NASA Technical Memorandum 82754

The Aerospace Technology Laboratory (A Perspective, Then and Now)

James F. Connors and Robert G. Hoffman
Lewis Research Center
Cleveland, Ohio

February 1982

NASA

THE AEROSPACE TECHNOLOGY LABORATORY

(A PERSPECTIVE, THEN AND NOW)

James F. Connors and Robert G. Hoffman

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

E-1070

SUMMARY

Today's technology laboratory consists of uniquely trained and experienced staff and specialized testing facilities. There people with particular technical expertise, knowledge, motivation, and analytic methods conduct systematic, innovative, and creative research. In advancing the essential basic and applied technologies for future flight systems, experiments are conducted in specialized ground-based facilities designed to simulate the rigors of tomorrow's proposed flight environments. The dramatic physical changes that have taken place in aerospace facilities since the Wright brothers' accomplishment 78 years ago are highlighted in this report. For illustrative purposes some of the technical facilities and operations of the NASA Lewis Research Center are described. These simulation facilities were designed to support research and technology studies in aerospace propulsion.

INTRODUCTION

In April 1981, the NASA space shuttle Columbia successfully completed its 2 1/2-day Earth-orbital mission. With this historic milestone the United States demonstrated the first true aerospace transportation system, giving this country the capability of employing a reusable craft to take off from the ground, fly into Earth orbit, perform its assigned mission, reenter the atmosphere, and land at a precisely designated point. This enormous achievement has taken place only 78 years after the Wright brothers (Wilbur and Orville) first accomplished manned, powered flight - basically, within the lifespan of a single individual. Recently, to dramatize the relative scale of these events, Norman Augustine (ref. 1) made the very interesting observation that the Wright brothers' entire mission (i.e., the "flyer" and its total trajectory) could have been contained solely within the inside volume of the shuttle's external tank. These years have been remarkable times and represent extraordinary progress in man's long drive to escape the confines of the planet Earth.

In retrospect, both the shuttle and the Wright flyer have evolved from significant technology developed in sophisticated simulation facilities, albeit on vastly different scales. For our purposes here, technology can be defined as the body of technical science and engineering information and systems "know-how" necessary for the design of practicable commercial, industrial, and military systems. Facilities can be viewed as ground-based testing devices wherein the rigors and environments of proposed future flight missions are duplicated or simulated as closely as practicable from an engineering standpoint. Excellent staff in the most modern test facilities is essential to the effective production of tomorrow's technology.

In this report today's complex aerospace technology facilities are contrasted to their humble beginnings with the Wright brothers. Staffing characteristics and the methodology of operations are also explored. The propulsion facilities and operations of the NASA Lewis Research Center are used as examples.

EVOLUTION OF AEROSPACE WIND TUNNEL FACILITIES

The origin of the wind tunnel as a facility to test heavier-than-air devices (i.e., aircraft systems and related components) for aerodynamic or propulsive efficiencies preceded the accomplishment of powered flight by more than 30 years. The first (refs. 2 to 4) was designed for the Aeronautical Society of Great Britain by Messrs. Wenham and Browning in 1871; the second, by Horatio Phillips in England in the early 1880's. In the United States the Wright brothers first built a wind tunnel in 1901 for testing wing models to establish the validity of air pressure tables in predicting the aerodynamic flight characteristics of their aircraft. This technology made possible their successful powered flight on the very first attempt. Without this wind tunnel data the Wright brothers would have fallen short and their historic achievement would have been deferred.

The first manned powered flight (fig. 1) occurred in 1903. The Wright flyer with a span of 40 feet and a length of 21 feet was powered by a four-cylinder, water-cooled engine and had a gross weight of 750 pounds. With a speed of approximately 30 mph, the flyer traversed a distance of 852 feet in 59 seconds. The first flight on that momentous day was only 120 feet. The flyer was controlled by the Wrights' remarkable wing-warping and rudder system.

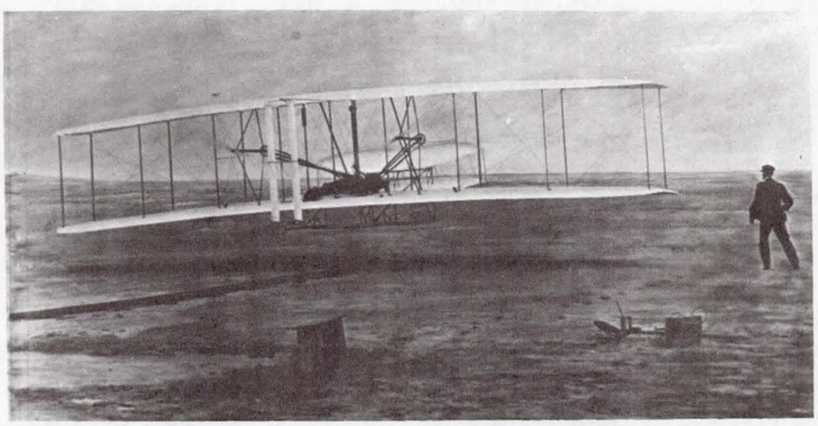


Figure 1. - Wright brothers achieving first manned, powered aircraft flight in December 1903.

To develop the necessary prior technology, the Wright brothers had constructed a wind tunnel (fig. 2) that had a 22-inch cross section and was 5 feet long. A belt-driven propeller, or fan, produced an airstream that moved between 25 and 35 mph. Flow-straightening grids were located at the entrance of the wind tunnel. A force-measuring system (i.e., delicate two-element force balances) was employed to determine forces on the models in the airstream. This test facility was located in the Wrights' Dayton bicycle shop. Functionally, it had all the elements of today's wind tunnels.

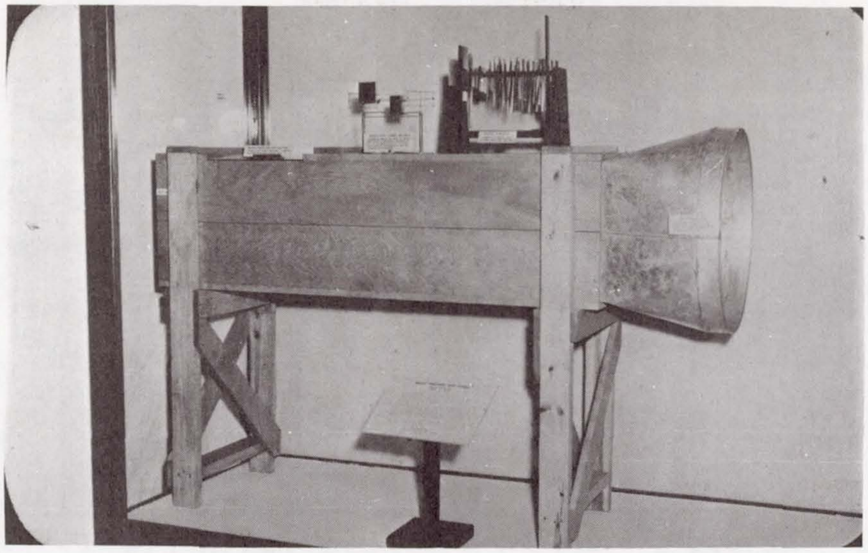


Figure 2. - Wright brothers' wind tunnel.

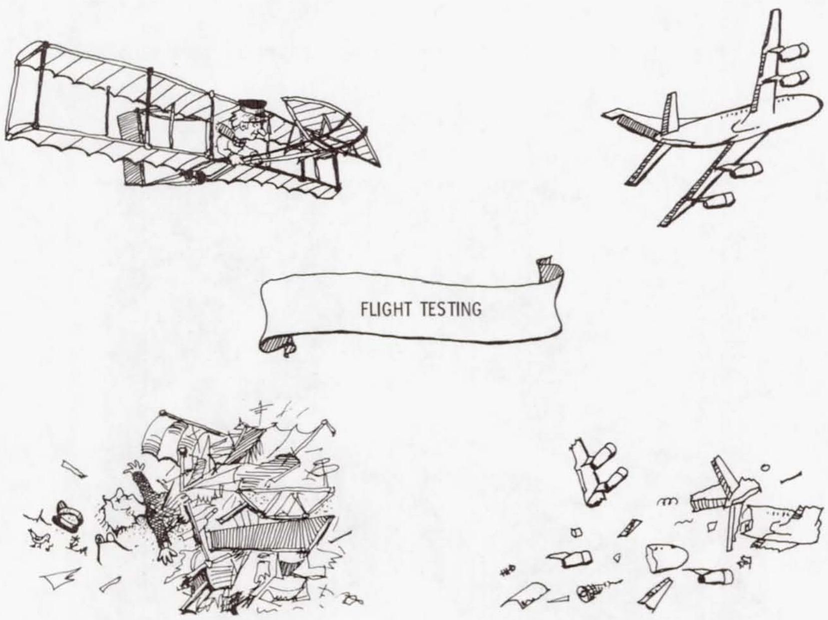


Figure 3. - Flight testing (can be difficult and costly learning process).

The Wright brothers tested more than 200 airfoils in a 2-month period. In their tunnel, they measured lift, drag (or drift, as they called it), and angle of attack over a range from 2° to 45°. They studied the effects on performance of camber, aspect ratio, thickness, curvature, leading- and trailing-edge shape, and upright structural members. This technology was crucial to the design and subsequent success of their flyer.

Flight testing, of course, would seem to be the most direct approach to effecting aircraft performance improvements. However, as illustrated in figure 3, in-flight experimentation can pose major safety and economic problems if the design data base (or technology) has not been sufficiently developed. Keep in mind that aircraft costs today are running in excess of $20 million per copy. In-flight failures could result in loss of lives and cost many millions of dollars.

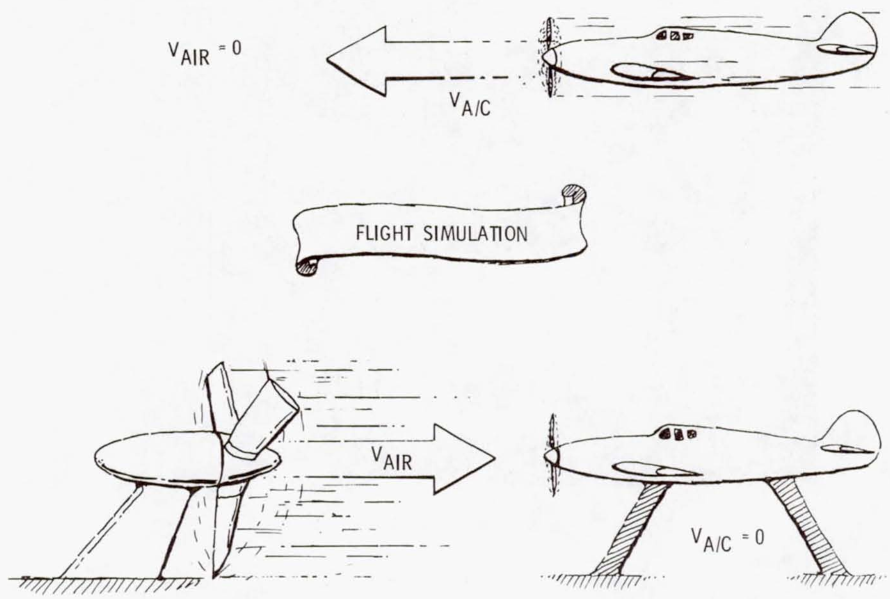


Figure 4. - Flight simulation (can minimize risk of failure and developmental costs).

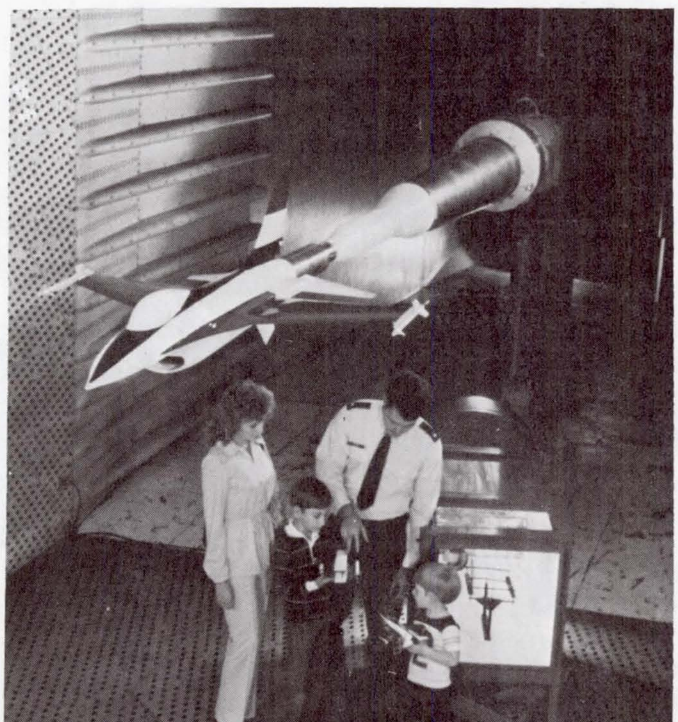


Figure 5. - Aeronautical facilities growth - comparison of 16- by 16-Foot Transonic Wind Tunnel at Arnold Engineering Development Center, Tullahoma, Tenn., containing an experimental model of F-16 aircraft, with a replica of Wright brothers' wind tunnel.

A logical alternative to flight testing is flight simulation (fig. 4), wherein the aircraft model is held stationary and an airstream is blown over it. This situation simulates the aircraft moving through ambient air as long as the relative velocity between the plane and the air is the same. Such a simulation device could be the wind tunnel, which provides a fan, a flow straightener, a nozzle to accelerate the air to the test velocity, a duct to contain and guide the airstream through the test section, a model support system, and a pressure- and force-measuring system. The advantages of ground testing in terms of safety and costs of performance failures are obvious. From the era of the Wright brothers to the present, flight-simulation testing facilities have become the hallmark of the aerospace technology laboratories.

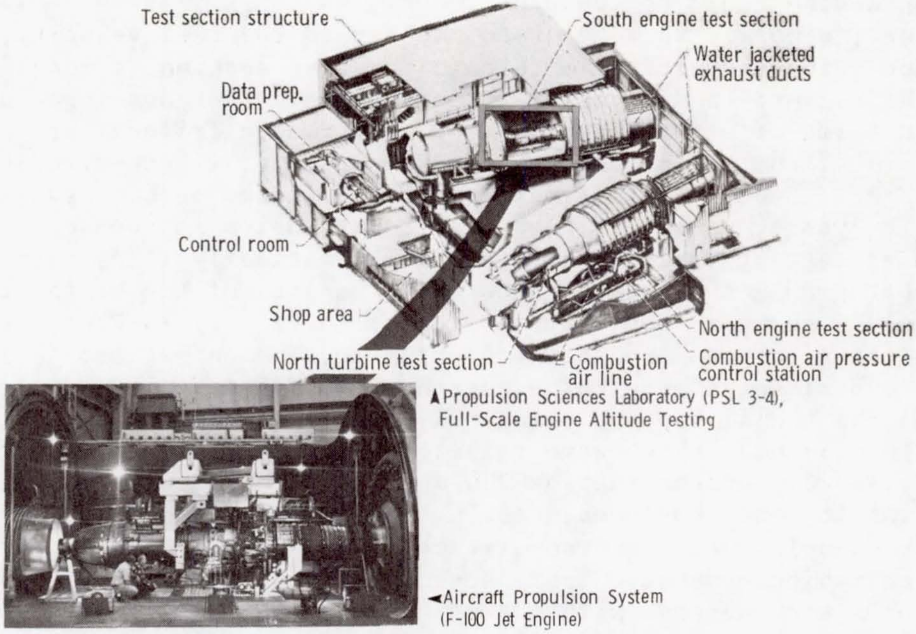
Over the years, there has been a great expansion in the scale of aerospace ground-based testing facilities. This is dramatically illustrated in the notable photograph of figure 5. Therein a replica of the Wright brothers' wind tunnel is shown in the test section of the 16- by 16-Foot Transonic Wind Tunnel at the Air Force Arnold Engineering Development Center in Tullahoma, Tenn. An experimental model of a current F-16 fighter aircraft is shown mounted on the tunnel support sting. A perforated-wall test section has been employed to eliminate shock wave reflections from the walls back onto the model at transonic speeds (approx 700 mph). Note the comparison. Obviously, as the technology has advanced, testing facilities have become much larger in scale, more complex, and more sophisticated. In the area of instrumentation alone, electronics has had a tremendous effect on all facility and data acquisition system designs with recent advances in the use of computers, microprocessors, strain gages, fiber optics, infrared scanners, etc. The effect of the computer and its associated electronics on testing techniques has been profound. The basic concept of flight simulation in ground-based facilities, however, has been preserved since the days of the first U.S. aerospace technology laboratory - the Wright brothers' Dayton bicycle shop.

LEWIS AEROSPACE PROPULSION FACILITIES

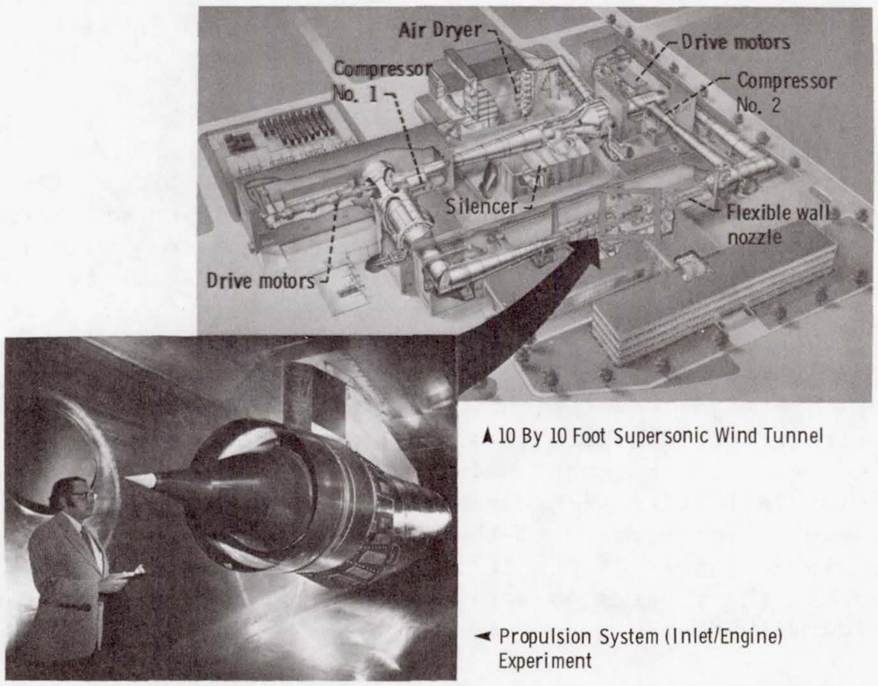
The Lewis Research Center is a NASA laboratory whose prime mission is to develop the technology for advanced aeronautical propulsion or energy conversion systems. Basically, the Center is an engine laboratory with its major activities focused on the development of aerospace propulsion systems technology. Engines, of course, are simply energy conversion systems wherein thermal energy is generated in the combustion process, thereby increasing the total momentum of the exiting gas and producing a propulsive force or thrust on the vehicle. The major Lewis technical facilities (ref. 5) are described herein to illustrate current approaches to simulating anticipated engine flight environments. Both aeronautical (i.e., airbreathing) and space (i.e., rocket) propulsion facilities are addressed. In format, the various facilities are displayed as an overview of the appropriate building complex with an enlarged photographic insert of the test section showing representative research hardware. The program objectives and activities are given briefly to illustrate facility design requirements.

Aeronautical Propulsion Facilities

The Propulsion Systems Laboratories (PSL) are altitude chambers (fig. 6(a)) capable of testing large-scale airbreathing engine systems under controlled simulated pressure altitudes from 5000 to 70 000 feet. The four chambers (only two of which are shown here) are connected to the Lewis central air



(a) Altitude chamber.



(b) Wind tunnel.

Figure 6. - Lewis aeronautical propulsion facilities.

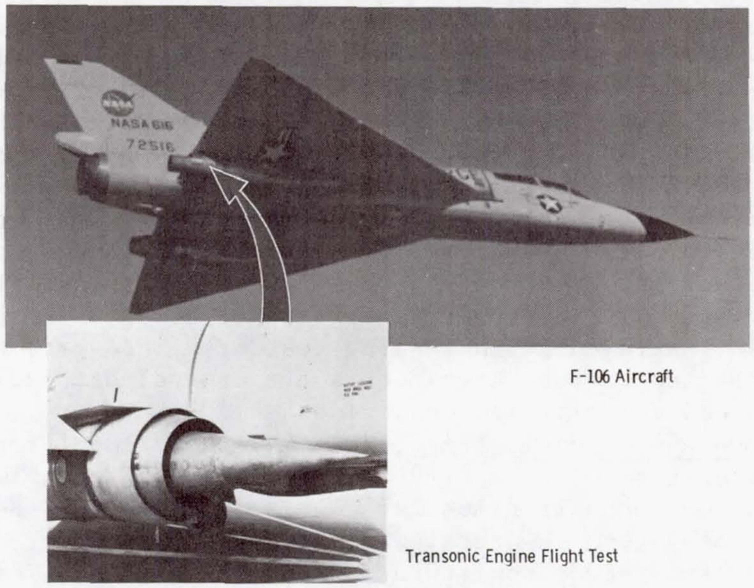
system, which provides combustion airflows as high as 450 lb/sec to the facility at 45 psig. The two chambers are 25 feet in diameter by 40 feet long and can accommodate engines with as much as 100 000 pounds of thrust in their force-measuring systems. System studies are conducted under varying conditions of temperature and pressure at the inlet to evaluate engine thrust, fuel consumption, stall limits, temperature, pressure, flow distortion, acceleration, vibration, and altitude ignition and flameout characteristics.

Shown in the test section (insert) is a current F-100 jet engine, two of which power the F-15 "Eagle" fighter aircraft. The engine is mounted on a force-measuring stand and is connected to a maze of instrumentation lines. Typically such an installation would require about 800 measurement points, with fast-response instrumentation feeding test data into a computer. Electronic pressure and temperature transducers are used almost exclusively for both steady-state and dynamic flow conditions.

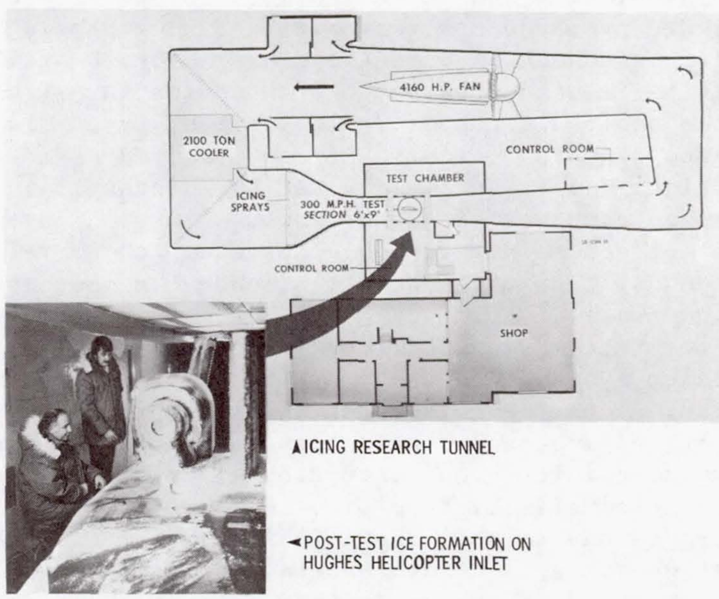
In a propulsion wind tunnel, flight or free-stream conditions of velocity, pressure, and temperature must be simulated for research experimentation with various hot-engine or combustion models. The Lewis 10- by 10-Foot Supersonic Wind Tunnel (fig. 6(b)) can be operated either as a closed-circuit tunnel for testing cold-flow aerodynamic configurations or as an open-circuit, single-pass tunnel for testing large-scale combustion models at Mach numbers from 2.0 to 3.5 (i.e., up to 3.5 times the speed of sound, or about 2100 mph). Altitude (pressure) simulation can be varied from 50 000 to 150 000 feet. Natural-gas heaters are provided upstream of the tunnel nozzle to simulate flight temperatures. Test section dimensions are 10 by 10 by 40 feet. A flexible-wall nozzle varies the area ratio between the throat and the test section to attain the desired air speed. The nozzle side walls are constructed of 1 3/8-inch stainless steel. At each desired speed setting the contour of each vertical wall is precisely set by 28 hydraulic actuators with camshaft controls to an accuracy of ± 0.005 inch. Other major tunnel components include large coolers ahead of each compressor to remove the heats of compression and an acoustic exit chamber to silence the hot, contaminated outflow of combustion tests.

The 10- by 10-Foot Supersonic Wind Tunnel has been designed to accommodate a variety of propulsion system technology studies involving both internal and external aerodynamics. These have included investigations of dynamic interactions between inlet, engine, and nozzle component performances; system control dynamics; dynamic inlet-flow distortion effects; and propulsion system/vehicle integration effects involving engine proximity interactions with nacelle and wing aerodynamics. Shown in the insert (fig. 6(b)) is a supersonic, translating-spike, internal-external compression inlet with an adjustable flow bypass ahead of the compressor of a General Electric J-85 engine. The entire propulsion system is mounted on struts from the tunnel ceiling. From experience it has been found that research data from large-scale engine hardware (approaching full scale) is necessary to establish valid predictions of in-flight performance. Large-scale research hardware demands large, complex testing facilities.

At transonic speeds, wind tunnel models are greatly restricted to relatively small-scale hardware, because of tunnel flow blockage and shock-wave wall reflection criteria. To combat such limitations, a transonic flying test facility (fig. 6(c)) was employed in the form of an F-106 aircraft. In this case the research propulsion system was installed under and partially through the trailing edge of the aircraft delta wing, thus simulating a potential



(c) Transonic flying test bed.



(d) Icing research wind tunnel.

Figure 6. - Concluded.

installation for a supersonic transport aircraft design. The main purpose of this approach was to use much larger scale hardware than would be possible in any existing transonic propulsion wind tunnel. Research objectives were to study engine performance and installation effects (with the inlet and exhaust nozzle immersed in the flow field of the wing) over the transonic speed range. The F-106 aircraft was operated on its main engine until test conditions were arrived at. During the transonic test run the test engine was operated and research propulsion system performance was deduced from changes in aircraft speed and acceleration. The inserted three-quarter rear view is a "plug" nozzle test configuration.

Designed to simulate another important aspect of the flight environment, the unique Lewis Icing Research Tunnel is displayed in figure 6(d). Historically, severe icing conditions at subsonic speeds and low altitudes have imposed heavy restrictions on safe aircraft operations and have dictated the need for efficient icing protection systems. Currently interest in protection against icing hazards is focused on small general aviation aircraft and rotorcraft (or helicopters). There has been an extraordinary growth in the number of these aircraft and a corresponding demand for an all-weather operational capability.

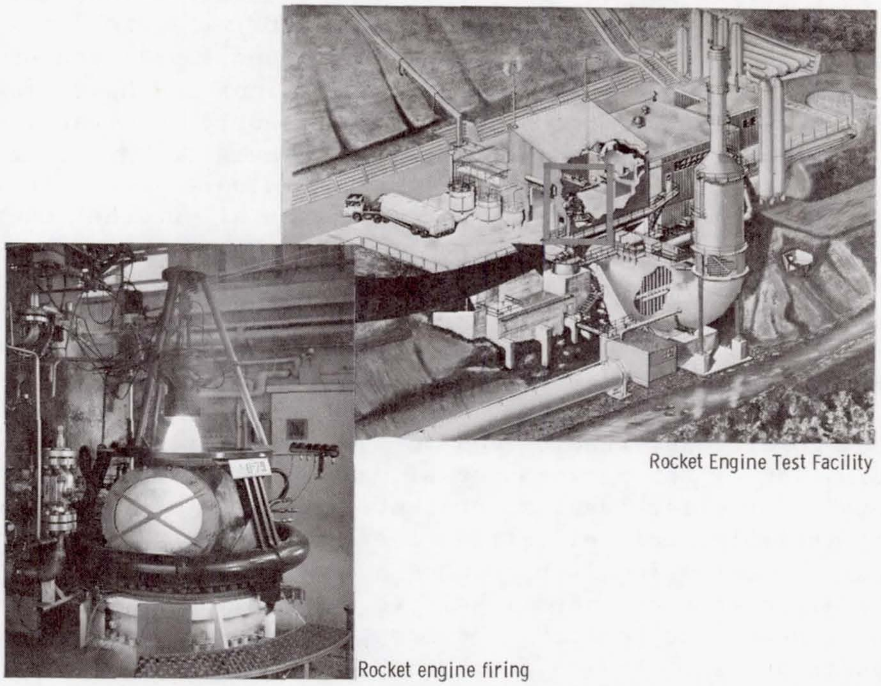
The Icing Research Tunnel is a single-return, closed-throat tunnel with test section dimensions of 6 by 9 by 20 feet and with an air speed range from 0 to 300 mph. Drive motor power is 4160 horsepower. A 2100-ton cooler and a water spray system are located just upstream of the bellmouth and permit the accurate simulation of precise icing conditions in the test section. Under these simulated conditions, studies can be made of the factors and mechanisms of ice formation and of the performance of various proposed anti-icing and deicing systems. For effectiveness, protection systems are evaluated on the basis of being reliable, cost effective, energy efficient, lightweight, and easy to maintain. Conventional approaches are to use pneumatic boots or electrothermal systems on the surfaces likely to be iced. A long-range research goal is to develop an "icephobic," in concept an ideal anti-icing surface agent that has an aversion to ice formation.

As shown in the insert (fig. 6(d)), propulsion system air intakes are susceptible to ice formation. Other components investigated include spinners, wings, radomes, antennas, and instrumentation probes. The advantages of studying and developing solutions to the icing problem in such a ground-based simulation facility are obvious when one considers the risks in terms of aircraft safety of flight experimentation under actual icing conditions. This icing research facility has also been a most valuable tool in the modeling of aircraft crash situations and in Federal Aviation Administration certifications of new aircraft and design modifications.

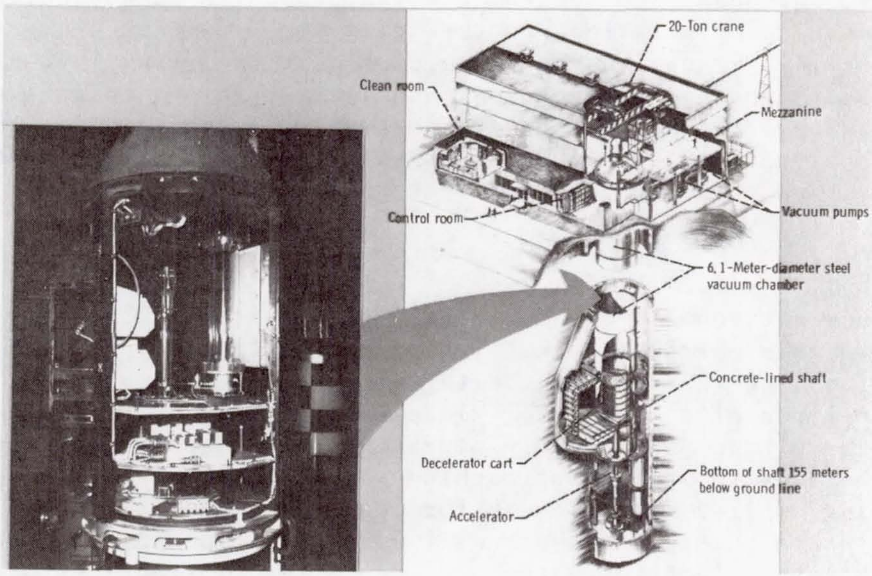
Space Propulsion Facilities

In the space environment the main propulsion system will likely be designed either as a chemical rocket (wherein both the fuel and the oxidant are supplied from the vehicle and the thrust is applied impulsively for relatively short periods of time, usually in seconds) or as an electric rocket (wherein a high-voltage power supply ionizes a heavy monopropellant and accelerates the ions to speeds approaching the speed of light, with the thrust capable of being applied continuously for long periods of time, i.e., years). The thrusts of such chemical rockets will be of the order of many thousands of pounds; and those of electric systems, of the order of fractions of a pound (usually millipounds). Propulsion test facilities have been designed to simulate the hard vacuum, the cold heat sink, and even the weightlessness of outer space. Technology developed in such simulation facilities then feeds into the design of tomorrow's space missions.

The Rocket Engine Test Facility shown in figure 7(a) is a vertically mounted chemical rocket static-sea-level test stand. Chamber pressures to 2100 psia and thrust levels to 20 000 pounds can be accommodated. High-impulse propellant systems (notably, liquid hydrogen and liquid oxygen) have



(a) Chemical rocket sea-level test stand.



PAYLOAD DROP PACKAGE USED FOR FUEL TRANSFER STUDIES

ZERO-GRAVITY FACILITY

CD-81-12792

(b) Zero-gravity drop tower.

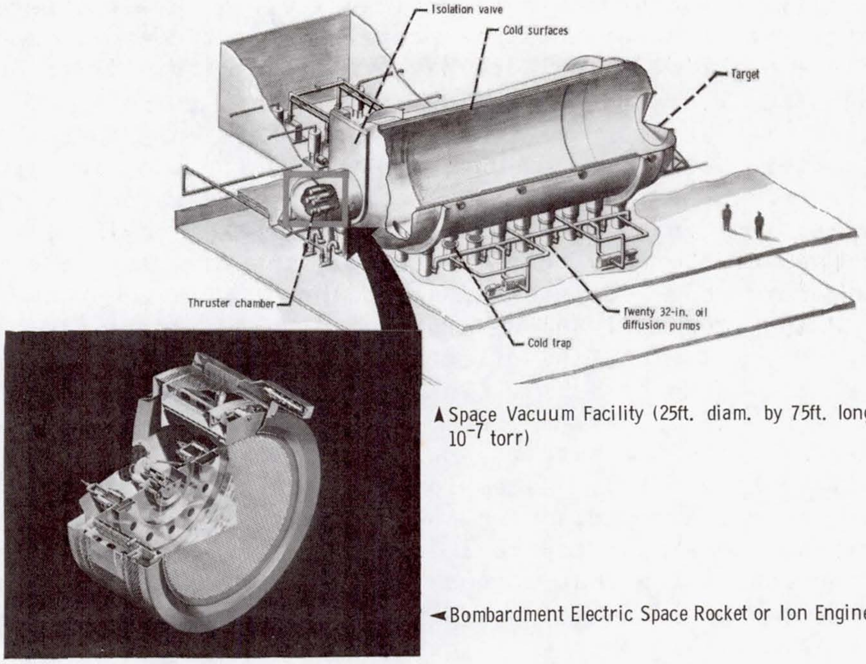
Figure 7. - Lewis space propulsion facilities.

been studied from the heat transfer and chamber regenerative cooling standpoints. Historically, Lewis hydrogen technology (ref. 6) has pioneered the application of hydrogen as an upper-stage propellant in the Apollo and Centaur missions. Other fuels investigated here have included liquid fluorine, liquid hydrogen, and the space storables hydrazine and nitrogen tetraoxide. In this ground facility, simulation of space conditions requires only that the combustion process parameters (chamber pressure, fuel-oxidant ratio, injector and chamber geometries, etc.) are duplicated, that the nozzle throat is choked, and that the nozzle flows full. The insert shows a rocket engine firing down into the water spray scrubber and muffler piping. The facility is complicated by the auxiliary requirements for storage and transfer of high-pressure propellants and for a shop to handle model preparation and installation.

In the foregoing simulation, the effects of weightlessness in space have been neglected or assumed to be small. This assumption, however, is not valid for the case of the partially filled liquid storage tank with a substantial liquid-vapor interface. To simulate the condition of weightlessness, the Zero-Gravity Facility (fig. 7(b)) was employed. This unique facility consists of a test chamber and a 20-foot-diameter, 468-foot-long steel tank with wall thicknesses from 5/8 inch at the top to 1 inch at the bottom. This chamber is installed in a concrete casing that extends 508 feet below grade. Small-scale experimental models can be launched upward via a pneumatic accelerator to the top and then free fall to be caught in a decelerator cart filled with expanded polystyrene pellets that moves into place after the upflight. Experiments mounted behind aerodynamic drag shields and falling freely in the evacuated chamber experience less than 10^{-5}g for 5 seconds; a two-way (or up and down) flight provides about 10 seconds of weightlessness.

Under this simulation of the zero-gravity environment, important technology has been obtained in fluid dynamics. A prime example has been the case of the liquid-propellant ullage tank. On the ground (1g), we recognize that in the half-filled spherical tank liquid would be held by gravitational force within a hemispherical shape at the bottom of the tank. Under zero gravity, however, it was experimentally demonstrated that the vapor ullage volume in a spherical tank assumed a spherical shape in the center of the tank and the liquid volume took on the shape of a spherical annulus around it. In the absence of gravitational forces on the liquid, surface tension forces predominate and control fluid buoyancy. The location of the fluid in the tank is critical to effective engine operations, particularly in the transfer process of moving propellant from the storage tank through a pump system to the injector in the combustion chamber. In flight, the ingestion of vapor would be highly deleterious to system performance (e.g., creating severe pump cavitation and surge and possibly causing loss of the mission). It was demonstrated in the Zero-Gravity Facility that this situation in space could be circumvented by using baffles to control the shape and location of the liquid-vapor interface in the tank. The resultant added surface area would be designed to provide the necessary surface tension forces to maintain liquid at the intake of the pumped transfer line. This also has been proven and demonstrated in the Zero-Gravity Facility.

While the chemical rocket can be called on to operate either in the atmosphere (e.g., launch) or in space (e.g., orbit transfer), its electrical counterpart - the ion engine - is strictly a space propulsion system, capable of operating only in the space environment. Simulation of this environment in a ground-based facility requires the attainment of a hard vacuum and a cold heat sink approaching those of outer space. Such a facility is Lewis' Electric



▲Space Vacuum Facility (25ft. diam. by 75ft. long; 10^{-7} torr)

◄Bombardment Electric Space Rocket or Ion Engine

(c) Electric rocket, space simulation facility.

Figure 7. - Concluded.

Propulsion Space Simulation Facility (fig. 7(c)). It is a large vacuum tank (25 ft in diameter by 75 ft long) with a pumping capability down to 10^{-7} torr accomplished by twenty 32-inch oil diffusion pumps. The inner surfaces of the tank and the target (upon which the ions in the thruster beam impinge) are cooled to liquid-nitrogen temperatures. These cold surfaces are necessary to condense out the heavy ions of the propellant (usually mercury) from the beam.

A representative bombardment ion engine (or thruster) was invented at the Lewis Research Center and is shown in the inserted view. A monopropellant (in this case, mercury) is vaporized on admission to the chamber. There the molecules are bombarded by electrons (emitted from the cathode) and ionized. A high-voltage electrostatic grid accelerates the ions to velocities approaching the speed of light in the exiting beam. In the electric propulsion scheme a relatively small mass of heavy particles is accelerated to very high velocity with great efficiency. Ion acceleration here is not limited by the melting-point temperatures of the containment structure, as is the case with chemical rockets, and can attain very high exit velocities approaching the speed of light. Specific impulse (lb thrust/lb propellant/sec) is of the order of 5000 to 10 000 seconds. In contrast, the specific impulse for a high-energy chemical rocket would be 400 to 450 seconds. The thrust of the ion rocket is generally measured in millipounds and is designed for long-duration continuous application (i.e., years). Long-life components (particularly cathodes, accelerator grids, and power supplies) are obvious current research targets.

In summary, technical facilities that simulate proposed flight environments have been and will continue to be essential tools for researchers in developing the technologies for tomorrow's aerospace propulsion systems and components.

So far, we have merely addressed the physical tools (i.e., the facilities) with which the business of the technology laboratory is carried out. The real strength of the laboratory however, is its people. Each laboratory seems to have a character and personality of its own, reflecting its approach to technology management and ultimately an esprit de corps. This personal team characteristic (involving such elements as motivation, dedication, dogged pursuit of a well-defined goal, and technical execution) was clearly evident in a recent event in aerospace history.

In 1977, a remarkable achievement in aerospace propulsion took place - the first human-powered flight, the flight of the Gossamer Condor. This aircraft, as illustrated in figure 8, was required to fly a figure eight around two pylons, 1/2 mile apart, and to clear a 10-foot-high obstacle at the start and finish in order to qualify for a £50,000 prize from a British industrialist. It had a wing span of 96 feet and weighed 70 pounds empty (or 207 lb with pilot). It was required to take off and land on human muscle power alone. Paul MacCready received the award for his team and Bryan Allen was the competitive bicyclist who provided the leg power and piloting. Later (1979), this same team designed, constructed, and flew an upgraded version, the

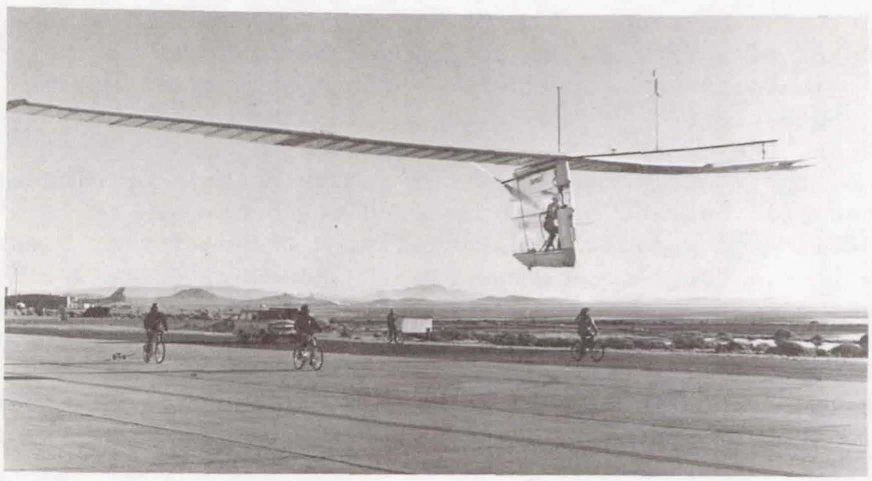


Figure 8. - First human-powered flight, the Gossamer Condor, in 1977. (Subsequently studied at NASA Langley and Dryden Centers.)

Gossamer Albatross, across the English Channel. Philosophically, the team members viewed their assignment as a "challenge to the human spirit" and had approached their task with enormous dedication.

The Gossamer Condor accomplishment, like the space shuttle, was another fine demonstration of technology application. In designing the aircraft, extensive use was made of the current technical data banks in aerodynamics, lightweight materials, computer techniques, etc. The successful translation of demonstrated, proven technology into flight application is the bottom-line "profit" of the research and development business. Moreoever, it is the product of a certain kind of people. Let us examine their modus operandi.

Basically, technology investigations follow a more-or-less systematic logic, described in the engineering schools as the scientific method (refs. 7 and 8) (fig. 9). It is the basic methodology of the research engineer. The systematic approach has been characterized as requiring an almost infinite

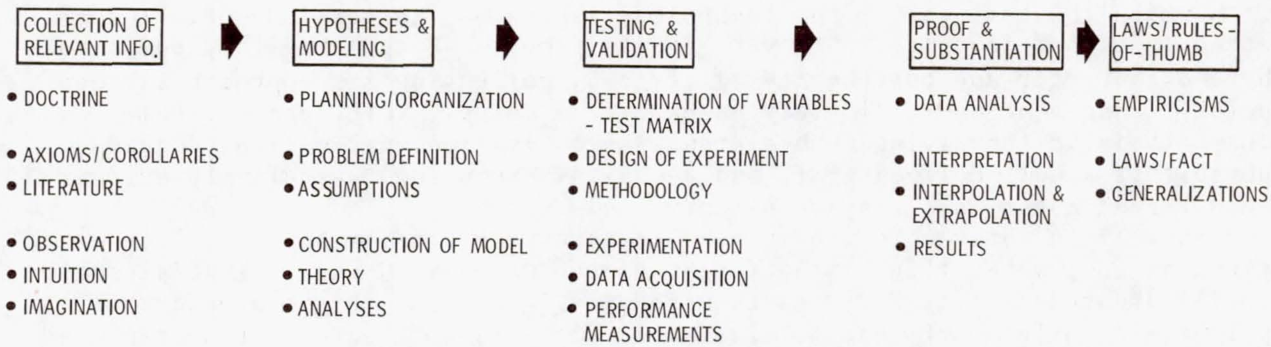


Figure 9. - The scientific method of investigation - methodology.

attention to details. Although optimization and trade-off processes might even be considered at times tedious and plodding, thoroughness is the theme. In general, the method is based on a search of the current literature and an examination of all relevant information. A hypothesis or theoretical model is derived from analyses and a proposition is formed. Comprehensive testing and evaluation procedures are employed to establish substantive proof before research findings can be accepted as physical law or fact. In some cases, full understanding of a flow mechanism may not be obtained, but certain parametric relationships are established through extensive testing. These empiricisms can be accepted as "rules of thumb"; the acceptance criterion being simply that "they work."

In practice, there are many variations in the details or elements of the methodology, and each researcher appears to develop his own sense of order, priorities, and line of attack. Occasionally, a pioneering or breakthrough idea will appear as a "bolt out of the blue." However, these are more the exception than the rule. In the basic science areas, theoretical physicists (ref. 9) by their nature tend to be in a class of their own, particularly those delving into the more esoteric and futuristic technologies (e.g., classical mechanics, relativity, and quantum mechanics). In their quest for the "truth," the great physicists of the past (Galileo, Newton, Einstein, etc.) have not followed prescribed rules of logic, analysis, and procedure; rather they have created their own. An idea in the world of physics has had to be more than right, it has to have a certain philosophic beauty. Indeed, the creativity of the great physicists has been observed to possess both poetic and emotional dimensions.

Insight, imagination, and perceptiveness are essential to research effectiveness and success. Results and conclusions of research investigations are subjected to the close scrutiny and peer criticism of the scientific community. This engenders a certain professional discipline and objectivity in the aerospace technology business.

With regard to the Wright brothers (ref. 10), they were "do it yourselfers" of the first order. Indeed, they were self-taught engineers and, in a span of 32 months, they became the most competent aeronautical engineers in the world. Good (B+) students in high school, they developed their basic mathematical skills and became avid readers of technical publications (including British and French) on aerodynamics and flying (Langley, Mouillard, Chanute, Means, etc.). Their search of the technical literature failed to come up with adequate aerodynamic lift-drag data to enable them to predict

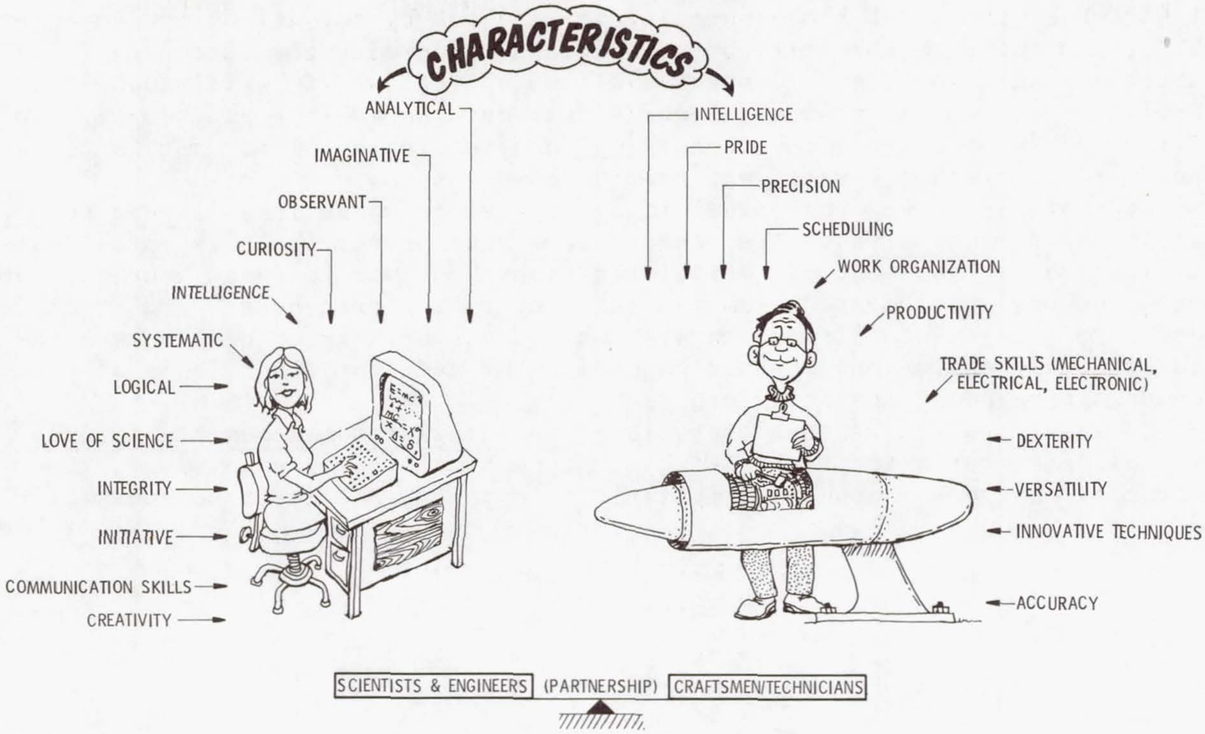


Figure 10. - The research team - people.

flight performance. This led them to their wind tunnel investigations to develop the necessary technology for the design and eventual success of their flyer. In essence, the Wright brothers were also following the basic scientific method of investigation; proof of their design concept occurred with mission success.

Over the years, many dramatic changes in the scale of operations have occurred. Today, an aerospace technology complex such as the Lewis Research Center requires staffing of the order of 3000 people. For organizational effectiveness, clear lines of authority and responsibility, good communications, and teamwork are essential. The research team (fig. 10) can be viewed as a partnership between the scientists and engineers on one hand and the craftsmen and technicians on the other. Each doing his own "thing." Some general characteristics of each are indicated. The professionals are the research (idea) generators: They determine the plan of attack, specify the hardware, prescribe the test requirements, and analyze and report on the findings. They should be strong in analysis and creativity. The technicians are the "doers" of the work: They perform the prescribed mechanical, electrical, and electronic support tasks, organize the work, develop work procedures and techniques, plan and meet schedules; meet quality work standards, and operate and maintain equipment. They should be strong in innovation and productivity. In an optimal organization, there is an obvious balance required between those that generate work and those that do work. The exact balance is difficult to quantify.

Unlike the do-it-yourself Wright brothers, the staff of a technology center must be organized to accommodate a large degree of personnel specialization and a great many professional and technical disciplines. At Lewis, for example, technical facilities management and operations could be represented by the functional block diagram of figure 11. The functions on the right side of the chart represent those normally carried out by scientists and engineers (S&E); and those on the left, by technicians and craftsmen. Because of its centralized air and electric power systems, operations of Lewis' technical facilities are complicated and require intricate scheduling procedures. For efficiency in operations the scheduling function is most important in terms of manpower utilization, costs, and energy conservation.

Undoubtedly, a key ingredient in any system of operations is personnel and management communication. The team concept must prevail. It is vital that all involved in safe and effective operations know who is doing what, to whom, when, and why. Documented team meetings, operating procedures, and schedules feed into management information systems and support direct oral communications. Shift operations further emphasize the need for clear lines of communication among operating groups.

To insure effective team operations, an integrated management approach (fig. 12) is most attractive. With large numbers of people involved, this scheme of management appears simplistic in concept, but it is somewhat dif-

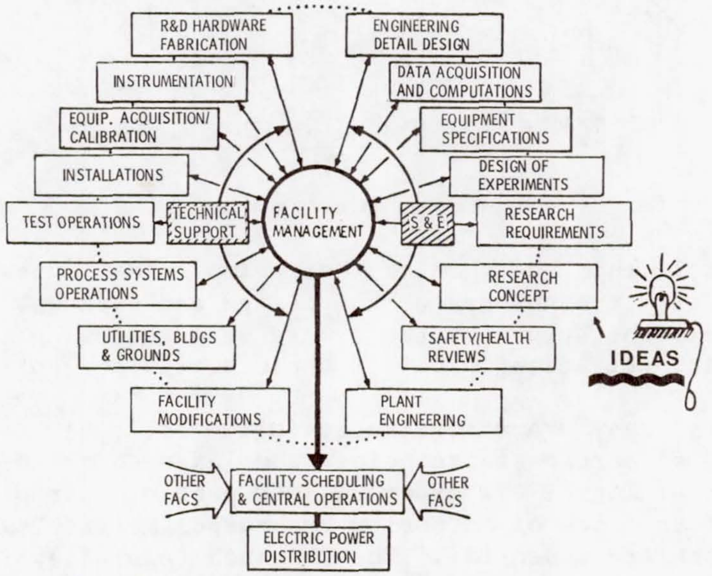


Figure 11. - Technical facilities management - operations.

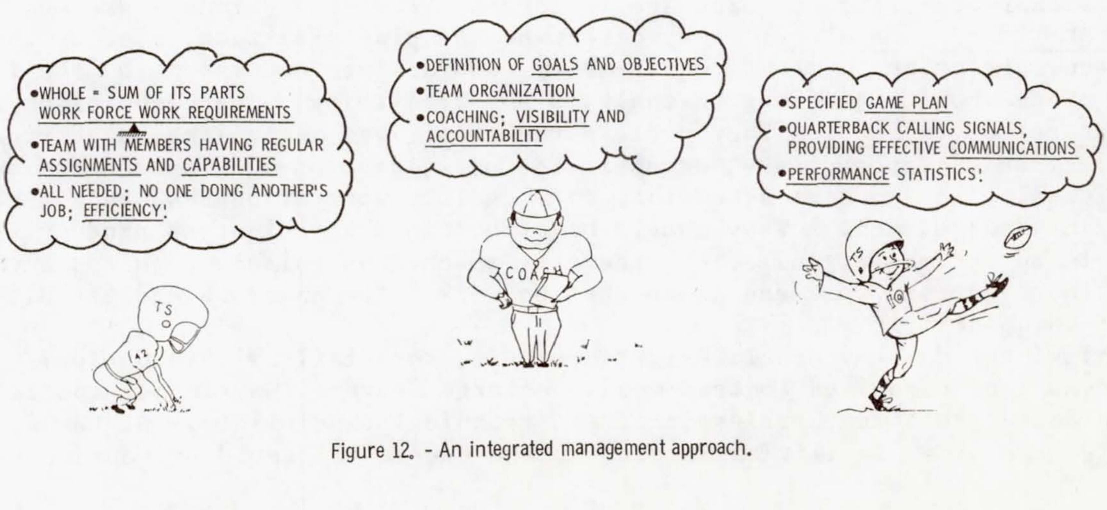


Figure 12. - An integrated management approach.

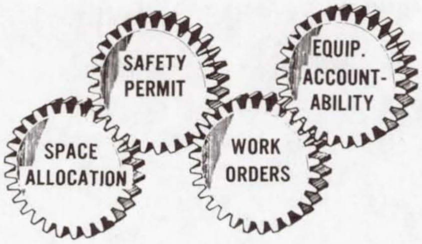


Figure 13. - Operational controls.

ficult to implement. It requires constant attention and effort by management. It touches on all the basics: clear lines of authority and responsibility, well-defined assignments (job descriptions), visibility of and accountability for actions, performance measurement, communication links, etc. What is the end product of all of this, so far as technical facilities operations are concerned? Efficiency, performance, motivation, and recognition - esprit de corps.

Anathema to any operation is an overabundance of ill-defined paperwork. However, some minimum paper requirements that are well conceived and well designed can effect meaningful operational controls. At Lewis, such controls are indicated by the gears in figure 13. These engaged gears reflect the workings of Lewis' operations. For example, the work order is a prescription of specific tasks to be performed; the safety permit is a clearance to operate a rig and signifies that an authorized third-party safety review has been conducted and the safety plan approved; space allocation is a written approval by management to install a rig or set up an operation in a specific area; and equipment accountability is a property management device to control the locations, movement, and custodial responsibilities for all inventoried and controlled equipment. Basically, these operational controls are tools for the effective management of resources (i.e., manpower and equipment utilization).

Today's aerospace technology center is a complex operation requiring staffing with significant numbers of research professionals and technical support personnel. Management efforts must be directed toward development of the team approach, stressing personnel awareness and two-way communications. Motivation and dedication of personnel contribute to the bottom-line goals of efficiency and productivity on one hand and innovation and creativity on the other.

CONCLUDING REMARKS

The dramatic changes that have taken place in aerospace technical facilities since the accomplishment of powered flight by the Wright brothers 78 years ago have been detailed in this report. For illustration, the aeronautics and space propulsion technology facilities of the NASA Lewis Research Center have been described. These facilities are basic tools for the researchers and are designed to simulate the rigors of future flight environments. The key ingredients of the modern aerospace technology laboratory are identified in the following outline:

(1) Research and technology mission

(a) Scope, direction, goals, and objectives
(b) Resources, management, and organization

(2) Technical team (unique people with experience and know-how)

(a) Professionals (scientists and engineers)
(b) Technical support staff (skilled trades and crafts persons)
(c) Contractor and industry partnership

(3) Facilities (unique mission-related testing capabilities)

(a) Environmental simulations
(b) Technical support shops
(c) Administrative facilities and housing

(4) Output (product)

(a) Technology information to scientific community (test data, evaluation and analysis, component and system performance)
(b) Technology demonstration projects

Over the years the laboratory has grown enormously in both size and complexity as aerospace technology has expanded. Facility staffing requirements are correspondingly large in number and involve a wide spectrum of professional disciplines and technical skills. Organization, management involvement and participation, and team communications have become increasingly important in today's technical facilities operations.

Looking into the crystal ball, we might ask what does the future hold for the aerospace researchers in their quest for improved meaningful simulations of the flight environments. The remarkable developments of aerospace technology, to date, have led to increased understanding of the mathematical and aerodynamic equations of motion that describe the airflow over components and aircraft systems. With the potential power of the modern large computer, flight simulations and the proving out of new design concepts will to a much larger extent be accomplished electronically (i.e., by computers). A new professional discipline, computational fluid mechanics, has been established and appears to offer great promise for future progress. Wind tunnels, as discussed herein, will not be eliminated but will diminish perhaps in need as the power of analysis becomes increasingly evident.

REFERENCES

1. Augustine, Norman R.: Weapon Systems Trends. Astronaut. Aeronaut., v. 19, no. 6, June 1981, pp. 28-33, 75-76.
2. Gibbs-Smith, Charles H.: The Aeroplane; Historical Survey of Its Origins and Development. London, Her Majesty's Stationery Office, 1960.
3. Baals, Donald D.; and Corliss, William R.: Wind Tunnels of NASA. NASA SP-440, 1981.
4. Exploring in Aeronautics. NASA EP-89, 1971.
5. Technical Facilities, Lewis Research Center, National Aeronautics and Space Administration, 1981.
6. Sloop, John L.: Liquid Hydrogen as a Propulsion Fuel, 1945-1959. NASA SP-4404, 1978.
7. Beveridge, W. I. B.: The Art of Scientific Investigation. Rev. ed. Norton, 1957.

8. Newell, Homer E.: Beyond the Atmosphere, Early Years of Space Science. NASA SP-4211, 1980.
9. March, Robert H.: Physics for Poets. Second ed. McGraw-Hill, 1978.
10. Ritchie, Malcolm L.: The Research and Development Methods of Wilbur and Orville Wright. Astronaut. Aeronaut., v. 16, July/August 1978, pp. 56-67.

1. Report No. NASA TM-82754	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle THE AEROSPACE TECHNOLOGY LABORATORY (A PERSPECTIVE, THEN AND NOW)		5. Report Date February 1982
		6. Performing Organization Code
7. Author(s) James F. Connors and Robert G. Hoffman		8. Performing Organization Report No. E-1070
		10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Today's technology laboratory consists of uniquely trained and experienced staff and specialized testing facilities. There people with particular technical expertise, knowledge, motivation, and analytic methods conduct systematic, innovative, and creative research. In advancing the essential basic and applied technologies for future flight systems, experiments are conducted in specialized ground-based facilities designed to simulate the rigors of tomorrow's proposed flight environments. The dramatic physical changes that have taken place in aerospace facilities since the Wright brothers' accomplishment 78 years ago are highlighted in this report. For illustrative purposes some of the technical facilities and operations of the NASA Lewis Research Center are described. These simulation facilities were designed to support research and technology studies in aerospace propulsion.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
The Aerospace Propulsion Technology Laboratory; Wind tunnel facilities; Propulsion facilities; Flight simulation; Space simulation; Altitude chambers; Operations	Unclassified - unlimited STAR Category 09

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22161

National Aeronautics and
Space Administration

Washington, D.C.
20546

Official Business
Penalty for Private Use, $300

SPECIAL FOURTH CLASS MAIL
BOOK

Postage and Fees Paid
National Aeronautics and
Space Administration
NASA-451

U.S.MAIL

NASA

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return