Caltech and Aeronautics

A Presentation
by the
California Institute of Technology

1958

Foreword

The outstanding accomplishment of Caltech in the field of aeronautics is not that it has taught, but that it has always had something new to teach. When most aircraft were glued together from bamboo, balsawood and canvas, Caltech was teaching the next generation of designers how to build hollow shells of stiffened sheet metal. Today, at the threshold of the Space Age, Caltech is combining astronomy, mathematics, physics, mechanics and chemistry into a new sort of aeronautical science, tailored to the needs of a new era that knows no spatial limitations.

To an important extent, Caltech's contributions to industrial and military aeronautics have been made possible, through the years, by equally valuable contributions, in the form of men, money and equipment, from industry and government. This support has filled a vital need in the past; it will become even more important in the future.

The following pages tell something of Caltech's role in aeronautics, its research accomplishments, its success as a teacher of men. Most important, this booklet sets forth the direction of Caltech's present and future research. It is an exciting vista.

THE ROLE OF CALTECH IN AERONAUTICS

Aeronautics, as taught at Caltech, is a graduate-school subject. A few courses in the fundamentals of the science are available to undergraduates working toward a Bachelor of Science degree in Engineering, but the essential activity of the Aeronautics staff is to teach a selected group of approximately 80 highly qualified, advanced-degree candidates who have already signified their intention to make a lifetime career in the field.

Of these, nearly a third are fifth-year students working toward a Master's degree by taking a largely classroom course of study and instruction. The balance are divided between those working toward either the Aeronautical Engineer or the Doctor of Philosophy degree. In either case, thesis work is required, based on original research by the student.

Since most of the faculty is also engaged in individual research, the result is an atmosphere of intense intellectual curiosity, ideal for the type of pioneering investigations that have become Caltech's hallmark. In effect, the mature and advanced thinking of the faculty continually opens up new areas of research for the graduate students.

An example of the type of broad "problem area" in which Caltech is deeply engaged is the new field of magneto-hydrodynamics. Here the problem is to determine the effect of magnetic fields on the conducting, ionized gases that surround a vehicle moving at high hypersonic speeds (ten times the speed of sound or faster). Not only are the fundamental principles largely unknown, but the laboratory equipment with which to study the phenomena have yet to be developed.

Caltech has already instituted a long-term research program in magneto-hydrodynamics. At the moment the work is largely theoretical, but some exploratory experiments have already been started. As specific elements of the problem become defined, they will be separated out and given to individual students or researchers for concentrated study. If the project is essentially short-term and readily accomplished, it would, in a typical case, be given to a student working toward the Aeronautical Engineer degree. If a large amount of original research is indicated, it is probable that a candidate for a doctorate would take it as his thesis project.

The Scientific Approach

Eventually, the principles and effects of magneto-hydrodynamics will become part of the "known" body of knowledge, used by engineers everywhere in the solution of routine design or operational problems. (Professors at Caltech can remember when the flow characteristics of ideal fluids, many of which can now be accurately calculated, were just as difficult to determine and understand.)

When this happens, it will be another example of how effectively scientific research can be used in the solution of practical engineering problems. Dr. Theodore von

Karman, director of the Aeronautics department's Guggenheim Laboratory at Caltech from 1928 through 1949, was one of the first scientists in this country to expound the idea that "hardware" problems in engineering could be solved by first examining the most fundamental factors involved in the most theoretical manner possible. When aircraft design was still largely a matter of cut and try, von Karman and his associates were investigating the fundamentals of fluid and solid mechanics. The effects of the study were revolutionary at the time; the basic approach is still capable of revolutionary results.

One reason why the scientific approach to engineering works so successfully at Caltech is that few boundaries exist between the scientific disciplines represented on the campus. Astronomers, for example, have long dealt with ionized gas clouds moving through electromagnetic fields of varying intensity. Their findings and theories are directly applicable to the new study of magneto-hydrodynamics, and the astronomers in turn are finding in aerodynamics the solution to some of their own problems.

Similarly, the dynamics of a burning gas stream is directly related to the chemical reactions that are taking place within it. Chemists and chemical engineers have much to contribute to an understanding of these reactions, and in return they can put to good use the new fluid mechanical knowledge on how to control such streams and predict their behavior.

As aerodynamic research is becoming more complex and abstract, it is drawing more heavily on mathematics and physics. One of the first major analog computers built in the West, for example, was designed and constructed by Caltech electronic engineers, and over half of its operating time has been devoted to the solution of aerodynamic problems.

Strength-of-materials is no longer a cut-and-try study, related to classical mechanics. To tailor the airborne and space vehicles of the future, better understanding is needed of why materials fail, and this means delving into the mechanics of molecular structures and atomic bonds. Caltech researchers are particularly concerned, for example, with crack propagation — why it occurs, and how it can be prevented. Their studies are leading them into theories that closely parallel and reinforce concepts developed by Caltech geologists concerning earth fractures and earthquakes.

Equipment for Research

The scientific approach to research stresses imagination and thought, rather than apparatus and equipment, but in the end the ideas must be tried and tested. Moreover, in teaching there is no substitute for example and demonstration. Through the years, Caltech has been fortunate in obtaining, largely through the generosity of friends and far-sighted individuals, a rich storehouse of equipment for aeronautical research, much of it built by Caltech personnel to their own specifications.

The Institute's first wind tunnel, for example, was in operation in 1917, and boasted velocities of 4 to 40 miles per hour. Aeronautics came of age at Caltech, however, with the completion in 1929 of the Guggenheim Aeronautical Laboratory, built around a 200-mph tunnel with a 10-foot working section. This tunnel has been operated (often on a two-shift basis) for almost 30 years, and although far surpassed in performance by later installations, it still is invaluable as a teaching and research aid.

The Guggenheim Laboratory (or GALCIT, as it is better known) now contains a number of other, smaller wind tunnels, some of them capable of hypersonic speeds, with Mach numbers of over 10. Department members have also built several shock tubes — for generating shock waves quickly and simply — and many other types of experimental apparatus. Total laboratory and classroom space within GALCIT is approximately 50,000 feet.

In addition to these on-campus facilities, Caltech research workers and students can also draw, under certain conditions, on the equipment and test apparatus of two major off-campus laboratories that are the result of Caltech research activities, but are not an integral part of the Aeronautics department. One of these is the giant Jet Propulsion Laboratory, supported by the U. S. Department of Defense, and now employing over 2,000 persons — 500 of them professional engineers or scientists. The other is the California Cooperative Wind Tunnel, built and supported by five major aircraft companies. The CWT, now capable of continuous wind velocities of 1.75 times the speed of sound, is operated by Caltech under a management agreement.

Men with Ideas

Despite the emphasis on research, Caltech never loses sight of the fact that its first obligation is to train the minds of men. In fact, one of the principal reasons for the research is to produce men with inquisitive minds who know how to satisfy their curiosity. In this sense the value of Caltech research can never be measured, for it must include the accomplishments of all those who have been exposed to its influence.

Nearly 1,000 engineers and scientists have now received advanced degrees in aeronautics at Caltech. Of these, approximately half have received a Master's degree; over one hundred, their doctorates.

The influence of Caltech in aeronautics has already spread far. Former students have served, or are serving, as Chief of the Office of Naval Research, as Chief of the Bureau of Aeronautics of the Navy, and as Deputy Chief of Staff for Research and Development of the U. S. Air Force. Many Caltech graduates are managers of major aircraft and missile company divisions, and some are presidents of companies, which, in several cases, they have founded themselves.

Even more important to the future of aeronautics, Caltech graduates head up the aeronautics departments of such major U. S. universities as Cornell, Johns Hopkins, Purdue, Pennsylvania State, and the Universities of Kansas and Michigan.

Caltech influence is also felt in industry and government through the activities of faculty members, serving as consultants or committee members. During most of World War II, for example, von Karman devoted his energies to founding and leading the Air Force Scientific Advisory Board. Other members of the staff are now serving on Air Force, Navy, Army and Department of Defense scientific committees, and at least five professors are on subcommittees of the National Advisory Committee for Aeronautics.

Finally, Caltech's Aeronautics department cannot help feeling a certain amount of pride in the fact that men it trained participated in the successful launching of the first U. S. earth satellite, designed and built by the Jet Propulsion Laboratory as a contribution to the International Geophysical Year.

Research of the Future

Caltech can be justly proud of its past accomplishments, but the true measure of its worth must be based on how effectively it is anticipating the future. The aeronautical sciences are entering into an entirely new era, with new demands, and the requirement for new solutions.

Vehicle speeds are now reaching high multiples of any experienced in the past. Velocities of ten to twenty thousand miles per hour and temperatures in the thousands of degrees introduce new and unknown problems in fluid flow. Vehicles are now operating throughout the entire environmental range from normal sea-level pressure and density to an almost perfect vacuum. In much of this range the classical concept of air as a continuous fluid breaks down completely.

Unprecedented rates of energy release are required, if the velocities mentioned above are to be realized. In addition, problems of an entirely different character are introduced by the necessity to maneuver and change orbits during true space flight. Here it seems likely that the requirement will be for very small thrusts, acting over long periods of time, which will involve completely new categories of propulsive systems. In order to achieve known objectives in terrestrial or astronautical flight, vehicles in many cases will have to be unmanned, and this will require guidance and control systems of extraordinary accuracy and reliability.

Every ounce of excess or parasite weight that must be accelerated to astronautic speeds imposes a tremendous penalty. At the same time, vehicles must operate under extremely difficult environmental conditions. The requirement is for the lightest, yet strongest structures, and radically new types of "exotic" materials and designs will have to be found and developed.

At the same time, continuing attention must be paid to problems that are old, but still unsolved. The fundamental motion and behavior of "classical" fluids are still only partially understood. The phenomena of turbulence, mixing, and flow separation continue to present formidable problems. Other avenues of development will eventually be blocked if a more fundamental understanding is not obtained of the factors underlying the strength and other physical properties of structural materials.

Caltech's Program

No single research organization could hope to contribute effectively to all these areas at one time. For this reason, the Caltech Aeronautics department will concentrate its research principally along the lines of the ten topics outlined below. Each subject may be specific, but it is also fundamental, and therefore of the broadest value in advancing the frontiers of knowledge.

1. Mathematical studies of the underlying significance and intrinsic content of the classical Navier-Stokes equations governing the motion of viscous, compressible fluids. Related to these are theoretical and experimental investigations into the fundamentals of turbulence.

2. Hypersonic flows without extreme tempera-

tures or variations in gas properties. Examples are: inviscid flow patterns and pressure distributions, boundary layer stability and noise production by turbulent boundary layers.

3. Gas properties at the extreme temperatures associated with the higher hypersonic velocities. This includes the field which von Karman has called Aero-thermo-chemistry, and the major experimental tool will be, at least initially, the shock tube.

4. Heat transfer under extreme high temperature conditions. Here a variety of facilities will be required, such as shock tubes, plasma jets, and others not yet developed or even invented.

5. Fluid behavior at extremely low density and pressure. Molecular beam and other techniques borrowed from the physicist will be required.

6. The gas dynamics of conducting (ionized) gases in the presence of electric and especially magnetic fields. This subject of magneto-hydrodynamics will almost certainly be one of the major preoccupations of the GALCIT staff, which has already made significant contributions to it.

7. Solid state physics of materials, especially

under extreme environmental conditions. The fatigue of structural materials is a specific problem of very great importance in this field.

8. Thin shell analysis and design. This is an old problem, but recent developments in long-range rocket missiles, satellites, and space vehicles have introduced combinations of physical dimensions which lie far outside the regions heretofore studied.

9. Structural dynamics, or the response of structures to vibrations, impacts, and other transient forces which the new environments impose. Included in this is the study of aeroelasticity, or the dynamical behavior of vehicles or components under rapidly varying aerodynamic loadings. In this connection the transonic and hypersonic regimes remain largely unexplored.

10. Fracture mechanics, or the mechanism by which failure of a material or structure occurs under the extreme environmental conditions to which aeronautical structures will be exposed.

What is Needed

To accomplish these research objectives, Caltech needs the help of every agency, corporation or individual who can justify the contribution.

Since Caltech's accomplishments are of men and minds, not hardware or equipment, the requirement is not for a large new wind tunnel, or other elaborate apparatus. Instead, the entire program outlined above, and probably more, can be achieved simply by a modest increase in the laboratory space available to the department, by the addition of some small-scale but sophisticated experimental apparatus, and by an increase of a few members to the permanent staff. No major additions have been made to the department's on-campus facilities since before World War II, and the limit has been reached on the amount of research and teaching that can be accomplished in the present building.

A 30,000-square-foot addition to the present GALCIT will furnish the essential classrooms, office and laboratory space required. To build and equip these quarters will cost an estimated $900,000. They represent one of the most urgent projects within the $16,100,000 Development Program that Caltech has recently launched.

Of even greater importance than these facilities are the necessary addtions to the Aeronautics staff that will be made possible. With Caltech's reputation in the field, and with the new competitive salary scales that are a part of the Development Program, it will be possible to attract the finest minds in the country to fill these new positions.

Over the years, Caltech's role in aeronautics has grown to one of worldwide significance and importance. The

Caltech Development Program is in part an effort to make sure that the trust and responsibilities that go with this position are not jeopardized.