Caltech's Guggenheim Aeronautical Laboratory

AERONAUTICS AT CALTECH

THE IMPRESSIVE RECORD of accomplishment of Caltech's Guggenheim Aeronautical Laboratory is described in a 25th anniversary booklet* published by the Institute this month.

The story really begins some ten years before the construction of the laboratory itself. The January, 1917, Catalogue of the Throop College of Technology (which later became the California Institute of Technology) contains the following:

> Just as this catalogue goes to press, generous and wise friends of the college have undertaken to provide facilities for research in the science of Aeronautics, with every prospect of the cooperation of the United States Government. A wind tunnel will immediately be built and equipped in the best fashion, and a graduate course will probably be provided for students desiring to specialize in this branch of physics and engineering.

Between $5,000 and $6,000 was made available for these purposes, and during the subsequent year a small wind tunnel was constructed having maximum wind velocity of 40 miles per hour. The Throop Catalogue for the following year contains the first mention of two staff members concerned with matters aeronautical. Mr. A. A. Merrill, one of the very early American pioneers, whose active participation in aviation dates back to the 1890's, appears as Research Assistant; he was given the responsibility for designing, supervising the construction of, and operating the wind tunnel. (He also doubled in brass as Instructor in Accounting.) Dr. Harry Bateman, a brilliant Cambridge-trained mathematician, is listed as Professor of Aeronautical Research and Mathematical Physics. The catalogues of the next few years list a number of aeronautical courses given by these two staff members. However, the number of students must have been very small, and there was no Aeronautics Department, nor were any aeronautical degrees awarded.

In 1926 R. A. Millikan secured a $300,000 grant from the Guggenheim Fund for the construction of a laboratory and the establishment of a graduate school of aeronautics at the Institute. Dr. Theodore von Kármán, the eminent applied mathematician, scientist and engineer, came here to advise on the educational policies and the experimental facilities of the new graduate school and laboratory.

In 1928 the laboratory was completed, and the GALCIT began its active career in aeronautical instruction and research. In 1928-29 the first class at the GALCIT had three enrolled students. During World War II and immediately afterward enrollment hit a peak of well over 100. Now it has leveled off at about 80. The academic staff has increased from 6 to 17 (plus a large number of graduate fellows and assistants.) Dr. von Kármán, who was Director of the laboratory from the beginning, was called to Washington to serve as special assistant to General Arnold in 1942, and later as Chairman of the Air Force Scientific Advisory Board. Dr. Clark Millikan, Acting Director of the lab since 1945, was appointed Director in 1949 when Kármán became Professor Emeritus.

MAJOR RESEARCH FIELDS

Fluid Mechanics. A large part of the research activities at the GALCIT has always been occupied with work on the fundamental aspects of fluid mechanics. In the early years the problems of paramount interest centered around boundary layer flow and turbulence. Now work in these fields has been supplemented by work in the fields of transonic, supersonic, and hypersonic flow and their host of new problems.

* *The Guggenheim Aeronautical Laboratory of the California Institute of Technology: The First Twenty-five Years.*

For a 25-year-old, Caltech's Guggenheim Aeronautical Laboratory has an impressive record of achievement

Clark B. Millikan, Director of the GALCIT

Applied Aerodynamics. Another important part of the research effort at the GALCIT has been (and still is) connected with applied aerodynamics— airfoil and wing theory, the linearized theory of supersonic wings and bodies, non-stationery wing theory, wind tunnel techniques, and those topics which couple dynamics and aerodynamics, (such as performance, stability, and control.)

Elasticity and Structures. From the beginning it was decided that one of the major fields of study to be emphasized was that of aircraft structural analysis and design. This work not only concentrates on fundamental research but maintains a practical interest in the current problems of the airframe companies.

Jet Propulsion and Rockets. Interest in rocket propulsion at Caltech dates back to 1935 when members of the GALCIT faculty and grad students began experimental and theoretical studies in this field. The first substantial outside support for the program came from the National Academy of Sciences in 1939, and in 1941 the Army Air Force took over sponsorship of the work. By 1941 the scope of both theoretical and experimental work had been greatly extended. In August 1941, the first practical solid propellant had been developed, and the first successful assisted-takeoff tests were made. These first rocket motors shortened takeoff distances of small aircraft by as much as 50 percent. After the development work was completed and the assisted-takeoff motors went into extensive service use, large-scale production was undertaken by the Aerojet Engineering Corporation, which was subsequently acquired by the General Tire and Rubber Company, and has recently become the Aerojet-General Corporation.

These major developments by the GALCIT Project, in addition to the lab's extremely important basic research studies, contributed to a large extent in the formation of the basic technical framework of the present guided-missile industry.

In 1944 the first long-range rocket research and development program in the United States was started. By this time the size of the GALCIT Project had increased to a point where the organization of a separate laboratory seemed desirable. Accordingly, on November 1, 1944, the Project separated from GALCIT and became known as the Jet Propulsion Laboratory. Through the formative years and down to the present time, members of the GALCIT staff have played an important part in the organization of JPL.

Wind Tunnels. Wind tunnels have always been a dominant feature of the GALCIT. The largest experimental facility in the laboratory as originally constructed was a 200-mile-per-hour wind tunnel with a test section 10 feet in diameter. When it was placed in operation in 1929 it was one of the highest performance wind tunnels in existence, and it has continued to render yeoman service even to the present.

A few statistics in connection with the industrial and governmental testing activities of the GALCIT 10-foot tunnel are of interest. As of May, 1954, a total of 790 separate wind-tunnel test programs had been carried out, and over 700 formal reports issued. These cover tests on over 550 distinct aircraft types for some 35 United States and foreign aircraft companies, as well as investigations for some 6 government agencies. Although the tunnel's performance is now greatly exceeded by many more recently constructed facilities, its operation on an overtime basis is still required.

Although this first wind tunnel is the largest in the GALCIT, it is far from being the only one. Over half-a-dozen small, low-speed tunnels have been constructed for specific research investigations—especially in connection with low-speed boundary-layer and turbulence researches—and several of these are still in active use.

A small transonic tunnel has been used by Professor Hans Liepmann's group to produce important and fundamental data on flow characteristics in the neighborhood of the speed of sound.

The first continuously operating, supersonic tunnel in this country to reach Mach numbers above four was designed jointly by Professors H. S. Tsien and M. Serrurier, and constructed some years ago under the sponsorship of the Army Ordnance Corps. Allen Puckett (now chief of the Systems Analysis and Aerodynamics Department at Hughes Aircraft) carried out many investigations using the tunnel as a pilot or model tunnel for a much larger wind tunnel built subsequently at the Ballistic Research Laboratory at Aberdeen Proving Ground. It continues to be a valuable research tool.

A hypersonic test facility has also been constructed at the GALCIT, with Army Ordnance and Air Force support, where Mach numbers of over 10 have been reached. This is currently being used in the exploration of the new and important field of very high Mach number flows.

Finally, a 175-mile-per-hour wind tunnel with a 3-foot by 4-foot test section was installed in 1950 to be used primarily for student instruction and thesis research. This was dedicated to A. A. Merrill in recognition of his pioneering work in aeronautics at the Institute, and is known as the Merrill Tunnel.

THE MOST IMPORTANT PRODUCT — GRADUATES

IN JUNE, 1929, the first two degrees were awarded by the Guggenheim Graduate School of Aeronautics: master's degrees to E. E. Sechler and A. E. Lombard. Both of these men subsequently received doctors' degrees and went on to aeronautical careers. Dr. Sechler is now Professor of Aeronautics at Caltech, and Dr. Lombard is Scientific Advisor in the Directorate of Research and Development, Headquarters U. S. A. F. Since that time, through June, 1953, a total of 964 graduate degrees have been awarded. Of these, 544 were fifth-year or master's degrees, 330 were sixth-year or "professional" degrees, and 90 were doctorates. The total number of students corresponding to these degrees is 744, since the same man often takes two degrees consecutively.

In 1933 Captain Paul Kemmer of the Army Air Corps, who was the first student sent by one of the military services, received the professional degree.

Every year since 1934 has seen a group of officers from the Naval Postgraduate School working towards professional degrees at the GALCIT, and many Air Force officers have also been assigned to the graduate school for study. A total of over 250 officers from the United States have received degrees from the GALCIT during the past twenty years, and there have been a number of officers from foreign countries.

The majority of the civilian students have gone on to engineering positions in the aircraft industry, where many now occupy key technical and administrative positions. Many others have entered academic life or research laboratories, and a considerable number are now in government service as research administrators or scientific and technical advisors.

These GALCIT alumni are typical of the large number who have attained distinction in a wide variety of activities: Three are now heads of aeronautics departments at major universities; W. R. Sears at Cornell, F. Clauser at Johns Hopkins, and M. Clauser at Purdue. H. S. Tsien is Goddard Professor at Caltech's Jet Propulsion Center. L. G. Dunn, formerly Director of Caltech's Jet Propulsion Laboratory, is now associate-director of the guided missile research program at the Ramo-Wooldridge Corporation in Los Angeles. Roy Marquardt is president of the Marquardt Aircraft Company. W. Bollay heads the Aerophysics Development Corporation. Rear Admiral C. M. Bolster recently retired as Chief of the Office of Naval Research and is currently Manager of Research at the General Tire and Rubber Company. Lieutenant General D. L. Putt is Deputy Chief of Staff for Research and Development of the U. S. Air Force.

RELATED ACTIVITIES

THREE MAJOR DEVELOPMENTS at the California Institute had their origins at the GALCIT and then grew into independent organizations. Although all are administratively quite separate from the GALCIT, close contact and cooperation are maintained with all three.

1. Jet Propulsion Laboratory

During World War II, the California Institute of Technology was asked to contribute creative engineering talent to a number of defense research projects, among them the development of jet propulsion devices. The results of this effort were of such value to the Department of Defense that, in the latter part of the war, the Jet Propulsion Laboratory was established to continue the program, under the administrative supervision of Caltech.

Since the end of the war, the Laboratory has grown from a small group assigned to the task of developing a simple thrust-producing device for the assisted-takeoff of aircraft to a completely equipped laboratory having a wide variety both of equipment and scientific talent. *(E&S, October 1952.)* The staff currently numbers over 1,000 persons.

Fundamentally, JPL is a research center whose efforts are directed toward the acquirement of basic information in the engineering sciences related to missile development and the various phases of jet propulsion. Especially in the field of aerodynamics, close liaison and cooperation are maintained with the GALCIT. Research and

development are conducted under contracts with governmental agencies, and close liaison is maintained between JPL and the various military services.

2. Southern California Cooperative Wind Tunnel

By the late 1930's it was becoming apparent that before many years aircraft would be flying fast enough so that the effects of the air's compressibility would become important. Wind tunnel facilities capable of producing velocities up to the neighborhood of the speed of sound (approximately 1100 feet per second under standard sea-level conditions) were obviously going to be required for the development of such aircraft. The GALCIT 10-foot wind tunnel had proved extremely valuable for development testing, but its 200-mile-per-hour top speed would clearly be inadequate. What would be needed was a tunnel with test section dimensions comparable to those of the 10-foot tunnel, but with a 750-mile-per-hour speed capability. Unfortunately, these two requirements implied extremely large power for the drive and a construction cost running into several million dollars.

After much thought and discussion a group of aircraft companies decided to undertake a cooperative effort to produce such a facility. The Curtiss-Wright Corporation agreed to finance the construction of a wind tunnel at Buffalo, and four southern California companies, Consolidated-Vultee, Douglas, Lockheed, and North American, jointly undertook to sponsor one in Pasadena. Essentially the same design was to be used for both.

The Pasadena tunnel, which is some three miles from the campus and adjacent to the Pasadena City Power Plant, was dedicated as the Southern California Cooperative Wind Tunnel in May, 1945, and shortly thereafter began routine operations . These have continued ever since on a two-shift basis. Some years ago the McDonnell Aircraft Co. purchased one-half of Consolidated-Vultee's interest in the tunnel, so that the CWT, as it is usually called, now has five owner companies. As of May, 1954, some 400 test programs had been completed, not only for the owner companies, but also for most of the other major aircraft companies of the country, as well as for numerous government agencies. The laboratory, with something over 150 employees, is operated by the California Institute under a management agreement, with an annual operating budget of over a million dollars. Clark Millikan is Director on a part-time basis, and J. E. Smith, a GALCIT alumnus, serves as full-time Associate Director.

Less than ten years after the CWT was designed aircraft performance had advanced so spectacularly that it was clear that supersonic speeds were soon to be matters of routine operation. The owner companies accordingly authorized an $8,000,000 modification program for the CWT. This will involve an increase in the drive power from 12,000 hp to 40,000 hp, and make possible testing at speeds up to 1.8 times the speed of sound. Construction on the modification program is currently in active process and should be completed and the tunnel ready for operation in mid-1955.

3. Guggenheim Jet Propulsion Center

The Jet Propulsion Center, an independent unit in the Division of Engineering of the California Institute of Technology, was established by the Daniel and Florence Guggenheim Foundation in 1948. The Center is an outgrowth of the activities of the Guggenheim Laboratory in the fields of rockets and turbomachinery, and its purpose and guiding principle are quite different from those of the Jet Propulsion Laboratory.

To quote the Institute Catalogue:

> "This center was created specifically to provide facilities for postgraduate education and research in jet propulsion and rocket engineering, with particular emphasis on peace-time uses. The objectives of this Center are to provide training in jet propulsion principles, to promote research and advanced thinking on rocket jet propulsion problems, and to be a center for peace-time commercial and scientific uses of rocket and jet propulsion."

An important part of this program is the Daniel and Florence Guggenheim Fellowships in Jet Propulsion. These Fellowships carry a stipend up to $2,000 a year in addition to tuition.

Research carried on in the Jet Propulsion Center emphasizes the fundamental problems in rocket and jet propulsion engineering. Current activities proceed along four main lines: (1) fluid mechanics of turbomachinery, (2) basic combustion problems, (3) gas emissivities and application of modern spectroscopy to detailed analysis of combustion, and (4) theory of the control and guidance of complex systems.

RELATIONS WITH GOVERNMENT

ONE OF THE GREATEST CONTRIBUTIONS which an academic institution can make to the defense of the country lies in the training which it can give to officer and civilian government servants so that they may better discharge their responsibilities. With the enormous increase since the beginning of the last war in the role of science in the armed forces, this is particularly true of a technical institution like the California Institute of Technology. Some details have already been given of this aspect of the GALCIT activities programs.

The laboratory has also contributed by carrying out technical and scientific investigations at the request of the armed services. The setting up of the rocket program and later of the Jet Propulsion Laboratory are examples which have been discussed. The members of the staff have also participated intensively in government activities. Kármán was for many years consultant to all three services, and after 1942 devoted most of his time to setting up and leading the Air Force Scientific Advisory Board. Millikan has served on advisory committees to the three services and was for three years Chairman of the Guided Missiles Committee of the Department of Defense Research and Development Board. Sechler has

served on Air Force Committees; he, Millikan, Lees, and Fung are currently active on such an assignment. Stewart has consulted with Army Ordnance and is a member of the Air Force Scientific Advisory Board. Millikan, Sechler, and Liepmann serve on sub-committees of the National Advisory Commitee for Aeronautics.

These are examples of services by the GALCIT staff for government agencies. On the other hand, the Army, Navy, Air Force, and NACA have very wisely adopted policies of supporting research projects at universities. The researches mentioned earlier have for many years been supported to a large extent by these agencies, and there are currently active projects sponsored by all four. Much of GALCIT's history of the past twenty-five years could not have been written had it not been for its close association with these agencies of the government.

RELATIONS WITH INDUSTRY

IN ITS RELATIONS with industry as with the government, probably the GALCIT's greatest contribution has been the students it has trained and sent out. Of these, the largest percentage has entered the engineering departments of aircraft companies. As has already been mentioned, it has been a continuous policy that close contact be maintained with industry in the GALCIT's day to day life. The first airplane design course was given by a practicing aeronautical engineer; and, ever since, one course each year is given by engineers from local aircraft companies.

The testing program in the 10-foot and Cooperative wind tunnels obviously results in intimate contacts between staff members and students and aircraft company engineers, and similar contacts are also frequent in other fields. Company engineers are invited to attend the GALCIT seminars, of which there are several each week, and the invitations are frequently accepted. Members of the staff are encouraged to undertake part-time consulting responsibilities if they care to do so, and many avail themselves of the opportunity. Experience has shown that, with a strong and active program of fundamental research on campus, such consulting activities actually contribute to the staff's creative work, rather than interfere with it. This is certainly due in part to the dynamic nature of the aircraft industry and to the number of problems whose solution requires the most advanced scientific knowledge and techniques.