experiments are directed toward achieving a better understanding of the fundamentals of combustion in these kinds of engine systems, and trying to determine techniques to reduce the fuel consumption as well as reducing emissions.

Additionally, alternative engines are being studied that might have an advantage over the current piston engines. For example, diesel engines are being looked at rather carefully (Fig. 16). Current diesel engines are too heavy, but recent studies have shown that advanced technologies such as ceramic piston heads and substantial turbocharging can reduce the weight of these engines significantly. If the weight does come down, the superior fuel economy of a diesel cycle can be exploited.

Another alternative concept is the rotary engine. It offers the potential of smooth operation, simplicity, and fairly low weight.

NASA is also continuing its studies of turbine engines, including an extension into the lower power range typical of pistons as well as improvement of the somewhat larger turbine engines that are currently used in the executive jets (Fig. 17). A recently completed program called QCGAT (Quiet, Clean General Aviation Turbofan) looked at the applicability of the technology of large transport engines to these smaller turbofan engines, particularly in relation to noise. There were two contracts put out, one with Garrett AiResearch and one with AVCO-Lycoming. Preliminary studies were followed by the building and testing of experimental engines. Fig. 18 shows one of these engines on a test stand at Lewis for evaluation. It has about 4000 pounds of thrust and could be used on an aircraft the size of a Lear Jet for high-altitude, high-speed operation. It is dramatically quieter than the current engines being used.

NASA has an extensive program for the improvement of propeller systems for many applications. The high-speed efforts were described earlier. Additional work is aimed at general aviation propellers, such as the one pictured in Fig. 19. The goals of such technology involve reducing the cost of the propellers, improving their efficiency, which can be translated directly into fuel consumption, reducing the noise, and reducing the weight. As suggested in Fig. 20, advanced designs may utilize such techniques as swept blades or tip-mounted devices called winglets, which have been applied successfully to aircraft wings. (See, e.g., Fig. 17.)

MILITARY AIRCRAFT

As the nation's principal R&D agency for aviation, NASA generates technology that is applicable to military as well as civilian aircraft. Some examples of the work are offered here.

Rotorcraft have become essential ingredients of the modern military force structure. (Of course, they are seeing increasing use for various civil applications as well.) A probable trend for the future is a shift to higher flight speeds for enhanced invulnerability and productivity. Such concepts as the X-wing configuration of Fig. 21 might be utilized. One consequence of these concepts is a decoupling of the power needed for vertical takeoff from that needed for forward flight. For example, the rotor may be stopped to form a fixed wing, and a separate propeller or fan used for horizontal thrust. A single propulsion system that can alternately drive a rotor or a fan might then be desirable. Convertible propulsion systems of this nature are now under study. One approach that utilizes gears and clutches is sketched in Fig. 22. Wind tunnel tests of an early version of this device are being planned in a joint program with DARPA.

For still higher speeds and/or longer ranges, vertical takeoff and landing (VTOL) aircraft are being considered, with particular emphasis on Navy missions. One propulsion concept, out of many that have been studied, is illustrated in Fig. 23. Two tandem fans, each with its own inlet, are employed to obtain high airflow capacity without an increase in frontal area. Tests of these unique inlets and nozzles are being conducted.

Another example of unusual inlets and nozzles is pictured in Fig. 24. In order to reduce radar and infrared detectability, unconventional shapes and placements of these components are being investigated for high-performance Air Force aircraft. Nozzles with thrust-deflection capability are also being investigated for enhanced maneuverability.

EMERGING TECHNOLOGIES

In addition to the vehicle-specific research described above, NASA maintains a continuing, general program to advance the state-of-the-art of all of the propulsion-related components and disciplines (Fig. 25). But rather than to describe them here, it is the intent of this section to comment on some new areas of technology. The point here is that several major technological advances were made in the 1970's that are not directly related to, but which could have a large impact on, propulsion. Utilizing these in propulsion research in the 1980's could lead to major improvements across the board in the propulsion systems of the 1990's.

Three general areas are:

(1) Advanced materials and processes
(2) Computer revolutions
(3) Advanced electronics and optics

The major advances that have been emerging in the area of materials include such things as powder metallurgy (which opens the door to a whole, vast, new arena of alloys), single-crystal and directionally solidified turbine blades (which enhance the temperature level of turbine engines), and ceramics (which potentially offer lower cost as well as higher temperature capability).

Advances in computers have been so rapid and widely employed that the term "computer revolution" is often used. These high-speed, sophisticated "number-cruncher" machines enable the engineer to solve problems now in the areas of fluid mechanics or structures that were impossible just a few years ago.

And, finally, advanced electronics, microminiaturization, and the development of advanced optical techniques enable entirely new approaches to engine control. In some proposed engines it is necessary to control 10 variables at once. This is beyond the capability of the conventional controls, and advanced control systems are essential to these concepts.

In another application these electronic and optical improvements open the door to advanced instrumentation that allow the measurement of flow through such moving components as turbines and compressors, without having to insert physical probes that could disturb the flow by their presence.

Several figures are offered to illustrate each of these emerging-technology categories:

Fig. 26 shows one application of ceramics. By placing a thin, insulating ceramic coating around a turbine blade, the combustion temperature of the cycle can be increased, which is very desirable, without any deleterious rise in the metal temperature of the blade. The key enabling technology is the bond coat between the base metal and the external ceramic. As the technology of bond coats evolves, ceramic coatings will be applied to all hot sections of engines.

Another example is in the computer area. As shown in Fig. 27 high speed computers allow visualization techniques that accurately predict the flow, including the boundary layer, through subsonic ducts. Vector analysis can yield pictures of cross flows within ducts. Contours of pressures and temperatures can be computed. The whole area of advanced structures and the prediction of vibrations and natural frequencies and so forth is just opening up using this new tool.

The third area mentioned was electronics and optics. Fig. 28 is a picture of the previously mentioned LDV system being used here to measure the flow within a rotating cascade without having to put a probe inside. This nonobtrusive technique is considered a breakthrough in how one can measure what is going on within these complicated machines.

FINAL REMARKS

This paper has reviewed some of the problems and opportunities confronting the aviation industry. This has been employed as a means of describing a number of NASA programs that address the associated propulsion technology needs of the future. Advanced technologies will be coupled with new propulsion concepts to provide greatly improved air transportation in the years to come.

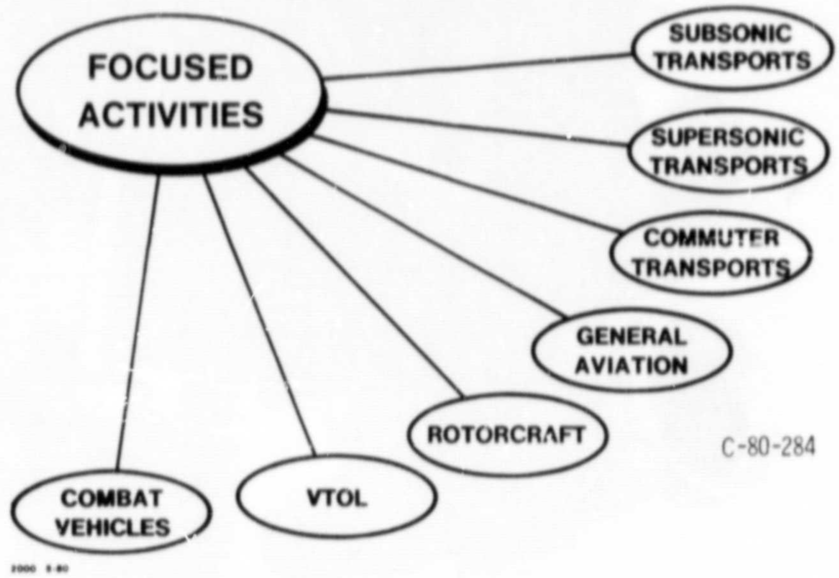

Figure 1. - Aero propulsion - vehicle specific.

Figure 2.


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Figure 3. - Refan engine.

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Figure 4. - First flight of DC-9 refan airplane.

Figure 5. - The McDonnell Douglas DC-9 Super 80.

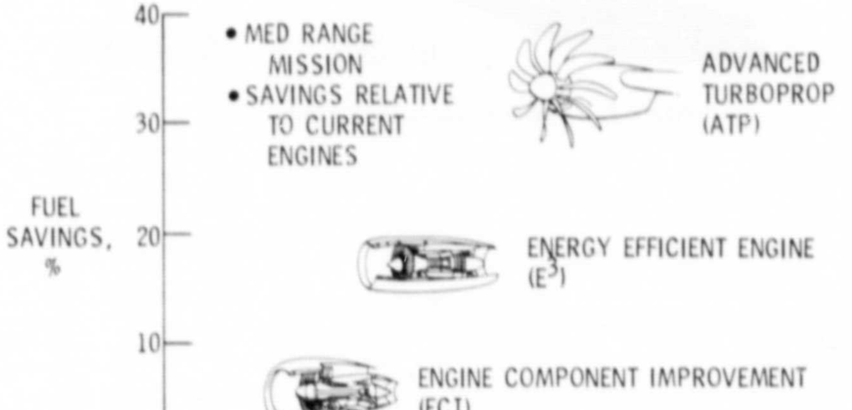
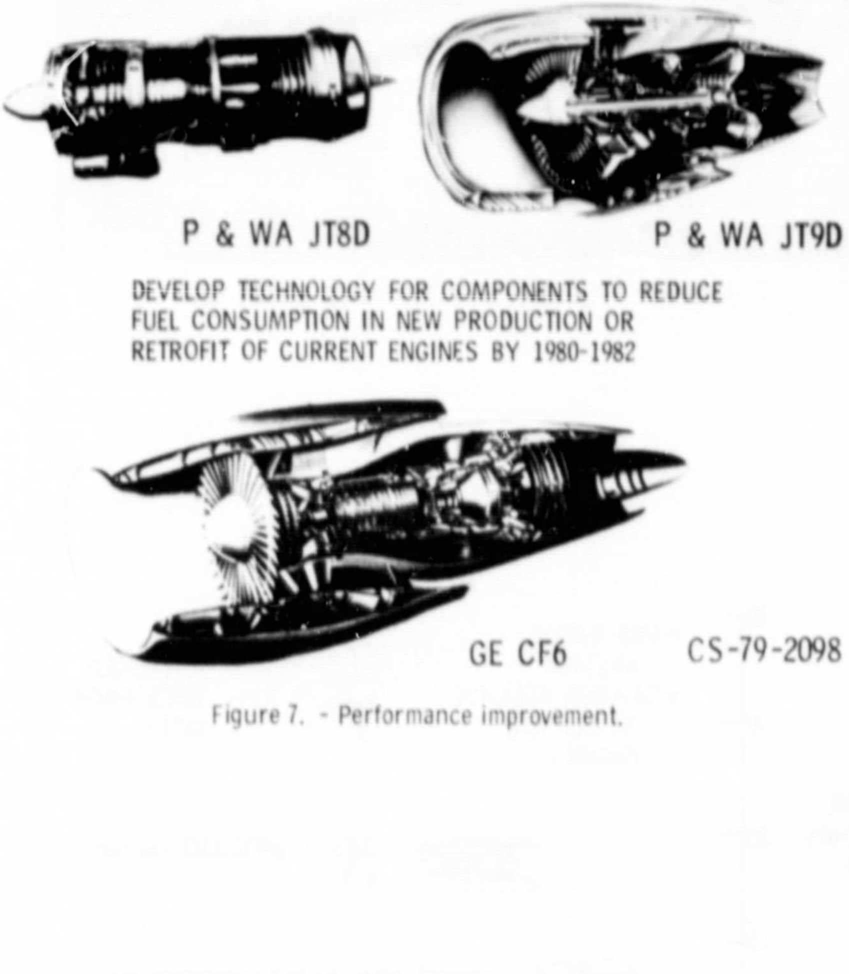


Figure 6. - ACEE propulsion projects. Projected fuel savings and technology readiness dates.



DEVELOP TECHNOLOGY FOR COMPONENTS TO REDUCE
FUEL CONSUMPTION IN NEW PRODUCTION OR
RETROFIT OF CURRENT ENGINES BY 1980-1982

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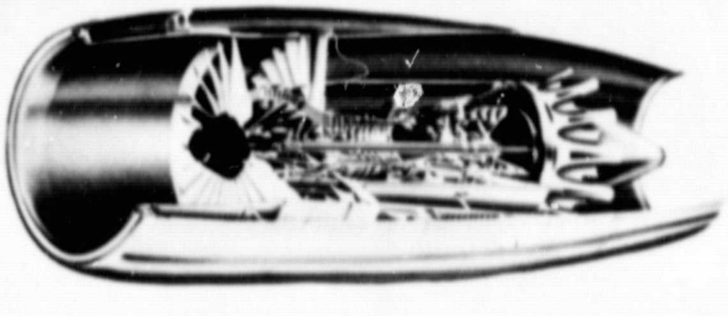
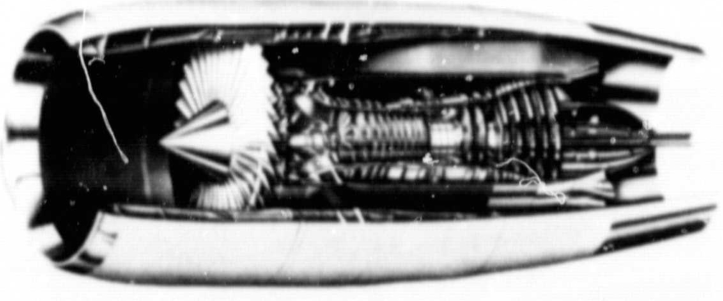
Figure 7. - Performance improvement.



PRATT & WHITNEY



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GENERAL ELECTRIC

Figure 8. - Energy efficient engines.

Figure 9. - Propeller model test in Lewis wind tunnel.

Figure 10. - Supersonic transport.

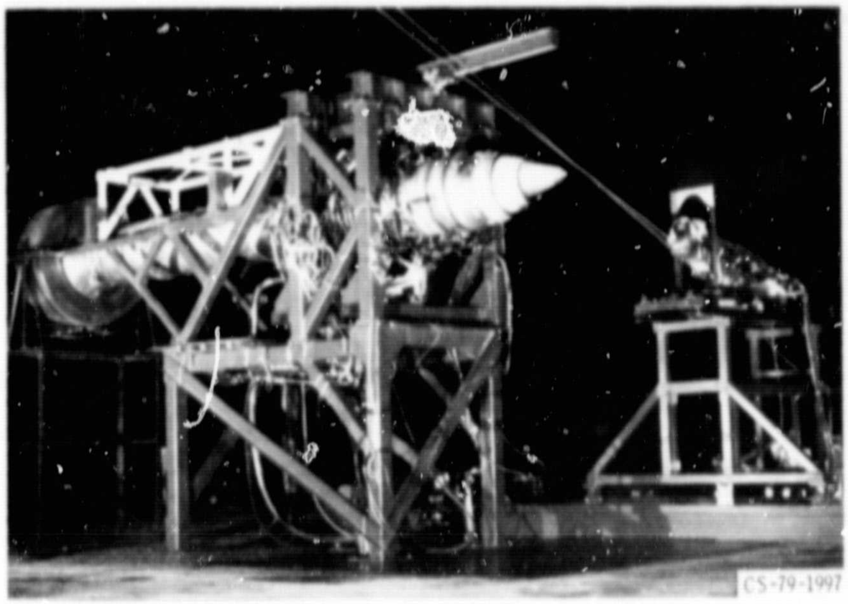

Figure 11. - Coannular noise test of GE engine.

Figure 12.

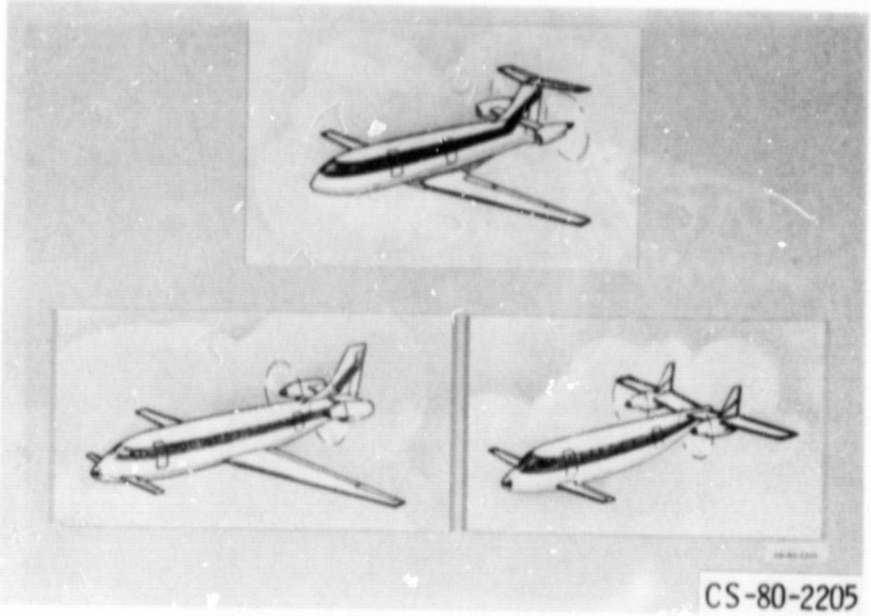

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Figure 13. - Commuter aircraft.

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Figure 14. - General aviation.

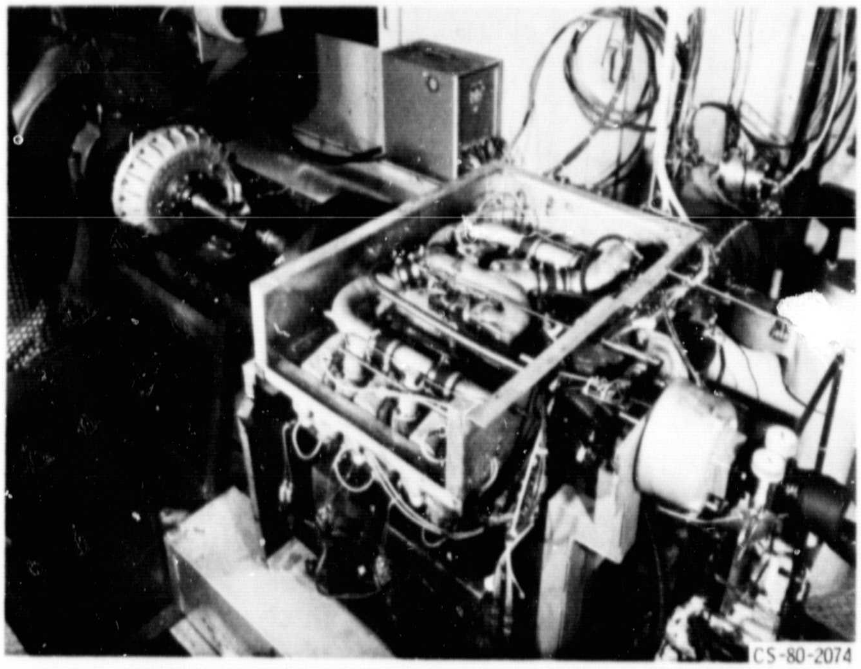
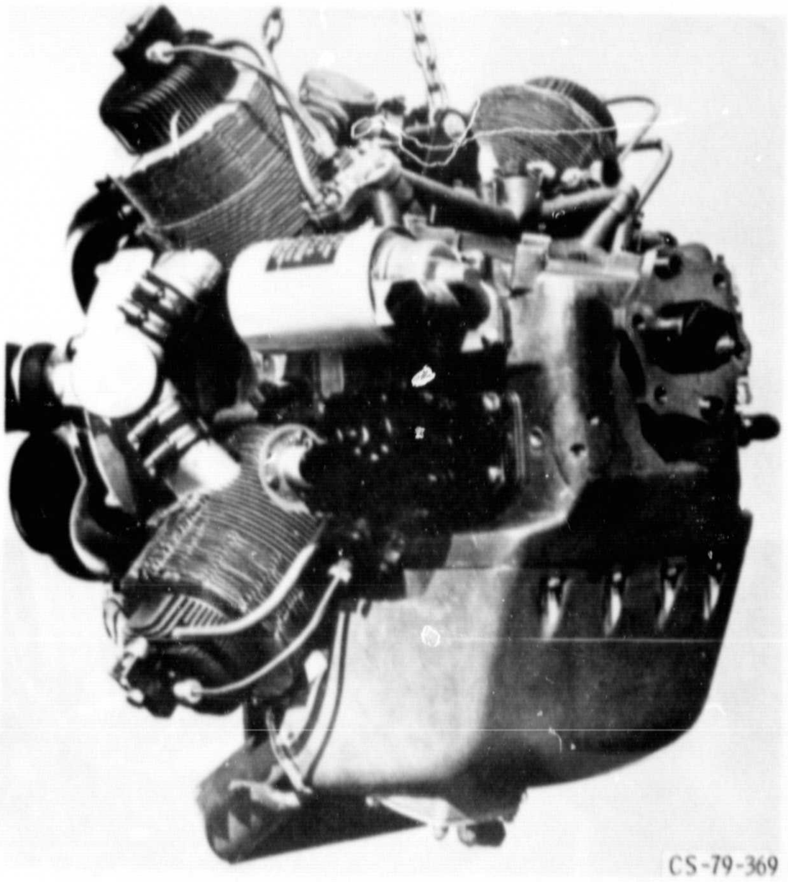


Figure 15. - General aviation reciprocating engine test facilities.



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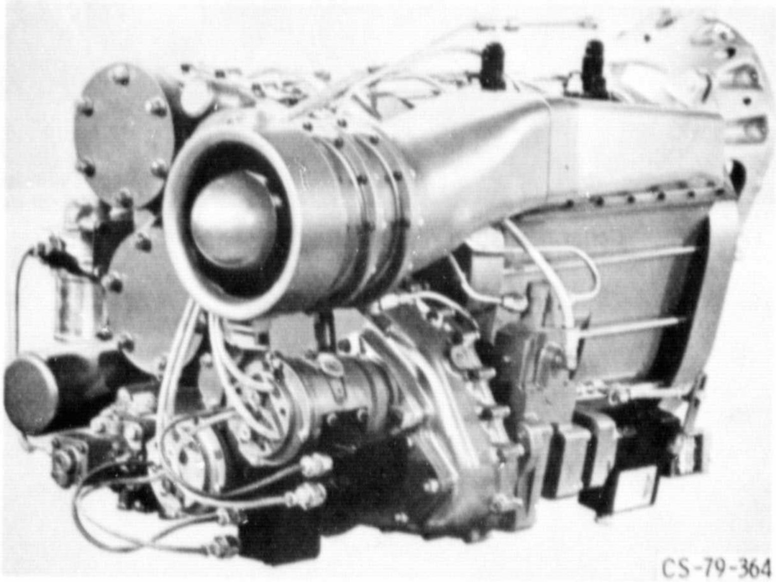
(a) DIESEL ENGINE.



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(b) ROTARY ENGINE.

Figure 16.

Figure 17. - Executive jet aircraft.

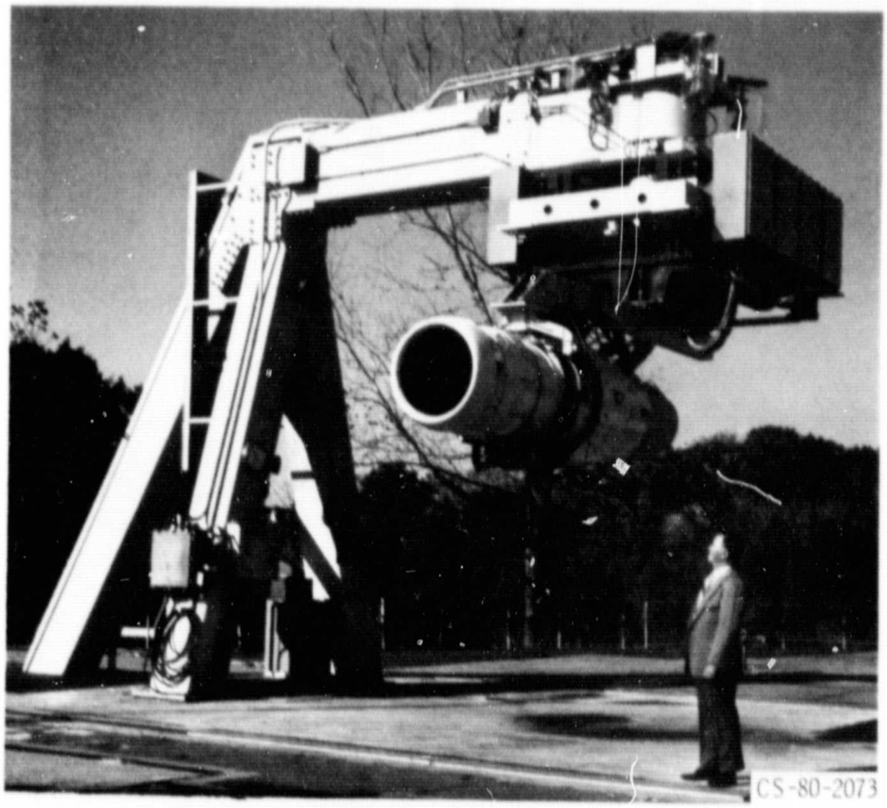

Figure 18. - Quiet, clean general aviation engine.

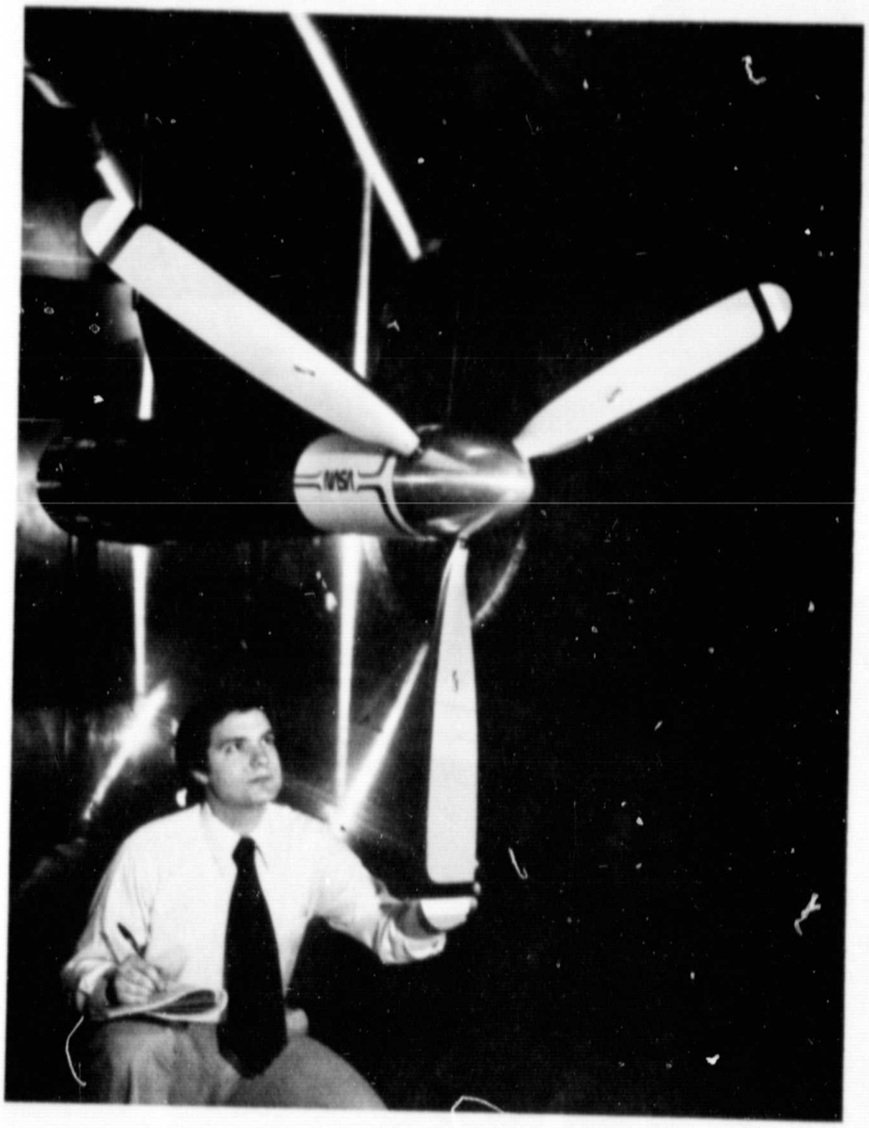

Figure 19.

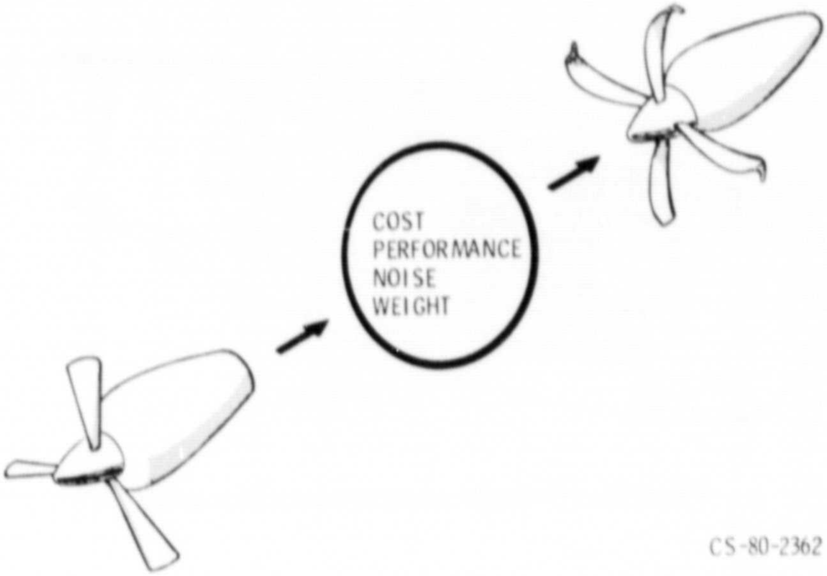

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Figure 20. - Low speed propeller technology thrusts.

Figure 21. - X-wing rotocraft.

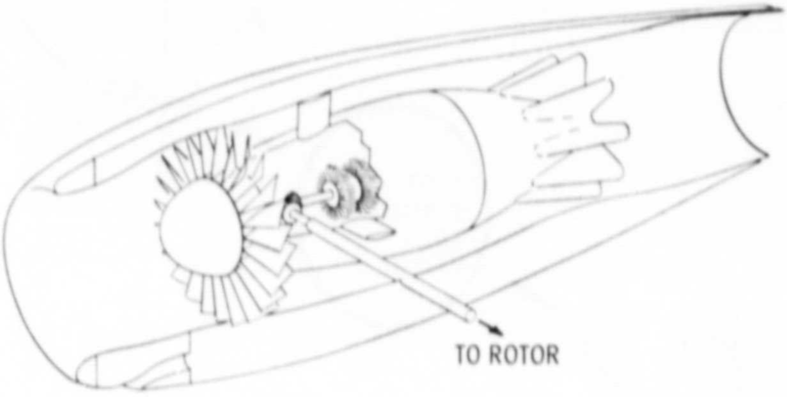

Figure 22. - Helicopter convertible propulsion system.

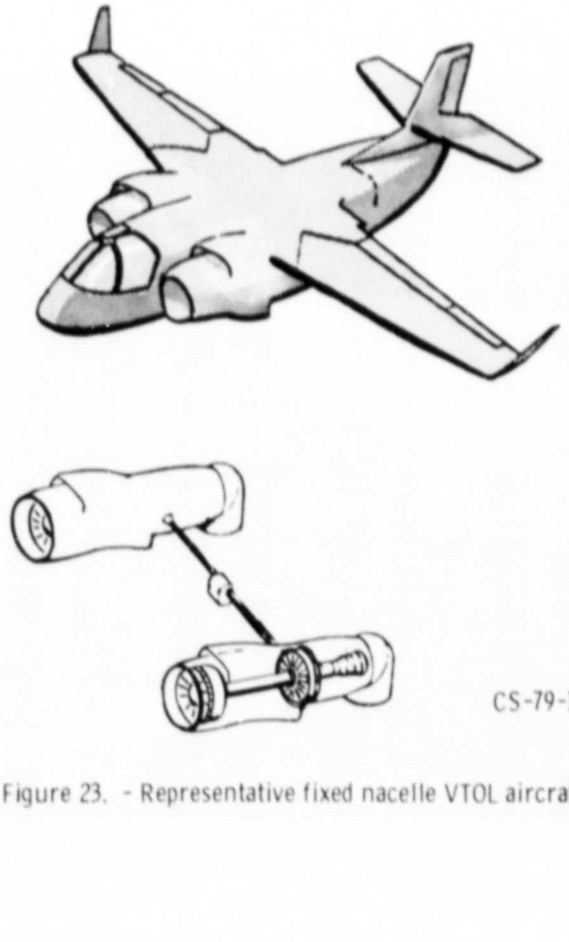

Figure 23. - Representative fixed nacelle VTOL aircraft.

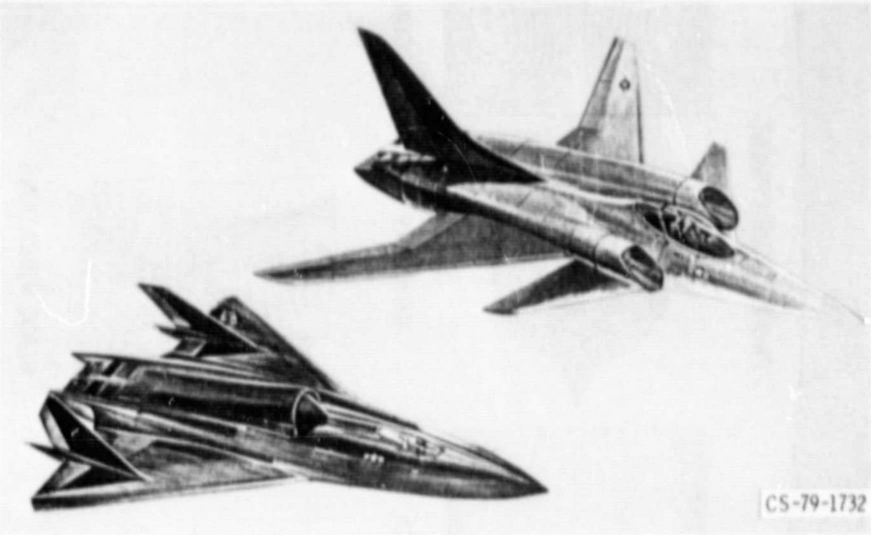

Figure 24. - Stealth configurations.

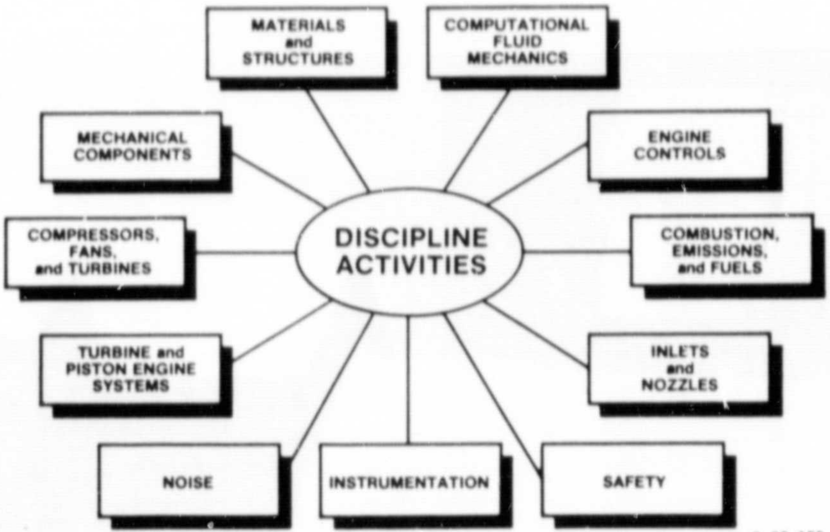

Figure 25. - Aeronautical propulsion.

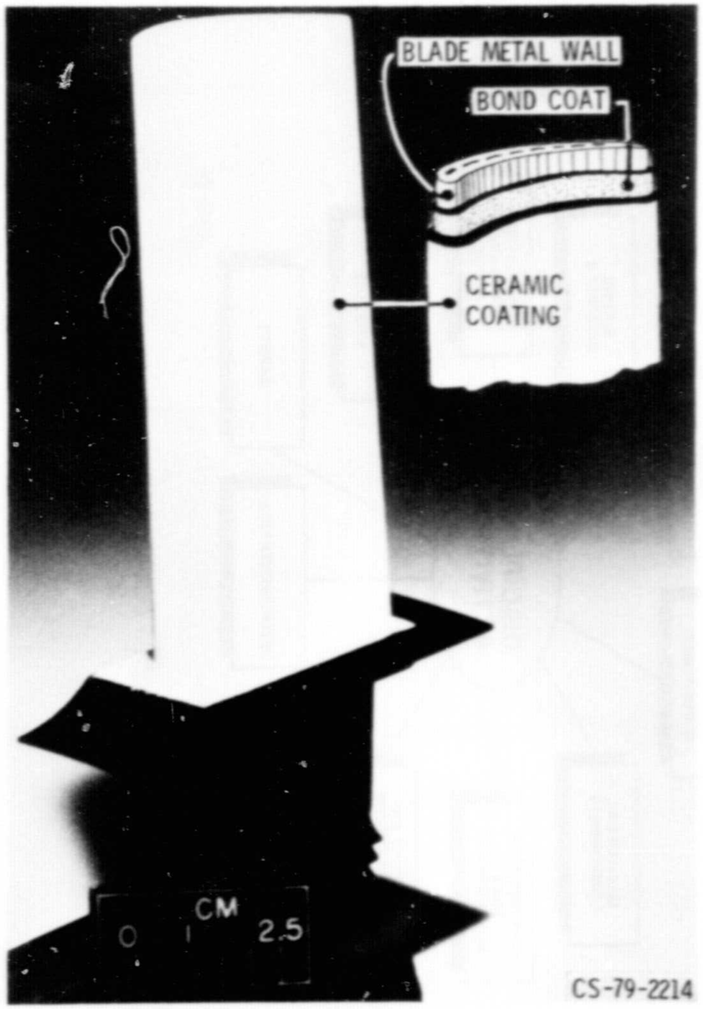

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Figure 26. - Thermal barrier coated turbine blade.

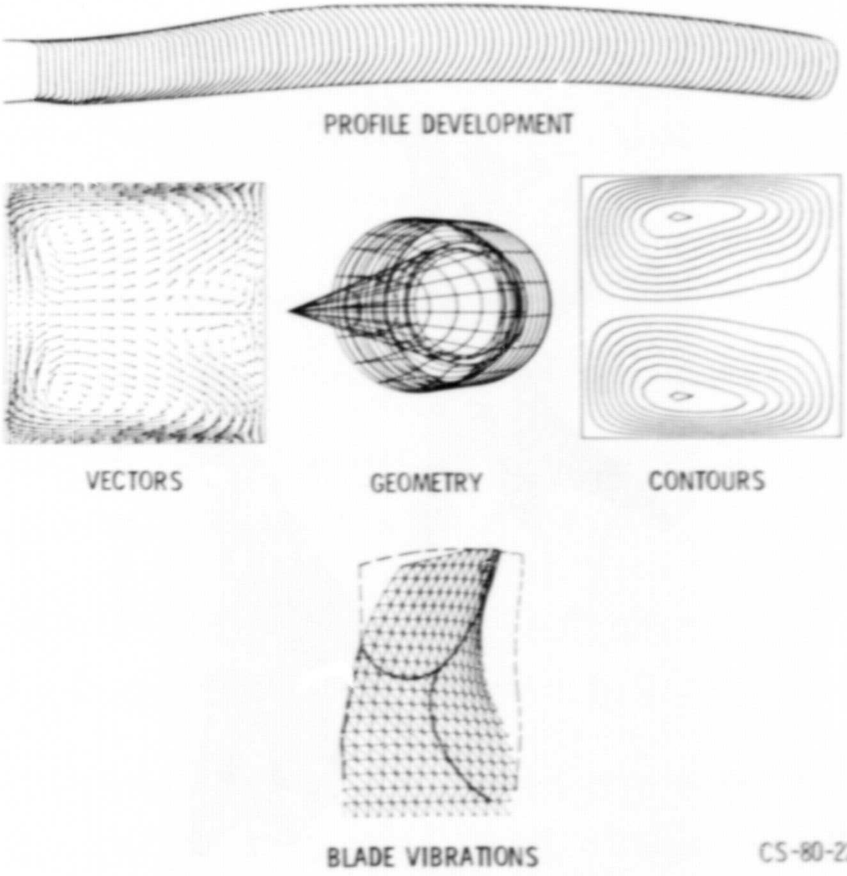

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Figure 27. - Computer analysis and graphics.

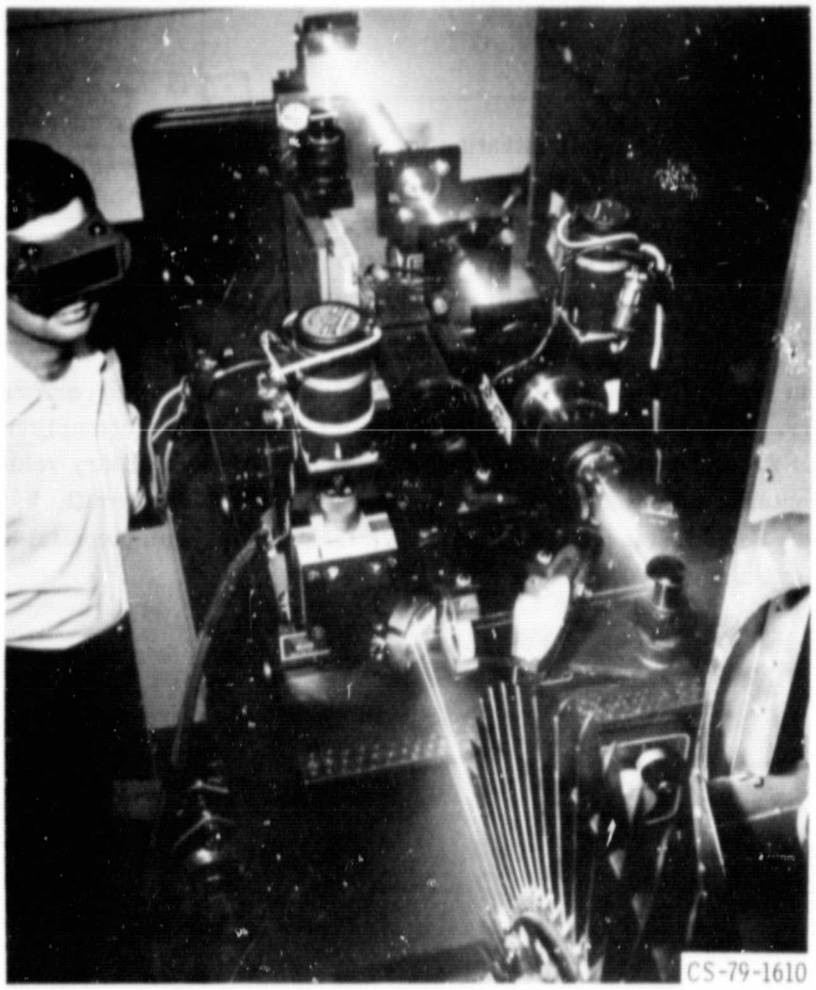

Figure 28. - Laser anemometer.