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The Turbojet Revolution at Lewis Research Center

In the Origins of the Turbojet Revolution (Baltimore: Johns Hopkins University Press, 1980), Edward W. Constant contrasts what he calls "normal technology" with a technological revolution which represents the initiation of a radically new practice. For Constant, the turbojet revolution began as a conceptual revolution based on the radical insight that, while aerodynamically the airframe might be capable of greater speeds, the performance of the engine which drove it -- a piston, or reciprocating engine -- was limited. Each improvement of the piston engine -- additional cylinders, supercharger and intercooler -- represented the addition of more weight. A completely different engine configuration was necessary. In the late 30s, Frank Whittle of the British Royal Air Force and Hans von Ohain, as well as others in Germany, independently grasped the potential of the much lighter gas turbine. Unlike the piston engine whose efficiency reached a definite limit, the efficiency of the turbine increased with the airplane's speed. Moreover, the simplicity of the turbojet, consisting of a compressor or blower driven by the turbine, was in striking contrast to the complexity of moving parts required in the piston engine.

That the turbojet revolution occurred later in the United States than in Europe cannot be disputed. Nor are the reasons which Constant gives for this belated recognition of the potential of the gas turbine as a means of aircraft propulsion at issue. Rather, my interest here this morning is to examine how this technological revolution was institutionalized. Patterns of institutional change differ according to the historical circumstances surrounding the perception of a revolutionary technology and its adoption. NASA's Lewis Research Center in Cleveland, Ohio, provides an instructive case study of the acceptance of the turbojet revolution. Originally called the Aircraft Engine Research Laboratory, it was one of two field centers authorized by Congress in 1940 to expand the aeronautical research of the National Advisory Committee for Aeronautics (NACA) at Langley Field. The new facility in Cleveland was to be devoted to research on aircraft power plants. As its construction was underway, the Power Plants Division at Langley was transferred to Cleveland to take up its research in what was touted to be the most advanced engine research laboratory in the world. Ironically, as the Cleveland laboratory was being built, advances in turbojet technology in Europe were making its facilities obsolete. It was a matter of luck, not foresight, that the laboratory's enormous wind tunnel, built primarily for the study of liquid-cooled engines under altitude conditions, could be rushed into service in 1944 to test the new turbojets first produced in the United States by the General Electric Company at West Lynn, Mass.

While institutional reorganizations do not necessarily reflect the reorientation which accompanies a technological revolution, institutional changes at Lewis Research Center in 1945 do in fact reflect the shift in engine research mandated by the introduction of the jet engine. Not only was the name of the institution changed to the Flight Propulsion Research Laboratory, but the entire workforce was reassigned. Work on the piston engine, which had dominated the institution's research efforts, was all but eliminated. (See "Survey of Fundamental Problems Requiring Research at the Aircraft Engine Laboratory," Dec. 1945; Plumbrook, P1303, Box 34) The staff dubbed this reorientation the "Big Switch." As one engineer described it: "During the war years, the work was concentrated on the ad hoc problem solving for military piston engines... The moment of truth came to NACA in 1945 and overnight the NACA management switched the laboratory emphasis from piston engines to jet engines and the staff was reorganized from stem to stern in the process." He continued: "The sweeping reorganization caught the lower-level supervisors by surprise. The author went home one night deeply engaged in writing a report on spark plug fouling to find in the morning that his desk was in another building and he was now officially engaged in rocket engine cooling research." (John Sloop, "NACA High Energy Propellant Research in the Fifties," AIAA 8th Annual Meeting, Washington, D.C., Oct. 28,1971)

The 1945 reorganization represented not only the demise of the piston engine, but also a change in the structure of leadership of the Power Plants Division which Cleveland inherited from Langley Field. Abe Silverstein, the former director of the center, denies that the decision came from the NACA's Headquarters. He claims that four individuals were involved. These were the heads of the divisions formed as a result of the reorganization: Ben Pinkel, Head of Fuels and Thermodynamics; John Collins, Engine Performance and Materials; Oscar Schey, Compressor and Turbine Research; and Silverstein at that time head of Wind Tunnels and Flight Research. Three individuals who had higher administrative positions in the laboratory's institutional structure were not included. These were Addison Rothrock, Carlton Kemper and Edward Sharp.

Sharp's exclusion is no mystery. He was the Manager of the laboratory, but because he was a competent administrator without formal training in engineering, he left technical decisions to the engineering staff. However, the explanation for Rothrock's and Kemper's absence from this meeting is less obvious. Rothrock had been in charge of the now abolished Fuels and Lubricants Section of the Power Plants Division at Langley Field. It had been the largest of the Power Plants sections there and one of the first to be moved to Cleveland. During the war it had made significant contributions to the improvement of aviation fuels. However, in turbojet engines, fuels were less important since the temperatures for combustion were so high that they could run on ordinary kerosene. Rothrock is said to have concurred with the restructuring in which he was made Chief of Research. Three years later he moved to Headquarters.

Kemper's loss of leadership was more dramatic. He had been the head of the Power Plants Division at Langley for fourteen years. Considered one of the country's leading automotive engineers, during his tenure the division had increased from a staff of 20 to over 200. However, at the Cleveland laboratory, instead of becoming manager as he had expected, he was given the title of Executive Engineer, a job which consisted of perfunctory reviewing technical reports. It was not long before he retired.

While these changes may have seemed revolutionary to those affected by the reorganization at the Cleveland laboratory, the turbojet revolution in the United States, though belated, was firmly in place by 1945. The late date of the NACA's full realization of its implications can only be explained by a chain of events which reach beyond the Cleveland laboratory and in which the British Whittle engine occupies center stage. As the first shovelfuls of earth were being turned in Cleveland in January 1741, Frank Whittle's engine was close to the point where it could be flight tested in Great Britain. The U.S. Army, aware of the Whittle engine and informed by intelligence reports of German advances in jet design, urged the NACA to investigate the whole field of jet propulsion, including rockets. The octogenarian William F. Durand, the former chairman of the NACA, was called out of retirement to head a Special NACA Committee on Jet Propulsion which was formed in March. Durand's committee monitored four projects for unorthodox jet engines: a turboprop by General Electric of Schenectady, a ducted-fan engine by Allis Chalmers, a small booster type turbojet by Westinghouse, and a NACA project under Eastman Jacobs for an engine based on the Campini ducted fan design.

Jacobs, an aerodynamicist, was already at work on the Campini type engine in 1939 prior to the formation of the Durand Jet Propulsion Committee. His engine did not use a turbine to power its two stage axial compressor, but a reciprocating engine. While the compressor performed reasonably well, his combustor for the engine designed by Carlton Kemper did not work properly. It failed to produce the blue annular flame which indicated full combustion. However, with the new importance of jet propulsion evinced by the creation of the Durand Committee, by mid 1941 Jacobs and Kemper had the full support of the NACA.

While G.E. at Schenetady, Westinghouse, Allis Chalmers and Jacobs at Langley Field struggled with their respective development problems, forbidden to collaborate with each other, the Whittle engine was flight tested and General H. Hap Arnold arranged to have plans of the engine brought from England by Colonel Donald Keirn in the fall of 1941. The General Electric Laboratory at West Lynn was chosen by the Arnold to build the Whittle engine.

Though complete secrecy was one of the stipulations in the British willingness to share their discovery, at some point, Durand was informed because on Feb. 27, 1942 he wrote to General Oliver Echols to request that the three companies involved in their respective projects be permitted to exchange information, "Of course," he added,"this request has no relation whatever to the particular project sponsored by the Army, now being carried on by the General Electric organization, and of English origin. It relates solely to the projects which have been developed as a result of meetings of the Jet Propulsion Committee." (WNRC, 255, 117.15)

Meanwhile in Cleveland, research was initiated on May 8, 1942 in the new 18 million dollar aircraft engine research laboratory. Ironically, it was the engine-propeller research building that was completed first. With fanfare, George Lewis, Director of Aeronautical Research for the NACA, and John F. Victory, Secretary of the NACA, stood in the control room and pushed the buttons to activate the large airplane engine. With a roar the propeller was set in motion. Instruments in the control room immediately began to record data on various graphs to "assist the aircraft engine industry to greater achievement in engine design and performance." (Press Release, Initiation of Research, "History") Durand, along with Echols and Arnold were among the honored guests. There is no record of their private thoughts on this historic occasion.

However, it is clear from a letter from Durand to Lewis, Sept 29, 1942, that Durand, aware that the Whittle engine was nearing flight test, was anxious that Jacobs' engine would prove a success:

> I wish very much that you would feel quite free to take hold of and direct the work of Jacobs along the lines agreed upon earlier. There is nothing in particular that we, as a committee can do with regard to the projects in the hands of he industrial companies. I have, however, felt

> a little anxious about Jacobs' work, due to the fact that the Committee is directly interested in that particular project in the sense that its success or failure will react directly on the reputation of the Committee -- at least in connection with this particular work. We are agreed that Jacobs needs some guidance in order that the system so far developed at Langley Field may be presented to the Navy in the best possible manner, and may have a fair show of demonstration as to ultimate capabilities. I shall, therefore, be very grateful to you if you will feel entirely free to represent me in connection with this work and guide Jacobs and his collaboators as may seem best to you. (WNRC 255. 117.15)

This letter shows that Durand, even though he knew of the Whittle project, may not have been aware of the revolutionary implications of the gas turbine. Fully informed of four unconventional projects all using the concept of jet propulsion, he chose to back the NACA design, an engine without a future which used an unwieldy reciprocating engine to drive a compressor making it too heavy for the amount of thrust it produced. (Pinkel letter, Sept. 2, 1984)

Time was running out for the NACA project. On Oct. 2, 1942, the G.E. I-A Whittle engine was successfully tested at Muroc Lake, California and Durand was there to see it. In a letter to Colonel Keirn, Oct 29, 1942 he wrote, "I was very sorry that you could not be with us in California... It really begins to look as though a definite start has been made along the lines we have been thinking about so long." (WNRC,255, 117.5 "Corresp. 1942)

In the meantime, a new burner was designed for Jacobs' engine by K.K. Nahigyan of the Engine Analysis Section, in which efficient combustion was achieved using liquid injection of the fuel. A successful formal demonstration of the apparatus was made to the Jet Propulsion Committee. Nonetheless, this solution to the combustion problem did not change the fact that the basic design of the engine was markedly inferior to the striking simplicity of the Whittle engine, of which the Langley Power Plants Division knew nothing. According to Ben Pinkel, not long after these tests were completed, he was called to the manager's office at Langley. He was informed by George Lewis that "officers of the top military echelon ...[had] instructed him that the war would be fought with five reciprocating engines, namely, the Wright 1820 and 3350, the Pratt Whitney 1830 and 4460, and the Allison V 1710, and that all work on jet propulsion should be stopped in order that all effort should be directed toward those reciprocating engines." (Pinkel letter) Thus it appears that the military made the decision which effectively stopped all work by the NACA on jet propulsion and encouraged research on improving the reciprocating engine well beyond the time when this research had any future.

It was not until 1943 that the military changed the Whittle project from secret to confidential and Keirn was sent to Cleveland to brief Ben Pinkel and seven other members of the Thermodynamics Section on the West Lynn turbojet project. They were sworn to secrecy. Keirn gave them a set of drawings for the construction of a special test cell designed by G.E. The G.E. I-A turbojet was delivered for testing under heavily armed guard. Later the laboratory tested the G.E. refinements of the Whittle engine, the I-14, I-16 and the I-40 in the Altitude Wind Tunnel. Throughout 1943 and most of 1944 this work was confidential. Few beyond the nucleus of workers around Ben Pinkel and Abe Silverstein in charge of the wind tunnel tests were aware of the new technology.

The extent to which the laboratory was tied to the "normal" prerevolutionary technology can be seen in the staff talks which were presented in 1943. In February, Arnold Biermann outlined the reasons why the study of single-cylinders was important. He prophesied that "in spite of years of development work on engine cylinders it is probable that the greatest improvement in engine performance will come from improvements in cylinder design." (Wing Tips, Feb. 12, 1943) In April, Edmond Bisson, head of the Piston Ring and Cylinder Barrel Section, told the staff of the urgent need for piston-ring research, and John Collins, then head of the Engine Research Division, discussing "Trends in Modern Aircraft Engine Design," forecast improvements in both liquid and air cooled engines. (Wing Tips, April 2, 1943) In June the importance of the propeller was stressed by E. Barton Bell of the Flight Research Division and Oscar Schey, chief of the Supercharger Division, Called the supercharger "the most essential part of the engine." (Wing Tips, July 9, 1943) It was not until May 24, 1944 that Ben Pinkel, Chief of the Thermodynamics Division was free to discuss the Whittle engine with the assembled technical staff. By then it was public knowledge. (Text in "History" loose leaf notebook)

With this chronology in mind let us now return to the "Big Switch" in 1945 and the reasons why Kemper was left out. The NACA had staked its prestige on the ill conceived Jacobs' engine. Kemper as chief of the Power Plants Division had been directly involved in the venture. Not only had the project failed, but his own contribution to the combustor problem had also failed. It seems reasonable to suggest that the NACA's dashed hopes in the Jacobs engine ended Kemper's effective leadership of engine research. The "Big Switch" was the beginning of Abe Silverstein's rise to prominent leadership and ushered in a new creative phase of gas turbine and rocket research. Silverstein's background was not aircraft engines, but aerodynamic problems associated with the running of the full scale wind tunnel at Langley Field. It was precisely in this area of air flow that some of the most perplexing problems of turbojet technology lay.

As a final irony in this story, it was the NACA axial flow compressor inherited from work done by Jacobs and Eugene Wasielewski and used in the Jacobs engine, not the centrifugal compressor of the Whittle engine, that became the standard for jet engines. It is no coincidence that the largest percentage of research attention in the new plan of research was that of compressors.

What does this particular case study of the turbojet revolution at Lewis Research Center contribute to the analysis of innovation? First, I think that it demonstrates some of the institutional constraints which are characteristic of the practice of technology as distinguished from science. A scientific revolution is fundamentally conceptual. A technological revolution, as Constant has demonstrated, is also conceptual, but to be fully realized it must be reified in a machine which is superior to the one that it replaces. The institutionalization of an innovation such as the turbojet could only be justified once its practical advantages had been demonstrated. That the turbojet revolution occurred in wartime meant that any decision which diverted research attention away from the immediate problems of reciprocating engines already in production would have enormous consequences. Even after the Whittle engine was flown at Muroc Lake, it hardly represented a weapon with tactical advantages over the conventional piston engine. The problem of flame ~~out at high altitudes, for example, needed to be solved.~~

Second, this case study suggests that neither the military nor the NACA knew that the turbine would become synonymous with jet propulsion. While the Army was aware of the superiority of the German jets to planes powered by reciprocating engines, when did it learn that the turbine was its distinguishing feature? In 1940, the future of the Whittle turbojet, while promising, was not assurred. While the secrecy surrounding the "Whittle matter" is one reason why Jacobs and the three companies continued to work on ~~unorthodox engines, completely uninformed of the European advances, it also~~ indicates that neither the Army, private industry, nor the NACA was fully convinced until 1943 that the turbine was the way of the future. It is possible that experience with the problems involved in the development of turbo-superchargers (compressor blades tended to fly off in all directions) may have contributed to the myopia which prevented American engineers from fully appreciating the revolutionary implications of the turbine.

In 1945 when the turbojet revolution was institutionalized in the "Big Switch" at the new laboratory in Cleveland, research on the jet engine became the new normal technology -- that cumulative, messy path along which the practice of technology seems to move, regardless of the unusual spectacular innovation which momentarily threatens to sweep away the technological practice of the past. In the final analysis, we must ask, how revolutionary, how radical were the institutional changes effected by the introduction of the turbojet? Can they be equated with the change in a scientific paradigm? I think not. While there are definite parallels which Dr. Constant has brilliantly outlined, technological innovation has both a conceptual <u>and</u> a practical side. The set of historical circumstances surrounding the introduction of the turbojet in the U.S. demonstrates the interacting and sometimes competing factors which complicate the history of technology. In contrast to the Kuhnian scientific community which generally takes its presuppositions to the grave, once new practice is determined by a significant innovation, the technological community has the remarkable flexibility to shift rather easily from the old technology to the new. When the gas turbine became the prototype for the jet engine, research problems were redefined and personnel were reassigned, but the old engineering staff, with the exception of Kemper and Rothrock, was the same Langley team which had made the move from Hampton, Va. This group confidently moved into peacetime research in the new Cleveland laboratory, enthusiastic about the potential of the gas turbine engine and confident of their ability to solve its problems.