WHAT'S PAST is PROLOGUE

A Personal History of Engineering

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The Focus of Rein Kroon

The engineering profession, like others, has its leadership cadre, those individuals who work with great technical advances and who have opportunity to pass such experience on to others. Such is the life of Reinout P. Kroon whose story encompasses a productive forty-year period.

This article is the story of Professor Kroon's life of technical accomplishment and relates directly to many challenges of our day. It is the transcript of a talk given at a Symposium of the Towne School at the University of Pennsylvania, Philadelphia, Pennsylvania, on October 7, 1970.

It has meaning, we believe, to those young people preparing for engineering careers and to young engineers who are at grips with current technical challenges in meeting society's needs. To senior engineering educators and to senior engineers in industry there may be an appreciation and, to some degree, a satisfaction in reading this story of significant contribution to the profession.

Robert L. Wells
Vice President, Management and Professional Personnel
Westinghouse Electric Corporation

Reinout P. Kroon was born in Hoorn, Holland in 1907. After completing his engineering education in Switzerland he came to the United States, joining Westinghouse as a Design School student in 1931. He became a development engineer in the Steam Division at South Philadelphia, engaged in applied mechanics work related to power apparatus.

In 1937 he was appointed Manager of the Experimental Division, responsible for analytical and experimental activities in thermodynamics, heat transfer and mechanics.

With the outbreak of World War II, he took charge of a small group of engineers and mechanics to start the original design and development of Westinghouse jet engines. He became Chief Engineer of the newly formed Aviation Gas Turbine Division. The engineering department encompassed a wide variety of engine development, design and testing and at one time had over 1000 employees.

In 1954, Kroon was made Director of Research, responsible for design studies of new types of powerplants and for analytical and experimental activities related to powerplant components.

As Chief Engineer of the Westinghouse Advanced Systems Planning Group he was in charge of a group of engineers and scientists engaged in the analysis of future systems for the Westinghouse Electric Corporation.

In 1960 he came to the University of Pennsylvania where he is Professor of Mechanical Engineering and Chairman of the Graduate Division of Mechanical Engineering.

Kroon is the author of a couple of dozen papers and holds a dozen patents.

He is the recipient of the Westinghouse Order of Merit, the A.S.M.E. "Spirit of St. Louis" Medal, and The Franklin Institute Longstreth Medal.

In the A.S.M.E., he was active in the executive committees of the Applied Mechanics Division and the Aviation Division. He served on the Basic Engineering Department Committee and was its Chairman in 1963. He was elected Fellow, A.S.M.E. and later Honorary Member.

Kroon's interests are wide-spread. His recent papers deal with the mechanical characteristic of bone, with turbine performance, and with the philosophy of science. His chief hobbies are the out-of-doors and music.

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Last spring, my colleague Dr. Burton Paul suggested that it was about time for me to tell others about my engineering experiences. At first, I was not convinced that I had anything special to say. But I came to realize that, by mere accident, I had lived during some exciting periods in engineering history and that some events which I witnessed at close range might be of interest to people who still have most of their career ahead of them.

Now, about the title "What's Past is Prologue." In checking this quote, I found another one, and this one is from Carl Sandburg, who said, "I tell you the past is nothing but a bucket of ashes." As an engineer, I side with Shakespeare. I believe that engineers must learn from their experience so that they do not have to make the same mistakes over and over again.

If you happen to be the first in your family to go into engineering, it may comfort you to know that I was in the same situation and that I have no regrets about my choice. I was born in a small town in Holland. In high school I had an inspiring physics teacher who was also an inventor and a historian. He encouraged independent work. I had an opportunity to spend a day in a large manufacturing company where ships and diesel engines were made. From what I saw and was told I decided that I wanted to become an engineer.

After I completed high school, our family moved to Zürich, Switzerland, but I was too young to begin studies at the E.T.H. (Federal Technical Institute of Technology). I spent one year working as a "volunteer" in two Swiss factories, getting first-hand knowledge of machine tools, foundry practice, etc. The Swiss had, and still have, an excellent program for the training of apprentices in many fields, as postal clerks, salesmen or mechanics. Apprentice mechanics are trained in factories and spend part of their time in school, studying mathematics, geometry, and other associated subjects. The federal government takes a direct interest in the program. One apprentice in our shop complained to the government that he had been doing the same kind of work too long. He was promptly reassigned to a new task. Because of the apprentice training program the Swiss workmen are highly skilled.

At the Federal Technical Institute I was lucky in having outstanding teachers. To us students Stodola was the greatest, a fine lecturer, philosopher, and humanitarian. He made many contributions to applied mechanics and applied thermodynamics. His book *Steam and Gas Turbines* (last edition 1926) is still a classic.

In physics there were Debye and Scherrer, in mechanics we had Meissner, and in machine design there was Ten Bosch. To us, they were like Greek gods; they had human attributes but they were so far above us that we had practically no personal contact.

Two features of our curriculum stand out in my memory. In our first year we took apart all kind of machine elements and made drawings of them. This not only taught us how to draw, it also made us familiar with the designs of control valves, transmissions, and many other mechanical devices. In our senior year we designed major pieces of machinery such as steam and diesel engines. The professors came to our drafting tables to go over our plans.

When I finished my studies at the Institute, jobs were scarce. The only opportunities I could find in Switzerland were for very routine assignments, like designing iron railings. I decided to emigrate to the United States, and I obtained an interview with two "Americans," representatives of Westinghouse. These turned out to be Timoshenko, a Russian, and Lessells, a Scot. I had expected to meet practical businessmen, but Timoshenko asked some very searching questions about my academic performance. It was agreed that I would enter the Westinghouse Design School in Pittsburgh.

But when I arrived in the United States, the stock market had crashed, and it did not look as if there would be another Westinghouse Design School. I became junior editor with a small technical publishing firm. My job consisted of making drawings and translating foreign articles. After a few months, a Westinghouse Design School got started anyway. In those days, applicants for Design School and for research jobs at Westinghouse had to solve half a dozen "Design School" problems which were prepared by engineers throughout the company. I still think that is a pretty good way to size up applicants. In Design School prominent engineers such as Soderberg and Nadai taught us subjects such as mathematics, dynamics, and elasticity.

While I was in Design School, I roomed with three other young engineers. One of them, J.G. Baker, had a lasting influence on my career. Baker was a genius, an inventor with a natural gift for analyzing physical phenomena. He could get so excited about a problem that he would wrestle with it day and night. It was my good fortune to work later on with Baker in the diagnosis of abnormal vibration of large turbines. This job is like that of a doctor trying to find out what ails a patient. But in walking up to a large machine which shakes all over, you cannot, of course, ask, "Where does it hurt you?" You must make your diagnosis from a few measurements: frequencies, phase angles and the like, and try to find out under what operating conditions the vibration takes place. We tried to list all kind of possible causes and to seek to eliminate all but one. Whenever my imagination ran wild, Baker pulled me up short by asking, "How do you know?" It taught me to be more critical about information or theories taken for granted, in engineering and particularly outside of engineering.

Starting with Baker, I have often been associated with people from whom I could learn much and who expanded my horizon. In my case it was dumb luck; I did not plan it that way. But it seems to me now, that in deciding a career, probably the most important issue is whether the environment is stimulating for growth. By comparison, initial salary, pension regulations, and the like are very secondary to the opportunity to develop oneself. You will recall that in the Middle Ages the apprentices wandered from master to master, looking for the best craftsmen from whom they could learn their trade.

After Design School was over, I transferred to the Westinghouse Steam Division in South Philadelphia, working for Jesse Ormondroyd, who was head of the so-called Experimental Division. Actually the work was as much analytical as it was experimental. Ormondroyd was a liberal arts graduate of the University of Pennsylvania, having majored in mathematics. He had made his mark in vibration analysis and proved to be a stimulating boss with many interests, including ornithology and music. I was to work on mechanical problems such as turbine blade vibration problems, rotor dynamics, and stress and deflection problems in steam turbines, condensers, and gears.

In Europe I had seen a rather stifling industrial hierarchy. Family standing pretty well determined a young man's position for his lifetime. Where I came from, everyone "knew his place." Even today there is some of this attitude. In a small Swiss village a rich old lady recently arranged to have a beautifully carved pew close to the pulpit in the church. One day she found a peasant sitting in the pew. She told him in no uncertain terms to get out. But the peasant said, "Before God we are all equal." To which the lady retorted: "That may be so in Heaven, but on earth we must have order."

I was to work under a vice-president who knew the lowliest employees by name and who made it his business to go through the shop and talk with them. I was surprised at the great freedom I had to tackle the jobs in any manner that I thought was right.

This was the time when many Russian professional people, having fled their country, found a haven in the United States. Each had his story, of escaping through Siberia or through the Middle East, of families killed in the revolution. They had become enemies of the State, intellectuals declared surplus by the Bolsheviks. They were members of a system which had not recognized early enough the drastic need for social changes.

Ironically, most of them were leftists in the days of the Czar. Anoshenko, the head of our laboratory, had escaped detection by the Czarist police by hanging by his hands amongst the clothes in a closet. Timoshenko had also started out as a liberal protecting leftist students; by the time I knew him he had become conservative. Timoshenko came once a month to Philadelphia to consult with us on our problems. He was an excellent consultant, a fine mathematician with a wide background and a remarkable memory.

The early thirties were the days of the Depression. I would urge any of you who have no personal recollections of the period to take an interest in it. It was an almost total collapse of the economic system, a gigantic *system failure.* All the ingredients for a healthy economy were there. There were plenty of people who wanted to work. There were plenty of facilities, factories, powerplants and the like. There certainly were plenty of consumers, people who needed food, clothing, shelter and the amenities of life. But the system had broken down. Many workers lost their jobs. Banks went bankrupt and savings were wiped out overnight. Farmers had to give up their farms. Many careers were destroyed. We can learn from the Depression that present-day economic systems are complex and vulnerable. Anyone who says, "Let's destroy everything and then build from the ground up," is talking about wiping out a large part of the population.

I was one of the lucky ones; I kept my job. While our work week was reduced to four days, my wife and I had enough to live. Many engineers were laid off. The remaining ones had few jobs to work on. There was much time for discussions, and there were all kinds of educational activities. As a result of this there developed during the depression years a small but very competent group of engineers, well-prepared to tackle important developments when the time came.

In the Depression there was little money available for development. Our standard procedure for making experimental apparatus was to go to the scrap heap to see what we could scrounge together. Then we designed the apparatus to make use of these scrap pieces.

I began to appreciate the contributions which good mechanics can make. Karl Deiner, a German who had worked for Mr. Westinghouse, Bob McCartney, a Scotsman, Bill Eckert and "Pop" Keenan, two native Americans, were all-around machinists to whom one could go with a rough sketch and obtain expert advice on how the apparatus could best be built.

One of the few projects undertaken by Westinghouse at South Philadelphia in the Depression was the building and most of the design of the structure of the 200″ Mount Palomar telescope, and I was to help out in this. We carried our oldest son, then one month old, in a basket on the train to Pasadena where we lived for five months.

Regarding the pictures shown here, I should tell you how I got these from photographs that were made in the thirties. Our photographer, Charles Yessel, knew his business. Mr. Westinghouse objected to having his picture taken. When an official photograph was needed, Yessel took a picture of the old man, seated at his desk, through the keyhole of the door. It became a famous photograph. Yessel kept a logbook of every picture he took. The Westinghouse photographs and a copy of Yessel's logbook are now kept at the Eleutherian Mills Historical Library near Wilmington. With the very kind help of Miss Julia Davis, curator of pictures, and of Mr. Walter Ellis, of the Westinghouse reproduction department at South Philadelphia, I was able to collect the pictures shown here.

The drawing shown as Fig. 1 was made by Russell Porter, artist and amateur astronomer, long before the telescope was put together. There are two major structural parts: (1) the tube which is pointed at the stars and which contains the main optical elements, and (2) the yoke, rota-

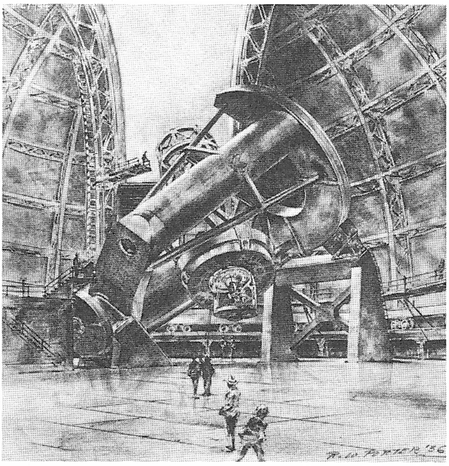

Figure 1 — Russell Porter's drawing of the 200 inch telescope

ting about the polar axis to make the tube follow the stars. The North portion of the yoke has the shape of a horseshoe so that the tube can fit inside to follow stars close to the Polar star.

The 200″ telescope had much more engineering applied to it than previous telescopes. When I arrived at the California Institute of Technology, Mark Serrurier had already done a marvelous design job on the tube. I was to concentrate on the yoke design.

It is sound engineering to design any structure so that it is amenable to analysis. In this case, it was advantageous to make the system such that any distortion of the yoke did not also cause distortion in the tube and to put as little strain as possible on the ball bearings carrying the declination axle (the axis about which the tube rotates with respect to the yoke). This was achieved by using a system of spokes, shown in Fig. 2. Spokes are stiff in tension and compression but flexible in bending. The spokes all intersect at a point on the declination axis. At the outside they are connected to the tube; at the inside they are fastened to an axle carried by the yoke. Thus the declination axis is located firmly; yet only small bending moments are transmitted through the spoke system.

The yoke must rotate about the polar axis as smoothly as possible to avoid jarring the instrument. Our chief engineer, Francis Hodgkinson, suggested that the bearings be made like "oil pads" with oil being fed into cavities, the oil oozing out through a small clearance between the yoke and the bearing pad. He was a little rusty on his fluid mechanics, and instead of computing the oil flow as viscous film flow, he calculated the power required as if the oil came through an orifice. His answer, 600 HP, almost ditched the whole scheme. When correctly computed as film flow, it turned out that his HP figure was too high by a factor of 1000 or so. It became my job to work out a bearing system that was stable (so that the oil would not ooze out all on one side) and to demonstrate its feasibility by

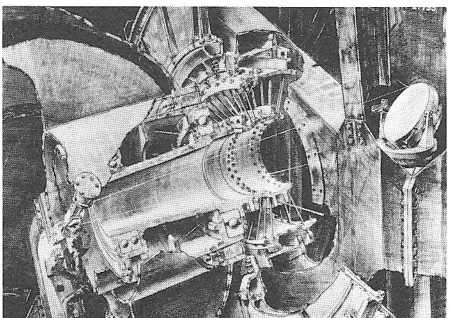

Figure 2 — Porter's sketch of the spoke system for the declination axis

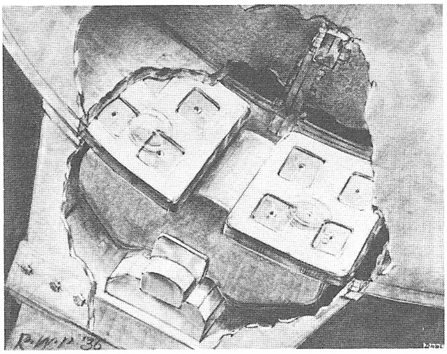

Figure 3 – Oil Pad design

experiment. In the oil pad design (Fig. 3), oil is admitted under pressure through orifices to four cavities in each pad. The clearance between the pad and the yoke is only a few thousands of one inch. The design has worked out very well. The astronomers have fun putting a milk bottle on the yoke and seeing how gradually the million pounds of steel gains velocity.

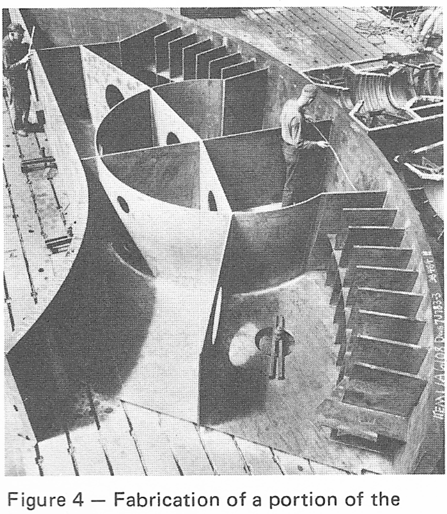

Figure 4 – Fabrication of a portion of the horseshoe

The rim of the horseshoe had to be stiff enough to maintain reasonable bearing clearance and to remain as round as possible. The number of practical design choices – with circumferential or cross-wise stiffening – was small. The structure involves plates in bending, in compression and in shear. It would have been possible to work out some kind of analytical solution. But great accuracy was not called for, weight was not critical. The important thing was to arrive at a design that would lend itself to easy and reliable manufacturing. I chose to make cardboard models of the most promising stiffening arrangements and measured their deflection under load. In one afternoon I found a good arrangement. (Fig. 4).

When the telescope elements were assembled at Philadelphia, there was a dedication ceremony, attended by many dignitaries. (Fig. 5). Einstein was there. The great man, with the wonderful mind, looked in amazement at the large steel parts and the big machine tools. He asked, "What happens if somebody makes a mistake in manufacturing?" He was told that the part might have to be scrapped. That took Einstein by surprise. He said,

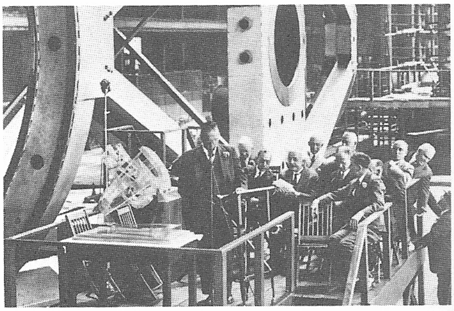

Figure 5 – Dedication ceremony, with Albert Einstein and Robert Millikan in attendance

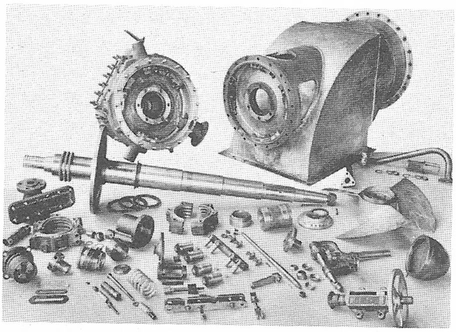

Figure 6 — Henry F. Schmidt's blower

"My work is so much simpler. When I find a mistake, I just tear up the paper I wrote on."

The design and drafting of the telescope were done by only a handful of people. Its manufacture at the South Philadelphia plant went so well that the structure was produced at a cost of thirty-seven cents per pound. When, a few years ago, a new telescope for Chile was considered, it was proposed to copy the structure of the thirty-year-old Palomar design.

Working with the astronomers on the telescope was, for an engineer, a lot of fun. For relaxation, we went camping in the desert where the coyotes howled at night.

There was at South Philadelphia an elderly engineer, Henry F. Schmidt, who had graduated from Columbia University in 1903. I inherited his *Table of Integrals.* From the notations which he made in this Table, I judge that he must have been an excellent student. Mr. Schmidt developed some interesting apparatus, particularly high speed blowers, which are essentially large fans to provide ventilation for ships. Schmidt's blower looked much like a ship propeller. The rotor is seen at the right side of Fig. 6. Several of us did our best to find out from him how he designed these fans, but we never could understand his reasoning. Someone said that Mr. Schmidt had a direct pipeline to God!

Along came Dr. Tietjens, well-known aerodynamicist and collaborator of the famous Prandtl. Tietjens took one look at Mr. Schmidt's blowers and decided that they lacked any basis for a sound design. Westinghouse management came up with a sporting proposition: Dr. Tietjens would design a blower of his own and both types would be tested. The tests were made. To the surprise of everyone but Mr. Schmidt, the Tietjens aerodynamic design proved inferior. The tests were repeated at MIT with the same result. I let you draw your own conclusions.

But Tietjens made history in pioneering hydrofoil boats in which the weight of the boat is carried by thin submerged foils, the boat itself being out of the water. In the mid-thirties an experimental hydrofoil boat was tested on the Delaware River and Paul Vaughan was the volunteer navigator. This boat had hydrofoils in the front and in the rear, but it soon developed that this design is unstable. Paul had to be in exactly the right position in the boat. When a wave came, he was tossed overboard.

To single out another project in which I became engaged, I cite the problem of turbine blade failures. In the 1930's a new type of steam turbine was introduced. This was the "topping" turbine, operating with the newly available high steam pressure and temperature and exhausting into existing steam turbines at lower pressure. Three large topping turbines were designed according to existing practice. But in something like twenty-

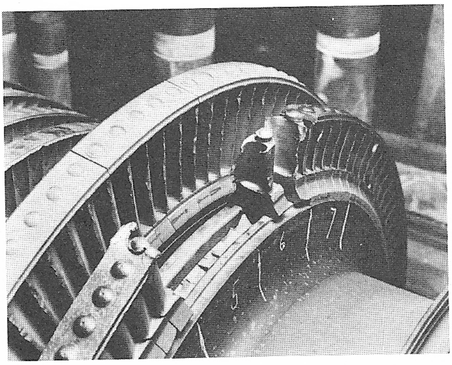

Figure 7 — Blade failure in the Curtis stage of a topping turbine

four hours, they had blade failures. The blades were replaced by stronger, wider blades; but these also broke in short order. Management became duly concerned. Millions of dollars were at stake. One vice-president, an Irishman who always carried a carnation in his buttonhole, offered an earthy solution to the problem: "Why don't they a get a red-headed boy to . . . on those blades?"

Fig. 7 gives a view of a blade row in which several blades had broken out. To find the cause for these failures and to create a design which would stand up, both analysis and experiment were brought into play.

Since electronic instrumentation was only in its infancy, an optical system (Fig. 8) was devised to record the motion of the blades. A small stellite mirror was mounted at the tip of the blade, and the light beam, deflected by the vibration of the blade, traced a record on photographic film.

As shown in Fig. 9, the first element, a so-called Curtis stage, consists of nozzles through which the steam is expanded to high velocity, a first rotating blade row, a stationary blade row and a second rotating row. The turbine power is produced by the change in tangential momentum of the steam flow as it is deflected in the rotating blades. For load control these turbines operate with what is known as "partial admission." Partial admission means that the steam jet occupies only a part of the circumference so that the blades are successively loaded as they enter the jet and unloaded as they leave the jet. It turned out that the intermittent steam load, acting on the blade

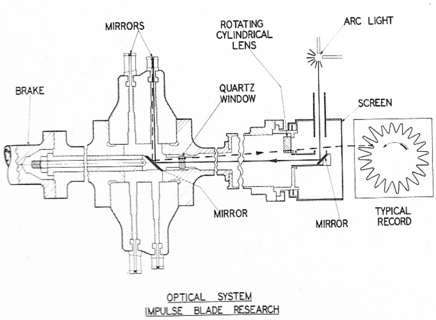

Figure 8 — Optical system to measure blade vibration

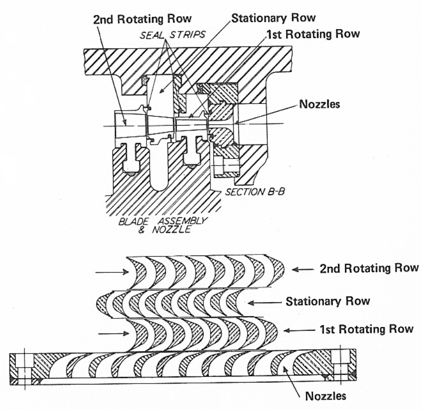

Figure 9 — Curtis blading of the 1930's

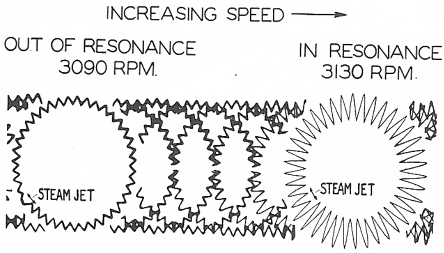

Figure 10 — Typical blade vibration records, taken at variable speed

structure which has extremely low damping, can produce severe vibrations.

Fig. 10 shows a typical experimental record made when a turbine was operated at variable speed. It confirmed that the vibration repeats every revolution (the light beam traces the same pattern over and over). It also confirmed the analysis that it is the entering and leaving of the steam jet which puts energy into the blade motion. When outside the jet, there are no exciting forces on the blade, and the vibration decreases until the blade enters the jet again. All this is now well-understood, at least in principle, and so are the remedies: increased damping, higher frequency, and making the shock loading more gradual. Partial admission blading can now operate safely at steam conditions much more severe than those of the 1930's.

In the 1930's, Charles Meyer, a member of our group, made systematic studies of gas turbine cycles, mostly for industrial use. Also, we participated in a NASA (then NACA) committee on new aircraft powerplants, under the leadership of Dr. William Durand, well-known for his books on aerodynamics and a gentleman of the old school.

On December 7, 1941, the attack on Pearl Harbor came, and the United States entered World War II. It was a very different situation than what we face now. Several countries had been overrun by Hitler. There was a strong feeling throughout the United States that the Nazis and the Japanese must be stopped. Many university professors became volunteers in the armed services.

It was agreed with the Navy, the day after Pearl Harbor, that Westinghouse would work on jet engine development. Dr. Durand asked each of the industrial participants on his committee how much it would cost to develop a jet engine. The General Electric people had an immediate answer: $100,000. We said that Westinghouse should be able to do likewise. This figure is of the right order for just building an engine, but to make a design really operational requires much testing and many engines so that the total amount of money needed is about 100 times larger.

A small group of engineers and mechanics, shown in Fig. 11, went to work

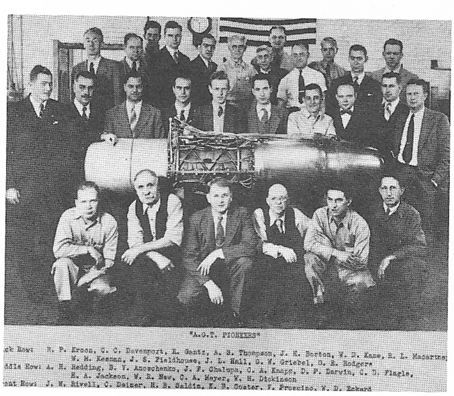

Figure 11 — Engineers and mechanics with the first Westinghouse jet engine

on the design and building of a small jet engine. In fourteen months they were ready to test the engine. As an indication of the spirit of the times, let me quote from the logbook of this first jet engine of American design . . . . "May our jet motors do their part in the fight for freedom and for a better world." As another indication of the times, let me also tell you what it said on the sign in our small laboratory. It read, "Safeguard your health – Do not spit on the floor – Use the cuspidor."

A jet engine (Fig. 12) consists essentially of a compressor in which atmospheric air is compressed, a combustor in which fuel is burned in the compressed air, a turbine in which the combustion products are expanded, and an exhaust nozzle in which the gases are further expanded to a high velocity. The compressor is driven directly by the turbine. The engine produces a forward thrust by accelerating the fluid going through it.

Of course, there were many challenging new design problems of high speed machinery, high temperatures, turbine and compressor design, etc. The most frightening one was the combustion problem. I had nightmares about blowing up everyone in sight by trying to burn large quantities of fuel in a small volume. Dr. Stewart Way, who had independently invented the jet engine and the ram jet, began some basic combustion research. But the breakthrough came from England. We were told in essence: "Fellows, there is nothing to it. All you have to do is to take an open tomato can and punch a lot of holes in it. Spray the fuel in at the closed end and let the air come through the holes." In principle, this is the way all combustors are designed, with many experimental and theoretical studies to provide design criteria.

Our first engine model was first flown at Patuxent, Maryland, under the belly of a regular propeller plane so that the pilot would have his regular power available in case the jet engine failed to function (Fig. 13). It was quite a sensation for me to see the engine in the air.

One of the most memorable aspects of the jet engine development was the camaraderie among the participants. There was J. S. McDonnell (Mr. "Mac"), a former test pilot, who started an aircraft business in an automobile showroom

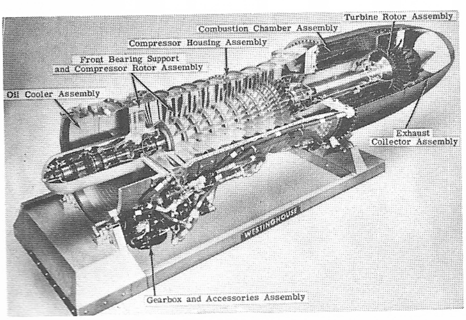

Figure 12 – Cut open view of the 24C jet engine

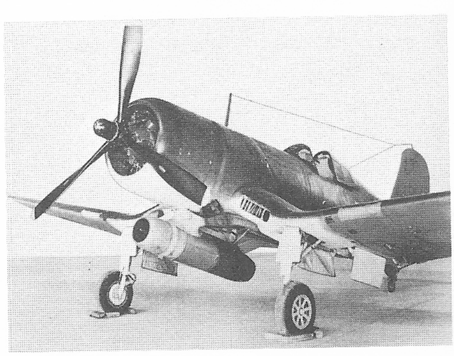

Figure 13 – The F4U Corsair airplane with the 19A jet engine

in St. Louis and built it up to a multi-million dollar enterprise. In England, there was Lord Hives, Chairman of the Board of Rolls Royce, who had begun as a test driver. Symington (then Secretary of the Air Force), Grumman, General Gavin, Hugh Dryden, who had been a specialist in turbulence and became Director of the NACA . . . . Too many to mention. To me they were fascinating personalities.

In time our small development group grew to a full-fledged engineering department with excellent laboratories, model shops, engine test cells and flight test facilities in Kansas City. But by the mid-fifties, it became clear that economically, of the five organizations engaged in jet development, only two could survive. We were "phased out." Another filtering process took place, and I came with a small group of senior engineers to Drexel Hill. Our job was to make preliminary studies of all kinds of new systems in which Westinghouse divisions might jointly be interested – from portable lightweight powerplants to temperature controlled suits for arctic climates. The reason that this group was later disbanded was also mainly one of economics. Engineers must be paid. The divisions preferred to put their money in their own engineering departments rather than in an independent group. I came to the University of Pennsylvania.

I have often thought about the moral consequences of what I was doing in developing jet engines, originally intended for military aircraft. I tried to convince myself that the engine itself is not an instrument of death and that in the long run the predominant use of jet engines would be for transport. Today indeed, by far the largest percentage of engines are in commercial airplanes and serve to bring the people of the world closer together.

I presented my first technical paper, before the A.S.M.E., in 1934. I memorized it word for word, and I doubt whether the audience enjoyed it much. But it was the beginning of an activity which has meant much to me. Serving on various committees of the A.S.M.E. – Applied Mechanics, Aviation, Basic Engineering – I was able to work with like-minded people on matters of common interest. I would urge our younger people to become active in professional organizations. These organizations are not perfect, but it is better to play a responsible part in them than to let them be ineffectual. They can be the voices of responsible leadership.

What about today's challenges to the engineer? You can open up any newspaper and read about pollution, about ruining our environment, killing its animals and threatening even man's own existence. Technology as such is blamed for lowering the quality of our life.

Often these complaints come from persons who take the technological achievements of running water, electric power, and telephone service for granted. People in countries where children die young because of inadequate knowledge and facilities, where people spend most of their life in drudgery, where a string or a piece of paper is a treasure, think very differently about technology. They know they have no future without it.

It is ridiculous to think about our civilization without technology. Our population is several hundred times as dense as that of the Indians who lived here. The

Indian civilization had stabilized. Its numbers were what could be supported in a society which required practically no minerals and which left the natural ecology intact. But we cannot feed all our people without modern transportation facilities, means of communication, mass production, and mechanized farming.

When we look a little closer at some of the messes we have gotten into, we recognize that most of them are the result of unforeseen consequences of our industrial development. Cars were meant to provide transportation to millions of people, not to pollute the atmosphere. Detergents were intended to wash clothes and dishes better, not to ruin our streams. D.D.T. was to rid us of insects so that we would have better crops, not to threaten our animals as well as ourselves.

This means that we have been much too shortsighted in our rapid application of technological advances. We have ignored some effects which now turn out to be critically important. We need methods which allow us to examine many factors simultaneously. We cannot plan housing projects without taking into account employment opportunities, transportation, recreation areas, waste removal, and other factors.

System Analysis, as it is called, has been applied to the operation of hospitals, to transportation problems, etc. It is not perfect. It is only as good as the assumptions that go into it. But the alternative is that we chase one mirage after another.

Fortunately, at the same time that our technological problems are more complex, we have better means of solving them by the use of computers. Computers are without doubt the most important technical development of these decades. Many future engineers will deal with system problems rather than with specific products.

System analysis involves trade-offs – highway space versus living space, redwood forests versus lumber here and now, and ultimately quality versus quantity of human life. Such trade-offs depend on the values we set for ourselves. It is well to realize that scientists and engineers comprise only 1-2% of our population. Many of the vital choices – what our cities are to be like, what kind of things we want to have around us – are made by the population at large. If we choose the wrong priorities, it is not the 1-2%, but the entire population which must bear responsibility.

Obviously, we cannot continue to ransack the earth for natural resources and to dump our trash on the land or in the water at an ever increasing rate. We must learn to make better use of our waste and to *recycle* our used materials into consumer products again. The discovery of processes to bring this recycling about will be one of the major new engineering challenges.

Clearly, the *technical* problems we face – pollution, trash removal, large scale transportation – will require high-grade *engineering* effort. Only engineers and scientists have the required training to solve technical problems. Our first requirement of the *engineer* is that he solve his problems well, that his bridges do not collapse, that his airplanes can fly safely. Tomorrow's society and the quality of life will depend heavily on how well engineers face up to the new challenges.

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