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Aerospace in the Future

John F. McCarthy, Jr.

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John F. McCarthy, Jr.
Lewis Research Center
Cleveland, Ohio

Keynote address presented at CECON '80
Cleveland Convention Center
Cleveland, Ohio, May 20-21, 1980

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AEROSPACE IN THE FUTURE*

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The theme today is "Aerospace in the Future." I would first like to show some trends on the national scene, then what Lewis Research Center is doing on the research and technology (R&T) base that is being established and will be very important in the late 1990's, and finally some predictions on what we think will happen.

Figure 1 shows what typifies the 1980's - accelerated change and improved communications. The R&T base is being established at a slower rate than we would like, and it is being used up so fast that unless we replenish it we will be behind other nations.

Figure 2 shows another trend that is typical of this time period - the complexity associated with new systems. Because decision time decreases constantly and because of the complexity of new systems, the cost associated with these systems is increasing very rapidly. For example, Pratt Whitney and General Electric are developing a new aircraft engine for commercial transports, and they have to invest about $1.5 billion. Boeing is developing the new transport aircrafts 747, 757, and 767; their investment is about $10 billion. So, literally, companies are investing their entire worth in new projects. This means that the R&T base has to be very sound before anyone will take that kind of risk.

Let us look at what is happening in the Federal government - in particular, NASA.

The Federal budget outlays amount to about 20 percent of the gross national product. This does not vary more than a half of 1 percent in any given year. What is changing with time is that less and less of the Federal budget is controllable (fig. 3). For example, in 1967 about 59 percent of the budget was uncontrollable; this means that you would have to change the laws in order for it to be spent in different areas by the Administration. This amount increased to over 73 percent in 1977 and over 76 percent in 1980. So, in an election year, when a budget squeeze is on, the pressure becomes greater and greater on an agency like NASA, which has a budget that is completely controllable. Also, the President and the Administration have less and less flexibility. For example, in 1980, about 14.4 percent of the controllable budget was for national defense. Because of the troubled world situation the President can not reduce the national defense budget. So, the only area he can change in controlling the budget without changing the laws is the remaining small 9.6 percent of the Federal budget.

Figure 4 shows the Federal budget outlays as functions of time; unfortunately, these are current dollars and most of the increase is due to inflation. Actually, the Federal budget in constant dollars is a modest cost. We can see where the money is going: payments for individuals, other nondefense outlays, and national defense, a rather constant outlay except that it is being eaten up by inflation much like the NASA budget is.

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*Keynote address presented at CECON '80, Cleveland Convention Center, Cleveland, Ohio, May 20-21, 1980.

Figure 5 shows the proposed budget for FY 81. Over the last 20 years the shift in the Federal budget has gone from national defense to payments for individuals, particularly welfare. For example, the amount for national defense has gone from about 50 to about 24 percent of the budget, while payments for individual welfare and other subsidies have gone from about 20 to 43 percent of the budget. Also, there is the interest payment on the national debt. It has gone up by a factor of 10 to 20, and in 1981 the interest consumes close to 10 percent of the budget. When people ask about NASA being a big spender, particularly for the space program, we point out that we spend less than 1 percent of the Federal budget and that the interest on the national debt is 10 times this amount. But, since we are a small spender and are controllable, we have a very difficult time defending our budget.

Another trend that I would like to discuss is what is happening to oil. Everyone knows that oil prices have gone up. Figure 6 gives a quantitative picture of the rate. In 1970 crude oil prices ranged from $1.78 to $3.18 a barrel. This has gone up to $26 to $40 a barrel in about 10 years, and no one knows where it will end.

Another concern is our dependence on foreign oil. Figure 7 shows the U.S. oil imports as a function of time. We import almost 50 percent of our oil from foreign sources. The downward trend shown in the figure means we are using less foreign oil in recent years because of the dramatic rise in gasoline prices. This trend toward conservation is desirable, and many R&T efforts are being pursued to insure that it continues.

Now, how is this petroleum used? Figure 8 shows the percent of petroleum used by major sectors as a function of time. Almost half of our petroleum is for surface transportation, diesel and gasoline fuels. Today, aviation only consumes about 6 percent. Some very dramatic gains have been made by NASA and industry to lower the fuel consumption of aircraft. Now, if this can be done for surface transportation, we have a multiplication factor of about seven to accomplish even greater savings. Indeed, a lot of work is being done on this problem. NASA's charter has been amended by Congress to allow us to work on terrestrial energy problems. Consequently, we have some very interesting terrestrial energy projects at Lewis.

Another trend is our balance of trade, and I would like to show why the U.S. must spend money on research and development. Figure 9 shows the balance of trade in billions of dollars as a function of time. For the first time in U.S. history, we had a negative balance of trade in 1971. Although our balance of trade oscillated for a couple of years, since 1976 it has been negative, reaching almost $40 billion, and there seems to be no end in sight. Everybody blames this problem on foreign oil. Few people realize that over $10 billion of our negative balance of trade is due to importing cars and trucks. This is partially offset by the aerospace balance of trade; in 1979, we realized a $10 billion positive balance of trade in this industry. Thus, a significant means of controlling inflation in this country, as far as our economic future is concerned, is research and technology (R&T). Lewis is a R&T center so we feel that many of the things we are doing can help to slow the rate at which inflation grows in our country and keep this nation a great place in which to live.

At Lewis, our emphasis is on the gains that can be made from our R&T in space, aeronautics, and energy. In the aeronautics field, figure 10 shows the plateaus in air and space transportation systems. NACA/NASA has gone from pioneering the aeronautical technology for airplanes pioneering to the astronautical technology for the space shuttle, which will be the workhouse of space transportation.

The Lewis Research Center is the lead NASA center for aeronautical propulsion. We are working on individual components like the high efficiency turboprop shown in figure 11. We have been getting 80-percent efficiency at Mach 0.8 with this new propeller. Because of deregulation of fuel pricing and the emphasis on fossil fuel consumption, this R&T work is of particular interest to the airlines and the aerospace industry. We have some very basic technology areas of study. Measuring internal aerodynamics as shown in figure 11 with a laser Doppler velocimeter lets us look at the flow distribution in a compressor or turbine while it is turning without interfering with the flow. We take full-scale engines, put them in test cells, and do research on such things as controls. This research helps us understand how systems interact. We also consider ourselves a center of excellence on high temperature materials R&T. One of the reasons that aeronautical propulsion has advanced over the last decade is because materials have been developed to withstand higher and higher temperatures. Turbine inlet temperatures now run at about 2500° to 3000° F.

At Lewis Research Center, we have all the disciplines shown in figure 12. This is why some consider Lewis to be one of the R&T aeronautical propulsion centers of excellence in the country. We are using these disciplines not only for aeronautics and space but also for terrestial energy, which we will discuss later.

Figure 13 shows quantatively some of the fuel efficiency improvements that have been realized in aeronautical propulsion. If you consider the first commercial turbojet of the early 1950's, we have realized a 40-percent improvement in relative specific fuel consumption. These improved engines are flying today, and this is only the beginning of the advancements being made.

Today's modern turbofan engine that is used on commercial jets (fig. 14) shows that we have already made a 5-percent savings in fuel consumption in a very short time. We have launched a long-term conservation program, and our R&T efforts have developed an energy efficient engine that will get an 18-percent improvement over today's engines. The advanced turboprop mentioned previously will realize at least a 33-percent fuel consumption improvement; this is of particular interest because of fuel pricing deregulation.

Lewis is also working on reducing aircraft noise (fig. 15). In the 1950's aircraft caused a lot of unhappiness by generating noise near the threshold of pain at 120 decibels. Intensive R&T has reduced engine noise to a more tolerable 97 decibels with future plans to get this down to 95 decibels. This is very dramatic when you realize that a decibel is a logarithmic measure of intensity.

Figure 16 shows a QCGAT; this is a quiet, clean, general aviation turbine engine that is being developed at Lewis in conjunction with industry. Notice all the "spaghetti" around the engine. This "spaghetti" is part of the sophisticated instrumentation and electronics needed for engine performance testing and noise research. And because of our electronics sophistication at NASA Lewis, we are also involved with satellite communications, another field to be discussed later. The Cleveland area is rapidly becoming not only an area of excellence for heavy mechanical machinery and tool equipment but also an area where sophisticated electronic equipment is being developed.

A typical application of the engine shown in figure 16 is the Beech-Lycoming general aviation airplane shown in figure 17. This airplane uses the QCGAT turbofan engine with its low specific fuel consumption, low noise,

and very, very low pollutants. This engine will indeed improve our environment considerably!

Another example of engine R&T being done at NASA Lewis is the work on vertical takeoff and landing engines. Figure 18 shows such an engine in one of our wind tunnels being tested for air flow and stability. These studies will help keep runways short so airports will not need as much land.

NASA Lewis is also doing R&T in the helicopter business (fig. 19). One of the prime thrusts is to improve the reliability of helicopters. Our goal is to get the mean time between overhaul up from 700 hours, which is the current figure, to over 4000 hours using the aeronautical disciplines shown in figure 12. These studies involve transmissions, shafts and couplings, gears, seals, lubricants, bearings, traction drives, and hybrid transmissions. Improvements in each of these will, when put together, give us a more reliable machine.

Helicopter R&T has been a proposed new start for NASA for several years. We are working with our sister centers Langley, Dryden, and Ames where helicopter vertical takeoffs and landings and rotocraft are also being studied. Figure 20 shows a concept that is being developed in conjunction with the Navy, a so-called "X-wing rotocraft." Here the wings rotate like a helicopter for vertical takeoff and landing, but in high-speed forward flight they are rigidly fixed. So the propulsion system essentially changes from turboprop to turbojet. It looks like a very promising concept; the chief problem, of course, is the propulsion system.

Figure 21 shows some examples of what NASA Lewis is doing in space R&T. Our mission in the space program is space propulsion and associated space technology. We developed the Centaur engine which is currently used in the Atlas Centaur launch vehicle. The Atlas Centaur Launch Vehicle Program is managed by Lewis.

We are looking at advanced engines for manned flight between near-Earth orbit and higher geosynchronous orbit. We have developed electric thrusters for planetary travel. NASA has started work on the Comet Rendezvous Mission planned for 1985 which is a typical application for these thrusters.

We are also looking at very low thrust chemical rockets (fig. 22) to exploit the capabilities of the space shuttle for large space structures. A typical application for these low thrust rockets would be in building and moving a big antenna in space. Then we could finally realize the cartoonist's concept of a Dick Tracy watch communication system. Figure 22 also shows structures being assembled in space that could be controlled by using the low thrust chemical rockets developed at the Lewis Research Center.

We at Lewis are not in the development business. We are in the R&T business. We work with industry as a team to develop a new product. When it is ready, we transfer that technology either to a mission center or to industry. Figure 23 shows a good example in advanced electrical propulsion R&T. In this figure are some of the thrusters we have developed in our facilities at Lewis. The large tank on the left is where we simulate space, such as vacuum and radiation conditions to test the electric propulsion device which uses mercury as a working fluid.

A proposed space application of this technology shown in figure 24 is the Solar Electric Propulsion System (SEPS), which is an engine for planetary missions. The NASA proposed spacecraft is to rendezvous with Halley's comet using 10 of these thrusters to propel scientific instruments and a solar array to study the comet close up. In addition, Lewis does all the solar power R&T for the agency. I mention this because of our new assignment in electronics and instrumention. NASA Lewis has recently been awarded

the mission of Satellite Communications Research and Technology. Figure 25 shows the Earth surrounded by existing and planned communication satellites as of January 1979. Although this chart is a little out of date, you can see that space is becoming crowded with communication satellites.

The present trend in satellite design is to put the high cost, sophisticated devices in the satellites and to use low-cost ground stations. Because of this, the power used by a satellite is increasing very rapidly. Quantitatively, figure 26 shows the trend in satellite power in watts as a function of time. The Communication Technology Satellite (CTS) was developed by Lewis in conjunction with the Canadians; this was a very successful experiment.

Figure 27 shows the ground terminal cost plotted logarithmically as a function of electric power. Our Communication Technology Satellite (CTS) benchmark is at about $8000 for 200 watts. Figure 28 shows what the CTS looked like in space and the region of the Earth that participated in this 14-gigahertz uplink and 12-gigahertz downlink experiment. The CTS was successfully launched in January 1976 with an expected design life of 2 years. The mission for CTS was successfully completed in October 1979.

Now, let us go to some new exciting things that are being done at NASA Lewis in the communications area. During 1978 and 1979, Western Union Telegraph Company and ITT conducted studies for Lewis to forecast telecommunications traffic demand for the period 1980 to 2000. The results of these combined studies are shown in figure 29. The total long-line communications market is expected to reach 10,000 equivalent 36-megahertz transponders by the year 2000. About 3000 equivalent transponders could be served by satellite systems with an expected capture of about 2000 transponders. The total C-band and K_u-band capacity will reach saturation in about 1990. Further growth in satellite communications services will require the introduction of 30/20 gigahertz systems.

NASA Lewis is also working on a 30/20 gigahertz communications project. The schedule for the systems being planned is shown in figure 30. The experiments and communications payload for spacecraft-A have been chosen to permit an early 1986 launch within acceptable development cost and schedule risk. The experiments and communications payload to satisfy the balance of the project objectives will be demonstrated in mission-B. A common spacecraft bus will carry each communications payload.

NASA Lewis has initiated procurements to provide the key communications technology elements needed to support these flight systems. Figure 31 identifies the elements of the technology program: a traveling wave tube, two new transmitters, a low noise receiver, a multiple beam antenna, a switch matrix, a bankpass processor, and low-cost ground terminals. Technology consultation and support of antenna technology will be provided by NASA Jet Propulsion Laboratories and Langley Research Center. Communications R&T will lead this nation to future satellite communication systems (fig. 32) and geostationary platforms (fig. 33) that will have a dramatic inpact on our economy.

NASA Lewis as an energy conversion center is also working on terrestrial energy R&T (fig. 34). Active R&T programs are being worked on for wind turbines, photovoltaic power systems, and automotive propulsion. Not many people realize how much energy can be harvested from the winds available in our nation. Figure 35 shows the annual U.S. average wind power. The dark regions have demonstrated excellent ability to produce wind power. Machines are being made to put this natural resource to work (fig. 36). The Mod-0 machine in Sandusky, Ohio, generates 100 kilowatts of electrical

power; three Mod-0A machines are in operation generating 200 kilowatts; and we have the Boeing Airplane Company and other contractors working on a 2500-kilowatt machine. We can visualize in the near future wind turbine farms spread throughout our nation harvesting the wind and saving fossil fuels.

Our wind turbines (fig. 37) are relatively small when compared to the Washington Monument. The Mod-0 and Mod-0A machines are 100 feet from the ground to the top of the nacelle and have 125-foot downwind blades; the Mod-1 machine is 135 feet tall with 200-foot blades; and the Mod-2 machine is 200 feet tall with 300-foot blades.

For air electric power generating system to be used by industry, it must be cost competitive; after all we must show a profit to the stockholders. Figure 38 shows that wind turbine technology is becoming a tough competitor especially as the costs of coal and oil go up. The Mod-0A wind turbines are able to generate electric power in a 15-mph site mean wind speed for about 38¢ per kilowatt-hour. Mod-1 got this cost down to 18¢ per kilowatt-hour, and Mod-2 got it down to 9¢ per kilowatt-hour. We figure that a mature product can reach 3¢ per kilowatt-hour. Coal-fired powerplants now generate electricity at about 4¢ per kilowatthour.

Lewis is doing R&T on photovoltaics - another process of obtaining electrical energy directly from the Sun. Figure 39 shows five examples of electric power systems operating directly from solar energy: the Schuchuli, Arizona, system generates 3500 watts from 24 solar panels; the Upper Volta, Africa, system generates 1800 watts from 12 solar panels; Lewis has about 50 panels of various kinds that can generate about 100,000 watts; Lassen, California, has a 1000-watt, 4-panel system installed in a forest rangers station; and Phoenix, Arizona, has a 500-watt, 2-panel system operating a traffic sign. Unfortunately, solar energy is not yet economically competitive with fossil fuel. Solar energy systems can generate electricity at about $1.25 per kilowatt-hour compared to the 3¢ or 4¢ for wind or coal. But, in places where electric power is not available by other means, it does indeed make sense. We are, of course, working on decreasing the cost.

I stated earlier that aircraft consume about 6 percent of the petroleum we use and surface transporation consumes about 45 percent; thus, there is a 7 to 1 improvement ratio. We expect very dramatic gains in reducing the fuel consumption of aircraft. If this same thing can be done with the automotive engine, this nation will be using a lot less oil. At Lewis we are working on two main thrusts, one of which is the automotive gas turbine engine (fig. 40). We are working as a team with, for example, General Motors, AiResearch, and Detroit Diesel Allison on such an engine. Using technologies associated with aeronautics for automotive gas turbines (low emission combustors, ceramics, gas bearings, turbomachinery, bearings and seals), we expect to develop an R&T base in automotive gas turbines in about 5 years. Our Government recognizes the importance of this research work and will supply the front-end R&T money. Eventually, industry will take over this technology and develop methods to go into production. The big 'if' is whether we can solve all the R&T problems. There are some technology problems in reliability, maintainability, producibility, and fabricability - things having to do with good design practices. One big technology challenge is to get a low cost ceramic material for the turbines and to obtain materials for an exhaust component that will give 80,000 miles of useful life from our R&T base in aerospace propulsion. Economically, this R&T makes good sense. In automotive development, it is essential to get low cost, high temperature materials; ceramics seems to be the right key for that technology.

In the meantime, we are getting field experience with gas turbines. Figure 41 shows a Detroit Diesel Allison gas turbine engine that is installed in a GM truck. This truck is being driven around the country with a gas turbine engine for field experience. We are also using gas turbine engines in Greyhound buses that run between Philadelphia, Baltimore, and Washington. And the Baltimore Transit System has installed one of our gas turbine engines for field experience. A lot is being learned from these demonstration vehicles.

In a parallel development we are looking at Stirling cycle engines. A Stirling engine is similar to a steam engine, but instead of steam we use hydrogen as the working fluid. This technology resides in Europe. We have a prime contract with Mechanical Technology, Inc. (MTI), and MTI has subcontracts with United Stirling of Sweden and American Motors General. Figure 42 shows a Stirling engine cross section and a field demonstration car with a Stirling engine installed in it. When we demonstrated this car to Washington officials, it burned kerosene, gasoline, and Bacardi rum with equal ease. We had almost zero pollutants and reasonably good efficiency for this demonstration. This is a good example of how independent nations can join our teams to develop an R&T base that is good for all involved.

We are also doing work in electric vehicles using our technical capabilities in motors and controllers (fig. 43). We have a road-load simulator test facility at Lewis where we can test the electric propulsion systems using electronics rather than local highways to punish the cars. With a change of tape, the electric propulsion system is subjected to a variety of road conditions. The big technology problem with electric cars is the batteries. NASA Lewis is working on batteries for space applications but not for terrestrial applications. Argonne Laboratories has that charter. We do have the responsibilities for the electric motor, controls, and power transmission. The electric vehicle may never be competitive with the internal combustion engine because of the range problem. The present range for an electric car is about 70 miles. The Department of Energy (DOE) hopes to increase this range to about 100 miles. This 100-mile range is where an electric car would become useful to the average American family as a second city car. In addition to these projects, we have others which I do not have time to mention.

There is one other very exciting project that we are working on at Lewis that is useful to Clevelanders. We are an energy conversion center at Lewis in the broadest sense, so we consume a lot of energy. We are working with the Cleveland Electric Illuminating Company (CEI) on a coal gasification cogeneration concept to generate electric power (fig. 44). We take high sulfur Ohio coal and convert it to electricity and steam with almost zero pollutants. The products are pure sulfur with a little bit of shear ash, electricity, steam at very high thermal efficiency. We would like to build a cogeneration plant at Lewis to supply our own energy needs and give the surplus energy to CEI. Here the problems are institutional and legal, not technical. We're ready technically, and this is why we are excited about the project.

In summary, figure 45 shows that in the 1950's and 1960's in the aerospace business the drivers were Higher, Faster, and Farther. Today the name of the game has changed to Economy, Energy conservation, and Environment, particularly noise and pollutants (fig. 46). The Lewis Research Center is contributing energy conversion R&T to help fulfill these national needs. Figure 47 shows how we do it with the team approach by working with other government agencies, a variety of universities, industry, and the many dif-

ferent users. Of course, we look to the users to help us identify our national needs - at present, they are environment, economy, and energy. Remember, NASA as an agency is doing this for about 0.8 of 1 percent of our national budget.

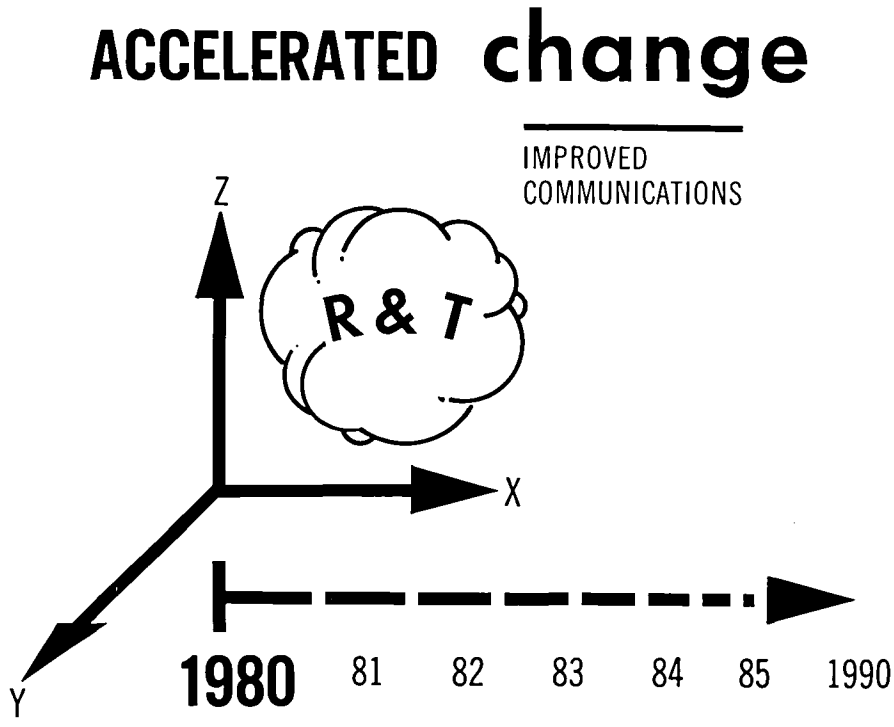


Figure 1. - What's happening in the 1980's.

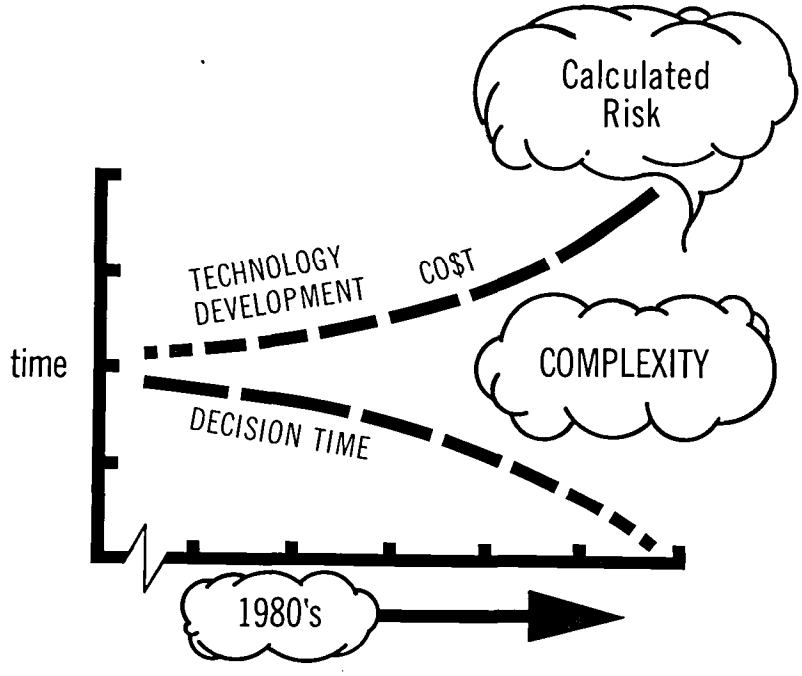


Figure 2. - The R&T Game.

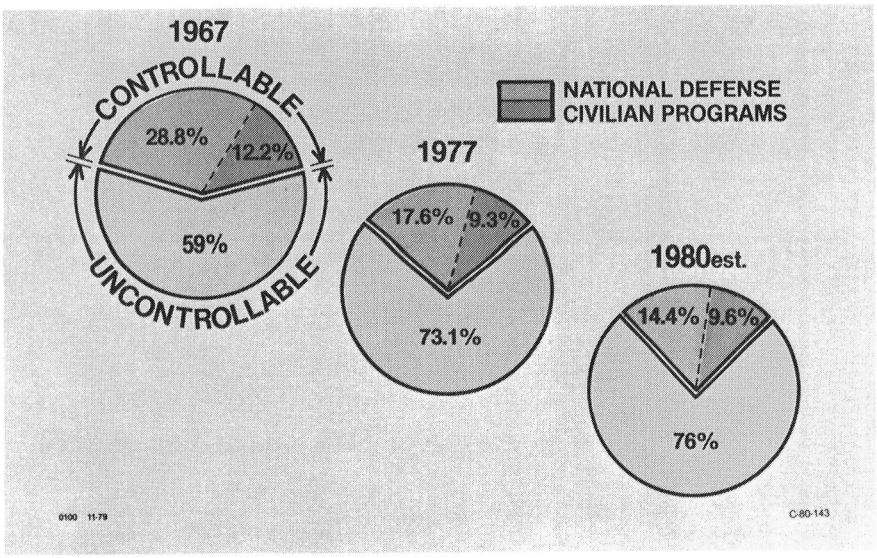


Figure 3. - Controllability Federal budget outlays.

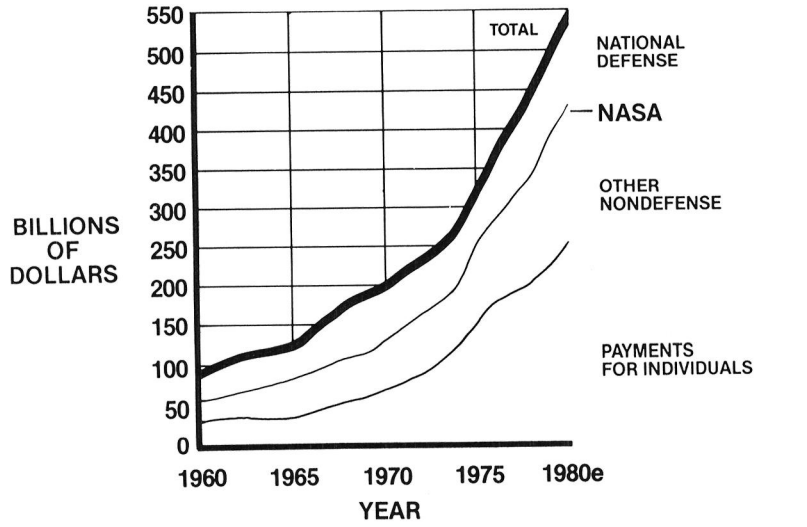


Figure 4. - Federal budget outlays.

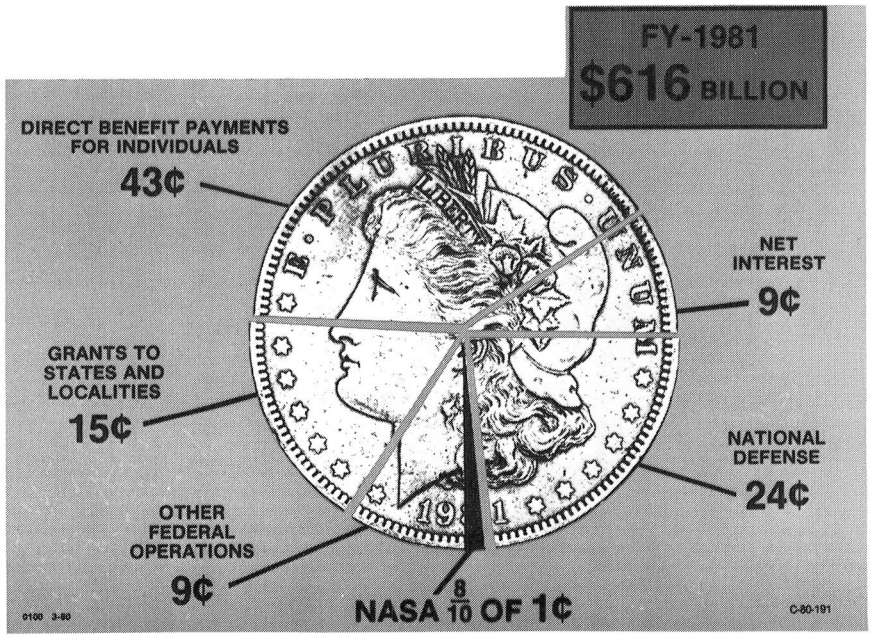


Figure 5. - NASA in the Federal budget dollar for FY 81.

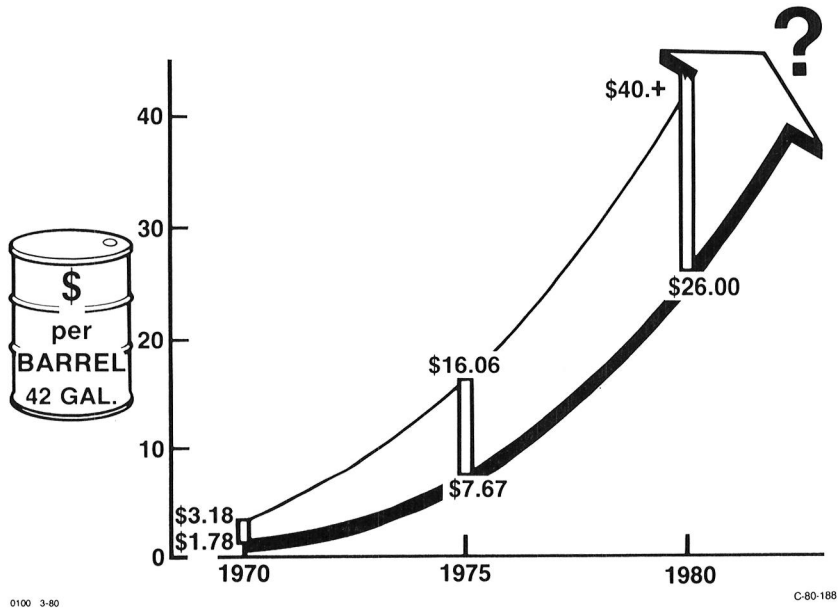


Figure 6. - Crude oil prices.

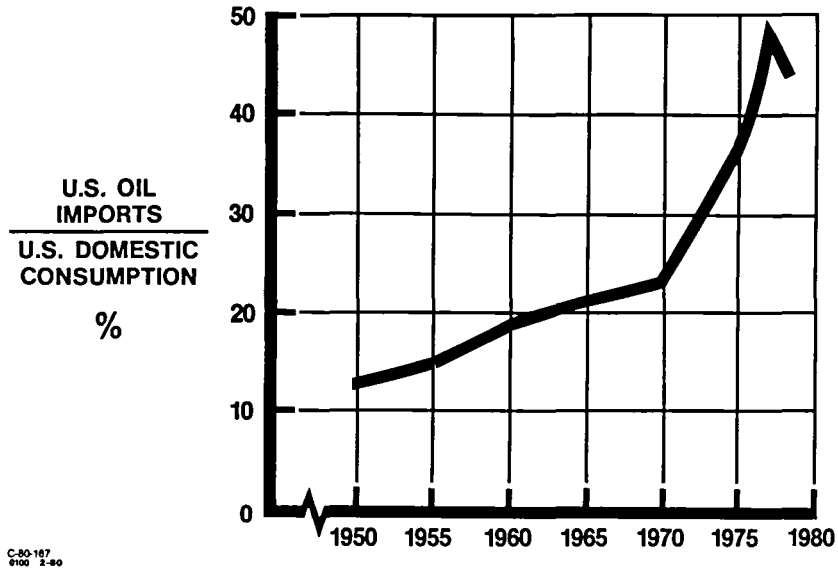


Figure 7. - U. S. dependence on foreign oil.

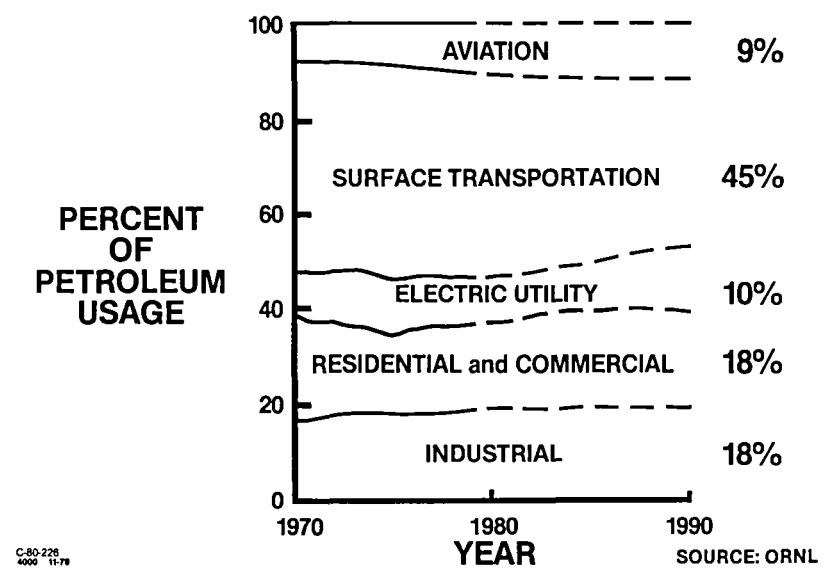


Figure 8. - U. S. petroleum use by class.

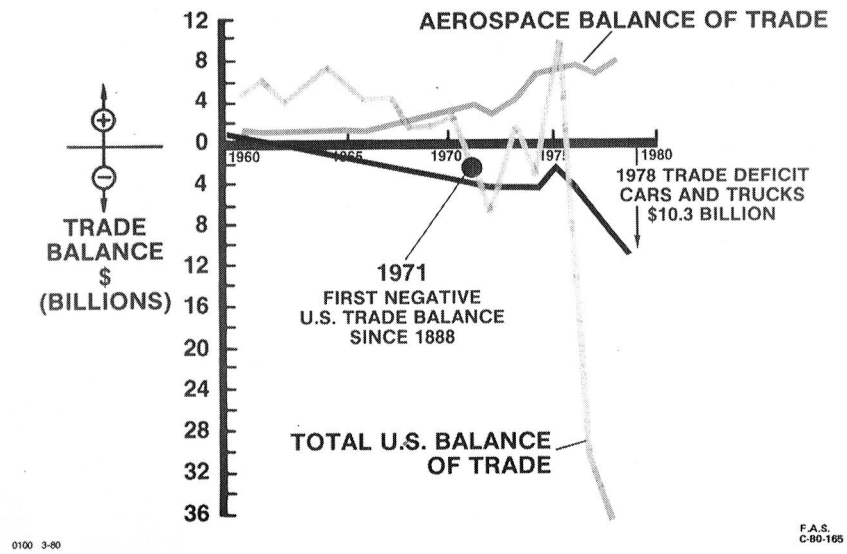


Figure 9. - Aerospace and the U. S. balance of trade.

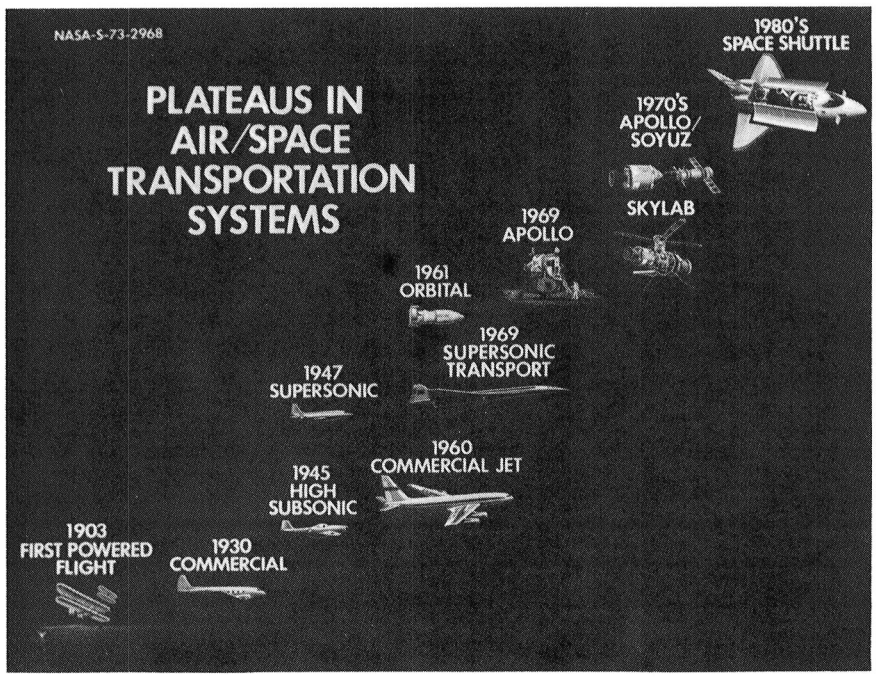


Figure 10. - Plateaus in air/space transportation systems.

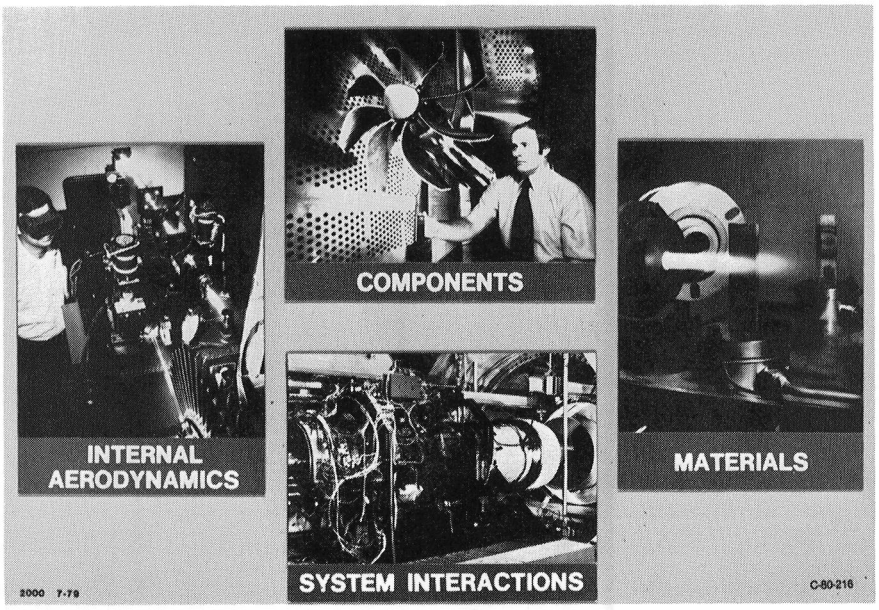


Figure 11. - Aeronautical propulsion R&T.

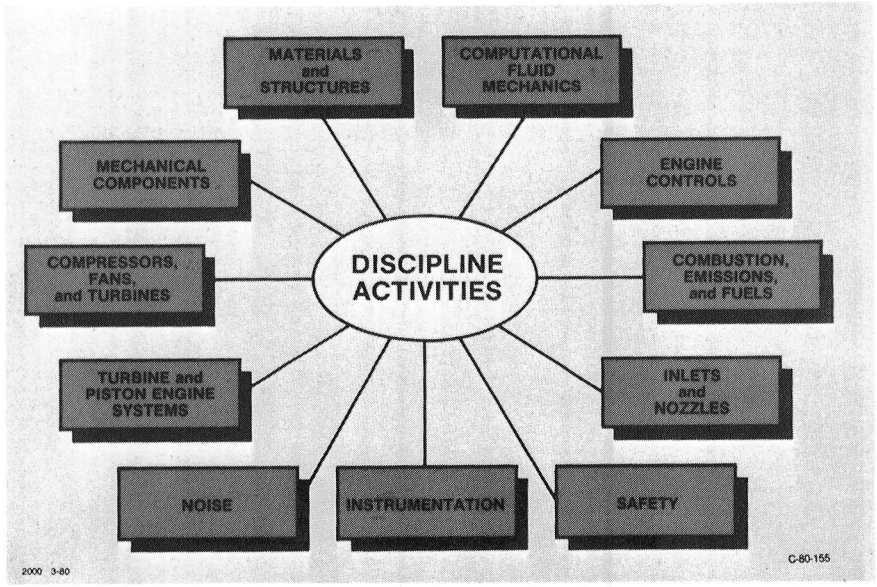


Figure 12. - Aeronautical propulsion discipline activities.

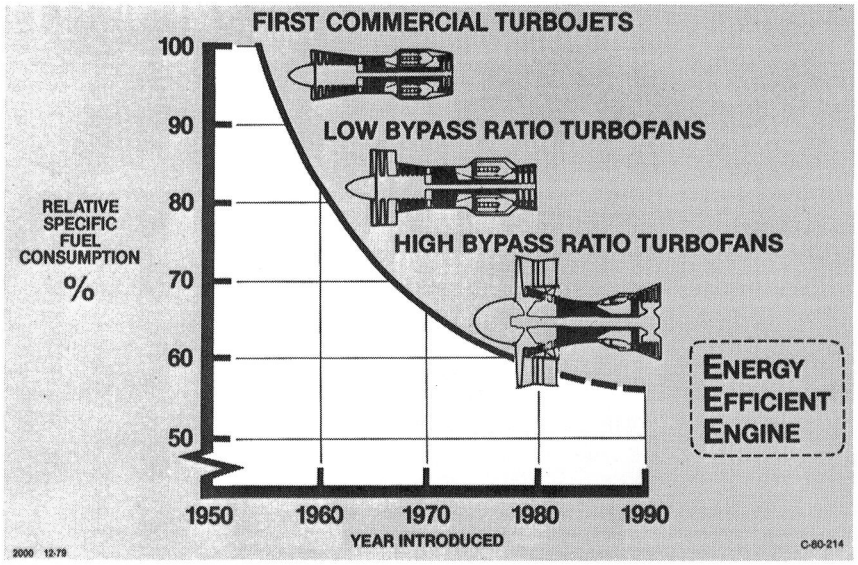


Figure 13. - Improvements in turbofan fuel efficiency.

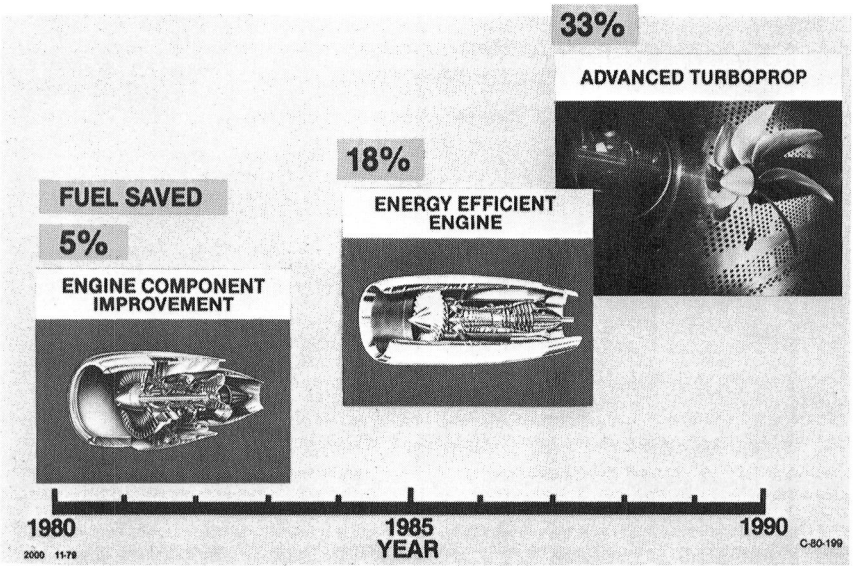


Figure 14. - Energy efficient propulsion technology.

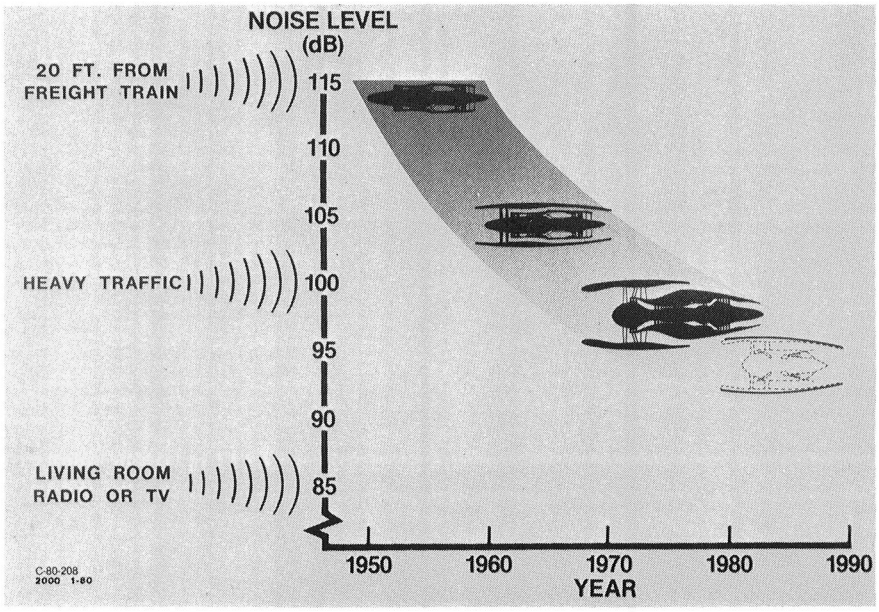


Figure 15. - Aircraft noise reduction.

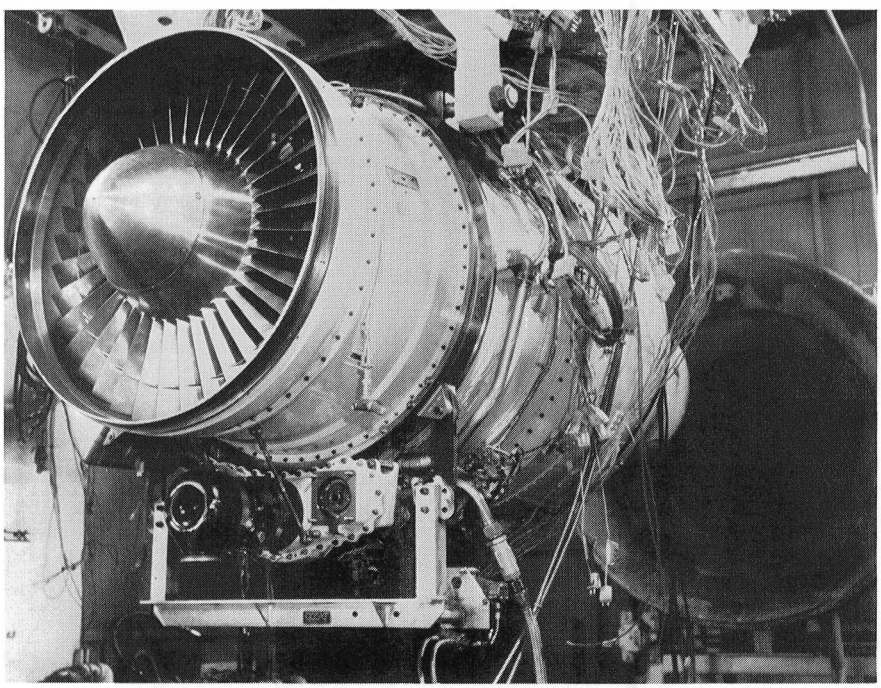


Figure 16. - Quite, clean, general aviation turbofan engine (QCGAT).



Figure 17. - Beech-Lycoming.

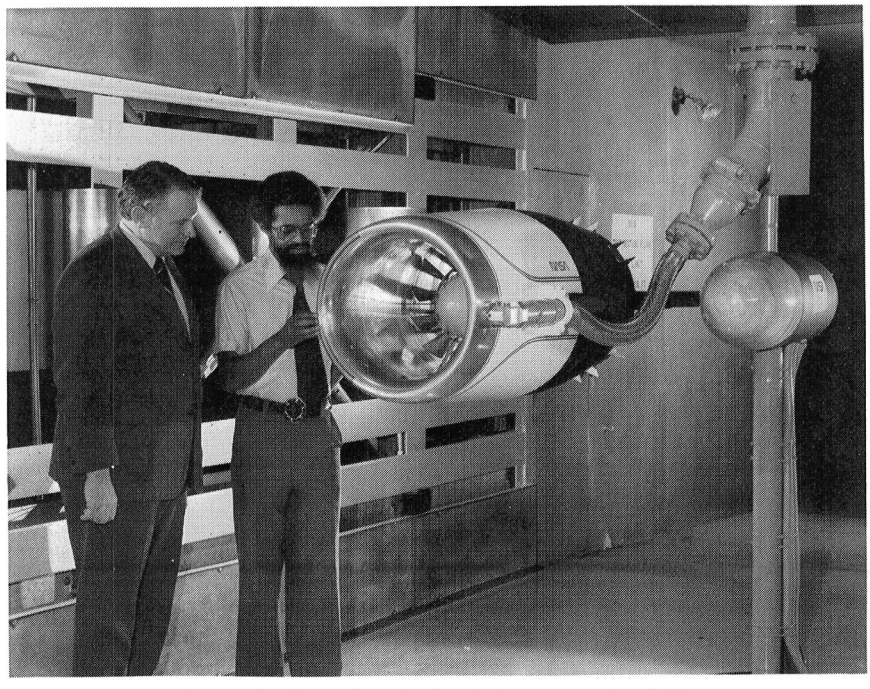


Figure 18. - Vertical take-off and landing turbofan engine in wind tunnel.

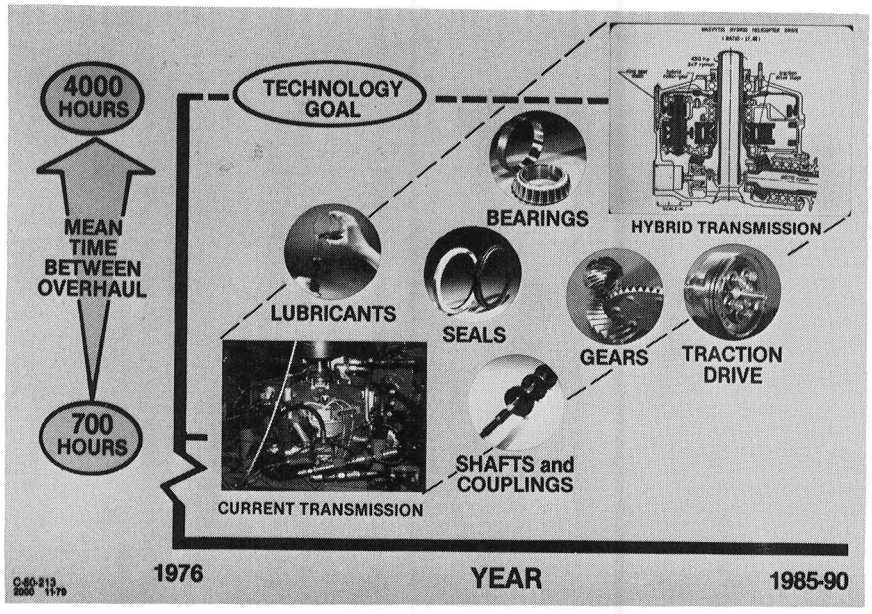


Figure 19. - Helicopter transmission R&T.

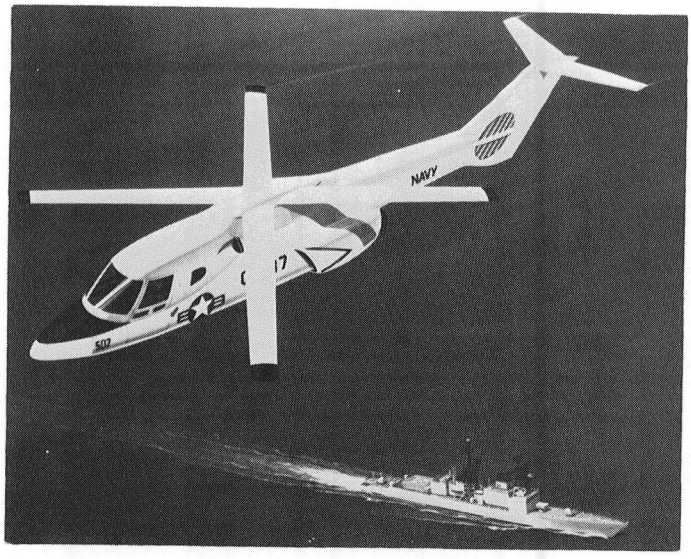


Figure 20. - X-wing rotorcraft.

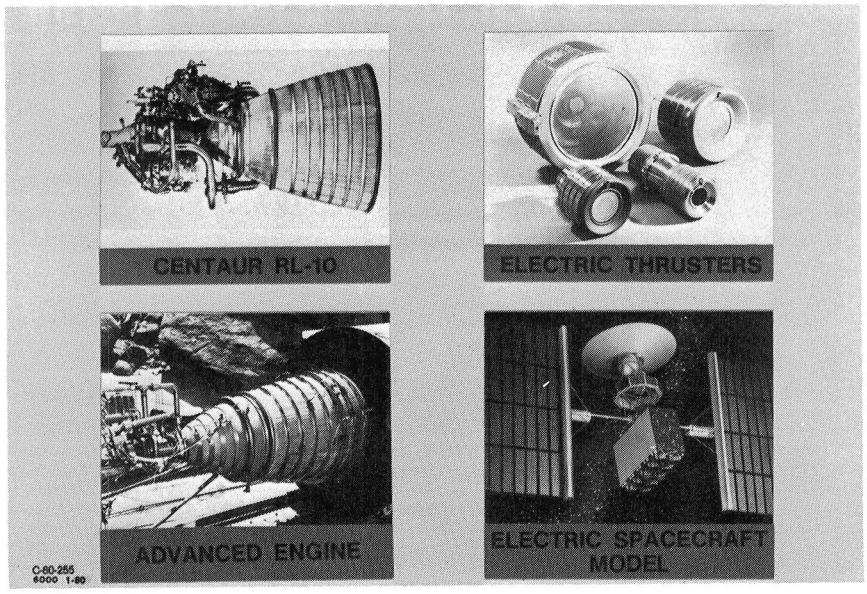


Figure 21. - Space propulsion R&T.

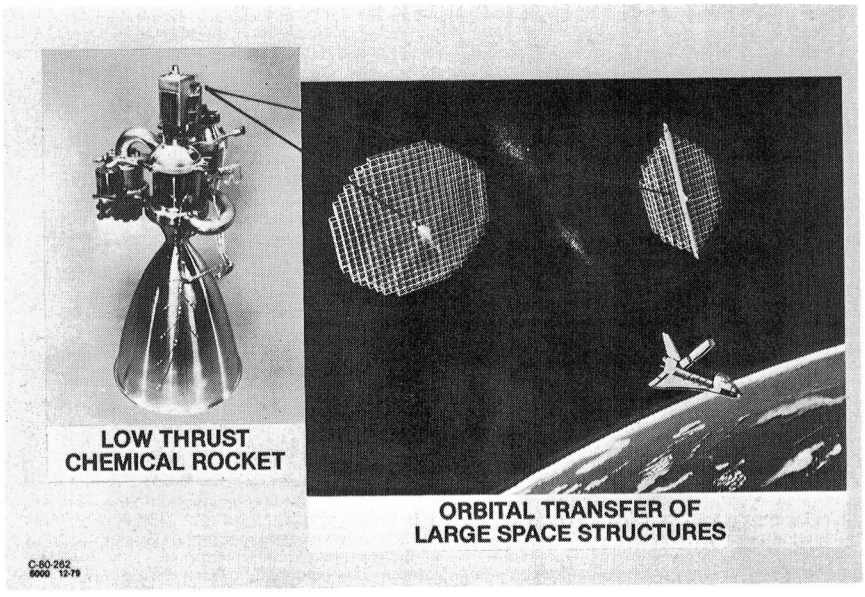


Figure 22. - Advanced space propulsion R&T.

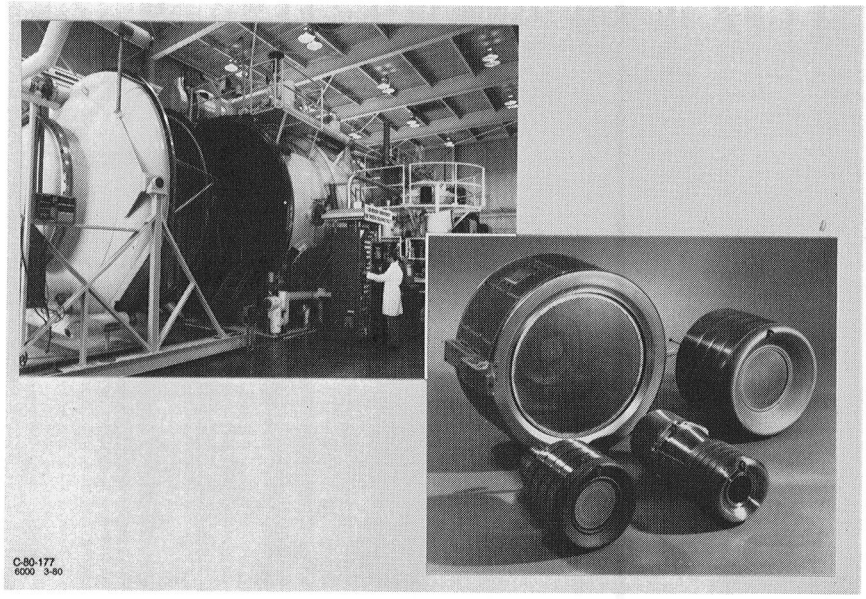


Figure 23. - Advanced electric propulsion R&T.

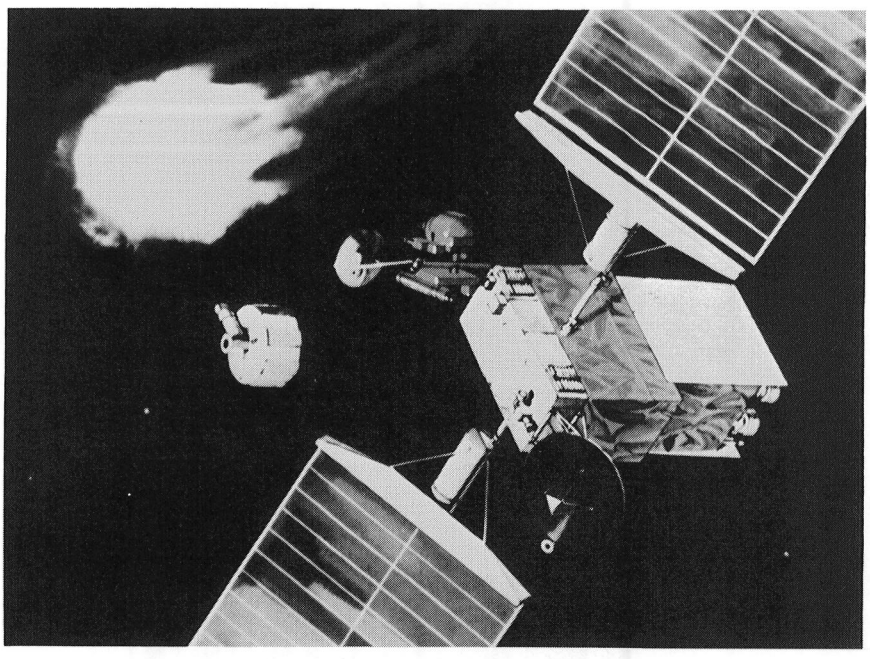


Figure 24. - Probe deployment at Halley's comet.

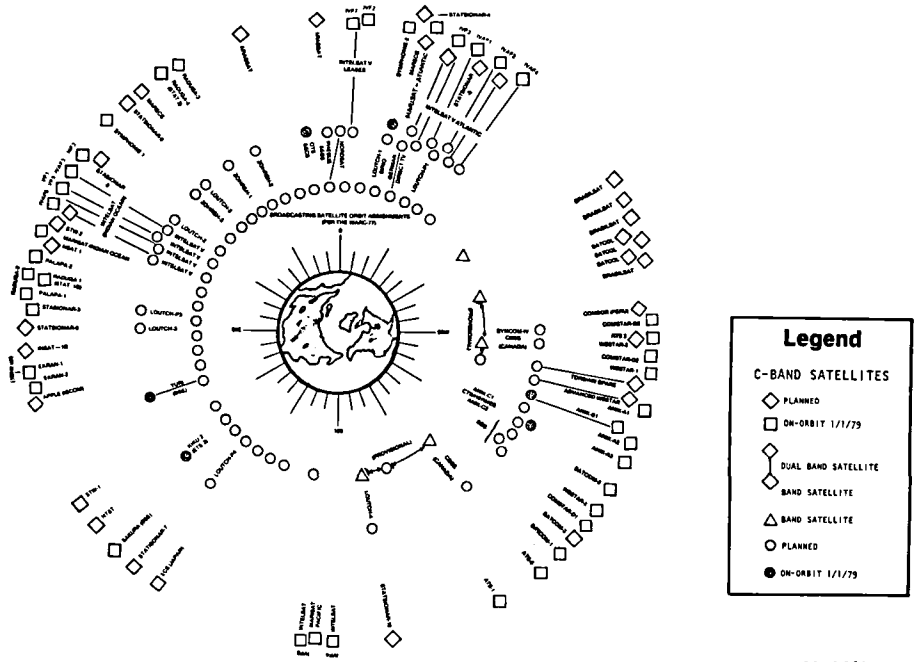


Figure 25. - Global satellite stations.

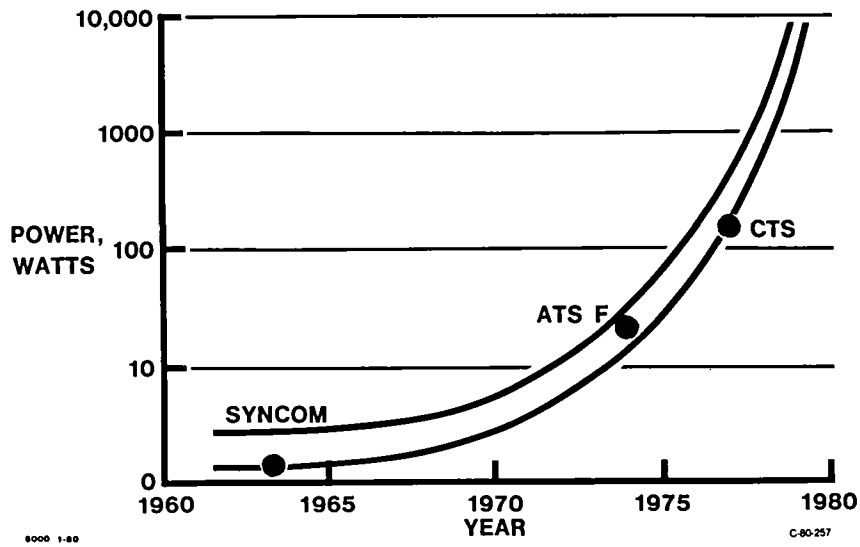


Figure 26. - Trends in satellite power.

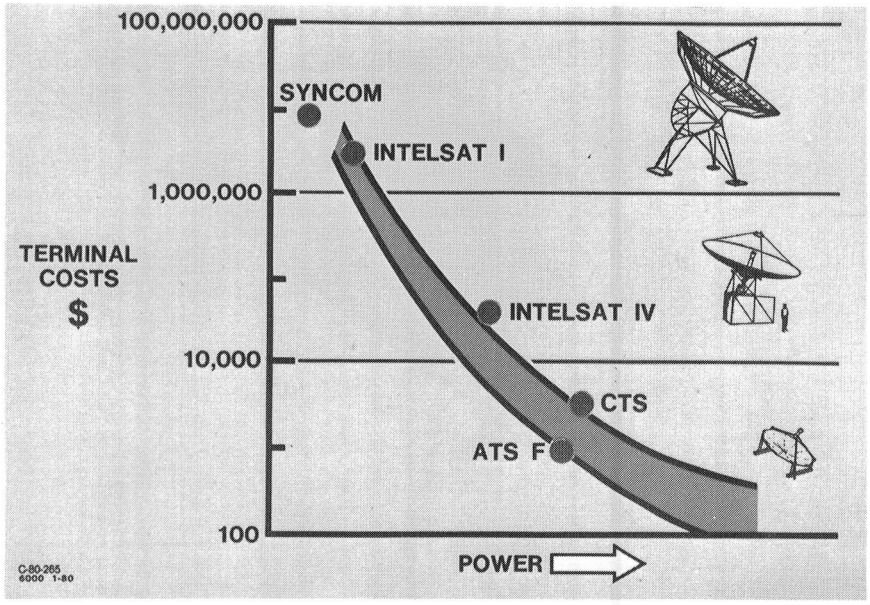


Figure 27. - Trends in ground terminal cost.

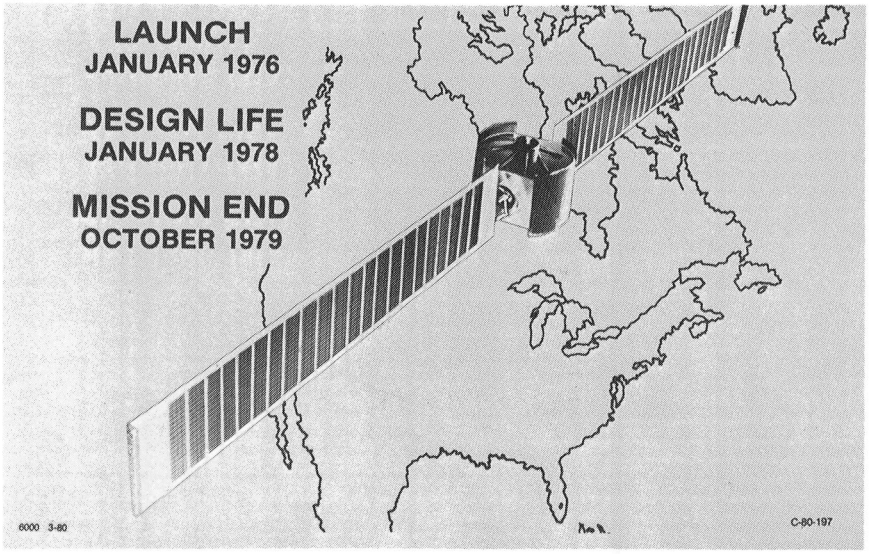


Figure 28. - Communications technology satellite (CTS) 14/12 GHz.

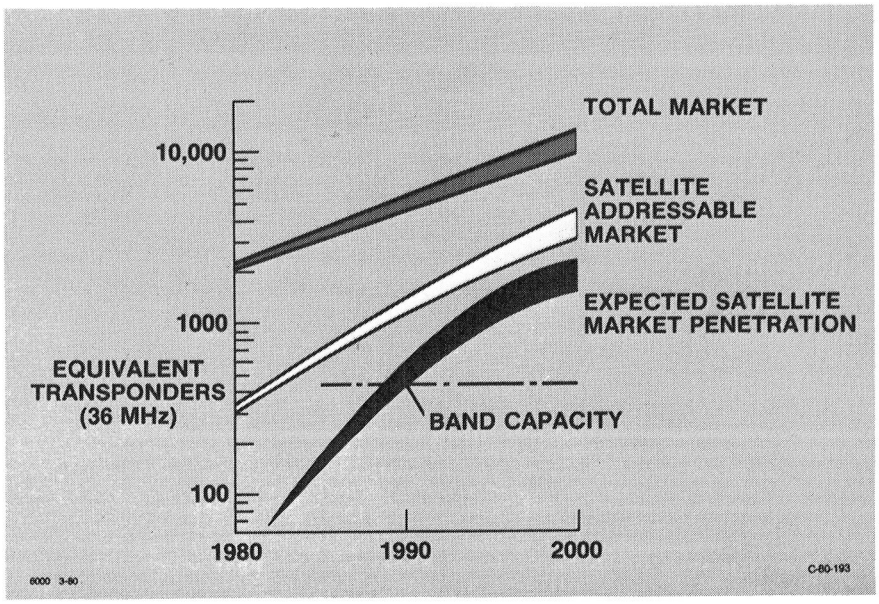


Figure 29. - Market studies show 30/20 GHz need.

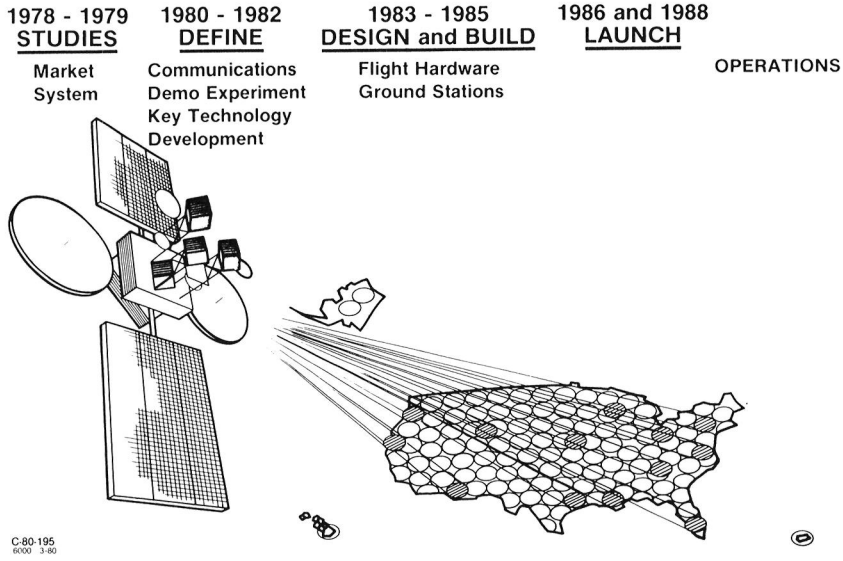


Figure 30. - 30/20 GHz communications project.

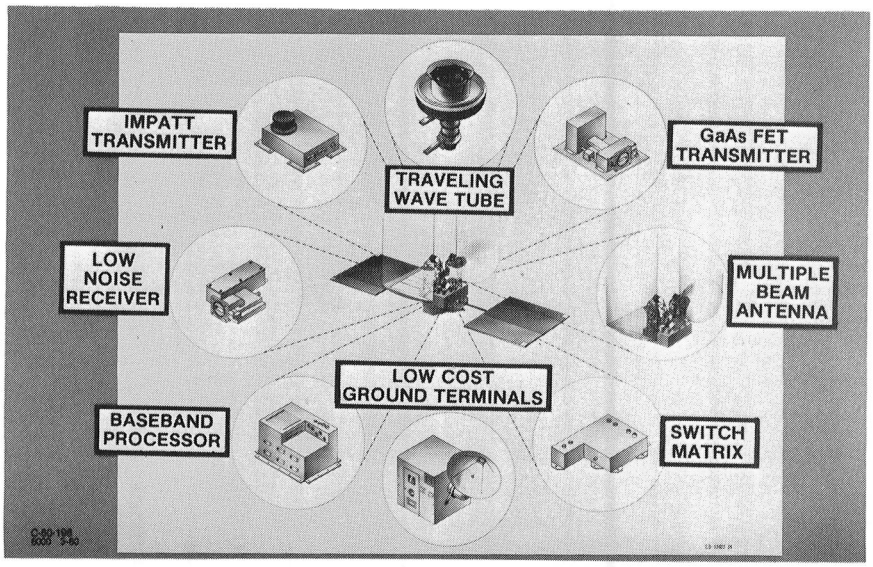


Figure 31. - Communications technology development elements.

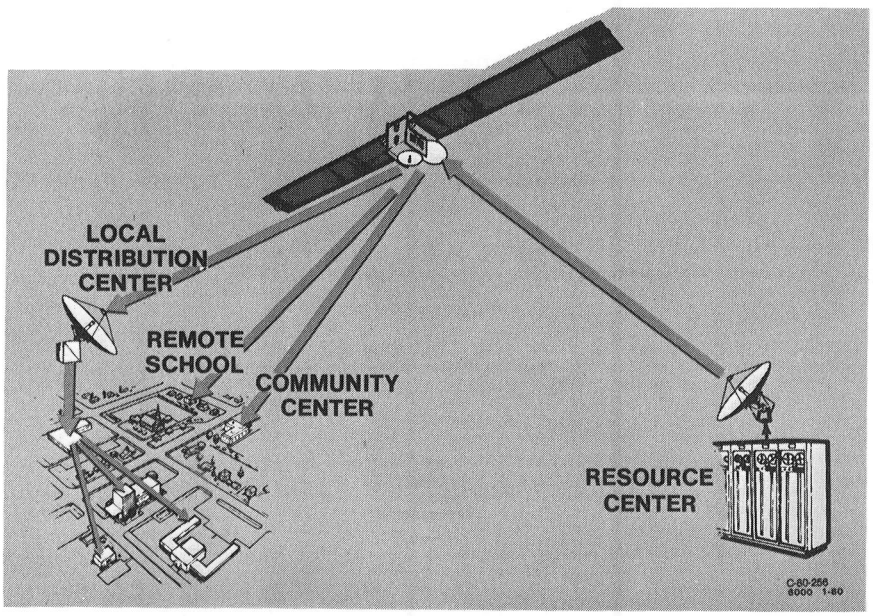


Figure 32. - Future communication satellite system.

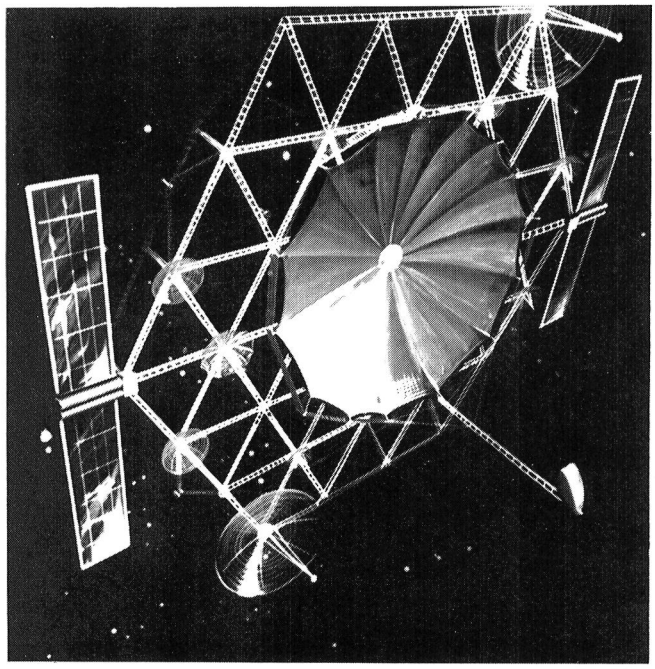


Figure 33. - Geostationary platform.

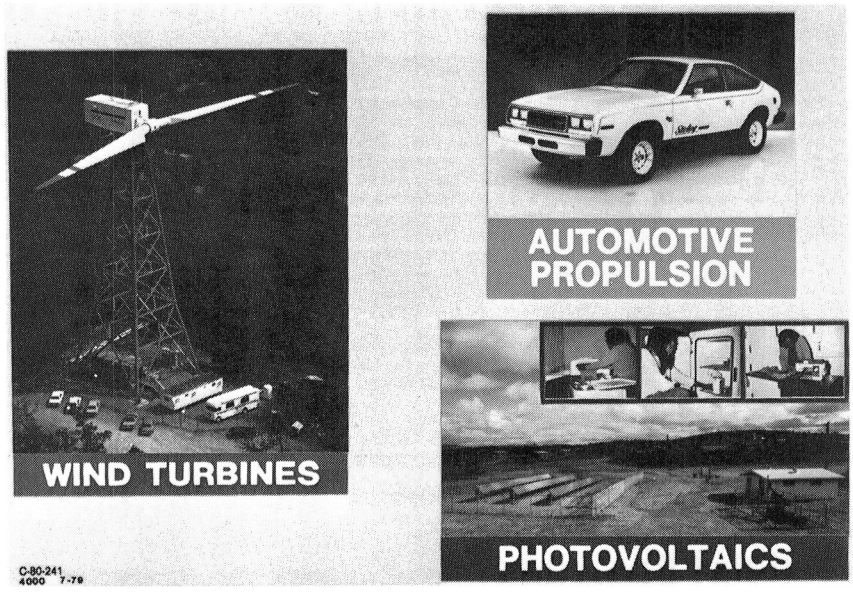


Figure 34. - Terrestrial energy R&T.

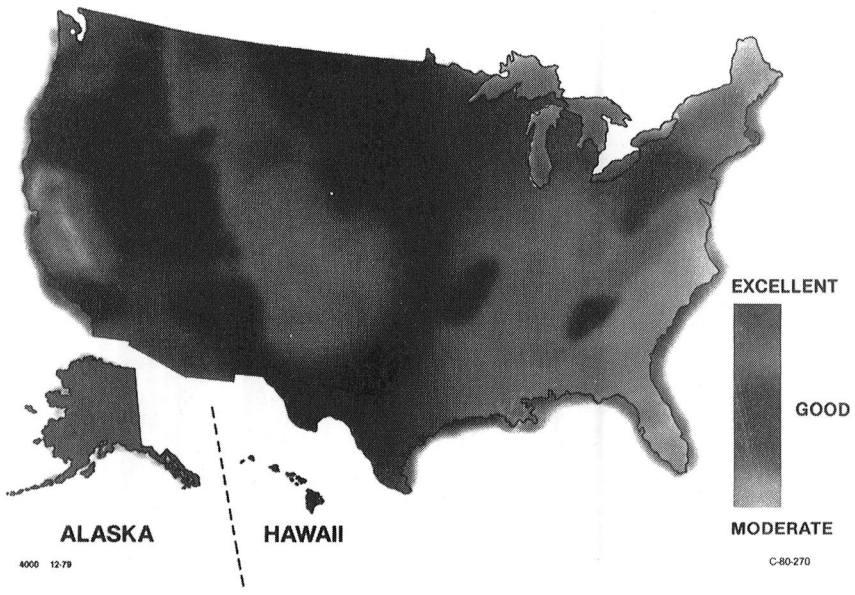


Figure 35. - Annual U. S. average wind power.

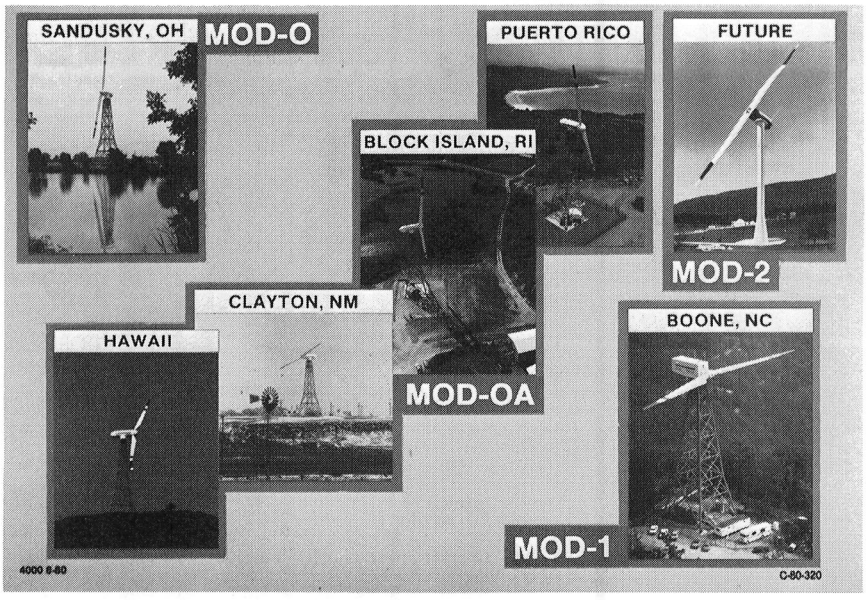


Figure 36. - Wind turbine technology.

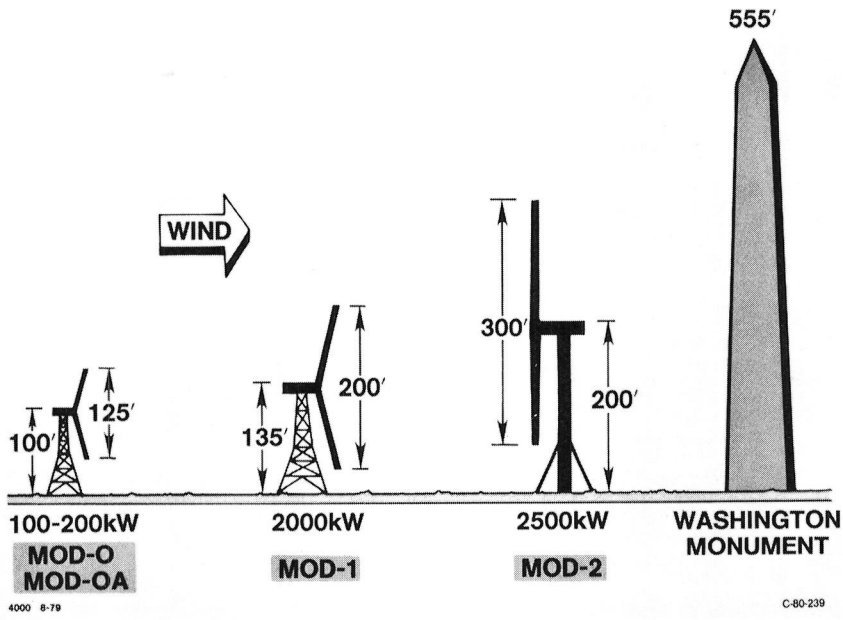


Figure 37. - Large wind turbines.

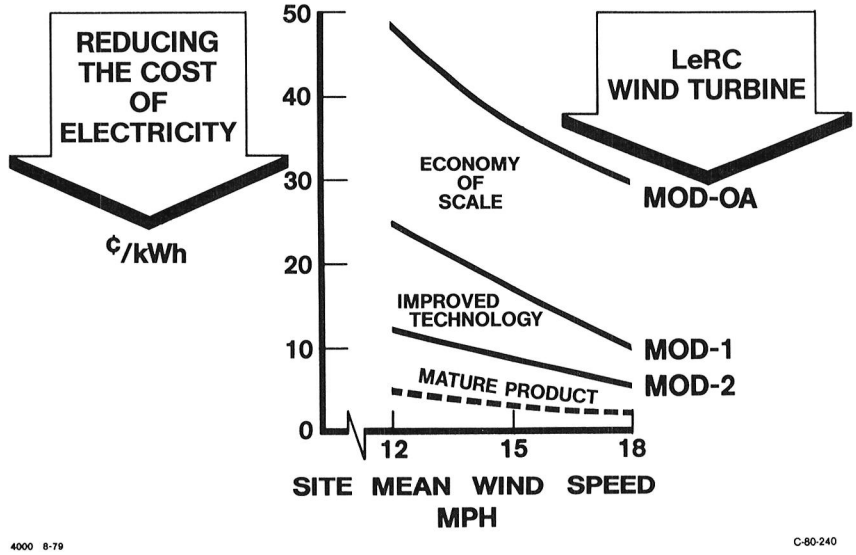


Figure 38. - Wind turbine technology.

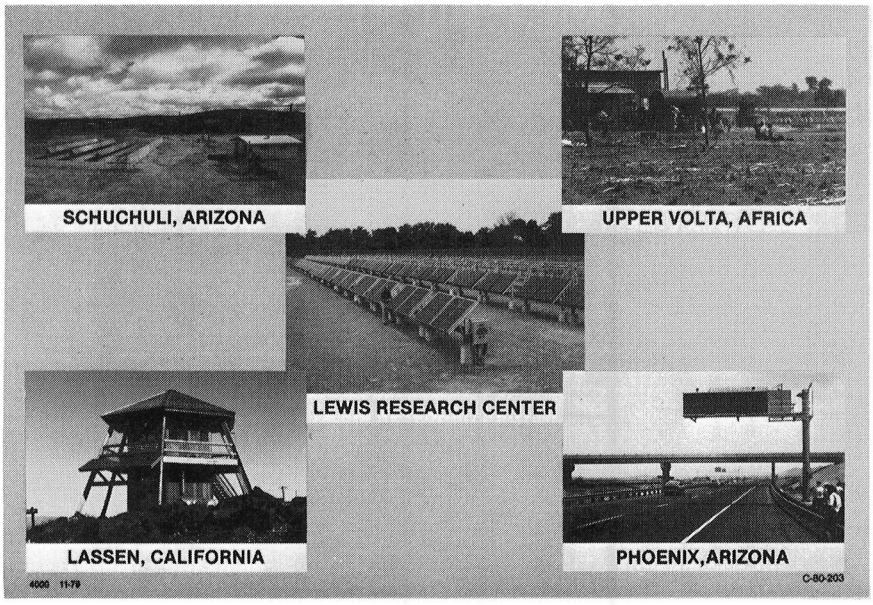


Figure 39. - Photovoltaics technology.

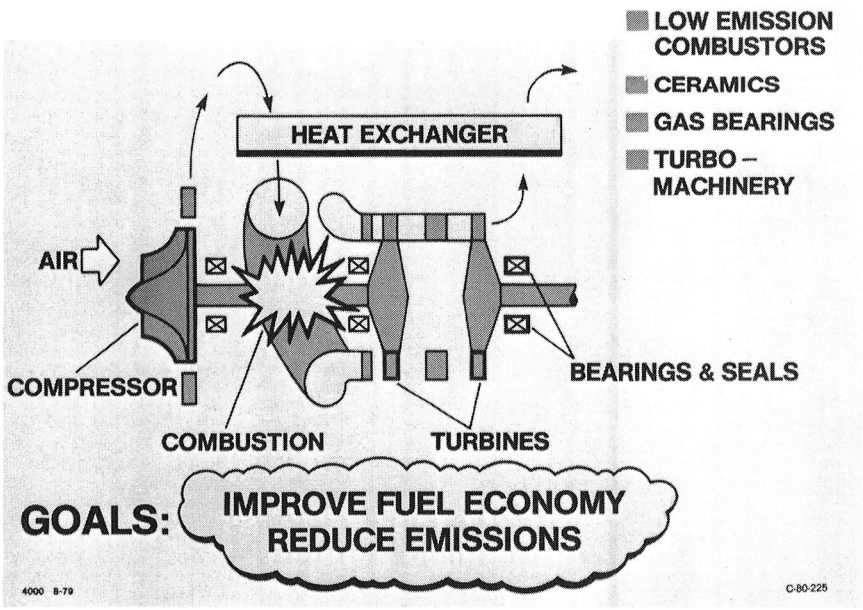


Figure 40. - Automotive gas turbine.

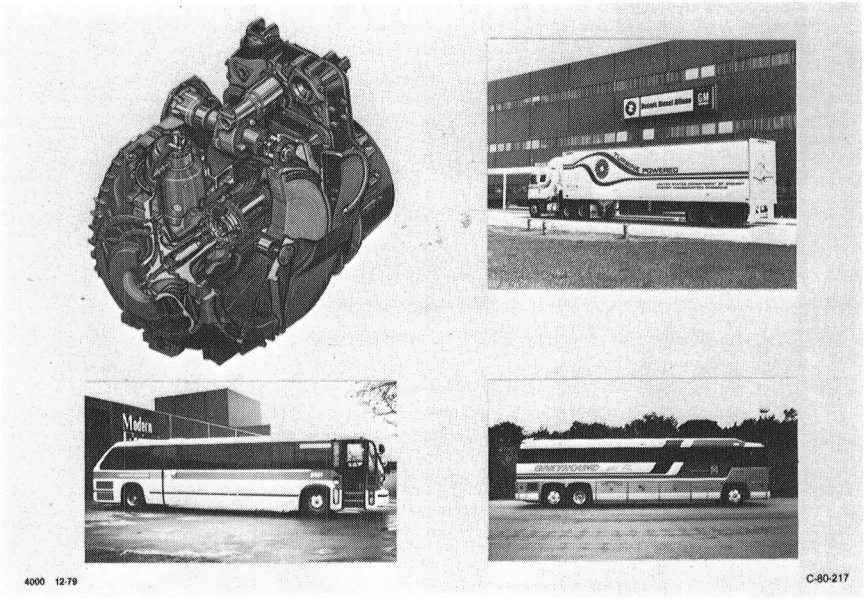


Figure 41. - Bus/truck gas turbine R&T.

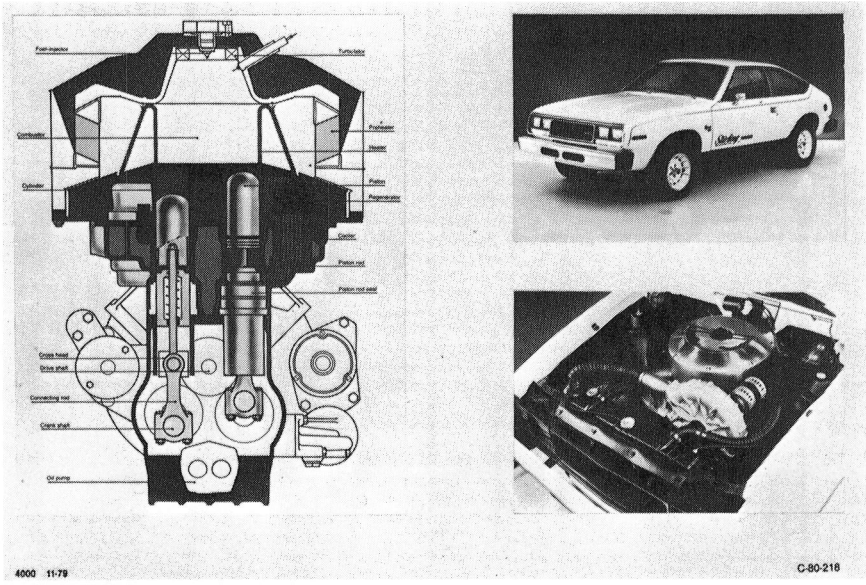


Figure 42. - Stirling cycle engines.

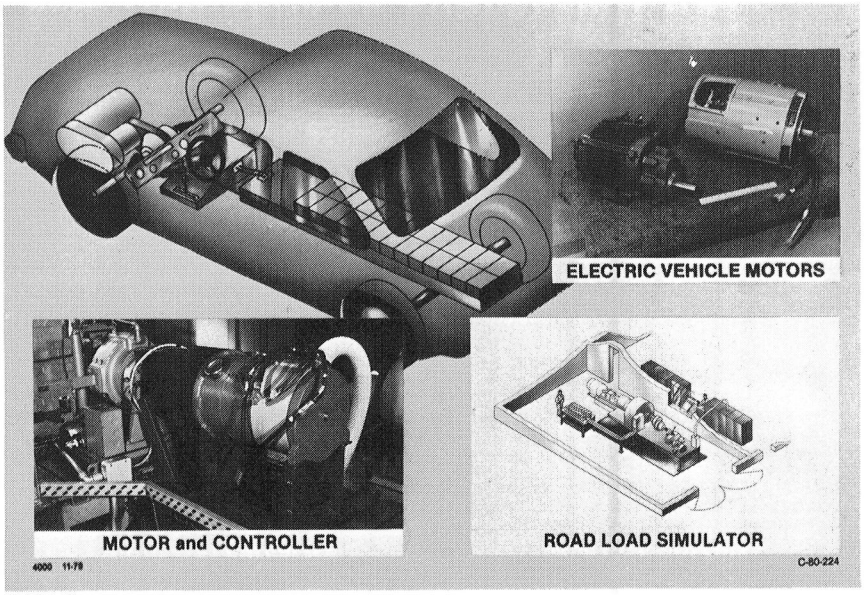


Figure 43. - Electric vehicle propulsion R&T.

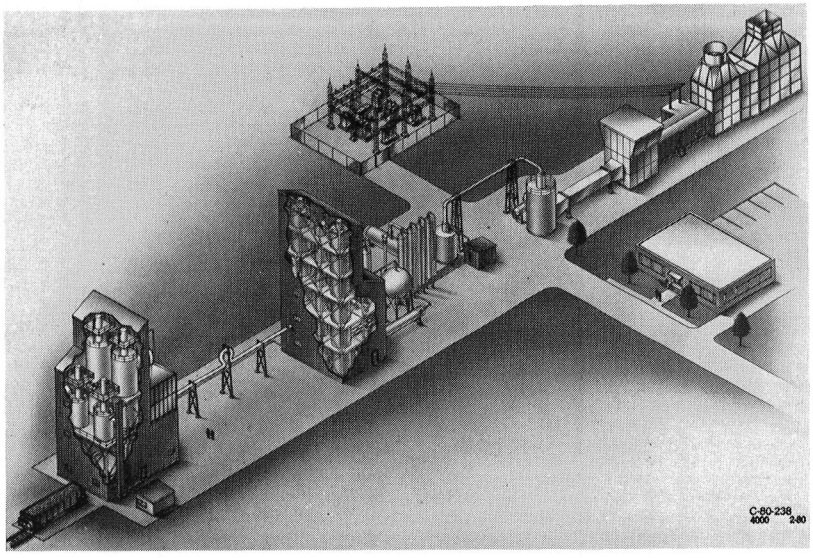


Figure 44. - Coal-to-gas cogeneration powerplant concept.

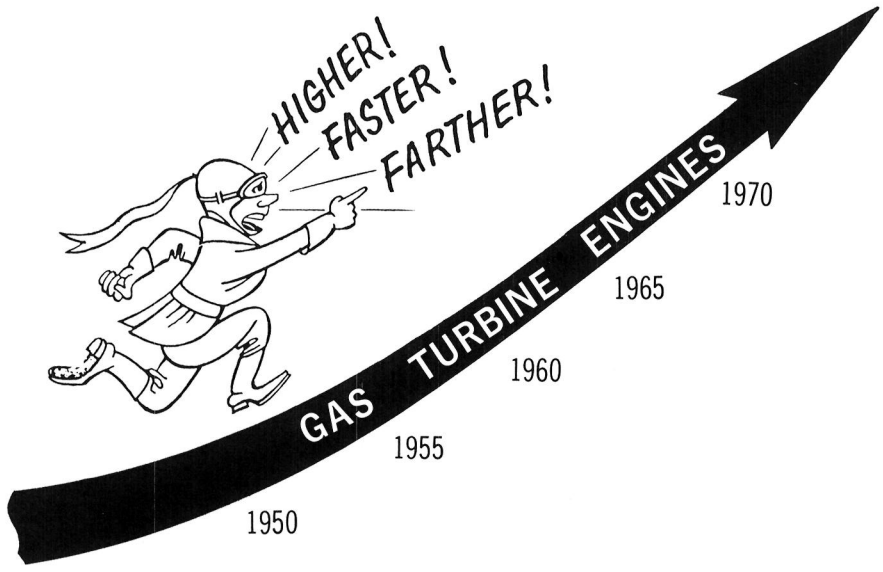


Figure 45. - The drivers - then.

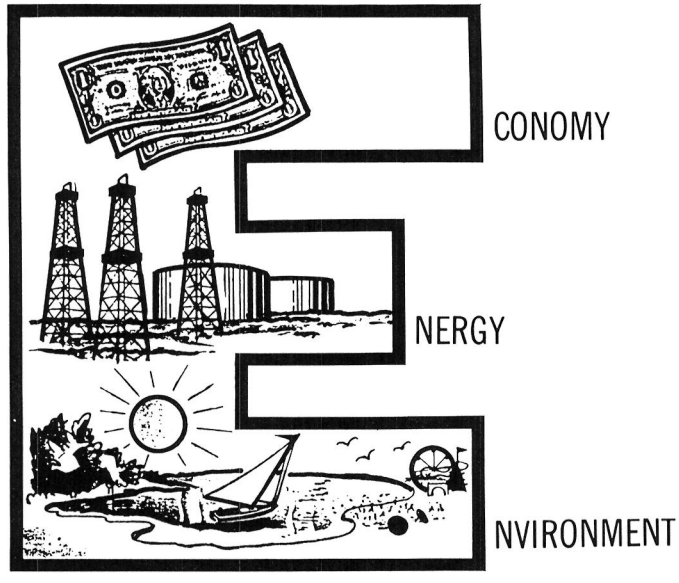


Figure 46. - The drivers.

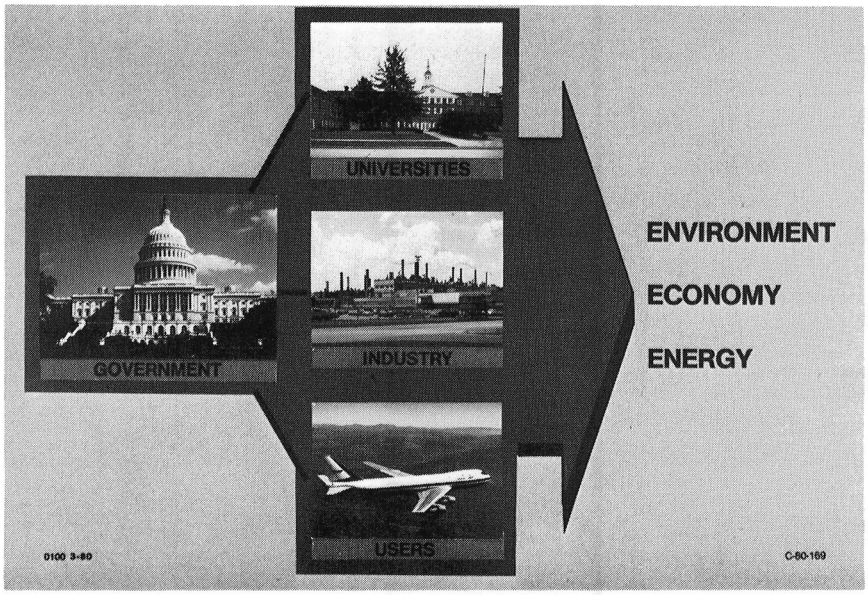


Figure 47. - The team approach.

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15. Supplementary Notes

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16. Abstract

This memorandum presents Dr. McCarthy's address to the 28th Annual CECON Exhibition for Electrical and Electronic Technologies, Cleveland, Ohio. National research and technology trends are introduced in the environment of accelerating change. NASA and the federal budget are discussed. The U.S. energy dependence on foreign oil, the increasing oil costs, and the U.S. petroleum use by class are presented. The $10 billion aerospace industry positive contribution to the U.S. balance of trade of 1979 is given as an indicator of the positive contribution of NASA's research to industry. The research work of the NASA Lewis Research Center in the areas of space, aeronautics, and energy is discussed as a team effort of government, industry, universities, and business to maintain U.S. world leadership in advanced technology.

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