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VOL. 72, NO. 3 MEMBER ECMA 35 CENTS DECEMBER 1967

wisconsin engineer

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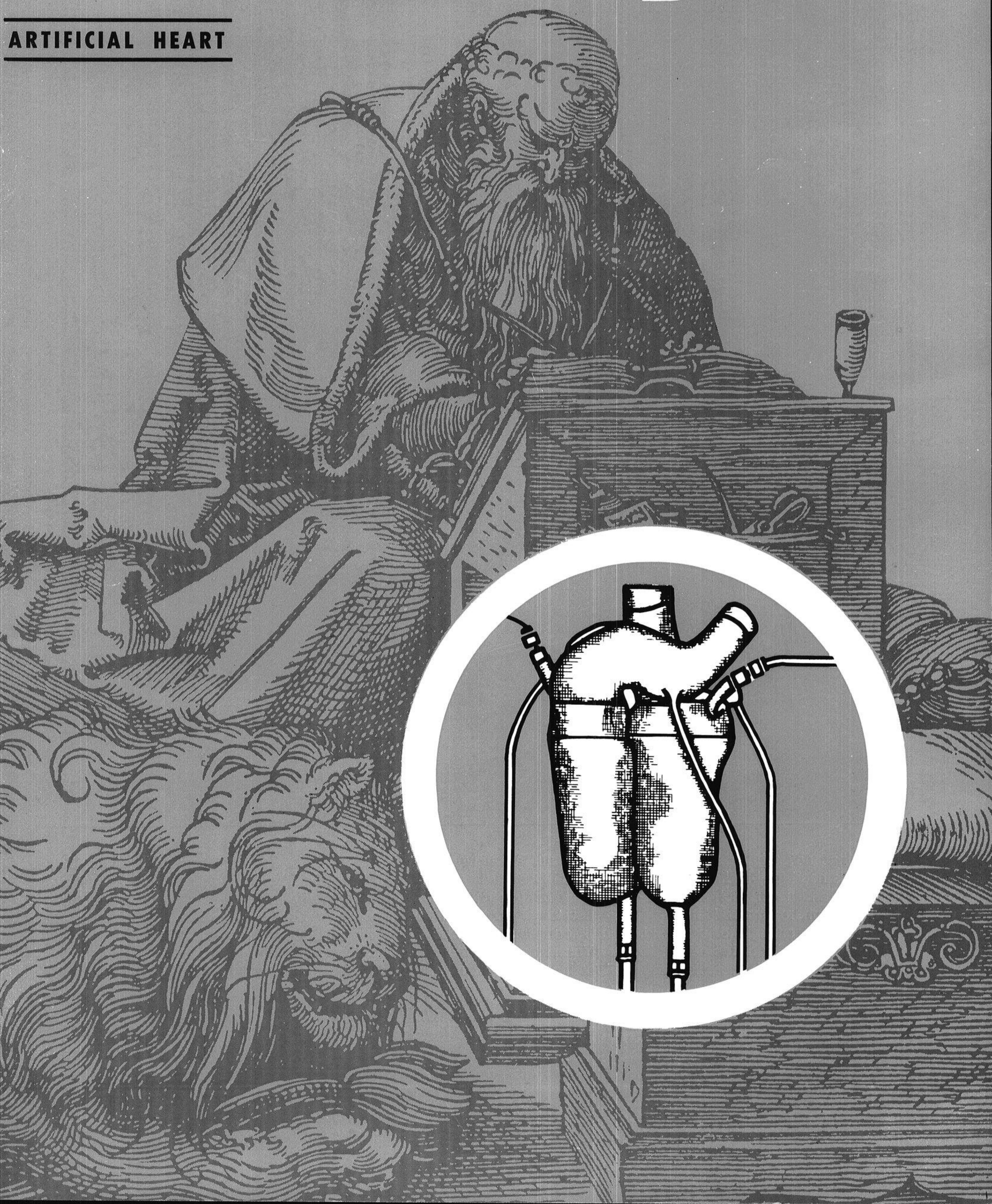

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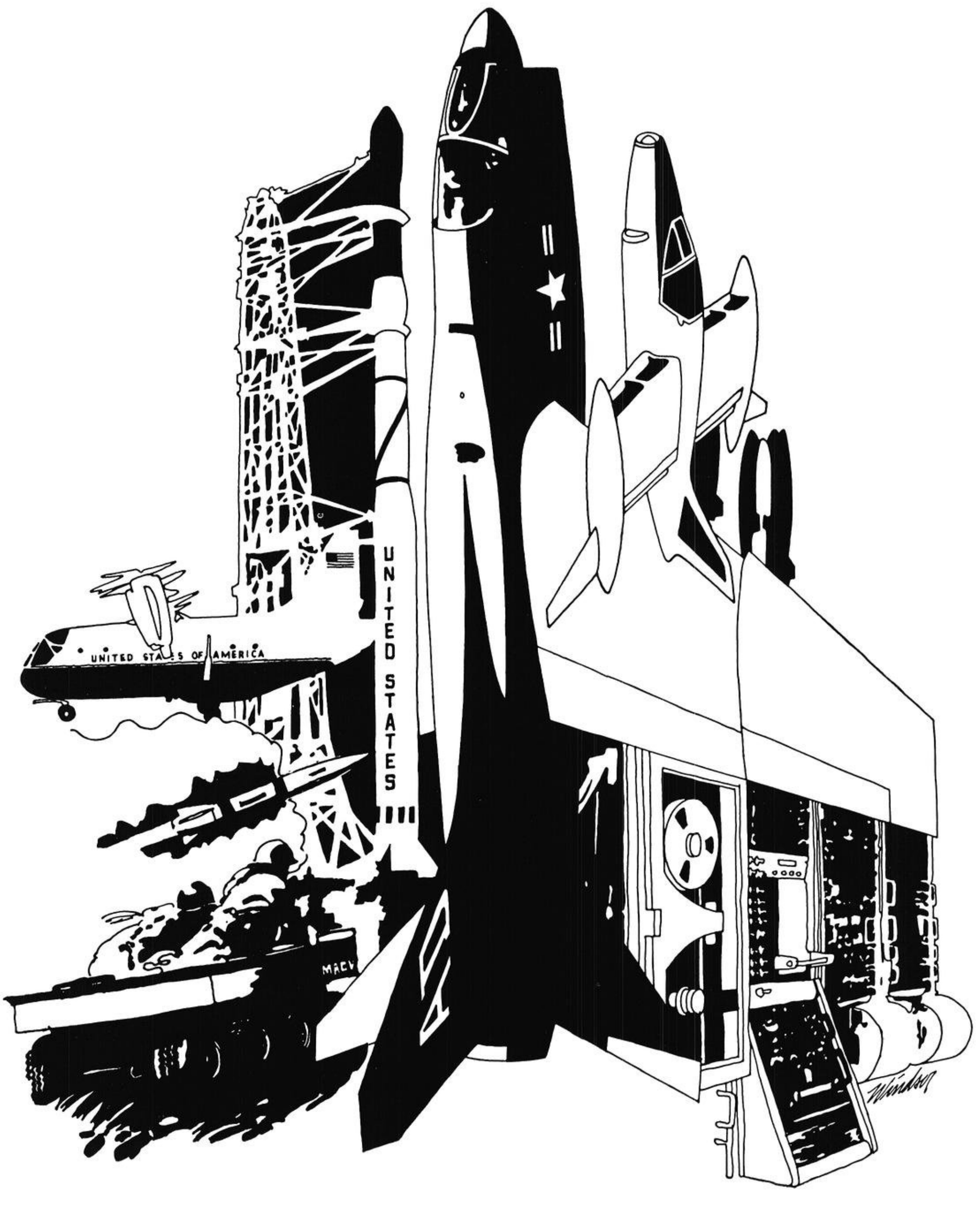

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EDITORIAL

Reflection

It isn't often that we pause in our rush to edit, study, paste-up, etc. and reflect that our magazine wouldn't be here without you and many, many other wonderful people. To our advisors, business associates, and readers a sincere thank-you for your kindness and interest and Season's Greetings from all the staff of the Wisconsin Engineer.

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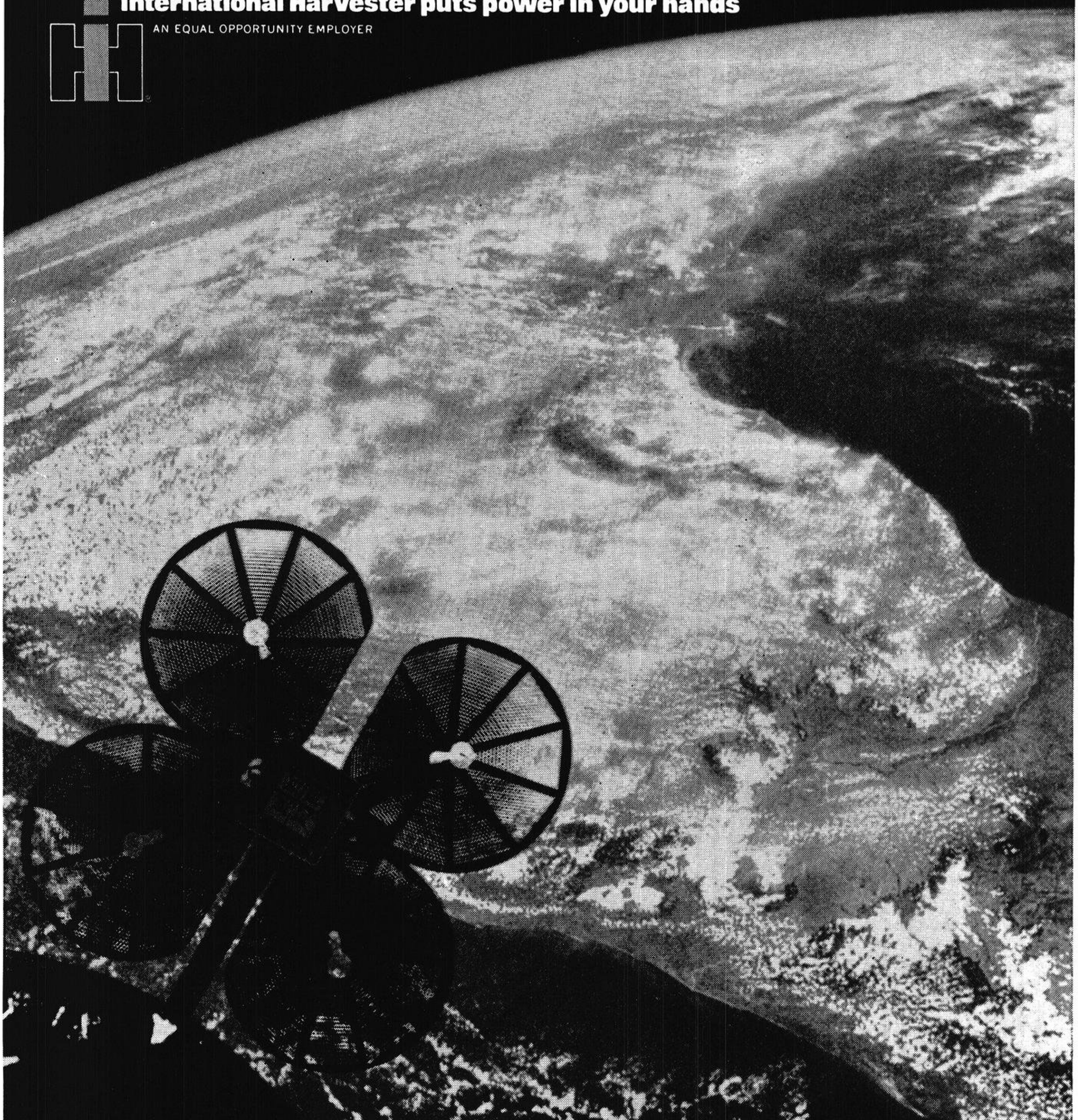

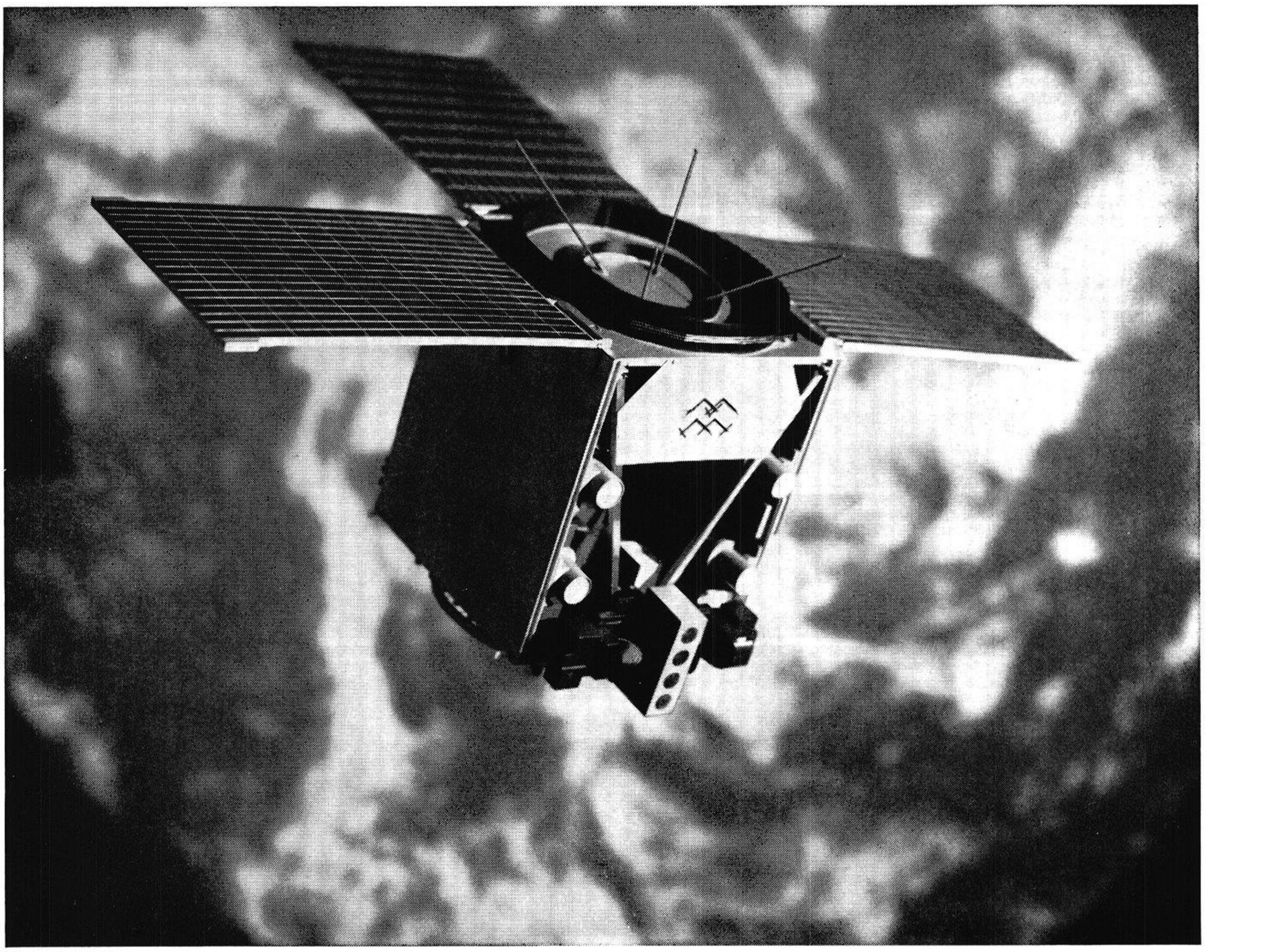

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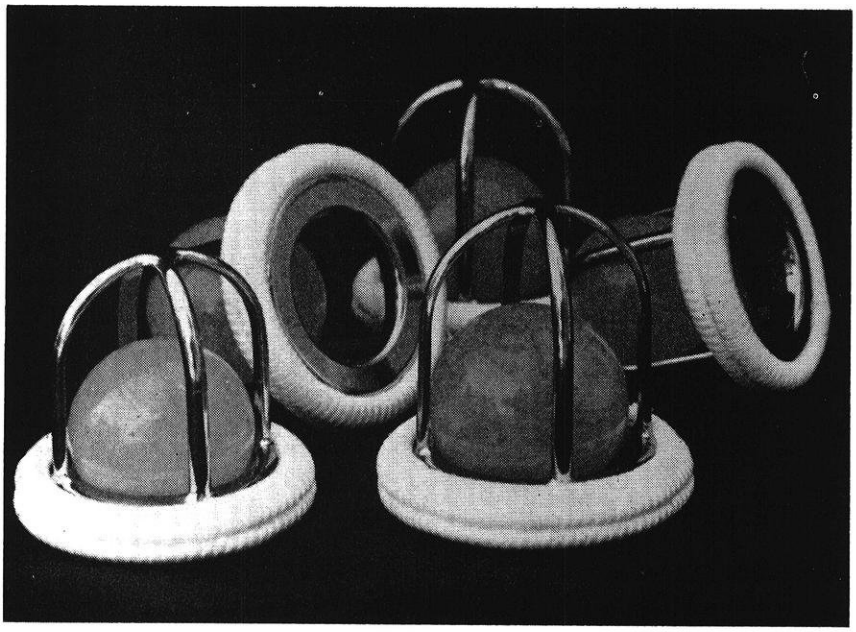


introducing bioengineering

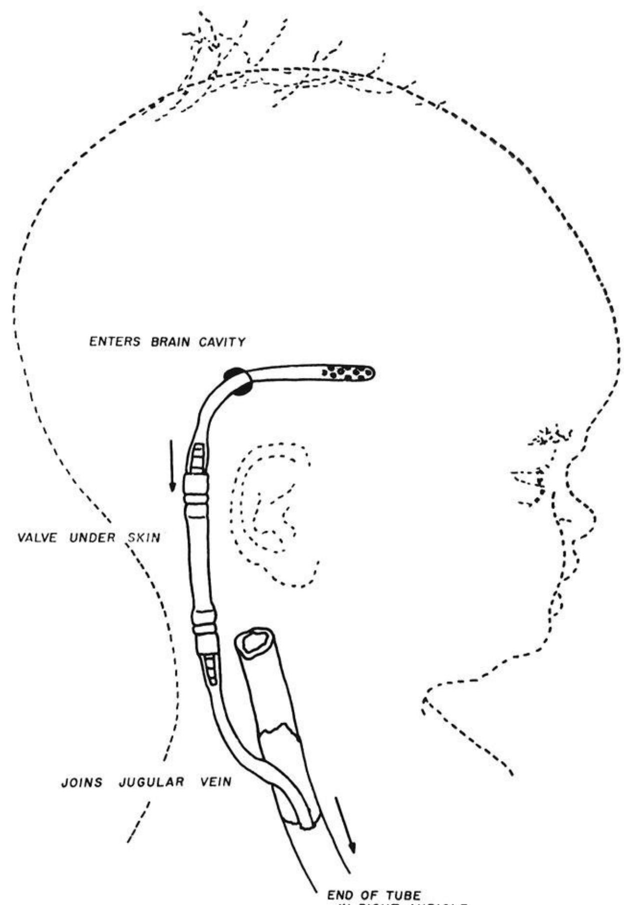
by Abby Trueblood

BIOENGINEERING is a new field in which the techniques of engineering are applied to the world of medicine. Man has tried for centuries to repair the human body, largely without success. Characters with hooks for hands and wooden limbs are found throughout literature. Often these attempts to replace missing limbs were successful, but the invasion of the tissues was, at that time, impossible. Intrusion into the abdominal cavity almost always killed the patient. This problem of the replacement of internal organs has hampered medical research and today forms the core of the area of study known as Biological Engineering, or Bioengineering.

The application of engineering techniques to medical problems has, until recently, been largely unknown. The two sciences have developed along two different lines, with the gap between them being mainly one of lack of communication. Today it is recognized that to bridge this gap people who have knowledge in both fields are needed. The acknowledgement of this fact has, in effect, led to the development of the field of Bioengineering.

As the research broadens in this area the demand for trained bioengineers will naturally increase. Already this demand is beginning to be met in some universities by the introduction of new courses in this area of study. The University of Wisconsin is one of those schools that has become aware of the pressing need for such carefully trained specialists.

The study of bioengineering combines the mathematical skills, knowledge of the physical sciences and engineering, with the analytical abilities of the engineer and the knowledge of the biological sys-



tems. This specified training enables the scientist to focus upon the solution of engineering problems associated with living systems.

Biological systems are complex and constantly in motion, and the engineer must learn to adapt his knowledge to these differing conditions. A bioengineer can train in either engineering or in a life science and learn to apply his learning in the other direction. As the field becomes more popular more and more students will be offered programs which combine the two disciplines.

The bioengineer is presently mining uranium ore with living micro organisms, he is searching for the secret of generating electrical energy from biological sources, and he is translating his knowledge of the guidance and control of the bat, the sea lion, and the moth into physical control systems for man-machine combinations.

However, by far the most fascinating and dramatic area of biological engineering is that of its application to the human body. The dream of early man to be able to repair his own body, both externally and internally, is beginning to become a reality. Efforts in this area have been long in evolving, but today there can be seen the fruits of this labor in the development of a growing number of artificial implants. There is still much to be done along these lines, but what has already been done deserves some examination.

The greatest advances in this field have been in the areas of diagnostic techniques and therapeutics. Problems have plagued the bioengineer; the largest being that of connecting foreign materials to the body. The question is not to be able to make the artificial organ but to be able to make it acceptable to the body and workable once it has been placed.

The human body protects itself from foreign intrusions by a number of physiological reactions to most materials. It has become necessary, therefore, to find materials that the body "ignores". There cannot be destruction of the blood cells, attack by the implant, or attack on the implant by the body tissues. External devices were developed successfully, largely because anti-clotting drugs had been discovered. This meant that the blood could be removed from the body, processed, and returned with no clotting within the apparatus and minimal damage to the blood cells.

Until recently the implanting of materials into the body had failed because of the tendency of the body to reject them. Some metals (certain stainless steels and chrome cobalt alloys) cause little tissue reaction but, because they are hard and rigid, they are not very useful.

Body erosion is caused by the fact that the body is soft and transient. This means that metals can only be used where there is little body motion, such as when they are firmly attached to a bone. This, of course, greatly restricts their uses and makes large scale applications impossible.

The body also tends to reject materials that are organic in nature. Materials such as plastics and rubbers are closely related to the organic substances in the body, and this results in an almost immediate tissue defense and consequent rejection of the material. The problem of body erosion and rejection has been practically eliminated by the use of silicon for implants. Why the body will accept these certain medical grade silicons for implants is not clearly understood, but scientists have willingly admitted their ignorance of this point to be able to take advantage of their discovery.

Silicones are not naturally occurring and must, therefore, be made by the chemist. They are formed by attaching organic groups to a chain of silicon and oxygen atoms. Because of its chemical makeup silicons have the inertness of quartz and the plastic qualities of fabrication. Silicons vary from liquids to rubbery solids to resins. The resins have little medical application, but both the fluid and the solid are well suited for medical purposes. There are four primary reasons for the continuing development of silicons for medical uses; 1. heat stability, 2. no deterioration with time, 3. no adherence, and 4. lack of tissue reactions. Heat stability is important because it means that the material can be sterilized and can be subjected to changing temperatures without be-coming either brittle or soft. Tests show that silicon implants appear not to be altered by time. This is unlike some polyurethanes which have been used in heart valves.

Because nothing will stick to silicon except other silicons, they can be used for efficient drains and for adhesion preventions. An artificial stroma can be used if adherence to body tissue is desired.

The importance of the lack of body reaction has already been noted. It should be kept in mind that the silicons to which these criteria apply are medical grade. Industrial grades of silicons are not considered safe for medical purposes.

The following is a partial list of some of the implant developments.

1. Holter Hydrocephalus Valve —(see fig.)—This is probably the most extensively used silicon implant in the human body. The implanted tube serves to drain excess fluid from the brain into the heart. The implantation is entirely subdermal, with one end placed in the brain and the tube running behind the ear into the throat (into the jugular vein) and continuing into the right auricle of the heart, where the fluid is discharged.

2. Pacemakers—These are implants which artificially stimulate the heartbeat. One adaptation is radio-operated, with the receiver implanted in the chest.

3. silicon rubber bands for the repair of blindness due to detached retina

4. bones of the skull have been replaced by stainless steel, chrome-cobalt alloys, Teflon and silicons

5. soft tissues of the face have been subdernally exchanged with silicons.

6. artificial blood vessels of Dacron or Teflon have been used to replace clogged or swollen arteries

7. heart valves—These are currently being developed, with the most popular being the Starr–Edwards ball-check valve. (see fig.). The Gott valve is one that was developed at the University of Wisconsin when Dr. Gott was here.

There are also six plastic surgeons and one dermatologist in this country who are licensed to use liquid silicons in their work. They may use it in almost any way other than for the purposes of enlarging a woman's bust. Women who desire the infamous silicon "treatment" must journey abroad to be helped.

By far the most dramatic use of silicons in medical implants has been in the area of the human heart, with hope existing that one day an entire artificial heart will be operated successfully.

The field of Bio-Medical Engineering is a young and exciting one. Its successes have been marred by failures but brightened by further successes in areas that man never dreamed he could conquer. A field as vital as this one is to human life should be carefully considered as a prospective field for young engineers. To be in the vanguard of this growing science would be a truly rewarding prospect.

How Union Carbide started a boom in Minnesota.

70 years ago, Minnesota's Mesabi Range was like a loaf of raisin bread. The raisins were pockets of rich, soft iron ore. The bread was a hard, low-grade iron ore, called taconite. It was a big loaf, about 110 miles long, three miles wide and 500 feet deep. So for fifty years, nobody bothered with the bread. They just dug out the raisins.

But 20 years ago, the raisins started to run out. And the miners were in trouble. Taconite is about 30 percent iron, so there was still enough iron in the loaf to last America's steel industry for at least 200 years. But you had to drill it and blast it—and taconite is harder than most steels, which made drilling almost impossible.

So Union Carbide invented the jet-piercer. Instead of a drill, it has a 4,000-degree flame. It heats the rock so fast it cracks away in small pieces that are blown clear. With a jet-piercer, you can make holes in taconite at up to 50 feet an hour. Then you can blast. And you've got a whole new industry on your hands.

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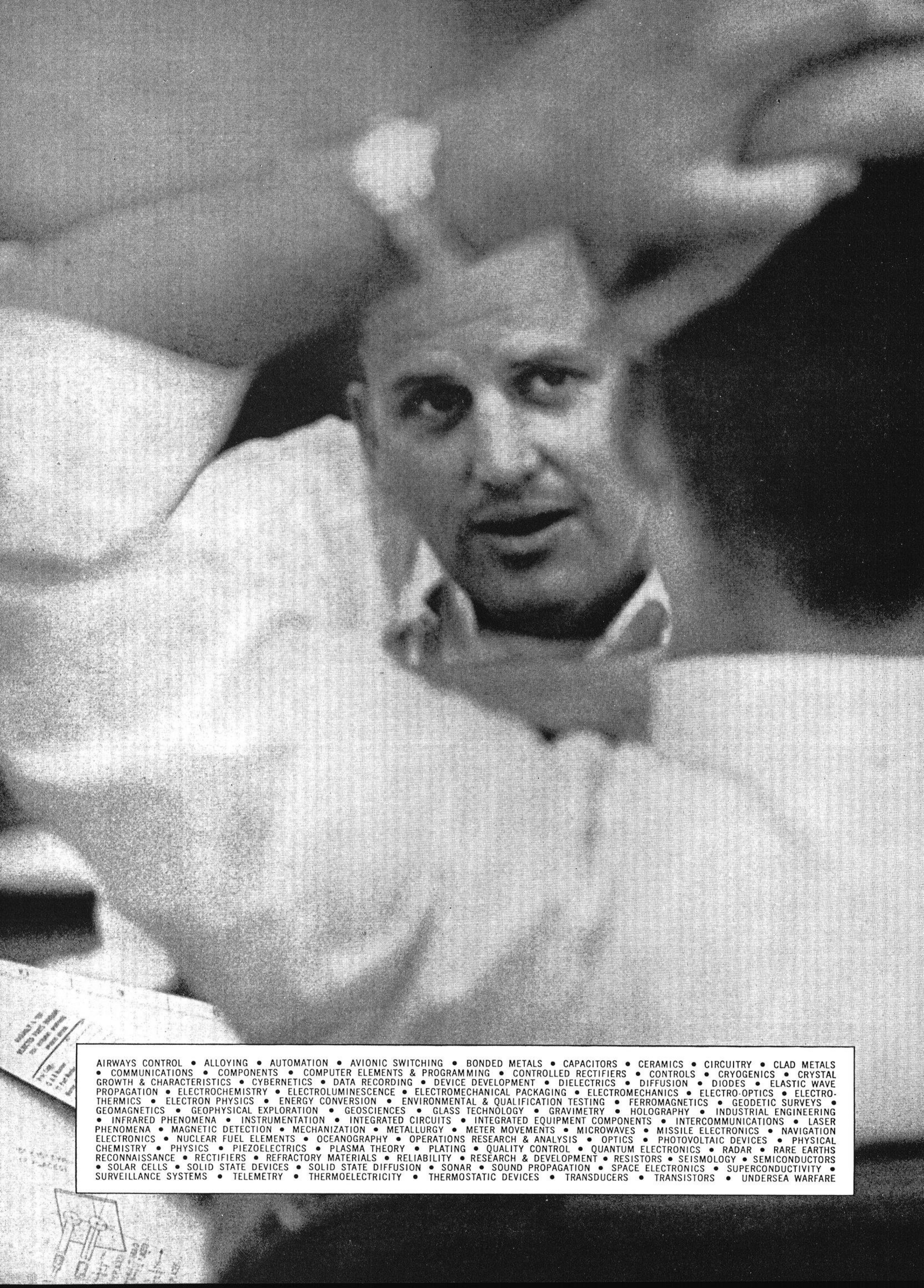

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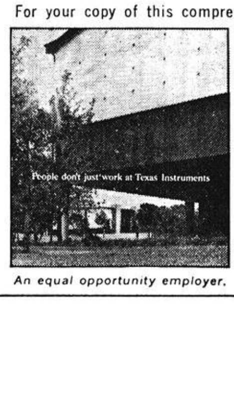

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the heart as a thermodynamic engine

by Jim Steinbeck

DURING the last 30 years the application of the experimental method has gained considerable insight into the manner in which the heart is able to carry out its duties. For instance, much has been learned regarding the automatic activity of the heart. We know the starting point of the excitatory process which is responsible for each beat, and we can trace the course of this process, in the form of a wave, throughout the parts of the heart. We can minutely study the pressure changes in the various cavities at each phase of the heart's cycle, and we know the action of the valves and the precise moment at which their closure is effected. We know the heart is controlled by the central nervous system, and that it, in turn, can send up messages of its own which will affect the condition of the blood vessels in other parts of the body.

To many cardiologists, however, the most remarkable and the most vital characteristics of the heart is its power of adaptation, of altering its activity, i.e. the amount of work it performs, according to the requirements of the body as a whole. It is the purpose of this report to analyze the mechanics of this adaptive ability, that is to say, the mechanical process by which work is done, to calculate this work, to calculate the total amount of energy required, and from these values to arrive at a figure denoting the efficiency of the heart's performance.

THE HEART AS A THERMODYNAMIC ENGINE

To an engineer a man's body is a machine, or rather a factory full of machines, all working harmoniously together for the good of the whole. Each "machine" is necessary to and dependent on all the others. All have to be supplied with fuel, in the form of food, in order to perform their functions. Moreover, since the energy of the machine is derived from the oxidation of foodstuffs, just as it is derived in a steam engine from the oxidation of coal, each has to be supplied by special mechanisms utilizing oxygen taken in from the air. The fact that they are immersed in the body fluids renders it necessary that the oxygen be supplied in a state of solution. All muscles, of which the heart is one, have to obtain their foodstuffs in the shape of carbohydrate, fat, or protein from the alimentary canal, and the oxygen for the consumption of these foodstuffs has to come from the lungs. The waste products must be removed and carried to the lungs or kidneys where they are finally eliminated from the body.

A great transport department is therefore necessary for the proper working of the body. The medium of this transport is the blood, which circulates by means of fine capillary blood vessels through all the organs of the body. This circulation is maintained by the heart, which acts as a pump, pumping the blood from the arteries into the veins. In the arteries the blood is distributed either to the lungs to pick up oxygen and to get rid of carbonic acid gas, or to all the working tissues of the body which it supplies with oxygen and fuel, taking away waste products in exchange. From the tissues or lungs mp - **Thump** - Thump - **Thump** - Thump - **Thump** - Thump - **Thump** - Thump - **Th**

it is returned to the veins and to the heart.

It is apparent that the demands made on this transport department must vary considerably in accordance with the activity of the body. During hard, muscular work the consumption of oxygen and fuel may be increased eight times above that required by the body at rest. This increase is rendered possible by a corresponding increase of the blood flow through the tissues. Under all conditions a considerable head of pressure, (which is raised during active work) is maintained in the blood on the arterial side of the circulation. It is the perpetual duty of the heart to pump blood from the veins into the arteries against this head of pressure, thus maintaining a level of flow which is dictated by the metabolic needs of the body.

THE CIRCULATION SYSTEM

The blood is circulated by the action of two pumps forming the right and left sides of the heart, which forces blood into a closed system of vessels consisting of two sections arranged in series. The pulmonary system is fed by the right ventricle and serves to bring the blood into contact with the air in the lungs where it gains oxygen and gives up carbon dioxide. The vessels of the pulmonary circuit, as in any other part, consist of arteries, veins, and capillaries. The arteries and veins are connected by the tiny capillaries. It is in these capillaries that the actual mass transfers take place; it is here that the blood entering in the reduced state is enriched. Having passed through the lungs, the blood is then conducted back to the left atrium. In this way, all the blood is exposed to the air each time it completes the double circuit. The longer circulation of the second section is powered by the left ventricle and serves to carry the aerated blood to the various tissues of the body. An elaborate system of controls exists to divert this stream to the various tissues in accordance with their needs.

DESCRIPTION OF THE HEART

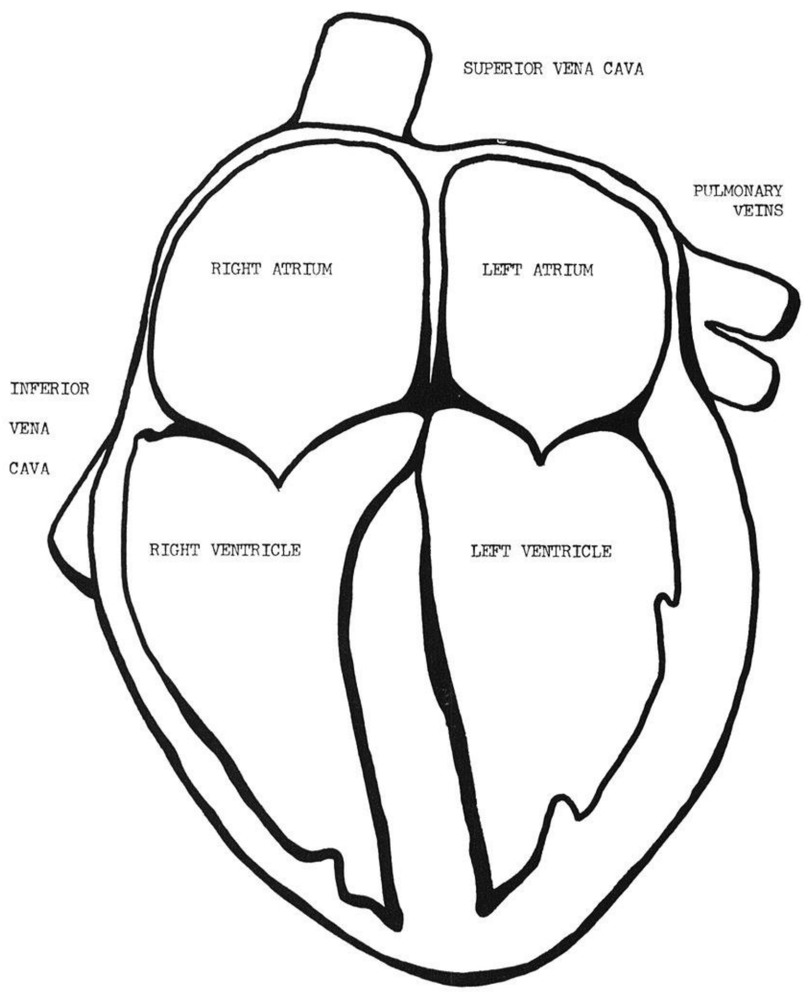
The human heart consists of two distinct pumps having a common wall, both of which are controlled by nerve impulses. Each of the two sides are in turn divided into two chambers. The chambers on the left side are the left atrium at the top and the left ventricle at the bottom. Similarly, on the right side there is also a right atrium and a right ventricle. The purpose of these pumps is to maintain a continuous flow of blood within the body through the circulatory system. The right side of the heart receives the blood returning from the body and sends it through the pulmonary system to the lungs to be rejuvenated with oxygen. The left side receives the flow from the lungs and sends it on its long journey through the body.

Just like any other muscle, the heart is also nourished by oxygenated blood. It is, however, entirely too thick to receive an adequate supply by diffusion of the blood within its chambers. Consequently, the heart has blood vessels of its own present within its walls. These vessels are the coronary arteries arising from the aorta and are distributed throughout the ventricles and the atrium. The arteries taper off into capillaries which are, in turn, drained by the veins. The venous blood completes the circuit by emptying into the right atrium along with all other venous blood.

DESCR:PT:ON OF THE VALVES

As with any other pump, the heart must maintain its efficiency through a system of valves. There are four valves within the heart uniquely designed to permit the blood to flow in one direction only. Those guarding the orifice between the atrium and the ventricle open into the ventricle, thus assuring that, within the heart, the blood moves downward from auricle to ventricle. The valve will close at the beginning of ventricular contraction and remained closed until the end of the relaxation period, thereby preventing the blood from being driven backwards into the atrium. Once the ejection period begins, the valves guarding the openings to the pulmonary and aortic arteries open outward so that the blood may begin its journey. Later, when the intra-ventricular pressure falls, they will close in order to prevent the pressure in the arteries from driving the blood back into the ventricles.

The opening and closing of the heart valves is not caused by any motion originating in themselves, but is operated solely by blood flow and pressure differences. When the auricular pressure comes to an end, eddy currents within the ventricle bring the leaflets of these A-V (Auriculo-Ventricular) valves gently into position. The pressure created thereafter by ventricular contraction closes them firmly. The operation of the aortic and pulmonary valves is also controlled in this fashion.



Cutaway of the Heart

DESCRIPTION OF THE HEART MUSCLE

The tissue of which the heart is built is entirely unique in that it is not found anywhere else in the body. It is both strong and flexible and is capable of storing great reserves of energy. Its uniqueness lies in the fact that, unlike all other muscle, the heart must function continuously without rest for as long as there is life. In the average male the heart cycle is completed 70 times every minute or about three billion times in a lifetime of 73 years. No other prime mover is as reliable as cardiac-muscle over such a long span of time. Furthermore, it is interesting to note that the heart has been designed to ignore any distracting stimuli which could intefere in the performance of its duties. Once the fibers of cardiac muscle begin to contract, the magnitude of the force of contraction cannot be altered by any additional stimulus. This is not to say that the strength of contraction cannot vary in time, but rather that no external stimuli can affect the continuity of given beat.

THE MECHANICS OF THE HEART'S OUTPUT

The heart is able to perform its duties through the highly coordinated action of its member parts. These parts are able to adjust to the varying needs of the body by utilizing the remarkable elastic qualities of cardiac fibers, the building blocks from which they are constructed.

THE CARDIAC CYCLE

The cardiac cycle is that sequence of events through which the heart passes every time it beats. The time required to complete an entire cycle is slightly less than one second. Beginning our discussion just as the period of ventricular contraction is completed, we note that the intraventricular pressure now falls below the auricular pressure and the mitral valve (A-V orifice) opens. The blood that has been collecting in the auricle as well as that coming from the lungs now enters the ventricle, which begins to fill as the pulmonary veins discharge, into the auricle. As soon as the intra-ventricular pressure rises, the mitral valve closes. At this point the ventricle begins to contract and the pressure within it rises rapidly. All of the valves remained closed, however, until the pressure is raised above that in the aorta artery, whereupon the semilunar valve (ventricular-aortic orifice) opens. When the ventricle contracts and ejects blood into the aorta, there is, by Newton's Law, a recoil reaction which forces the apex of the heart downward. This downward motion lengthens the auricles and increases their capacity, which in turn causes a fall in pressure which aids in their filling. Later, as the ejection of blood slackens, the recoil reaction weakens and the base of the heart moves up to its normal position. This motion plus the pulmonary floor again raises the auricular pressure. Furthermore, the ventricular pressure is low by this time so that the semilunar valve has closed. Consequently, when the intra-auricular pressure exceeds the pressure in the ventricle, the mitral valve will again open and the cycle will be complete. The same sequence of events occurs on the right side of the heart. Because, however, the pulmonary circuit is much shorter than the circuit through the body, the driving forces need not be as great and, as a result, the pressure involved are much smaller.

HOW THE HEART DOES WORK

It has already been mentioned that the well-nourished heart possesses great reserves of energy. During muscular exercises the the heart can eject without difficulty the greater quantity of blood needed. A robust man, whose heart weighs about two-thirds of a pound, can pump about 80 pounds of blood per minute during extreme exertion. The amazing mechanism by which the heart is able to perform such vast quantities of work is as follows: It has been found that the degree of stretch to which cardiac muscle is subjected is directly proportional to the contractive force. That is to say, the length of the muscle fibers before excitation determines the force of the ensuing contraction. When the heart grows tired, it is merely necessary to lengthen the fiber, i.e. to increase the filling of the heart in order to obtain the desired contractile force. This means that a tired heart must dilate in order to carry on its work. The most startling feature is that as the dilation causes the fibers to take up a new length at which they can fulfill their duties, the increase in work is manifested as an increase in pressure. But at the higher pressure there is a marked increase in the blood supply to the heart muscle. The improved nourishment of the muscle causes an improvement in its physiological condition, and this improvement shows itself by allowing the heart to become stronger even as it works. We therefore find that the primary dilation of the heart is followed by a slow recovery to normal size. The processes involved in this adaptation are analogous to the workings of a motor cycle. Here also the energy is derived from the oxidation of combustible substances, in this case gasoline and air. When once adjusted, the motor cycle will travel regularly without further interference on a flat surface. As soon as the road begins to mount, however, the engine begins to slow down and may stop altogether. To avoid this occurring, the rider lets in a greater mixture of gas and air, the chemical energy made available by each explosion is thereby increased, and the cycle mounts the hill at the same pace it had before on the level. In the heart there is an automatic arrangement by which, as to speak, more mixture is thrown in as soon as more work is required of it.

The heart, therefore, has the marvelous power of adjusting its output of mechanical energy. When more work is needed, the muscles stretch and more work is received. The weight which stretches the muscles prior to contraction is, of course, the mass or blood entering the ventricles. Thus, automatically, does the heart find the necessary energy to perform the extra work necessitated by strain. In this case, the heart simply does not empty itself completely during the first few beats. The residual blood is used to dilate the heart, i.e. lengthen the fibers. From then on the heart completely empties its chambers during contraction. Cardiac power is very much like a rubber band which rebounds more powerfully when it is fully stretched.

CALCULATING THE WORK OF THE HEART

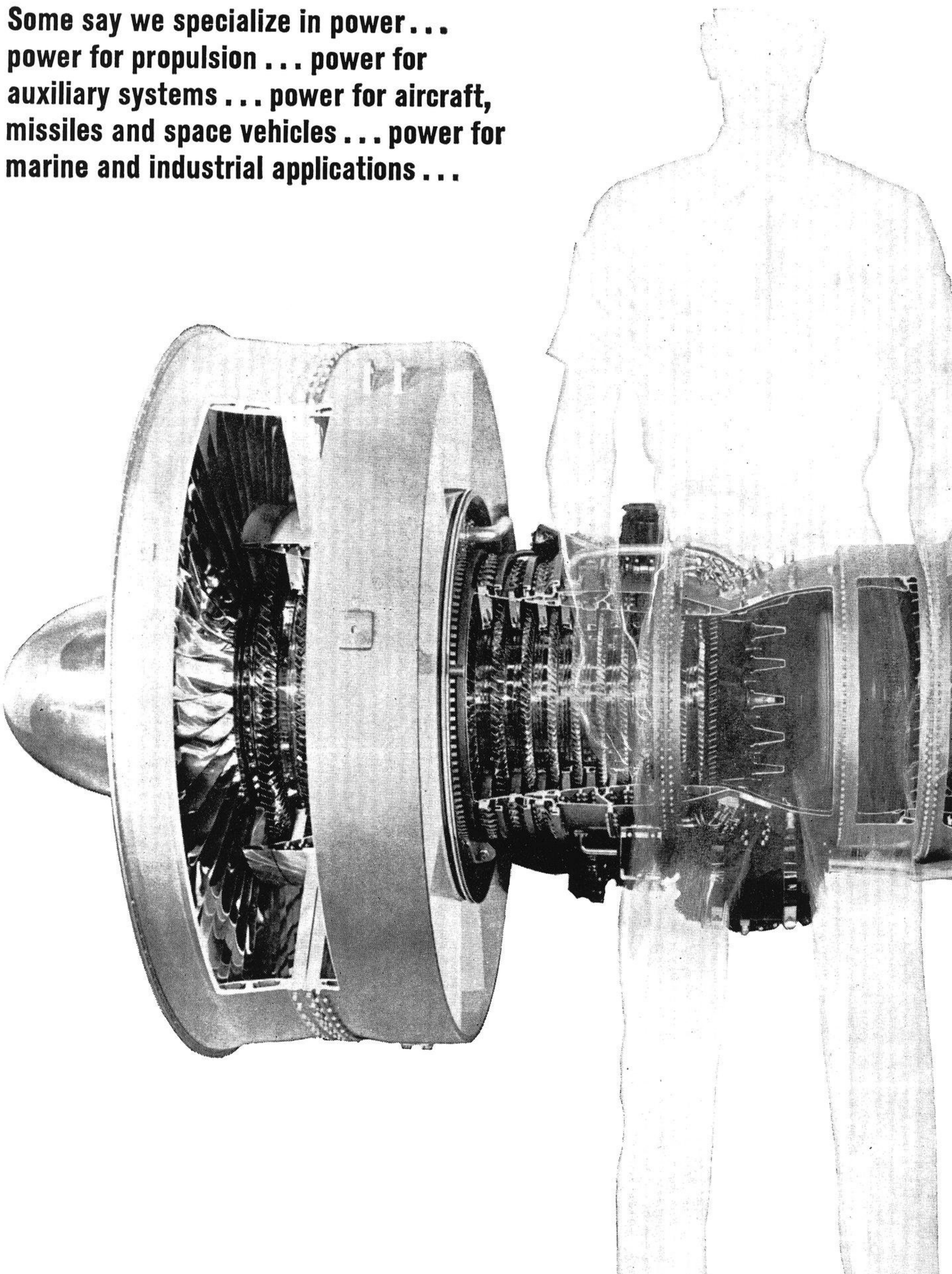
The work done by the heart in contraction is entirely expended by raising the pressure within its cavities and the available energy is entirely pressure energy. When the pressure rises the semilunar valve opens and the blood is thrust into the aorta through this nearly frictionless orifice. In the aorta most of the energy is used to raise the arterial pressure and force apart the walls of the vessel. The remainder of the work done is used to develop kinetic energy and thereby increase the velocity of the blood.

The changes in state which occur in the aorta of a resting man have been determined and, from these values, it is possible to compute the work output of the heart in the basal state (resting).

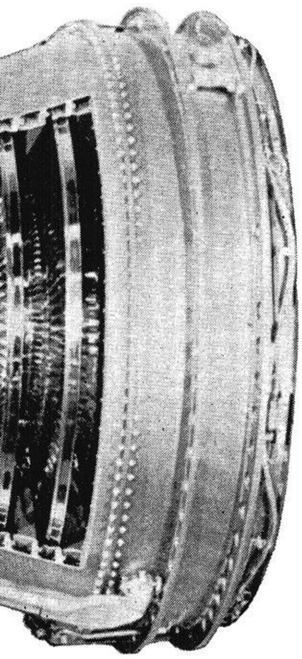
For the left ventricle:

PV work = (stroke volume) (mean aortic pressure during contraction)
stroke volume = 83 ml = 5.06 in. sq
mean aortic pressure = 93 mm Hg = 1.8 psi

(Continued on page 22)



. . . they're right. And wrong.



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continued from page 19

$\therefore$ W = PV = 2.06 (1.8) = 9.1 in-lbs/stroke

for a heart rate of 65 beats per minute . . .

W = 9.1(65)/12 = *49.3 ft-lbs/min*

Kinetic Energy = ½ mV^2/g

time of cardiac cycle = 60/65 = .92 sec

cross-sectional area of the aorta = 2.9 in sq

$\therefore$ velocity = (83) (63)/(2.5x 60) = 31 cm/sec = 12.9 in/sec

contraction period = .32 sec

velocity during contraction = (.92/.32)(12.9) = 37.1 in/sec

flow rate = m = (83 ml) (.061 in/ml) (.0361 lbm ½0/in^3) (65 strokes/min) (1.05)
= 12.5 lbs/min

$\therefore$ KE = (12.5) $(37.1/12)^2/32.2$ = *3.8 ft-lbs/min*

For the right ventricle:

similar conditions yield . . .

W = PV = *10.6 ft-lbs/min*

(lower pressures in pulmonary circuit)

KE = 3.8 *ft-lbs/min*

GRAND TOTAL = *67.5 ft-lbs/min*

The work of the atrium is negligible.

CALCULATING THE ENERGY INTO THE HEART

The heart is a compact mass of muscle with the fundamental function of converting chemical potential energy into mechanical work. The heart derives its energy from the breakdown of essential foodstuffs by a complex series of enzyme reactions. The purpose of these reactions is to release free energy to be stored in energy-rich compounds. This energy is eventually utilized by the contractile apparatus of the heart to do work.

The chemical and physical changes in muscle are the resultant effects of several energy yielding and energy using processes: chemical breakdown and resyntheses, contraction and relaxation, connected in series. The stages through which these high energy compounds pass in the course of transformation into mechanical energy are still unknown. However, it is well known that the major source of energy for muscle tissue is the oxygen found in the bloodstream. Knowing the energy equivalent of oxygen, it is possible to evaluate the energy exchange taking place in the heart by other than chemical methods. Thermodynamics, the study of mass and energy transfers, is the alternate route which is open to us. Knowing that the conversion of chemical energy into contractile energy is approximately 40% efficient, and that the restoration process back into the original state is approximately 50% efficient, we can predict that the entire process from chemical energy to work should be about 20% efficient (½x40). The exact calculations for a man at rest are as follows:

oxygen consumption of the heart = 3–4 ml/gm/hr

choose the medium value of 3.5 ml/gm/hr = 5.85 ml/100gm/min

weight of the heart = 300 gm

energy equivalent of oxygen = 2.06 kg-m/ml O_2

$\therefore$ energy input = 5.85 (300) (2.06) (7.23 ft.1lbs/kg-m) = 262 *ft-lbs/min*

Having calculated both the energy input and the work output, the efficiency is readily computed:

efficiency = (67.5/262) = .258 = *25.8%* (basal state)

DISCUSSION OF HEAT LOSSES

It is possible, to a limited degree, to calculate the amount of energy degenerated into unavailable heat which manifests itself as a temperature rise across the coronary system. No such measurements have been made on man; however, a value of .3 degrees F was found to be the case in a dog's heart. Because the ratio of the mass of the dog's heart to the mass of a man's heart is about two-thirds, it is reasonable to estimate that the amount of blood in the coronary circuit of man will be the inverse of two-thirds, or three-halves the amount found in a dog. Consequently, we would expect the temperature rise to be only two-thirds as great because of the increased mass flow rate. If we grant this assumption, the following calculations can be made:

coronary blood flow
= 65 ml/100gm/min
= 195 ml/min, for a heart of 300 gm

The energy lost will be in the form of heat so . . .

$Q = mc_p(T_2 - T_1)$

m = 195 ml/min = .465 lbs/min

c_p = .83 BTU/lbs-F

$T_2 - T_1$ = (2/)(.3)=.2 degree F

$\therefore$ Q = .465 (.83) (.2) (778 ft-lbs/BTU) = *60 ft-lbs/min*

This value is only about one-third of the energy degenerated into heat. The other two-thirds is carried out by the blood passing through the chambers, and some undoubtedly escapes through the wall of the heart itself. Unfortunately, there is no data as yet available regarding the temperature rise of the blood pumped through the heart. Once this is known, it will be a simple substraction problem to determine the heat which escapes through the heart's wall. It is altogether possible that virtually all the heat leaves the heart in the form of a temperature rise in the bloodstream. All that would be necessary to make the heart an adiabatic engine (no heat transfer except by mass transfer) is a rise in temperature of two-hundredths of a degree. This, of course, is very difficult to detect and until adequate instrumentation is developed, we will have to remain in the dark.

DISCUSSION OF THE HEART'S EFFICIENCY

The efficiency of the heart is not constant, but varies in proportion to the work required. It can in fact drop as low as 12% or reach as high as 36%. It is interesting to note that the steam engine, a common prime mover, has a thermal efficiency of about 15%. The heart is much more versatile, and during violent activity output may be increased by a factor of eight. There are two ways by which it is able to increase this output: Either it can speed up the heart rate or it can increase the volume of blood ejected with each stroke. Either way more blood is furnished to the body per unit time. The heart is always as efficient as it has to be, or it will expire in the attempt.

The non-athletic individual tends to meet the demands of muscular activity by increasing his heart rate, while an athlete will employ the more efficient approach of simply increasing his stroke volume and keeping his rate down. His heart is larger; its cavities hold more blood, and he can meet increased demands by taking advantage of the greater contractive force of a dilated heart. Even in the heart of an athlete, though, the heart rate will be forced to go up during extreme exertion. If there is no rest, the cardiac output will fall off even if more blood is still needed. This is not due to an encroachment on the time needed for energy conversion, but to an encroachment on the time needed for filling the pump chambers. The heart beats rapidly, but not enough blood, and therefore not enough oxygen, is ejected with each stroke. A defective oxygen supply diminishes within seconds the contractile powers of warm-blooded muscle. When a man is at the end of his strength, as it is termed, and his muscles begin to fail him, it is the circulation of aerated blood which has failed. The heart, being a muscle, is also affected, and it too can fail unless some form of relief arrives.

CONCLUSION

The heart is the most vital component of a wonderfully efficient circulatory system. The working fluid is the blood which supplies all the organs with the nutrients necessary for life, and it is maintained in a constant state of motion by the pumping action of the heart. Because we are human and our bodily activities vary constantly throughout the day, we are not, so to speak, connected to a constant load. Our output is instead quite flexible and the heart is designed to furnish the body with the amount of fuel dictated by the loading conditions. All this is handled with an efficiency which is far greater than that of any engine as yet built by man.

METALLIC IMPLANTS

by Armand Matarrese

ME '67

● Early surgeons realized the problems related to the use of metallic implants in the human body. The threat of failure of an implant due to metallic fatigue and the possibility of corrosion is of major concern. Stainless steel has met these problems fairly well however, and has proven its value through clinical use. The recent employment of vitallium, a comparatively new alloy of cobalt chromium base content, has shown great superiority.

The human bone is singularly superior in serving its purpose. Unfortunately it can fracture under undue stress, and must be supported and sometimes replaced if the damage is severe. The implants consist of fixation devices such as metal plates, screws, and rods. The search for these devices and the methods of using them has often been frustrating.

HISTORY OF IMPLANTS

The history of implants goes back to the beginning of surgery. Early attempts with clumsy devices and little knowledge of the human body, almost always ended in failure. It was not until the latter part of the 19th century that the perfection of surgical techniques have made the treatment of fractures by internal fixation possible. Three outstanding surgeons made significant contributions in this area.

Lambotte of Brussels experimented with the various materials such as annealed iron, copper, and magnesium and produced a great number of devices for internal fixation. He also suggested that the reaction in the tissue to the devices consisting of dissimilar metals might be due to electrolysis, the causing of chemical changes by passage of an electric current through an electrolyte.

Lane, in England, made notable contributions to the design of special plates and screws for internal fixation, and perfected a "no touch" technique for their application which was aimed at reducing wound contamination.

Sherman in the United States introduced a special plate which was heavier and less likely to break. Sherman plates were used until the mid 1930's when research by Jones, Hudac, Murray, and others proved that bone tissue was much more tolerant of stainless steel.

Venable and Stuck, two orthopedic surgeons, observed that cobalt alloys used by a dentist they knew had noncorrosive qualities. Recognizing the potential of such alloys, they developed plates and screws for use as internal fixation devices. They also proved Lambotte's assumption that electrolysis is the cause of tissue reaction. Much of the knowledge of the mechanical properties of the bones onto which these devices are fixed has been gained through the efforts of Cohen, Marty, Frankel, and Scheisn.

TWO IMPLANT CLASSES

There are two different classes under the term orthopedic implant. The first, fixation devices, splint the damaged bone during healing, and are usually removed when restoration has been accomplished. The second class, prothesis, is the replacement of diseased or drastically injured bone. This latter class will probably remain in the patient for his lifetime, and therefore the device must retain adequate strength for a long time, and this strength should be sufficient to eliminate restrictions on the patient. Both fixation and prothesis devices are subject to repeated stress.

Bone has the remarkable property of orderly self-repair by continuous absorption and replacement which gives resilience, and prevents the development of fatigue fractures in healthy bone. These properties of resilience and fatigue resistance have been secured in metallic implants. Repeated stress on the implants can lead to intergranular corrosion and fatigue fractures of the devices.

IMPLANT REQUIREMENTS

Before a material can be used, it must meet certain requirements, the most important of which is the compatibility with body tissues and fluids. The limiting factor is that the metal must be nontoxic, nonirritating, and must resist any interaction such as corrosion pitting, which would degrade its strength.

Table 1 lists materials used for orthopedic implants and gives typical values for mechanical properties. All the listed materials are denser, stronger, and have a higher elastic modulus than the bone they fix or replace. These influences on local distributions of stress and strain could impose very high stress concentrations in the bone, and cause fatigue cracking. The living bone however has remarkable adaptive powers and can alleviate such effect.

FATIGUE LIMIT

The fatigue limit of a material is the highest amplitude of stress which can be withstood millions of times without failure, and must be considered for internal fixation devices. Table 2 is a summary of fatigue tests on stainless steel and vitallium for several different loadings. A comparison of the fatigue limit and ultimate tensile strength (table 2) shows that they can not be expected to withstand repeated loads of more than 35% of their "static" breaking load.

One of the areas of greatest concern is the battle against corrosion of surgical implants. Corrosion is an electrochemical process requiring a solution of electrolytes which are readily available in any aqueous medium. An anodic area is set up and electrons are released and form metal ions by oxidation and disintegration of the metal. Ions of metal pass into solution. A cathodic area, which metal contact will allow, exists in relation to the anode with a path for the negatively charged electrons to pass to it. The anode and cathode may exist on the same piece of metal. These areas of potential difference may change in location, allowing visible corrosion to be seen all over the metal surface.

If the interface between the metal and its environment is entirely homogeneous, the areas of potential difference would not exist. In order for a corrosion cell to be set up, certain areas of the metal surface must be chemically or physically different from the

Table 1—Estimated Fatigue Limits for Some Implant Materials

Material	Condition	Type of Load	Fatigue Limit, ksi
Type 316 SS	annealed	B	35
Type 316 SS	annealed	RB	38
Type 316 SS	annealed	B	33
Type 317 SS	annealed	B	42
Vitallium	cast	RB	35 to 40
Vitallium	wrought	RB	55 to 75
Vitallium	wrought	AX	70

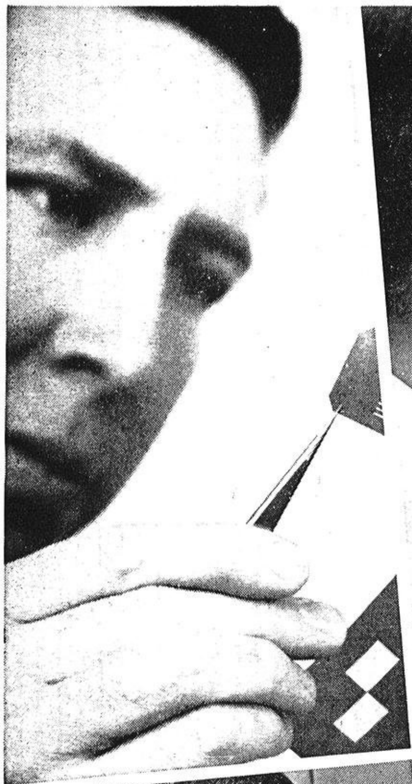
Values represent some range in heat treatment. B-plan—bending; RB—rotating bending; AX—axial loading.

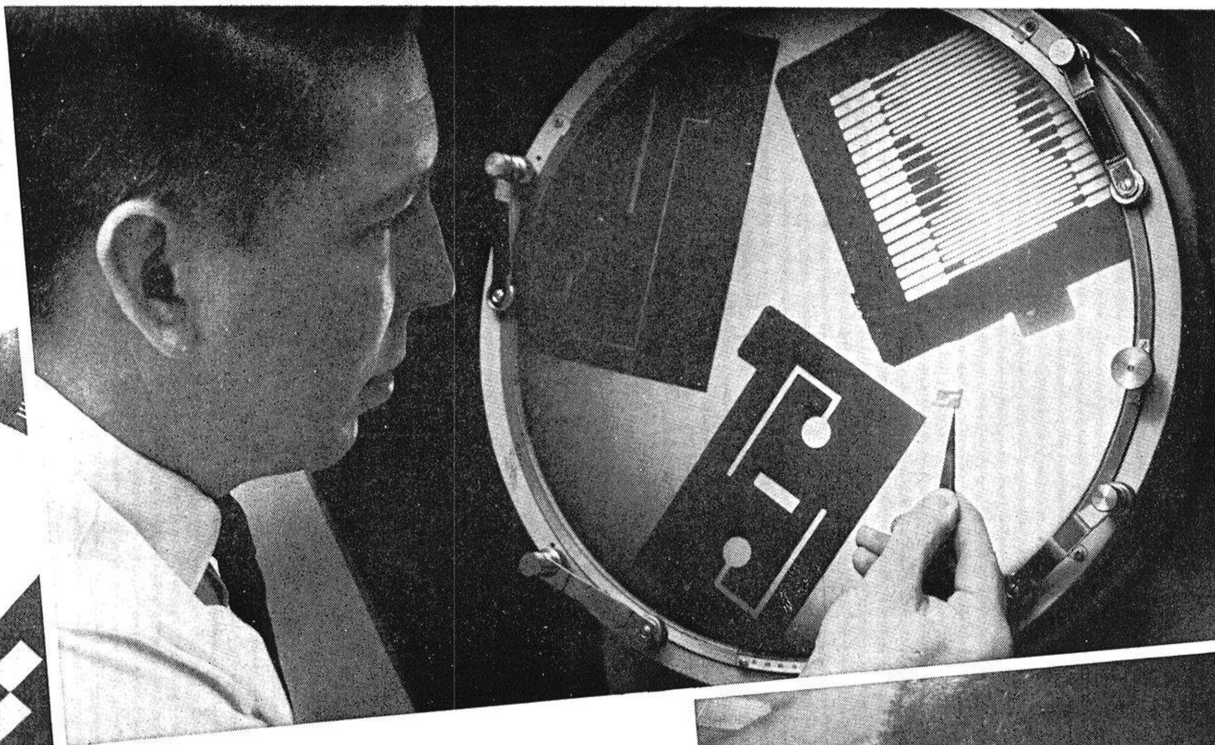
Table 2—Some Implant Materials

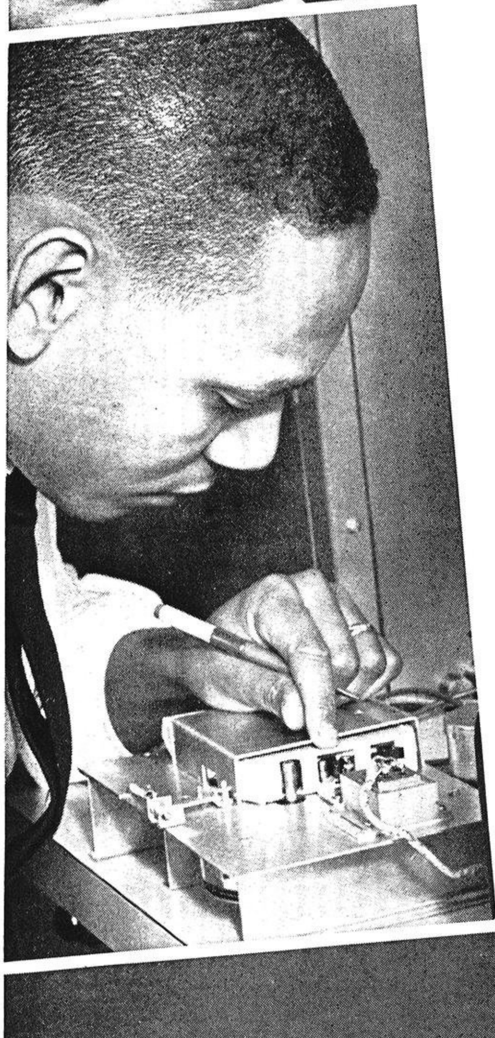
Item	Material	Condition	Ultimate Tensile Strength, ksi
1	SS*	annealed	90
2	SS	cold-worked	125
3	Vitallium	cast	95
4	Vitallium	wrought	150 to 185
5	Titanium	annealed	90
6	Bone	wet	13 to 17.7

Item	Tensile Yield Strength, ksi	Young's Modulus, ksi	Density lb/in ³
1	40	28 x 10	0.29
2	100	29	0.29
3	65	36	0.30
4	70 to 185	35	0.33
5	75	16	0.16
6	---	2.9	----

*SS—Stainless Steel.







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rest. The environment must also be homogeneous.

When dissimilar metals are coupled together in an electrolyte, they have a potential difference, which is the greatest source of corrosion in typical metallic implants. In this corrosive environment, it is possible for alternating stress to crack an implant well within the safe stress range. Using tools of one alloy to place an implant of another implant of another alloy results in the transfer of bits of thin alloy which can cause corrosion. Scratches on the surface of the implant which are caused by other pieces of metal are also dangerous because the implant will be seeded with pieces of the metal edge; have its protective surface oxide film damaged; have fragments of a foreign metal welded onto it; and have metal on each side of the scratch which has been plastically deformed. Each of these four factors is a direct threat to the passivity or corrosion resistance of the implant.

In the late 1930's it was realized that vanadium steel, which had served as the major implant material since it was proposed by Sherman in 1932, was lacking the corrosion and fatigue resistance for modern surgical implant applications. Work by Venable and studies by Hudack and Key led to the recommendation of the chromium-cobalt alloy, vitallium, and types 302 and 316 stainless steels as more suitable implant materials.

Surgeons and manufacturers soon recognized the advantages of type 316 and the closely related type 317 stainless steels for body implants, and at present nearly all stainless steel implants are of this type. The composition of these particular materials is shown in table 3.

A major reason for choice of stainless steel for body implant application is the greatly improved ability of these steels to withstand pitting and crevice corrosion in chloride environments. The addition of molybdenum to these stainless steels in amounts greater than two per cent is the major source of their increased resistance to attack in chloride environments.

The fine grain size that this material possesses insures better mechanical and chemical properties as well as more uniform cold-forming characteristics. In addition, it has been demonstrated that in general, fine grain size increases fatigue strength. Fatigue loading is a result of known and many unknown stress factors which exist in the body during dynamic weight transfer, which may load a device to several times the body weight during only small changes in position. Hence, an implant is subjected to a wide range and frequency of stress cycles. Due to its limitations in size and because of the confines in which it is necessarily implanted, fatigue failure may result in extended service.

Table 3—Chemical Analysis of Type 316 and 317 Stainless Steels (per cent)

Carbon	0.02
Chromium	17.23
Nickel	13.75
Molybdenum	2.32
Manganese	1.60
Silicon	0.63
Sulfur	0.017
Phosphorus	0.013
Copper	0.11
Nitrogen	0.024

Table 4—Composition of Vitallium (per cent)

Chromium	30.3
Cobalt	62.3
Nickel	0.0
Molybdenum	5.0
Manganese	0.5
Silicon	0.3
Iron	0.7
Carbon	0.4

There is general knowledge that better fatigue properties can be achieved in the 300 series stainless steels by a low-temperature stress relief anneal. This anneal is accomplished by heating the material up to a temperature below its recrystalization point for a brief period of time. This relieves any stresses inborn in the material due to process of cooling from its first pouring or from the processes of machining. After extensive testing and experimentation, this theory has been proved. Results of mechanical property studies clearly indicate an increase in useful mechanical properties for type 316 stainless steel after stress relief in the 750 to 800 F range.

Probably the most striking result of the mechanical property studies was the unusual increase in ductility concurrent with increases in tensile strength yield strength, hardness, and fatigue properties after stress relief.

VITALLIUM AS AN IMPLANT

Vitallium is a comparatively new alloy in the field of surgical implants. Its remarkable resistance to corrosion is superior to any material now used in metal implants. The chemical composition of vitallium is listed in table 4.

Studies have shown that the cobalt-base alloys (Co-Cr-Mo), of which vitallium is the main concern, show lowest incidence of obligatory plate removal. This is the removal of a plate because of irritation to the patient. A clinical study is shown in table 5.

As a result of this clinical survey it can be said that the 316 stainless steel is inferior to the cobalt-chromium alloy (Vitallium). For the stainless steels, one in every five plates installed had to be removed. The case for vitallium was much improved. Only one out of every 33 plates implanted had to be removed, and visible corrosion of the metal has never been seen.

Examination of the medical technical literature as well as the metallurgical literature on implants, confirms the creditable performance of cobalt-base alloys in general are more subjected to work hardening than the 316 stainless steel. They may be drilled and ground but to a limited extent. The preliminaries are so expensive that it is easy to understand a certain caution on the part of the manufacturer in embarking on new designs or modifying old ones until the success of the new item is assured. Stainless steel is, therefore, almost essential in the development of prototypes, but ought to be abandoned as soon as the design is firmly established.

Research is still proceeding to improve vitallium's ductility, while maintaining strength and corrosion resistant properties.

The importance of corrosion resistance and high fatigue limits was discussed earlier. It is apparent that of the presently available structural materials, none can come close to matching the fatigue resistance of the bone or tendon of the human anatomy. This problem therefore has to be met either by making the implant sufficiently massive, or by designing the implant properly so that the effects of fatigue are minimal.

STIFFNESS PROBLEMS

There is a problem of contour, size, and shape of the surface which is optimum for the transfer of load between the implant and the living tissue and vice versa. This problem is in part related to the stiffness of the materials (Young's modulus), and, in part it is related to the fact that structural members are loaded in a diversity of ways and with widely varying magnitudes during the time of use. The problem of matching the elastic modulus of the implant to that of the tissue, which has the function of supplementing, and of providing an implant free of significant risk of fatigue failure, has not been solved.

Surgical implants have to be corrosion resistant to fluids and tissues. In many cases, they may have contact with the corrosive environment for years, perhaps as many as 80. More important is the fact that any ions released must not be damaging to human materials such as bone, tissues, and fluids.

CONCLUSION

Probably the greatest problem to overcome in the development of an ideal implant is that of communication. There is a lack of communication among the surgeons, the metallurgists, and the design engineers. The need for more direct correlation between the two fields is in the area of metallic implants is apparent. The bioengineering field is a growing profession and a step in the right direction for a quicker and more efficient solution to medical problems requiring engineering skill.

Bio-Engineering Courses

● The College of Engineering here at the University of Wisconsin has already begun to offer courses in the field of Biological Engineering. In addition to courses in Mechanical, Chemical, and Electrical Engineering, the Physics Department offers courses in related topics.

The best introduction to the field of Biological Engineering would be in Mechanical Engineering 603: Topics in Bio-Medical Engineering. The course, which is offered Spring semesters, is designed to introduce the student to developments in this growing field. It is taught as a matter with guest speakers and faculty members discussing various topics within Biological Engineering.

Some of the topics to be discussed this spring semester will be: an introduction to biological–engineering, basic physiology, medical physics, metallic implants in orthopedic surgery, rehabilitation problems, engineering aspects of dentistry, cardiovascular system, computer simulation in biology, models of the nervous system, heart valve developments, and the artificial kidney.

To be eligible for the course one should be a Senior in good standing in either Engineering or a biological science. The course does not require that engineers have training in biological sciences. One credit will be given to students only attending the lectures. Two to three credits can be earned by presenting a project done during ths semester to the group. Further questions about the course should be directed to Professors Daggett, Harker, Mitchell, G. E. Myers, or Seireg.

Students particularly interested in Chemical Engineering might elect to take Chemical Engineering 560: Biochemical Engineering, also offered Spring semesters. A three credit course, it mainly focuses on applications of chemical engineering principles in biochemical industries. Prerequisites for the course include Ch E 326: Transfer Operations and Chem. 562: Physical Chemistry. Further questions should be directed to the instructor, Professor Lightfoot.

The Electrical Engineering Department also has two courses in the area of Biological Engineering in their curriculum. Both of these courses are new and deserve investigation by interested students.

The first is Nerve and Muscle Mechanics and Models (EE 625) This is a three credit course given during Spring semesters. The course will be taught by Professor Geisler and is specially designed for Seniors and graduate students with particular interest in the field of Biological Engineering. The enrollment is to be small, hopefully, only ten to fifteen students. Previous courses in intermediate electricity serve as the only prerequisites for the course. Study of nerve and muscle mechanisms and their mathematical and electrical models will be the major focus of the course.

The other related course in Electrical Engineering is EE 909: Special Topics in Bioengineering. This course is designed for graduate students intending to do research in Biological Engineering. The focus of the course will be broad enough so that graduate students from all engineering fields will find it valuable. This course should not be confused with Topics in Bio-Medical Engineering (ME 603); the two courses are not overlapping in content, and the course offered by the Mechanical Engineering Department is open to Seniors.

Credit for the course will be from one to three credits for the amount of work done. Subject matter will vary from semester to semester to reflect the combined interests of the students and faculty members involved. There will be no text, consequently, most of the reading will be from pertinent articles in scientific literature.

The first time the course is offered it will be taught by Professor Geisler, who is currently Chairman of the University Committee on Bioengineering. He is also an Associate Profsessor of both Neurophysiology and Electrical Engineering. Students interested in either of these courses offered by the Electrical Engineering Department should either contact that office or Professor Geisler for further questions.

The Physics Department (Letters and Science) offers courses in Biophysics (461) and Radioisotopes in Medicine and Biology (463). Both are related to the field of Biological Engineering.

Biophysics is a three credit course with the prerequisite of Physics 442: Atomic Physics, or consult of instructor. The program of the course is centered around X-ray diffraction analysis of biological structures, physical principles of proteins and nucleic acids, and interactions of radiation with biological systems.

The other course, Radioisotopes in Medicine and Biology, is a two credit course offered Fall semesters. It deals with the physical principles of radioisotopes used in medicine and biological sciences and includes the operation of related equipment. General Physics is the only prerequisite. Interested students, who meet the requirements of either of these courses should investigate the possibilities these courses offer.

Other courses related to the field of Biological Engineering are sure to appear with increasing rapidity. As the field broadens and more students become attracted to it, the demand for such courses will be met. The field of Biological Engineering is a new one, it's dynamic, and offers a tremendous opportunity to the student to combine the disciplines of Engineering and the biological sciences to serve the most useful of possible ends-to help man learn more to enable him to live a longer and more productive life.

Abby T.


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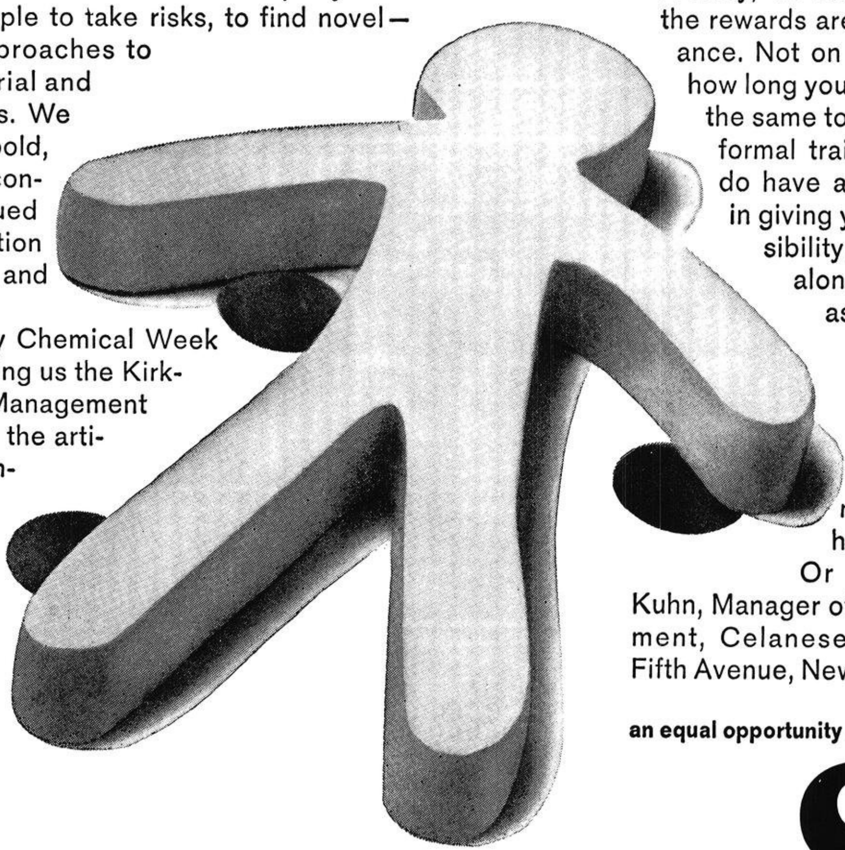

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Or write to: John B. Kuhn, Manager of University Recruitment, Celanese Corporation, 522 Fifth Avenue, New York, N.Y. 10036.

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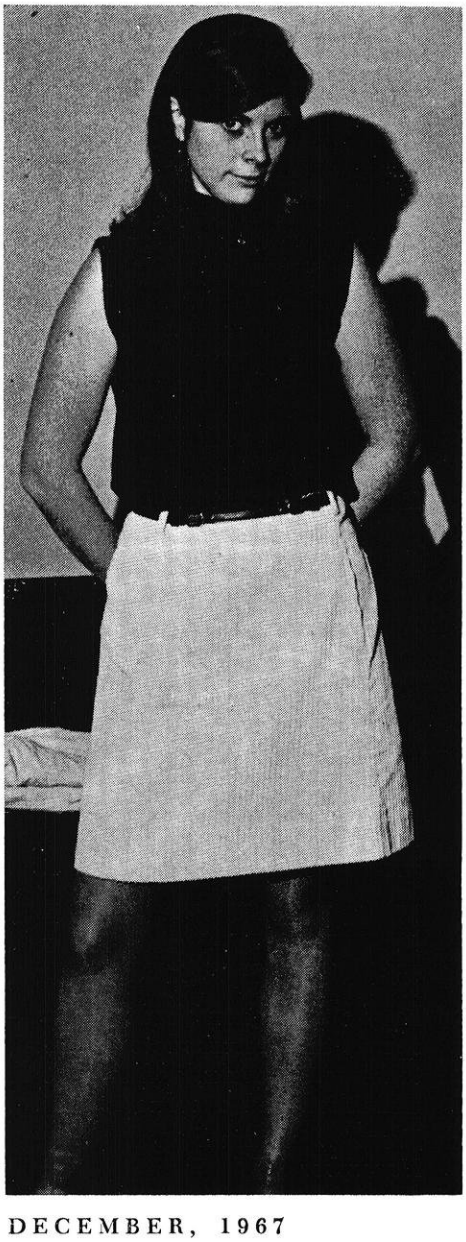
CELANESE

PICTORIAL:

Libby Rowe

Libby, a math major (!) from Western Springs, Illinois, digs riding and enjoys skiing. Libby, an Alpha Phi, likes engineers (it runs in her family). Miss Rowe is a excellent example of why out-of-state enrollment shouldn't be limited to 15%.



PLANT TRIP 1937

FALL brings us football, falling leaves, mid-semesters, and senior inspection trips, all as a matter of course. To lower classmen the last has a romantic ring, but to seniors inspection trips are but one of three things: (1) A chance to make whoopee amid the bright lights; (2) A technical orgy; or (3) A pain in the neck.

But this is neither the time nor place for a handbook on inspecting; we can but relate the milder events of the last expeditionary force to Chicago. The metallurgists are still a little dazed by it all. Ten strong, and under the wing of Professor R. S. McCaffery, they descended on the Wisconsin, Inland, and Carnegie–Illinois Steel Companies October 6, and spent two quiet days "casing the jernts." As they tell it, they were really out to learn, scampered about with proper curiosity, asked intelligent questions, and lived the righteous life. Knowing metallurgists, we are skeptical . . . having heard rumors of how Nick Friese in shirt-sleeves (higher thermal efficiency) floored 'em as he led the "polka" at the University of Chicago's International House. "Fred the Buzzard" Bemis, practicing his engineering econ, decided fruit is to be eaten rather than to adorn tables, so cleaned out the fruit baskets of Carnegie–Illinois' exclusive dining room; he is also suspected of having spent his evenings robbing fruit stands in company with that ex-model youth, William Wright. Incidentally, the above dining room is barred to all employees under the rank of superintendent; ever gentlemen, our heroes washed the grime from their hands before sitting down . . . but no one had said anything about washing faces, too! Joe Beck is still wondering which sparks from the spark testing grinder were which. "Sleepy" Place also has that brooding look on his pan, this due to the "robbing" he took for his couple of beers at the Blackhawk. "Anyway, I had a good time," sez he. What the rest did at night they won't say. Tony Ozanick and pipe camped together in grimy, villainous South Chicago, his old stamping grounds, but whether it was because he just likes mill scenery, because no one would endure the flue gases produced by that notorious tobacco incinerator, or because he had found a rose among the thorns, none can say.

October 18th through 21st found a new regiment of plumbers, the electricals and mechanicals encamped in the Windy City. Their annual inspection trip to the Rialto proved a flop, but still the evenings could not be called dull. We don't believe that Pritchard and Albrecht ever did find out how soft the hotel beds were. There must have been *something* about Gordy Fuller that prompted the house detective to stay on his tail all one evening. Nor was "Oh Gordie" Michelson the only one to look on the wine when it was red. Even Professor "Pat" Hyland, it is rumored, spent the first evening bending elbows with his former students.

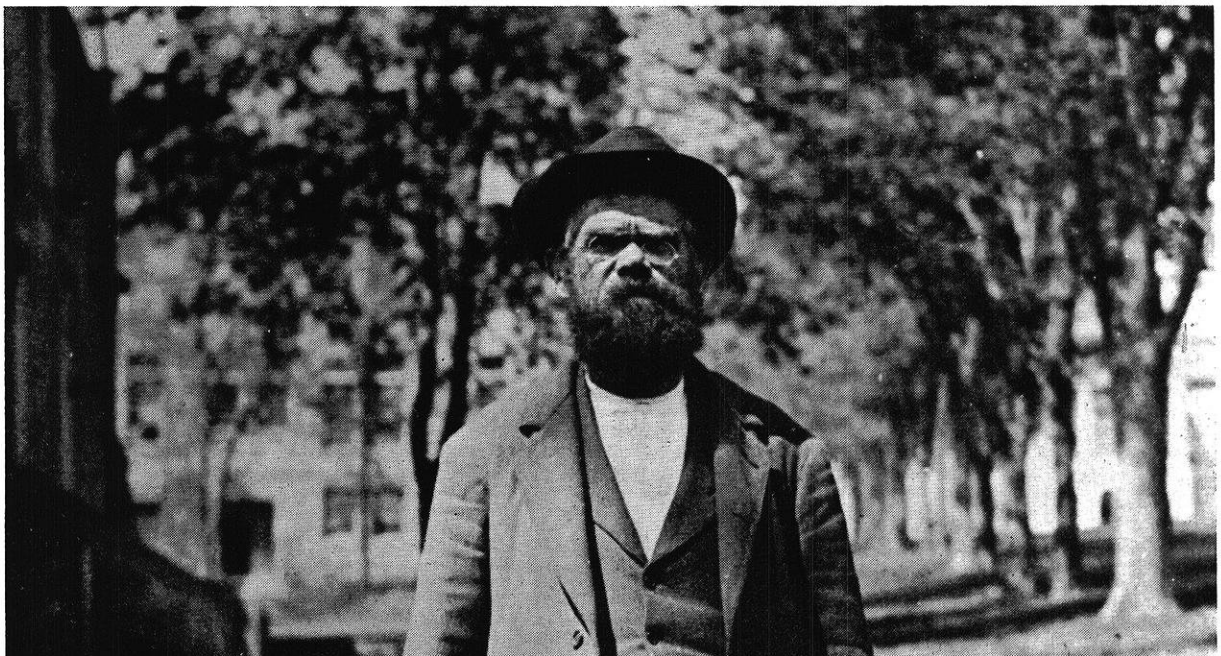
The souvenir business was not so brisk this year, the boys being older and wiser due to last spring's experiences. An alternator or an I-beam bulge too much under the coat. The electricals, however, had planned to bring back a baby gas job, each man having a piece assigned; this plan fell through as Baird declined to turn in the cylinder block.

A couple of days of stiff hiking, the clamor of shops and the smoke of mills used up most of this excess energy. The electricals still had the old zip, it seems, for scouts were sent out at regular intervals to gather up their Professors Bennett and Watson who had a knack for getting lost back along the production line. Dave Bogue, mechanical, likewise never caught on to the idea that most companies frown on candid camera fiends. Wayne Mitchell wanted to sleep so much that he climbed into the baggage rack of the bus and dozed on the journeys to and from the plants. Bob Sharp neatly cut the afternoon tour of the steel mill to go shopping in Marshall Field and Company, but there was a heart interest in that, too. The mechanicals, who did some fast construction estimating of the girls in the Elgin Watch Works report regretfully that the latter are still true to Robert Taylor, whose phizzz is to be seen tacked up all over the shop. Phooey . . . and he only a distant L. & S. graduate. In the human interest line, the driver of bus A, fraternally known as "Jake," became the bouncing father of a proud boy just before the start home, which left him too excited to continue the trip. Whereupon the mechanicals good-heartedly took up a collection to buy the baby a present and bade him godspeed, then returned to Madison, to home, to books, and to piles of unfinished and overdue reports.

From "Wisconsin Engineer," November 1937

PICTORIAL

wisconsin's album



AN EARLY HIPPIE

HUMOR

FILEABLES

Then there was the engineer who made his own drink at a party. It's called a Gin D. It's made with equal parts of gin, milk, and sugar. It seems that the sugar gives you energy, the milk gives you pep, and the gin gives you ideas of what to do with all your pep and energy.

* * *

Having escorted the young lady home from their first date, the rather reserved lad was invited in for a nightcap. As the girl prepared the drinks, the fellow strolled about, a bit ill at ease, admiring her apartment.

"Be careful if you sit on that couch," she cautioned. "If you press down on the arm and pull forward on the seat while pushing against the back cushion, it turns into a bed."

* * *

Prof.: "What is an engineer?"

Student: "A person who passes as an exacting expert on the basis of being able to turn out with prolific fortitude innate strings of incomprehensible formulae calculating with micromatic precision from vague assumptions which are based on debatable figures taken from inconclusive experiments carried out with instruments of problematical accuracy by persons of doubtful reliability and questionable mentality for the avowed purpose of annoying and confounding a hopeless chimerical group of fanatics referred to all frequently as Engineers."

* * *

C.E.: "Let's give the bride a shower."

E.E.: "Count me in—I'll bring the soap."

* * *

MEN ONLY READ THIS

Out of ninety thousand women there will be eighty-nine thousand, nine hundred and ninety-four who read this. The other six will be blind.

* * *

ME: Is the Jolly Green Giant a bigot?

EE: Well, he ain't a small one.

* * *

There was a girl whose measurements were 20–24–36. She really looked like an ironing board. One day her fairy godmother appeared to her and said: "Every time you ask a man to marry you and he says, 'No', you will grow an inch on top." The girl went out and asked a man if he would marry her and he refused. Sure enough, she added an inch on top. She asked another and he refused too. She grew another inch. After asking 14 more guys she was a perfect 36. But still no one would marry her. "Aha," she said, "I know why nobody will marry me. There are too many girls who are 36–24–36. So I'll go them one better I'll ask one more man. So the next man she saw, she asked, "Will you marry me?" "No," he cried, "a thousand times no."

* * *

He drove quite a distance into the country, stopped the car and asked the girl, "Are you a Chesterfield or a Camel girl?"

Somewhat confused she asked, "What do you mean?"

He said, "Would you rather satisfy or walk a mile?"

* * *

Did you hear about the Jewish Santa Claus who came down the chimney and said, "Ho, ho, ho, what toys would you children like to buy today?"

* * *

EE: I'm glad I have a sense of humor. Everytime I see something funny, I laugh and laugh.

IE: I bet you have a hell of a time shaving.

* * *

"Police?" came the voice on the phone. "I want to report a burglar trapped in an old maid's bedroom!" After getting the address, the sergeant asked who was calling. "This," cried the frantic voice, "is the burglar!"

* * *

An M.E. and an I.E. were walking through a graveyard when they came upon a stone engraved "Here lies a lawyer and an honest man." "Hmm," remarked the I.E., "doesn't seem big enough for two."

* * *

"You're a cheat!" the first lawyer accused his opponent.

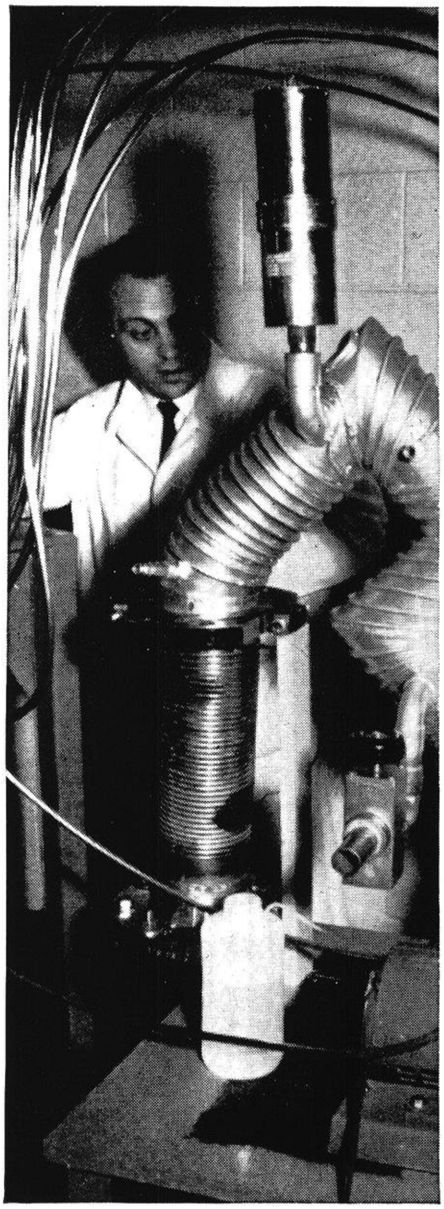
"You're a liar!" the other retorted.

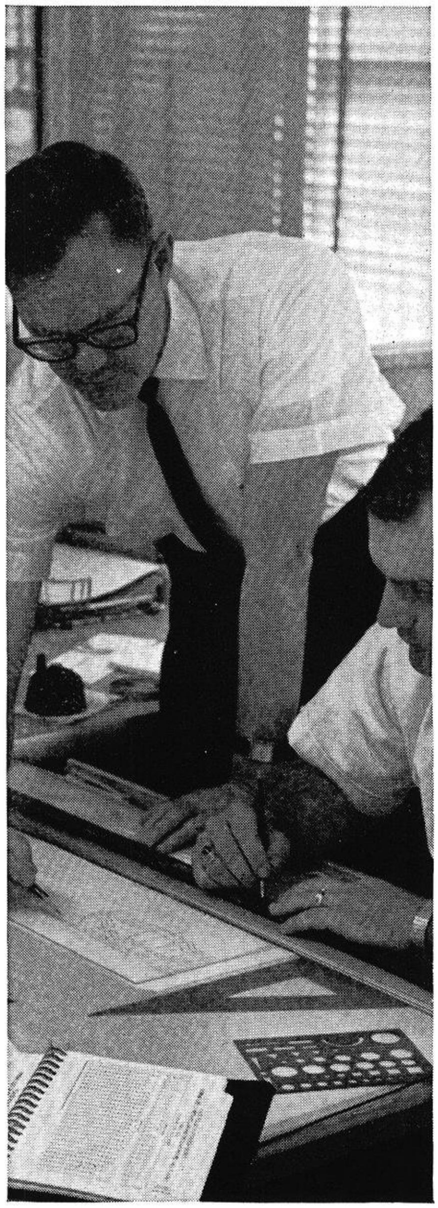
Then from the judge: "Now that these attorneys have identified each other, we shall proceed with the case."

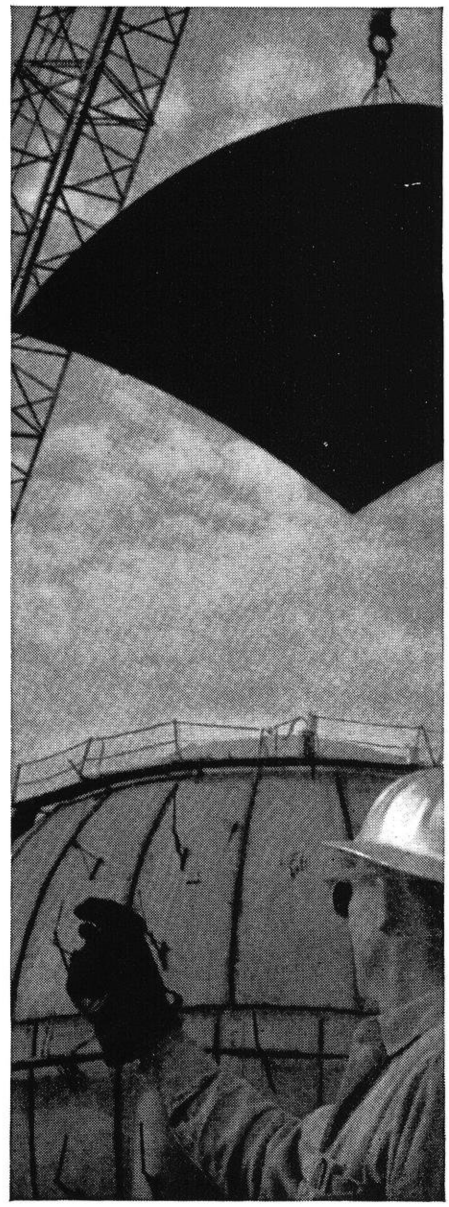
* * *

Did you hear about the oilman who decided to reform? The first week he cut out tobacco. The second week he cut out liquor. The third week he cut out women. The fourth week he cut out paper dolls.

* * *







"Traffic is terrible today!"

". . . Accident in the left hand lane of the Queens-Midtown access ramp. Right lanes moving slowly. Fifteen minute delay at the Brooklyn Battery Tunnel. Lincoln Tunnel backed up to the Jersey Turnpike. Extensive delays on Route 46 in the Ft. Lee area. That's the traffic picture for now, Bob."

However, technical people at GE are doing something about it. Development and design engineers are creating and improving electronic controls and propulsion systems to guide and power transit trains at 160 mph. Application engineers are developing computerized traffic control systems. Manufacturing engineers are developing production equipment and new methods to build better transportation products. And technical marketing specialists are bringing these products and systems to the marketplace by working with municipal and government agencies.

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