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Suntan

The largest and most extraordinary project for using hydrogen as a fuel was carried out by the Air Force in 1956–1958 in supersecrecy. Very few people are aware of it, even now, yet over a hundred million dollars were spent—perhaps as much as a quarter of a billion dollars. Although the project was cancelled before completion, it led directly to the first rocket engine that flew using hydrogen. The project was code-named Suntan, and even this was kept secret.[1] It had all the air of cloak and dagger melodrama and indeed, its principal precursor was just that. Suntan was an effort by the Air Force to develop a hydrogen-fueled airplane with performance superior to the secret spy plane, the U-2.

Suntan had its roots in Air Force interest in very high-altitude flight during the first half of the 1950s. One approach, along conventional lines, was pushed by Maj. John D. Seaberg of the Wright Air Development Center, beginning in late 1952. This involved a modification of the Martin RB-57 and the start of the Bell X-16, although the latter was cancelled in mid-1955. A different approach, sparked by a proposal by Randolph Rae in 1954 to build a glider-like airplane powered by the Rex engine, focused on the potential advantages of using liquid hydrogen. The Air Force interest in hydrogen was supported by Abe Silverstein, associate director of the Lewis laboratory of the National Advisory Committee for Aeronautics.

By the end of 1955, the Air Force had in progress a number of research and development activities on the feasibility of using liquid hydrogen in flight. The Garrett Corporation, which bought Rae's patents and formed a Rex division with Rae as chief engineer, was three months into a contract for design studies of Rex engines and had concentrated on the largest and latest, the air-breathing Rex III. Kelly Johnson's Skunk Works at Lockheed Aircraft, past their peak effort in designing and building prototype U-2s for the CIA, was two months into a three-month design study of hydrogen-fueled aircraft for Garrett. United Aircraft (now United Technologies) was in the second quarter of a study of using hydrogen in a conventional turbojet engine, and a competitor, General Electric, was also showing interest in hydrogen. Beech Aircraft and Garrett were investigating liquid hydrogen tanks, insulation, and behavior of hydrogen in storage. The Air Force and NACA agreed that the Lewis laboratory would determine the feasibility of flying an airplane fueled with liquid hydrogen. The Air Force would provide the estimated $1 million needed, as well as lend equipment.

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The driving force behind the Air Force's mounting interest in hydrogen was the determination to develop an airplane with performance superior to the U-2. Dissatisfied with its supporting role to the CIA, the Air Force sought not only to take over the operational phase of the U-2 but also to regain the initiative in equipment by developing a second-generation airplane. One prospect was the Rae-Garrett proposal, but that approach did not seem quite the right answer. In late 1955, the time was ripe for a new proposal, and soon one was made by Kelly Johnson. He was immediately seen as the right man with the right idea.

Air Force Moves Fast

The high-flying U-2 was the latest symbol of Johnson's ability to design and build a new airplane quickly in his unique and unconventional Skunk Works. Familiar with hydrogen from conducting airplane design studies for Rae and Garrett, Johnson was impressed with its potential. Early in 1956, armed with a proposal for a hydrogen-fueled supersonic airplane as a follow-on to the U-2, he visited the Pentagon where he had no difficulty seeing high Air Force officials, including Lt. Gen. Donald L. Putt, the deputy chief of staff for development.[2] Johnson offered to build two prototype hydrogen-fueled airplanes, with the first to fly within 18 months. They would fly at an altitude of 30 300 meters, a speed of Mach 2.5, and have a range of 4070 kilometers.[3] To the Air Force, which had missed the opportunity to buy Johnson's original U-2 proposal, the offer was too tempting to resist; they bought it.

New airplanes, however, are not bought without due deliberation. The Air Force went through the proper motions, but the circumstances made the outcome a foregone conclusion. After receiving the proposal, Putt called a meeting on 18 January 1956. Among those present were his counterpart for materiel, Lt. Gen. Clarence S. Irvine; Lt. Gen. Thomas S. Power, head of the Air Research and Development Command; and Col. Norman C. Appold, head of Wright Air Development Center's power plant laboratory. The purpose of the meeting was to evaluate Johnson's proposal, but in his opening remarks, Putt made it clear that the Air Force wanted a new high-altitude airplane within two or three years, whether or not it was the one that Johnson proposed.[4]

The short time that Putt specified was in keeping with Johnson's reputation, but incredibly short if liquid hydrogen, with its array of formidable problems, was to be the fuel. Engine development was considered the pacing item and the reason Appold, the Air Force's chief propulsion expert, had been summoned to the meeting.

Putt wanted six months of study and experimentation to determine the feasibility of attaining the performance goals specified by Johnson. He named Col. Ralph Nunziato, a former test pilot and a member of his staff handling intelligence-gathering equipment, to be his project officer. Power named Appold to head the ARDC team, a clear indication of the critical importance of the propulsion system to the overall effort.

Appold's first assignment was to select a qualified engine manufacturer to study a hydrogen-fueled engine and if feasible, develop it. Given a month to do this by Putt, Appold selected two candidates: the General Electric Company and the Pratt &

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Whitney division of United Aircraft. He met with their representatives,* asked for and received proposals within two weeks, evaluated them, and selected Pratt & Whitney. He reported his actions at another meeting in Putt's office on 20 February, and the selection was approved.[5]

Contract negotiations with Pratt & Whitney started early in April and by the first of May, a six-month contract had been signed. Agreement was also reached with Lockheed. Officials of Pratt & Whitney, impressed with the potential of hydrogen and wishing to avoid the red-tape of a cost-plus-fixed-fee contract, agreed to a fixed cost contract. As it turned out, their costs exceeded the fixed amount and Pratt & Whitney lost money.† Lockheed held out for a provisional contract that could be renegotiated and repriced at the end of the contract. Both firms, however, were hard at work by the first of April 1956. The contracts were made retroactive, to cover the fast start.[6]

In the weeks that followed the initial meeting in February, Appold and Nunziato were very busy dealing with the two companies and consulting with specialists at the Wright Air Development Center on the feasibility of providing large quantities of liquid hydrogen. Although Appold continued as head of the power plant laboratory, it was clear that his new assignment would soon require full attention, as well as a staff. He chose Lt. Col. John D. Seaberg, the aeronautical engineer assigned to weapon systems who had started work on high-altitude aircraft in 1952 (pp. 113–14), to manage work on flight-type liquid hydrogen tanks, airframe, and complete airplane systems. Major Alfred J. Gardner, a combat pilot during World War II, holder of two master's degrees in engineering, and a propulsion specialist, was chosen to manage the engine development. Capt. Jay R. Brill, West Pointer, mechanical and nuclear engineer, would manage the logistics, including the quantity production of liquid hydrogen and its storage, transportation, and handling. The team worked initially at Wright Field and moved to ARDC headquarters in Baltimore in June, as a special projects office.[7]

Considering the highly classified U-2 and the Air Force's desire to build a superior airplane, it is not surprising that the new project was very closely held. It was given a special classification higher than "Top Secret," the highest standard category. Full access was limited to about 25 people, an extremely small number considering the size and complexity of the large research and development effort.[8]

Two compelling reasons beyond technical management and Air Force security called for a special projects office: fast contractual action and contractor security. To get an airplane developed in the two or three years that Putt demanded meant bypassing the normal, but time-consuming, management and procurement processes. Appold turned to Col. Lee Fulton, head of procurement at ARDC Headquarters and his deputy, Robert Miedel, for help; Miedel served as temporary procurement officer. They soon had a blanket "determination and findings" statement from Richard Horner, assistant secretary of the Air Force for research and development, and

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*Jack Parker, Gen. Mgr., Aircraft Gas Turbines Div., General Electric Co., and Charles Dribble, a G.E. engineer; Wright Parkins, William Gwinn, and Perry Pratt of Pratt & Whitney.

†Pratt & Whitney received $15.3 million for the first phase of work and spent $17.1 million. Interview, Ernest Schweibert with Lt. Richard Doll, Dec. 1958.

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directives from the Air Force deputy chiefs of staff for development and materiel, Putt and Irvine. These authorities allowed the Suntan team to waive normal procurement procedures and award contracts directly, with a minimum of review. This cut months from the procurement process.

Miedel bowed out in June 1956 by appointing William E. Miller as contracting officer and negotiator on all Suntan contracts, and Lt. Col. J. R. Beyers as head of contract management. Two special auditors were assigned by the Auditor General. Miller's group also handled property and contractor security.[9]

Extraordinary measures were taken to conceal Suntan from the curious and the unauthorized. The Suntan team at ARDC changed project numbers from time to time; some contracts were written through other Air Force offices, so they could not be related to Suntan. At contractor plants, Suntan workers were isolated and guarded from other units and operated as independently as possible. Special measures were taken to prevent identification of Suntan visitors by those not connected with the project.* Documentation was kept to a minimum.[10]

Lockheed CL-400

The initial contract with Lockheed called for two prototype reconnaissance aircraft, with the first to fly in 18 months. Hard on its heels, also in 1956, Lockheed received a contract for six of the aircraft. The design Lockheed selected was designated CL-400 and was capable of a speed of Mach 2.5 at an altitude of 30 300 meters.[11] The CL-400 was described openly for the first time in 1973 by Ben Rich at a symposium on hydrogen-fueled aircraft at the NASA Langley Research Center. Figure 34, taken from his paper, shows the characteristics of the CL-400. It had a fuselage diameter of three meters and a length of 49 meters to accommodate the 9740 kilograms of liquid hydrogen. The retractable ventral (bottom) fin improved directional stability at supersonic speeds.

The engines, designated 304-2, were to be supplied by Pratt & Whitney and will be described later. Each weighed 2850 kilograms, provided 42 kilonewtons at sea-level, and 27 at Mach 2.5 and 29000 meters altitude.

The mission profile is shown by figure 35. The range was 4070 kilometers and could be extended only by a considerable increase in airplane size. Airplane sizes with lengths as long as a football field, as well as other variables, were studied at the Skunk Works. The relatively short radius of 2000 kilometers was later to become a matter of great concern.

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*Of numerous stories of security incidents, one of the most interesting involved a good-looking female engineer of the Skunk Works who almost—and inadvertently—blew Suntan's cover. She attended a symposium on hydrogen at the NBS Cryogenics Laboratory and following established practice of the Skunk Works, registered as representing herself. Standing nearby was a male engineer who knew she worked for Lockheed but had forgotten her name. He peeked at the register and immediately grew suspicious, wondering why Lockheed was interested in hydrogen and hiding it. Interview with Col. Gardner, 19 Sept. 1973.

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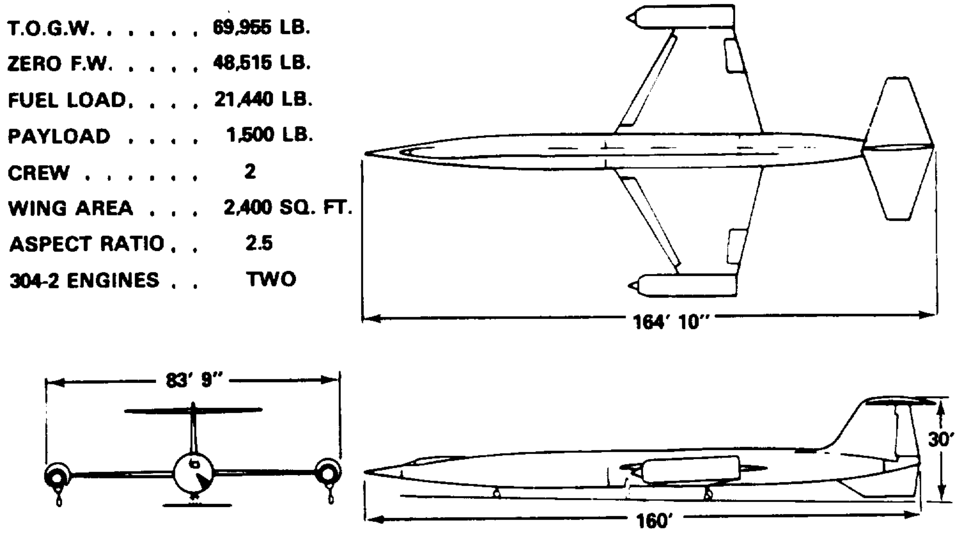

Fig. 34. Lockheed CL-400 reconnaissance aircraft using liquid hydrogen as fuel, ca. 1955. Ben R. Rich, "Lockheed CL-400 Liquid Hydrogen-Fueled Mach 2.5 Reconnaissance Vehicle," read at a symposium on hydrogen-fueled aircraft, NASA Langley Research Center, 15–16 May 1973.

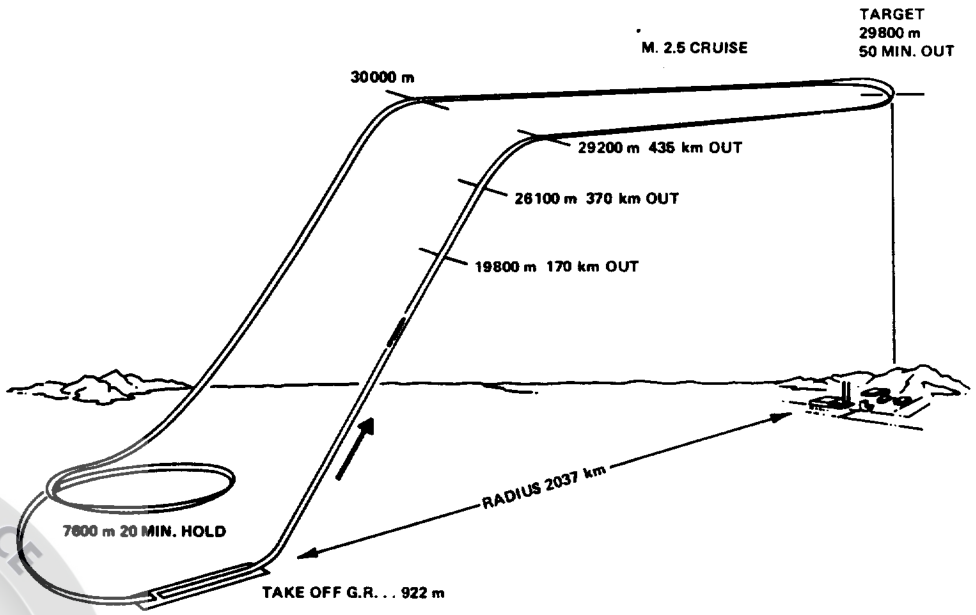

Fig. 35. Mission profile for the Lockheed CL-400 using liquid hydrogen as fuel. (Source same as fig. 34.)

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Fig. 36. Clarence L. (Kelly) Johnson, aircraft designer and builder extraordinary, father of the U-2 reconnaissance airplane and its first proposed successor in 1956–1958, the hydrogen-fueled CL-400. (Courtesy of Lockheed Aircraft Corp.)

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Fort Robertson at the Skunk Works

Kelly Johnson saw his task as much more than designing and building a hydrogen-fueled airplane. He was also concerned about its operation, for if it was to be successful, liquid hydrogen had to be produced and shipped in quantity and be handled like gasoline. On 16 March 1956, he and his staff met with representatives of J. H. Pomeroy and Company of Los Angeles, a consulting engineering firm. Johnson wanted Pomeroy to study the engineering feasibility and cost of producing parahydrogen in quantity, and he was interested in three production rates—45000, 135000, and 225000 kilograms per day. He wanted the plant location to be in the Antelope Valley of California. Pomeroy agreed to undertake the study, and ten days later Johnson sent them a letter of intent with ground rules.[12]

At the outset of the project, Johnson assigned one of his assistants, Ben Rich, a thermodynamics and heat transfer expert, the dual responsibilities of propulsion and the handling of hydrogen. Rich, who knew little about liquid hydrogen at the time, checked Mark's *Mechanical Engineering Handbook* which stated that liquid hydrogen was an impractical fluid and only a laboratory curiosity. He was to understand why in his subsequent visits to laboratories and firms working with liquid hydrogen. Among those contacted were Professor William Giauque, University of California at Berkeley, and Russell B. Scott at the Cryogenic Laboratory of the U.S. Bureau of Standards at Boulder. Rich concluded that liquid hydrogen was mostly in the hands of highly skilled scientists, and few of them appreciated the practical problems he saw in adapting liquid hydrogen to routine use as an airplane fuel. In that application, a temperature range from the boiling point of liquid hydrogen, 20.3 K, to the frictional temperature of the airplane skin at Mach 2.5, about 670 K, had to be handled with designs and materials dictated by volume and weight restrictions. The earthbound design and construction methods used with liquid hydrogen generally were unsuitable. Moreover, Rich found that he was thinking of far greater quantities of liquid hydrogen than others; he used the unit "acre-feet" to emphasize his point. All these considerations made it obvious that the Skunk Works staff had to learn how to handle liquid hydrogen and to adapt it to the particular application. This required a liquid hydrogen test facility. During World War II, a bomb shelter revetment had been built adjacent to the Skunk Works, and it was selected as the site of the hydrogen facility. It was named "Fort Robertson" after the man who was in charge of the test operations. A Collins cryostat, capable of producing nine liters of liquid hydrogen per hour, was installed to test materials, bearings, seals, and small components. When larger quantities were needed for tank flow and spill tests, liquid hydrogen was obtained from the Bureau of Standards Cryogenic Laboratory at Boulder and stored in a 2200 liter refrigerated dewar built by the Air Force for the hydrogen bomb program. The Skunk Works also relied heavily on the experts at the NBS Cryogenic Laboratory, particularly Russell Scott, regarded as "Mr. Hydrogen," who became a consultant.

On 1 October 1956, the J. H. Pomeroy Company reported on hydrogen liquefaction plants. The report is an excellent summary of the state-of-the-art, and cites 52 references.[13] An entire plant was planned—from incoming natural gas for producing gaseous hydrogen to underground storage of liquid hydrogen. A plant of 45000 kilograms per day capacity was studied in detail, as well as multiples of it—well above

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the size of the Boulder installation, which had the largest capacity in existence in the U.S. Pomeroy considered the 45000 kilogram per day capacity to be about the largest practical size. Construction cost was estimated at $45 million and operating costs at $0.386 per kilogram. A million cubic meters of natural gas per day would be required.* Pomeroy discussed an expansion engine process that would, with some additional R&D, be available. With catalysts, it would permit continuous liquefaction of parahydrogen.

Hydrogen Tanks and Systems

For a hydrogen-fueled airplane, the very low temperature and density of liquid hydrogen pose special design problems for tanks, pumps, lines, instrumentation, and other components in the fuel system. The special requirements imposed by hydrogen are recognized immediately by all who consider such designs and, of course, received major attention by the men of the Skunk Works. The CL-400 design divided the hydrogen tankage into three sections; the forward tank had a capacity of 67000 liters; aft, 54000; and center (sump), 15000. The two main tanks were kept at 2.3 atmospheres pressure and the sump tank slightly lower for fuel transfer. In the sump was a booster pump, built by Pesco Products, that supplied liquid hydrogen to the engines at a pressure of 4.4 atmospheres. The engines were mounted at the wing tips, which meant that the liquid hydrogen had to pass through a hot wing with surface temperatures up to 436 K. The design provided a vacuum-jacketed, insulated line for this purpose.

There were many unknowns in the design of the hydrogen tanks and other fuel components, and numerous experiments were conducted to obtain more information. These were done at Fort Robertson and included half-scale models of the sump tank, the vacuum-jacketed lines for carrying hydrogen from the tanks through the hot wings to the engines, booster pumps, valves, controls, and other components. These were tested in thermal environments simulating flight conditions. Later a full-scale sump pump was built and shipped to Pratt & Whitney for their use in engine testing.

Is Hydrogen a Practical Fuel?

Among the first concerns of Johnson and Rich were the fire and explosion hazards of hydrogen. Could it be handled as safely as gasoline? In his early visits to laboratories using liquid hydrogen, Rich inquired about fires and explosions, but obtained little information. The laboratories went to great lengths to avoid these problems. The only previous explosions Rich learned about were some minor ones Professor William Giauque experienced when oxygen crystals formed in a heat exchanger containing hydrogen. The paucity of information led Johnson and Rich to devise a series of experiments to determine for themselves the hazards of hydrogen fires and explosions.

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*$CH_4 + H_2O$ (steam) → $3H_2 + CO$

$CO + H_2O$ (steam) → $H_2 + CO_2$

The CO^2 byproduct would be marketed to keep costs down.

For this they turned to their only testing ground, Fort Robertson—less than a kilometer from the runways of the Burbank airport.

Tests were devised in which tanks containing liquid hydrogen under pressure were ruptured. In many cases, the hydrogen quickly escaped without ignition. The experimenters then provided a rocket squib (a small powder charge) to ignite the escaping hydrogen. The resulting fireball quickly dissipated because of the rapid flame speed of hydrogen and its low density. Containers of hydrogen and gasoline were placed side by side and ruptured. When the hydrogen can was ruptured and ignited, the flame quickly dissipated; but when the same thing was done with gasoline, the gasoline and flame stayed near the container and did much more damage. The gasoline fire was an order of magnitude more severe than the hydrogen fire. The experimenters tried to induce hydrogen to explode, with limited success. In 61 attempts, only two explosions occurred and in both, they had to mix oxygen with the hydrogen. Their largest explosion was produced by mixing a half liter of liquid oxygen with a similar volume of liquid hydrogen. Johnson and Rich were convinced that, with proper care, liquid hydrogen could be handled quite safely and was a practical fuel—a conclusion that was amply verified by the space program in the 1960s. At the time, however, Johnson and Rich filmed their fire and explosion experiments to convince doubters.

The confidence of Johnson and Rich in hydrogen handling was not always shared by their hydrogen consultant, Russell Scott, who was often amazed at what he saw going on in the test areas of Fort Robertson.[14] The facility, however, was well equipped with an explosion-proof electrical system, non-sparking safety tools, hydrogen sniffers or monitors, and other safety devices. In the three years of work and the handling of thousands of liters of liquid hydrogen, there was not a single accident caused by hydrogen. There was, however, one close call. In keeping with Kelly Johnson's philosophy of austerity, the ovens used for simulating hot wing temperatures of Mach 2.5 flight were made partially of wood. There were five such ovens, and early one morning, about 2 a.m., one of them caught fire. The Skunk Works personnel, including Rich, were summoned because the fire department could not be called, for security reasons. At the time there were 2000 liters of liquid hydrogen stored in the area and Rich decided that the best course of action was to dump the liquid hydrogen on the ground. It was winter and very humid; the cold hydrogen quickly filled the revetment with fog about five feet thick. Rich and about two dozen other people were in the revetment and all they could see of each other were their heads, an eerie sight. Luckily, the hydrogen did not ignite.

Suntan at United Aircraft

United Aircraft Corporation* became involved in liquid hydrogen as a propulsion fuel in 1955 on the initiative of the power plant laboratory at Wright Field. Acting on a directive from its headquarters, the laboratory initiated a procurement request in January 1955 to investigate hydrogen as a fuel in turbojet engines. In February, invitations to bid were sent to United Aircraft and three other major engine

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*Name changed to United Technologies Corp. in 1975.

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manufacturers. Proposals were submitted in March; United Aircraft won the competition and was awarded a contract on 15 June (p. 126).

The contract was not with the corporation's Pratt & Whitney division but with the research department headed by John Lee. The work was exploratory and included cycle analyses, aircraft weight analyses, and some experiments. One of the men involved was Wesley A. Kuhrt, to whom hydrogen was no stranger. When 13 years old, he made hydrogen in his cellar laboratory by adding zinc to hydrochloric acid. Suddenly there was an explosion; glass fragments were imbedded in his chest, but he escaped serious injury. The incident neither cooled his enthusiasm for science nor created a fear of hydrogen.[15]

The Pratt & Whitney division had followed Air Force and NACA interest in hydrogen during 1955 and was also aware of Rae's Rex engines.[16] The Suntan project began for the division with a call from Appold in January 1956; by February, division officials began to believe they would win the contract for the engine. On 17 February, Perry Pratt, chief engineer, summarized what he had learned about hydrogen in jet engines. He cited six companies with experience in pumping hydrogen and described an engine that was somewhat similar to the Rex engine.* Pratt had examined the hydrogen supply problem and concluded that conversion of liquid hydrogen to its para form at time of liquefaction was feasible, and this made hydrogen storage, and shipment by truck, rail, or air practical. This optimistic report was written on Friday.[17] The following Monday, Pratt was in California visiting various people knowledgeable about hydrogen, including Kelly Johnson at Lockheed.[18] By this time, it was highly probable that Johnson and Pratt, collaborators in adapting the J-57 engine for the U-2, were aware that they would again be working together on the Suntan project.

William Sens, a Pratt & Whitney engineer, accompanied Pratt on the California trip and while there learned about Rex engines. This excited him, for six weeks earlier he had conceived an idea about hydrogen-fueled engines following a conversation with John Chamberlain, a combustion expert at United Aircraft's research laboratory. Chamberlain had pointed out that heated hydrogen was capable of a large amount of work in a thermodynamic cycle. Sens began thinking of using heated hydrogen to drive a turbine which would power an engine fan or compressor. After passing through the turbine, the hydrogen would be injected and burned in the airstream of the engine. Immediately after returning from California, Sens sent a proposal to Pratt for developing a hydrogen engine meeting the following requirements:

Altitude	30 500 m
Speed	M 2.5
Thrust	20 000 N (4500 lb)
Thrust specific fuel consumption	0.076 kg/N·hr (0.75 lb/lb thrust·hr)
Nacelle weight	2722–3175 kg
Engine diameter	155 cm

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*Reaction Motors, Carter Pump, North American, Aerojet, Cambridge Corp., and National Bureau of Standards. Pratt mentioned an engine fan diameter of 150 cm, the same diameter that Johnson and Rae had agreed upon in the Lockheed airplane study for Garrett, and which had been officially reported to the Air Force two days earlier.

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These specifications indicate that Sens was also aware of Johnson's propulsion requirements or those of the CL325-1 prepared by Johnson for Garrett (table 4, p. 134).[19]

Sens described his proposed engine as having a dual cycle, with the basic one resembling a supercharged ramjet:

> Air is . . . compressed by a low pressure ratio compressor, heated by combustion of hydrogen vapor and discharged through a . . . nozzle. In addition, heat is extracted from the air stream by means of a heat exchanger after part of the combustion of the hydrogen has taken place. This heat is used to vaporize and heat the hydrogen being used in the combustion process. In the secondary cycle the liquid hydrogen fuel is compressed to a high pressure by means of a multi-stage centrifugal type pump. The high pressure hydrogen is then vaporized and heated to a relatively high temperature in the heat exchanger located in the high temperature air stream. The hydrogen is then expanded through a multi-stage axial-flow turbine to a pressure only slightly above that of the fan discharge air. The turbine power output is used to drive the compressor used in the air cycle. Because of the large speed difference between the hydrogen turbine and the air compressor, it is necessary to use a single speed reduction gear between the two components.[20]

Sens discussed anticipated problems and the applicability of existing Pratt & Whitney experience to solve them.

Sens was not the only one in the corporation considering possible hydrogen engines. Wesley Kuhrt in the research department had been working on them for some time, and on 1 March 1956, he conceived three engine systems for which he later filed and was granted patents.[21] One was a turbofan engine (fig. 37). Air entering the inlet is compressed by the fan and flows around the centerbody to the aft section, where gaseous hydrogen is injected and burns stoichiometrically. The hot gases expand through the exhaust nozzle to produce thrust. The source of power for the air fan is a turbine driven by heated hydrogen prior to combustion. Liquid hydrogen flows to the heat exchanger around the exhaust nozzle where it gasifies and is raised to a reasonably high temperature. From the heat exchanger the hot hydrogen drives a multistage turbine which is connected to the air fan through a gear box. After leaving the turbine, the hydrogen is injected in the engine air stream and burned. Kuhrt's engine is similar to Rae's Rex III in that both employ a heat exchanger to heat the hydrogen to drive a turbine, but Kuhrt's concept is much simpler than the Rex III (p. 131).

For Kuhrt, the beginning of the Suntan work at United Aircraft was a call in early 1956 to come to the office of Wright Parkins. Present were Perry Pratt, Col. Norman Appold, and others. Appold stressed the need to get started quickly on a project to use hydrogen in aircraft engines.[22]

For Richard J. Coar, a rising, brilliant young mechanical engineer hard at work on developing the J-75 turbojet, the Suntan program also began early in 1956 when he was "yanked off his project" and assigned to the hydrogen engine work. His first task was engine analysis and learning all he could about hydrogen. He visited the Bureau of Mines, the Arthur D. Little Company, and a conference at the Bureau of Standards

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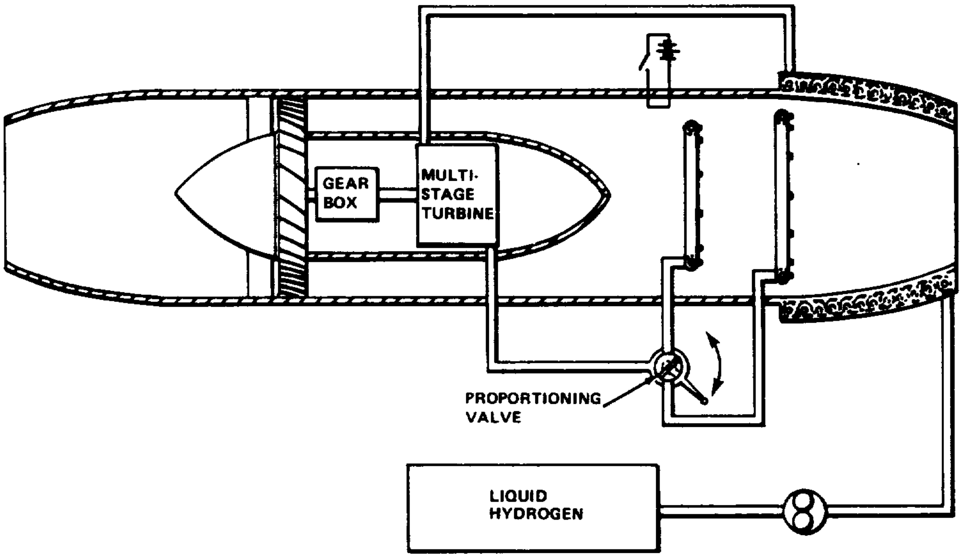

Fig. 37. Wesley A. Kuhrt's turbofan jet engine using liquid hydrogen as fuel, the precursor to Pratt & Whitney Aircraft's 304 engine. From Patent 3 241 311, 22 Mar. 1966, filed 5 Apr. 1957. (Courtesy of United Technologies Corp.)

Cryogenic Laboratory at Boulder. Inspection of the liquefaction plant convinced him that production of liquid hydrogen would be a major obstacle to military use of hydrogen. The plant was small and the laboratory techniques required highly skilled personnel. In April, Coar went to Baltimore to negotiate a contract with the Air Force. It was on one page and technical negotiations were completed in a day—a marked contrast to the long and agonizing process that Rae, Garrett, and the Air Force had gone through earlier.[23]

Pratt & Whitney's initial approach to the problem was to analyse the various hydrogen engines that had been proposed, select one, and develop it so as to take the greatest advantage of hydrogen's unique properties. This remained their mainline approach but in a short while, they realized that modification of an existing engine would provide a quicker, though less efficient, engine for early flight experience. They proposed to modify a J-57 for this purpose, the Air Force agreed, and the contract was amended.

Shamrock

In the spring of 1956, Suntan engine activities at Pratt & Whitney were in full swing. Coar selected Richard C. Mulready, a bright young engineer, as his assistant. Liquid hydrogen handling tests began immediately with hydrogen obtained from the Cambridge Corporation in dewars. Associated with this activity were preparations for component and engine testing, including obtaining a supply of liquid hydrogen. With the help of Capt. Jay Brill, a hydrogen liquefier of 227-kilogram-per-day capacity was purchased from Herrick L. Johnston and installed in the engine test area behind the

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East Hartford plant. The test area was called the "Klondike" because of the cold Connecticut winters and well-ventilated test stands that were designed to prevent the accumulation of hydrogen. Coar and Mulready also began to round up all the gaseous hydrogen tube trailers they could find to supply the liquefier.[24]

The second activity, code named "Shamrock," began in April to convert a J-57 to burn hydrogen. The design was completed in May; thereafter, component testing and engine modifications ran concurrently. The hydrogen liquefier was ready in September, engine testing began in October. The test engineers were agreeably surprised by the ease of engine operation. They ran it at full power and throttled back so far that the air fan was revolving so slowly the individual blades could be counted. Under this latter condition, the throttle could be opened and the engine would quickly and smoothly accelerate to full power. They found that the temperature distribution was good and there were no major problems. Such satisfactory results came only after careful design studies, modifications, and component testing. Among these precursory activities were the development of a heat exchanger using air bled from the compressor to gasify the hydrogen, modifications to the J-57 electronic fuel control system, and development of an oil-lubricated, liquid-hydrogen pump. Figures 38 and 39 show a schematic of the modified J-57 and comparison with the standard model.

By the fall of 1957, the J-57 experiments demonstrated beyond question that a conventional turbojet could be readily adapted to use hydrogen. Such engines could have been used to meet Kelly Johnson's tight airplane development schedule, but modifying an existing turbojet could not optimize the advantages of hydrogen. The Pratt & Whitney engineers had realized this early in their studies, as had their counterparts in the Rex division of Garrett and the Air Force. The mainline Pratt & Whitney effort from the start focused on a design of a special hydrogen engine, and its design started in April 1956 with the first contract.[25]

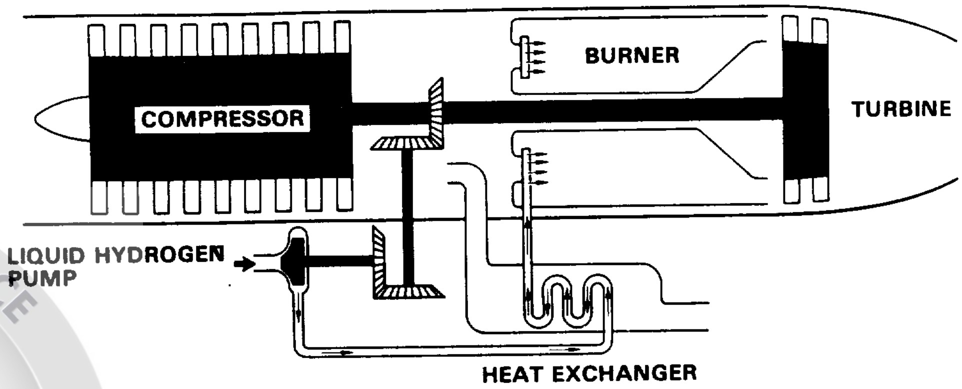

Fig. 38. Schematic of the Pratt & Whitney Aircraft J-57 jet engine modified to use liquid hydrogen as fuel, 1956. (Courtesy of Pratt & Whitney.)

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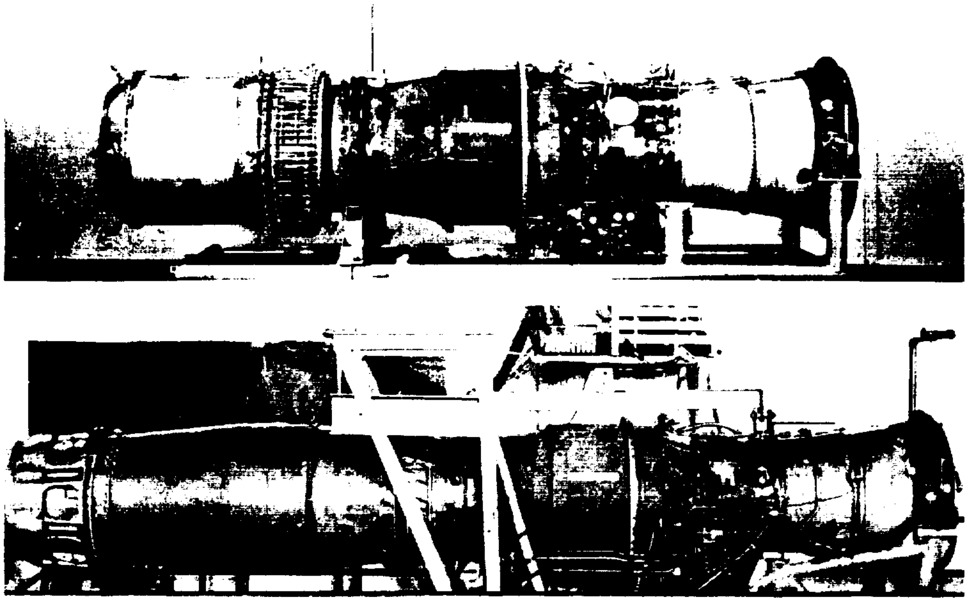

Fig. 39. Comparison of Pratt & Whitney's J-57 with afterburner (about 6¼ meters long) and using hydrocarbon fuel (bottom) with the engine modified to use liquid hydrogen (top), 1956. (Courtesy of Pratt & Whitney.)

The Model 304 Engine

By mid-August 1956, Pratt & Whitney engineers had designed the new engine to use hydrogen. It was designated the "304," taken from the division's engine order number 703040, 16 April 1956.[26] It was essentially the one proposed earlier by Sens and Kuhrt and is shown schematically by figure 40. Liquid hydrogen was pumped at high pressure through a heat exchanger in the aft section of the engine. The heated hydrogen drove a multistage turbine which, through a reduction gear, powered a multistage air fan. The fan compressed incoming air, the primary working fluid of the engine. Part of the hydrogen discharged from the turbine was injected and burned in the air-stream behind the fan. The amount of hydrogen injected and burned was controlled to limit the temperature of the combustion gases which furnished the heat for the heat exchanger downstream. The remaining hydrogen was injected and burned in the after-burner section beyond the heat exchanger, and the hot gases and air expanded through the nozzle to produce propulsive thrust. The engine was similar to the Rex III but much simpler, as only one heat exchanger was used. The maximum diameter of the 304 engine was 203 centimeters, as compared to the 150 centimeters proposed by Garrett for Rex III. Nacelle length was 10.7 meters; weight 2722 kilograms; thrust at 30 500 meters altitude, 21.4 kilonewtons (4800 lb); and specific fuel consumption 0.082 kilogram/newton · hour (0.8 lb/lb · hr). These are close to the specifications in Sens's draft of 24 February 1956.

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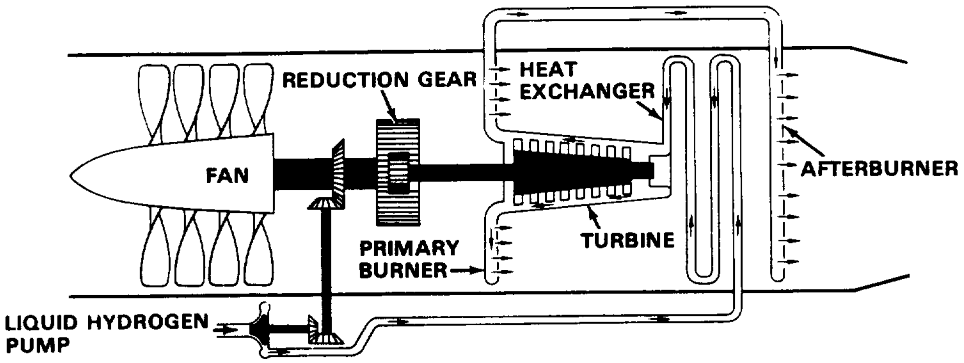

Fig. 40. Schematic of Pratt & Whitney's model 304 engine designed to use liquid hydrogen as fuel, 1956. (Courtesy of Pratt & Whitney.)

Pratt & Whitney engineers were well experienced in all the components of the 304 engine except the liquid-hydrogen pump and the hot-gas heat-exchanger. They purchased a liquid-hydrogen pump for study, but became dissatisfied with it and proceeded to make a better one.[27] They saw two critical problems: an impeller that would handle liquid hydrogen without cavitation, and adequate sealing between the high-pressure liquid hydrogen at 20 K and the oil-lubricated bearing. Apparently they were not familiar with the work at Ohio State University on oil-free ball bearings operating in liquid hydrogen (pp. 25–26). They designed a two-stage centrifugal pump with a seal protecting conventional bearing lubrication. Figure 41 is a photograph of the pump rotor. The pump worked well and a total of 25 hours test time was accumulated in 75 tests over two years.*

The hot-gas–to–hydrogen heat exchanger (fig. 42) was the most unusual and interesting component of the 304 engine. With an outside diameter of 182 centimeters, the unit consisted of banks of 48-millimeter stainless steel tubing in an involute pattern to ensure uniform air flow. An enormous amount of tubing was used—enough to stretch over 8 kilometers; 2240 tube joints were furnace-brazed. The hydrogen passing through the heat exchanger was heated from 20 K to 1000 K, and the entering combustion gas temperature was 1500 K. The rate of heat transfer was 21 000 kilowatts (72 million Btu/hr), enough to heat 700 six-room houses.[28]

Pratt & Whitney engineers, experts in designing gas turbines, built the 304 hydrogen turbine with 18 stages, the largest of which was 45 centimeters in diameter. Operating temperature was 1000 K and power output was 8950 kilowatts (12000 hp). The turbines were tested for a total of 64 hours over a two year period. The 12-stage high-pressure group is shown by figure 43.

The first model 304 engine was assembled in East Hartford, Connecticut, by 18 August 1957—sixteen months after go-ahead (fig. 44.).

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*One pump accumulated 4½ hours of test time with speeds as high as 25 300 rpm, pressures of 75 atm, and a flow of 1.9 kg/s.

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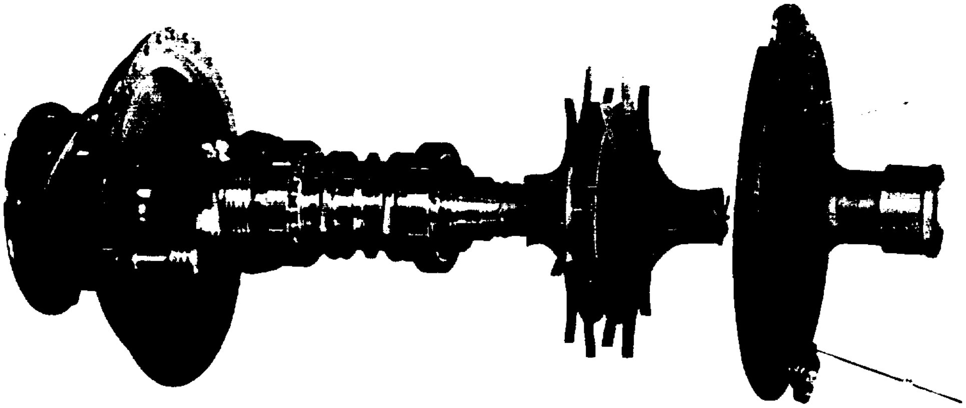

Fig. 41. Pratt & Whitney's liquid-hydrogen pump for the model 304 jet engine. The seal between the rotor and bearings operated dry; the bearing lubrication was conventional. (Courtesy of Pratt & Whitney.)

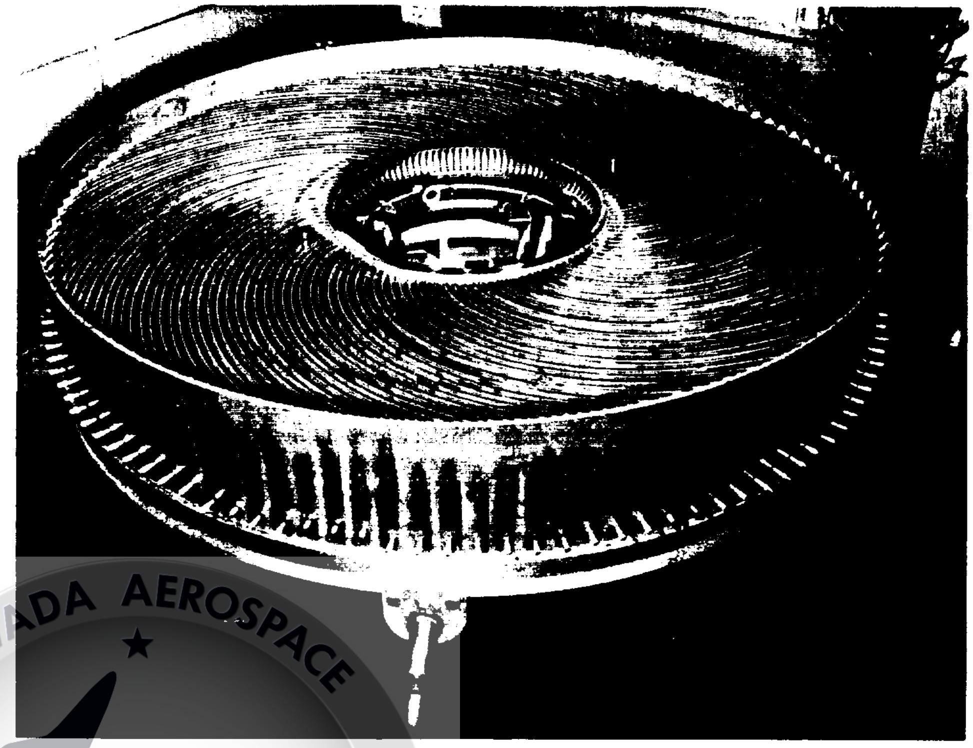

Fig. 42. Hydrogen heat exchanger in Pratt & Whitney's model 304 jet engine using liquid hydrogen as fuel. (Courtesy of Pratt & Whitney.)

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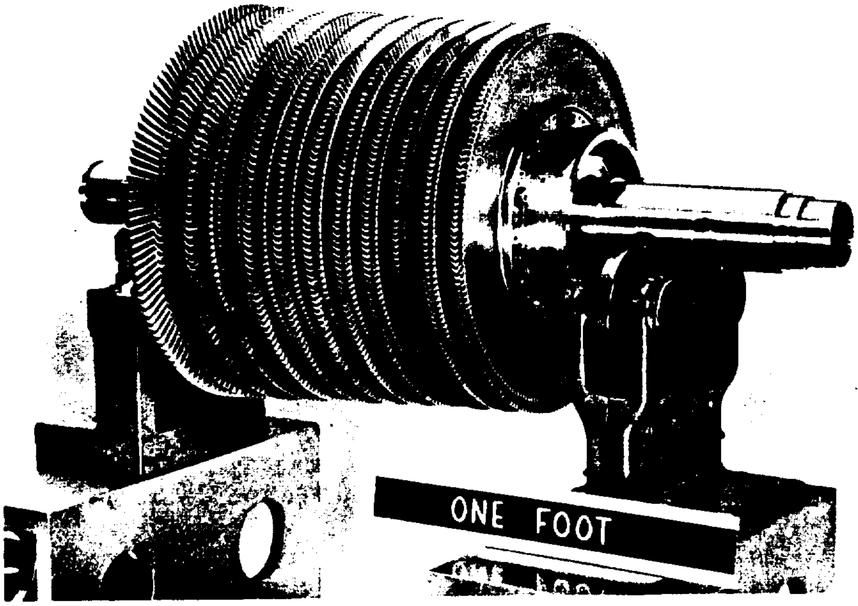

Fig. 43. High-pressure group of the 12 stages of hydrogen turbine expansion used by Pratt & Whitney's model 304 engine. The early stages operated near 1000 K. (Courtesy of Pratt & Whitney.)

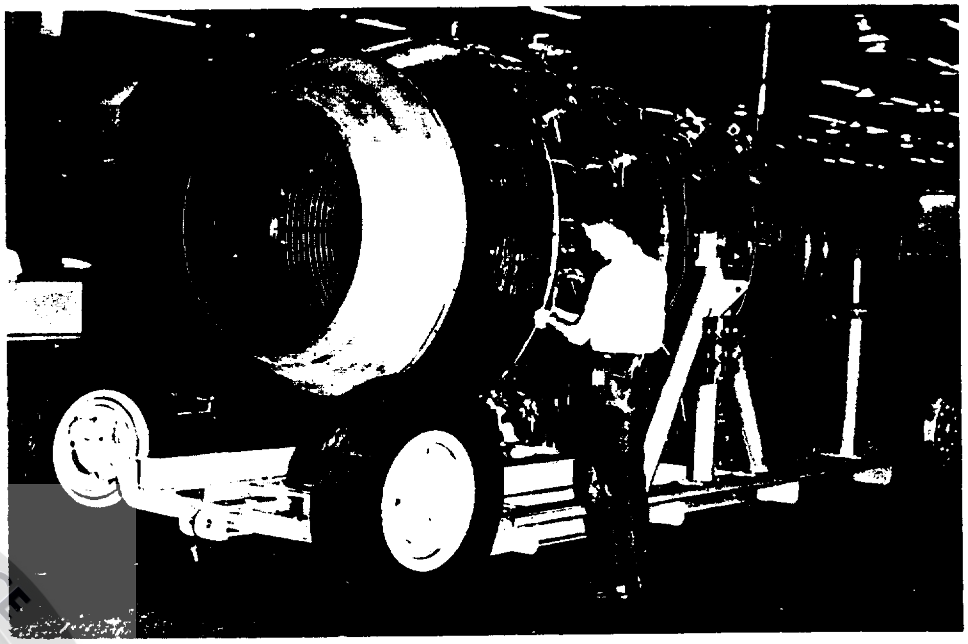

Fig. 44. Pratt & Whitney's model 304 engine using liquid hydrogen as fuel. Visible inside the nozzle is the afterburner fuel injector. The engine was first tested in September 1957. The numerous wires on the engine led to sensors for measuring performance. (Courtesy of Pratt & Whitney.)

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Engine Tests

The testing of the 304 engines was carried out at Pratt & Whitney's new center west of West Palm Beach, Florida. The test center, still under construction in the fall of 1957, was the result of several years of planning by United Aircraft officials to overcome the limited space for testing at their Connecticut plant. Problems of safety and noise made a more remote site desirable, and there were considerations of dispersal of facilities for defense reasons. These had led to the choice of West Palm Beach County as a desirable test site. United Aircraft acquired a large tract of land, swapped part of it for adjacent land owned by the state, and ended up with 27 square kilometers of sand, scrub pine, swamp, and alligators—well suited for remote testing of new engines. In the negotiations for the hydrogen engine contract, United Aircraft officials indicated a willingness to invest $20 million in permanent facilities at the new center if the Air Force would pay for all movable equipment, also estimated to be about $20 million.[29] The cost sharing was agreed upon in principal, if not in the exact amounts, and construction proceeded. During initial operations, the test crew often had to call for a bulldozer to clear the unpaved roads of deep ruts to allow passage; alligators were a common sight.[30]

The first 304 engine tests began on 11 September 1957 using three fluids: nitrogen, gaseous hydrogen, and liquid hydrogen. The inert nitrogen was used to check the fuel system and rotating machinery, especially bearings and seals. The first series of runs lasted through October; 4½ hours were logged, including 38 minutes with liquid hydrogen. The engine was removed for inspection and overhaul when turbine oil consumption became excessive. When reinstalled for a second series of runs on 20 December 1957, no significant failures occurred, but the engine was periodically removed, inspected, overhauled and reinstalled.[31]

Six series of runs were made through the first part of July 1958 and 5½ hours of operation with hydrogen were accumulated. Only minor problems were encountered until the last run, when there was a major failure of bearings, turbine, and heat exchanger. Meanwhile, a second engine of the same type had been installed on a twin test stand; its first run was made on 16 January 1958. Tests continued on the second engine into the first part of April, with a little over 10 hours of operation with hydrogen. The engine was removed when the low pressure section of the turbine failed.

During the testing period, Coar and Mulready designed and built a second model of the 304 engine, which had an additional (fifth) compressor stage and lower specific fuel consumption. The first 304-2 was assembled at East Hartford on 20 June 1958 and four days later was operated at the Florida test center. Tests continued for a month, with 3 1/3 hours of accumulated running time with hydrogen before the engine experienced a complete turbine failure. It was removed for repair and strengthening of the turbine disks. While this engine was in the shop, another 304 engine (presumably of the first design) was installed and operations began in mid-August. This engine operated satisfactorily through September and accumulated over 6 hours time using hydrogen. Table 5 shows a comparison of the specifications and performance of the two versions of the 304.

By the end of September 1958, the repaired 304-2 engine was back on the stand and made a short run, and another 304 engine was nearing assembly at East Hartford.

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Fig. 45. Key Pratt & Whitney engineers in developing the model 304 aircraft engine and the RL-10 rocket engine using liquid hydrogen, L to R: Perry W. Pratt, Richard J. Coar, and Richard C. Mulready. Pratt was chief engineer of P&W during the development of both engines. Coar was project engineer of the 304 engine and became the chief engineer of the Florida center where the RL-10 was developed. Mulready succeeded Coar as project engineer of the 304, became project engineer of the RL-10 in 1958, and assistant chief engineer of the Florida center in 1961. Pratt has retired; Coar is vice-president for engineering; and Mulready is corporate manager for new business development.

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TABLE 5.—*Characteristics of Pratt & Whitney's Model 304 Engines*

	Model 304-1	Test Performance		Model 304-2	Test Performance
Characteristic	Spec A6600	Eng. 1	Eng. 2	Spec A-6600A	
Sea-level static thrust newtons (lbs)	55600 (12500)	55422 (12460)	53429 (12012)	60048 (13500)	35028 (7875)
Thrust specific fuel consumption, kg/N·hr	1.10	1.252	1.220	0.900	.937
Compressor speed, rpm	3600	3630	3300	3600	2503
Pump discharge pressure, atm	—	54	42	—	34
Overall turbine efficiency	—	—	.475	-	.507

Note Model 304-1 had 4 compressor stages.
Model 304-2 had 5 compressor stages.

Neither was destined to run again, for time had run out on the Suntan project. In all, the engines were operated 25½ hours with hydrogen, and all indications were that the development was proceeding satisfactorily.

Baby Bear, Mama Bear, and Papa Bear

Concurrent with the engine testing was an extensive program of component testing, and the combined operations created a heavy demand for liquid hydrogen, a situation anticipated by the Air Force.

Capt. Jay Brill's primary assignment on the Suntan management team was the logistics of liquid hydrogen. In one of his first moves, he contacted the Atomic Energy Commission to scrounge the excess equipment used for the "wet" hydrogen bomb program. He was able to obtain several of the refrigerated transport dewars developed for the AEC program (p. 68). In April 1956, he began a survey of industrial firms to assess their capability and interest in building hydrogen liquefiers and producing liquid hydrogen for the program. Wright Field had prepared a specification for liquid hydrogen which was given the code name "SF-1" fuel. Brill was accompanied on his visits by Marc and Blackwell (Blacky) Dunnam. Marc was chief of the fuels and oil division of the Power Plant Laboratory and Blacky had experience with cryogenic equipment. They visited the Linde Company in New York, Hydro-Carbon Research in New Jersey, and the Air Products Company in Allentown, Pennsylvania. Brill returned to Dayton convinced that large hydrogen liquefiers could be built with existing technology. The Arthur D. Little Company was awarded a contract to serve as a consultant in hydrogen liquefaction and to study hydrogen handling and safety

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procedures. The Air Force also made use of the services of Russell Scott and other experts at the Bureau of Standards Cryogenic Laboratory at Boulder.[32]

In his survey of industrial firms, Brill found that there was plenty of gaseous hydrogen capacity by several processes. One firm produced excess hydrogen as a by-product in Painesville, Ohio. This was near Pesco Products division of Borg Warner Corporation, a firm Appold had involved in developing a liquid hydrogen transfer pump for the CL-400 airplane. It was also near the NACA Lewis Laboratory, which would soon need liquid hydrogen for its flight investigation. For these reasons, the Air Force contracted with Air Products, about May 1956, to build a 680-kilogram-per-day liquid hydrogen plant in Painesville. At the same time, two other contracts for similar size plants were awarded. One was to Stearns-Roger for a plant at Bakersfield, California, to support the CL-400 program at Lockheed and the other was to Hydro-Carbon Research for a plant to support Pratt & Whitney at East Hartford. The Painesville plant was named "Baby Bear" and was the first to become operational, in May 1957, at a cost of $2 million. The California plant was placed into operation in the fall of 1957, but the contract with Hydro-Carbon Research was cancelled for budgetary reasons.[33] Pratt & Whitney's initial hydrogen needs at East Hartford, over its own capacity, were supplied by truck from Baby Bear.

Another of Brill's tasks was the transportation of liquid hydrogen. Specifications for over-the-highway trailers had been drawn up by Wright Field and a contract was awarded to the Cambridge Corporation. Concurrently, permission was sought and obtained from the Interstate Commerce Commission to transport liquid hydrogen over the highway. The trailers were labeled "flammable liquid," since to reveal the true contents would blow the security cover. The U-1 semi-trailer built by the Cambridge Corporation had a capacity of 26 500 liters, with a hydrogen loss rate of approximately 2 percent per day. Figure 46 shows the U-1 and its successor, the U-2. The latter's specifications were issued on 15 March 1957 because the U-1 ran into a natural, but unanticipated, problem. The very low density of hydrogen made tandem axles on the semi-trailer unnecessary, so the U-1 had only one. During subsequent use of this equipment, there occurred an endless series of problems, all stemming from the single axle, which was unheard of for such a large trailer. It seems that each time one of these large semi-trailers went through a state weighing station, it roused suspicion, doubt about the equipment, and inquiries about the nature of the load.* The Suntan team considered painting a false second axle on the trailer but this was too obvious, and they gave in by ordering the U-2 with its second axle—one that was not needed for the load but which raised no questions on the road.[34]

To satisfy the anticipated demands for liquid hydrogen at Pratt & Whitney's Florida test center, the Air Force decided to locate a large hydrogen liquefaction plant nearby. United Aircraft obligingly deeded a tract of land to the government for the plant. The Air Force was unsuccessful in interesting private capital to put up the plant, so it funded its construction and operation by Air Products. The plant, with a 4500-kilogram-per-day capacity, was placed in operation in the fall of 1957, at a cost of $6.2

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*In one instance, a suspicious and frustrated weighing official found one semi-trailer 45 kilograms too heavy. He ordered the driver to unload the excess but of course, the driver was powerless to do so. The Air Force had to go all the way to the governor of the state to secure a release for the load. Interview with Blackwell C. Dunnam, WADC, WPAFB, OH, 6 June 1974.

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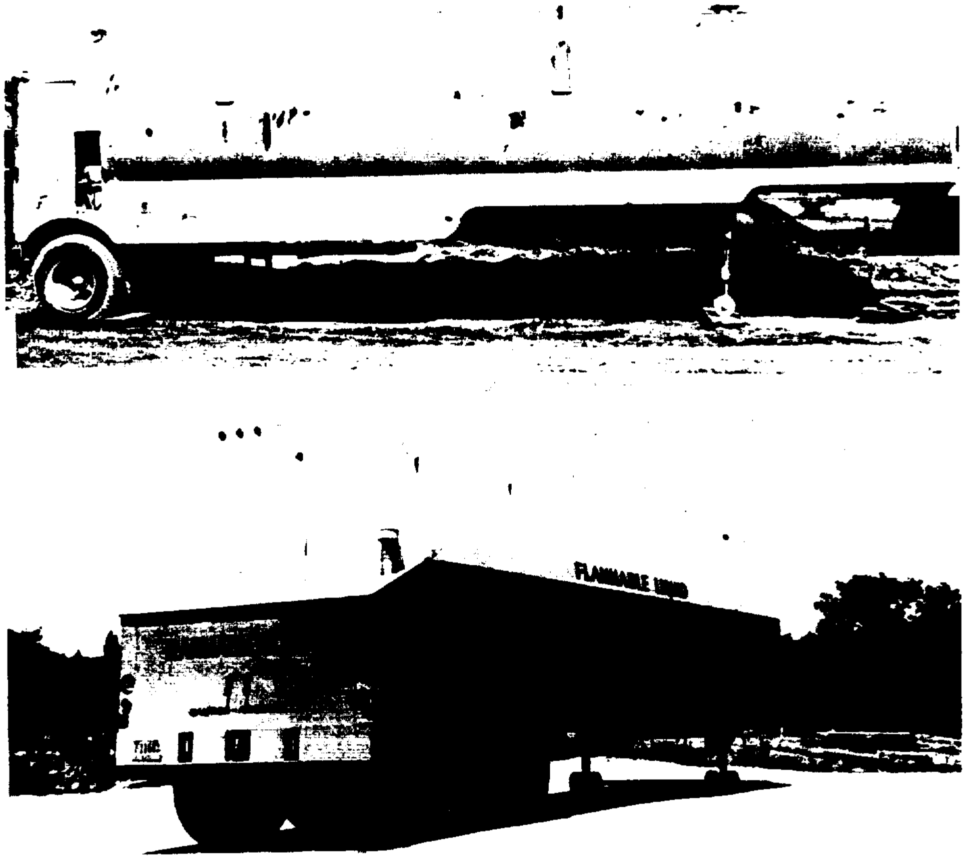

Fig. 46. The U-1 semi-trailer (top) first used to haul liquid hydrogen. The single axle, adequate for low-density hydrogen, caused so many problems with puzzled truck-weighing officials that it was replaced with the U-2 having a second axle. (Courtesy of AFSC.)

million.[35] The Suntan team called this plant "Mama Bear," but locally it was known as the APIX fertilizer plant. APIX was an acronym for Air Products Incorporated, Experimental; the fertilizer association was encouraged by the Air Force and Air Products to conceal the true identity of the product.* Mama Bear used crude oil in a chemical process to obtain gaseous hydrogen. Liquid hydrogen storage tanks at the plant were connected to the Pratt & Whitney test cells by a double-wall, vacuum-jacketed 7.5-centimeter line, 610 meters long. By April 1958, the line had carried 833 000 liters of liquid hydrogen at rates up to 1700 liters per minute for component and engine tests.

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*Workmen were observant and soon the word spread locally that hydrogen was involved. A retired Army colonel, in his role in local Civil Defense, became alarmed that a hydrogen bomb was being manufactured in the midst of an unsuspecting community. A delegation of security officials from Washington had to visit him and convince him to keep quiet. Interview with Col. A. Gardner (USAF, ret.), 19 Sept. 1973.

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Even before Mama Bear was completed, the Air Force planned a much larger hydrogen liquefaction plant to meet the anticipated testing needs of the 304 engine development. The contract was awarded to Air Products in 1957, and the plant was built a few hundred yards away from Mama Bear. It cost $27 million and when placed into operation in January 1959, had a capacity of 27200 kilograms per day—the world's largest. Crude oil was first used to obtain gaseous hydrogen but later methane was used. This plant, called "Papa Bear," came too late for the Suntan program but served a very useful role in the space program that followed.

Suntan Fades

In addition to its technological problems, the Suntan project was the subject of conflicting technical views over its feasibility and the best way to accomplish reconnaissance. In fact, Suntan did not get very far as a wholly supported project. Within six months, a difference of technical opinion over achievable range surfaced and this contributed to the gradual demise of the project. True to its name, Suntan had no clearcut ending: it just faded away. By the middle of 1957, opposition had effectively doomed the project although it lingered through 1958 and was not cancelled until the management team, weary of waiting, so requested in February 1959. Surprisingly, one of the main opponents was the man who conceived and sold the project to the Air Force, Kelly Johnson. The main defendant was the Suntan management team, particularly Appold and Seaberg, who for some months were able to convince high officials to keep the project going in the face of mounting opposition and budgetary restraints.[36]

Johnson's change of mind apparently came during the first six months of study and experimentation on the feasibility of the hydrogen-fueled airplane. The Air Force had insisted on a minimum radius to target of 2800 kilometers and was convinced that this distance and more was feasible. Johnson, on the other hand, believed that a radius of 2000 kilometers was about the best that could be achieved. The two sides stuck to their views throughout the life of the project.[37]

Following the initial phase of study and experimentation, the project proceeded during Fiscal Year 1957 as originally planned, with an allocation of about $19 million. Lockheed ordered 4 kilometers of aluminum extrusions to build the CL-400; Pratt & Whitney went full speed in developing the 304 engine; the Massachusetts Institute of Technology contracted to provide a guidance system; and Air Products contracted to build a large hydrogen liquefaction plant adjacent to the Pratt & Whitney test center in Florida.[38]

The bottom line on how well a project is faring in government circles is the fraction of the budgeted funds that is actually allocated to it. The Air Force obtained approval for $95 million for Suntan development for the fiscal year beginning in July 1957. The first significant indication that the project was in trouble came when the Suntan management team requested release of these funds to maintain the development schedule. The request was placed on the 22 August agenda of the Air Council, the Air Force's highest management group. In preparation for this meeting, the Suntan team met with crusty, blunt Gen. Curtis E. LeMay, former boss of the Strategic Air Command who had moved up to vice chief of staff in July. It was the first time that

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LeMay had received a full briefing on Suntan and his initial reaction brought dismay to the team. "What," he exploded, "put my pilots up there with a . . . bomb?"[39] LeMay not only took a dim view of using liquid hydrogen but also was apparently under pressure to find funds for other important projects. On 19 September, the team received the bad news: of the $95 million approved in the budget for Suntan, only $32.3 million would be made available for it; the remainder would be transferred to other projects. In spite of additional efforts by Gen. Samuel E. Anderson, the new head of the Air Research and Development Command, to restore the funding, the decision remained firm.[40]

Johnson's views apparently contributed to the Air Force decision to cut Suntan. Sometime during the mid-1957 period, he was visited by James H. Douglas, Jr., who had succeeded Donald A. Quarles as Secretary of the Air Force in March 1957. Douglas was accompanied by Lt. Gen. Clarence A. Irvine, deputy chief of staff for materiel and a member of the Air Council. The visitors, concerned about the short radius of the CL-400 and mindful of Johnson's ability to stretch the range of other aircraft, asked him how much margin for growth was in the CL-400. The answer: practically none.[41]

Ordinarily, range can be extended by adding more fuel or improving the fuel consumption of the propulsion system for a given thrust. Johnson could see a range growth of only a paltry 3 percent or so from adding more fuel. ". . . we have crammed the maximum amount of hydrogen in the fuselage that it can hold. You do not carry hydrogen in the flat surfaces of the wing," he explained.[42] Johnson turned to Perry Pratt for estimated improvements in the 304 engine and his answer was equally pessimistic: no more than 5 or 6 percent improvement in specific fuel consumption could be expected over a five-year period. The very low growth estimates were compounded by operational logistics problems of liquid hydrogen. As Ben Rich asked: "How do you justify hauling enough LH_2 around the world to exploit a short-range airplane?"[43]

Having exhausted their appeals by October 1957, the Suntan team drastically curtailed the project to fit the funds available. Pratt & Whitney was given $18.7 million to continue development of the 304 engine at an undiminished pace. A total of $11.6 million was allocated for hydrogen liquefaction plant construction and operation and $3 million was set aside for later use. Development of the CL-400 was cancelled, but Lockheed was asked to continue the fuel system tests; $3 million was recovered from the changes. The MIT guidance contract also was cancelled.[44]

The Suntan team, particularly Seaberg, was not convinced that Johnson's pessimism over range was justified. Contracts for additional design studies were let not only with Lockheed but also with North American Aviation, Boeing, and Convair-Fort Worth. The additional study at Lockheed did nothing to change Johnson's view. In all, 14 designs were considered, ranging from bombers to Mach 4 reconnaissance aircraft with comparisons between using petroleum fuels and liquid hydrogen. For the same range, Lockheed found that aircraft using liquid hydrogen were larger but weighed less at takeoff than those using petroleum fuels. At a given speed, hydrogen-fueled aircraft exceeded the altitude limits of petroleum-fueled aircraft by 3000 to 6000 meters.[45] By March 1958, a Boeing design appeared to be the most promising of the new studies. Powered by four engines, it would fly at Mach 2.5, 30 500 meters altitude,

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and have a radius of 4100 kilometers—almost twice that of the CL-400. The Boeing airplane was also considerably larger than the CL-400, with a length of 61 meters, a delta wing span of 61 meters, and a takeoff weight of 75 750 kilograms.[46]

The final results of the design studies were presented to the Air Council on 12 June 1958. LeMay, who chaired the meeting, raised the same objections as previously but allowed a full discussion of the subject. The Suntan team felt that the general reaction was favorable, but this was dispelled by two significant points in the summary of the meeting. Even if a successful new reconnaissance aircraft were developed, the President might not allow its use because of international political risks. If this happened, LeMay argued, the Air Force would only be building museum pieces. The second point was even more devastating. The Air Force had given a competing project higher priority; since it was underfunded there was no justification for allocating funds to Suntan.[47]

The June meeting spelled the effective end of Suntan, but the Air Council thought that the engine work should continue for its value in advancing the technology. Since the Suntan mission was broader than the Air Force, however, the June decision was not the final word. A joint committee of the Department of Defense and the Central Intelligence Agency was formed to make recommendations regarding Suntan. The committee, headed by Edwin Land of the Polaroid Corporation,* held meetings during the summer and fall of 1958 and the Suntan management team was held together pending the results. Although not privy to the committee's findings, the team sensed the trend and terminated the Pratt & Whitney contract in November. By February 1959, with still no word from the committee or formal directive from Air Force headquarters, the team requested that the project be ended. Of the $19 million allocated for FY 1959, about half had been transferred to the Advanced Research Projects Agency for rocket projects.[48]

In retrospect, several principals of the Suntan project saw different reasons for its ending. To Kelly Johnson, designer of the aircraft, the short range and hydrogen logistics were the predominating reasons; he considered the meeting with Douglas as the effective end of the project.[49] For Norman Appold, the project manager, the end came for other reasons. Suntan was one of a variety of options for gathering intelligence.[50] The implications of flying aircraft over Russian territory, which had been on the minds of the Air Council and others since the beginning of the U-2 and its potential flameout problem, became very real with Gary Powers's experience in 1960.

For Ralph Nunziato, with access to top-level Pentagon meetings and decisions, the reasons for cancelling Suntan were purely economic. In a presentation to the Air Council, he indicated that the next phase of development would need an estimated $150 million. It was a period of stringent budgetary limitations and Suntan lost out to other projects.[51]

Even the amount spent on Suntan remains in doubt. The consensus of several involved is that about $100 million was spent and some documentation appears to support this.[52] But Appold, the project manager, firmly believes the total to be closer to

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*Other members: Courtland Perkins of Princeton, Edward M. Purcell and H. Guyford Stever of MIT, and Allan Donovan of Space Technology Laboratories. Richard E. Horner of the Air Force and Garrison Norton of the Navy were ex officio members.

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$250 million, and Richard Horner, who was assistant secretary of the Air Force for R&D, concurs.[53] Since Suntan covered many activities and since great pains were taken to camouflage the project by directing funds through various channels, the actual total cost remains unknown.

Suntan Technology and Equipment

What was learned with the Suntan project? The technology of liquid hydrogen was advanced in several ways. There is concurrently a revival of interest in hydrogen-fueled aircraft. As before, however, their potential value is controversial. NASA held a special conference on hydrogen-fueled aircraft in 1973 and has sponsored industry design studies of both subsonic and supersonic configurations. Although no specific development has started, NASA continues to sponsor research applicable to hydrogen-fueled aircraft.

On the other hand, Kelly Johnson, who turned back to petroleum fuels and designed the highly successful SR-71, remains disenchanted with liquid hydrogen. In 1974, he summed up his view: "Today, there is regenerated interest in liquid hydrogen for aircraft propulsion, but considering all phases of the problem, I do not think we will have such aircraft in the foreseeable future."[54] Seaberg, who managed design study contracts with Boeing, Convair, and North American Aviation as part of the Suntan effort in 1957, agrees with Johnson's 1974 assessment.[55] The essence of technological progress, however, is the conversion of the impossible to the possible, so the case for hydrogen-fueled aircraft remains open.

Although Suntan technology and equipment have yet to find application in aircraft, they soon found application in rocket propulsion. In 1958, the Suntan management team began searching for ways to use the technology their project had generated, as well as equipment like the boost pump and the hydrogen liquefaction plants. One result was a proposal to use liquid hydrogen in a rocket engine for the rapidly developing space program. Like a phoenix rising from the ashes, the technology and equipment of Suntan would indeed play a major role in the space program of the 1960s. To learn how this occurred, we must next consider several other developments that were running concurrently with Suntan—activities at Pratt & Whitney, General Dynamics, North American Aviation, NACA, and the Department of Defense.

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Fig. 47. Suntan management team: Col. Norman C. Appold, top left; Lt. Col. John D. Seaberg, top right; Maj. Alfred J. Gardner, bottom left; and Capt. Jay R. Brill. All engineers, Appold and Gardner each held two masters degrees, Brill one. Appold and Gardner were combat pilots and Seaberg a base executive during WW II. Brill graduated from West Point 3 years after the war. Appold headed the engine laboratory at Wright Field for 5 years prior to becoming the Suntan project manager. After Suntan, Seaberg managed the Centaur development for both the Air Force and NASA, assisted by Gardner and Brill. All except Brill retired as colonels: Appold heads the C-5 project for Lockheed-Georgia; Seaberg manages remotely-piloted-vehicle R&D at Wright Field; and Gardner is an assistant to the president of Lockheed Missiles and Space Co. Brill became a brigadier general in 1975 and manages the A-10 development at Wright Field.

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SUMMARY, PART II

The 1950–1957 period was one of great technological advances in the use of liquid hydrogen as a fuel in rockets and aircraft. Thermonuclear research provided the first large stimulus to hydrogen technology at the start of the period; from it came a large new cryogenics laboratory, larger hydrogen liquefiers, mobile dewars for transporting hydrogen, and other advances.

The Lewis laboratory of the National Advisory Committee for Aeronautics advocated liquid hydrogen for rockets in 1950 and for aircraft in 1954, conducted research showing hydrogen's potential, and demonstrated that liquid hydrogen could be safely used in manned flight.

The Air Force, always seeking to extend flight capabilities, took a strong interest in very-high-altitude flight in 1953, became interested in hydrogen for this purpose in 1954 as the result of an imaginative proposal of Randolph Rae, helped the Central Intelligence Agency develop the U-2 airplane using conventional fuel, and mounted a massive, crash project to exceed the U-2's performance by using hydrogen. The hydrogen airplane did not materialize, but the liquid hydrogen plants and test facilities constructed by the Air Force would find full utilization in the emerging space program.

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