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# NASA Research in Aircraft Propulsion

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## NASA RESEARCH IN AIRCRAFT PROPULSION

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### INTRODUCTION

The activities of NASA in the field of aeronautics are indicated in figure 1 to be oriented around three broad objectives: to promote an improved civil air transportation system encompassing both the large transport and the smaller general aviation aircraft, to enhance the competitive position of the U.S. industry in the international marketplace, and to contribute to the aviation capabilities of the U.S. military services. The accomplishment of these objectives is achieved through the research and technology (R&T) programs of its field centers. The principal roles of these centers are summarized in figure 2. The Langley Research Center focuses its effort on the needs of conventional takeoff and landing (CTOL) aircraft for transport, combat, and general aviation purposes. The Ames Research Center performs a similar function for special purpose aircraft such as rotorcraft and vertical or short takeoff and landing (V/STOL) systems. An extensive flight research program is conducted in conjunction with the nearby Dryden Flight Research Center. The Lewis Research Center specializes in the R&T programs required for the propulsion systems of all these types of aircraft. Figure 3 indicates that the objectives of the propulsion program are to advance the state of the art in propulsion systems and components and also to address the propulsion needs of specific vehicles. These advances will provide new opportunities for improved aircraft performance and complements the efforts of the other centers in identifying innovative and creative concepts that yield new capabilities in aircraft design.

The emphasis of this particular report will be

on the propulsion R&T program being performed at the Lewis Research Center. The first portion will address the propulsion needs of specific vehicles, and the second portion the generic research in propulsion systems and components.

### SPECIFIC VEHICLE ACTIVITIES

The propulsion requirements of specific types of aircraft are established in NASA by focusing activities toward the needs of those aircraft in the manner illustrated in figure 4. The NASA centers work jointly with the aircraft industry in establishing the technological advances required for major improvements in future aircraft of the types that are listed. These advances are prioritized and, to the extent that resources permit, are further pursued with inhouse, contract, and university grant research programs. Each of the seven activities shown on the figure will be explained in a little more detail in subsequent figures.

The largest contract projects in NASA's aeronautics program are directed to subsonic transport technology. The current emphasis is to improve their energy efficiency to lessen the economic impact of high fuel prices. The propulsion portions of that program are illustrated in figure 5. In the near term, component improvements were achieved for modest gains in efficiency for new models of transport engines currently in production: the JT8D, JT9D, and the CF6. A longer term effort is directed to all new designs of high bypass turbofan engines with significant savings in fuel. Most of the gains are achieved by using very high pressures and temperatures in the core to enhance thermal efficiency. Modest gains in propulsive efficiency are provided by a mixer for the fan and core flows. Much larger gains in propulsive efficiency can be achieved with a propeller rather than a fan. The uncertainty, however, is whether or not that gain can be maintained at the high cruise speeds of interest for transport aircraft. NASA is pursuing a program to resolve that uncertainty in a longer term effort. If successful, then the large

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fuel savings indicated in figure 5 for the advanced turboprop could become a reality.

The next aircraft type to be considered is the supersonic cruise vehicle. For the past decade, NASA has maintained a modest level of effort to advance technology required for efficient aircraft of that type with particular emphasis on transport concepts. Because of recent budgetary constraints, the scope of that effort has been diminished and other applications of that technology are being explored. Current plans for supersonic cruise research are indicated in figure 6. System studies are being used to evaluate a variety of engine cycle concepts and core temperature requirements. Effort is continuing on advanced jet noise suppressors in a search for effective devices with low performance losses. Programs in inlet technology are establishing acoustic suppression characteristics of supersonic design concepts and are exploring stability and control techniques for mixed compression configurations. Design studies are also underway to assess the feasibility of a supersonic through flow fan. Because of the reduction in inlet weight, significant increases in range can potentially be achieved.

Another type of transport aircraft with its unique set of technical requirements is in the commuter class. Although NASA does not presently support a focused program for this aircraft type, it has completed studies of advanced concepts and is providing some generic research in its disciplinary programs which are described in a later portion of this report. These studies of Small Transport Aircraft Technology (STAT) yielded the propulsion related results shown in figure 7. Turboprop concepts were the only ones of interest and significant benefits were projected with improvements in the illustrated components. For small gas turbines of this type, radial flow compressor and turbine stages are of increased interest because passage heights become too small for good efficiency in conventional axial designs.

Closely related to the commuter transport technology requirements is that associated with general aviation. This category is represented by the small business aircraft with single or twin propeller powered propulsion systems with around 500 shaft horsepower. Propulsion concept studies recently supported by NASA are illustrated in figure 8. Advances in propeller technology were highlighted that enhance aero acoustic performance and utilize composite structural designs for improved safety. Four different advanced engine types proved to be competitive in this power range. A general preference was indicated by the study results for rotary combustion (Wankel), diesel piston, spark ignition piston, and turbine engines in that order of prioritization. The rotary combustion engine appeared to offer the best combination of fuel efficiency, low weight, simplicity, and low initial cost. Key technologies to make it an effective aircraft engine are improved seals, cooling, and air flow capacity and a multifuel capability. A modest research program of this type has been initiated.

The next aircraft type for discussion is the rotorcraft. Figure 9 illustrates one of the advanced concepts presently being considered in the U.S.—the X wing. Such an aircraft requires a convertible engine: turboshaft power for the rotor during hover; and turbofan power for thrust during level flight. NASA and the Defense Advanced Research Projects Agency (DARPA) are sponsoring an exploratory effort of this type using a TF34 engine illustrated in the figure.

For all types of rotorcraft, NASA-Lewis is conducting research on advanced transmissions for power transfer. Traction drive concepts are of particular interest in this effort. Additional effort is directed to enhance the efficiency of small gas turbine engine components. A relatively new effort at Lewis is a research program directed to the icing problems of rotorcraft in order that an all weather capability can be achieved.

A V/STOL airplane currently offers the most challenging opportunities to the propulsion community. The aircraft capabilities are highly sensitive to the level of sophistication in propulsion component design, and many imaginative propulsion system concepts appear competitive for both subsonic and supersonic applications. The tilt nacelle airplane model shown in figure 10 is one such concept and has recently been tested at the Ames Research Center. At Lewis, a series of one-third scale inlet models were used to explore methods of achieving high angles of attack without flow separation. Additional studies were made of thrust modulation techniques such as with variable inlet guide vanes (VIGV's). A different propulsion concept illustrated on the right of the figure is the tandem fan. It uses a single core to drive two separate fans with independent inlet and exhaust systems. A unique exhaust concept for this propulsion system is the front nozzle which is closely coupled to the fan. Flow visualization is achieved with multi-color paints in the study that is depicted in the figure.

An even greater diversity of propulsion requirements is evident in the class of combat aircraft. Figure 11 illustrates some related activities in NASA. The F-15 aircraft shown here is being used at the Dryden Flight Research Center for research into integrated digital controls for the propulsion system. Precursor tests were performed in an altitude test cell at Lewis to evaluate the electronic control for the engine of that aircraft. Another flight program at Dryden uses a remotely piloted vehicle to explore the integration of diverse technologies to achieve extreme maneuverability at transonic speeds and hence is called the HIMAT (Highly Maneuverable Aircraft Technology). One phase of that effort was an inlet test at Lewis to insure compatibility of the inlet flow characteristics to prevent compressor stall during afterburner augmentation of the thrust. An entirely different type of propulsion system which is also illustrated is a solid fuel ramjet under test in one of the Lewis wind tunnels. Multiple inlets are used to supply a single combustion chamber containing solid propellant. Matching of the inlets and their stability was the principal area of study in this program.

#### DISCIPLINE ACTIVITIES

The work described in the previous section illustrates that the needs of specific vehicles impose requirements on the propulsion system that result in innovative and creative solutions that produce a better aircraft. A companion effort equally important is the generic advances in component technology that produce opportunities for enhanced capabilities of aircraft of all types. Figure 12 summarizes eleven disciplinary activities underway at the Lewis Research Center. As in the previous section, a figure will be used to depict typical activities of each type here indicated.

A very rapidly advancing technology is that associated with computational methods as depicted in figure 13. Very impressive achievements have resulted

from the utilization of the large digital computers for structures, fluid mechanics, geometry definition, and even to a limited extent the additional complexities of combustion phenomena.

The success of the digital computer has also made it a new and powerful factor in control system technology. Figure 14 indicates the large increase in controlled variables that are required in advanced engines. The hydromechanical control is rapidly giving way to the electronic digital control which provides greater reliability and flexibility for optimal performance characteristics of complex engines. There is particular interest in applying optical sensors to enhance control system reliability.

Figure 15 illustrates some current activities related to combustion research. The emphasis is on the impact of alternate sources of hydrocarbon fuels and on improved analytical techniques and their verification for combustion modeling. Applications are oriented to aircraft needs, but generic results also relate to ground power needs.

Figure 16 indicates the scope of interest for inlet and exhaust nozzle research currently pursued at Lewis. Areas of emphasis include supersonic inlet performance and control, off design performance of supersonic ejectors, efficiency of turbofan mixer nozzles, exhaust nozzle cooling, angle of attack characteristics of subsonic inlets, and thrust deflection characteristics of exhaust systems.

In the area of aircraft safety, the emphasis at Lewis is on aircraft icing research. As indicated in figure 17, the emphasis is on accretion characteristics of airfoils and inlets. Advanced ice protection techniques such as icephobics, electroimpulse, electrothermal, and pneumatic devices are being explored. Additional effort is being expended for modern instrumentation concepts for icing measurements and for improved methods of simulating natural icing conditions in ground test facilities and flight tankers.

Additional instrumentation research is in progress for propulsion systems, as illustrated in figure 18. Principal objectives are related to flow, clearance, emission, and stress measurements in engines. Significant progress has especially been achieved in the application of optical methods, as in laser velocimetry.

Research is continuing in turbomachinery and jet noise. Figure 19 illustrates fan and propeller noise research at Lewis using an anechoic chamber and both low and high speed wind tunnels. Outdoor facilities are used for engine and jet noise. The jet noise work places current emphasis on dual stream effects as encountered with coannular nozzles.

Engine systems research of the type illustrated in figure 20 is currently in progress. The emphasis with large turbine engines is on system dynamics due to large perturbations (such as stall) and the appropriate control procedures for recovery. A new effort has been initiated for small turbine engines to enhance contingency power by using water injection to augment cooling of the turbine. Research with piston engines is oriented to emissions and multifuel capabilities, and with rotary combustion engines efforts are being made to improve air flow handling capacity as with turbocharging.

The next subject is related to advanced turbomachinery aerodynamics. Figure 21 illustrates the scope of this effort for compressors, fans, turbines, and propellers. Of particular interest is the work being performed to determine the aerodynamic effects of film cooling on turbine performance.

A large area of research is dedicated to the mechanical components of engines such as those depicted in figure 22. This work encompasses shaft dynamics, seals of many types, gears, bearings, and lubrication. The results of this work are applicable to turbofan engines in the manner illustrated and also to turboshaft engines and to transmissions such as those for rotorcraft.

In the area of high temperature materials, very advanced concepts are evolving as illustrated in figure 23 for disks and blades. Particular emphasis is currently being placed on the technology for conservation of critical materials that are in limited supply, such as chromium, cobalt, columbium, and tantalum. Additional effort is being initiated for improved prediction methods of life and durability of hot components. Figure 24 illustrates additional areas of structures research with special emphasis on the application of composite materials and analysis techniques.

#### CONCLUDING REMARKS

This report presents a broad overview of the scope of research presently being supported by NASA in aircraft propulsion. Aircraft systems work is performed to identify the requirements for the propulsion system that enhance the mission capabilities of the aircraft. It is an important source of innovation and creativity that drives the direction of propulsion research. In a companion effort, component research of a generic nature is performed to provide a better basis for design and provides an evolutionary process for technological growth that increases the capabilities of all types of aircraft. They are both important.

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AIR TRANSPORTATION SYSTEM
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AVIATION MARKETPLACE
- MAINTENANCE of SUPERIORITY of U.S.  
MILITARY AIRCRAFT

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Figure 1. - NASA Aeronautics - Mission Objectives.

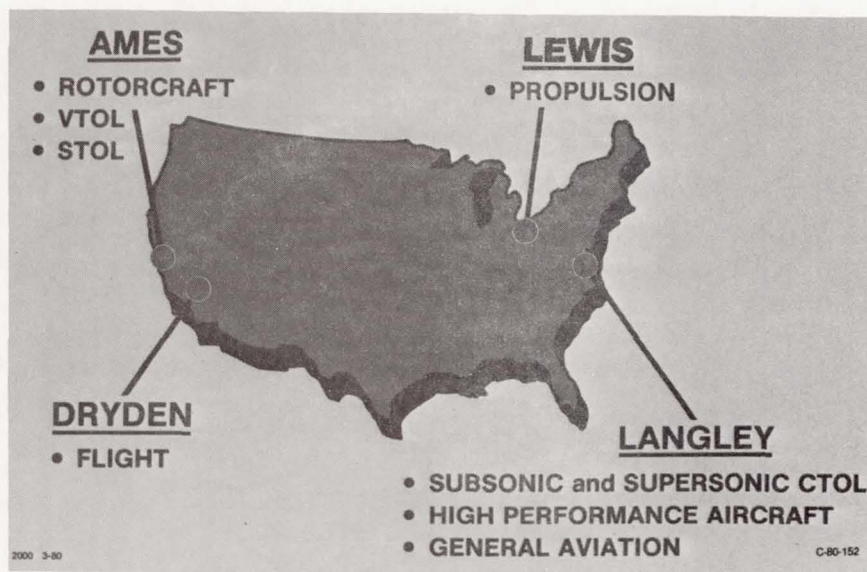


Figure 2. - Roles of NASA Aeronautics - Field Centers.



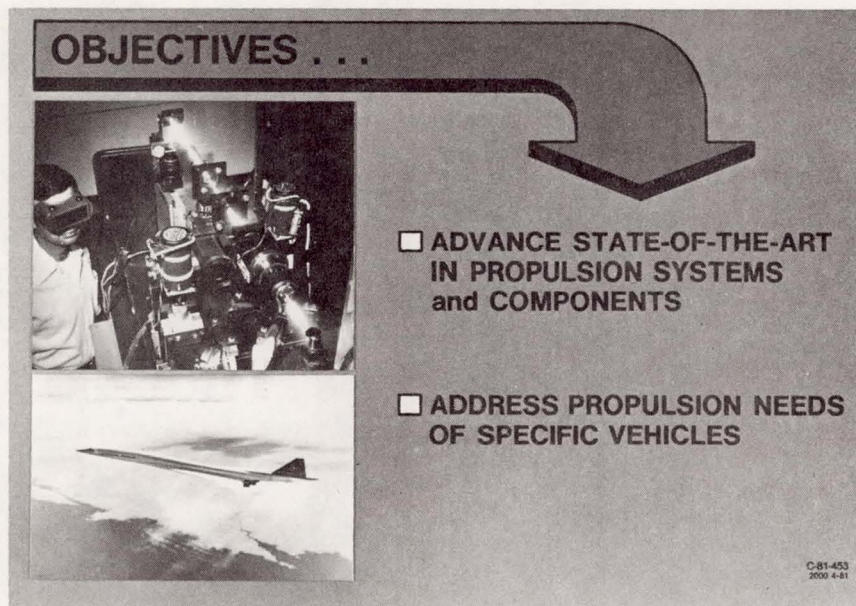


Figure 3. - Aeronautical Propulsion Research Objectives.

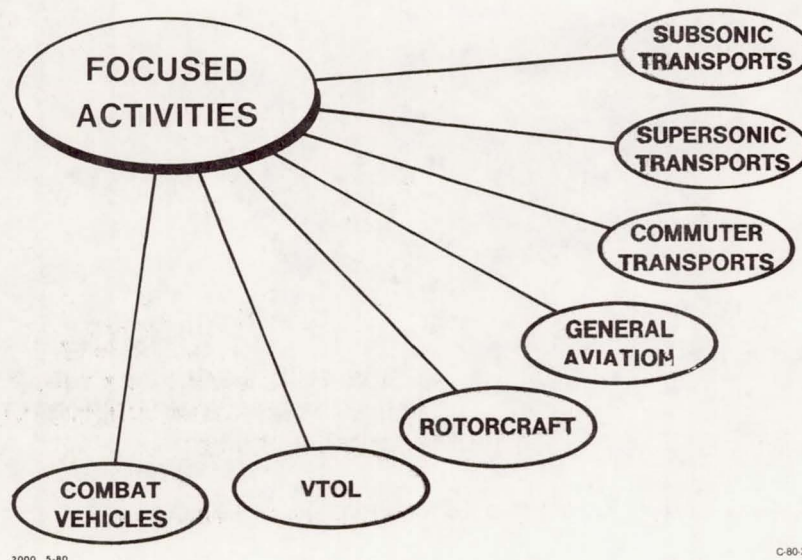


Figure 4. - Research programs for specific vehicles.

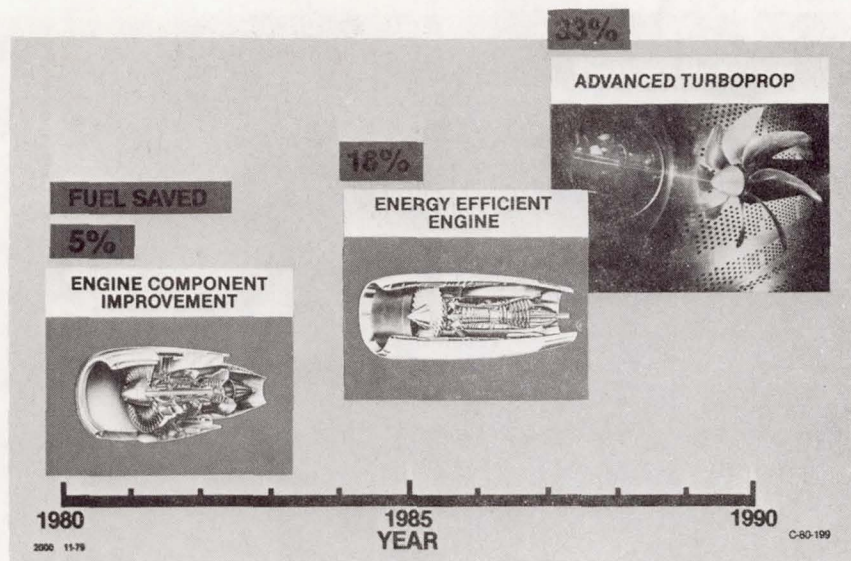


Figure 5. - Energy efficient propulsion technology.

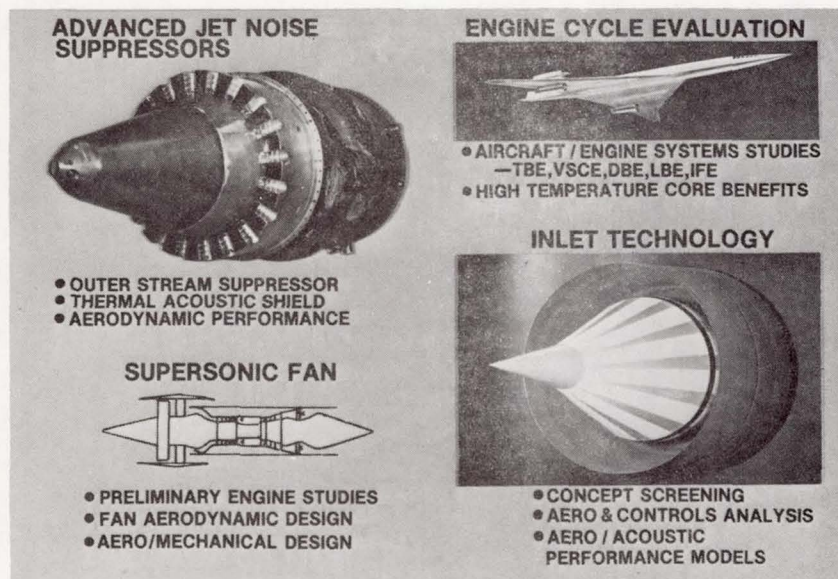


Figure 6. - Supersonic cruise research.



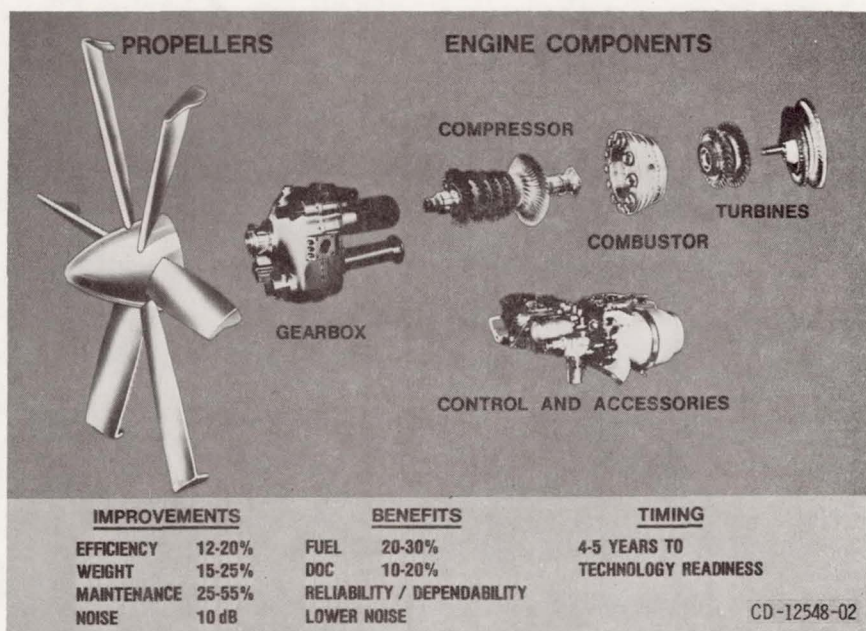


Figure 7. - Research in small transport aircraft technology.

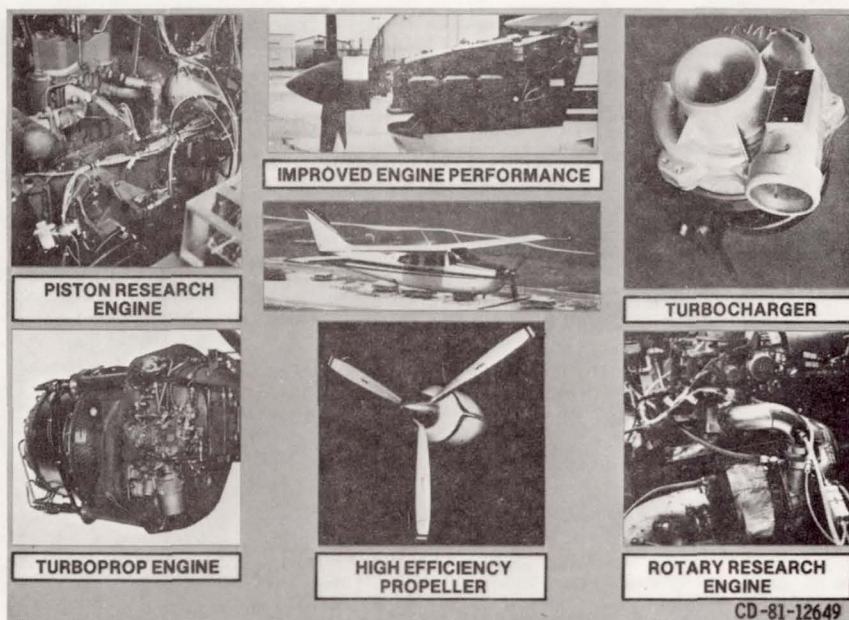


Figure 8. - Propulsion R&T for general aviation.



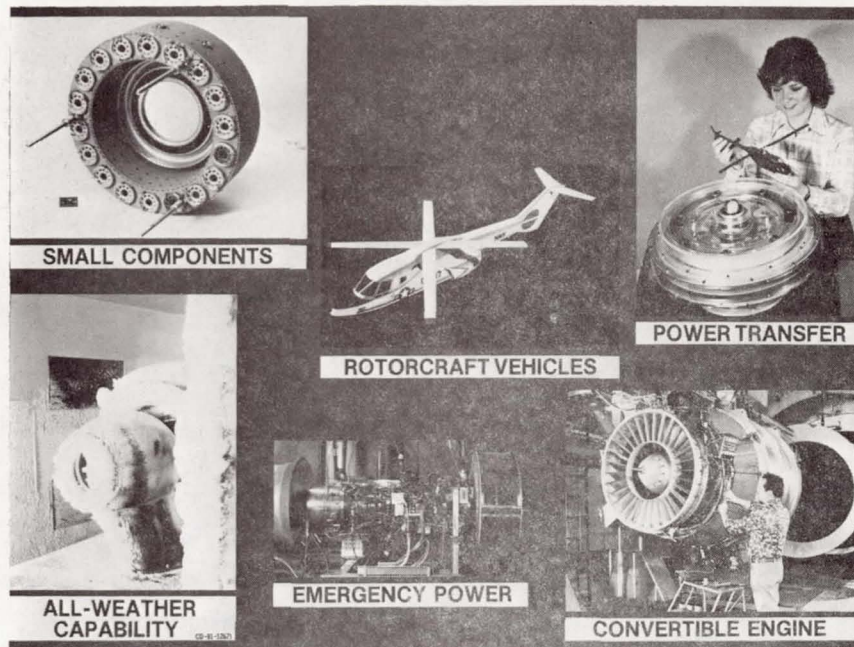


Figure 9. - Advanced rotorcraft propulsion technology.

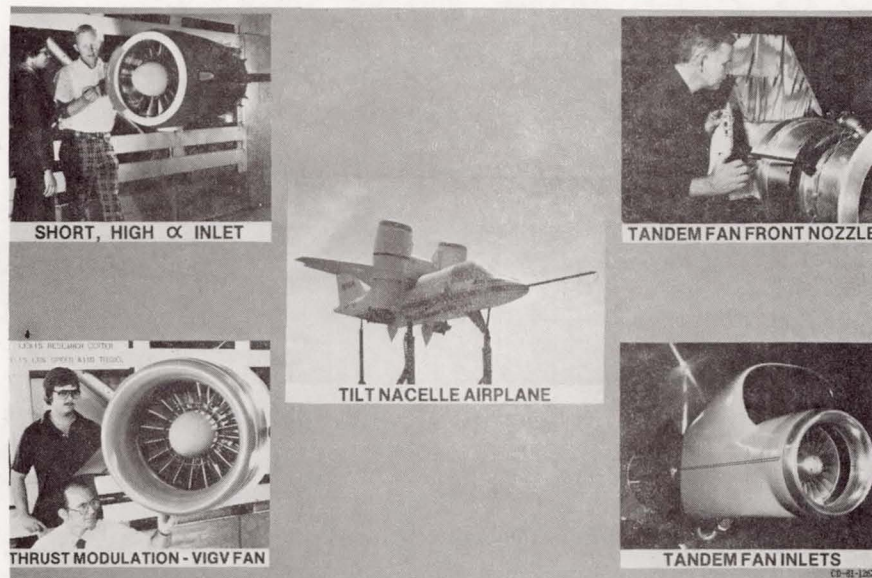


Figure 10. - V/STOL Propulsion Research.

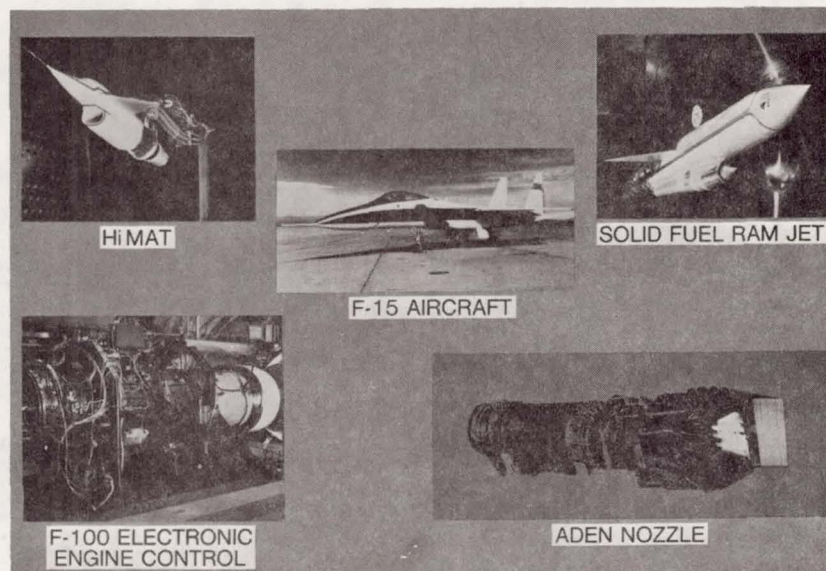


Figure 11. - Research programs for combat vehicles.

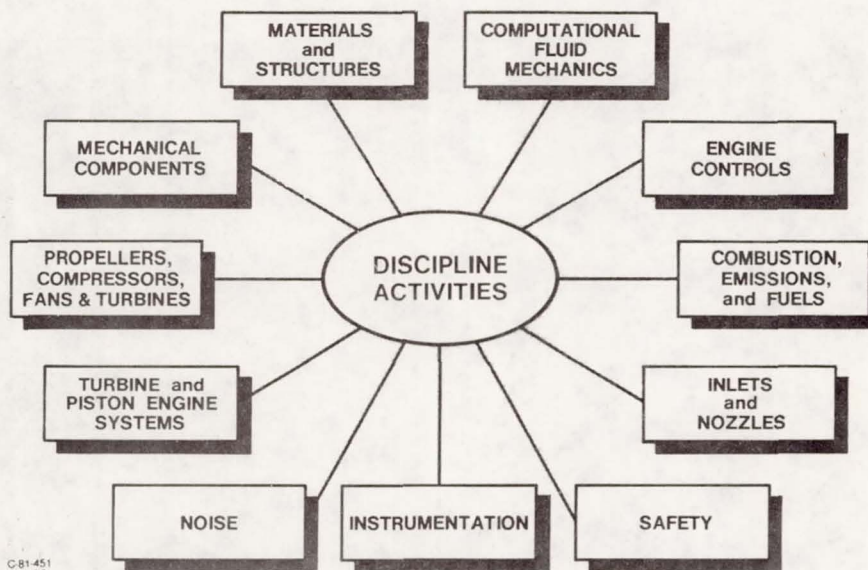


Figure 12. - Disciplinary research for aeronautical propulsion.



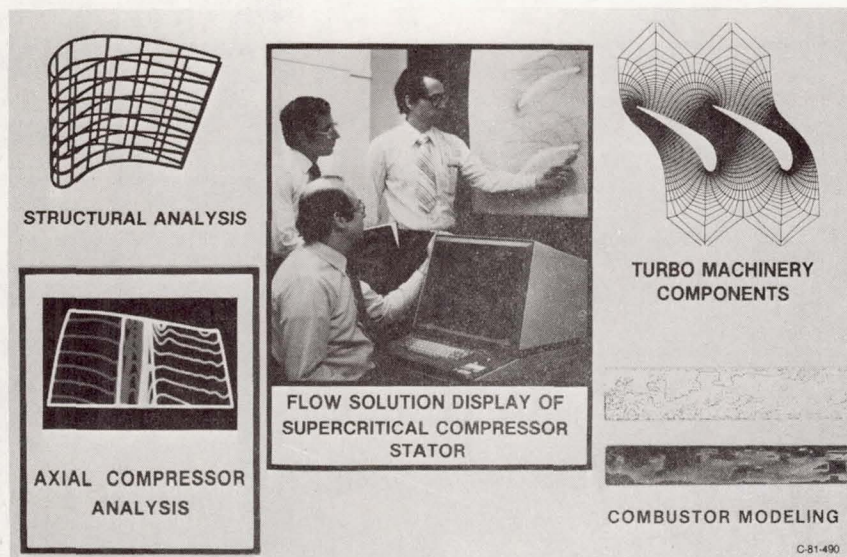


Figure 13. - Computational and analytical research.

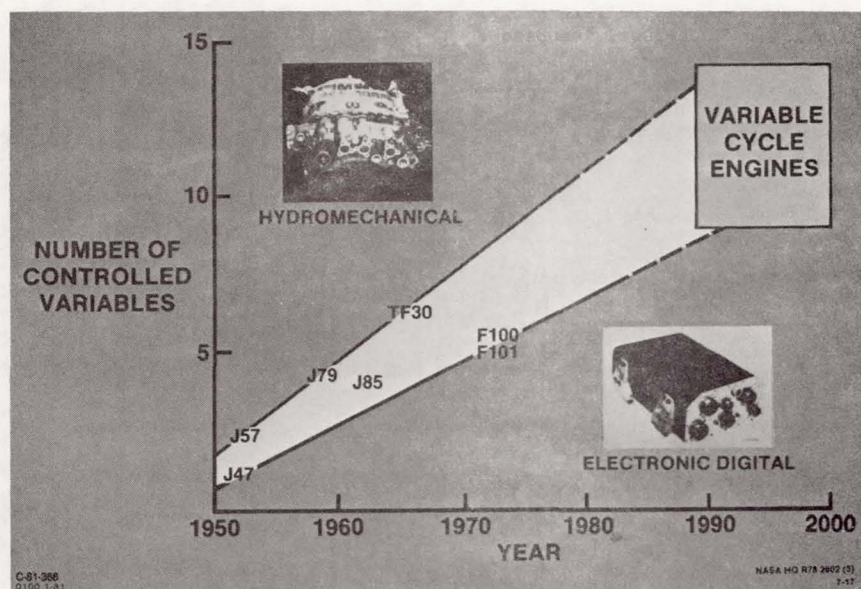


Figure 14. - Engine controls evolution.



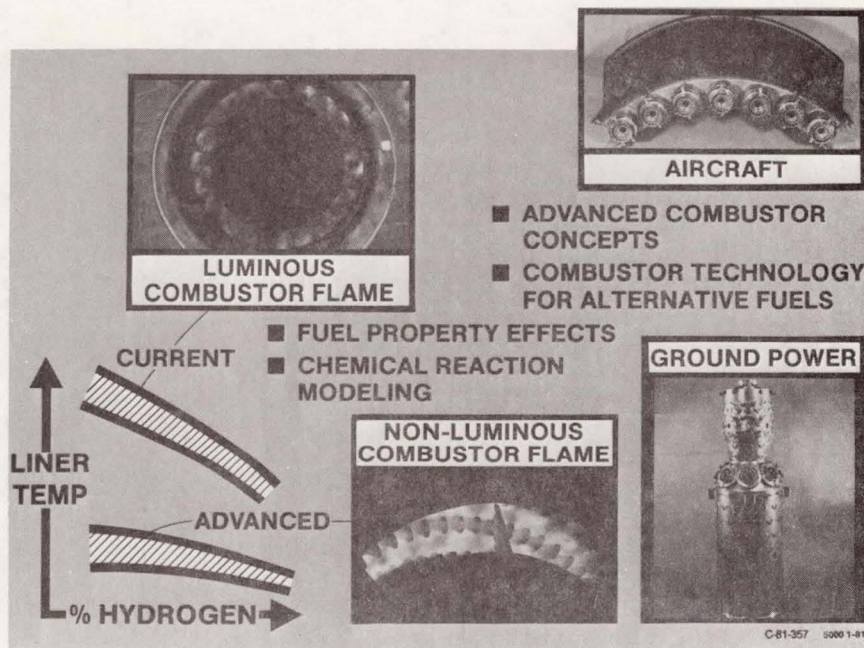


Figure 15. - Combustion R&T.

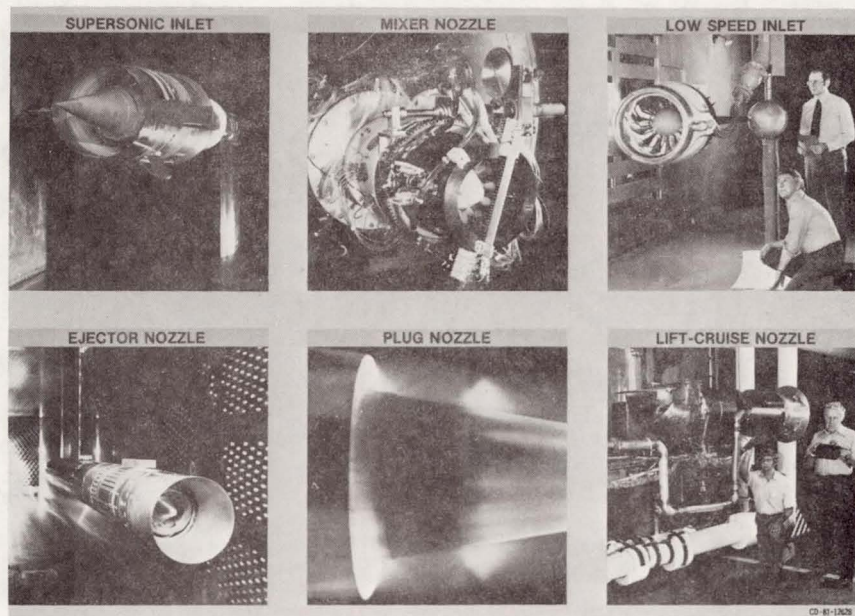


Figure 16. - Research for inlets and nozzles.



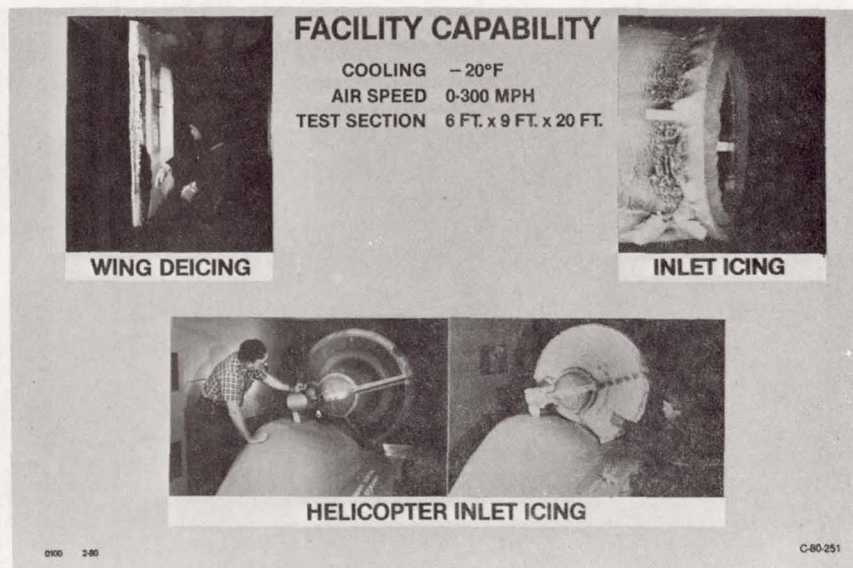


Figure 17. - Icing Research.

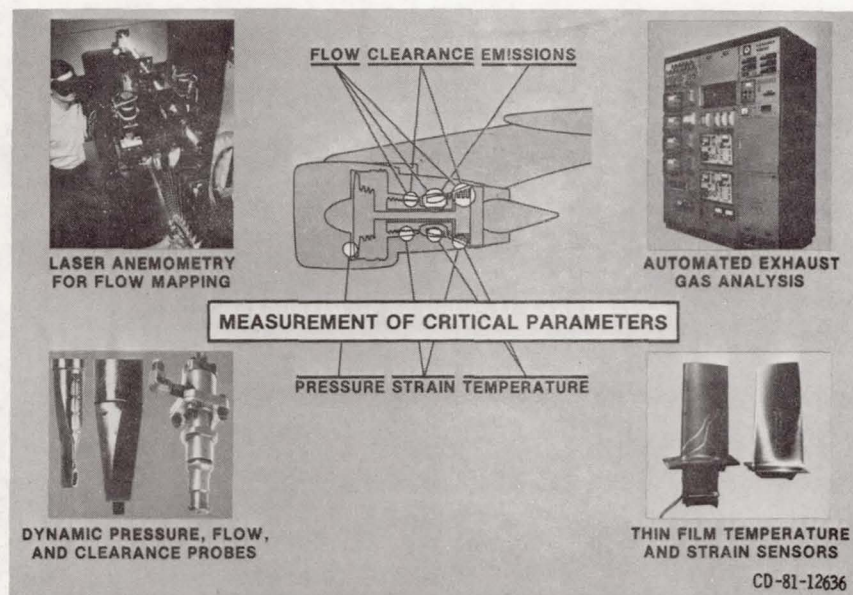


Figure 18. - Advanced instrumentation for propulsion research.



Figure 19. - Propulsion systems noise reductions.

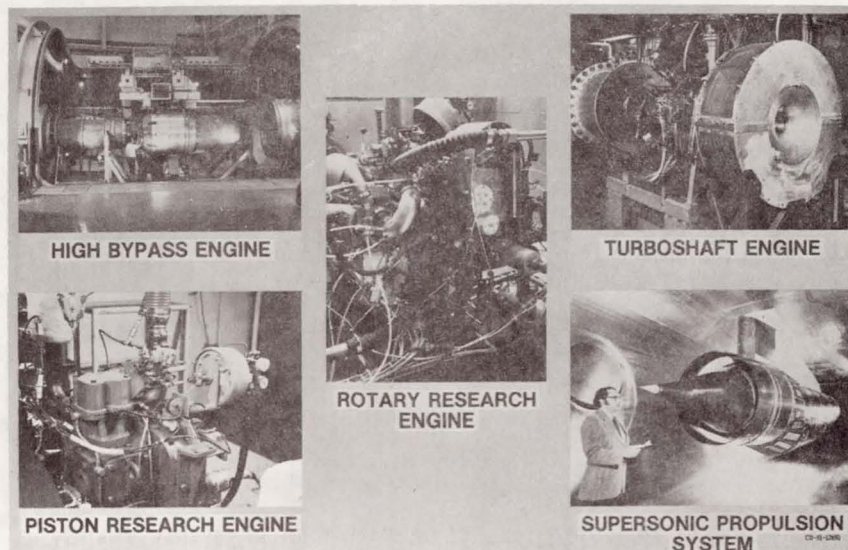


Figure 20. - Turbine and piston engine systems.



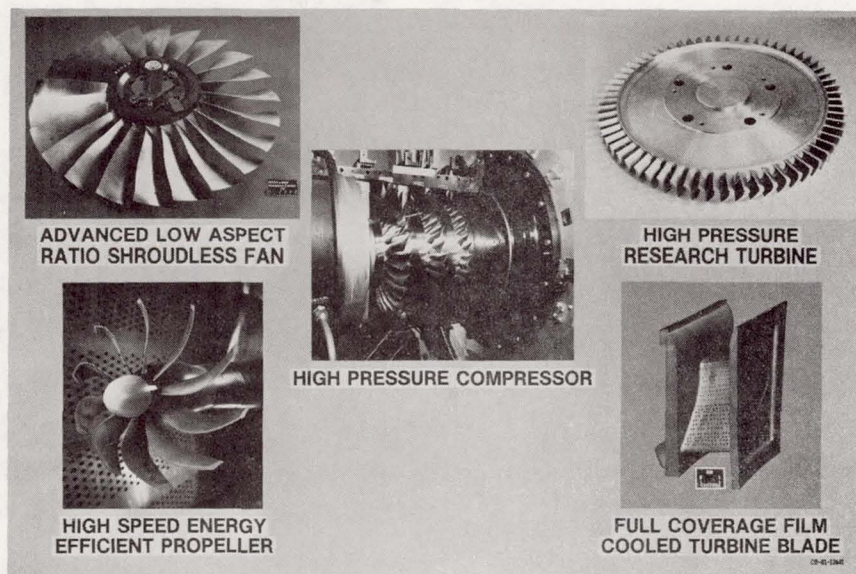


Figure 21. - Research programs for rotating components.

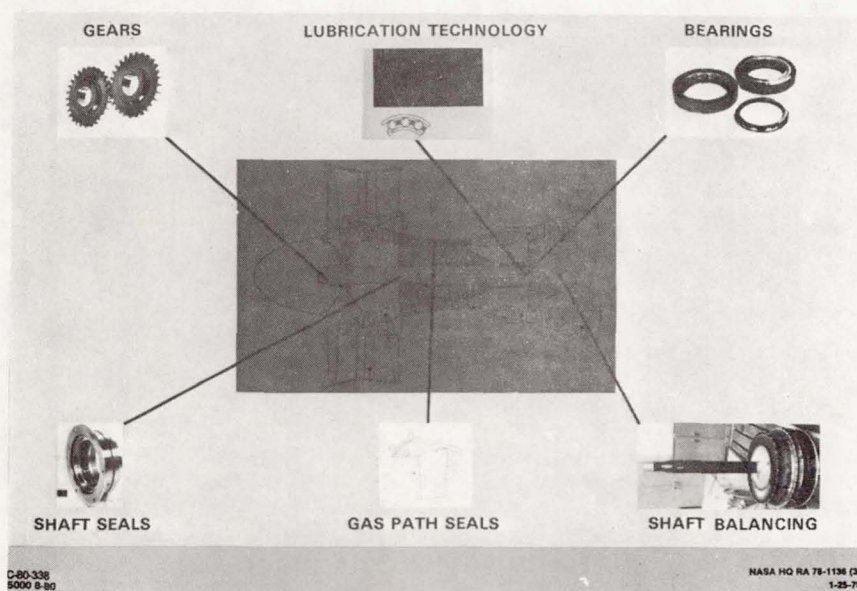


Figure 22. - Power transfer components.

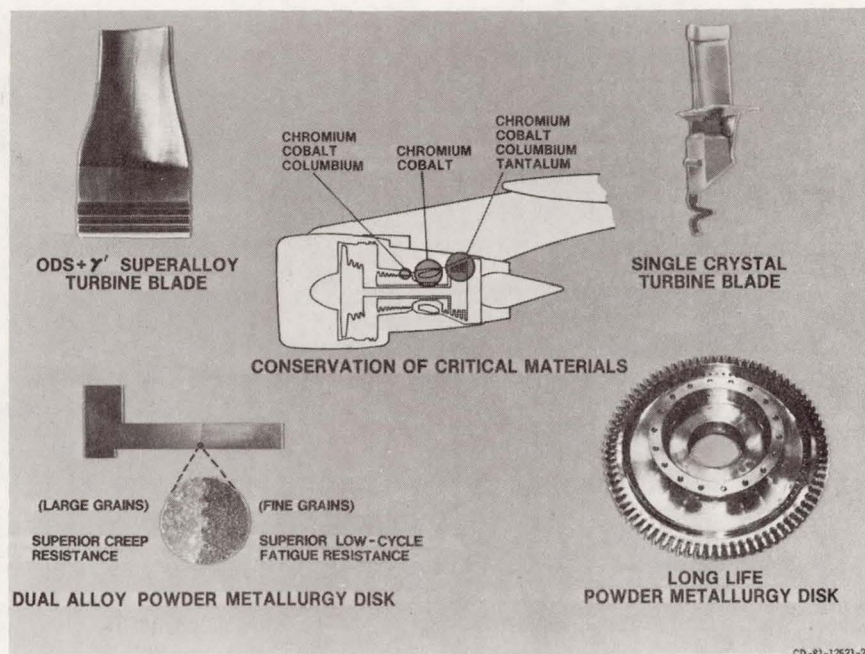


Figure 23. - Advanced high temperature superalloys.

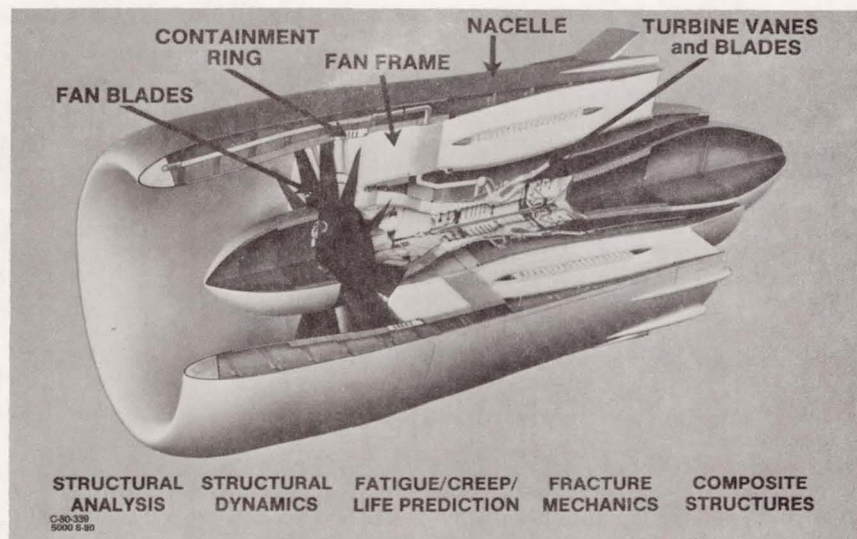


Figure 24. - Engine structures research.



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