

#### 14. FUTURE DEVELOPMENT PROGRAMS

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From the programs, such as have been discussed previously (i.e., both government sponsored and in-house), the exhaust emission data from piston aircraft engines point to the need for not only more detailed data but also for a greater quantity of data as well. That is to say that although the exhaust emission trends are adequately defined by those data currently in hand additional data need to be collected in order to fully assess the piston aircraft engine as an emission source. For example, the effect of changing fuel-air ratio or spark advance on the emission levels of engines has been well defined for the engines tested. However, based on a limited amount of data, Avco Lycoming has shown that basic engine production tolerances have an effect on emission levels. If production tolerances are reflected as pollutant yields, then it is expected that, in addition, the emissions would also be influenced by the amount and type of accessories installed on each basic engine. These data have not been accumulated.

Therefore, while future industrial development programs are obviously aimed at utilizing the data on hand to reduce emission levels, an equal amount of time must be expended for simply defining, in greater detail, where individual problems lie within standard engine models and to what extent they can be, or need to be, accommodated. In essence, Avco Lycoming is taking a two pronged attack on the emissions program. And while the individual concepts proposed are intended to accomplish the overall goal of reduced pollutant levels, each technique essentially has its direction aimed toward (1) completely defining the emission problem or source points or (2) developing new materials, hardware, or operational procedures to exercise the trends defined by the data collected.

A review of the programs at Avco Lycoming to reduce the emission output of aircraft powerplants is listed below. The concepts listed here are not necessarily all those projects under study, but instead are provided to indicate the direction being pursued most vigorously. Also, it should be noted that programs not originally intended as an emission reduction item may indirectly reduce exhaust emissions through more efficient fuel utilization or less stringent operational limits, as in the cases of detonation restrictions or cylinder temperature maximums.

At Avco Lycoming the following programs are being investigated as company funded projects:

(1) Continued establishment of baseline emissions for various engine models. It has been previously noted that different models (or a total of 14 engines) including variations of the Avco Lycoming piston aircraft engines have been tested under recent testing, both in-house and government funded. However, when compared to the more than 350 different models currently being produced, it is obvious that a major effort remains (fig. 14-1).

(2) Continued characterization of effect of production tolerances on emissions. From the limited data available (fig. 14-2), it is apparent that exhaust emissions are influenced by inputs other than fuel-air ratio. These influences, while not completely defined, may be incorporated into the broad term of production tolerances. These tolerances will then necessarily be added to the overall emission characteristics of engines to provide a safety factor for future exhaust emission verification.

(3) Carbureted engine development and flight tests. Following much the same trends as were used in the previous flight test of injected engines, Avco Lycoming is currently establishing a program to evaluate leaner carburetor settings. This program will be aimed at leaner settings for all modes (fig. 14-3) except takeoff; therefore, the certification of the aircraft will not be affected.

(4) Cylinder cooling/fin design programs. Avco Lycoming has developed an improved cooling cylinder head assembly. However, it has been questioned as to whether the design used is the optimum or if a better design is possible. Avco Lycoming is investigating both the theoretical and experimental aspects of this question.

(5) Revised combustion chamber configuration. The combustion chamber used on piston aircraft engines is basically the hemispherical dome configuration. Avco Lycoming has under development a new configuration combustion chamber to determine its effect on engine emissions.

(6) Revised fuel metering systems. Data accumulated under the flight test program have provided an impetus for developing new fuel systems for piston aircraft engines. Based on the fuel schedules, Avco Lycoming is evaluating the benefits obtainable from minor redesigns of current fuel metering systems to a complete new concept in fuel metering for piston aircraft engines.

In addition to these programs that are aimed at the engine itself, the interaction of the airframe and the engine is also being studied. In such a program a joint effort is being made by NASA and Mississippi State University to determine the various influence of aircraft cowl design on engine cooling. Avco Lycoming has supported this effort by pro-

viding equipment and supervisory input. This systematic approach at engine cooling may provide an important side benefit to allow reductions in emissions through improved airframe design.

Avco Lycoming is currently involved in these programs in an effort to reduce the pollutant emissions from piston aircraft engines. While each program possesses potential benefits, no unique technique has been perfected to yield a viable approach to meeting the proposed standards by 1980. Test stand and flight test data accumulated to date indicate that the current emission levels as specified in Part 87 of the EPA Regulations are too stringent for compliance with present state-of-the-art of piston engine aircraft technology. Avco Lycoming is not in a position at the present time to recommend a revised emission level. To reach this position we believe two things need to be done.

First, a unified and well-defined test procedure needs to be developed. As has been shown, there are some rather basic questions that need to be resolved.

Second, a broader base of data needs to be developed. We have tested some engines but we have not tested a sufficient variety of engines or enough engines of the same kind to come up with a data base that will allow us to predict with a degree of accuracy the type of emissions we can expect from existing engines.

To illustrate the magnitude of the affected installations, the following engine production schedule for July 1976 was tabulated to show the intermix of engines:

#### SCHEDULED ENGINE PRODUCTION - JULY 1976:

Number of Engines: 1010

##### Normally aspirated:

Carbureted models	30
Carburetor settings	20
Injected models	36
Injector settings	24

##### Turbocharged:

Carbureted models	3
Carburetor settings	2
Injected models	15
Injector settings	6

Based on the previous schedule, 52 different fuel metering systems would be required for flight and field testing before production implementation on presently certified installations.

Finally, some have proposed that we go to leaning the engines as an interim step in an attempt to reduce exhaust emissions. This approach may seem simple and straightforward, but an underlying network of complexity restricts Avco Lycoming from taking such action until all facets of the concept are considered. Not only inputs such as development and certification time, unit cost, and availability of production hardware, but engine aircraft performance acceptability and customer acceptance programs must be evaluated through flight and field service tests. The great variety of engines shipped in July illustrates the additional complexity of the job.

Therefore, we believe that the program which answers our two questions and our own in-house programs of the six steps we are taking will give us the necessary information that will allow us to state the emission level currently attained, potential steps to be taken to reduce emissions, and the related cost benefit ratio. Until then we cannot truthfully address ourselves to the questions.

If a fuel metering device were developed that would reduce emissions, we would estimate its costs and the associated costs of implementing an emission control as follows. Based on current knowledge and making an assumption that not only do we know what to do but that technically we can do what's required, our best estimate of the cost to our customer would be of the order of \$1000 per engine or \$12 million per year. Naturally, the cost to the ultimate customer would be higher than this.

## DISCUSSION

- Q - G. Kittredge: You stated that your company was not in a position to say that they would be able to comply with the standards laid out in Part 87. Was this in terms of the 1979 implementation date? In other words, if the date itself were conceivably to be adjusted backwards, would that change your prognosis?
- A - S. Jedrziwski: Right. We are not in a position, right now, to say that we can or cannot meet the 1979 standards as they are written. We have data indicating that we cannot, but we don't have enough data on all of our engines to say that every one of our engines cannot meet it. We can't even recommend to you now whether we need 2, 3, or 4 years.
- Q - G. Kittredge: Based on the fairly promising information that was presented yesterday, would you agree that some of your engines can meet it?
- A - S. Jedrziwski: I don't think we indicated that yesterday. I think that the information presented yesterday indicated there was a trend. We could obtain the emission level by hand tailoring the fuel metering devices or leaning beyond the practical production limits. We don't know how we can arrive at that point with a production piece of hardware.
- Q - G. Kittredge: If the standards were to be modified in the manner suggested in Mr. Houtman's paper and if you only had to comply with a CO standard, how would this affect your prognosis?
- A - S. Jedrziwski: Without knowing what all our engines are doing, I don't believe we're in a position now to say whether we can meet the emissions. We could do it with certain models. We can't do it with all our engine line.
- Q - W. Houtman: Up to now I understood that our test procedures problems had pretty well gone away and yet you indicated that procedures were critical items to be resolved.
- A - S. Jedrziwski: Yes, they're not clearly defined. They're not spelled out. There have been some suggestions made during the last day and a half here.
- Q - W. Houtman: You're referring strictly to the calculation procedure?
- A - S. Jedrziwski: Calculations plus maybe some response times, length of the line, heated lines, and so forth. There is some question on what particular instrumentation is completely acceptable and what isn't. There are also questions on the sampling standard gases. We didn't bring all the fine details out during the last day and a half, but there are still some items that need resolving. We're not in a position now to recommend to you what they should be or how carefully they would have to be examined.
- Q - W. Houtman: It might be difficult to resolve them unless we get some idea where the problems are.

A - S. Jedrziński: Right, and as I indicated we're not in a position to go to you yet with these recommendations.

Q - F. Monts: Does Lycoming or anyone else understand what is required to show compliance in a production basis with the EPA standards?

A - S. Jedrziński: We have read them, and it means that every engine must be tested. If you're referring to the cost, we pulled that out of the air. We're testing a sampling plan and not every engine. If we would have to test every engine for emissions before it went out the door, it would probably increase the cost another \$500 per engine.

Q - F. Monts: Is there now in the federal regulations an established procedure for compliance testing?

A - S. Jedrziński: Yes. Part 87 spells that out.

COMMENT - W. Houtman: The regulations state that every engine must meet the standards. It does not state that every engine must be tested. Again, compliance is an area of FAA responsibility. So you might ask the FAA people on that.

COMMENT - S. Jedrziński: That's why we need clarification on whether every engine has to be tested or whether it can be done on a sampling plan.

Q - C. Rembleski: Have you considered how much of a margin you're going to have to have so that you don't have to test each production engine assuming you have a sampling plan?

A - S. Jedrziński: We're now sampling engines from production. We have to squeeze these in between other engines and production items, so that it's taking a very long time. We're trying to establish the so-called tolerance band. We need more input before we can clearly define what we need or what the engines are actually doing.

COMMENT - N. Krull: The EPA did raise the point that the enforcement of Part 87 is up to the FAA. In our presentation we pointed out that we had done some testing on an experimental test stand with some six of ten engines in a program. We recognized that we need a great deal more information on engine to engine variation, installation to installation variation, before we can come up with an enforcement policy. This policy, including what the test requirements will be, is something that has to be agreed on between the EPA and the FAA. We have started discussions on that already. It does require more data before we can come to a conclusion.

COMMENT - L. Helms: It seems to me that we in industry should at least try to be a little more responsive to Mr. Kittredge's earlier point. What I'm about to say is not a statement of policy, because it's obvious that I have not had a chance to think it out nor meet with my colleagues. I don't really know the answer to his question regarding where we would stand on CO if the hydrocarbons and NO<sub>x</sub> were eliminated. I think we

might be able to sit down and work out this type of thing. We might be able to look at the data from Lycoming and TCM on the basis of where the major pollutant contributions were. If it was during takeoff and climb, which is where it appears to be by the ppm count, perhaps the fuel scheduling modal analysis could be reduced to two modes. Based on this, and concentrating on CO, we might be able to come up with some type of automatic fuel control system on a more rapid basis. If this system is applied by a phased program on unsupercharged four cylinder engines first, we might be able to make the standards next year. Next, we might go to six cylinder or carbureted engines, and finally to the turbocharged engines. It's a proposal that we just haven't had a chance to think out. But I can envision the possibility that we could, in fact, come up with some type of program outline. I can't be any more definitive, but I think we owed you a positive response to your question.

COMMENT - E. Becker: I think we're losing sight of one thing. The elimination of two of the pollutants does not change the order of magnitude of the effort of reducing the CO problem.

COMMENT - L. Duke: Taking away the hydrocarbon and NO<sub>x</sub> limits is not directing ourselves to the real problem. On the engines we've seen to date, and we've made the point we're not done yet, the major problem is the CO, especially the four cylinder naturally aspirated engines where there's not a problem with NO<sub>x</sub> or hydrocarbons.

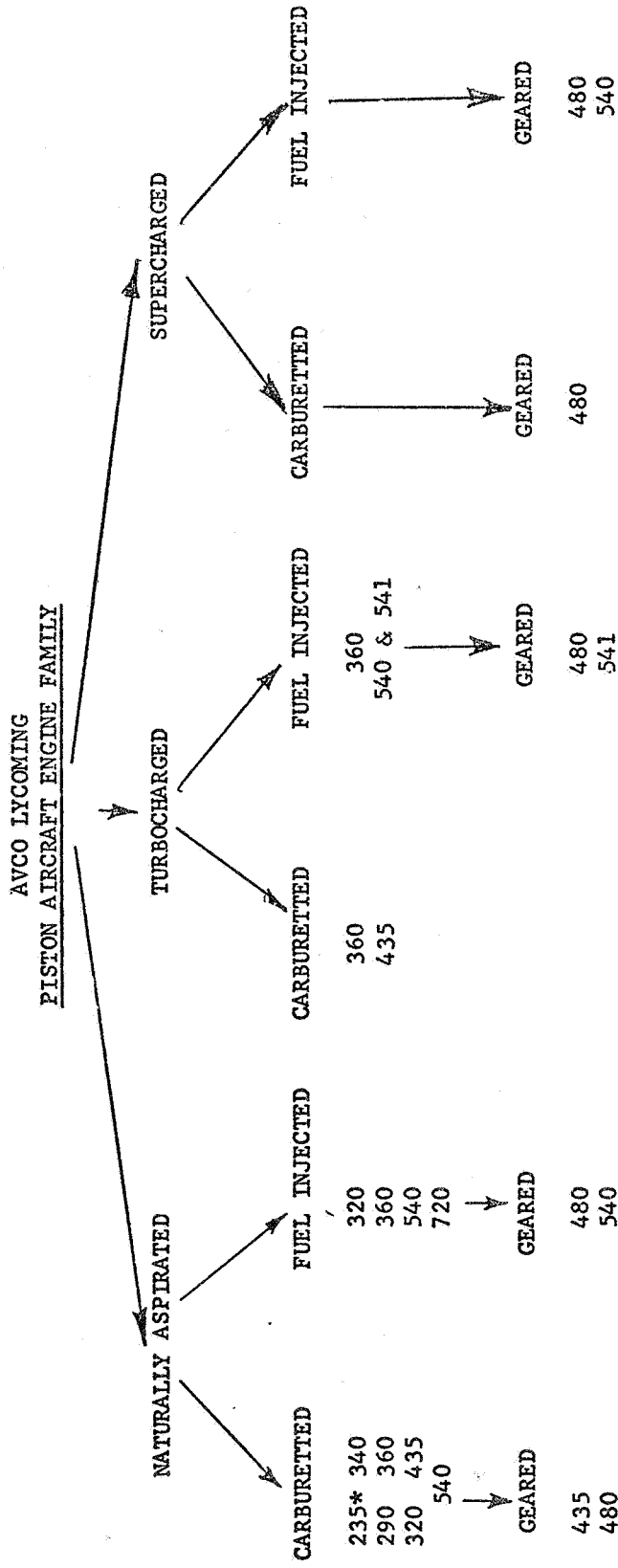
COMMENT - W. Houtman: Just to clarify the recommendation I made, it was not the intent to completely relax the standards and it wasn't an argument for relaxation. When making the recommendation to drop the HC and NO<sub>x</sub>, based on the analysis, there was no need to control these pollutants. There seemed to be some confusion that some very good CO control systems were being ignored because of high NO<sub>x</sub>. We don't expect a difference on HC and NO<sub>x</sub> as a result of removing HC and NO<sub>x</sub>. The HC and NO<sub>x</sub> standards were set at levels we would expect to see as a result of the CO controls.

COMMENT - P. Kempke: I agree with what's been said with regard to CO being the problem. If the hydrocarbon and NO<sub>x</sub> standards were dropped, some of the development work would be simplified in the sense that the measurements of those two pollutants would not be a problem. It would minimize the amount of temperature-humidity correction factors that have to be applied to the testing. However, I certainly agree that it does not change the overall problems facing the engines today. The CO is the big problem.

Q - G. Hicks: Regarding your sampling techniques, you indicate you have some type of sampling technique that you applied in the testing of the engines and not all engines were tested. Would you feel it would be a help to you if you had greater clarification in the regulation to indicate the type of tolerance bands that would be required in your sampling technique and the establishment of confidence intervals in your statistical analysis?

A - S. Jedrzejewski: In our determination of costs, we have based that cost on sampling selected engines. Only 1 out of 10 or maybe 1 out of 20 engines off the production line would be run through the emission level test to see whether or not it complies. Whether the sampling plan has to be on production or whether it has to be done only on certification, we're not in a position to know or make a recommendation at this time. EPA has spelled out that every engine that leaves the line has to meet the emission level. FAA and EPA, as I indicated, are getting together to work out a sampling plan or whatever is acceptable.





\* Denotes Engine Displacement

ALL CLASSES OF ENGINES ACCOUNT FOR OVER 350 MODELS.

Figure 14-1

# TAKE OFF EMISSIONS

NOTE: 10-360-A1B6D  
 DATA ADJUSTED BY RATIO - □ - 3/4 N 883-X RUNS: 23-32  
 (SPEC. MODE BHP+FAF)/(OBS BHP+FAF) X - 3/4 N L-15492-51A - RUNS: 77-79  
 + - 3/4 N L-15503-51A - RUNS: 24-26

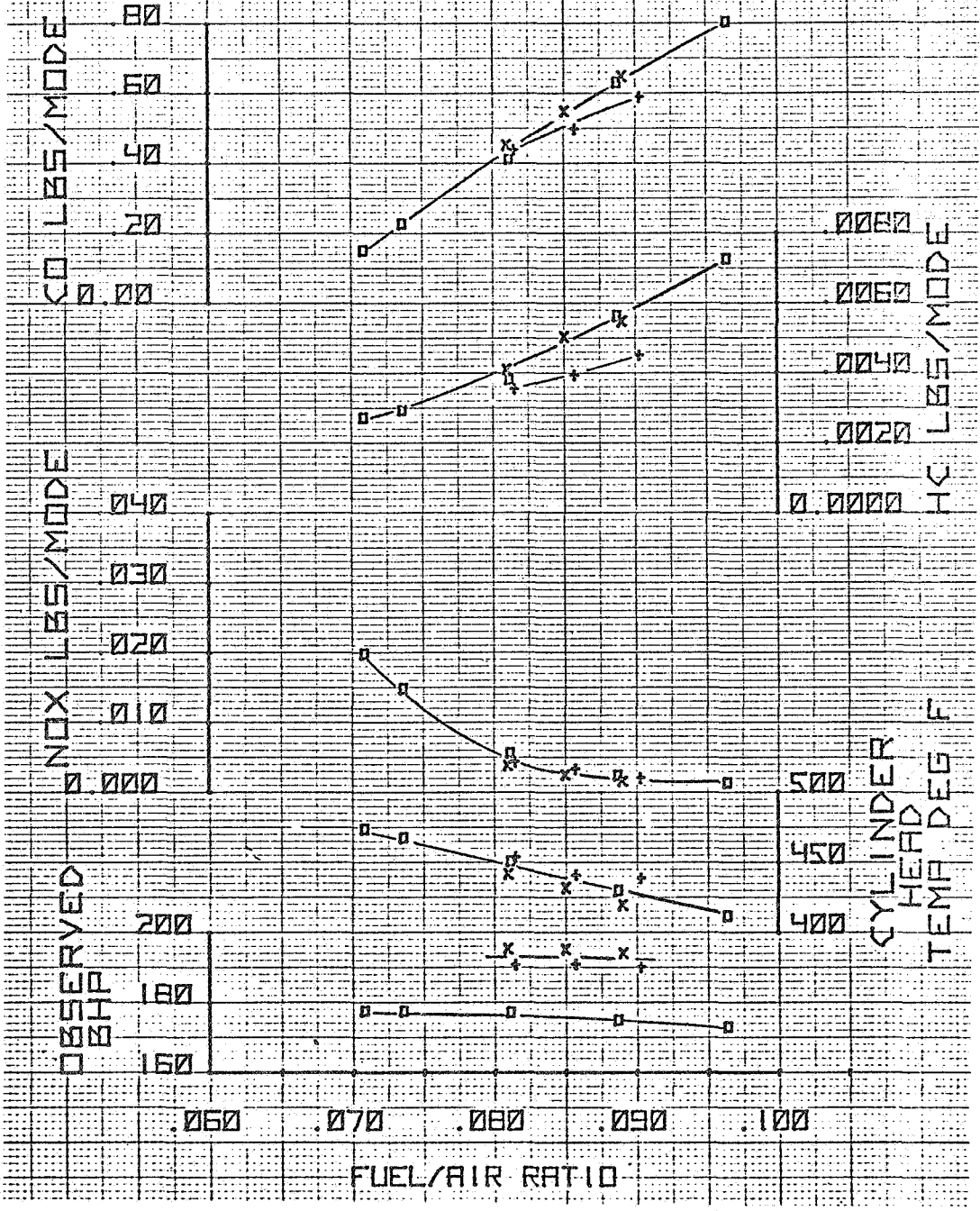


Figure 14-2

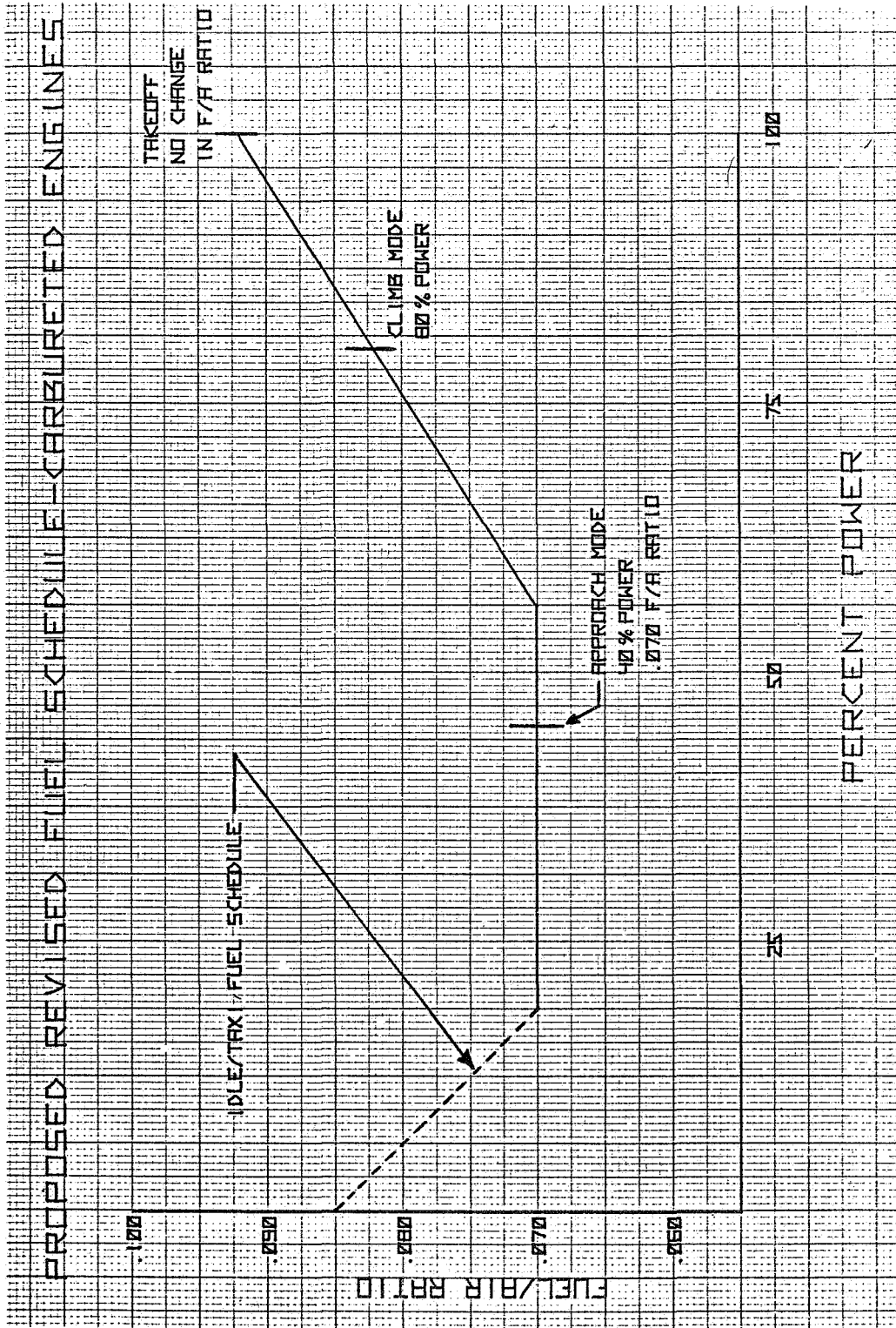


Figure 14-3