12. AVCO LYCOMING/NASA CONTRACT STATUS

Larry C. Duke

Avco Lycoming
Williamsport, Pennsylvania

Avcc Lycoming and Teledyne Continental are cooperating with the NASA Lewis Research Center in a study of ways to reduce emissions from aircraft piston engines. This study is based on the standards promulgated by the Environmental Protection Agency (EPA) for carbon monoxide (CO), unburned hydrocarbon (HC), and oxides-of-nitrogen (NO_x) emissions. We drew on many concepts that have been used in the automotive industry and also on practical experience. For example, 1973 and 1974 cars experience acceleration problems, particularly in accelerating from stoplights. Simple leaning procedures and spark advance changes were ruled out as suitable emission reduction methods. Our past experience showed that these methods can cause hesitation problems. And when tried by the automotive industry, leaning procedures degraded fuel economy to a certain extent. These factors, plus concern for diminishing fuel reserves, emphasize the importance of the objectives set forth in the NASA Request for Proposal (RFP).

The contract called for design and testing of aircraft piston engines to determine the effects of hardware changes on exhaust emissions, fuel consumption, safety, weight, performance, maintainability, and so forth. Specifically, the investigation was designed to document pollutant yields, namely unburned hydrocarbons, CO, and NO_x, from aircraft piston test engines. These engines would be modified to include a major redesign of the engine as well as two relatively minor changes. The RFP was a little broader than that; it allowed more than two minor changes to be made to the engines. We have combined two minor concepts into one to make a viable system in itself. Also, we wanted to document the effects of these changes on fuel consumption and to look at safety, cost, weight, and the other significant factors. Finally, we wanted to establish some operational limits in which these concepts may be used safely and in good engineering practice.

An in-house study reduced our original 10 concepts to three that we considered worthy of further testing and investigation. The first concept, a major one, was variable valve timing. High-power, high-speed engines such as TIGO-541, which is rated at 450 horsepower and 3200 rpm, have high valve overlap. Bringing that engine back to idle or off-speed conditions from that rated power setting causes too much valve overlap and short circuiting of the intake charge. The raw fuel coming into the engine thus goes directly into the exhaust. As mentioned in an earlier paper, the higher power turbocharged engines were over the EPA hydrocarbon limits. A breakdown of the emissions contributed by each mode shows that most of the hydrocarbons come from the taxi mode, which is essentially a low-power mode where the effect of high valve overlap is very pronounced. A variable valve timing system allows the timing to be optimized at each power condition. At idle/taxi conditions the timing can be optimized for emissions control. At cruise conditions, which are also considered in component development, the timing can be optimized to produce fuel-lean conditions without the need to compromise as much for the power condition.

Two minor concepts were also considered. One was ultrasonic fuel atomization. This concept is directed uniquely to carbureted engines. Some carbureted engines have cylinder-to-cylinder distribution problems at part throttle. The cylinder-to-cylinder distribution of air actually makes the engine run in conditions that are not ideal for it. One cylinder may be running lean, and another one rich. Therefore, in cruise conditions, when the pilot is "leaning out" to obtain fuel economy, he will essentially be limited by the leanest cylinder in the engine, that is, the one that starts to get rough first. That cylinder will limit how much he can lean out and thus limit fuel economy. In the ultrasonic atomization concept, better breakup of the fuel should distribute fuel droplets more evenly, or minimize the quantity of large fuel droplets, and actually direct them or allow them to flow with the airstream to each cylinder.

The second minor change we considered was to the ignition system, where several changes were combined into one concept. A high energy, multiple-spark discharge system, basically a modified magneto, was combined with spark plug tip penetration tests. At low power, ignition of the intake charge is not always as good as desired. Better ignition will not only lower both CO and hydrocarbon emissions but also improve fuel economy.

VARIABLE VALVE TIMING SYSTEM

Each concept has gone through its initial design stage. Figure 12-1 shows a product of the initial design stage of the variable valve timing system. This is the camshaft of the engine, which is essentially the heart of the valve timing system. Basically, the camshaft is made of two concentric shafts. There are two disks with several holes in them at the right end of the shaft. One disk is connected to the inner shaft and one is connected to the outer shaft through a sequence of holes. The positions of these two shafts can actually be changed with respect to one another. One shaft has pinned to it all the intake lobes of the camshaft. The outer shaft has pinned to it all the exhaust lobes of the camshaft. So essentially we have two concentric shafts: one controlling exhaust lobes, one controlling intake lobes. The intake-to-exhaust-valve overlap can be varied by turning the shafts relative to one another. In a standard engine, camshafts produce valve overlaps of about 35 to 50 shaft degrees. The variable design allows the overlap to be varied from essentially no overlap, to a degree or so of overlap, to about half again as much as the standard overlap. This is a fair range (approx 70 crankshaft degrees), and by a simple cutting or remachining process that range can be extended a little further.

At the left end of the camshaft (fig. 12-1) is another set of disks. These disks are also connected to two concentric shafts: one directly to the drive gear, the other to the camshaft proper. The gear in the accessory housing of the engine is the actual driving gear for the camshaft. Changing the position of one of these disks changes the timing of the opening of the intake valve. Both the intake and exhaust valve openings can be shifted relative to the engine timing. The first set of disks regulates the occurrence of the valve action; the second set regulates the relative action of one valve to the other.

This variable valve timing system is now being incorporated into an engine. This engine will initially be tested on a dynamometer. Since it is a new type of engine, some work must be done on it prior to emissions and performance testing. Essentially, we have to run through a torsional survey to ensure the integrity of the dynamic rotating system.

Variable valve timing is a major redesign of the engine, and as is evident from the type of fabrication, it is not an automatically controlled system. Because of the slip disks (the ones with the pins in them), the engine must be physically stopped, changed to the next condition, and then started again to get several data points. The variable overlap disk actually protrudes from the front of the engine, while the variable timing disk is in the accessory housing at the rear of the engine. Further development programs in this NASA-funded effort will examine ways of automating this system once the optimum conditions and timing are defined.

ULTRASONIC FUEL ATOMIZATION

The second concept that we are studying is ultrasonic fuel atomization. The atomizer has been adapted to a vertical-draft engine. It bolts to the oil sump and intake arrangement. The intake distribution system is contained within the oil sump. Figure 12-2 shows this adaption on an Autotronics Control Corporation engine. The atomizer fits between the carburetor and the sump in this development stage and is controlled by a separate drive power unit that is mounted elsewhere on the test stand. The atomizer is about 4 inches long and is visible in figure 12-2 as the circular tube protruding toward the glass window. A power drive unit mounted on the side opposite the window vibrates the tube at ultrasonic frequencies. Fuel coming from the carburetor is directed onto the tube by two venturi-type wedges that are mounted inside the ultrasonic atomizer. Any large fuel droplets should hit this tube, be atomized by the ultrasonic action of the tube, and then continue into the sump in a normal manner and out to each intake pipe. In further development work, if the concept seems beneficial, this engine-atomizer combination will be applied to a current aircraft design. That is, the sump will be modified so that the ultrasonic atomizer can fit into it. Then the carburetor can be returned to its standard location so that the overall physical size of the engine will remain the same.

Of course, this is still far in the future. So far, we have tested this engine-atomizer combination on a dynamometer. Although there has been no detailed analysis yet, the venturi wedges seem to be limiting the full-throttle manifold pressure, causing a penalty in power output on the order of 3 percent. We expected a penalty but wanted to make sure of its magnitude. As examination of brake specific fuel consumption on the dynamometer test showed that the fuel consumption characteristics have remained unchanged. However, there were some indications of improved cylinder-to-cylinder distribution. No final conclusions on this will be made until after emissions testing has been performed. Fine tuning cylinder-to-cylinder distribution should show up in emissions testing but may not be reflected either in fuel consumption or power measurements. Thus, the ultrasonic fuel atomization concept is halfway through its development stage.

IGNITION SYSTEM CHANGES

The final concept is ignition system changes. Figure 12-3 shows a standard spark plug used in aircraft piston engines. The design philosophy that was used is apparent. The spark plug is actually in a small cove adjacent to the combustion chamber but protected from the combustion chamber itself. This design criterion was developed in detonation and high-power running tests, where it was found that projecting the spark plug tip too far into the chamber could cause detonation. The spark plug location is also dictated by the physical space available to install it. However, it may be that, by projecting the nose core forward into the chamber, detonation can be used to provide both lower emissions and greater fuel economy. Certainly, at low-power conditions where the combustion chamber pressures are not high and there is appreciable exhaust gas dilution, a spark plug that does not protrude sufficiently into the combustion chamber cannot provide an effective spark to the gases in the chamber.

Figure 12-4 shows the nose core extended so that it begins to project into the combustion chamber proper. Figure 12-5 shows the nose core extending further into the combustion chamber. This is a prototype system on which substantial work will be required. Detonation problems have been identified in the past, and we are reexamining them to see where detonation and emissions reduction can be traded off. The ignition system is to the point where the engine is built and ready to run as soon as a test stand is available.

CONCLUDING REMARKS

When will these innovations be available commercially? They are all "down the road" items. They are fairly radical systems, different from standard practice, and require much in-service testing to fully assess them. Figure 12-6 is a schedule showing roughly when each of these systems might come into use. The program has been divided into two parts: the major concept, variable valve timing; and the two minor concepts together, ultrasonic fuel atomization and ignition system changes. The NASA contract is structured as a 3-year program. The program started in October 1975 and will continue to August or September 1978. In that period, component development tests will have brought these concepts to a point where they are applicable to aircraft. Certainly, a major amount of engine development will be required after the NASA contract is completed, especially on the major concept. This concept will need to be endurance tested so that it can be certified as viable for use in an aircraft. About $2\frac{1}{2}$ years of additional in-house work will be needed to make sure that every parameter is covered and that the system compensates for the variable valve timing automatically. This will require an engine certification program including an automatic control system. Difficult problems will have to be studied and solved. For the minor concepts, a fairly short period of about an additional 1/2 year will be needed for engine certification. Next, these concepts will be service tested and then certified in manufacturers' airframes. The major concept will require a new aircraft design, especially in the cowling area. The last step will be production release, production tooling, and actual marketing of the product.

In conclusion, for the minor concepts, it will be perhaps 1982 or 1983 before either is on the market. For the variable valve timing system, which is a radical change, it will be 1986 or 1987 before it will be available commerically. Of course, this is merely a rough estimate of the time needed to develop these concepts.

DISCUSSION

COMMENT - E. Kempke: NASA is extremely pleased with the wide variety of concepts that are being pursued in these two contracts. Each of the concepts we feel exhibits good potential benefits. They're challenging kinds of work with no assurances of success but the potential benefits are there and we feel that the wide variety of concepts should give us a good assessment of where the technology stands with regard to making impacts on the reduction of emissions in the future.

Q - H. Nay: The implementation development schedule you showed had quite a number of engines. If one of these concepts, either the major concept or one of the minor ones, appears to be attractive and you want to implement it, are the saying you can recertify all of your engines in that period of time?

A - L. Duke: No, that's a good point which I failed to bring out. As you can see, these concepts are really designed toward a specific engine - either a carbureted type or a unique engine. I've tried to carry the theme implying that all of these implementations are going to be designed along those same lines as if for one specific engine. This is especially true for the variable valve timing system where we feel that each system will have to be developed on its own for each particular engine or engine model. After you get the first engine out you can start shrinking these implementation schedules, but essentially this is one engine class type.

Q - H. Nay: How many basic types of engines from a seperate development standpoint are you looking at? I know you have some 384 models in production but those break down into specific configurations as affected by emissions, types, changes, etc. How many different classes relative to that criterion?

A - L. Duke: We have approximately 29 Type Certifications (TC's), which would cover engines from carbureted up to turbocharged geared. If you want to divide them into four or five classes, you could say of the order of five or six engines may be covered by one type of concept.

Q - H. Nay: Am I correct in concluding that there would be 29 separate certification programs required and varying amounts of development leading up to the establishment of the configuration that you're going to certificate under those 29 TC's?

A - L. Duke: That's right.

COMMENT - N. Nay: I just might expand right here and talk about the airframe/aircraft certification. The bar that you show represents an aircraft. There are, as far as the industry is concerned, about 64 separate and distinct aircraft involved.

Q - H. Nay: Mr. Helms made the point about the capacity of handling developments on a time schedule basis. Let's talk about your 29 TC aircraft engines. How many engines would you estimate you could recertificate a year if you had all the basic technology in hand and had it developed and proven for one of these major concepts on an engine?
A - S. Jedrziewski: I would say a maximum of 2, and that would really be pushing it.

Q - H. Nay: In other words, if this was the only thing in-house, so to speak, you could do about 2 a year?
A - L. Duke: Right.

COMMENT - H. Nay: That ties in pretty well with the airframe part of the thing. I've had conversations with Mr. Helms and Mr. Rembleski and we looked at this in the past in some detail. In each of the major aircraft divisions we figured that we could do about 2 to maybe a maximum of 3 TC's with some considerable expansion of facilities and capabilities. We are talking basically about a 10-year cycle for the industry to get up to date on a major change of this type.

Q - W. Westfield: On ultrasonic fuel vaporization, you said that you had seen some improvement in cylinder to cylinder distribution. Is this on an actual engine or on a flow-type rig?
A - L. Duke: This was on the actual engine on the dynamometer. It was not emissions data, but it was based on exhaust temperature data. It showed less of a spread indicating some better improvement in cylinder to cylinder distribution. Before we make the final assessment, we'll have to test it on an emissions stand where we are planning to do cylinder to cylinder distribution studies.

Q - W. Westfield: Could you describe how you do cylinder to cylinder studies other than by the temperature patterns?
A - L. Duke: Generally when we talk about cylinder to cylinder distribution in aircraft work we're talking about cylinder head temperatures and where the maximum temperatures of each cylinder occur with respect to fuel-air ratio. That is an indication of what the cylinder to cylinder distribution is if you want a macroscopic view. When we go to the test stand, we're talking about looking at cylinder to cylinder distributions with exhaust analysis equipment. These are microscopic analyses. We are taking measurements both ways and our intent is to correlate the two.

Q - D. Page: I understand the variable valve project is directed primarily toward the turbo supercharged engine in order to reduce hydrocarbons. This approach is addressing only a part of the problem on a certain class of engine. This concept will have to be integrated into the entire family of engines, which in turn must be integrated into the entire family of airplanes. It's going to involve a large amount of cooperation within the entire industry. Have you any comments on what you expect to do and where you expect to come out?

A - L. Duke: You've made a point that these concepts are not intended to satisfy emission limits. They are aimed at getting to those limits but the concept by itself will not satisfy the limit. Improving cylinder to cylinder distribution alone without leaning will not make a carbureted engine meet the EPA standards. I think the NASA contribution to general aviation is their sponsorship as a whole, so that anything that we do in this program will essentially be applicable to anyone who wants to use it, within limits.

COMMENT - L. Helms: He raises an excellent subject. To some extent it's evident that a certain amount of sterility of subject has occurred throughout the last 2 days because this subject is, and properly should be, emissions. We've given little or no consideration in our discussions to other items which are classed with equal priority by other equally insistent governmental offices. Sometimes I'm often struck by the various offices that cloister themselves in their own environment. We in industry are being continually pressed very hard for fuel conservation efficiency, which is in tune with leaning. There are some individuals who imply that we can aerodynamically cool the engine. However, you have to consider that more cooling air means a larger cowling, which means more drag in cruise, and thus poor fuel economy. I mentioned yesterday that increase in drag also reduces our rate of climb and puts us down to the point where we can't make the 84 dB curve for noise. Now we're back to the same position with EPA on noise. We say that we can increase engine rpm and help the cooling flow, but that increases the tip Mach number of the propeller. So now we have the same noise problem We in industry would prefer to decrease that rpm to get the noise down. Outside of the technical areas, we have the National Transportation Safety Board (NTSB), pressing us for systems for expanded safety. We obviously feel, as we know most of you do, that safety should be paramount. All of those discussions exclude the requirements of the International Civil Aviation Organization (ICAO), agreements which are handled by other segments of the government and to which we must respond. The Commerce and State Department are pushing us for more export sales because general aviation is a real gold mine for them. We have about a $2 hundred million a year favorable balance of trade. I continually get comments from the Commerce Department and State Department on what can you fellows do to do better. A key item is that our resources are not limitless and, as such, some of them are very foolishly expended because of the various government agency requirements. The best example I can think of is our new Lakeland plant where we did an industrial engineering survey which resulted in the installation of red lights at eye level to warn our employees of a potential of fire. A group from OSHA came in and said that people may not be looking and wanted bells, very large bells, mounted on the wall with an automatic alarming sensoring system. We took out the lights and put the bells on the walls. It took us 6 months and cost us some $15 to $20 thousand. Another group came in and said the environment was too noisy even though we had the small ear plugs. They wanted the large ones so we furnished those. A third group came in and said those people with ear muffs couldn't hear those bells. Now the result of this was a study in which they came with the solution of getting rid of the bells and putting eye level lights on the plant. My remarks are not capricious and they're not casual. The isolation of one segment of the government yet interacting on another is something which we have to live with day to day. A very good point was raised about the total problem rather than just one engine, one aircraft, and one certification effort.

Q - C. Rembleske: Will the requirements for the installation of engines incorporating your concepts be changed in such a way that existing airframes will not adapt to that concept?

A - L. Duke: No. As far as the existing airframe goes, I'm sure that it will adapt to products like this if we could change cowling or mount configuration. Personally, I think that it is a good opportunity for the airframe manufacturers to incorporate new ideas on their own as far as aerodynamics or whatever since there is a re-certification required here. You may not be in agreement with that, but that does present itself as an opportunity.

COMMENT - C. Rembleske: Many times we utilize the same type of engine or the same engine with minor modifications in several of our aircraft. Each and every one of those aircraft is an individual aircraft and as such must be treated throughout the certification program as a separate and distinct problem. While we may utilize the same engine, we very often find that there are radical differences between installation in different aircraft models within our own plant. Turbine powered aircraft do not have that problem. Once a configuration has been established that will work for one turbine engine we have found that it's a relatively simple task to transform that installation to another aircraft. This has not proven to be the case in the reciprocating type installations. There we have found that only minor variations or changes in the final airplane characteristics have established complete new programs and have changed requirements from one aircraft model to the other. It's not a simple problem taking one engine and putting it into a similar aircraft. We do have major problems in those development areas.

COMMENT - W. Mirsky: In reference to your ultrasonic carburetor, I did quite a bit of work on ultrasonics. Before I did the work my hearing was good. Some years later my hearing was bad and I don't know if the ultrasonics was responsible for this decrease in hearing. I think it might be worth your while to get in touch with some medical people who may have expertise in this area to see what the potential health hazard would be when you are exposed to the ultrasonics. Because you cannot hear it, you don't know how much energy is involved and you don't know what potential damage may be occurring to your hearing.

COMMENT - L. Duke: When we were running the tests I kept wondering if I was losing my hearing or not.

Q - G. Kittredge: I have a question about your variable valve timing project which touches on some of the comments that Mr. Helms just made. It seems to me that this is a basic, complex, and presumably more costly engine change than the other two engine concepts you're looking at. It looks as though it might have to have more arguments going for it to sell that kind of a change than just meeting the emissions, particularly the CO, standard. It would seem reasonable that variable valve time would also realize some benefits in terms of part throttle fuel consumption. Have you looked at this in your analysis or will I have to wait for experimental data?

A - L. Duke: As part of the analysis in NASA's program, we have looked at the EPA cycle and the various power levels as to what fuel economies you can have, primarily for level cruise conditions. Our first goal is emissions, but we put an equal emphasis on fuel consumption as to what we're trying to reduce or improve.

Q - G. Kittredge: Do you think that variable valve timing might have some payoff for you in that area?

A - L. Duke: Yes, we do.

Q - F. Monts: You mentioned that the variable valve timing concept would require new installation requirements and perhaps different installation concepts. What has variable valve timing to do with our present constraints in installation?

A - L. Duke: As I see it, the controlling factor is the actuating mechanism. If we're talking about something that's automatically controlled and can be contained within the engine that's one thing. If we're talking about an electronic control that has to be separated or divorced from the engine, that's quite something else. The problems may not be metal bending but could be new problems of installing that control unit in an aircraft, regardless of whether it's electronic or hydraulic.

Q - F. Monts: Will the ultrasonic concept to make carburetors vaporize fuel better work with a horizontal type of carburetor as well as an updraft carburetor?

A - L. Duke: Yes, from all indications we have from Autotronics it will although it may require a little modification to their design.

Q - H. Nay: Is one installation effect of the variable valve timing a significant weight increase?

A - L. Duke: Yes. In this design we're talking about a cam shaft that has doubled in weight. This is an early design so we are talking about a heavier installation right now.

Q - H. Nay: In your presentation yesterday on IO-360 work you showed it as being basically high idealized, under laboratory conditions, with the fuel control adjusted after the engine was warmed up. Under those conditions, the EPA standards levels of emissions could be met. I didn't see any allowance for the real world production tolerances. Could you give us an estimate of what those production tolerances would be? Also, the reduction in CO with that approach is totally dependent on a yet to be developed automatic mixture control device to use in the low power range as well as the application of existing technology in automatic mixture control devices applicable to the higher power range. I'd also like you to comment specifically on the production tolerances expected with the automatic mixture control devices.

A - L. Duke: We did show an idealized case fully compensated that came to 98 percent of the CO limit. There were no production tolerances, no real world situations. Taking off the compensating hardware, which was the other case shown on that graph, caused the CO to go up to 140 percent of the limit. With no compensation at all, you were up to some 40 percent over the limit. Adding on the production tolerances of the injectors that are being produced now, that 140 percent would be the minimum obtainable. An engineering estimate of the CO with a rich limit system would be 160 or 170 percent of the limit. The production band spread that we saw in the normally aspirated engine tested showed a 20 to 30 percent variation in the emissions at the same mode. Essentially, we're talking about the CO being anywhere from 100 to 200 percent of the limit. There could be as much as a 100-percent spread if you took away all of these nicities that were shown. Some tolerance band still exists on installing the automatic mixture control because it's not a perfect item and will have variations. I would guess those variations have on the order of 2 to 3 percent variation on fuel-air ratio. I can't come up with a number as to what the overall reflected emissions would be, but it could be some 20 percent.

Q - L. Helms: The ultrasonic fuel vaporization device was shown mounted externally down below the oil sump. It was stated that the device would be buried inside the oil sump in a final configuration. Yesterday's discussion showed the oil temperature rising in three cases to an unacceptable level, which was very surprising to me. Would the displacement within the sump of even that amount of oil require a larger sump? Secondly, is it possible that we're creating a new problem which entails a major oil cooler development?

A - L. Duke: I don't know the answer because of the difference in engines we're talking about. Before we were talking about an IO-360, 200 horsepower engine; here we're talking about carbureted engines, presumably of the lower hp range. We could definitely have a problem there. But that's something that's so far down the road we have not even started to consider it yet.

Q - C. Rembleske: In this ultrasonic fuel vaporization system for carbureted engines, what effect will that have on the ice forming characteristics on the various types of carbureation-type systems we have today?

A - L. Duke: It is a potential problem, but it is far down the development stage and it is something that is in the service and engine certification testing area. It is something that we cannot really answer on a test stand; it has to come from in-flight testing.

Q - C. Rembleske: Do you know of any work that has been actually done in that area relative to this type of carburetion system?
A - L. Duke: I do not.

Q - C. Gonzalez: Have you considered coupling the variable valve timing with the ignition timing changes since they both involve an accessory or gear case shifting device on the back of the engine?
A - L. Duke: We are approaching the program as if there are separate and individual concepts to be studied. At the end of the program there may be an opportunity to combine high energy spark with variable valve timing or even changing the timing of the ignition. If Continental can show progress in variable ignition timing, perhaps that, in conjunction with our improved spark, would be a good overall system.

Q - C. Gonzalez: In the event of a malfunction on the valve timing system, will it fail in such a way that the system will develop full power?
A - L. Duke: It would have to fail in full power since safety is one of our criteria.

Q - C. Gonzalez: If you go to a vaporization system, obviously you need an electrical source. Are you considering one? What would be the consequences of this electrical source becoming inactive and resulting in the ultrasonic device becoming inoperative? Are you considering an automatic enrichment under those conditons?
A - L. Duke: We've not gone as far as running lean or as running so lean that we saw we were in trouble if we turned the ultrasonic vaporizer off. We have conducted tests on the dynamometer where we ran with the vaporizer on and off and did not see any measurable power difference. My first impression is that the vaporizer does not affect a gross term such as horsepower as it does the minuscule term of emissions. There is no power penalty to pay.

Q - D. Page: It looks like we're attacking this problem piece meal. I ultimately foresee an engine with both the variable cam timing and the ultrasonic carburetor. It could be possible that you'd wish to have an idle range carburetor and run the engine under power conditions with a fuel injection system. The FAA, of course, is going to look at it with an extremely jaundiced eye. If it were my region I would probably give the manufacturer a real physical fitness program. There's something about the development schedule shown that rangles me. I'm saying maybe we'll get down to the year 1982 or 1984 and then we'll discover we can't fire what we've got in the cylinder. This is like a jigsaw puzzle. You don't know what the girl looks like till you get the last piece in the puzzle and it scares me to start out on a program like this without knowing that all pieces of the puzzle are in the box. Do you have any comments as to what you conceive might be out there that you haven't even through of yet?

A - L. Duke: Those kinds of questions are certainly well put when you have a definite program like we've all experienced in piston aircraft engines. If I want to certify an engine that was certified at 350 hp to one certified at 380 hp, I know my beginning, I know my end, and I know what goes in between because I've done it all before. I can tell you in 3 days exactly what it's going to require. But these programs are different. They are basically research programs. There is no one answer to all the questions. We can only project and assume that if everything goes right, this is what we think will happen.

COMMENT - G. Banerian: I think that there's a bit of confusion as to what the real motivation of NASA research is. Most of you know that NASA research, like military research, is directed to long range solutions. We want to provide a good data bank for decision making for future systems. Unfortunately, from yesterday's virtually tweaking of the engine, to today's radical changes, there is confusion that seems to imply that our main motivation is to help industry to comply with the 1979 standards. That's not our main reason to be in business. Now, it's true that we are doing things that may be adaptable; for instance, ultrasonic fuel vaporization may be adopted in time. But that's not the main motivation behind our research. We want to essentially tell you about the technology which is downstream and the dates of implementation. The dates of satisfactory completion are contingement on the success of the technical program and the amount of funds that are put into it. We'll uncover problems and eventually we will have systems that are totally integrated, this includes the ignition and the carburetion systems. Even though some elements may be heavier than the cam shaft, ultimately they should lead to a higher efficiency system with the pollution aspects taken care of concurrently. Our program is essentially a long range one and not meant necessarily to help you comply with the 1979 standards.

Figure 12-1

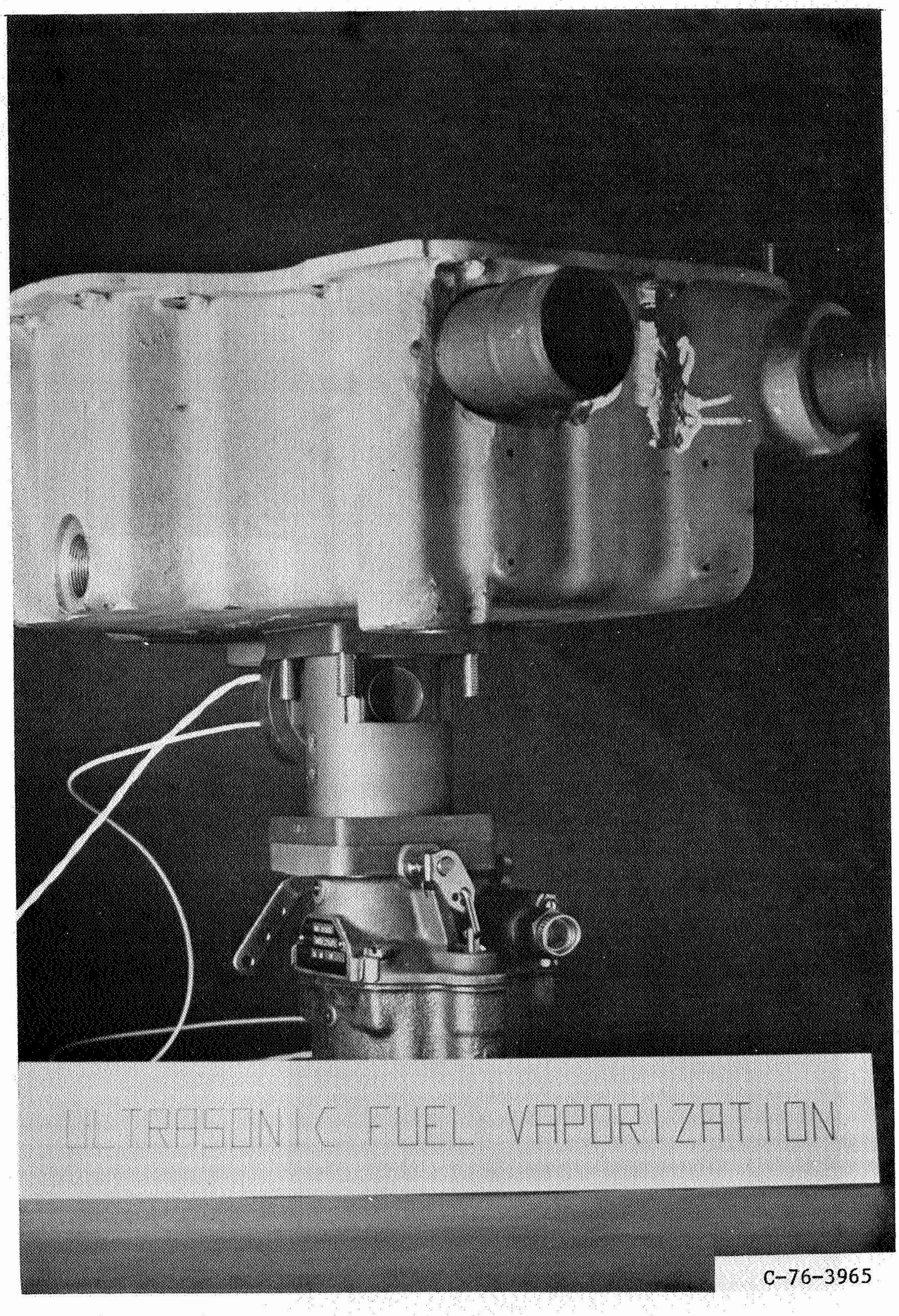

Figure 12-2

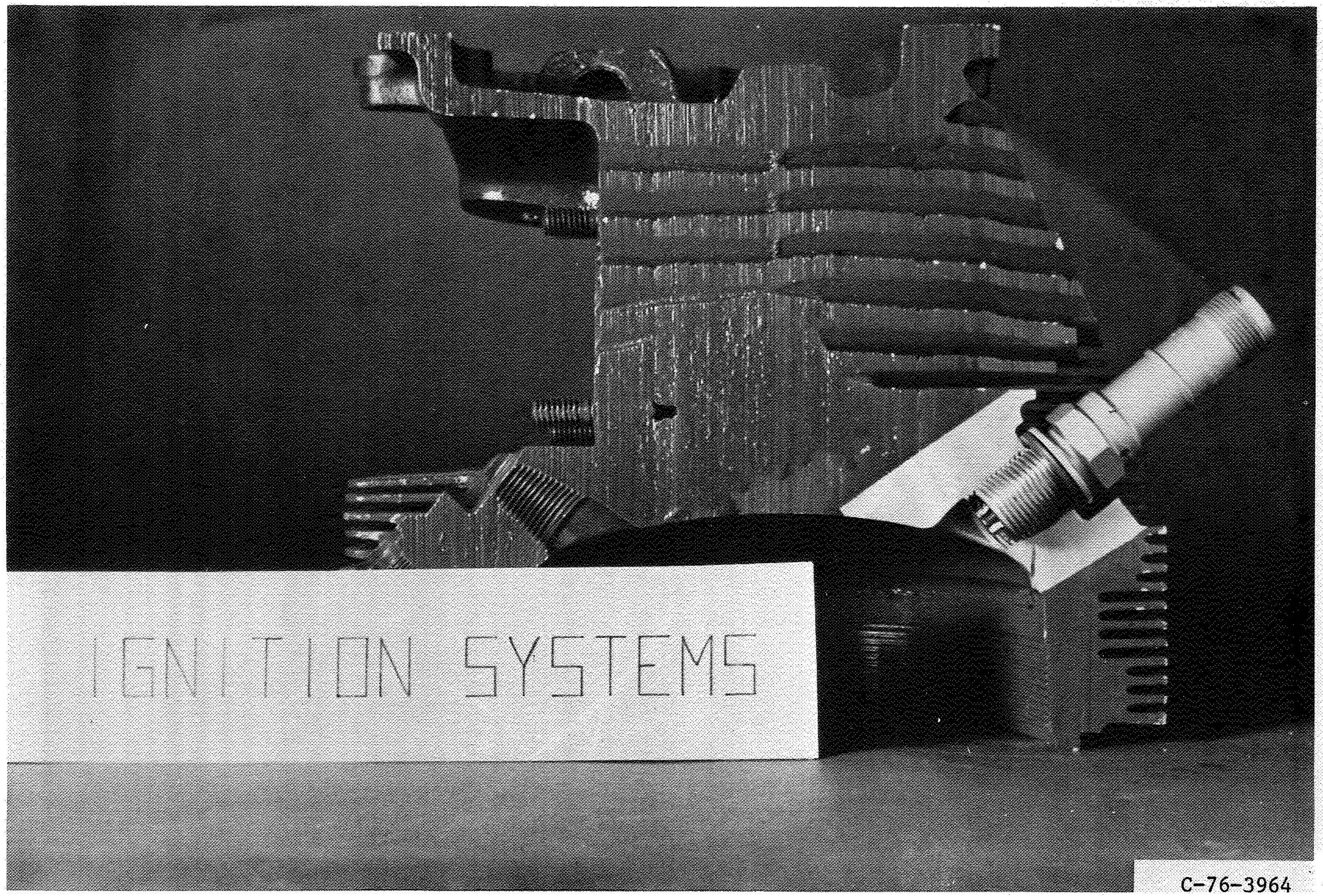

Figure 12-3

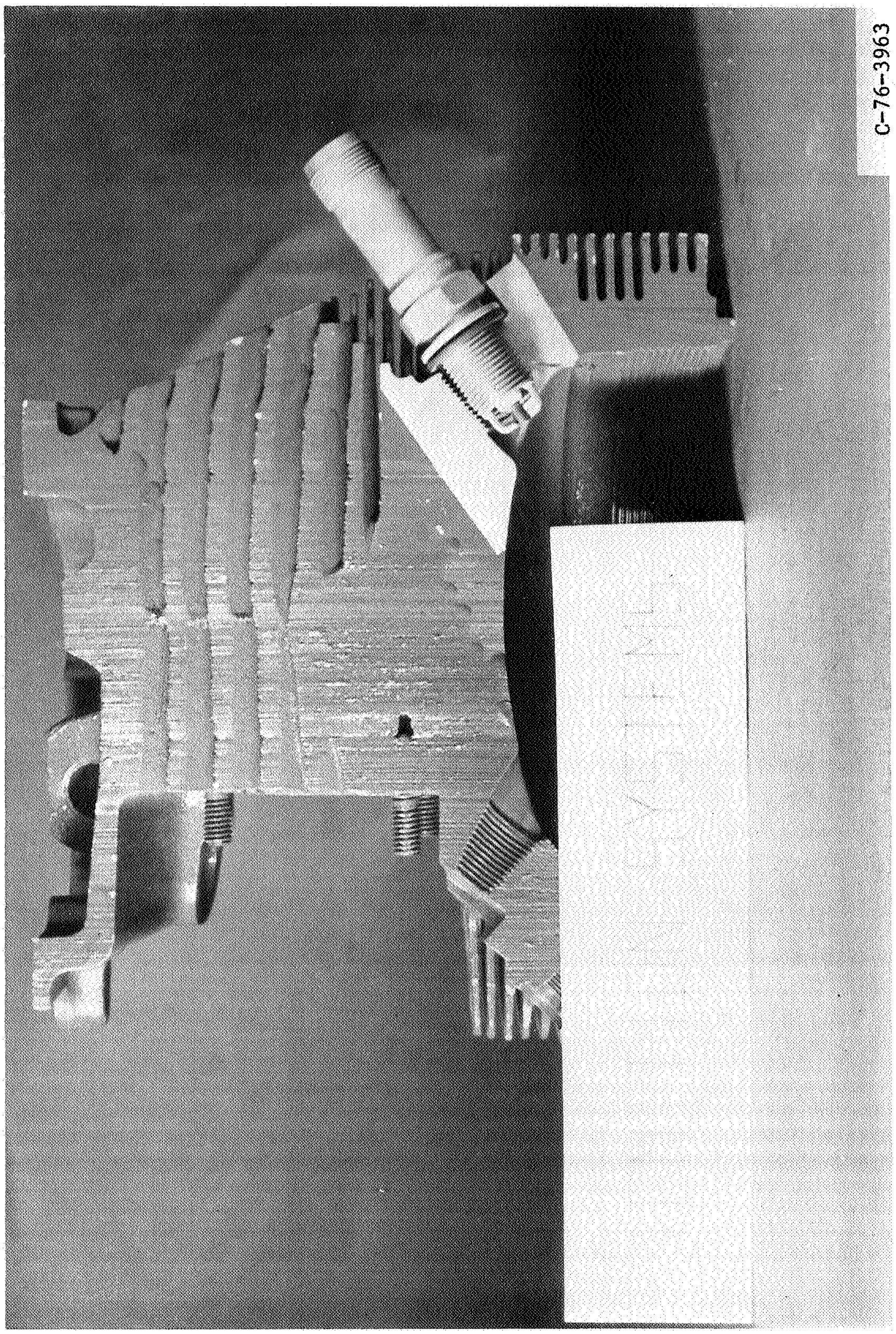

Figure 12-4

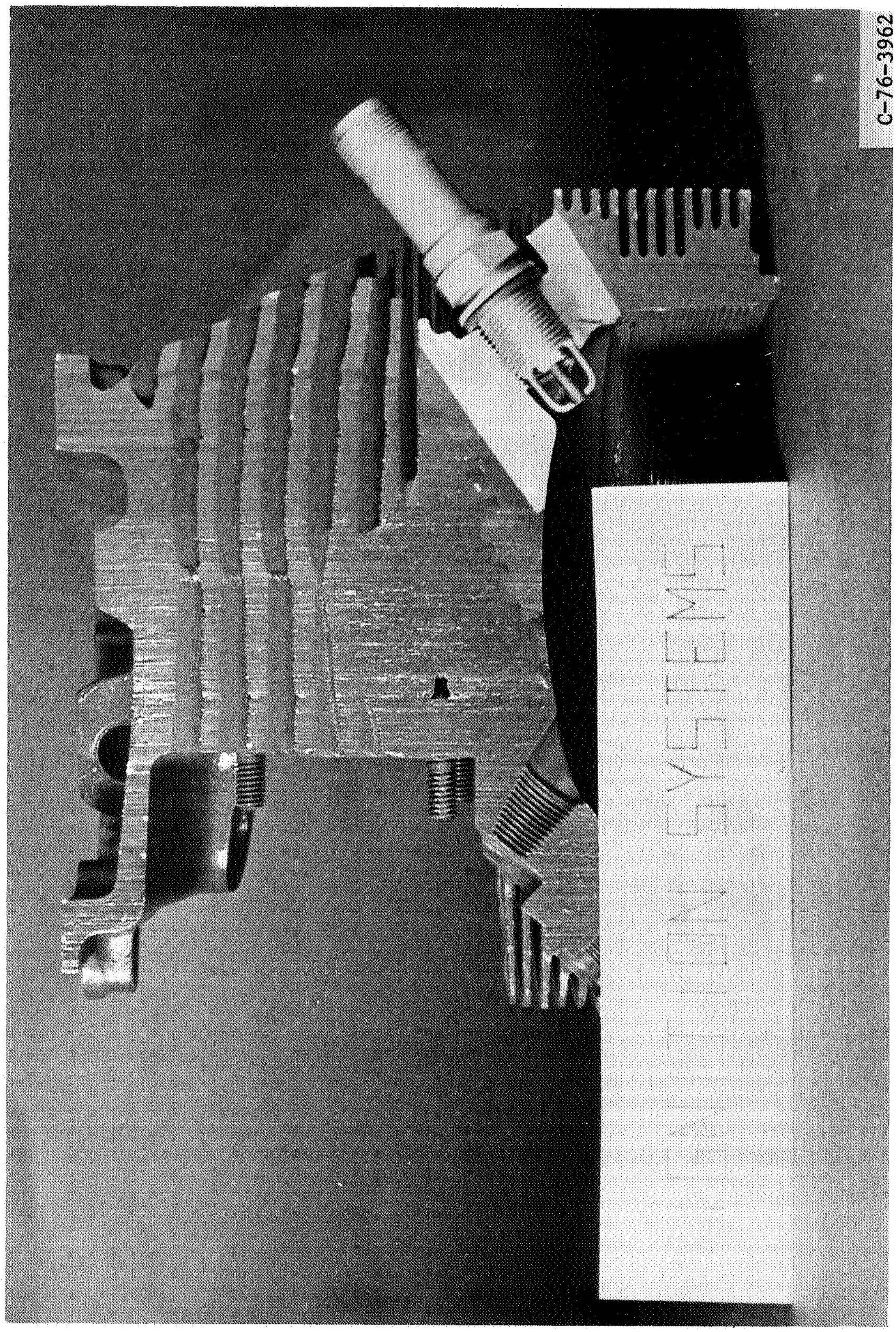

Figure 12-5

PROJECTED TIME SCHEDULE FOR
PRODUCTION AVAILABILITY OF
EMISSION REDUCTION CONCEPTS

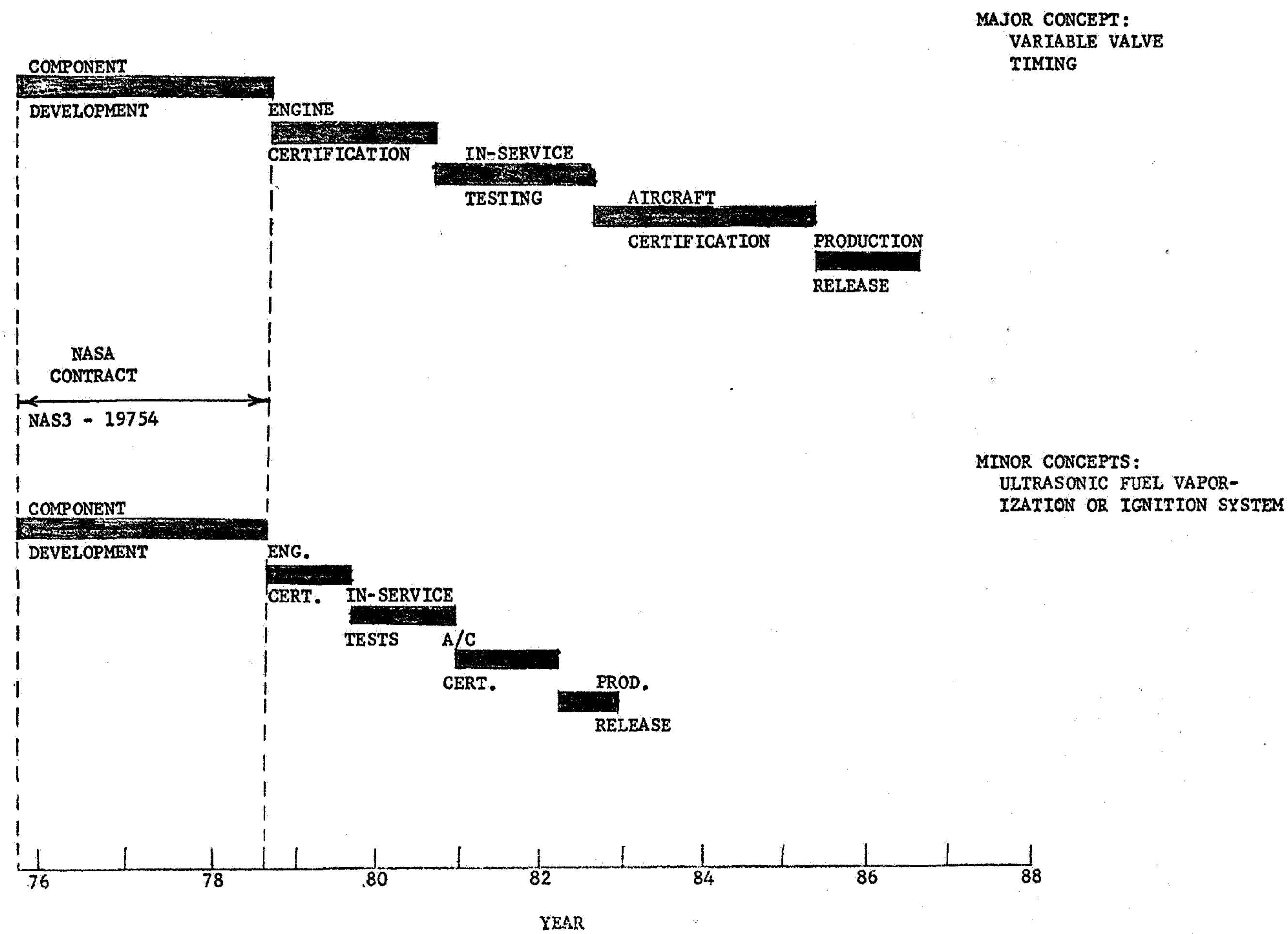

Figure 12-6