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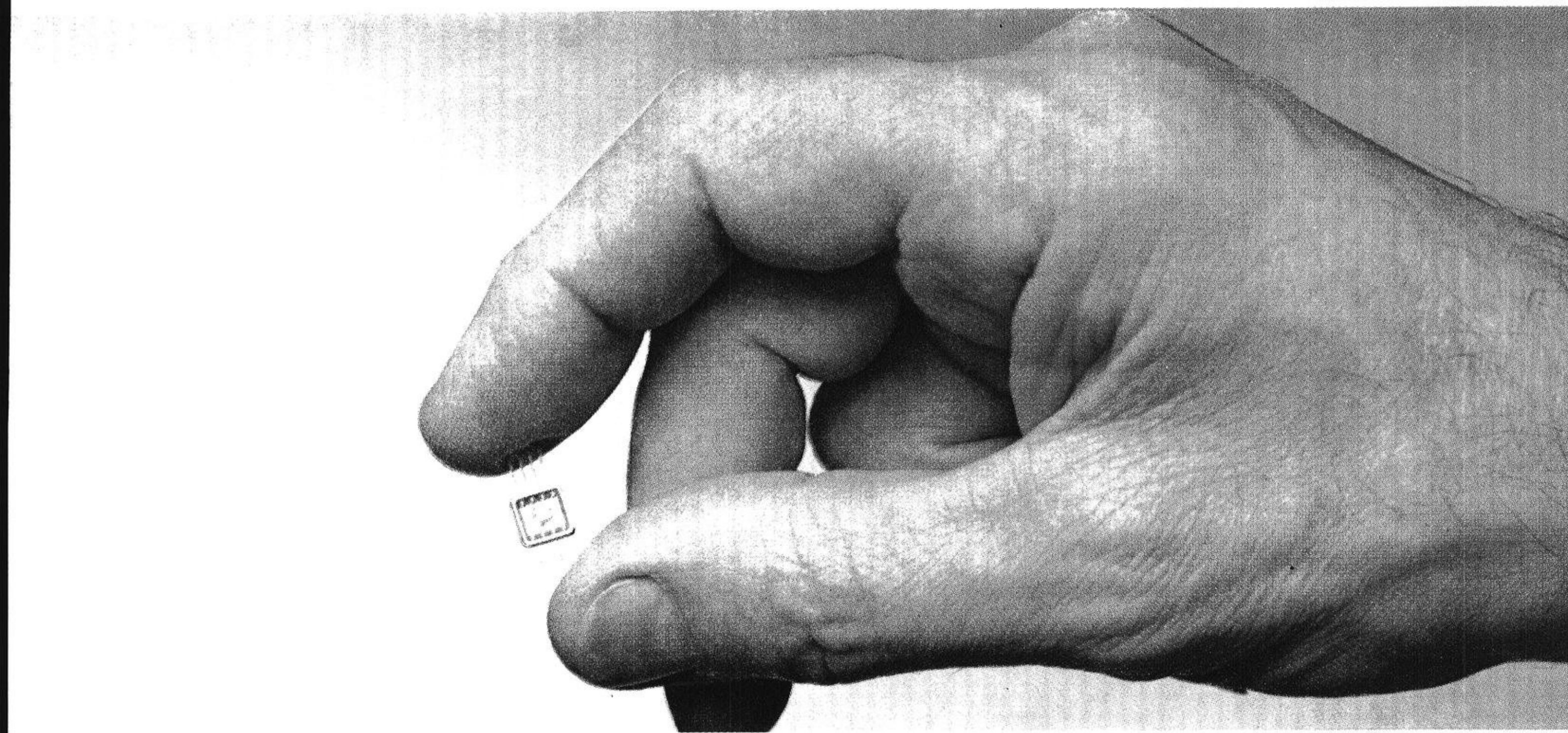
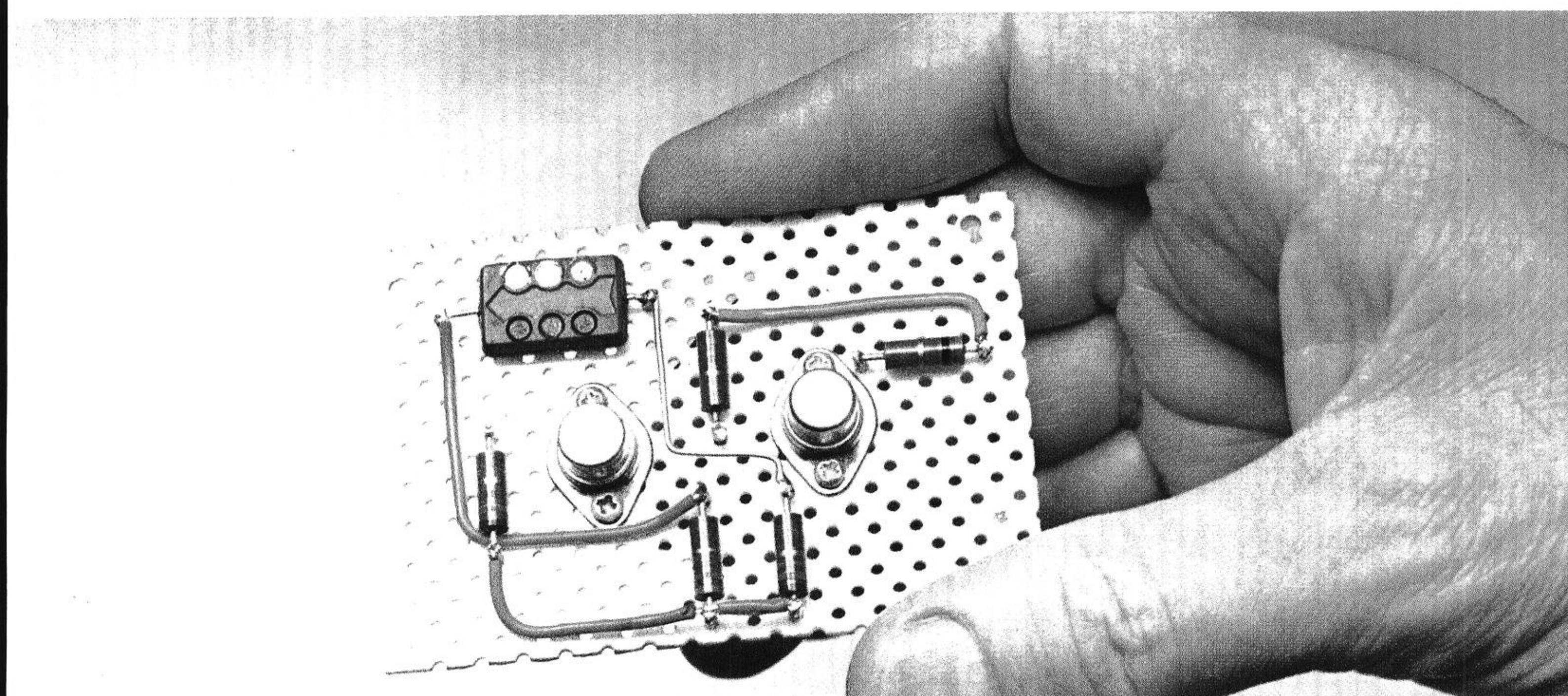
SNO-CAT

THE WISCONSIN ENGINEER

APRIL 1965 • 25 CENTS
MEMBER E. C. M. A.



This tiny device is an ultra-reliable Westinghouse TV amplifier



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So they developed a new kind, using techniques called "molecular electronics." The device is a functional electronic block, one quarter-inch square. (That's the capsule. Actually, the electronics are on a bit of specially-treated silicon the size of a chip diamond.)

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April in Brief

THIS MONTH . . .

After a special March issue, featuring the Engineering Exposition, it's back to the articles for us in April, and that's no foolin'.

Since we still have snow on our mind due to Wisconsin's latent spring, we thought Jack Long's article quite appropriate. Jack relates to his readers a first-hand account of many experiences in Antarctica. And to think that winter is just beginning down there! Read all about the Sno-Cat, starting on page 10.

Stresses in turbine and compressor blades are the subject of Peter Schwalbe's technical discussion. We think that you will find this stress analysis report quite interesting, since Pete has included many instances of design and operation problems.

To herald the advent of spring (we hope?) is another Girl-of-the-Month. Also, you'll want to check the complete list of award-winning Engineering Exposition exhibits.

PLAN AHEAD . . .

The Senior Staff of the *Wisconsin Engineer* will be holding interviews for those people aspiring to join the 1965–1966 staff. Will we see you in 333 M.E. on May 5th or 7th?

Who's helping make water come clean again?

The same Union Carbide that helped develop a new stainless steel used in subway cars.

Streams and rivers in many parts of the country were being plagued with foam, partly due to detergents. In some areas foam even came through the faucets . . . because old detergents kept on foaming after they went down the drain.

Now things are changing—the result of ten years' work by detergent manufacturers. We've helped by being the first to come up with new kinds of detergent chemicals that let the suds do their work in the wash and yet allow foam to be broken down quickly after use.

We've been busy improving many things. Our research work on stainless steel helped develop a new grade of steel that has recently been used to reduce the weight and cost of subway cars. We came up with new kinds of corrosion-resistant alloys for use in the chemical industry. And recently we introduced a plastic drinking straw that won't turn soggy.

To keep bringing you these and many other new and improved products, we'll be investing half a billion dollars on new plant construction during the next two years.

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VOLUME 69, NUMBER 7

APRIL 1965

ARTICLES

THE WISCONSIN ENGINEER

The Student Engineer's Magazine Founded in 1896

FEATURES

THIS MONTH'S COVER

Artist Jim Tyndall leaves no doubt in your mind what our lead article pertains to. More illustrations accompany the article which starts on page 10.

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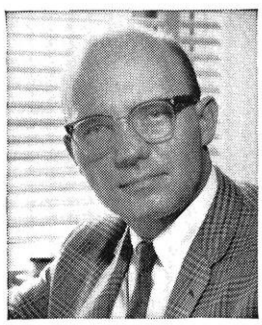

James E. Mercereau
B.A., Physics, Pomona College
M.A., Physics, Univ. of Ill.
Ph.D., Calif. Institute of Tech.

What does it take to "spark" a man to his very best . . . to bring out the fullest expression of his ability and training? At Ford Motor Company we are convinced that an invigorating business and professional climate is one essential. A prime ingredient of this climate is the stimulation that comes from working with the top people in a field . . . such as Dr. James Mercereau.

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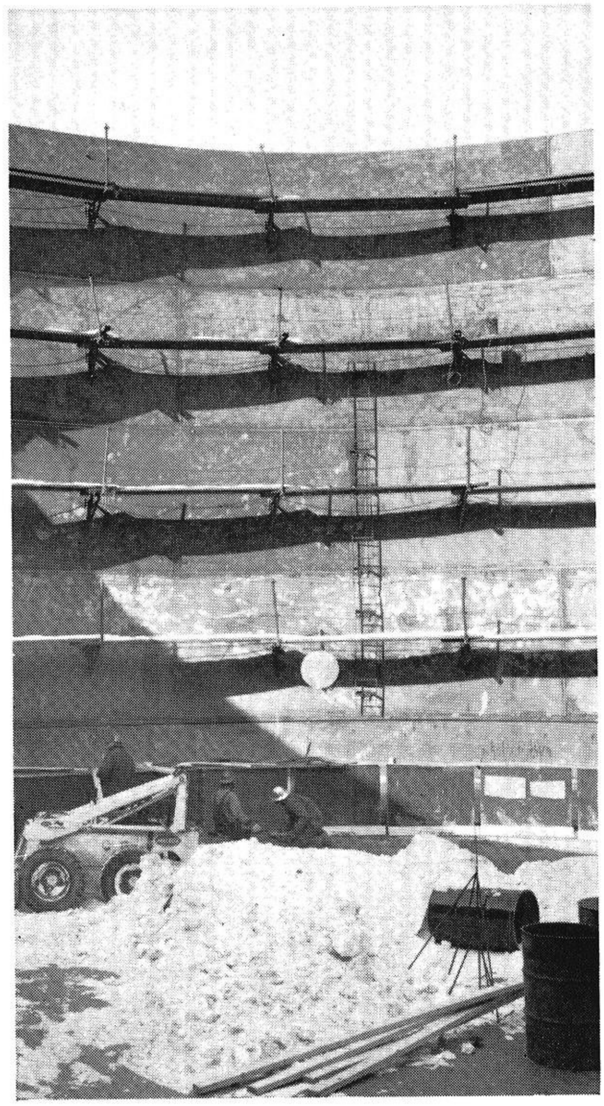

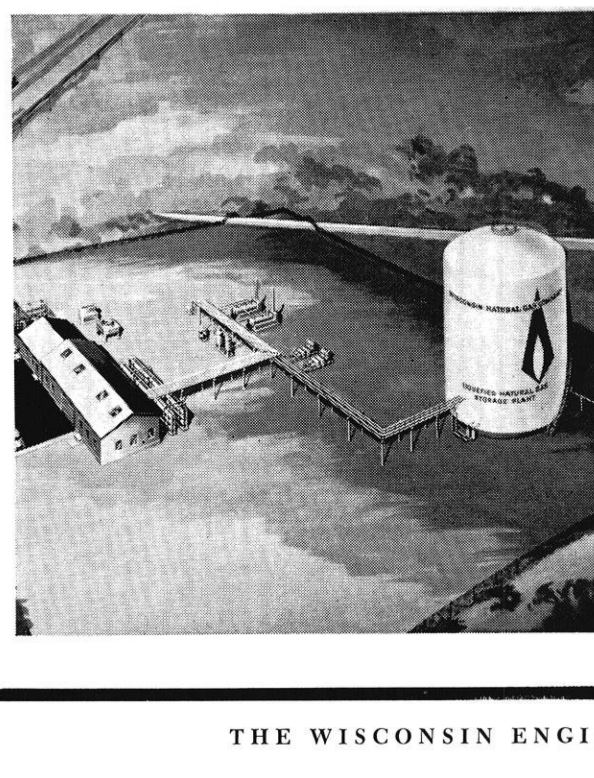

Across the Editor's Desk

YANKEE GO HOME!

(For seven months we have been contemplating the appropriateness and necessity of a comment on one of America's biggest problems. We can hedge no longer, even if a liberal legislator might call for an investigation. Sure, we do know who Bob Siegriest is, but you won't find KKK or Sheriff Jim Clark Fan Club membership cards in our office. Furthermore, we do not live with Birchers or Minutemen.)

To be sure, the recent events in Alabama motivated the nation to react in many ways, shapes, and forms. Perhaps five-column banner headlines do more than just sell newspapers? But does everybody really know what is happening? We think not and intend to provide you with a few facts that have been conveniently hidden beneath the picket-carrying martyrdom called the civil rights movement.

Now we all know of this Nobel Prize-winning Baptist minister who likes to organize marches, as long as he can have a few thousand warm bodies *behind* him (it's better for PR that way.) A plea is sent, and out of the North they come by the thousands—from New York, Detroit, Boston, and Madison. By bus, car and plane they come, these puppets of SNCC, CORE, Dr. King, and maybe even . . . . Oh yes! Lest we forget, they describe themselves as dedicated and courageous in a valiant effort to fulfill a moral responsibility. We describe them with just one word—IGNORANT! As they arrive, the South reverberates with "damn Yankees!" and justifiably so.

But why, you wonderful liberal Badgers ask? Consider first that in general these carpet-baggers have not lived in the South. Then please grant us that environment, customs, and culture are not understood and assimilated overnight. Do these Philistines know what they are doing there, besides supporting a man who has stated that he will obey only those laws which he considers just? By the virtues of the Constitution of the United States of America, it is not for Dr. King to judge. We have courts to interpret the laws, all of them, and *all* of them are to be obeyed!

But we digress. Voting rights are what the demonstrations and pleas are for. The conflict apparently centers around a test administered to each person seeking registration. Now, is it too much to ask a person, black or white, a few reasonable questions? It is more than desirable that the voter be able to read the ballot and know who or what he is voting on.

Lest we be accused of being reactionary rascists, we state here and now that we are for civil rights. But, we must qualify this statement by saying that we do not believe that "it" can happen overnight. We think the key to understanding and progress in civil rights lies in a wider understanding and realization of this. Then, perhaps, we wouldn't have to join with the South in saying: Yankees, it is none of your business; progress would be accelerated if you quit meddling.

—R. J. Smith

Madison suburbanite (Waunakee) Jack B. Long spent four years in Antarctica and is a veteran of six continental traverses, one of which went to the South Pole. Also a mountaineer, Jack has scaled some of the highest peaks of Europe and Africa. Another hobby of Jack's is flying. At present he is rebuilding a pre-WWII bi-plane. A senior M.E., he is also employed as a traverse engineer.

The Tucker 843 SNO-CAT

By JACK B. LONG

INTRODUCTION

THIS report on the 843 Tucker Sno–Cat provides information on this vehicle for its first two years of operation in the Antarctic.

This vehicle has four tracks with a rectangular cab on top. The overall machine is 25 ft. long, 10½ ft. high, 9′ wide, and weighs 12 tons. It is powered with 175 hp, turbocharged, diesel engine and has 5 speeds forward. Electrical, hydraulic, compressed air and mechanical winch power systems are available.

The cab of the 843 Sno–Cat was designed to live in and has proven comfortable. Two of these vehicles were built to travel together and they provide complete living and working facilities for 8 men: bunks, desks, kitchen, special scientific apparatus. It is tall enough to stand in and is well heated with two types of heaters.

Without towed load, the vehicle is operated in third, fourth, and fifth gears with speeds of 6, 12, and 18 mph. With a towed load, it operates in third gear with a speed of 5 mph. This was demonstrated on two traverses with towed loads varying between 7 and 15 tons per vehicle. If the load is extremely large and the snow very soft, the vehicles pull in second gear at 3 mph.

Fuel consumption figures are available from two traverses. Snow surface and vehicle load caused the daily fuel consumption to vary between 1 and .5 nautical miles per gallon. But the overall fuel consumption is .77 nautical miles per gallon.

Routine maintenance on the 843 Sno–Cat is easy to perform, with much of the engine work obtainable from the vehicle cab. Repairs and modifications have involved a large investment of time and effort.

The 843 Sno–Cat has extended the nonsupport range and improved the living conditions of Antarctic traverse, but, much time and effort has been spent in preparing the vehicle for each traverse.

In 1959 the United States felt the need for an oversnow traverse to operate during the summer months on the high, cold, south polar plateau. This plateau, about the size of the United States, occupies the major part of the Antarctic continent and at that time was entirely unexplored. Here the altitudes vary from 10,000 to 15,000 feet with temperatures that vary during the austral summer from -10 to -65°F.

Under these conditions, vehicles used on this traverse would not only have to operate, but provide comfortable living and working quarters for eight men, operate reliably for the 3 to 4 month duration of the traverse, and pull enough supplies to be self sufficient for 1,000 miles of traverse. These requirements could not be met by the vehicles used previously in the lower, warmer parts of the Antarctic where self sufficiency was not required. A new traverse vehicle was needed. To this end two Model 843 Tucker Sno–Cats were conceived, designed and built for the Geophysical and Polar Research Center, University of Wisconsin, who receive funds from the National Science Foundation to operate the overland Antarctic traverses.

This article on the 843 Sno–Cat provides information on the first 3 years of this vehicle's operation in the Antarctic during which time the vehicle did prove a success in comfort and self support for the 3,000 miles traversed. All following references to the 843 Sno–Cat will be simply "Sno–Cat," except where necessary for clarification.

Continuing mechanical problems in the drive system required the investment of many replacement parts and man-hours of work to make the vehicle reliable. Although some of the information is peculiar to this unique vehicle, much of the operational information is of value to anyone operating oversnow equipment in polar areas.

This report is divided into three sections which cover the description, operation, and maintenance of the Sno–Cat. The description covers the physical arrangement of the vehicle and the various equipment contained within. The section on the operation of the Sno–

Figure 1.—The Tucker 843 Sno–Cat.

Cat provides information on vehicle performance with and without loads. Maintenance is discussed in the body of the report. The report on the Sno–Cat concludes with a summary, the intended modifications and some recommendations for future Sno–Cats.

DESCRIPTION

General Specifications

The Sno–Cat, seen in Figure 1, resembles a black shoe box mounted on four tracks. It is 25 feet long, 10½ feet high, and 9 feet wide, and weighs 12 tons when ready to operate (with fuel and batteries). It is capable of speeds of 18 mph when empty, and of speeds of 5 mph over Antarctic terrain when towing 15-ton loads.

Engine

A Cummins JT-6B, 175 H.P., turbo-charged, diesel engine powers the vehicle. This particular engine combines high speed operation (from 1,800 rpm to 2,300 rpm) and turbo-charging to reduce power loss at high altitudes. The engine protrudes up into the cab and is covered with a hood. A radiator shutter, which is closed while preheating the engine, controls engine temperature while driving. An electrically heated plug (custom made) preheats the oil pan and a diesel burning Universal DG–28E heater, requiring no electricity, is used to heat the engine coolant. Canvas engine curtains cover the exposed bottom and sides of the engine housing to exclude outside air during engine preheating and also help maintain engine temperature when the Sno–Cat is running.

Drive System

Power from the engine is transferred to a 305V Clark five-speed transmission with a 14 inch Lipe-Rollway clutch assembly. A drive shaft connects the transmission to the transfer case where two drive shafts provide output power, one for the front drive differential and one for the rear. The differentials are connected to pontoons where the power is transferred from the drive axle through a sprocket to the track linkage system, seen in Figure 2. The only brake on the vehicle is a hand-operated band type attached behind the transmission.

Auxiliary Power Systems

A hydraulic system is used for steering. The hydraulic pump, powered by belts from the diesel engine, sends fluid to booster cylinders which via tie-rods pivot front and rear differentials. This type of steering maintains pulling power while turning since there is no braking applied to the tracks. The Bendix Westinghouse Tu Flow 300 air compressor is also belt-driven from the diesel engine and supplies air to a 2.6–cu. ft. air tank located under the hood. Air pressure is maintained at 125 lbs. and is used for refueling the Sno–Cat from the 2-ton FWD 1000-gallon Rolli-Trailer which it tows. A Tulsa

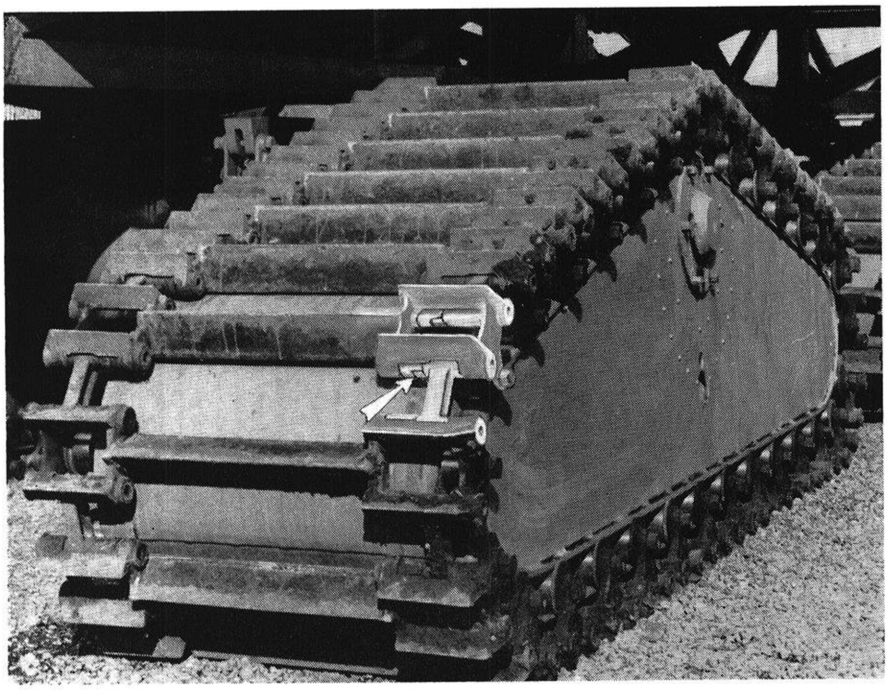

Figure 2.—The Track linkage system.

10-ton winch mounted upon the front of the Sno–Cat is powered by a drive shaft coming from a gear power take-off on the transmission An A-frame can be mounted either at the front of the Sno–Cat over the winch or at the rear where the winch cable may be taken under the vehicle via guides. Blocks must be installed between the Sno–Cat frame and axle housing to prevent overloading of the springs when lifting heavy loads. A trailer hitch with pins for pulling at 18 or 40 inches above ground level is also located at the rear.

Cab Specifications

The black, rectangular, "shoebox" cab is 24 feet long, 8 feet wide, 6 feet high, and is insulated on its top, bottom, and sides with 1 inch of glass wool. The outside wall is of heat-treated aluminum; ¼ inch plywood covers the interior walls with 1 inch square metal tubing packed with glass wool as studding. Because of its heat absorbing qualities, flat black paint was chosen for the exterior. Three doors, one on each side towards the front and a third at the rear provide access. In addition, two hatches are located in the roof, one forward over the engine and one in the rear. There are two windshields, a driver's window, riders' window, rear door window, and two double paned skylights in the roof.

Controls

The front 8 feet of the cab contain the Sno–Cat controls: steering wheel, foot throttle, clutch pedal, handbrake, winch control, batteries, Southwind 1030CC24V defroster (30,000 B.T.U. fresh air), windshield wiper, engine preheater, Coleman Model 871 (35,000 B.T.U.) space heater, engine hood, and instrument panel. The instrument panel includes an engine tachometer, engine coolant temperature gauge, engine oil pressure gauge, steering hydraulic pressure gauge, air pressure gauge, speedometer, odometer (reading in hundredths of a mile), ammeter, starting motor gearengaging lever, fuel primer pump, hand throttle, radiator shutter control knob, defroster control box, windshield wiper switch, oil preheater switch, headlight switch, starting motor toggle switch, intake manifold glowplug indicator light, oil preheater indicator light, and ignition switch. An AN/GRC-9 radio is suspended from the ceiling over the engine hood within easy reach of the driver.

Electrical System

The 843 Sno–Cat supplies 28 volts D.C. at 50 amps from a Leece Neville alternator-rectifier system. Electrical wiring runs within the walls throughout the vehicle with outlets available for plugging in 24V fans, soldering irons, inverters, etc.

Scientific Equipment

In one vehicle, containing permanently mounted scientific equipment, the charging system also takes care of batteries for the seismological instruments. One full-length rack holds the amplifier and control banks for the Texas Instruments seismograph system. The accompanying oscillograph and developing tanks for the seismographs are mounted on a stand at a convenient height. A special gravity-meter tripod, shown in Figure 3 suspended from a hook in the ceiling, can be let down through a hole in the floor to rest on the snow surface. When pulled up and locked in place, the base of the tripod seals the hole. The gravity meter is carried in a cushioned mount next to the tripod. This vehicle was termed "Seismology–Cat" on the traverses, and will be referred to as such throughout this report.

Kitchen

A kitchen is located in the rear 8 feet of the Glaciology–Cat which is equipped with dining table (folding top), snow melting and water storage box, cooking table, benches (with hinged tops for food storage), shelves, and cupboards. This room has one door that separates the kitchen from the rest of the Sno–Cat and another opening to the outside. This vehicle was referred to as the "Glaciology–Cat" in the field and the same name is adopted here.

Furnishings

Both vehicles have similar furnishings, consisting of five bunks that fold against the wall, five built-in desks, cabinets, and shelves. Three desk tops are also used for sleeping, making a total of eight sleeping spaces. The only permanent seats are those in front for the driver and rider; both equipped with adjustable rubber torsion bars.

Figure 3.—The gravity-meter tripod.

Heating System

Two heating systems in the cab can be used whether the vehicle is in operation or parked. Two 35,000 B.T.U., forced air, Southwind 1030C heaters operate when the Sno–Cat is running. One is located in the front and used mainly for defrosting; the other heater is centrally located in the cab. Generally neither of these heaters is required as the engine supplies sufficient heat for passenger comfort. When the vehicle is not in operation and battery power must be conserved for starting the engine, a Coleman Model 871, 35,000 B.T.U., space heater can be used. As this heater has a gravity feed fuel system and no fans, it operates without battery drain.

OPERATION

No Pulled Load

A fully equipped Sno–Cat carrying ten passengers, but pulling no load will travel in fifth gear over small sastrugi and hard snow at speeds up to 18 mph. There is little or no drawbar capacity in fifth gear on hard snow. Equal speeds are possible on hard glare sea ice with an estimated drawbar capacity of 250 lbs. On sea ice, this speed is very hard on the tracks as there is no snow lubrication of track rollers and pontoon rails.

Fourth gear is better for cruising, causing less track wear at 10 to 12 mph and offering reserve power for driving in soft snow or pulling a small sled. The additional power provides a much smoother ride as vehicle speed can be recovered without shifting after slowing for a bump. Drawbar capacity in fourth gear is 500 lbs. on moderately smooth, hard snow surfaces, and increases to 750 lbs. on very hard surfaces.

Third gear is the most used for cruising, whether the vehicle is pulling a full load or not. In this gear 5 to 6 mph can be maintained under almost all snow and loading conditions. Actual pulling capabilities of third gear were not measured but the drawbar pull is estimated to be about 3,000 lbs.

If the snow surface is soft and the towed load is large, a lower gear may have to be used. Gears lower than third are also used for putting the vehicle in motion and for slow speed operation. When shifting from first to second gear, the vehicle comes to a complete stop. To get into higher gears a rapid shift is necessary as the vehicle decelerates rapidly, especially in soft snow with heavy towed loads.

Pulled Load

The Sno–Cats have been used on two different traverses, pulling loads for a total of 2,000 nautical miles. During the 600-mile Discovery Deep Traverse, two Sno–Cats pulled Otaco 10-ton sleds with an initial 8-ton load that decreased in weight as fuel and explosives were consumed. Temperature conditions on this trip ranged from —7°C to —43°C and the surface varied from smooth to moderately rough. The Sno–Cats pulled the 8-ton loads in third gear at 5 mph with the engines operating at 2,100 rpm. Starts after the vehicles were warm were made in second gear with a quick shift into third gear. Difficulty in moving a sled after parking for the night was encountered once. This was presumably caused by sled runners freezing to the snow. Subsequently when starting the Sno–Cats were first backed up to introduce a little slack into the linkage in the sled runner system before moving ahead. This extra slack gave the 843 Sno–Cats some momentum on starting and the jolt on the sled broke the runners free.

On the second traverse from NAF McMurdo up the Skelton Glacier and then to the South Pole, the Sno–Cats each pulled a Rolli-Trailer shown in Figure 4 and a 1-ton sled. A maximum load of 15 tons (including the weight of the Rolli-Trailer, 1-ton sled, and supplies) was pulled at 5 mph for 1,280 nautical miles, the load decreasing between resupply points.

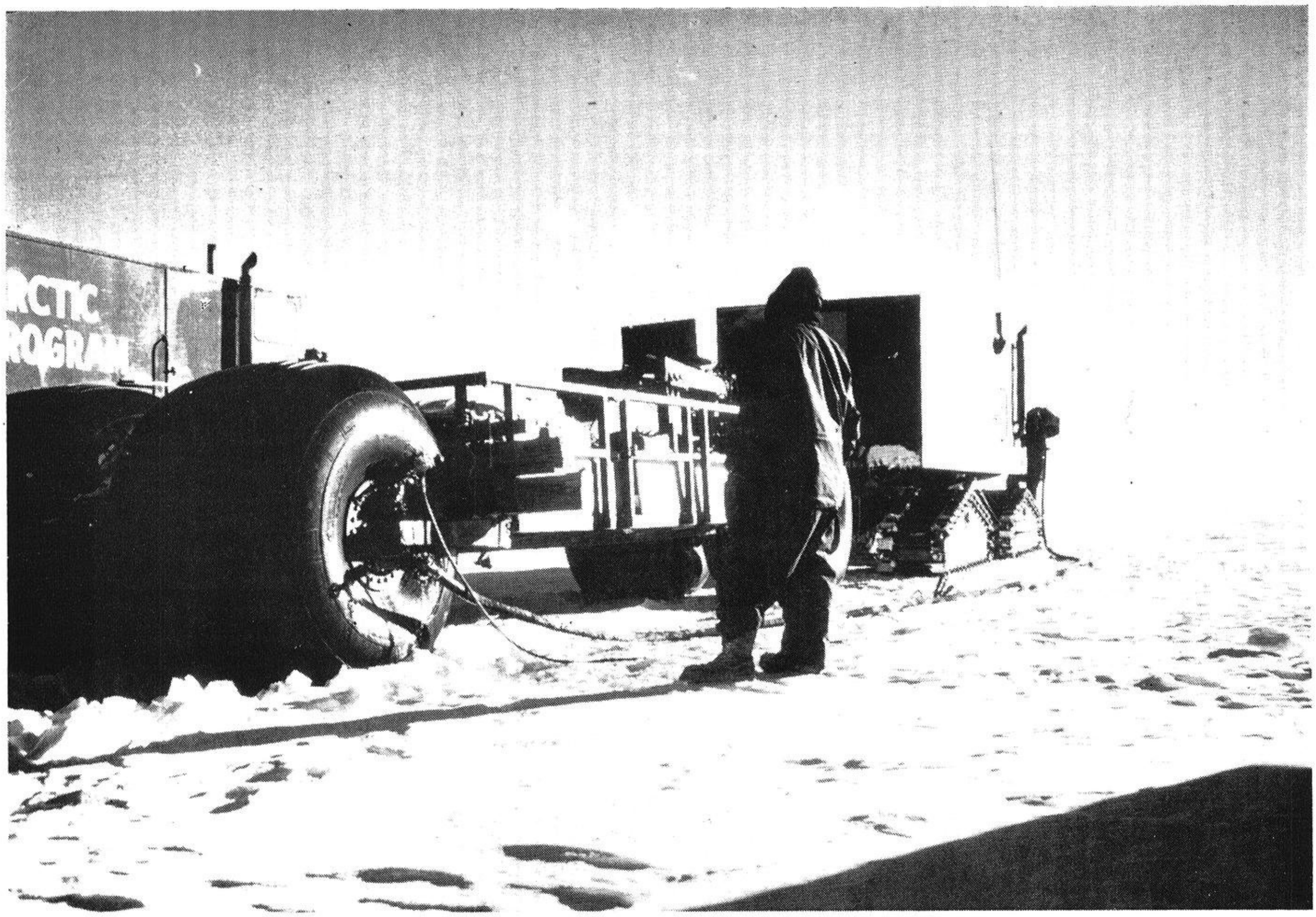

Figure 4.—The Rolli-Trailer.

Dynamometer tests were made once on the second traverse. These tests were conducted in snow that was relatively soft with the Rolli-Trailers and sleds fully loaded. The dynamometer was hooked between the Sno–Cat and Rolli-Trailer hitches. Momentary measurements of starts varied between 14,800 lbs. and 11,700 lbs. Cruising figures were obtained by driving in a straight line through undisturbed snow surfaces in second gear at 2.5 mph and 2,100 rpm. Runs were made in both directions to account for any slope of terrain. On all test runs the dynamometer measured a minimum of 4,500 lbs. and a maximum of 5,500 lbs. of pull. Unhooking the loaded 1-ton sled from the Rolli-Trailer made a difference of 400-lbs. pull. These tests were made in what would be considered soft snow for the Antarctic. The Rolli-Trailer tires sank about 10 inches below the normal snow surface causing a 6-inch pile of snow to be pushed in front of the tires. Under these conditions vehicle wear and fuel consumption were increased.

Fuel Consumption

Diesel fuel consumption records for Sno–Cats are available from the Discovery Deep Traverse and the the McMurdo-Pole Traverse. On the Discovery Deep Traverse, where 10-ton Otaco sleds were used, the total weight pulled was 11 tons per vehicle (sled and supplies). This dropped to 7 tons at the end of the traverse after consumption of food, dynamite, and fuel. A daily record was not kept and figures for total fuel consumption were used to compute fuel mileage. It was assumed that both Sno–Cats burned the same amount of fuel, since both pulled the same size loads. The average fuel consumption over the 600-mile trip was 0.77 nautical miles per gallon; this includes the fuel used in the diesel-burning preheaters and personnel heaters.

The fuel consumption chart for the McMurdo-Pole Traverse was made up from the daily log books of the Sno–Cats where each vehicle pulled a Rolli-Trailer. In addition, the Seismology–Cat pulled a loaded one-ton sled. These loads were pulled at altitudes above 9,000 feet where fuel consumption varied between 1 and 0.5 nautical miles per gallon; changes in the snow surface and loads pulled caused the variation in fuel consumption. Over the whole traverse the average for the Glaciology-Cat was 0.78 nautical miles per gallon, and for the Seismology–Cat was 0.75 nautical miles per gallon. The difference in consumption reflects the heavier loads pulled by the Seismology–Cat as well as extra idling required during refueling. This load difference was probably also responsible for the greater breakage in the Seismology–Cat.

Thus, with these operating characteristics of the 843 Sno–Cat, the traverse self support range was extended from 500 miles with the 743-AN Sno–Cats to 1,000 miles with the 843 Sno–Cats. This extension is due to the ability of the 843 Sno–Cat to pull large loads at a reasonable rate of fuel consumption without breaking down.

The two 843 Sno–Cats pull a total fuel load of 4,000 gallons of diesel fuel. At a high estimate of 4 gallons consumed per nautical mile for the three traverse vehicles; this works out to a 1,000 mile self support range.

MAINTENANCE

Routine Maintenance

The 843 Sno–Cat is larger than previous United States scientific traverse vehicles but maintenance is easier, because the number of grease points remain the same but are more accessible than on the 743 models. Before greasing the tracks and body it was found necessary in some points to heat the fittings and grease journals. This melted any ice in the incoming grease and dispersed the water evenly. Greasing the track rollers without heat movedapproximately 35% of the outside races offi their shoulders until the races hit the pontoon. Grease jobs, engine oil change, and filter changes were .done every 500 miles. The large hood allows ample room for engine adjustments with exception of the engine fuel pump which is hard to remove or adjust in place.

Repairs and Modifications

On arrival of the Sno–Cat in January 1960 in McMurdo, most of the repair time was spent in correcting the damage caused by the corrosion of salt water. But, soon a weakness in the tie rods and track system appeared which took considerable time for repairs.

The tie rods were breaking their tapered spindles in the tie rod ends. During one morning of operating the Sno–Cats with no pulled loads, 3 tie rod ends broke. At this rate, the spare tie rod ends were soon expended. Therefore in order to operate the vehicles, the rear fifth wheels were detached from the steering systems and secured to the frame. This limited the maneuverability of the vehicles, but it also stopped further breakage till new tie rod ends could be obtained.

The new tie rod ends were obtained in October of 1961. These contained spindles made of a much tougher metal. After the installation of these tie rod ends, the problem of breakage was eliminated.

At the same time that the tie rod problem became apparent, it was also suspected that the Tucker track design for the Sno–Cat was also going to cause trouble. For after the Discovery Deep Traverse of 600 miles in March, 1960, some of the track pin lock springs were unevenly worn more than half way.

Replacement lock springs with a better heat treat were installed for the 1960–61 South Pole Traverse. But, by the time the vehicles had traveled an approximate 1500 miles to the South Pole, many of the lock springs were completely worn through—such that the sprocket was pushing directly on the track pin, resulting in scarred pins.

The system of lock springs was abandoned and in November of 1961, solid steel rings were installed. These rings are expected to have much longer life than the lock springs.

The tie rod ends and track systems have been the main problems involved in repairs and modifications. There have been many smaller repairs and modifications, but it should be noted that, with exception of universal joints, the frame and drive system up to the tracks have given no trouble and yet pull a 15 ton load.

Repairs and modifications on the Sno–Cat are generally simple to perform. However, it is necessary to get used to a large vehicle with large heavy components. Generally, for any major repair, two traverse engineers work together, using such heavy duty tools as 20-ton hydraulic jacks, 1½ ton cable-ratchet hoists and 5 foot pry bars to move the heavier components. But, to make up for these heavier components, there is much more working room in and around the vehicle as compared to smaller vehicles.

CONCLUSION

General

The Sno–Cat provided comfort and extended the traverse self support range. But, considerable time and effort was spent in keeping the reliability of the vehicle up.

The comfort of the Sno–Cat is far greater than previously used traverse vehicles. This is necessary for the vehicle is designed to operate in the highest, coldest part of the Antarctic where scientists need a compact, comfortable shelter of some kind.

Comfort is very important, for the traverse vehicle represents more than a means of transportation. The vehicles are the homes and offices of eight men for three to four months. Freedom to stand up and walk rather than crawl and climb in is a morale booster.

The two Sno–Cats provide a total living and working floor space of 8 ft. by 34 ft. and head room of 5 ft. 10 in. In this space with beds, desks, kitchen, dining table, chairs, shelves and scientific equipment, it was shown on the 1960–61 McMurdo-South Pole Traverse that 8 men could live and work comfortably on the South Polar Plateau.

The Sno–Cat gives a smooth ride due to its overall length and the construction of its pontoons, which independently follow the contour of the snow surface. The doors are large and are equipped with steps so that it is easy to get in and out of the vehicle with bulky clothes and clumsy boots. The flat black exterior color of the Sno–Cats aided in heating the vehicles by absorption of the sun's heat, which, combined with forced air heaters and space heaters, make the vehicle comfortably warm. The availability of more space in the interior allowed installation of a space heater, providing a heat source during the days when the vehicle is not operating and electrical energy must be conserved for starting the engine. The space heaters proved especially valuable when the temperature dropped below −46°C.

The traverse self support range was extended from 500 to 1,000 nautical miles. This increase is due to the ability of the 843 Sno–Cats to pull large loads over rough or through soft snow surfaces with a reasonable fuel consumption rate without breaking down.

. The important factors responsible for the increased traverse

(Continued on page 19)

Peter K. Schwalbe is an M.E.-4 from Kenosha, Wisconsin. Jack was membership chairman for ASME and is now President of the organization. He intends to work in the same field he wrote about, stress analysis, after graduation.

Stress Analysis of Turbine and Compressor Blades

By PETER K. SCHWALBE

INTRODUCTION

IN THE design of blades for gas turbines many factors have to be considered. There is the basic problem of translating the thermodynamic principles of gas turbine analysis into the actual operating machines; then there are the practical problems of cost, material, weight, space, tolerances, vibration, noise, mechanical stresses, and safety. This article will be limited to a discussion of mechanical stresses in turbine blades and a short analysis of vibration.

The attempt here is not necessarily to solve all the problems which arise due to stress, but to indicate recognition of them and present them to a reader of reasonably adequate technical background. Such a survey is valuable in focusing attention on the types of problems encountered, and in arousing the reader's interest which might lead him to a more detailed study in this field.

Moving blades of a gas turbine must withstand a centrifugal force which may increase their weight up to 25,000 times their normal values. In addition, rotor and stator blades are subjected to fluctuating forces from wakes left by the preceding row of blades; these changing forces may cause 1,000,000 stress reversals per minute, leading to tremendous fatigue and vibration problems. In the exhaust turbine these large stresses occur at temperatures of 1600°F, presenting problems of creep. Materials for turbine blades have to withstand these demanding loads and maximum temperatures of around 1600°F. It would be desirable to operate at much higher temperatures, because the turbine efficiency is directly proportional to the maximum operating temperture.

TYPES OF STRESS FOUND IN TURBINE BLADES

Various kinds of stresses are encountered in a turbine blade. In general these stresses are caused by inertia forces of the moving blades, or by the pressure forces of the working gas on the blade surface. Thermal stresses do not present much of a problem in the blade itself, because, for a thermal stress to occur, a large temperature gradient has to be present and the temperature in a turbine blade is fairly uniform throughout its length.

In calculating the optimum stress allowable in turbine blades, consideration has to be given to the creep strength at the operating temperature and to the fatigue strength for the required life of the blade. These problems will be discussed under the heading of stress phenomena.

Centrifugal Stress

An outward radial force acting on the mass center of the rotating blade sets up a centrifugal stress. To determine the centrifugal force at the base of any given blade, an integration is required since the acceleration is a function of the radius R. Assuming that the rotor is at constant angular velocity ω, the inertia force dF acting on the element of the blade is the product of the mass of the element dM and the centripetal acceleration $A^n = \omega^2 R$, where w is the RPM of the rotor. The mass of the element is the product of density ρ and the volume of the element bt(dR).

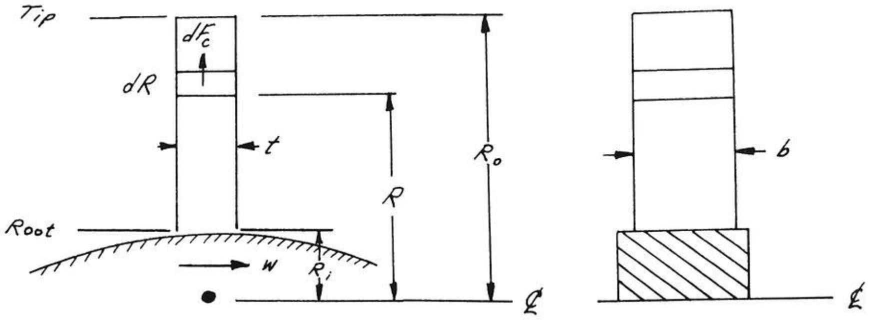

Figure 1.—Determining the stress on a rotating turbine blade.

$$dF_c = \omega^2 R \rho bt(dR)$$

$$F_c = bt\rho\omega^2 \int_{R_i}^{R_o} RdR$$

Stress is defined as a force per unit area. The average tensile stress s_b at the base of the blade due to the centrifugal force is

$$s_b = \frac{F_c}{bt} = \rho\omega^2 \int_{R_i}^{R_o} RdR \qquad (1)$$

The above equation shows that the stress developed at any section in the blade is dependent on four variables: the density of the blade material, the rotor speed, the radius of the tip (R_o), and the radius of the crossection under consideration (R_i). The radius of the rotor and its angular velocity are established by the design of the engine to satisfy the thermodynamic principles. The only real variable the designer can manipulate is the material of the blade. For example an aluminum alloy blade would carry a centrifugal stress of only about one third that of a steel blade.

Equation (1) demonstrates that the stress in a blade of uniform cross-sectional area decreases from a maximum at the root to a minimum at the tip. Since stress is equal to force per unit area, in order to make the stress at the root equal to the stress at the tip the cross-sectional area at the tip could be decreased. A substantial amount of blade material can be saved if the blades are tapered from root to tip so as to obtain a uniform decrease in area. This fact is of special importance for turbines in aircraft application.

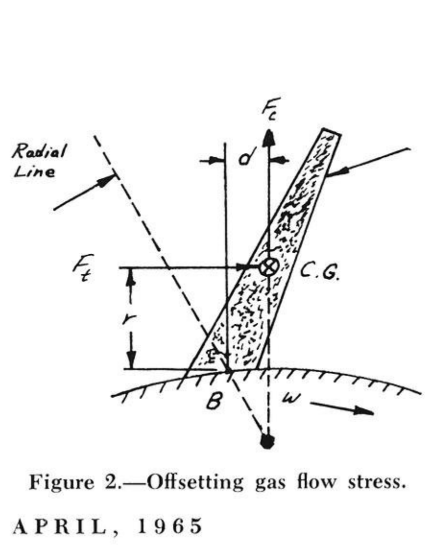

Figure 2.—Offsetting gas flow stress.

Blade Offset Stress

The stress caused by the bending moment about the root of the blade is called offset stress. The forces indicated in Figure 2 are the centrifugal force and the tangential component of the gas pressure force. If point B in the base of the blade is taken as the reference point, the center of gravity of the blade lies to the right of a radial line through point B. This is because the blade has been purposely tilted in the direction of rotation. With this arrangement, the centrifugal force creates a counter clockwise bending moment $F_c xd$ around point B, and the tangential gas pressure force causes a clock wise bending moment $F_t Xr$ around point B. Note that the moment of the gas force can be exactly canceled by the moment of the centrifugal force if the blade is tilted the correct amount in the direction of rotation. Such a design results in exact cancellation for only one set of gas-flow conditions occurring simultaneously with any one certain RPM. The method may be used to design for a particular high operating load and speed. For other operational conditions the bending stress is then reduced but not entirely canceled.

Gas Pressure Stress

The flow of fluid over turbine and compressior blades causes pressure variations over the blade surfaces. These variations between the two tangential faces of a turbine blade cause the turbine rotor to turn. The pressure differentials can be reduced to forces acting in the tangential direction of the blade. In addition to tangential forces, axial forces caused by momentum changes of the gas as it passes through the blades are acting on the blades.

The magnitude of the resultant tangential and axial force can be determined from the known changes in main stream conditions. With these forces their bending moments and hence the blade-bending stress can be calculated. If the line of action of the tangential and axial forces does not pass through the center of gravity of the blade, there will be additional torsional effects. (This twist is discussed in the next section.)

The resultant gas force on each strip is broken into the respective tangential and axial components, and moments about the centroidal axes in the root section or any other section can be calculated. There will be two moments, one about the AA axis and one about the TT axis, when moments at the root are considered. A summation of moments about the root axis AA of tangential force components yields the moment for the gas forces on the whole blade about that axis, and similarily a summation yields the moment for the whole blade about the root axis TT.

With the moments in the root section now known, the next problem is the calculation of stresses. The principles of mechanics require that the two bending moments be obtained about the two principle axes in the root section. Principle axes are mutually perpendicular through the centroid about which the *second moment* of area *is* a maximum and minimum. For symmetrical areas, axes of symmetry are always principle axes. Figure 3, the common turbine or compressor blade root section, illustrates an example of an unsymmetrical area. The principle axes are found to be an angle θ from the axial direction about which moments have been determined. The angle θ at which the priciple axes are found to be located, is calculated by Mohr's Circle Method.

Let the known moments about the tangential and axial axes be M_{TT} and M_{AA}, respectively. If M_{TT} is resolved about the axes XX and YY (See Figure 4) the following is obtained:

$$M_{xx} = M_{TT}\cos\theta$$
$$M_{yy} = M_{TT}\sin\theta$$

Similarly for the resolution of M_{AA},

$$M_{xx} = -M_{AA}\sin\theta$$
$$M_{yy} = M_{AA}\cos\theta$$

Therefore the total moments about the principle axes are:

$$M_{xx} = M_{TT}\cos\theta - M_{AA}\sin\theta$$
$$M_{yy} = M_{TT}\sin\theta + M_{AA}\cos\theta$$

The algebraic signs are determined according to the convention shown in Figure 4.

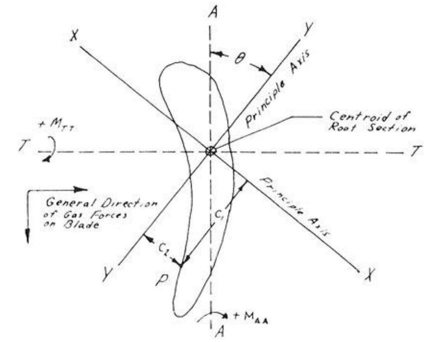

Figure 3.—Gas flow over a turbine causes stresses which are broken up into tangential and axial moments.

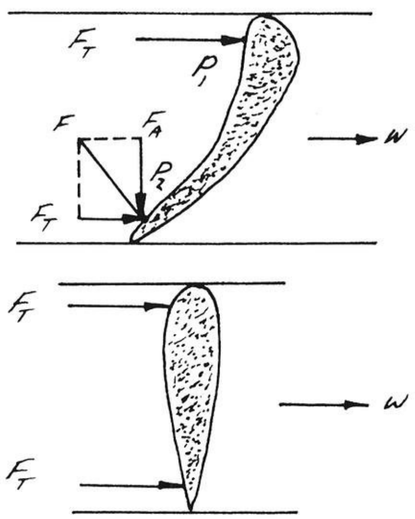

Figure 4.—Gas pressure acts at right angles to the blade surface, setting up twisting stress.

Now that the moments about the principle axes are determined, normal stresses may be calculated from the equation $s = \frac{Mc}{I}$ for each point in the cross-section. For example, at point P the stress caused by the moments about axis XX is,

$$s_1 = \frac{M_{xx}C_1}{I_{xx}}$$

where: s = normal bending stress

M_{xx} = bending moment about the principle axis XX

C_1 = distance from point P to the axis XX

I_{xx} = second moment of inertia of the entire cross-sectional area about the axis XX.

Similarity, at point P the stress caused by the moment about axis YY is,

$$s_2 = \frac{M_{yy}C_2}{I_{yy}}$$

The total bending stress at point P is then the algebraic sum of the two, provided this sum does not exceed the elastic limit of the material.

$$s_P = s_1 + s_2$$

The above formulas for bending stress hold only for materials within the elastic limit. A linear relationship between stress and strain is assumed for materials within the elastic limit. That is, if the stress producing load is removed, the part under load will return.

Twisting Stress

A shearing stress, brought about by a torque acting on the blade around its radial axis is referred to as twisting stress, and occurs only in a highly twisted blade. The gas pressure force will always act at right angles to the blade surface as is shown in Figure 4. At point P_1 the gas pressure force is equal to the tangential component, and the axial component is equal to zero; at point P_2 the gas pressure force is resolved into a tangential component and an axial component. In considering an element towards the base of the blade, Figure 4, it is noticed that this element is not twisted as much as the uppermost element.

The gas pressure force on the lower element does not have an axial component; therefore the upper element has forces acting on it which tend to rotate it with respect to the lower part of the blade. The upper part of the blade might be thought of as trying to untwist, thus causing the shearing stress. This torsional action is usually small in comparison with the other loads and stresses encountered by a blade. For purposes of determining a design limit for blades, this stress is totally neglected.

PHENOMENA RESULTING FROM BLADE STRESS

Once stress calculations have been performed, the ultimate goal is to find materials which can withstand these stresses effectively. For the present, attention may be focused on how the stress limits in a material are affected by the manner in which the load is applied. The amount of stress a material can withstand depends on such factors as the temperature of the blade, the extent of time over which the stress occurs, the rate at which the loads are fluctuating or reversing, and of course the magnitude of the applied load.

Creep Analysis

Creep is defined as the continuous deformation of a material under load with time, and takes various forms depending upon the conditions. The more common case, which is of direct concern to blade design, is when the temperature is constant and the change of strain is observed under constant load conditions. These conditions in a material lead to a form of curve of strain against time. In the primary stage, creep occurs at a diminishing rate; the rate stays constant in the secondary stage, and it increases in the third stage till fracture takes place. By checking the curve it is found that it takes 1,000 hours till failure occurs. It is usual to specify materials by stresses derived from families of such curves, which give a creep rate of say 10^{-6}% per hour. At higher temperatures creep becomes a very serious problem. For a given design configuration and for the same life expectancy of the blade an increase of 80°F might result in a reduction of allowable operating stress of 75%. The design limits for a turbine which has a life expectancy of maybe 25 years of use in a power plant, are very different from those limits appropriate for a turbine of a high speed fighter plane whose service life is perhaps three to four years.

Vibration and Fatigue Analysis

Vibration in turbine and compressor blades is excited by alternating pressures in the gas stream set up by interruptions in stream by intake spiders, stator blades, inlet guide vanes, and nonuniform pressure distributions at the inlet.

For example, as a rotating blade moves from a position between the stator blades to a position directly behind the stator blade, the pressure forces on the blade change magnitude from a high value to a lower one. If there are 120 rotor blades, each rotor blade experiences 120 pressure changes per revolution; and if the motor rotates 200 rounds per second, then the blade vibrates 24,000 times a second. If the frequency of disturbance occurs at or near the natural frequency of the blade, the amplitude of vibration might increase to such large values that failure of the blade will result. Consider a small force, which if applied statically, produces a negligibly small deflection and stress. This same force when applied periodically at or near a natural frequency, will add energy to the system with each application and build up the magnitude of deflection. Every system has certain dampening elements in its, which in the case of the blade are the forces between the molecules of the material as the blade is displaced from one extreme position to the other. If the amount of energy added to the system with each periodic disturbance finds an equilibrium point with the amount of energy dissipated due to damping, the problem is relatively under control. If, however, an equilibrium point cannot be obtained, the blade will fail.

The object of vibration study in blade design is to remove or reduced the possibility of fatigue failure in the blades during their working life. If a blade vibrates, the stress in the blade fluctuates; in some cases a complete reversal from tensile stress to compressive stress might take place. These stress fluctuations take place at around 24,000 times a second, as mentioned above. This condition is known as fatigue stress and occurs primarily at the surface of the blade. Therefore it is very important that the surface is superfinished; it cannot have any grooves or scratches because these imperfections act as stress concentration areas. Fatigue strength is dependent upon the magnitude and number of stress fluctuations per unit time. The fatigue strength also changes with temperature; an increase in temperature usually means a decrease in fatigue strength.

CONCLUSION

The considerations made above refer to the most basic problems encountered in the stress analysis work of turbine and compressor blades. Probably the single and most important point which governs the material selection of the blade is the continual high temperatures developed in the turbine. It was seen that creep and fatigue strength are very dependent on temperature. The damping properties of a material, in suppressing excessive vibration, are also affected by temperature, and so are the pure physical properties of a material, such as expansion coefficient, specific weight, ductility, etc. A rise in temperature may also cause a change in the chemical structure of an alloy. A combination of elements has to be picked so that these changes in the elements do not, for the most part, occur in the temperature operating range. Once a material has been found that will satisfy these demanding requirements, the material has to be shaped into the form set forth by the thermodynamic principles of the gas turbine. The profile of a turbine or compressor blade is not readily reproducible by even the most modern machining methods.

The search for a suitable blade material has led to the use of plastics. Also, preliminary investigations are under way looking toward the use fibercloth-reinforced materials. Several reasons for replacing metal with reinforced plastic are cost savings, weight reduction, and elimination of fatigue problems. The field of gas turbine blade design is a wide open field and the success in solving the existing problems will depend, to a large extent, on the development of new alloys. **END**

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Sno-Cat

(Continued from page 15)

range are the engine and the vehicle towing capacity. First, the Cummins diesel engine consumes less fuel per pound-pulled than do similar capacity gasoline engines. In addition, the diesel engines, with their turbo chargers, operated at full horse power with sea level efficiency at the altitudes encountered on the Polar Plateau.

The second factor extending the traverse range is the increased strength of the model Sno–Cat which was designed to pull heavy loads for long distance. The vehicle has sufficient strength in the drive system, frame, and trailer hitch, and has a greater track area to handle heavy towed loads in soft snow. The larger towing capacity made it possible to tow Rolli-Trailers (which are estimated to haul 50% greater loads than bobsleds) with the same travel speed, repair requirements, and fuel consumption as the previously used traverse vehicles with smaller loads.

Reliability on the traverses, came after the investment of considerable time and effort. The main item requiring time and effort is the track system. Not only did the original track system prove short lived, about 750 miles, but to replace and adjust it required much effort and time. It is hoped that the new track system will prove more trouble free.

The Cummins diesel engine, equipped with a preheater, started reliably in cold weather and at high altitudes with no loss of time. While operating under load the engine gave no trouble. The rest of the Sno–Cat systems, with the exception of the tracks and upper drive shaft, met the heavy load requirements day after day with only minor repairs. It is felt, that once the track system is reliable and easily maintained, the 843 Sno–Cat will be extremely reliable with a minimum investment of effort and time.

(Continued on page 24)

1965 ENGINEERING EXPOSITION

PRIZE WINNING EXHIBITS

STUDENT ORGANIZATIONS

1. Theta Tau—"Delay in the 4th Dimension"
2. ASME—"Air Effect Machine"
3. ASCE—"Phases of Civil Engineering"

STUDENT GROUPS

1. George Ignatgens, Tom Brunner & Frank Mesner—"Automated Conveyor System"
2. Orthagonal Cutting
3. Rodney Raether "Automatic Thermal Fabrication

INDIVIDUALS

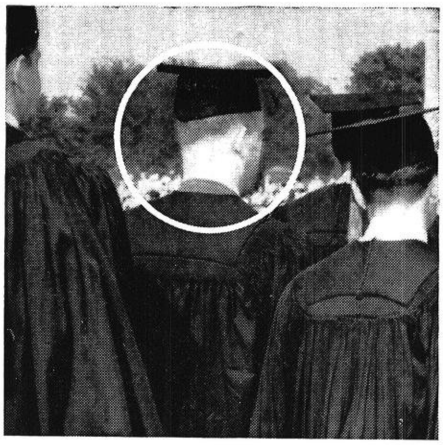
1. Frank Janes—"Schlieren System"
2. Tom Parks & John Holtan—"Jumping Wire"
3. Robert Schasse—"Spacecraft Guidance by the Stars"

GRADUATE STUDENTS

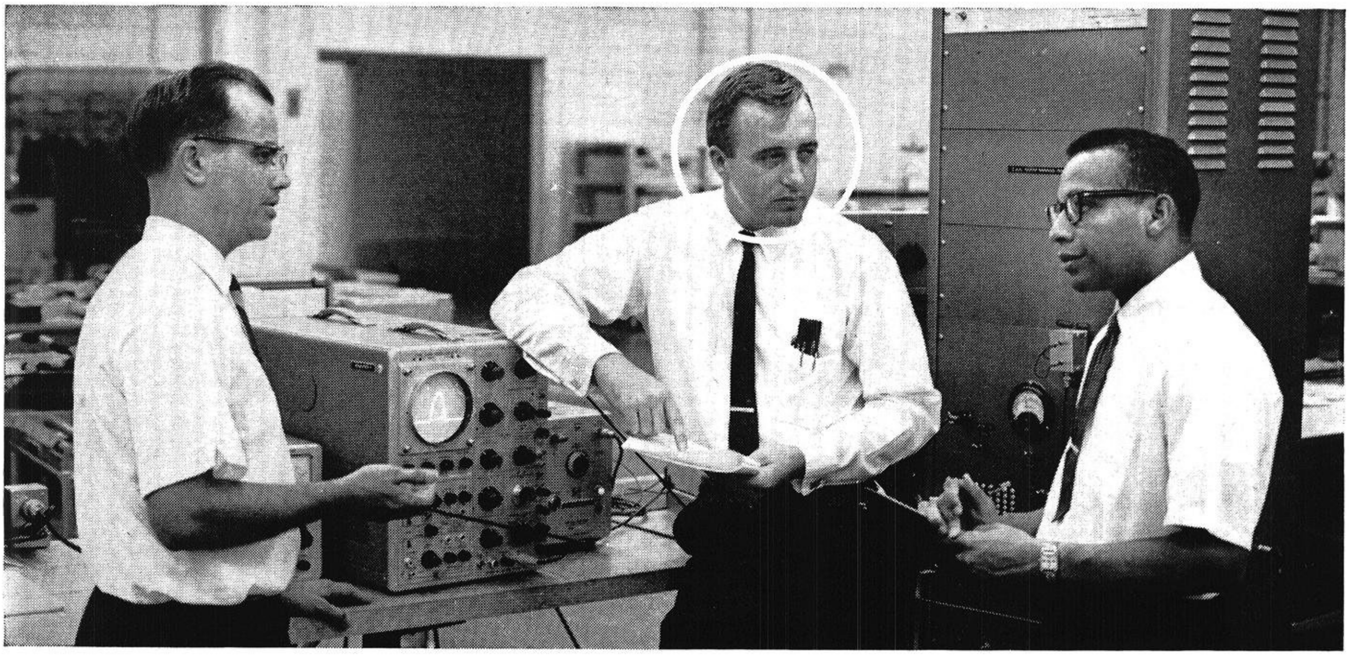
1. Warren Hingst, Munthin Aldruby & Tom Moran—"Radio Frequency Excited Plasma Tunnel"
2. Daniel Nass—"Extractive Metallurgy—Metals Through Chemistry"

CRAFTSMANSHIP

1. Kappa Eta Kappa—"F.M. Stereo Demonstration"
2. John P. Byrns—"SCA Multiplex Demonstration"



Tom Huck sought scientific excitement



He's finding it at Western Electric

Ohio University conferred a B.S.E.E. degree on C. T. Huck in 1956. Tom knew of Western Electric's history of manufacturing development. He realized, too, that our personnel development program was expanding to meet tomorrow's demands.

After graduation, Tom immediately began to work on the development of electronic switching systems. Then, in 1958, Tom went to Bell Telephone Laboratories on a temporary assignment to help in the advancement of our national military capabilities. At their Whippany, New Jersey, labs, Tom worked with the Western Electric development team on computer circuitry for the Nike Zeus guidance system. Tom then moved on to a new assignment at Western Electric's Columbus, Ohio, Works. There, Tom is working on the development of testing circuitry for the memory phase of electronic switching systems.

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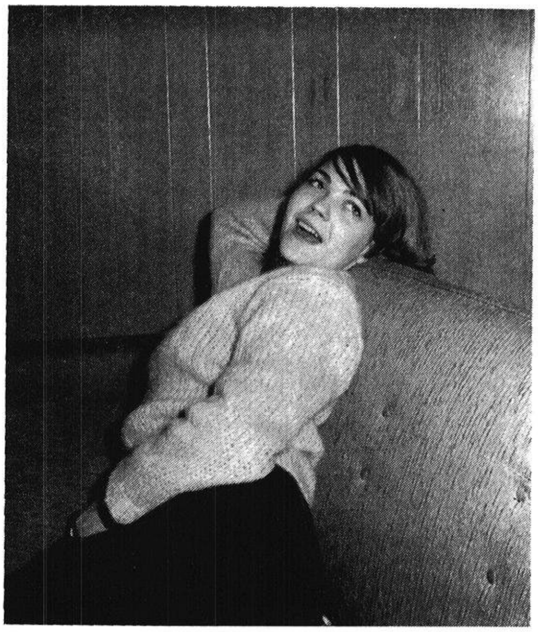
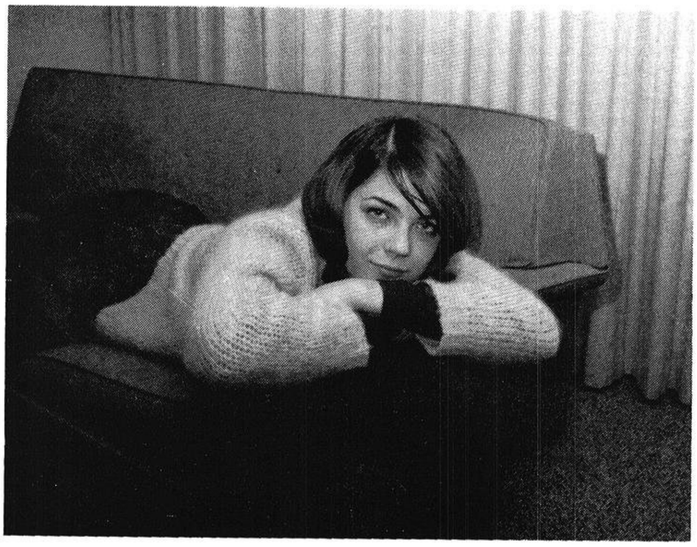
GIRL OF THE MONTH

Cheryl Bagwell.

"In the Good Old Summertime," or something like that. Yes, it was inevitable—our thoughts have turned away from books towards what the girls have been thinking all winter. Our 5′-8″ blue-eyed brown-haired beauty hails from Westport, Connecticut. Academically, she's a sophomore interested in having Computer Sciences as a major. Cherie lives at Chad and is currently co-captain of the women's swim team. We're sure you'll agree that she's the best-looking thing we've seen near a computer for a long time.



What are you climbing the walls for?



No, I'm not busy tonight.

You called?

W. E. Staff Photos by
Bob Stoelting

Sno-Cat

(Continued from page 19)

Modifications

The main alteration to the vehicles was in the drive system, where a six-speed automatic transmission replaced the five speed manual shift transmission. The manual shift transmission was mismatched with the diesel engine causing a shifting problem. The manual transmissions had gear ratio steps as great as 69%. Any step beyond 40%, which drops the engine below 1800 rpm, creates a rapidly decreasing ratio of horsepower.

The power loss is especially noticeable at altitudes above 5,000 ft. where full power of the engine is dependent upon fast spinning of the turbine which is dependent upon engine rpm. When an upshift is made with the manual transmissions, the large step between the gears drops the engine rpm. Power loss occurs as the turbine slows down and less air is forced into the combustion chamber.

In addition, vehicles with towed loads do not coast, so that regardless of the speed of the shift, the vehicles slow up rapidly during the shifting process. This adds to the drop in rpm and loss of horsepower which make it necessary to downshift immediately unless the vehicle is on hard snow.

This shifting problem was increased when inexperienced drivers operated the vehicles. In attempting the rapid shift they usually engaged the wrong gear or sometimes even got in reverse. Sometimes they would hesitate on releasing the clutch until the engine was at maximum rpm and the vehicle almost stopped. In their confusion they then may slip the clutch to maintain engine speed, thereby burning the clutch plate and cracking the flywheel.

The automatic transmissions should eliminate most of the driver's problems, but most important, the six-speeds forward in 40% steps will match the engine requirements. Connected with the transmission is a torque convertor which will maintain proper engine rpm, keeping the engine turbine spinning fast enough for proper horsepower at high altitude. The torque convertor coupled with the ability to shift instantly at full throttle, will eliminate difficulty caused by lack of coasting ability.

The drive line system to the winches on the 843 Sno–Cats was replaced by hydraulic power. This change was made necessary by the power take-off arrangement on the automatic transmissions.

Recommendations

In addition to the alterations that were made prior to the 1962–63 Pole Traverse, there are other conditions that should be corrected in the future. Five universal-joints have failed to date. The universal-joints are strong enough for the loads, so it appears that the angle through which the universal-joints work is too great.

The transfer cases leaked oil so that it was necessary to add gear oil every day; this was additionally troublesome as the fill plug for the transfer case was too small for convenient use. The cause of oil leakage is not known.

The largest problem is still in track system. Regardless of the possible success of the new untested track system, its adjustment will take about 16 man-hours per Sno–Cat. This adjustment has been made two times per vehicle in 2,200 miles and about 15% of the links show cracks from the adjustment. It is estimated that only three more adjustments are possible before major alterations are necessary for further adjustment.

Although considerable effort was spent on repairs and alterations of the 843 Sno–Cats, the self-supported range, reliability and comfort of traverse vehicles have made the effort worth while. When the planned modifications are incorporated, the vehicles are expected to operate with much less mechanical maintenance and to pull larger loads with more economy than previous traverse vehicles. END

"PRINTABLES"

An M.E. went to a psychiatrist and told the doctor that he had a physical attraction for horses. The psychiatrist told him that there was nothing wrong with that, in fact most people have a fondness for animals.

"But this is more than just a fondness,' said the M.E., "it is a very strong physical attraction."

The psychiatrist said," Is this attraction for male or female horses?"

"Female horses," said the M.E., "what do you think I am, queer?"

* * *

Salesman: "I have here the one and only sure cure for dandruff."

Housewife: "Really, how does it work?"

Salesman: "Oh, it's awfully simple—it's a mixture of alcohol and sand."

Housewife: "But how does it cure dandruff?"

Salesman: "Well you just rub the mixture on your hair; then the bugs get drunk and kill each other throwing rocks."

* * *

They had been sitting in the swing in the moonlight alone. No word broke the stillness for half an hour until—

"Suppose you had money," she said, "what would you do?"

He threw out his chest, in all the glory of young manhood, "I'd travel."

He felt her warm, young hand slide into his. When he looked she was gone.

In his hand was a nickel.

* * *

She: "What made you decide to become a parachute jumper?"

Pilot: "A plane with three dead engines."

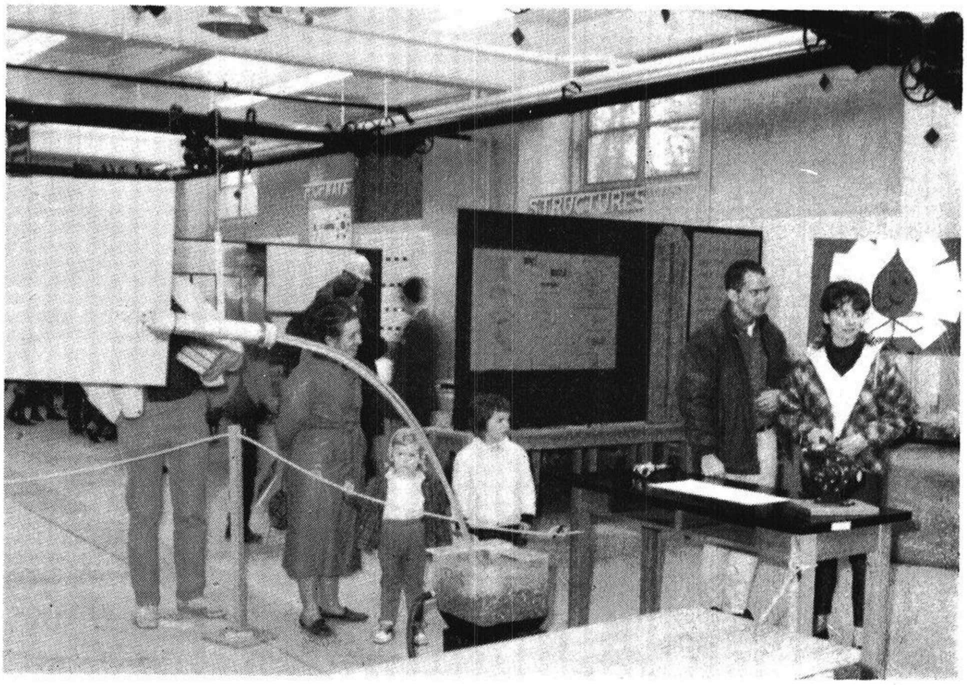
* * *

A farmer wrote in to a mail order house asking their prices on toilet tissue. He received this reply, "see our catalog page 641 for prices.", to which he replied that if he had a copy of their catalog he wouldn't need the tissue.

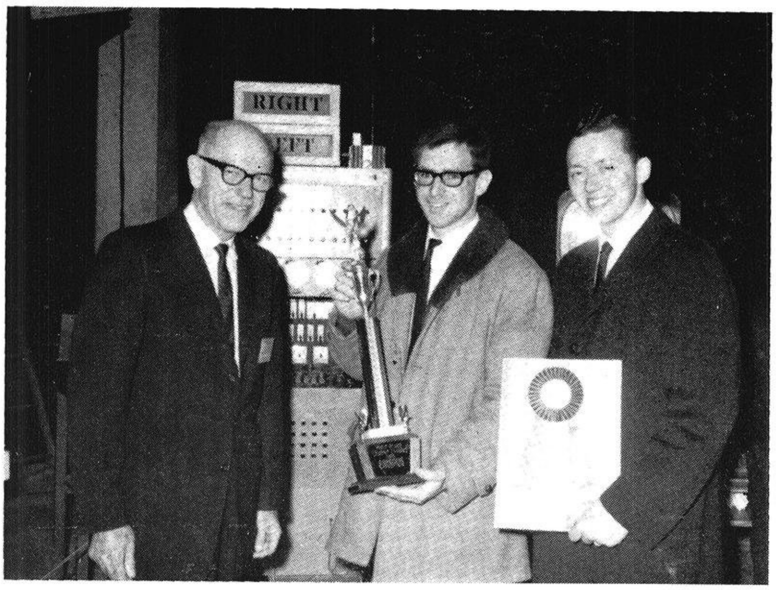
Estimated 15,000 Attend 1965 Engineering Exposition

Shown above are some of the estimated 15,000 people who attended the recent four-day 1965 Engineering Exposition. Termed a great success by General Chairman Don Holloway, the triennial event offered a wide range of exhibits, with every major and minor division of modern engineering represented. The **Wisconsin Engineer** extends its compliments to the Exposition Committee for a job well done!

A COMPLETE LIST OF PRIZE-WINNING EXHIBITS IS ON PAGE 20



Shown here is the ASCE composite exhibit, which was located in the new Hydraulics Lab. ASCE took third place in organization exhibits.

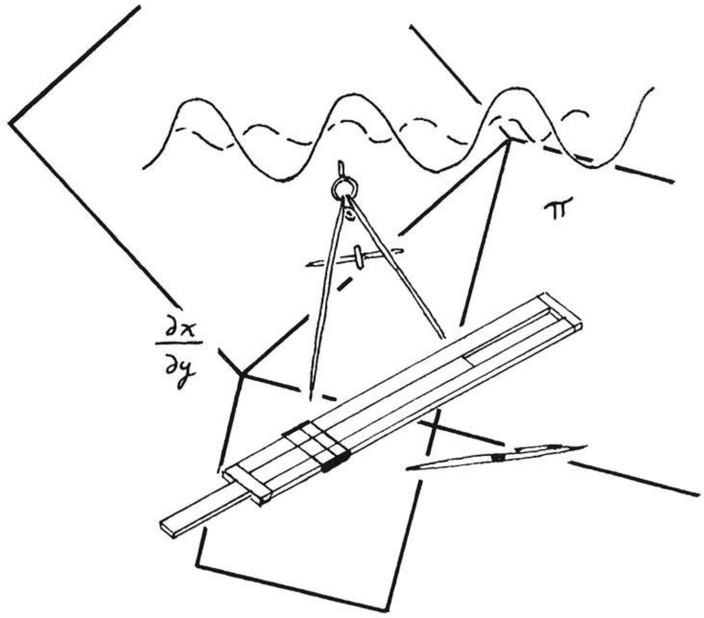


"Delay in the Fourth Dimension," by Theta Tau, won a first place trophy in organizations division. Here Dave Lucoff & Dwight Zeck accept the award from Dean Kurt F. Wendt.

First place for a student group exhibit went to George Ignatjens, Thomas Brunner and Franklin Mesner for their automated conveyor system. Dean Wendt is shown presenting the award to Robert Goetz.

W. E. Staff Photos by Bob Stoelting

THE MENTAL MAZE



By CLIFTON FONSTAD, JR. ee4

APRIL means that you have only this one more chance to win a Maze Master award this year. Next month's answers will be given after the problems and there will be no May Maze Master. So that you can get to the puzzles quickly then, we'll cut the words of wisdom short and simply make note of the fact that the Mental Maze is just packed with illustrations and good puzzles to go with them this month.

Now, let's get started on the first puzzle—the first turn in this month's Mental Maze.

1. The first puzzle is one for the industrial engineers. Anyone can work it though so have a go at it.

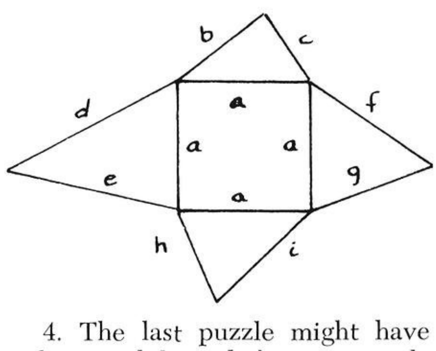
If a tinker and his helper can refabulate a widgit in 2 days, and if the tinker working with his apprentice instead would take 3 days, while the helper and the apprentice would take 6 days to do the job, how long would it take each working alone to refabulate the widgit?

2. Here's an interesting problem sent down from a fan at Tioga Tech. One of the landmarks on the Tech campus is a large tower with a clock at the top. This clock tolls out the hours as regularly today as it did fifty years ago but it has changed some. When the clock was installed it took it eight seconds to strike eight; now it takes six seconds to strike six.

Our question is—how many seconds does it take the clock to strike twelve? How long did it take originally?

3. If you're still with us and didn't get tricked too badly by the last couple turns in the maze see if you can get past this next one. Suppose you want to construct the following figure out of matchsticks. In the center is a square with an integral number of matchsticks on each side. Then using each side of the square as a base four triangles are constructed—each is different and each has sides made with an integral number of matchsticks. The result looks like the diagram below where a, b, c, are integers representing the number of matchsticks in each line.

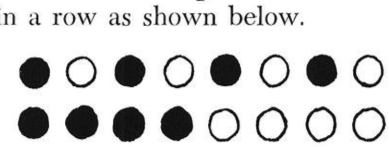
What is the minimum number of matchsticks that can be used to form such a figure?



4. The last puzzle might have taken a while so let's try a couple shorter ones.

In a domino set that runs up to double-six, there are 28 pieces or bones. In a set that runs up to double-nine there are 55 bones. How many bones are there in a domino set that runs up to double-twelve? Who would want a domino set that big?

5. Now, for those of you with money here is a coin shuffing problem. Start out with four pennies and four nickels placed alternately in a row as shown below.



One move is made by moving any two adjacent coins together to another position on the line. Make four such moves and rearrange the coins in a line so that all the pennies and all the nickels are together as shown in the second drawing.

6. To close out April's maze try playing with a little Algebra. There are three computers in the basement of the Lesser Antilles and Farther North Studies Building on campus. Computer A is as old as computers B and C together. Last year B was twice as old as C and in two years computer A will be twice as old as computer C. How old are the three computers?

ANSWERS

The answers to last month's Mental Maze are:

1. 2/5
2. 54,45 years
3. 70 yards
4. $\frac{13485}{2697} = \frac{13845}{2769} = \frac{14865}{2973} = \frac{18645}{3729} = 5$
5. 5 men
6. 416 pages

This is your last chance to win a Maze Master award and the five dollars that goes with it because next month we have to publish the answers with the Maze. So hurry and send your solutions to the Mental Maze, *Wisconsin Engineer*, 333 Mechanical Engineering, University of Wisconsin, Madison. Remember, too, you don't have to have all the correct answers to win.

Should You Work for a Big Company?

An interview with General Electric's S. W. Corbin, Vice President and General Manager, Industrial Sales Division.

S. W. CORBIN

■ Wells Corbin heads what is probably the world's largest industrial sales organization, employing more than 8000 persons and selling hundreds of thousands of diverse products. He joined General Electric in 1930 as a student engineer after graduation from Union College with a BSEE. After moving through several assignments in industrial engineering and sales management, he assumed his present position in 1960. He was elected a General Electric vice president in 1963.

Q. **Mr. Corbin, why should I work for a big company? Are there some special advantages?**

A. Just for a minute, consider what the scope of product mix often found in a big company means to you. A broad range of products and services gives you a variety of starting places now. It widens tremendously your opportunity for growth. Engineers and scientists at General Electric research, design, manufacture and sell thousands of products from microminiature electronic components and computer-controlled steel-mill systems for industry; to the world's largest turbine-generators for utilities; to radios, TV sets and appliances for consumers; to satellites and other complex systems for aerospace and defense.

Q. **How about attaining positions of responsibility?**

A. How much responsibility do you want? If you'd like to contribute to the design of tomorrow's atomic reactors—or work on the installation of complex industrial systems—or take part in supervising the manufacture of exotic machine-tool controls—or design new hardware or software for G-E computers—or direct a million dollars in annual sales through distributors—you can do it, in a big company like General Electric, if you show you have the ability. There's no limit to responsibility . . . except your own talent and desire.

Q. **Can big companies offer advantages in training and career development programs?**

A. Yes. We employ large numbers of people each year so we can often set up specialized training programs that are hard to duplicate elsewhere. Our Technical Marketing Program, for example, has specialized assignments both for initial training and career development that vary depending on whether you want a future in sales, application engineering or installation and service engineering. In the Manufacturing Program, assignments are given in manufacturing engineering, factory supervision, quality control, materials management or plant engineering. Other specialized programs exist, like the Product Engineering Program for you prospective creative design engineers, and the highly selective Research Training Program.

Q. **Doesn't that mean there will be more competition for the top jobs?**

A. You'll always find competition for a good job, no matter where you go! But in a company like G.E. where there are 150 product operations, with broad research and sales organizations to back them up, you'll have less chance for your ambition to be stalemated. Why? Simply because there are more top jobs to compete for.

Q. **How can a big company help me fight technological obsolescence?**

A. Wherever you are in General Electric, you'll be helping create a rapid pace of product development to serve highly competitive markets. As a member of the G-E team, you'll be on the leading edge of the wave of advancement—by adapting new research findings to product designs, by keeping your customers informed of new product developments that can improve or even revolutionize their operations, and by developing new machines, processes and methods to manufacture these new products. And there will be classwork too. There's too much to be done to let you get out of date!

FOR MORE INFORMATION on careers for engineers and scientists at General Electric, write Personalized Career Planning, General Electric, Section 699-12, Schenectady, N. Y. 12305

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