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THE AUTOMOTIVE INDUSTRY
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THE AUTOMOTIVE INDUSTRY

Colonel Jordan and Gentlemen I am glad to have the opportunity of being here. I have no prepared lecture to give you. I thought I might tell you that we appreciate the problem you gentlemen have in this armament business, and that it might be of interest to you to know why we got the way we are instead of some other way.

Our whole business is built around the internal combustion engine. The motor car, the aeroplane, and all of the types of things that we build start with the gasoline engine. Therefore, what you can do with any given type of thing depends on the economical type of power that you may be able to use.

The history of the development of the gasoline engine has been briefly this We started out with a large single cylinder engine with heavy reciprocating parts, and in most cases steam engineers did the original designs. It took us a long time to come down the road before we began to realize that a thousand feet a minute piston speed was not the best thing for a gasoline engine, because the nature of the explosion, the expansion of the gas, etc. seemed to work better if we let them turn a little faster. We also found that there was a very definite practical limitation to the size of a piston. I am going to just touch this now and then I will come back and tell you what we found out about it. Around three or four inches of bore was about the practical place to stop for two reasons first, the weight of the reciprocating parts, and second, that the sensitivity to variations in fuel goes up as the diameter goes up. Therefore, the automotive engine is a fairly small bore.

We followed for a long while the fantasy of the so-called small bore, long stroke engine. We went to Europe and listened to the proponents of the small bore, long stroke engine over there. The efficiency experts came in, and they got the thermodynamic fellows to make a calculation to show that this was the most efficient way to make an engine, but some of us did not believe it so we made a series of four or five engines in which we made the stroke as long and the bore as small as we could get it on one side and ended up on the other side with the bore a little bit bigger than the stroke. Then we said "There is something else back of this besides efficiency," because there wasn't any difference in these things - that is, there were advantages pro and con. Then we went over to Europe and finally found out that the reason they made small bore, long stroke engines was because they taxed their vehicles on bore but not on stroke, so the less bore they could use and the more stroke they could get, the lower the tax. That was the thermodynamics back of the engineering. In the last few years we have been shortening up our strokes and making the bores as large as is practical due to the combustion characteristics.

As to the horsepower, the horsepower per cylinder for practical operating conditions is a pretty well fixed thing. You can take four or six or eight or ten or a dozen cylinders or anything you want. When it comes to the question of the types of engines that we make, the four cylinder engine has gone out very largely, not on account of its not being a good engine but because of the fact that there is a secondary vibration in there that is twice the engine speed and you have to put some gadgets in to take that out and they cost just about as much as do more cylinders on the engine. Consequently, the automobile engine [illegible] is up today with the smallest number of cylinders being six. When you go from there on up, again it is a question of the amount of power you want and what the past history of your particular manufacturer has been. Whether he wants it a V8 or a Line 8 or this or that or the other thing does not make very much difference one way or the other. By that method we have been able to get our engines up in efficiency and down in weight and size, considering the commercial applications which they have to fill.

In order to build a motor car today that sells retail for $600.00 you must have quantity. Consequently, the specific tooling of an engine becomes a very important thing, also the checking of every detail of it so that you know it is right. I imagine it costs anywhere from two to five million dollars to build a set of tools for an ordinary engine, and, of course, if you are only going to make a couple of thousands of them that is foolish. Once in a while we get into the trend where our fellows get what we call "toolitis." In other words, they cannot make anything without a lot of tools. And yet, on the other hand, if you are going to make a lot of engines you cannot afford <u>not</u> to do that tooling job. When you do go into a highly intensive tooling job your tests and everything have to be beyond a question before you crystallize that design. So it is well if you can have a few engines built the year or so before, fifty or a hundred of them, and run them under all conditions and get everything ironed out first so that you do not take any chances when you do crystallize your tooling. You have to know pretty well ahead what you are going to do before you can go into one of these very large tooling programs. When you get that the cost of your particular article comes down immensely because there is no filing and fitting or anything like that.

Now from your standpoint it seems to me that one of the things you gentlemen have to figure on in mobilizing your type of transport is to find out whether or not you can use standard power plants. One of the most important things in picking out any vehicle is whether or not you can get any standard power unit for it. You have to have special machines, we realize that, but there are a lot of them that do not have to be special. We have exactly the same thing in manufacturing. We may be able to use fifteen standard machines, but we have to have one very special machine to do, say some particular type of broaching operation. If we know we are going to have to do this particular type of broaching operation we can study the thing thoroughly and may be able to bring the thing up to that point on standard machines. If we start here on this special machine and work back we may have the whole ten of them special. All those things have to be given consideration. That is, what is the most high production standardized unit that you can use and still not sacrifice your final result? I am going to be just as positive as you fellows could ever be that your final result is the important thing. Having established what that final result is, then the thing is to go back and see how we can get that with the least possible amount of trouble and difficulty all the way along the line.

We used to make a great many special machines in the motor industry - for instance, special milling machines might cost two hundred thousand dollars apiece. That is gone now because we found that if we engineered a thing in a certain way we could use standard machinery and if we change the design next year or the year after we still have the basic part of the machine and can make special tools to fit on the standard machine. We found that this thing happened quite often: we would order some of the these very special machines and before they were built we would change the model and it was not an uncommon thing to scrap machines that were not quite finished. Because the tool maker got into some trouble and the tool designer changed his mind and the thing got delayed a little bit, it ended up by the model having gone out of production when the special machines built for last year's model were not quite finished. That was a very good thing because that brought to mind the importance of considering this thing from the standpoint of overall utilization, because if you scrap this couple of hundred thousand dollar machine it is just as much tool cost as if you had made it and used it. So they said "Look how many good milling machines, drills, shavers, and this and that you could have bought for this amount of money, and maybe if you had used your head a little bit you could have passed this thing down here and used the standard machinery with special equipment and gotten as good results." That was not a rapid transition, however. It did not just drop off the cliff, but it happened over a long period of thime, so that we are now getting a modulated characteristic between the very special machine which you have to make to do something special and the perfectly standard apparatus.

Well, you have the same problem. There are a certain number of our standard vehicles, I imagine, that you could use. The cost, of course, is going to be very much lower if you can use them. For the special vehicle, I think that if I had your job I would not go to one of these big mass production organizations and ask them to make me a few hundred or a few thousand of a special thing. It seems to me the best thing to do is this If you had to buy a thousand perfectly standard trucks of some kind that you want to make special you could afford to buy those perfectly standard and then go over here to some smaller concern which has a good job-shop sense (by that I mean a fellow who knows how to get things done without spending all the money in the world for tools). That fellow can make the modifications, put a new transmission in or whatever you may want done, and do it in a much shorter time and at much lower cost than you could ever get it run through the larger plant because the larger plant just is not fitted up for it. These geared up organizations you see do not have any inventory. In a great many of our plants the inventory is in the freight cars - the material coming in and the finished goods inventory going out. The whole thing is timed so that the cars carrying material today are pushed up along side the building and the material is unloaded out of the cars right into the machines. They call this "cross current operation." Here you are unloading flat stock, over here you are unloading sheet steel, and these materials go straight through the machines and are loaded on to another car on the opposite side of that operation and shifted to the assembling plant. There is a timing of the cars coming up, and of everything else. Now if you ask that fellow to make two or three special pieces he has no one to make them - he has no mechanics in that sense of the word. You would have more chance of getting body changes made by going over here to one of the good wrecking garages in Washington that has been used to repairing bodies. They could put something on there very nicely for you, but if you went to a factory they just could not do it.

The best story I have on that concerns a friend of mine who at one time bought a lot of hinges of a certain kind. The standard hinge, I think, had four holes in it and he wanted some with three holes. He ordered the three hole hinges - just those ordinary strap hinges. He did not get them for a long time, and when finally he did get them they charged him about four times as much for them as they charged for the regular ones, and of course my friend blew up. The fellow said: "My God! We had to make all of those hinges by hand. We had to carry them through until the place where we punch the holes and then we had to make a little jig to punch the three holes." My friend said: "I ought to get the hinges cheaper with just three holes in them instead of four. If I had known there would be that much difficulty I could have used the four hole hinges."

When you come down to special apparatus none of the things I am telling you has anything to do with the situation. When you get to the motor, as I say, you have to select the kind of power, etc., that you want. I am talking about the motor vehicle run on the ground. The transmission, axles, tires, and things like that you have to have special, but the more of the standard equipment you can use the more available it is in quantity and in an emergency you can get it more quickly.

We were just talking down at the office about the setup that they have in Germany. I just came back from there a short time ago. What they did, and I think it was a pretty good way to do it, was to set up theoretically (as from your end here) what they would like to have. Then they said "We need X thousands of this type of vehicle and what we ought to do is to proportion that out so many to this automobile company, so many to that one, etc." But, when the boys got the specifications they said. "Don't do that. We can make you this many standard vehicles for this amount of money. What you had better do is to have this concern over here make all of your special vehicles instead of splitting the work up. We will make all of the standard material we can for this particular car." Then they found that by changing slightly a commercial type of vehicle it could be made available in case it was needed for a very definite purpose and all of the special stuff come from one place. Well, that helped, and they got it very much cheaper and very much quicker.

Now when you get to the motor, the axle, and the body utilities, those are very special things, but - I am talking now about the automobile, of course - if you can take the standard units as they are turned out today that is by all odds the quickest way of getting delivery at the lowest possible price.

I might tell you what has happened in the commercial vehicle business because it has had this very interesting trend five or ten years ago this question of the heavy duty truck was quite an important thing. A man used to pay a high price for a truck and then overload it. That is one thing you can always be sure is going to happen to any truck. A man pays five or six thousand dollars for a truck, overloads it, breaks an axle, and comes back and kicks to the manufacturer about it. So they kept making these trucks bigger and stronger, not realizing that the fellows could always overload them. Well, along came the Ford, Chevrolet type of truck that sold for just about what one wheel of the big truck sold for and the net result of it is that there are very, very few of the large trucks made any more. You may ask. "Don't they overload the Chevrolet trucks, the Ford trucks, and the Dodge trucks?" Certainly they do. If a man overloads his truck and breaks the axle he comes back and kicks to the fellow who sold it to him, but the fellow says "Hell, you overloaded it" - and the man goes and gets a new one. He can do this because the amount of money involved would buy very little of the big truck. That is the way it has worked out. The difference is simply this. Where we used to make in a year twenty-five or thirty thousand one or two ton trucks I imagine that Ford, Chrysler, and General Motors now produce between four and six hundred thousand of them. I think we make about two hundred thousand trucks in Chevrolet, and I imagine the Ford and Chrysler organizations do about the same. This is the reason that happened - the price was so low they just took those trucks and if necessary replaced them.

I mentioned the size of the piston in the engine. That brings in the very important question of fuel. The biggest thing that has helped our industry is the work that has been done on fuel for the past ten or fifteen years. I started work on fuel back in 1914 or '15 and it ended up with Ethyl gas. The thing we were trying to do was to get rid of this so-called spark, carbon, and compression knock. The knock was not due to any of those things, it was due entirely to the fuel. In any given type of motor that you have you must be sure that you get the thing pitched right. That is particularly true in aircraft. We have been able to get up to about a hundred octane number in commercial grades of aircraft fuel, which means that we are now able to push the horsepower of these motors up, especially the take-off horsepower, way above anything we ever thought of doing. Of course, as you can push the compression of these engines up the overall economy of them comes up and we are getting economy today in high compression aircraft that is almost as good as the Diesel engines. In fact, if you get compression ratios up to ten and one-half to one or one hundred sixty pounds compression pressure those engines will give you just about the same efficiency in pounds of fuel per horsepower as the Diesel.

A very important thing, it seems to me, in all divisions of air transport is an appreciation of what you can do with the present type of thing, slightly modified, if you get better fuels. When we were talking about eighty octane fuel a number of years ago everybody thought that was too high. We have gone from eighty to a hundred. So we see the fuel industry has stepped up to that one. I am perfectly sure that for a lot of your work you could get special fuels up to one hundred twenty octane rating, which would mean that for special types of services you would modify slightly the compression ratio of your present aviation motor and go a long way toward producing a new result. The gasoline engine today can be produced to meet almost any of these requirements.

In the automobile we tried to keep the piston small because you can have a wider variation of fuels with the small piston without getting into trouble than you can if you have a large one. In aviation where you have to have large horsepower engines and you have to accept the larger pistons, then the question of modification of fuel becomes an increasingly important thing.

So much of the gasoline phase of it.

The Diesel is becoming more and more important all the time. We have been playing around with it for a number of years. There has been more talk about Diesel engines and less done about them than anything I know of. Here is the difference between a gasoline engine and a Diesel engine so far as engineering factors are concerned The explosion pressures in a Diesel engine are about fifty per cent higher than they are in a gasoline engine. Well, right away you have to make your connecting rods bigger, your bearings bigger, and the same number of cylinders are bound to be bigger. If you took two engines of exactly the same horsepower the weight of the Diesel goes up enormously if you accept the present type of four cycle design. As you make your connecting rods heavier and your pistons heavier you are slowing your machine down, which means you have to make it bigger, which means you have to make it heavier, which means you have to run slower. To get a light-weight Diesel engine you cannot just take a gasoline engine cylinder block off and put a Diesel engine cylinder block on. Many commercial fellows wish they could do that. There has been very much more money spent on that wishbone type of engineering – trying to wish a Diesel cylinder block on a gasoline crankshaft – than in trying to solve the problem, simply because some fellow says "There must be some way of doing that." Well, there is some way of doing it but it is not that way. That is your fundamental difficulty right there – you are bound to accept these higher pressures. There may be some way around that, but up to the present time we do not know what that way is.

Concerning our railroad engines, what we elected to do there was to make those a peculiar type of two cycle engine. The two cycle engine has a bad reputation all over the world, both gasoline and Diesel, Diesel especially. Of course, the larger Diesels they have to make two cycle for the same reason that they have to make the little ones two cycle, but there are more conversational reasons why you should not make them two cycle when they are small. It is another case where the fellows try to follow the mass production ideas too far. We have exactly the same thing. A fellow says "I want you to take the gasoline engine out of this truck and put a Diesel engine in its place." You cannot do that. However, if you make a Diesel truck you can take the Diesel engine out and put a gasoline engine in. That works all right, but you cannot do it the other way around. What we elected to do was to make a peculiar type of two cycle engine. Our type is nothing more than this When a piston comes to the bottom of a stroke it opens a series of ports through which the new air can come in. There are four valves in the head which are exhaust valves and the air is blown right straight through. This is what is known as the "Uniflow" type. When that is done the valves are closed. There is no mixture to become involved in a Diesel engine, nothing but air. The fuel is injected, burns, and the piston goes down again. If you open your exhaust valve so you get a shot every revolution you get theoretically twice as much horsepower out of that cylinder as you would if you take a shot every other revolution. The cynic says: "Yes, theoretically you get twice as much horsepower." Well, practically, we get a little more than twice as much horsepower, for a very definite reason. Here is an interesting thing about that. This injection problem is the main problem in a Diesel engine. These railroad engines are quite large, eight inch bore, ten inch stroke. Say they are running 750 revolutions per minute - they would be running twice as fast for 1500 revolutions, and your injection piston speeds, and everything else should have to go up. By going to a two-cycle engine, these speeds do not have to go up a bit to double the number of explosions, because the pistons are running up and down no faster at 750 taking a shot every revolution than they do taking a shot every other revolution. The rate of injection is exactly the same. We were able to get the weight down to approximately that of a gasoline engine by that method. How far you can carry that down I do not know. We are experimenting with it down in the lower sizes. However, the thing can be done that way. On the railroad they say "We are able to get quite large engines in a rather small space."

The problem you have in the Diesel engine is the same problem that you have in the gasoline engine - fuel availability. That is, there is just about as much variation in the fuels for Diesel engines as there is in the fuels for gasoline engines, because a lot of that variability comes from the type of crudes from which the fuels are distilled. Up until approximately ten years ago we always thought of the engine as an entirely separate part from the fuel, but that is not correct because your fuel is just as much a part of the engine as the piston pins or the connecting rods or the crank-shift or anything else. You have got to know what kind of piece you are going to put in the tank as well as what kind of piece you are going to put in the engine. We started the work of tying all that together back in 1914. It has been a long job. Even right after the war I don't think the fuel engineers knew the automotive engineers. These two industries, each making parts for the other fellow's use, did not know each other. We had trouble getting together. They said "If you would fix your engine our fuel would be all right," and our boys said "If you would fix your fuel the engines would be all right." You have heard of those things happening.

The first point in that research work was to find out what belonged to fuel and what belonged to engine. That was the difficult job. The very interesting thing about it was that almost all of the engine tests up to that time had been made on Pennsylvania crude. Everybody had run the same test with the same kind of fuel and nobody had ever thought there was any variability in the fuel. The first shot we tried to give the fellows was to show them that their ideas about what fuel was were not so at all. Briefly, here is the way it was The lower the gravity of the fuel, the heavier it got and the more knocks there were in your engine. That is number one. Therefore, the lighter the fuel the more volatile it is. They were measuring the whole value of fuel with a specific gravity meter. We said "We do not think that has anything to do with the situation." Finally we put on this demonstration to a group of fellows We took the lightest fuel, which is ordinary sulphuric ether - just pour it in your hand and it evaporates right away - and we said "If your volatility story is any good this ought to be the finest fuel man could make." However, an engine can ot be run on that, it knocks its head off, it is as bad a knocker as anything you can get. We said "All we want to do is to prove to you that volatility and knocking are not tied together in any way, shape or form - that it is only in the type of material you have been using, and you can modify that to get anything you want." If you go out to Ventura, California, to the deep sand wells, take some crude oil and distill the gasoline off it, you get a material very much like Pennsylvania gasoline. If you take material from the shallow wells a quarter of a mile away and distill the gasoline off you have an entirely different thing - one is about forty octane number and the other is about seventy-five. That is the first time they began to notice that there was a difference in this very important characteristic of fuels. We ran into it at first. I had been working on these fuels to some extent during the war, when we were asked to act as fuel consultants for the various activities down here. When we recommended the use of California gasoline for aircraft, which was the quickest thing we could do, everybody said "Those boys have stock in the California oil wells." Even as late as 1919-20 the question of anti-knock detonating characteristics of gasoline had never been recognized at all. However, we began to get into this anti-knock thing and today it is recognized as being even more important than volatility because it determines how much horsepower you can pull without getting into difficulty.

You might be interested to know what that detonation is, because the knock you get is quite an interesting thing. We have done an enormous amount of research on it. Many of the same boys that started with me in 1914-15 are still on the job. What happens is this The fuel starts to burn in a perfectly normal manner, the flame moving at a steady rate through the charge. Then suddenly a flame starts in the back corner and the remaining unburned charge bursts into flame, accompanied by an almost instantaneous rise in pressure. Then it comes back and follows the normal curve. We had speculated a great deal as to what that was. We had made all sorts of instrumentation, but finally about two or three years ago we got nerve enough to tackle it in what I think was the right way. We said "Let's build an engine with a transparent cylinder head and devise some method of cooling it so we can run this engine at full load and look into it while it is running." After many of the trials and tribulations that you have in doing a fool thing like that we finally found out that it was relatively easy to do - as most of those things work out. We got an engine that could be run and one could look down into the cylinder and see what happened. What you have to do there - of course, it is just all flashing light - is to get one of these stroboscopes, which do not run the same speed as the engine, and look through a rotating disk and see that thing happen very slowly. However, different fellows cannot see the same thing, and you get into a controversy there. Our type of engineer argues a lot, you see. Nevertheless, when you get the facts pinned right down there is not much argument, so you can always tell about what stage of development we are in on any project by the amount of argument - a pretty good indicator. We said: "Can we take a picture of this and get rid of the argument? Let's have an inanimate, unprejudiced eye look at this thing. How many pictures ought we to take for an explosion?" We finally found out we had to take a picture about every two degrees of the rotation of the crankshaft, so we went to all the high-speed motion picture fellows to see whether or not we could get a picture machine. We had to get around five thousand pictures a second, which was stretching the thing a little bit for the boys. One of them said "I will make a camera and furnish it for you if you will just buy the films," because in this question of starting a film and getting it up to that speed and stopping it again you would use about fifty times as much as you got pictures on. However, that did not sound practical, so after we quit talking to the fellows who had been trying to sell us these trick cameras, we said "Suppose there were not trick cameras, how would we do it?" Finally we centered on this very simple method. We simply made a flywheel on the engine big enough to come up to about the top of the cylinder, we put a mirror over the cylinder so the light came up to the mirror and was reflected over toward the big flywheel, and then we put an ordinary photographic lens in front of the flywheel for the light to pass through. Then we got the Eastman Kodak Company to make us forty matched lenses like you use in a little 16 mm Cine-Kodak, and we spaced those about two degrees apart. We put forty little cameras in the flywheel, then went back of these lenses and put a prism to turn it so the light would fall on the film on the flywheel. Then, when the engine is run, the flywheel and, of course, the film and everything go round together. It does not make any difference how fast it is going. When you see the particular explosion you would like to get you push a button, it opens the shutter and takes thirty pictures of one explosion. There is a little space in between them so you cannot put them on a motion picture projector, but you can take a motion picture camera and copy it so you have it in motion picture sequence. We take two pictures of each one. It projects too fast if we use one only, but if you take two or three exposures of each frame and then make a motion picture film up into a little ring and put it in a motion picture projector you can sit there and watch that explosion happen over and over again. After the boys sit there for half an hour and look at it they do not argue any more because they all see the same thing at the same time. All I can tell you about this is that practically everything everybody thought about it was not so. Of course, in a great many cases that is true.

One of the difficulties when we started studying the automobile engine and the fuel relationship thereto was the question What is the temperature of the gases when this explosion takes place? The text books will tell you about 2600 or 2700 degrees F. We knew it was higher than that, and we did not have to do much instrumentation because you could take a small piece of tungsten wire about the size of a hair and put it down in there and after about three explosions it would be gone. One of the fellows said "That wire is too delicate - it breaks in that explosion." We took it out and put it under a microscope and found that it was not broken at all. We put a couple of research men on the job and in six years (it took them six years to do this job) they finally developed a method of measuring the actual temperatures of the gas at any place in the combustion cycle. We do it with the so-called spectroscope. That is, if you have a light shining into a spectroscope and look on a plate it will show certain lines. That is what is called an emission type of spectrum. If you take this same gas and shine a light through it you will find in your spectroscope that where you used to have bright lines when the gas was burning you now have black lines. You see, if the gas is luminous it gives off bright lines, but if you pass a light through the gas when it is not burning it gives black lines. In other words, it absorbs the same kind of light that it gives out. If you balance the temperature of the gas that is burning against the temperature of an outside source so that it is on a balance between being a bright line spectrum and a black line spectrum the outside temperature and the inside temperature are the same. Consequently, we were able to get an outside source where we could get instrumentation to measure the temperature and check it with what is inside the cylinder.

It took us six years to do that job and here is what we found For an ordinary gasoline engine the temperature of the gas goes up to about four thousand degrees F. - which made a terrible difference - and when it is detonating it is up around forty-four or forty-five hundred degrees. We got a jump from twenty-seven hundred degrees in theory up to forty-four hundred. When some of these things go to the fourth power of the variable you can see you would be slightly off in percentage if you took this lower figure. After we got this motion picture of studying the combustion we began to see a lot of things and we are going to be able to contribute very valuable information to our engine designers and to the fuel people.

The knock you hear is absolutely a knock in which the hammers are nothing but gas molecules. They have to be moving pretty fast to make a knock, and they do move fast. We have been able with these motion pictures to actually measure the velocity of gas movement. All the bright things we do we stumble on to. When we start out to do something we usually are so serious minded and so technical on the thing that if it were not for stumbling on to something we would not get it at all. What happened was this. One day we were running this engine and just across the hall the boys were trying out an experimental salt spray for testing corrosion of one thing or another, and all the pictures we got that day had streaks in them. What had happened was that a little bit of the dry salt had come across the alley and gotten into the air intake, had become luminescent, or very brightly illuminated, and during the time of exposure that little luminous particle had moved so far on the plate - it had moved that far in that length of time. All we had to do was put a pair of calipers on it and put it on a rule and we knew what that actually meant to the engine. We brought these pictures up to the same size as the combustion chamber and then we could say "In that length of time that thing moved that far." Well, it was not difficult to get the velocity. We did not use salt after that - we used lamp black, the particles of which glow. Those velocities get up very high. During detonation, one of those hard hammer blows, the gas velocity gets up around one hundred fifty to two hundred miles a minute - enormous velocity - and has a temperature of around four or five thousand degrees. You may talk about the hot winds of Kansas but these are very much worse. When you begin to see those things you say. "No wonder this engine knocks with conditions like that in the cylinder."

What I am telling you this story for is that I do not want you to think of buying a motor vehicle at any time for any kind of service without thinking at the same time about what you are going to run it with. I do not care what you want to run it with as long as we know what it is. That is, if you want to run this vehicle on the lowest grade of gasoline made, it is OK, but here is what you pay for it. If this motor is a hundred horse-power on a normal rating and you want to use this low grade of gasoline you have to accept about twenty to twenty-five per cent reduction in horsepower. It will run just as well but this is the price you pay. If you have a place where that service is necessary all you need to do is to get a new set of pistons and reduce the compression and the thing will run all right. If you are going to make a very long flight by air, in which you have to be very careful about the amount of fuel you use, you want to use the highest compression type of engine you can get and a fuel that can stand that high compression. Your fuel economy jumps from about a pound of fuel per horsepower hour on this very poor grade of gasoline in the low compression engine to a little under four-tenths of a pound of fuel per horsepower hour on the high compression engine. With the best gasoline and the highest compression engine, you will use about forty per cent of the amount of fuel per horsepower hour that will be consumed using the poorest fuel that you can get commercially. Those two things have to go together, and I think it is the most important single thing that we need to keep in mind in figuring motor transport. If you design the engine to use a higher grade of gasoline than you are able to obtain, you are likely to damage things very much more than if you knew it in advance and had the engines made for the lower grade fuel. Of course, that means only another type of piston. You usually change these compression ratios by the pistons.

That briefly is our story. If you can use standard stuff the price is way down; if it is a hand-made job, you have to pay a higher price for it. Consequently, if you can use standardized units, whether it is in its entirety or in part, that is the thing to do, but in no case should you figure on any kind of internal combustion engines, either Diesel or gasoline, without taking into consideration the type of fuel that is going to be available at that time and for that purpose. In some cases it is very much better to make the vehicle adapted for a lower grade of fuel than you figure on because you will not get caught if you get a better grade of fuel but you might get into serious difficulty with a worse grade.

That briefly is the story of the internal combustion engine and its relationship to the development of power in transport. It is not as complicated as many people think. It has taken us a long time to get this very simple thing that I have told you of this morning - it has taken years. It is like digging a stone out of the mud. You get it out and it is all covered with mud. You say "The stone is there," and you wash it off with a hose and finally you have to get down and scrub it with a brush, and you say "That is a very interesting stone." It was always an interesting stone, the thing is that it was covered up with mud. A great many things we have dug out in the research laboratory everybody knew were there, they could probe down and hit them, but it has taken a long time to wash them up and get all the dirt off them. When that is done we say "Very simple!" We have a motto in our laboratory which reads: "A problem thoroughly understood is always fairly simple." Everyone that we have ever solved has been. They all work out.

I am going to tell you fellows just one little research story. Perhaps some of you have heard it. If you have, please excuse me for telling it. It is the best one I know of concerning the type of resistence you fellows are going to meet on the outside. You know that when you ask a fellow to do something he has not been used to doing he cannot do it This happened a good many years ago. I could see the closed body coming, and I said "My heavens! We cannot take thirty-five days to finish those bodies." Cadillac was taking thirty-five days and Buick was taking seventeen days - those are about the prices of the cars, thirty-five hundred and seventeen hundred. I said "If you are going to make a thousand cars a day that would mean seventeen thousand bodies you would have in the paint shop at one time, and you would never get any of them out, without scratching them up. We ought to see if we cannot shorten up this paint time." So I did a perfectly normal thing. I got the best paint experts in the country and the best painters and chemists, and we had a little meeting. I said "We have to reduce this time, what can we do?" Well, they allow, after thinking it over, that they might get that thirty-five days down to thirty-three and the seventeen days down to about sixteen. I said "That isn't helping any. We have to get away down."
They said "How long do you think it ought to take to paint an automobile?" "I would like to paint it in an hour."
I would not want it to go on record as to what they said about me.
However, I said "Why can't you paint it in an hour?"
They replied "The paint will not dry."
I said "My God! Can't you do something to hurry it up a little bit?"
"We have been working at that for years and you cannot do anything to hasten the drying of paint," they said.

We fussed around all day and when we were going out to lunch one fellow said "I think we put that guy back in the corner where he is going to stay for a while."
However, I still had my problem and putting me back in the corner did not do any good. I was walking down Fifth Avenue one day looking in the windows as a country boy usually does and I saw some pin trays in one of the windows. So I went in and bought a seventy-five cent pin tray for twelve dollars. That is about the way it was, but it has some new kind of lacquer on it. I asked the fellow what it was, and he said "Some new kind of lacquer."
I said "Where did you get it?"
He referred me to the house where he got those pin trays. I went there and finally found that this lacquer was made over in a little place in New Jersey. I went over there the next day and found the fellow who made the lacquer back in the shed. I said "I want to get a quart of that stuff."
He said "My God! I never made a quart at one time. What do you want to do with a quart of it?"
"I want to try to paint an automobile door "
You could never do it in the world."
"Why?"
"It dries too damn fast. You put that in a spray gun and it will never get to the door, it will dry up and blow away."
I said "Can't you do anything to slow that down?"
"Not a damn thing."
Well, there I had on one side one paint that dried too fast and we could not do anything to slow it down and on the other side one that dried too slowly and we could not do anything to speed it up. I did not think nature was going to play a dirty trick like that, so I started to study those two things and we finally got those very rapid-drying lacquers.

The finale of that story is this A paint man, one of the fellows who had been in my original conference, came in to see me one day. Someone had sent me one of these color cards (You have seen them) with all the different panels of color on it, and I had opened it out on the desk and it was lying there when this fellow came in. He had driven down to the laboratory (our laboratory was then in Dayton - before we moved to Detroit). I said "If you were having your car repainted, which one of those colors would you prefer?" He picked out a color. We sat in theoffice for quite some time. The laboratory was about six or seven miles south of Dayton so we drove up to Dayton for lunch. We came back, and finally he pulled out his watch and said "I have to be going - but where is my car?"

I s id "That is your car right there. Isn't that the color you anted it painted?"
While e had gone to lunch he had been given a repaint job. We were not so far off at guessing it at an hour - and that was a shot in the dark.

There are a lot of things you can do in this world if you know what you have to do and have some time to do it. I think that is a grand thing about your organization. You have a little chance before the emergency happens to plan what you need, and you can sit down and analyze the thing. I could pretty nearly say to you that it does not make any difference how strange some of these things are which you may have to have. If you are given a little time, with proper understanding and cooperation, it can be worked out. However, that is one thing we must do, we fellows must meet you and you fellows must meet us. We must get together so the industrialists will not think "These Army, these Navy, and these Marine fellows are peculiar guys, aren't they?" and you fellows will not say "My God! Those industrailists are a bunch of hardboiled eggs." We are both all right in our place, but each fellow does not see what the other fellow's place is. If we can just get together and analyze these situations so we can see what it is all about, then you will not think we are so peculiar and we will not think you are so peculiar.

You have these special jobs to do. When you get into a scrap you have to have right now the thing that is the best to use, and I think this study that you are making here of trying to find out the relationship between national defense and industry is one of the most constructive things that I have ever seen done, and I deem it a great honor to have the opportunity to talk to you this morning.

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Colonel Jordan Mr. Kettering would be very glad to answer any questions from the Class. There is one man in the Air Corps who came into my office yesterday and asked me something about high octane fuel. I would like him to get on his feet and ask the same question again, because Mr. Kettering is laying for him.

Q. Will there be any probable supply of high octane gas in an emergency?

A. I cannot answer that, not being in the fuel business. However, I will just show you what this octane thing is.

Theoretically, it should be no more difficult to make a high octane number than a low octane number, and without getting into the details of the thing I will show you what the normal fuel is and what a simple thing causes this octane number. Don't get frightened because there are some chemical formulas involved, because they are no different than the number of rungs in the back of a chair. Practically all the fuels we use are made up of carbon and hydrogen, and the simplest combination we have is one carbon and four hydrogens. That is called methane gas. Now we put in two carbons, or three, or four, etc., and there will be a hudrogen on each side of each carbon because you have to have four of these little lines to each one of the carbons. When we get to seven, that is called "heptane," which is just an obscure way of saying seven. Science is, or at least we have a very good idea it is, something not very well understood, because as soon as we do understand it we say "My God! That is simple." The names of these compounds are another way of counting, an obscure way of saying "four, five, six, seven," and if I put another one on here you would have "octane," or eight. Those, when they are all in a row like that, are called "straight-chain" compounds. It is a very interesting thing that the longer the chain like that, the worse it knocks. Here is an eight carbon item that you cannot use for fuel at all.

Now, if you take exactly those same carbons and hydrogens - it comes out exactly the same, that is, it is octane too, but this one you can hardly make knock at all. In other words, that is a hundred octane number. It is just a rearrangement, and is purely mechanical. This whole question of octane number is the mechanics of molecules of fuel. Why there was so much difficulty was because everybody was trying to think of it in terms of chemistry when these molecules are just as much machines as the engine itself. The big contribution we made to the whole story was when we showed the boys that it wasn't the question of gravity or a question of anything but the way in which this stuff was put together. A single line between atoms is what they call a single bond. Funny things happen. If you were to rub off one of these fellows and put a double bond in, and then you rub another one off, things happen fast. That may make the fuel better, or it may make it worse.

Let's see what we are dealing with. This is all elementary mechanics. Think of these lines as being little springs between solid balls. If we shook the model at the right frequency it would vibrate — not unlike a bridge with a dog trotting across at a certain rate. If you grouped it up in another manner and had the dog jump on it, it would not shake at all. It is purely a question of what we call the synchronous or resonance frequency. The point I am making is that it should not be any more difficult to make one molecule than another, but the Pennsylvania deep sand wells automatically give this and some of the shallow wells give that, and we are just in the process of learning how to take any one of these things and transform it over into the kind of thing we want. Then if we say that as of a certain time we want one hundred or one hundred twenty octane fuel in quantities such and such delivered at such and such place there is a chance of getting it. However, this is an entirely new concept, an entirely new business, to change these molecules around. We know how to distill them off and make gasoline, but how to change one form into another form is quite a trick.

The way the octane number of a fuel is gotten is this They take octane and they take the seven carbon atom heptane, which is a bad knocker, and mix those two together. In other words, per cents of the straight heptane, or seven carbon atom, are mixed with per cents of octane. The one hundred octane number is pure octane, the zero octane number would be the heptane pure. Theoretically you could not go above one hundred octane number, but we have a lot of materials that are less likely to knock even than pure octane at very, very high compression. We are just getting our oil chemists and our oil physicists to realize what can be done with these fuels by just shifting the shape around. We have gone into the question of how effective is lead tetraethyl when you add it to one of these things, and it is perfectly marvelous what can happen. A cubic centimeter of lead per gallon will raise the octane number of one fuel by so much. You must not be surprised when you add the same amount to another fuel if you have as much as ten times difference. Why? I haven't the slightest idea, but we know that is th case. We re simply gambling now and working with the science of molecules, treating them as machines or as things that vibrate. I should say that if a demand were created it would not take them long to furnish this hundred octane number in carlots for twenty cents a gallon. They said they could not possibly make it for l ss than a dollar a gallon. That was all right, a dollar a gallon was cheap, but with certain refining processes and changing around it came out that they were able to do that. As a munitions proposition, you could be safe in making certain types of app ratus just as you make certain bores for guns that shoot certain types of ammunition, if it was an economically desirable thing to do. It does not pay to go much above one hundred twenty because the efficiency curve of an engine falls off - that is, a ten and one-half to one compression ratio, which will get you about .37 to .4 pounds of fuel per horsepower hour, is about the maximum you can hope to get.

Q. In a war emergency when it might be necessary to change some of the automotive plants to the manufacture of aeroplane engines, approximately how long would it take to make that conversion?

A. That would depend altogether on the demand rate. For instance, if you came to the Cadillac Motor Car Company (and I am citing them because they make three different sizes of engines, eight, twelve, and sixteen cylinders, and they are not tooled up in the same way as Chevrolet) it would depend altogether on the demand rate. There are certain types of tools which take about so long to make and if you used the whole twenty-four hours a day and put three crews of men on it, it would take so long to get that tool. You could start out by making by hand certain of the long-time parts. If you took one of these radial engines (and I do not know what the long-time part on that is, whether it is cylinder, crankshaft, or crankcase) your whole time problem would be how many do you want? Suppose we wanted to tool up for something and suppose we took a hundred a day as a minimum at which to start, it would take, I should say, on an emergency basis three or four months to start turning out engines. The first day we ran you would not get many but you could begin to expect the first engine to be put together from the tools in three to four months' time. That is just my guess. Of course, if you put that up to a tool maker he would say. "You are crazy," because he is thinking of the thing as not being an emergency. He would want at least six months to nine months to tool that job. Nevertheless, I think you could get it down to about three or four months.

Q. Mr. Kettering, your very simple explanation of the octane fuel suggests another question about bearing materials We have the tin bearings and from our point of view the position of tin makes it a problem. On the other hand, we have the copper-lead bearings and they have been largely designated for use in aircraft engines. We discover that although lead and copper are very easily obtained that the matter of mixing them is another problem, and as a matter of fact one of the General Motors subsidiaries, as I understand it is the only successful producer of this type of bearings, so we really have a single course.

A. I should say that in an emergency that could be broadened very quickly. You touched on one of the other points of the automotive engine - lubrication - and, if it does not bore you, I should like to tell you a lubrication story. We got into the habit of feeling oils and talking about viscosity, etc., and I said "I do not believe that is all there is to oil." We had an experience, caused by a friendly conversation up in Canada about five or six years ago. Two fellows driving down the road stopped and talked to each other just after the snow had been plowed off the road, so that one wheel of each automobile was standing in the snowdrift. When they got through talking each fellow started his car and spun the wheels on the snow. After spinning the wheels on the snow for a time they got out - no chains on - and found that something was wrong with their axles. They had spun the wheels until they had stuck up the differential gears. They came down and asked what they should do about it. We did not want to break axles, so we built up a little machine, a testing fixture, and we found that we could give them a bushing that they could slip in those gears very easily and avoid this trouble. It was not happening very often, we had only a few cases a year, but just enough to be bothersome. I said "Why don't we turn around and approach this oil business exactly the other way? Here is the assumption this oil testing machine is a dangerous thing, it is in the hands of your enemy and he can kill you with it. The only thing the game is going to allow you to do is to supply the lubricant. You have to pick out the worst thing on earth that you can think of to lubricate that machine with so it will not work. What are you going to use?" Thinking about viscosity, we decided to get the thinnest darn stuff we could. After much thinking the boys decided that chloroethyl ether was the stuff, because that was so thin it evaporated rapidly. We tried to pour that in the bearing, but we could not use it because as soon as the bearing warmed up it blew away. We finally set a copper tube in the normal oil place and screwed this can of ether on there, and then by laying a warm towel or rag on it that would evaporate and push the stuff down into the bearing. It would not go in there as a liquid at all. We began betting as to how much pressure there was on that, six thousand pounds per square inch projected area being about what our best lubricating oil would hold on the testing machine before it would stick up. The boys started out by putting fifty pounds, then a hundred pounds, then a little more and a little more and finally we ran out of weights at thirty thousand pounds - a perfectly dry gas lubricated bearing. Later on we were perfectly able to actually extrude the hardened shaft by getting some more weights on there without sticking up. That kind of washed the viscosity thing out of the picture although viscosity is still an important factor in a lot of lubrication. There is a material known as extreme pressure lubricant, which we are using today in practically all rear axles and such places, and it is different from viscosity lubrication. The oil forms a weak chemical compound with one part of that bearing. Viscosity is nothing but the attraction of one molecule of that material for another of the same kind, and if you put that in between two plates and put a pressure on it and the pressure gets higher than that normal attraction it will shove the stuff out. If you form a weak compound with the metal, however, it can be four or five times as strong, because you have the chemical bond between the lubricant and part of the bearing instead of just the solution pressure between two parts of the same type of material.

When we come to this bearing question, of course the bearing and the lubricant go together. We want to get rid of tin for an entirely different reason than you fellows do. As you are running your engines faster the bearing pressures are higher and tin reaches a limit at which it pounds out. The way we have gotten round that so far is by these new bearing materials and by cutting down the thickness of the babbit so that it does not flow sideways. The copper-lead bearing is a very peculiar mixture of copper and lead, which has some advantages and some disadvantages. You cannot burn one of the things out, you cannot hammer them out - some of them crack - but there is a difficulty in that certain kinds of lubricating oils, after they have been used for a while, become slightly acid and that dissolves the lead out of that bearing and all you have left is a copper sponge. We have had some trouble with that. However, I think we can solve the problem. I think the lubricating oil fellows are putting oxidation inhibitors in their oil, which prevents that acid from forming and consequently your bearings do not dissolve **away**. Copper-lead bearings have a tendency to scratch. By the time we get another war I think we will have hardened crankshafts so that will be out of the picture. Some of the new methods of hardening shafts locally are developed to a very high degree. The Ohio Crankshaft Company at Cleveland have a furnace which heats the surface of the shaft by induction, squirts water on it, and completes the hardening operations in about ten seconds. It looks as though we are going to be able to get started to play with this, but it will take a little time to get our hands into it. I expect hardened shafts, especially in aircraft. I think you are using hardened shafts there now, maybe not glass hard, but they are pretty hard.

In regard to the making of copper-lead bearings, that technique has been developed to the point today so that you could almost over night teach another fellow how to do the job. The one important trick in it is this There are two things in a copper-lead bearing, one is the copper and lead and the other is the way it crystallizes. The way we make our bearings experimentally - I do not know how they are making them in the factory - is to take a little pan and pour in this melted alloy of lead and copper to crystallize very, very sharp crystals under certain temperature control. You want those crystals to all stand up so that when your bearing is rolled up you have all these little fellows standing on end. That will make a very, very fine bearing, but if you have them lying down on the side it will be no good at all - just like soldiers standing up and lying down. That is one thing you will not need to worry about because I am sure before you could get an increase in engines we could get four or five fellows to make those bearings for you. This question of bearings and lubrication is just as important as the fuels and the engines. I know the oil fellows can take care of the oils and we could get you many sources of supply rather quickly on this.

Q. May I ask, sir, an explanation. Industry is vitally interested in national defense, and you create and scrap many machine tools each year. Do you ever give any consideration as to whether or not the tools, before you scrap them, might be used for the manufacture of other munitions?

A. The type of machines that are scrapped normally are very special machines. They are not any good for anything. However, we have a method of passing those machines on down the line. For instance, we retooled our laboratory completely last year and put in the very latest machinery. We had a lot of good machinery there but the mechanical equipment in a laboratory like ours is terribly important because we are always trying to do the next thing. Theoretically, we scrapped our old machinery, but it was not actually scrapped. Here is the way we followed that thing through For instance, a milling machine went to the used machinery dealer. We said "Follow that for us, will you?" The machine dealer sold it to a fellow who did not need quite as good a machine as we did. That fellow in turn, took out an old machine from his shop and passed it on down to a third man. This is the man who scrapped his machine. The standard useful machinery is not scrapped, it simply replaces worse machinery, and the thing finally scrapped is this special machinery, a special jig or fixture that is not worth saving because it just clutters up your place.

An economist came out to see us one time who was writing a paper on the high cost of model changes in the automobile industry. I said "It does not cost anything to change models, it is an economy or we would not do it. The new automobile is worth so much more and the people get so much better job for the same amount of money that it does not cost anything to change." It just happened that a short time before that a sprinkler head in my office had broken and sprayed down on my desk. They had taken my desk out to have it cleaned up and I was using as a desk a table that I had used for books. This fellow was sitting there and while we were talking they brought my desk in. I said "Here is a good example. Here is this new desk coming in, and theoretically I am scrapping the table, but actually the table is not what gets scrapped. In the last analysis the thing that gets scrapped is a soap box that some washerwoman has a tub setting on."

This particular tool that I spoke about that we traced through was a milling machine. It went over to a fellow who is in the manufacturing business. He is manufacturing something for which that was a fine tool. The thing that he scrapped went down to a fellow in the junk yard where it was used for cutting up material, and it was perfectly good enough for that. He wanted something to hold a tool so he could go through to get the valuable parts off, and the thing he threw out was his old machine - that went to the scrap heap. That is the perfectly normal flow of useful goods but the special fixture or jig it does not pay to keep - you can make a new one very much easier.

Colonel Jordan On behalf of the School, and I know I am stating exactly what the Student Body and the Faculty think, sir, we are under a great debt of gratitude to you for coming down here and talking to us.

Dr. Kettering This is just as much my business as it is your business, because you fellows are going to take care of me if we get into trouble.