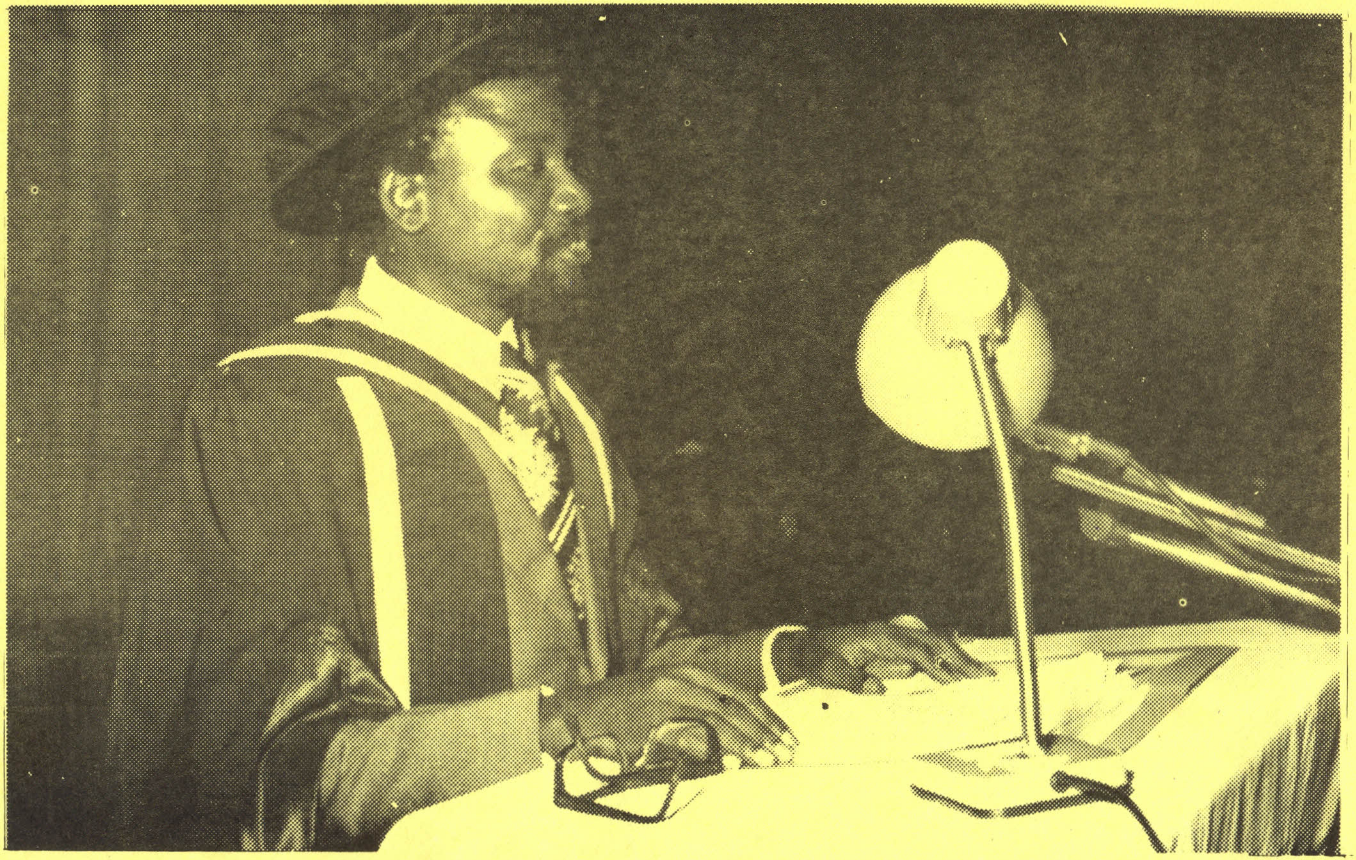
OBAFEMI AWOLOWO UNIVERSITY. ILE-IFE. NIGERIA

Inaugural Lecture Series 90

THE HEART, LIFE, AND SOUL OF TECHNOLOGY

By O. O. Mojola

OBAFEMI AWOLOWO UNIVERSITY PRESS LIMITED



O. O. Mojola
Professor of Mechanical Engineering

THE HEART, LIFE, AND SOUL OF TECHNOLOGY

by

O. O. Mojola
Professor of Mechanical Engineering

Inaugural Lecture delivered at
Obafemi Awolowo University
on 12th April, 1988

Inaugural Lecture Series 90

OBAFEMI AWOLOWO UNIVERSITY PRESS LIMITED
ILE - IFE, NIGERIA

ISSN 0189-7845

Printed by

Popoola Printers & Stationeries Supplier

No. 7 Isale Agbara Street,
Box 326, Ile-Ife.

1. PROLOGUE

The ivory-tower ritual of delivering an inaugural lecture which I am now called upon to perform was of course transplanted into this country by the British. Within Britain itself, there was some semblance of this activity at the University of Oxford at least as early as 1623 when, as the first Camden Professor of History, Digory Whear mounted the rostrum to deliver his *oratio auspicalis* in the *Schola Grammaticae.* By the time of Edward Thwaites (Regius Professor of Greek, also at Oxford) in 1708, the inaugural lecture had become somewhat formalised, and the lecture has since come to be perceived by scholars as something of an intellectual feast prepared by the lecturer according to his own recipe.

My recipe for this lecture, the first from the Department of Mechanical Engineering of this University, is a fairly brief exposition of some aspects of technology. The *expose* shall be lightly flavoured with summaries in the appropriate places of some of my contributions to knowledge and activities in the field for more than twenty years. I shall be digging into the past, tugging at the present, and (occasionally) crystal-gazing into the future. The thrust of my arguments shall be directed at some of those key elements which I consider to be the real foundations of technology. Hence my choice of a rather basal title: The Heart, Life, and Soul of Technology.

According to G.K. Chesterton (a famous English essayist, novelist, and critic), "All slang is metaphor and all metaphor is poetry." But my use of the metaphors Heart, Life and Soul in the title of this lecture (and of similar metaphors elsewhere in the lecture), is largely a deliberate attempt to humanise technology. Afterall, technology, like the sabbath, is made for man and not man for technology.

This lecture is divided into three major parts: the Heart of Technology, the Life of Technology, and the Soul of Technology. I shall endeavour to critically appraise each of these in turn but with much greater emphasis on the first.

Brevity, as the saying goes, is the soul of wit, and it will not be possible for me to cover all pertinent matters, let alone treat them in very great detail. I apologise in advance to the layman if I cannot restrain myself from being carried away occasionally by the tide of technicalities. The truth of the matter is that it is very difficult to be totallv non-technical in a lecture on technology.

2. THE HEART OF TECHNOLOGY

2.1 Technology and Mechanical Engineering

The word "technology" conjures up different images in the minds of different people and, before we go any further, let us be quite clear what we mean by technology.

In broad terms, technology is any practical art which utilises scientific knowledge. But in the narrower "industrial" sense in which the term is used in this lecture, technology may be regarded as the science of the *industrial* arts and crafts. The word "engineering" is often used as a synonym for technology, but engineering (or, strictly speaking, engineering technology) is only a part of technology.

Before the Industrial Revolution began in Britain around 1750, there were only two kinds of engineers: the military engineer and the civil engineer. The military engineer, described by the Romans as "*architectus militaris*", was responsible for the construction of fortifications, catapults, cannons, and other offensive and defensive installations and weapons. The civil engineer was charged with the duty of building roads, bridges, harbours, aqueducts, and other structures.

The diversification of industries during the Industrial Revolution led to an increasing degree of specialisation in the functions and activities of engineers and, inevitably, technology became fragmented. With the founding on 27th January, 1847, of the Institution of Mechanical Engineers in Britain, mechanical engineering formally broke away from the dichotomy of civil and military engineering, and subsequently gave birth (in Britain) to electrical engineering in 1871, chemical engineering in 1922, agricultural engineering in 1938, and so on. This process of splintering has continued unabated through the years, and today we now have at least fifty clearly defined engineering specialties in technology. But this extensive fragmentation should not be interpreted to mean that technology is a rag-bag collection of disjointed bits and pieces. It is not. In fact, the contrary is the case, because a few common threads of thought run right through the entire gamut of technology, giving it intellectual cohesion and making it worthy of academic study in the university.

One of these common threads is the basic necessity for engineers to generate, sustain, control, and use motion in all its ramifications. The science of motion is mechanics, and there is no branch of technology in which the engineering application of mechanics does not play a vital if not a dominant role. But the "engineering application of mechanics" is really (at least in a strict literal sense) a verbosity for "mechanical engineering". I therefore wish to submit that the heart of technology is mechanical engineering.

2.2 Mechanical Engineering and the World of Motion

2.2.1 Generalities

Although mechanical engineering was not formally recognised as such until the Industrial Revolution, its activities actually began in the prehistoric period when man started to fashion the simplest mechanical tools such as the axe, the chisel, and the hammer, using materials like stone, wood, and bone.

If mechanical engineering is the heart of technology, then motion is the life-blood.

In one of his unpublished papers written in Latin and titled "De Gravitatione et Aequipondio Fluidorum" ("On the Gravity and Equilibrium of Fluids"), Isaac Newton defined motion as change of place. The change of place must occur over a period of time, and the motion may be perpetual in nature but never in technology.

The world of motion is intimately related to the world of force, because motion and force are the opposite sides of the same coin. Force gives rise to motion and motion to force, and for material body which is not quantum-mechanically small and is not moving at relativistic speed, the relationship between motion and force is neatly summarised by the three celebrated laws of motion formulated by Newton.

Mechanical engineering is mainly the totality of technology (analysis, design, manufacture, operation, maintenance, etc) associated with all material bodies which can be called "machines", either because they transform mechanical energy due to motion into other (non-mechanical) forms of energy, or vice versa, or because they generate, transmit, or modify motion, force, or both, in order to do work. These machines cover all types of domestic, commercial, and industrial applications, and operate in all sorts of environment such as under water, over land, or far out in deep space.

The need by early man to multiply his physical effort severalfold in order to move heavy objects led to the development of the primordial simple "machines": the lever, the inclined plane, the wedge, the wheel & axle, the pulley, and the screw.

Levers are of three kinds which are distinguished by the relative positioning of the fulcrum, the load, and the effort. One of the early applications of the lever was the digging stick for land cultivation. The wedge was derived from the inclined plane and was particularly useful in ancient times for splitting rocks and logs of wood. The wheel made its appearance unannounced around 3,500BC. It led inevitably to the wheel & axle around 3,000BC, and was turned into the pulley by the mechanical engineers of Sumer and Assyria about the time the biblical Joshua was capturing Jericho. The screw (often credited to Archytas of Tarentum) surfaced around 500BC, and is essentially an inclined plane wrapped round a circular cylinder.

On the basis of their operation, these six simple machines can be reduced, fundamentally, to only two: the lever and the inclined plane. The fundamental importance of the lever was recognised by Archimedes who worked out its theory, and it was this recognition that led him to announce grandiloquently in his native Greek:

Δός μοι ποῦ στῶ kαι kινῶ τὴν γῆν

Translation: Give me a place to stand and I shall move the world. In theory, he could of course move the world, but in practice he would require a lever which, in every sense, would be out of this world.

The simple machines were the building blocks of more sophisticated machines during the ancient times. But times have changed and mechanical engineering has matured with a wide range of simple machines which are now properly called "machine elements", and of which virtually all modern machinery is composed. The lever has been generalised into linkages and its principle adapted to the operation of belt-, rope-, cable-, and chain-drives, among other machine elements. The wheel has given rise to elements like gears, sprockets, cams, bearings, shafts, discs, and flywheels.

The primary function of these machine elements and others like them, is to transmit motion from one part of a machine to another. But the choice of transmission elements for a specific task can sometimes turn into a bewildering exercise for the engineer in the face of unlimited attractive possibilities. An infinite array of motions in two and three dimensions can be transmitted, for example, by linkage mechanisms, a classic illustration of which is the slider-crank mechanism which converts reciprocation into rotation, and vice versa, and provides the underlying mechanism for an internal combustion engine, a piston pump, and a reciprocating compressor.

Direct-contact mechanisms like gears, allow motion to be transmitted in the same direction or around corners, with constant or variable speed ratios, and between shafts that are parallel or non-parallel, intersecting or non-intersecting, and using tooth elements whose range of profiles includes the epicycloid, which is generated by a point on the circumference of a circle that rolls without slipping round the outer circumference of another circle. As for epicyclic gear systems, such as those employed in the automatic transmissions of motor-vehicles, cue is taken from the motions and even the names of the heavenly bodies (sun and planets).

The manufacture of machine elements, and hence of complete machines, by means of machine tools, is also intimately connected with motion. Machining is the backbone of the mechanical manufacturing processes, and it is remarkable that, with the possible exception of the "chipless" methods of removing metal, all machining processes depend on relative motion between the workpiece and the cutting tool. The kinematics of machine tools requires the operation of two systems of control for the workpiece and the cutting tool, and the two systems must be well coordinated to generate the motions necessary for producing a given geometric shape and size within specified tolerances.

2.2.2 Machines for Transportation by Road, Rail, Water, Air, and Space.

All transportation machines are basically mechanical, and in no area, perhaps, has mechanical engineering contributed more ostensibly to the world of motion and had a more profound effect of the lives of people, than that of transportation.

Prehistoric man depended a lot on his feet for his locomotion at an average speed of about 4.9 km/h. To move materials and sometimes himself over long distances by land, he made use of draft animals like the ass, which is native to Africa. Extensive use was also made of mechanical devices like the Y-sledge (the travois) which was very popular in the cattle regions of Africa, and with the appearance of the vertical wheel (around 3,500BC), the (normal) sledge was transformed into wheeled chariots and subsequently horse-drawn carriages in Mesopotamia. Movement on water, naturally, was more difficult, but it was made possible by means of reed rafts, bark canoes, and dugouts, some of which in a modernised form, are still in use today in this part of the world.

Reliable systems of transportation were slow to develop, but the world now has a rich variety of transportation machines which possess one, two, or three degrees of freedom in terms of translational motion, and which operate on, above, or below ground level; on, above, or below water; within the dense lower portion of the atmosphere, at the rarified higher altitudes inside the thermosphere, or deep in the vacuum of outer space. Let us take a brief look at some of these.

The bicycle evolved from the "velocipede", a euphemism for a mobile "bone-shaker", and much of the credit for this evolution must go to Pierre Michaux and his son Ernest for their pioneering efforts in the 1850s in France. Because of its ease of operation and relatively low cost, the bicycle outnumbers all road transportation machines in many countries of the world today. Indeed, world production of bicycles during the last decade averaged over 36,000,000 units, each capable of propelling an easy rider at up to 19 km/h, which is roughly four times the normal walking pace.

The tricycle, which greatly enjoyed the favour of short men with short legs in the 1880s, was a derivative of the bicycle, and is essentially a foot-peal-operated bicycle with an additional wheel to increase the stability of motion. The motorising of the bicycle to attain higher speed of propulsion on two wheels, was brought about by the introduction of very small portable internal-combustion engines, and has led to the development of the motor cycle and the moped (an abbreviation of "motor-assisted pedal cycle") with wire-spoke wheels, and motor scooters with solid wheels like those of a motor car.

After many years of international techno-political controversy, it is now generally agreed that the first true self-propelled motor-vehicle was built in 1769 by Nicholas Joseph Cugnot, an artillery officer in the French Army. The vehicle was a huge tricycle with a steam-powered engine; it carried four people and ran for 20 minutes at a pedestrian pace of about 3.6 km/h. However, the most original contributions to the development of the modern motor-vehicle with a petrol or diesel engine came from Carl Benz and Gottlieb Daimler of Germnay who, independently, tested their first vehicle in 1885 and 1886, respectively. Other illustrious pioneer contributors to the modern motor-vehicle include Louis Renault, Andre Citroen, and Armand Peugeot all of France; Henry Ford and Walter Chrysler of the United States of America; William Morris and Herbert Austin of Britain.

Emily Jellinek, an associate of Gottlieb Daimler, had a daughter called Mercedes, and when Daimler teamed up in 1926 with Carl Benz to form a joint company, the world-famous Mercedes-Benz came into being. Henry Royce and Charles Rolls had earlier (1906) combined forces in Britain to produce what is now the exquisitely elegant Rolls-Royce for the extremely wealthy. Ferdinand Porsche in Germany designed the popular Volkswagen Beetle, and Giovanni Agnelli gave the world "Fabbrica Italiana Automobili Torino" otherwise known as FIAT.

The motor-vehicle is a microcosm of motion. A medium-sized saloon car with a four-stroke-cycle engine is assembled from over 13,000 different parts, made from almost 60 different materials, and has some 1,500 components in synchronised motion. In the engine alone, there are at least 120 moving parts that have to be continuously lubricated; and if the crankshaft turns at a maximum speed of 6,000 revolutions per minute, each piston would be sliding up and down within its cylinder as many as 100 times a second, while the camshaft which operates the inlet and outlet valves rotates 3,000 times a minute. For the comfort of passengers, especially on rough bumpy roads, suspension systems of coil and leaf springs, torsion bars, and shock absorbers are designed to move toward and away from the ground at up to 1,200 times every minute. A good car with an engine capacity of 2,000cc can move from rest to 100 km/h in 8 seconds; and with good brakes and good tyres, it should be possible to bring the car back to rest in less than 5 seconds, during which sufficient heat would be generated to boil one-quarter gallon of water.

Like the motor-vehicle, the railway train originated from a simple system of horse-drawn carriages. The system in this case was the early tram which rode on flanged cast-iron rails and which was often used to move heavy and bulky materials like coal and stone from mines and quarries to wharves. With the emergence in Britain of steam locomotives like Richard Trevithick's *New Castle* in 1804, horses gradually disappeared from the scene, the flange on the rail was shifted to the wheel, and the cast-iron rails soon became steel. The world's first public railway line, which linked Stockton to Darlington in England, was opened on 27th September, 1825; and for more than a century, the steam locomotives dominated rail transportation which helped to open up new territory, encouraged large-scale mobility of people and goods, and promoted manufacturing, trading, and even socialising. With regard to socialising, let me draw attention to an interesting demographic study of the institution of marriage within a group of Oxfordshire villages in England, conducted by Kuchemann, Boyce, & Harrison (1967). They found that, between 1650 and 1850, only in one-third of the marriages contracted did one of the partners come from outside a 10 km radius. But with the construction of a railway line in 1850 through the neighbourhood, the ratio suddenly jumped to two-thirds!

The success of the railway train as an economic, high-volume, heavy-duty machine for land transportation, derives from the fact that the friction experienced by steel wheels rolling on steel rails is only about one-ninth of the friction between motor-vehicle tyres and the highway. Diesel and electric traction systems have now virtually replaced the steam locomotive in much of the world's trackage of about 1.2 million kilometres.

Although the motion of a ship on water requires four times as much force as that needed to move a railway wagon of comparable weight over steel rails, ships like ocean liners and oil tankers have long served as the marine equivalent of the railway train as heavy-duty transportation machines. The history of the ship can be traced to ancient times, and the sail was the principal means of propulsion until the 19th century when the steam engine came into use, followed later by the steam turbine, and eventually the modern diesel engine. The size, weight, and cruising speed of ships have increased considerably over the years, and it is not uncommon nowadays for a huge tanker (335 m and 53 m wide) to carry 300,000 metric tons of crude oil at a cruising speed of 35 km/h from one end of the earth to the other. The main difficulty with this mechanical monstrosity is its very large inertia. In compliance with Newton's first law of motion, once the tanker starts cruising, more than one hour and 13 kilometres of continuous braking may be required to reduce its speed to a slow pace of (say) 8 km/h. Fortunately, over 70% of the earth's crust is covered with water.

The entire globe is of course covered with a blanket of air known as the atmosphere and, for thousands of years before Christendom, man had dreamt of moving through the air like the bird, the bat, and the insect, the three true flyers of the animal kingdom. Slowly, the dreams began to give way to serious studies of bird flight and actual attempts to fly by means of the flapping-wing technique of birds. But all these attempts failed miserably, because the force-motion characteristics of the flapping wings of birds, were, at that time, too complicated to be carbon-copied, let alone understood and mechanised.

Birds propel themselves not only by flapping their wings but also by soaring and gliding through the air, and progress with mechanical flight became possible only when attention was switched from flapping to gliding motion. There is no doubt that it was the extensive experimentation conducted with gliders by aviation pioneers like George Cayley, Otto Lilienthal, Octave Chanute, Samuel Langley, and two brothers, ——— Wilbur and Orville Wright, that really led to the first successful heavier-than-air flight performed by the Wright brothers on 17th December, 1903, near Kitty Hawk, North Carolina, in the United States. Their aircraft (nicknamed Flyer I) was a wire-braced biplane with a wing-spread of 12.3 m and empty weight of 274 kg. Made of a wooden frame covered with canvas, the aircraft had a front elevator and a rear rudder for stability and control, and two propellers chain-driven by a 12 hp four-cylinder petrol engine. With Orville Wright as the pilot, the aircraft took off at 10.35 a.m., flew for 12 seconds against a cold wind of more than 32 km/h and landed safely, having covered a distance of about 37 m.

Within half a century of the Wright brothers' flight, the aircraft as a flying machine underwent an incredible metamorphosis. Its open box-type structure (with an intricate web of trusses and cables) evolved into a streamlined monocoque fuselage; the wood-and-canvas biplane with high straight wings developed into a largely metallic monoplane with wings that could be lowered, swept back, tapered,, cambered, twisted, and even "dihedraled".* The fixed pitch of the engine propellers became variable, jet propulsion came into being, and the sound barrier was finally crossed.

Commercial aviation began in Europe in 1919 and is now nearly the proverbial three score years and ten. Subject to the availability of standard (aircraft take-off and landing) facilities, there is no place on the earth today which cannot be reached from any other place within 48 hours, if use is made of a supersonic slender-wing aircraft like the Concorde (which can fly at more than twice the speed of sound) or a wide-body jet like the Boeing 747 (that is capable of carrying a payload of 75,000 kg over a distance of 11,000 km

*Set at a dihedral angle.

nonstop). Still, the civil aircraft industry is interested in building machines which are not only bigger than the current fleet, but can also fly faster, higher, and farther. It is therefore likely that there will emerge in the future. a series of hypersonic aircraft carrying passengers nonstop round the world at a top speed of 5* to 24 times the speed of sound. A Mach-24 aircraft is likely to be the *ultimate* machine in commercial aviation, at least as far as speed is concerned because, at greater speeds, the aircraft would have to be forcibly prevented from leaving the atmosphere to go into orbit round the earth. Secondly, as shown by Gabrielli & von Karman (1950), there is for every type of transportation machine a certain limiting speed beyond which the machine becomes uneconomic.

The line of demarcation between atmospheric and space flight is not very sharp, but it is convenient to define a spacecraft as a transportation machine that operates above an altitude of 160 km, which may be regarded as the upper limit of the sensible atmosphere.

Spacecraft comes in many forms, shapes, and sizes, and it serves various functions. It includes sounding rockets used for taking measurements at altitudes ranging from 40 to 160 km; satellites for communications, navigation, weather monitoring and prediction, basic scientific studies, and survey of the earth's food and material resources; probes for outer and deep space exploration.

The launching by the U.S.S.R. on 4th October, 1957, of Sputnik I (the first artificial earth satellite) took the world by surprise, heralded in the space age, and triggered off various national space programmes. The most successful of these programmes (at least in the public view) was the American Apollo project which, during the Apollo 11 mission, generated what is probably the most spectacular event in the whole of technology so far this century. I am

*A Mach-5 aircraft is under development by France and the United States independently.

referring here to the landing of the first men on the moon, 384,000 km away, on 20th July, 1969, at 9.17 p.m. Nigerian time. Neil Armstrong, the Commander of the historic Apollo 11 mission stepped on the lunar soil about 6½ hrs later, and left his footprints not only figuratively but also literally on the sands of time, because the moon has no atmosphere to erode its soil and, barring substantial micrometeoritic impact and future human interference, the footprints should be preserved for 100 million years!

By December 1972, man had landed on the moon six times, and some 2,000 satellites and space probes had been successfully launched worldwide. But these impressive figures of human achievement conceal the great complexity of a space-craft as a transportation machine and the highest standards of reliability engineering associated with it. The launch vehicle (Saturn V) for the Apollo programme, for example, is a giant assembly of systems, subsystems, and components, with 6 million individual parts. It is a three-stage vehicle, the first of which alone produces 3.4 million kg of thrust from engines burning 15 tonnes of kerosene and liquid oxygen every second for 2½ minutes, and accompanied by a noise (in watts) greater than that of 4,000 Boeing 707s put together. The spacecraft itself is navigated through space by means of inertial guidance based on precision accelerometers and spinning gyroscopes. For safe re-entry of the spacecraft into the earth's atmosphere at a speed of 40,000 km/h and acceleration of more than 10 g, its angle of trajectory must be controlled to within $\pm 1^0$, its ablating heat shield must withstand temperatures of $3{,}000^0$ C, speeds must be determined to 1 in 11,000 m/s, engine burning times to one-tenth of a second, and distances to only a few metres.

The current use of recoverable launch vehicles in the form of the Space Shuttle is widening the scope, while reducing the cost, of space transportation. But how much of space man will ever be able to personally explore will depend greatly on how fast his space machine can move. At the present level of rocket technology, a return trip to Pluto, the outermost planet of our solar system, would take 16 years.

The whole of our solar system is therefore (at least in theory) within reach, but much more powerful rockets would be required to drastically reduce the travelling time, if the trip is to be interesting to man. Beyond our solar system, the next stop in space is Proxima Centauri (or Alpha Centauri C), the nearest star, located 4.3 light-years away, where a light-year is the distance travelled by light in one year at an enormous speed of 298,000 km/s. On the basis of Einstein's theory of relativity, no machine can move at speeds close to that of light. Yet, motion at high relativistic speeds (by means of photonic rockets, for example) is simply inevitable if the awesome distances to the nearest stars within our galaxy are to be covered in realistic times. Considering that Andromeda, the nearest galaxy to our own, is about 1½ million light-years away, the possibility of *manned* intergalactic flight should perhaps be ruled out *forever*, unless to start with, the light barrier can be broken. Today, the breaking of the light barrier is regarded as an absolute scientific impossibility if not downright heresy; the relevant technology is totally inconceivable and belongs wholly to the realm of pure fiction. Nevertheless, it must be conceded that in this leading-edge area of technology, fiction may become fact after due passage of time.

2.2.3 Fluids, Machines, and Motion

My contribution to the world of motion through mechanical engineering has been in the field of Fluid Mechanics, a profoundly interesting subject which underlies the design and operation of many engineering systems in technology, and finds extensive applications in disciplines such as meteorology, oceanography, physical chemistry, and cardiovascular physiology.

In mechanical engineering, the hardware applications of Fluid Mechanics include fluid machines such as pumps, fans, compressors, and turbines; transportation machines like motor-vehicles, railway trains, boats, ships, and aerospace vehicles at high speeds; machine tools with hydraulic or pneumatic operation; lubricating systems for plant and machinery; jet engines; engine silencers; hydraulic brakes and clutches; pipelines and ductwork for mechanical building services (like refrigeration, air-conditioning, heating, and ventilation) and industrial installations; pressure vessels; fluidic devices; flow valves, filters, and seals.

Fundamentally, Fluid Mechanics is concerned with the behaviour of fluids in motion relative to solid bodies or other fluids, the forces generated by the motion, and the engineering implications. It is tempting to describe a fluid simply as a material substance that flows, but that would be a gross oversimplification. Strictly speaking, "everything flows", as declared by Heraclitus (a Greek philosopher), provided of course that the forces acting are large enough and the period of observation is sufficiently long. It is known, for example, that metallic lead under high pressures can flow through a tube, a soil can flow beneath the foundation of a building; even "the mountains might flow down", according to the Book of Isaiah! However, in contradistinction to solid matter which would flow *only* when subjected to large enough forces to undergo plastic deformation, a fluid would flow *whenever* it is acted upon by a shear force, no matter how small the force may be. This inability of a fluid to withstand a shear force at rest provides a very solid definition for a true fluid which, in mechanical engineering, may be a liquid (such as water), a gas (such as air), or a vapour (such as steam).

The ease of deformability and mobility of a flowing substance is known as *fluidity*. The fluidity of a fluid, if you would pardon my tautology, is the inverse of an all-important fluid property called *viscosity*. Viscosity is a measure of fluid friction because it determines the resistance of a fluid to motion, and it is historically significant that the assumption of zero viscosity led in the 18th and 19th centuries to the development of a classical theory of Fluid Mechanics (known then as "classical hydrodynamics"), which, though useful in inviscid flows, failed woefully to explain some of the most elementary facts of observation in viscous flows. Conciliation of this theory with engineering practice therefore proved impossible until 1904 when Ludwig Prandtl introduced the concept of the *boundary layer.* He hypothesized that for fluids of small but non-zero viscosity, the entire flow-field around (or within) a solid body can be divided into two contiguous regions:

(i) a boundary layer, which is a thin layer of fluid adjacent to a solid boundary and in which viscous effects are important,

(ii) the rest of the flow-field in which viscosity can be neglected.

This boundary layer concept has generated for many practical flows approximate but useful solutions which arise from drastic simplifications of the full Navier-Stokes equations governing fluid motion.

Apart from the difficulties posed by the presence of viscosity, other complications can also arise (in Fluid Mechanics) from factors like compressibility, which is a measure of the bulk modulus of elasticity of the fluid; non-Newtonian behaviour, due to a complex fluid rheology; rarefied gas dynamics, which appears when the continuum assumption breaks down; magnetofluid-dynamics due to an electrically conducting fluid; superfluidity at cryogenic temperatures; and periodic oscillation of the flow.

In terms of difficulty, all of these complications pale into insignificance when compared with the extreme complexity that presents itself when a flow undergoes transition from *laminar* to *turbulent* state of motion. A flow is said to be laminar if it is smooth and well-ordered, and the resistance of the fluid to motion derives solely from momentum exchange processes occurring at the molecular level. Turbulent flow, by contrast, is an irregular, eddying motion in which flow variables like velocity and pressure are randomly varying functions of time and space. It is hardly a surprise therefore that, unlike laminar flow which is amenable to rigorous analysis, turbulent flow has so far defied a truly rational solution, in spite of 200 years of research effort and the fact that it is the more common type of flow encountered in technology as well as in nature. Turbulent flow has been so notoriously intractable that it is believed in some circles that a completely rational theory for it will never be found. Indeed, at a conference held in France in 1961, Theodore von Karman was reported to have said* that, when he should finally leave for the great beyond to meet his Creator face to face, the first point on which he would seek divine revelation would be the mystery of turbulence!

One of my specific contributions to fluid motion is a comprehensive study of three-dimensional, turbulent boundary layers along streamwise corners, formed by the intersection of plane or curved surfaces. The motivation for this work has been a desire to generate basic engineering data which would inform the design and operation of a very broad range of practical flow systems, such as those associated with wing-body junctions of aircraft; roots of rotor and stator blades of turbomachinery; pipelines, nozzles, diffusers, heat exchangers, nuclear reactors, and other engineering components and systems with noncircular ***polygonal*** flow passages.

In its simplest form, this corner flow problem compounds the difficulties due to viscosity with those of turbulence, three-dimensionality of mean motion, and geometric singularity at the corner. In my wholistic approach to the problem, use has been made of experimental, analytic, and synthetic tools. For a particular case of 90° unbounded corner, detailed exploration of the flow, with and without external pressure gradients, included measurements of the mean velocities, static pressures, wall shear stresses, and all the components of the Reynolds stress tensor. Determination of the Reynolds stresses necessitated my generalising to three dimensions of standard hotwire anemometry analysis

---

*Horace Lamb is often credited with a similar statement.

for flows with one- or two-dimensional mean motion. Guided by these measurements, I was able to formulate, for the corner region, analytical and empirical criteria for flow separation, empirical criteria for transition from laminar to turbulent flow, unified correlations for the velocity field, etc. Secondary flow of Prandtl's second kind was found to feature prominently in all measurements, and a general morphology of secondary flows of this kind was constructed from an intricate synthesis of empirical data for both bounded and unbounded corners.

3. THE LIFE OF TECHNOLOGY

The life of technology is the availability,conversion, and utilisation of energy. My reason for this assertion is simple.

Energy is the capacity for doing work, subject to a constraint imposed by the Second Law of Thermodynamics, to the effect that heat energy cannot be completely transformed into work. It follows immediately that in technology (and, indeed, in nature) no machine, device, system, or process can do any work whatsoever unless energy is available for its use.

3.1 Energy Resources

With the possible exception of tidal energy (which is the combination of the kinetic and gravitational potential energy of the earth-moon-sun system) and terrestrial energy (which is made up of geothermal energy, nuclear energy, and gravitational energy), all energy resources available to man derive ultimately from the sun.

The sun is a huge inferno of gaseous matter in which, among other reactions, hydrogen is being converted to helium by nuclear fusion, accompanied by loss of mass at the rate of 4.3×10^9 kg/s and prodigious energy release of 3.86×10^{26} J per second that is radiated into space. The earth intercepts a little less than half-a-billionth (1.74×10^{17} J per second) of the total energy released, and it is this terrestrial solar energy income which is partly expended to drive our climate and weather, all biological processes such as photosynthesis, and all ecological cycles involving chemical elements like carbon, nitrogen, sulphur, and phosphorus.

In technology, energy resources may be classified as renewable or nonrenewable. A renewable energy resource is an energy resource which is replenished almost as fast as it is used. But a nonrenewable energy resource is an expendable stored energy resource. Examples of nonrenewable energy resources are nuclear fuels such as uranium, thorium, deuterium and lithium and fossil fuels like coal, liquid petroleum (oil), natural gas, oil shale, tar sand, and peat.

Nonrenewable energy resources are generally attractive from the points of view of energy concentration, extraction, transportation, storage, and handling; and, fortunately, Nigeria is abundantly blessed with these resources. We currently have about 367 million tonnes of proven coal reserves and 980 million tonnes of inferred resources, 2.5 trillion cubic metres of proven natural gas reserves and 16 trillion cubic metres of inferred resources, 16.8 billion barrels of crude oil reserves, large deposits of uranium, oil shale, and tar sand. But because these energy resources are not being replenished as they are removed, it is doubtful if much would remain by the end of next century. Therefore, it would be economically prudent, if not politically expedient, for Nigeria to *now* limit the *rate* of depletion of its nonrenewable energy resources, while intensifying efforts to fully develop renewable energy resources like geothermal energy, direct solar energy in the form of beam (direct) and scattered (diffuse) solar radiation, and indirect solar energy which is manifested by the energy in the wind, wave, biomass (fuelwood, etc.), flowing or falling water, ocean thermal gradients, etc.

My research work in energy technology has leaned heavily towards the renewable energy options, with special emphasis on direct solar energy, wind energy, and water energy. I have devoted considerable time and (appropriately) energy to an on-going comprehensive energy-resource assessment for Nigeria and Ile - Ife in particular.

On account of its good fortune, location (in the sunny tropics), and physical geography, Nigeria is found to possess a massive resource base in terms of renewable energy. Geothermal energy sources like the Ikogosı warm spings (in Ondo State) abound in this country. Annual amount of bright sunshine, which can be simply correlated with solar radiation, ranges from about 1,500 hours for a southern location like Port-Harcourt to about 3,200 hours for a northern station such as Sokoto. Strong winds are prevalent in the coastal areas (like Badagry, Lagos, Epe, Warri, Port-Harcourt, Opobo, and Calabar) of the south, in the highlands of Plateau State, and in the open grassland of the north. The continent of Africa has over 40% of the water energy resource of the entire world; understandably, Nigeria alone has a water energy resource greater than those of several European countries (for example, Britain, France, Germany, and Austria) put together.

As for Ile-Ife, I have for many years been monitoring on a *daily* basis the total solar radiation and wind speed at the University Campus, using a bimetallic actinograph (mechanical pyranometer) and a cup-counter anemometer respectively. Although a very detailed study of the vast amount of data collected is still in progress, a preliminary analysis has revealed substantial energy resources for Ile-Ife. The intensity of solar radiation, for example, has been found to be as high a 1.147 KW/m^2, which is about 85% of the solar constant (1.353 KW/m^2) and must be close to the maximum possible value attainable anywhere on the earth.

3.2 Energy Conversion and Utilisation

Ordinarily, energy can neither be created nor destroyed, but it certainly can be converted from one form to another to fulfil needs such as heating, cooling, illumination, refrigeration, transportation, and industrial drive, using machines like prime movers, generators, and motors.

Over the last thirty years, the total installed generating capacity of the electric power stations connected to our national grid has risen, in steps, from about 94 MW to more than 4,600 MW. But in terms of actual electricity generation and consumption, particularly consumption, the generating capacity has been grossly under-utilised. When this is coupled with out bulging population and the electrical energy starvation of the rural areas where most of our people live, the result is that, today, Nigeria has one of the lowest per capita consumption of electrical energy in the world; even West African countries like Guinea, Ivory Coast, and LIberia are doing much better. The full import of this statement can be appreciated when one recognises that per capita consumption of energy is strongly correlated with a nation's Gross National Product (GNP) and its living standards.

Contrary to popular opinion, our energy problem does not begin and end with the beleaguered National Electric Power Authority (NEPA). What we chiefly need to do is to painstakingly evolve and execute a foresightful, all-embracing, national energy policy which, among other things, would catalogue and integrate all our renewable and non-renewable, commercial and noncommercial energy options, emphasise energy conversion technologies that are not only cost-effective but are also environmentally benign, and strike a happy balance between centralised and decentralised energy systems in which men and machines operate optimally.

My research investigations in renewable energy conversion and utilisation have principally sought, through the use of direct and indirect solar energy, to drastically raise the level of energy consumption in our rural areas. These areas have depended on fuelwood as their major energy resource, the consumption of which on a very large scale can lead, and has in fact led in some places, to serious ecological problems of deforestation, soil erosion, and desertification.

The rural energy needs have led to my involvement in the analysis, design, construction, and testing of a number of solar energy devices and wind machines, among which are solar crop dryers, solar water heaters, solar stoves, solar distillation plants, solar pump, and a variety of wind turbines for the production of mechanical shaft power and electricity. Some of these solar energy devices and wind machines still require further research and development efforts for their design optimisation, but some have been advanced to a stage at which they can be profitably commercialised by entrepreneurs. This brings me to the third and final major leg of this lecture, — the soul of technology.

4. THE SOUL OF TECHNOLOGY

The soul of anything is the almost undefinable entity which gives it vitality, freshness, and essence. The soul of technology is industrial production for the provision of basic goods and services.

The technological underdevelopment and economic misfortunes of this country are closely tied to its intolerably low level of industrial production. Instead of concentrating on local production, Nigeria has for many years been importing just about everything and anything, and our import statistics bear eloquent testimony to this. For example, from October 1960, when we gained Independence, to December 1975, Nigeria imported some 575,000 motor-vehicles, 2¼ million cycles, 8 million metric tons of cement, 254 million bags and sacks, 13 billion litres of petroleum oils (aviation spirit, motor spirit, kerosene, fuel oil, diesel oil, and lubricating oil), among countless other items.

Machinery and transport equipment have always dominated our imports, and from October 1960 to September 1987, they gulped some ₦42 billion* and accounted for about 40% of total imports for that period. Machinery and transport equipment lie at the core of mechanical engineering, and industrial production is impossible without them.

*No account has been taken of the generally declining value of the naira over this period.

Unquestionably, our flat-footed economy would acquire considerable momentum if we could manufacture locally and cheaply a huge chunk of the machinery and transport equipment that we now import. Here then is the challenge that stares us in the face, and mechanical engineering can and should play a leading part in meeting this challenge, although our academia, industry, government, and the society at large also have important roles to play.

The English word 'engineer' came into use during the Middle Ages and can be traced to the Franco-German title *'ingenieur'*, which is a derivative of the Latin noun *'ingenium'*, meaning ingenuity or skill in inventing or contriving. This explains why good engineering programmes emphasise not only the acquisition by students of the powerful tools of analysis but also the creative synthesis of ideas for design and production. Considering the present national problem of gainful employment for engineering graduates and the relatedness of invention, innovation, entrepreneurship, and industrial productivity. it would seem highly desirable that our academia should find space in its admittedly crowded engineering curricula for courses on invention, innovation, and technological entrepreneurship. Such courses should induce widespread formation of technology-based businesses and the movement of technology into the market-place. A course on invention, for example, might include topics like case histories of invention, use of analogy and 'bisociation', symmetry and asymmetry, visualisation of complex engineering products and processes in three-dimensional space, and nature study.

A close study of nature (including the biological aspects) by engineers can be quite revealing and rewarding. Weight for weight, bone is stronger than steel. The common bedbug can measure temperature to an accuracy of better than $\frac{1}{1000}$ °C. The data-processing ability of the brain is unmatched by any computer. The use of automation by the eye is unsurpassed by any camera; and the graceful aerodynamics of bird flight has never ceased to fascinate and inspire the aircraft industry. Incidentally, it was nature study that led me many years ago to the conception of a 'rain-turbine', which is a novel machine that extracts useful energy from the aerodynamics of raindrops near the ground.

Although our index of industrial production has increased more than tenfold over the last 25 years, the contributions of Nigeria's industrial sector still account for less than 10% of the Gross Domestic Product. Lack of investment capital, raw materials crunch, and other constraints notwithstanding, the industrial sector has clearly not performed as well as it should. Our industries, in my view, could do with some infusion of the Japanese (people-centred) style of industrial management which is geared, not to immediate profitability, but to long-term company growth, increased market share, bold entrepreneurship, continual product improvement, optimum use of scientific information, and huge investments in Research and Development (R & D). This management approach, combined with a bit of serendipity, would drastically improve the performance of our industries and result in the commercialisation of some of the research results wasting away in our universities and research institutes.

The social stigma of inferiority usually attached to 'Made-in-Nigeria' goods will not vanish until such goods religiously satisfy the requirements of functionality and are also found to be aesthetically appealing, reflecting our national predilections for size, form, and colour. Of course, nothing venture, nothing have; and, according to Thomas Edison, the quintessential innovator, "Genius is 1% inspiration and 99% perspiration".

A primary contribution of government towards industrial production is the provision of a solid industrial infrastructure in terms of transportation, energy, water, and communications. Heavy industries for the manufacture of iron and steel products, petrochemicals, and the like, constitute the industrial base of any nation. Their establishment is usually also the responsibility of government because of their capital-intensiveness, and the Nigerian situation is no exception.

Although Nigeria's iron & steel and the petrochemical industries have both commenced commercial production of some basic industrial inputs, our dreams of a sound industrial economy are still very far from being realised. The pace of development of the steel industry, for example, is painfully slow and urgently needs to be quickened by the government. Our hope is anchored to this industry for the production of a long list of items, including flat steel, which is required for the manufacture of motor-vehicle bodies and a host of other goods. Until this steel industry is fully functional, we shall continue to merely assemble the products manufactured elsewhere and at costs that would translate into local consumer prices which are outrageously unaffordable. Nigeria, no doubt, has partially acquired through assembly plants, some downstream technologies like operation and maintenance, but assembly *per se* is no substitute for full production.

After more than 27 years of Independence, we should be close to, if not already, manufacturing, with 100% local content, our bicycles, motor-cycles, motor-vehicles, refrigerators, air-conditioners, and some other durable consumer goods; and we hve the experiences and the following track records of countries like Japan, South Korea, Brazil, and India, to learn from:

(i) Japan

When the Second World War ended in 1945, Japanese industries were in ruins. Today, substantially because of the heavy contributions of machinery and transport equipment, the industrial production of Japan accounts for roughly 10% of the world's total output and is more than ten times the industrial output of the entire continent of Africa.

(ii) South Korea

In 1945 when the Korean penisula was split into north and south, most of the industries of the divided country were located in the north. However, in 1961, South Korea began a vigorous industrialisation process; and, today, it has one of the most powerful economies in the developing world and some of the most internationally competitive industries, particularly in the areas of motor-vehicles, ships, computers, chemicals, and steel.

(iii) **Brazil**

Brazil is made famous industrially not only by the fact that it has the largest hydroelectric complex in the world but also by the fact that about 80% of its locally produced motor-cars run on 'gasohol', which is a mixture of gasoline (petrol) and alcohol (derived from biomass sources), rather than gasoline (petrol).

In 1970, Brazil did not produce any aircraft but it is today the world's sixth largest producer.

(iv) **India**

At the time of Independence in 1947, India scarcely produced anything more complicated that jute bags. But in less than 40 years, it had learnt to locally manufacture almost everything, including motor-vehicles, ships, aircraft, nuclear power plants, and even satellites.

At the federal, state, and local levels, our government should establish with industry and academia, the type of fine working relationship that exists between these three segments of society in many industrialised countries today. Such close relationships can be forged through many channels, especially through government policies. The government should not merely seek to protect the local industry but should also take it into confidence. In addition, ample financial support should be provided for industry-oriented R & D activities in our universities and research institutes.

Technology is often said to be a factor of social change. But the dynamics of this change should not be the concern of social scientists alone. Engineers, like other professionals in a society, should be acutely aware of the social consequences of their actions. The society, in return, should create a socio-cultural environment in which the engineer can function and technology can flourish through industrial production. In creating this environment, at least two issues must be borne in mind. One is the evolution of a scientific culture in which the inspired guess of yesterday can quickly become the science of today and the technology of tomorrow. The other is the appreciation of hard work and the promotion of excellence in *all* walks of life; and, on this last point, I cannot agree more with John W. Gardner (1961) when he said:

> "The society which scorns excellence in plumbing because plumbing is a humble activity, and tolerates shoddiness in philosophy because it is an exalted activity, will have neither good plumbing nor good philosophy. Neither its pipes nor its theories will hold water."

5. EPILOGUE

I have attempted in this lecture to expound some of the kernels of technology and some of my contributions to their intricacies. I have sought to demonstrate that the heart of technology is mechanical engineering; its life is the availability, conversion, and utilisation of energy; and its soul is industrial production for the provision of basic goods and services.

I have argued that mechanical engineering is the heart of technology, because it is central to all of technology. It underlies most types of machinery and tools and every mode and form of transportation. It is a cornerstone of energy systems, and the bedrock of environmental control installations. It is the prime mover of manufacturing processes for industrial production. Et cetera, et cetera.

We do not have to re-invent the wheel. But our wheel of technological progress as a nation should be kept in perpetual motion, which can be sustained by a political will to succeed, the drive of our industrialists, the scholarship of our academics, the ingenuity of a few, and the energy of the masses.