7. AVCO LYCOMING EMISSION AND FLIGHT TEST RESULTS*

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EMISSION PROGRAM RESULTS

The Federal limits for piston aircraft engines, as stated by the EPA, Part 87, are defined as pollutant (CO, HC, NO_x) mass totals per rated horsepower obtained from engine operation through a prescribed LTO cycle, with modes specified by power and length of time. Table 7-1 shows a comparison between the 5-mode test cycle, as outlined by the EPA in Part 87, and the expanded 7-mode cycle currently being used by Avco Lycoming, with specific requirements for modes, mode times, engine speeds, and power settings not clearly defined in the specifications.

From the initiation of emissions testing, Avco Lycoming has felt that an important aid to the standard baseline cycle is the "leanout run" or mixture distribution run for each mode (fig. 7-1). As experience has increased with regard to data analysis and presentation, Avco Lycoming has found that, for development test work, the value of accurate pollutant trend data with respect to variable mixture strength exceeds that of individual baseline results. Whereas the baseline cyclic results are true only for the ambient conditions and fuel schedules for that baseline, leanout curves can be used to formulate cyclic results for a variety of fuel schedules (and/or production tolerances) over a range of ambient conditions.

Table 7-2 shows a comparison between the average of seven baseline cycles and the projected baseline cycle from the leanout curves for the IO-320-D engine. The results are typical of what Avco Lycoming has found in emissions testing to date; that is, sufficiently accurate baseline cycles can be constructed from pollutant trends of leanout data.

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*The data contained in this report are partially sponsored by FAA-NAFEC and have not been approved by them at this time. Therefore, the conclusions presented are solely those of Avco Lycoming and may not necessarily reflect those derived by the FAA.

Table 7-3 shows a summary of the Avco Lycoming emissions program including those engines tested under the FAA-NAFEC contract. One advantage in formulating the cyclic results from leanout curves is that the pollutant totals for both the rich and lean production fuel schedules can be projected, as shown by figure 7-2. None of the 14 engines models tested to date by Avco Lycoming with their current production fuel schedules comply with the Federal standards. The variation in pollutant results, as shown between the IO-320 and O-320, is primarily due to the difference in production fuel schedules, not between fuel injector and carburetor.

Due to variations in the mode times and exhaust volume flow rates throughout the cycle, there are substantial differences in the contributions by mode to the cyclic total. As shown by figure 7-3, which gives a breakdown of pollutant contribution by mode for the IO-360-A, it can be seen that the taxi, climb, and approach modes produce approximately 9, 52, and 34 percent, respectively, of the CO cyclic totals.

In order to establish what possible improvements can be obtained by revised fuel schedules, it is important to assess the contribution from each mode separately. To show the effect of leaner fuel schedules for individual or combinations of modes on the cyclic pollutant totals, Avco Lycoming has developed the emission profile. The emission profile is constructed from the pollutant leanout curve trends, usually for those pollutants exceeding the Federal limits.

The emissions profile provides a fast, simple means of constructing various fuel schedules and determining the cyclic pollutant totals. For instance, figure 7-4 shows the emission profile for the IO-360-A engine with both the rich and lean limit production fuel schedules shown. Reconstructing the development of the lean limit fuel schedule is as follows:

(1) Select idle mode fuel-air (F/A) ratio (0.092) on upper left quadrant axis.

(2) Proceed vertically upward to intersect F/A ratio line for takeoff mode (0.085).

(3) Proceed horizontally to the right to intersect the F/A ratio line for the taxi mode (0.092).

(4) Extend line vertically down to intersect with climb F/A ratio line (0.085).

(5) Proceed horizontally to the left to intersect approach F/A ratio line.

(6) Proceed vertically upward to intersect with lower left quadrant axis and read cyclic total for CO.

Figure 7-5 shows the lean fuel schedule limits which Avco Lycoming predicted with respect to detonation and accelerations prior to flight test. These estimates were made based on a fuel system uncompensated for density for use with 0° to 100° F ambient temperatures. Avco Lycoming developed the profile to accommodate the concept of specifically tailored fuel schedules providing varying degrees of mixture leaning for individual modes and to permit quick and simple assessment of the benefits in cyclic pollutant totals. However, since test stand data were used in the development of the profiles, no limitations regarding cooling have been projected onto the profiles.

When reviewing emissions trends displayed on leanout curves or emissions profiles, limitations as to cylinder cooling, detonation, and acceleration must be identified, Avco Lycoming has found that based on the leanout emissions trends generated on the test stand and without regard to the limited quantity of cooling air available in the airframe installation, fuel schedules can be chosen whereby cyclic emissions comply with Federal regulations for all engine models tested to date. However, if sufficient tolerance is added to the fuel schedule to produce acceptable aircraft operation over the ambient temperature range from 0° to 100° F along with current production fuel system tolerances, projected cyclic emissions are outside Federal Limits for all engines tested. Therefore, Avco Lycoming does not presently stipulate "test stand" limitations since at best these limits would be artifical and unrepresentative of the aircraft installation. Limits as shown on the emissions profile are based on actual past flight test experience, inflight detonation surveys, and true realistic appraisal of aircraft constraints. Avco Lycoming has accumulated valuable cooling data in its recent flight test program. A review of these data has shown a positive indication that with some corrections, test stand cooling data can be projected to the actual installation. Additional data will be required to provide sufficient data sample for complete analysis. Acquisition of this data is in progress.

The effect that manufacturing tolerances have on the absolute pollutant levels for a given engine model and fuel schedule is important. Avco Lycoming is currently sampling representative engines from several engine models to define engine-to-engine emission variation. Figures 7-6 and 7-7 show leanout curves for the takeoff and approach modes, respectively, with data from three IO-360-A engines. Leanout data for the takeoff and climb modes for two model TIO-540-J engines are shown by figures 7-8 and 7-9. Accumulated test data on additional engines should provide a representative sample to sufficiently determine the extent of variation.

FLIGHT TEST RESULTS

The Avco Lycoming flight test program for reduced emissions was conducted to determine and document the lean fuel schedule limits for current production aircraft based on flight safety. Based on analysis of the emissions profile, Avco Lycoming proposed to evaluate the effect of leaner schedules in the idle/taxi, climb, and approach modes. These modes were selected as areas where it was felt that possible improvements could be made with the greatest improvement in cyclic emissions reduction. Leaning in the takeoff mode, which would produce negligible cyclic pollutant reduction but require aircraft recertification, was not evaluated. The fuel systems to produce these leaner stepped fuel schedules were tailored specifically for the flight test and are not currently production items.

The flight test consisted of three phases:

(1) Cold weather testing to evaluate the effect of leaner mixtures in the idle/taxi and approach modes on safe engine acceleration.

(2) Hot weather ground testing to insure adequate ground cooling margin.

(3) Hot weather flight tests to study the possibility of leaning in the 80 percent climb mode.

Table 7-4 shows a brief description of the five aircraft flight tested in the Avco Lycoming program. To study the effect of installation variation on fuel schedule limitation, four aircraft with the 200 hp IO-360 engine were tested: Piper Arrow 200, Cessna Cardinal (tested under NAFEC contract), Rockwell Commander 112, and Beech Sierra. In addition, the Piper Pressurized Navajo was tested to evaluate possible emissions reductions on Avco Lycoming's highest power output current production engine, the TIGO-541.

The revised fuel schedule employed for the cold weather acceleration testing is shown by figure 7-10. A special lean idle plate was tailored to produce leaner fuel schedules in the idle/taxi modes. The fuel injector, a Bendix RSA-5AB1, incorporated a two-hole main metering valve which maintained a 0.067 F/A ratio from approximately 25 to 50 percent power (approach mode) and then enrichened with increased throttle angle to current production rich limits. An AMC unit to compensate for changes in ambient temperatures and air density was included to insure that the schedule would be maintained. The lean idle plate provided a nominal F/A ratio of 0.086 and 0.072 for idle (600 rpm) and taxi (1200 rpm), respectively.

For the acceleration testing, the throttle angle, engine speed, and manifold pressure were recorded for approximately 30 accels with the standard fuel injector set at manufacturer's recommended idle mixture setting and 30 accels with the revised injector with leaner fuel schedules. A similar flight test for both injector systems was developed which included 90 mph, 125 mph, and ILS approaches initiating at 4000 feet with accelerations at 1000-foot intervals during descent. Acceleration rates varied from 0.2 to 30 seconds from idle or part throttle to full throttle. The idle mixture was set immediately prior to each flight to insure consistent lean mixture settings with varying ambient conditions. Table 7-5 shows the flight program outline developed for Avco Lycoming's flight test program.

Figures 7-11 to 7-14 show comparisons of engine response for rapid throttle movements with the standard and revised injector systems for each of the aircraft tested. The accelerations are at various altitudes and flight conditions. Due to a limited time to procure the revised fuel injector system, the idle to full throttle plate travel was 80° instead of the 70° travel for the standard injector. The acceleration characteristics of each aircraft were similar, and the recorded transients showed a very slight hesitation with rapid acceleration of the revised injector system; however, none of the test pilots reported a noticeable hesitation during the flight test. Figures 7-15 and 7-16 show slow accels made on the Rockwell 112 and Piper Arrow. A flat spot in engine response is clearly evident from these curves corresponding to the leaner than best power fuel schedule in the 25 to 50 percent power range. All aircraft exhibited identical responses, and pilot reports noted engine roughness in this area. In addition, magneto checks, usually performed in this range, showed abnormally high single ignition rpm drop resulting from the lean mixture.

Throughout the emissions program Avco Lycoming has noted that accurate fuel and air flow measurements at idle and taxi are extremely important. Due to the low quantities of flows at these conditions, minor errors in flow measurements can yield serious problems. For example, at idle an error of as little as 0.2 pound per hour in fuel flow can mean a 5 percent error in the measured F/A ratio - the maximum allowable, as indicated by the EPA, Part 87, for exhaust emission testing. These same tight tolerances would apply to the allowable fuel system variations in the idle/taxi modes.

A similar injector system with larger capacity was ground tested on the Piper Pressurized Navajo. The leaner fuel schedule in the idle-taxi range appeared acceptable for the limited ground acceleration testing completed. No transient recording of engine parameters was taken. However, a definite problem area was identified in the transition range between the idle plate and main metering system of the injector. Severe stumble and hesitation resulted during all accels in this area. Attempts at correcting this problem failed and it was decided that development work of that nature was better performed on the flow bench and test stand. It was noted during testing that in the 30 to 60 percent power range, turbine inlet temperature was at the red line at full rich mixture operation and was not acceptable.

Ground cooling evaluation of the leaner fuel schedules in the idle-taxi modes showed absolutely no cooling problem for any aircraft.

Cooling climbs to evaluate leaner fuel schedules in the 80 percent power range (Arrow, Cardinal, Sierra, and RC112) were made at 85 KIAS with best power fuel flow maintaining constant 80 percent power through critical altitude. Figure 7-17 shows a comparison of the 80 percent constant power climb versus the standard full throttle climb and the subsequent power loss with altitude for both standard conditions and corrected to 100° F. Avco Lycoming does not propose leaning beyond best power fuel flow in the climb mode.

A summary of the 80 percent power cooling climb results is shown by figure 7-18. Two cooling climbs were made with each aircraft from approximately a 500-foot altitude with stabilized conditions through critical altitude and peak temperatures. The summary shows the following:

(1) Three of the aircraft maintained engine CHT's within the 475° F maximum allowable through the 80 percent constant power climb at best power F/A ratio. The fourth aircraft had maximum corrected CHT's of 476° and 480° F, respectively, for the two climbs - or just over the limit.

(2) Two of the aircraft maintained the oil temperature within the 245° F maximum allowable.

After completion of the flight test program for five aircraft with fuel system modified for emissions reduction, Avco Lycoming has outlined the following problem areas and conclusions:

(1) The Bendix fuel injector (without density compensating unit) meters fuel by sensing induction air flow volume. Colder inlet air temperatures result in leaner mixtures supplied to the engine. Figure 7-19 shows the approximate relation between metered F/A ratio and induction air temperature. Note that the line indicating best power at 0° F shows that the resulting fuel schedule would yield a F/A ratio of approximately 0.084 at 60° F. The lean limit for the IO-360-A engine is 0.085 F/A measured between 60° to 80° F air temperature. Since the aircraft/engine combination must perform safely over wide temperature ranges, an AMC unit will be required to make any significant changes from current production fuel schedules. No assessment has been made by Avco Lycoming as to production tolerances of this unit.

(2) Leaner fuel schedules can be tolerated in the idle-taxi range of the IO-360 engine without affecting the acceleration of the engine. However, when considering even extremely tight production tolerances for the fuel injector in the idle range, there is negligible benefit when projecting the fuel schedule to 60° to 80° F induction air temperature.

To make any reasonable improvement in this area, a density compensating unit for the idle-taxi range must be incorporated into the injector unit. What the resultant production tolerance of such a system would be, or whether it would nullify any benefit to reduced emissions, is not known by Avco Lycoming at this time.

(3) The leaner fuel schedules in the idle, taxi, and approach modes, as evaluated in the cold weather test phase, revealed several major problem areas. Engine roughness, flat spots in engine response, and excessive engine speed drops during single ignition magneto operation would require solutions before any thought of production effectivity. At this time Avco Lycoming recommends a lean limit fuel schedule for these modes at best power fuel flow, which could eliminate these problem areas. With additional development work, it may be feasible at some time to revise the approach mode flow schedule towards stoichiometric as tested in the flight test program.

(4) The results of the 80 percent cooling climb test show that all of the aircraft (Arrow, Cardinal, Sierra, and RC112) could safely tolerate somewhat leaner fuel schedules in the 80 percent climb mode with regard to cylinder head limitations. However, modifications would be required to maintain acceptable engine oil cooling.

(5) Figure 7-20 shows the ultimate proposed fuel schedule pending solution of the problem areas considered in item (3). The fuel system to produce this schedule is not currently in production and would require new body castings and extensive development work. Four to six years of development are required before units would be available to Avco Lycoming for in-service test evaluation.

(6) The results of this test program are applicable to really only one engine model. They are not necessarily true of the other 350 models in production by Avco Lycoming; fuel injected, carbureted, turbocharged, and geared supercharged engines. Avco Lycoming is proceeding with a test program for carbureted engines and possible emissions reductions. A program for evaluating improvements to turbocharged engines is being formulated.

(7) The Avco Lycoming flight test program has shown that leaner fuel schedules can be safely tolerated. Figure 7-21 shows the emission profile for the IO-360 engine based on the flight test results. The solid line shows possible emissions reductions for a fuel system without density compensation. The dotted line shows the possibilities with a compensated system. There has been no effort to assign production tolerances to these results. Even with density compensation the profile shows that the projected cyclic total would be approximately 98 percent of the Federal limit for CO. Any production tolerance would exceed this limit.

(8) Avco Lycoming has conducted emissions surveys on six turbocharged engines of five different engine models on the flight test stand. A limited flight test of one turbocharged model, the TIGO-541, revealed unique problem areas dissimilar to those encountered with normally aspirated engines. The majority of turbocharged engine models are employed in twin engine aircraft, which have far more severe cooling climb requirements than single engine installations. Therefore, Avco Lycoming expects that the possible revisions to current fuel schedules for these engines will be extremely limited and will demand comprehensive testing. The turbocharged engine family may require a separate and more lenient set of Federal emissions limits.

With emissions reduction as a goal, time for fuel system development and implementation is the major factor. Evaluation of all current fuel systems and engine configurations with respect to possible improvements cannot be accomplished in the time remaining when factors such as flight safety, system integrity, and total cost impact must be considered.

DISCUSSION

Q - D. Powell: If you take your most complicated fuel schedule with the couple bends in it, I see the 0.067 fuel-air ratio in the approach mode, and if I then go to the circle graph, it shows about 0.077 in the approach mode. Then, if you move that back to the 0.067 (like the previous chart), it shows that you are about 25 percent under the standards. Did I misread that?

A - L. Duke: No, you read it correctly. What we're trying to do is to identify the problem with this slow acceleration where we saw the engine go flat. One way of alleviating the problem and getting something into production would be to run at best power, 0.077 in the approach mode. We feel this will get us through that condition without a big service problem, and right now, our remedy is to just enrich it. That just gets us to the limit, but then we don't have any tolerance for production. If we go to the 0.067 stoichiometric, then we've again got the problem. That may be a development problem that can be worked out in the injector itself, but at this moment that's a problem to us.

Q - G. Kittredge: That's a nice systematic piece of work which I found very interesting. I understand from angry letters that have been flowing across my desk that there is a trend away from 80/87 grade low lead gasoline towards standardization on a higher grade, a new version of the 100/130 octane. Won't that give you some additional margin on detonation limits that would work in the direction of compensating for that particular problem?

A - L. Duke: This engine happened to be certified on 100/130 octane fuel. This is at the limit for that gasoline right now, so for this engine there would be no benefit. Older engines certified on the older gasoline may have some advantage.

Q - G. Kittredge: I didn't quite understand the introductory remarks in your presentation or in Eric Becker's. You indicated some reservations with the lean-out approach to establishing the emissions behavior of engines because it did not adequately correspond to the way the engine was operated in service. That would have a bearing on how we should respond to the earlier recommendation that you heard.

A - L. Duke: If you're doing research work, you shouldn't be basing all your work on running just baseline approaches. It is necessary to know exactly what the engine is doing at each mode or over a range of operating conditions. Certainly for future compliance testing where specifications would be well-defined and engine test conditions such as standard day and exact power are spelled out, baseline cycles would be fine. For now, since we don't have a lot of detailed specifications, we were suggesting that those involved look mainly at manual lean-out runs to collect that data. It gives you a background from which, if you must correct, you have something to correct from. Baseline runs should not be used to characterize the engine.

COMMENT - G. Kittredge: I was very encouraged by your data showing that, although it took a lot of work, you did get very close to the CO standard, perhaps as much as 25 percent below if you can get rid of your flat spot. The earlier FAA data showing that these engines, relatively unmodified, can be brought below the standards is quite reassuring. We realize that it has taken a lot longer than anybody expected and we understand some of the reasons for this.

Q - F. Monts: I'd like to quote from an article by Peter Drucker. In comment to the fact that we have now identified the problem he says, "I hope we're over our belief that if you define a problem you don't have any more work to do. Now that you've identified the problem, you've only showed how much work there yet is to be done." My question is, did you run the climb cooling at an in-route climb speed or at best rate of climb speed for takeoff power?

A - L. Duke: We ran them all at the same conditions - best rate of climb speed as recommended by the manufacturers.

Q - F. Monts: There actually is no certification procedure for the single engine and 80 percent climb is there?

A - L. Duke: No.

Q - C. Gonzalez: Did you make any attempt to evaluate the startup and warmup characteristics of this revised full schedule?

A - L. Duke: We did qualitatively. I didn't report anything because we didn't really have it instrumented for that situation. We only took what the test pilot related to us, and his general opinion was that the engine started okay. However, at idle when he wanted to pull away from the chocks he had to wait a longer period of time before he could actually advance the throttle and move away. So essentially he had a longer wait for the engine to warm up before he could move away from the chocks.

Q - C. Gonzales: Did you run most of these tests in the winter season?

A - L. Duke: The acceleration tests were run essentially in the winter season. The temperature was in the neighborhood of 30° to 40°, but not the coldest it could have been run at.

Q - C. Gonzales: Were the fuel-air ratio adjustments made prior to the flights for the day carried out after the engine was warmed up or before the engine was warmed up?

A - L. Duke: After the engine was warmed up.

Q - W. Houtman: What investigations or analyses did you do to determine the cause of the slow acceleration or the flat spot on the speed curve?

A - L. Duke: We examined the power the engine should have been putting out at the condition of the flat spot in relation to what the injector was set for for the leaned-out approach condition. Those two appear to be in that 25 to 50 percent power range, and we estimated that the transition was between the idle circuit and the main metering circuit.

Q - W. Houtman: Do you think this might be strictly a hardware problem or is it a fundamental problem with operation at that point?

A - L. Duke: I think it's a little of both. It starts out appearing to be a definite hardware problem, but I think it carried over into actual installation problems too. It is certainly apparent in the turbocharged engine where we tried to do the same thing and saw all kinds of problems when the engine turbine appeared to be getting up to speed. In some instances it may be a straightforward developmental hardware problem, but that can't be carried over to all situations.

Q - W. Houtman: What would you consider the critical elements to be in the development period of 4 to 6 years?

A - L. Duke: Right now you can buy certain injectors with AMC units installed on it. The unit we tested is not a production injector. It was a cobbled up job. Also, the AMC unit is functional from approximately 25 percent power to 100 percent power. It was previously stated that taxi mode is a major source of pollution. It should be noted that the taxi mode was outside the compensated area of the AMC unit. That's the major area, getting that compensation to work for idle and taxi.

Q - P. Kempke: What work has been done on AMC units for carbureted engine?

A - L. Duke: We've essentially done no work for carbureted engines. We have programs underway to do that. There is no AMC unit for a carburetor like there is an injector AMC unit.

COMMENT - D. Tripp: On that slow acceleration, it looks like a classical carburetor fuel metering situation in which you have a constant manifold vacuum and a slowly opening throttle position. It would seem that by some hardware changes of a better optimized enrichment you could get over that condition.

A - L. Duke: The engine is not on the enrichment section when it encounters the problem. On the fast acceleration the engine goes right into the enrichment section, but when going very slowly, it is not getting into that enrichment section.

Q - E. Becker: Was any effort made to go back and check whether that stagger exists with the normal schedule as existed with the leaned condition?

A - L. Duke: Yes, an effort was made, and it does not exist.

Q - L. Helms: Your comment that you could have a bad mag drop is certainly applicable, but that's not our major concern. With due deference to the engine manufacturers and Bendix, the real problem we have is that that's the precise engine rpm where all pilots are taught to make their approach and landing. If there's any time he needs a rapid response, that's it, because of the danger of undershoot. So our major concern in the installation of the engine is that that's the one point where we don't want any hangup of any kind. The second part is that it seems to me that the data you presented seem to underscore that the fuel schedules were set manually by a mechanic after the engine was warmed up. The greater the number of the individual modes that we can eliminate, the greater is the possibility of being able to come up with an AMC system in either a shorter period of time or with greater degree of vernier control. The earlier data we saw this morning indicated that most of the actual ppm pollution occurs in climb and approach. If the requirements for scheduling were reduced to just those two and eliminate the others, we have eliminated the major portion of the pollution. But the problem for fuel scheduling would be drastically simplified, am I correct?

A - L. Duke: That's a good observation.

Q - W. Mirsky: What are the possibilities of further reduction in CO due to better fuel-air distribution from cylinder to cylinder and also better mixture quality? In some cases at a given equivalence ratio, I find that you have high CO with high oxygen present with the CO levels higher than what you normally see for automotive practice. So, isn't there some potential for CO reduction by improved distribution and improved mixture quality?

A - L. Duke: There certainly is. Those items are covered under a different section concerned with future development and NASA contract work and don't fit under the NAFEC project. However, they are under investigation. This is especially true in carbureted engines, where there are various degrees of cylinder to cylinder distribution.

Q - F. Monts: Isn't the mixture distribution on this engine that you're talking about one of the better ones?

A - L. Duke: Yes, on this engine the distribution is good especially at the power modes. At idle and taxi it degrades a little. An injected engine normally has very good cylinder to cylinder distribution. This engine is an injected engine. It does have good distribution from cylinder to cylinder. The comment is really directed toward carbureted engines.

Q - N. Krull: Larry, this slow accel you found with a slow throttle advance is quite evident in the data. Was there any attempt when you got into this situation to rapidly advance the throttle and see whether the engine would actually pick up or would continue to hang in this condition?

A - R. Moffett: Yes, we tested extensively on the ground to try and determine if there is a hangup. The only think I can say is when you use a rapid accel you accelerate right through the flat spot. We never did see a hestitation.

TABLE 7-1

EMISSIONS TEST CYCLE

TEST CYCLE SPECIFIED IN FEDERAL REGISTER

MODE	% RATED SPEED	% RATED POWER	TUNE IN MODE (MIN.)
IDLE/TAXI			12
T.O.	100%	100%	.3
CLIMB		75-100%	5
APPROACH		40%	6
IDLE/TAXI			4
			27.3

EXPANDED TEST CYCLE

MODE	% RATED SPEED	% RATED POWER	TUNE IN MODE (MIN.)
IDLE	600 (Manufacturer's Recomm.)	——	1
TAXI	1200 (Manufacturer's Est.)	——	11
T.O.	100%	100%	.3
CLIMB	90%	80%	5
APPROACH	87%	40%	6
TAXI	1200	——	3
IDLE	600	——	1
			27.3

TABLE 7-2

COMPARISON OF BASELINE CYCLE AVERAGE
WITH PROJECTED CYCLIC TOTALS FROM LEAN OUT CURVES

IO-320-D ENGINE
AVCO LYCOMING TEST RESULTS

	CO LBS/HP-CYCLE	HC LBS/HP-CYCLE	NOX LBS/HP-CYCLE
AVERAGE 7 BASELINE CYCLES	.066	.00116	.000286
PROJECTED CYCLIC TOTALS BASED ON LEAN OUT DATA TRENDS	.065	.00112	.000273

TABLE 7-3

AVCO LYCOMING EMISSIONS TEST SUMMARY

NO. TESTED	ENGINE	RATED POWER	CARB.	FUEL INJ.	TURBO	GEARED
2	O-320-D	160	X			
2	IO-320-D	160		X		
1	IO-360-B	180		X		
3	IO-360-A	200		X		
2	TIO-540-J	350		X	X	
1	TO-360	210	X		X	
3	TIGO-541-D,E,G	450		X	X	X
TOTAL 14						

TABLE 7-4

AIRCRAFT SUMMARY - AVCO LYCOMING FLIGHT TEST

	AIRCRAFT #1	AIRCRAFT #2	AIRCRAFT #3	AIRCRAFT #4	AIRCRAFT #5
ENGINE(S)	IO-360-C1C	IO-360-A1B6D	IO-360-A1B	IO-360-C1D6	TIGO-541-E1A
RATED POWER	200 BHP	200 BHP	200BHP	200 BHP	425 BHP
GROSS WEIGHT	2650 LB	2800 LB	2750 LB	2650 LB	7800 LB
EMPTY WEIGHT	1522 LB	1680 LB	1711 LB	1688 LB	4900 LB
RANGE 55% POWER	780 NM	1015 NM	721 NM	867 NM	1340 NM
MPG 55% CRUISE	16.3 MPG	16.9 MPG	13.9 MPG	12.8 MPG	5.7 MPG
75% CRUISE SPEED	143 KTS	148 KTS	131 KTS	140 KTS	231 KTS
MPG 75% CRUISE	13.6 MPG	13.8 MPG	12.8 MPG	11.2 MPG	4.3 MPG
SERVICE CEILING	15,000 FT	17,100 FT	14,342 FT	13,900 FT	29,000 FT
CLIMB RATE	900 FPM	925 FPM	893 FPM	1020 FPM	1600 FPM
COWL FLAPS		X		X	X
VAR. PITCH PROP	X	X	X	X	X
RETRC. GEAR	X	X	X	X	X

X = YES

REFERENCE: 1975 AIRCRAFT DIRECTORY FLYING ANNUAL

TABLE 7-5

TAXI

R. A. START
R B. MOVE FROM SPOT
R C. TAXI TO RUNWAY
R D. RUN-UP
R E. MOVE TO T.O. POSITION
F. IDLE AGAINST STOP

A. NORMAL 90 IAS APPROACH

R 1. TAKE OFF
2. 4000 AGL 2400 RPM 25" 3 MIN.
R 3. SNAP IDLE - SLOW TO 90 - GR. F.
R 4. FAST ACCEL 5 SNAP IDLE 90 IAS
R 5. 3000' 1 SEC ACCEL. 5 SNAP IDLE
R 6. 2000' 1 SEC ACCEL. 5 SNAP IDLE
R 7. 1000' RAPID ACCEL 3 DECEL
R 8. FLARE PANIC ACCEL GO AROUND

B. HIGH SPEED 125 IAS APPROACH

9. 4000 AGL 2400 RPM 25" 3 MIN
R 10. SNAP IDLE 125 IAS GR-FL
R 11. 3000' RAPID ACCEL 3 DECEL
R 12. 2000' RAPID ACCEL " "
R 13. 1000' RAPID ACCEL " "
R 14. FLARE PANIC ACCEL GO 'ROUND

C. SHALLOW ANGLE ILS APPROACH

15. 4000' AGL
R 16. 2350 RPM 16.5" Hg 40%
17. GEAR DWN FLAPS AR
R 18. 3000' SLOW ACCEL 3 DECEL
R 19. 2000' FAST ACCEL 3 DECEL
R 20. PROP CONTROL TO HI RPM
R 21. 1000' FAST ACCEL
R 22. CHOP THROTTLE FLARE
R 23. SNAP ACCEL
R 24. CHOP THROTTLE LAND

D. NORMAL 90 IAS APPROACH

25. 3000'
R 26. CLOSE THROTTLE 90 IAS
27. GEAR FLAPS
R 28. 2000' SLOW ACCEL 3 DECEL
R 29. 1000' SLOW ACCEL 3 DECEL
R 30. FLARE, LAND, ROLL OUT, TURN OFF
R 31. TAXI TO HANGAR - SHUT DOWN

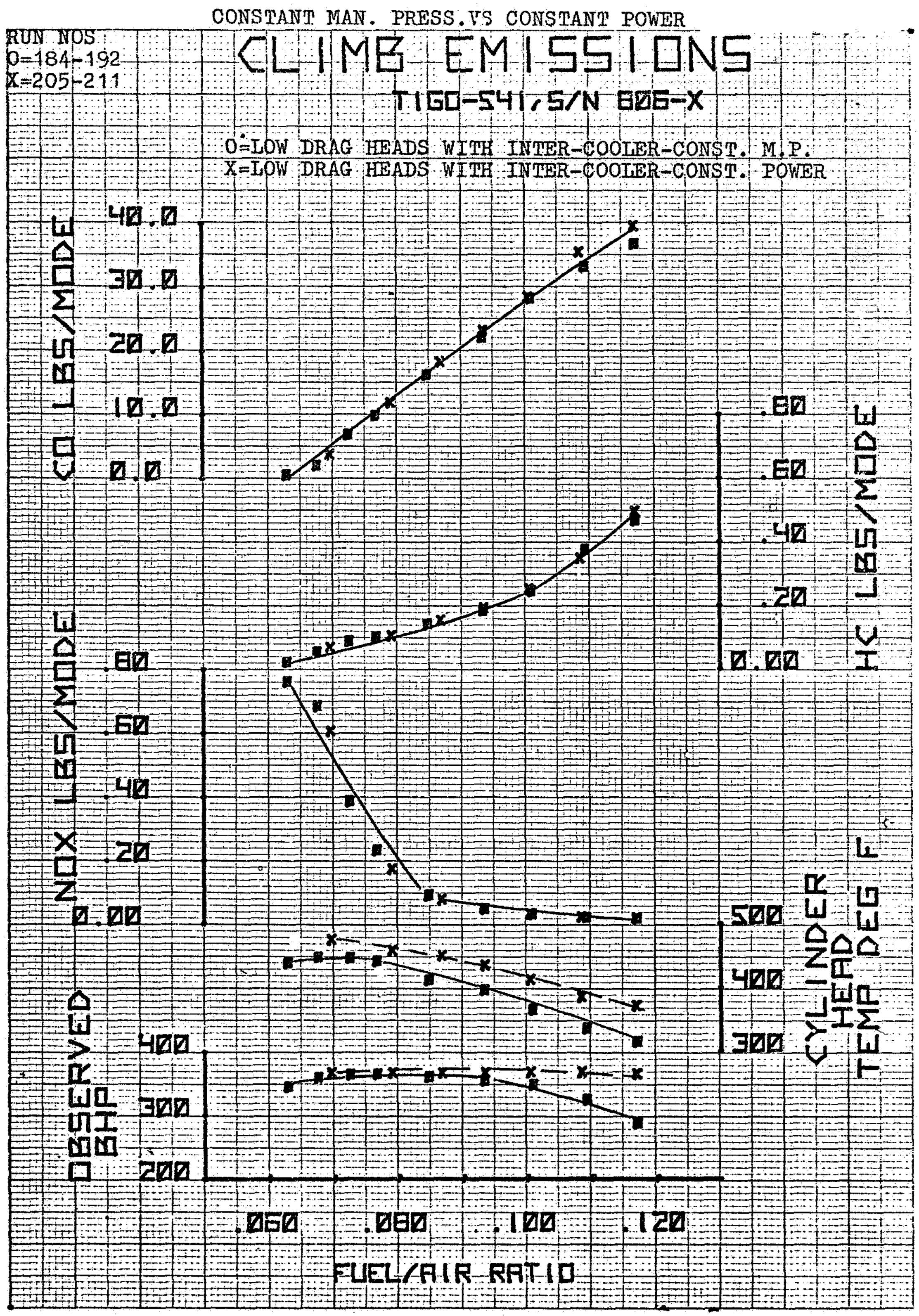

CONSTANT MAN. PRESS. VS CONSTANT POWER
RUN NOS
O=184-192
X=205-211
CLIMB EMISSIONS
TIGO-541, S/N 806-X
O=LOW DRAG HEADS WITH INTER-COOLER-CONST. M.P.
X=LOW DRAG HEADS WITH INTER-COOLER-CONST. POWER
CO LBS/MODE
40.0
30.0
20.0
10.0
0.0
HC LBS/MODE
.80
.60
.40
.20
0.00
NOX LBS/MODE
.80
.60
.40
.20
0.00
CYLINDER HEAD TEMP DEG F
500
400
300
OBSERVED BHP
400
300
200
.060
.080
.100
.120
FUEL/AIR RATIO

Figure 7-1

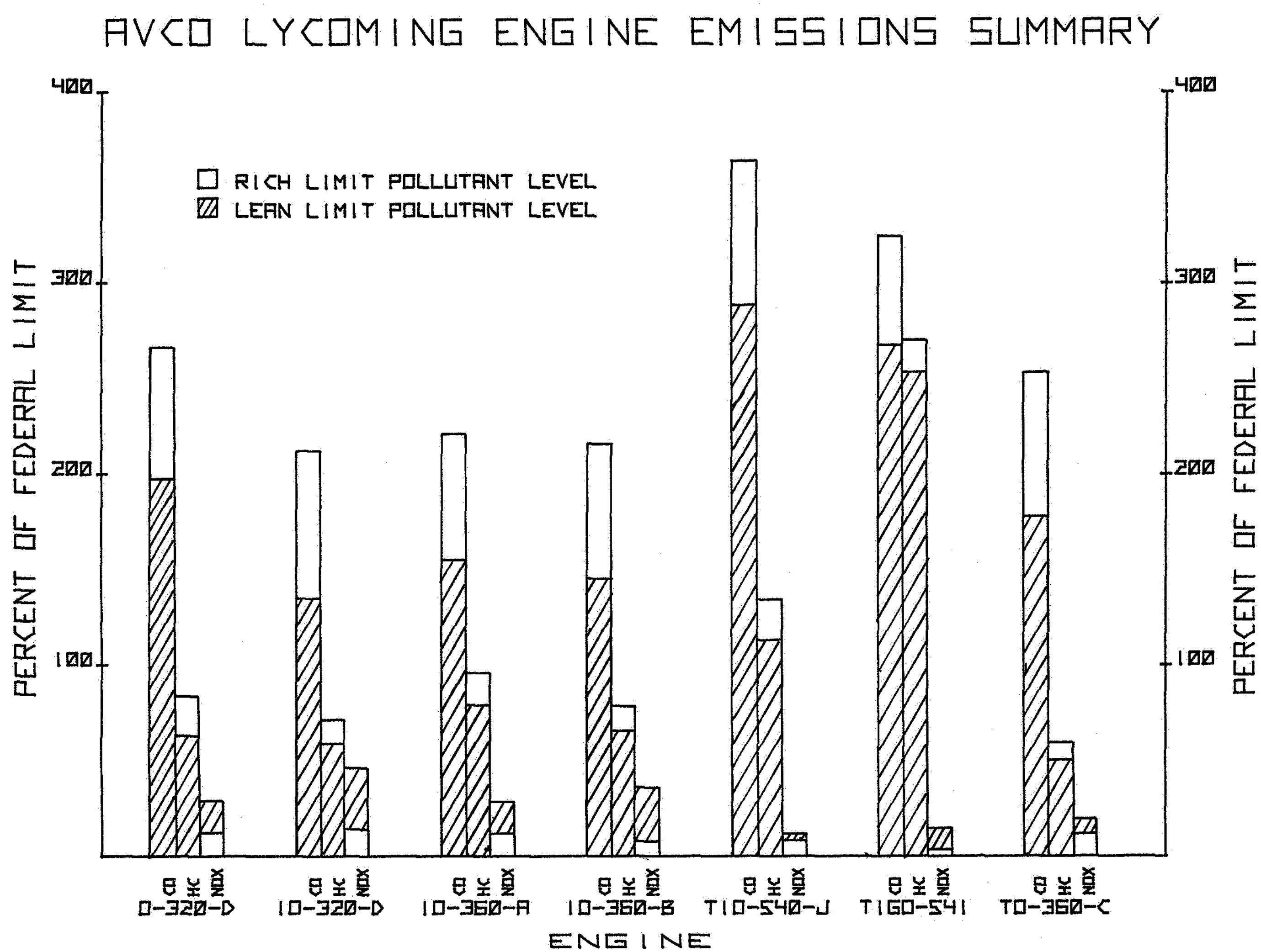
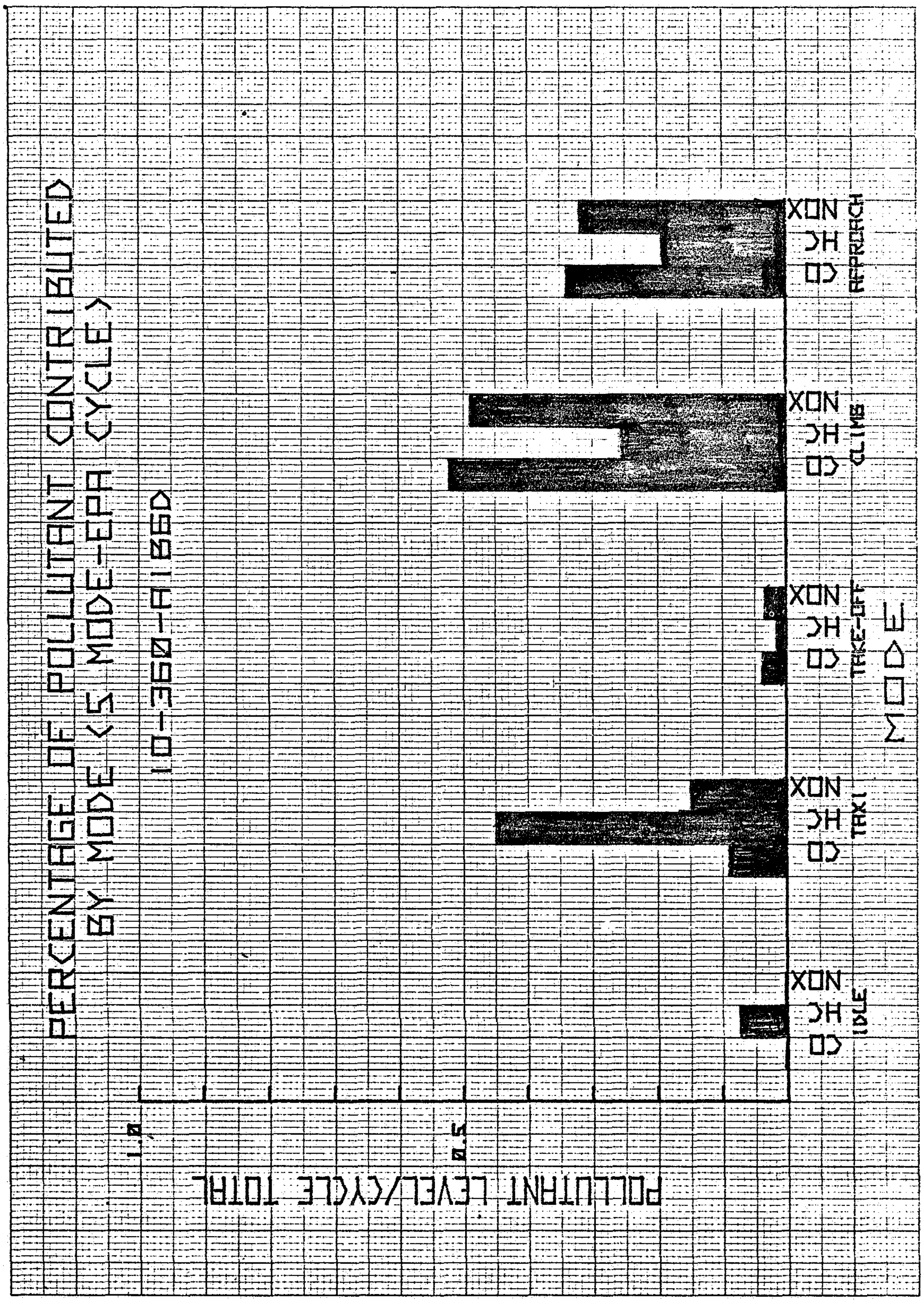

AVCO LYCOMING ENGINE EMISSIONS SUMMARY
RICH LIMIT POLLUTANT LEVEL
LEAN LIMIT POLLUTANT LEVEL
PERCENT OF FEDERAL LIMIT
400
300
200
100
CO HC NOX
O-320-D
IO-320-D
IO-360-A
IO-360-B
TIO-540-J
TIGO-541
TO-360-C
ENGINE

Figure 7-2



PERCENTAGE OF POLLUTANT CONTRIBUTED
BY MODE (5 MODE-EPA CYCLE)
IO-360-A1B6D
1.0
0.5
POLLUTANT LEVEL/CYCLE TOTAL
CO HC NOX
IDLE
TAXI
TAKE-OFF
CLIMB
APPROACH
MODE

Figure 7-3

CO EMISSION PROFILE

IO-360-A1B6D, S/N 888-X

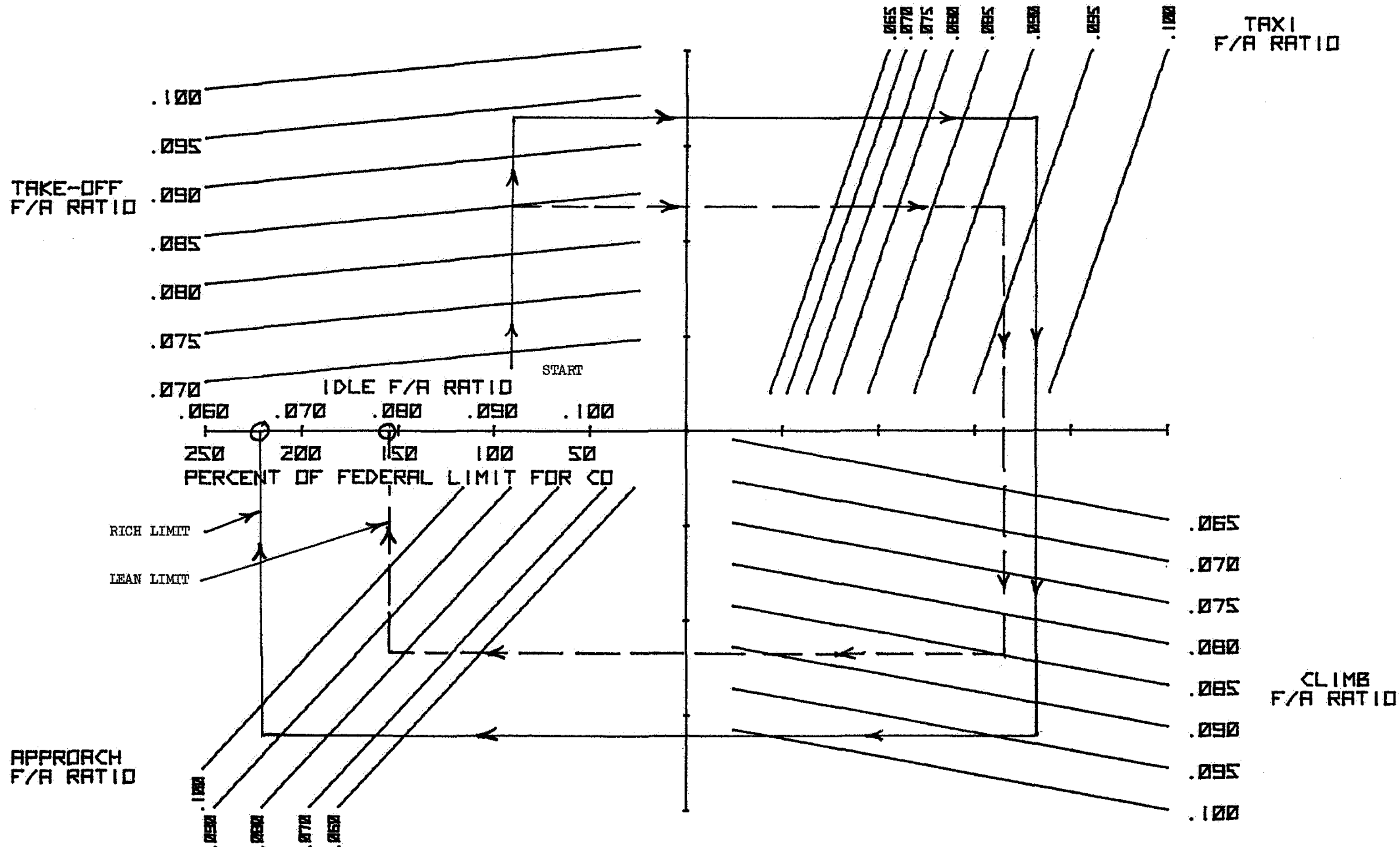


Figure 7-4

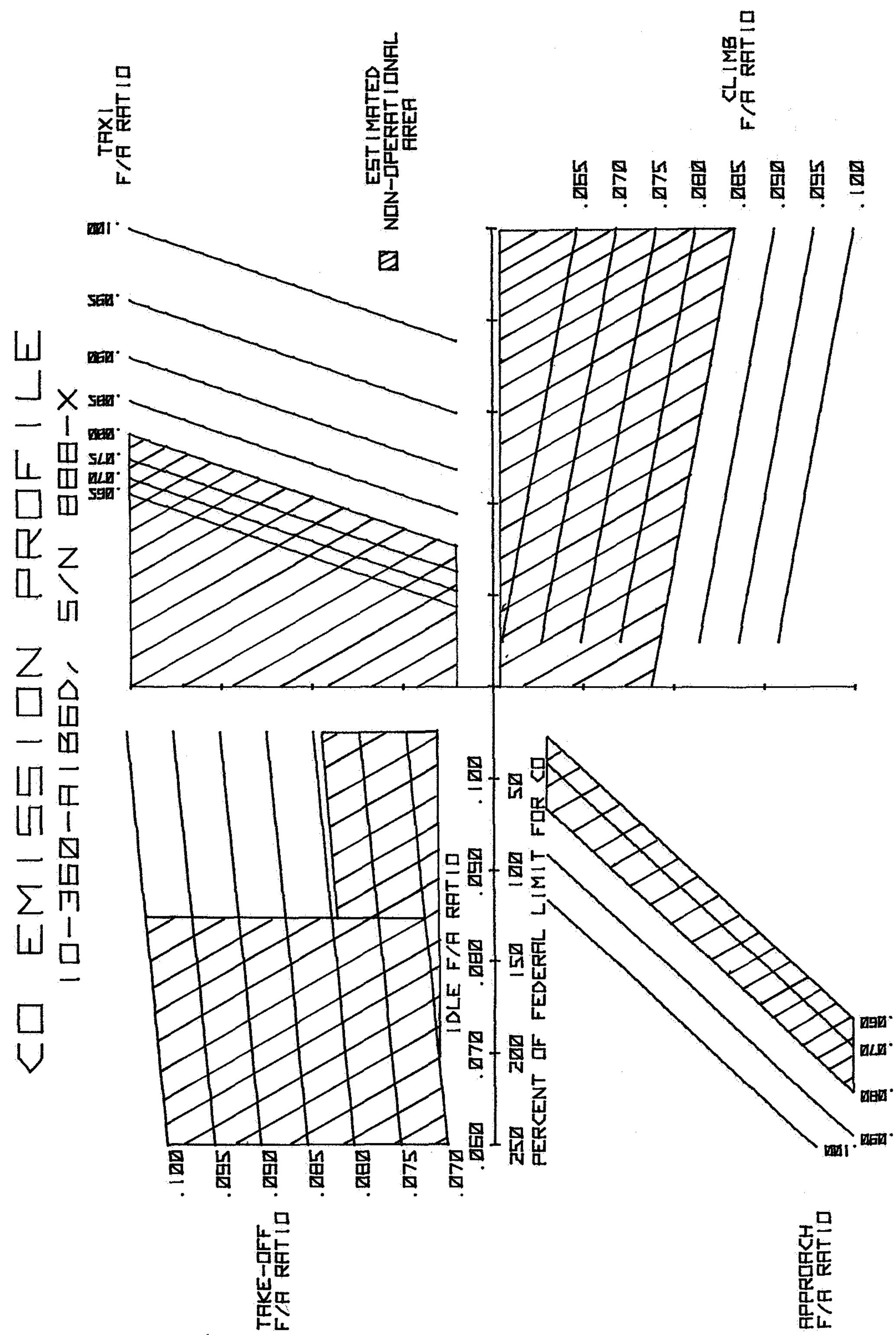

CO EMISSION PROFILE
IO-360-A1B6D, S/N 888-X
TAXI
F/A RATIO
ESTIMATED
NON-OPERATIONAL
AREA
.065
.070
.075
.080
.085
.090
.095
.100
CLIMB
F/A RATIO
TAKE-OFF
F/A RATIO
IDLE F/A RATIO
.060
.070
.080
.090
.100
250
200
150
100
50
PERCENT OF FEDERAL LIMIT FOR CO
APPROACH
F/A RATIO

Figure 7-5

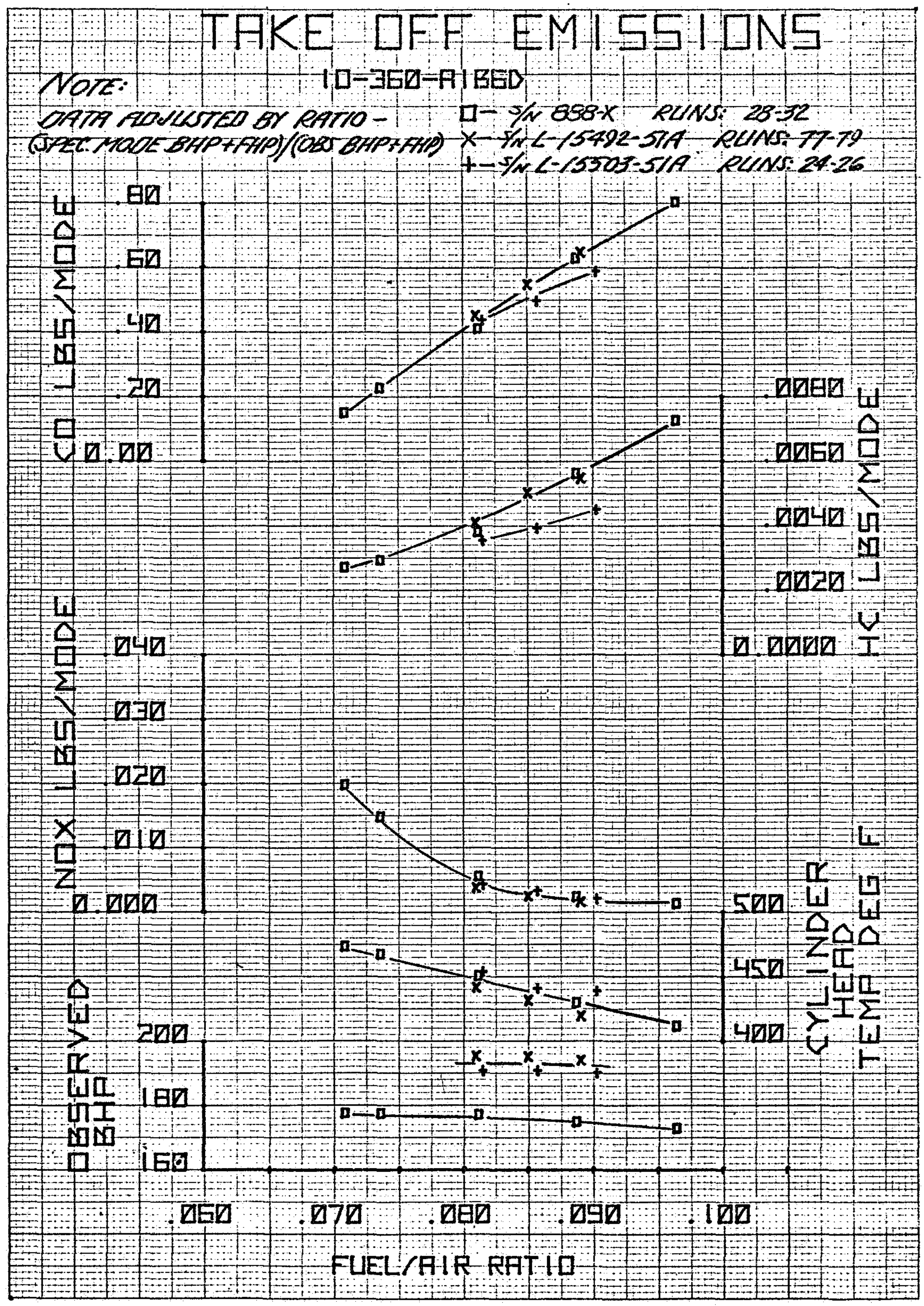

TAKE OFF EMISSIONS
IO-360-A1B6D
NOTE:
DATA ADJUSTED BY RATIO -
(SPEC. MODE BHP+FHP)/(OBS BHP+FHP)
□ - S/N 838-X RUNS: 28-32
X - S/N L-15492-51A RUNS: 77-79
+ - S/N L-15303-51A RUNS: 24-26
CO LBS/MODE
.80
.60
.40
.20
0.00
HC LBS/MODE
.0080
.0060
.0040
.0020
0.0000
NOX LBS/MODE
.040
.030
.020
.010
0.000
CYLINDER HEAD TEMP DEG F
500
450
400
OBSERVED BHP
200
180
160
.050
.070
.080
.090
.100
FUEL/AIR RATIO

Figure 7-6

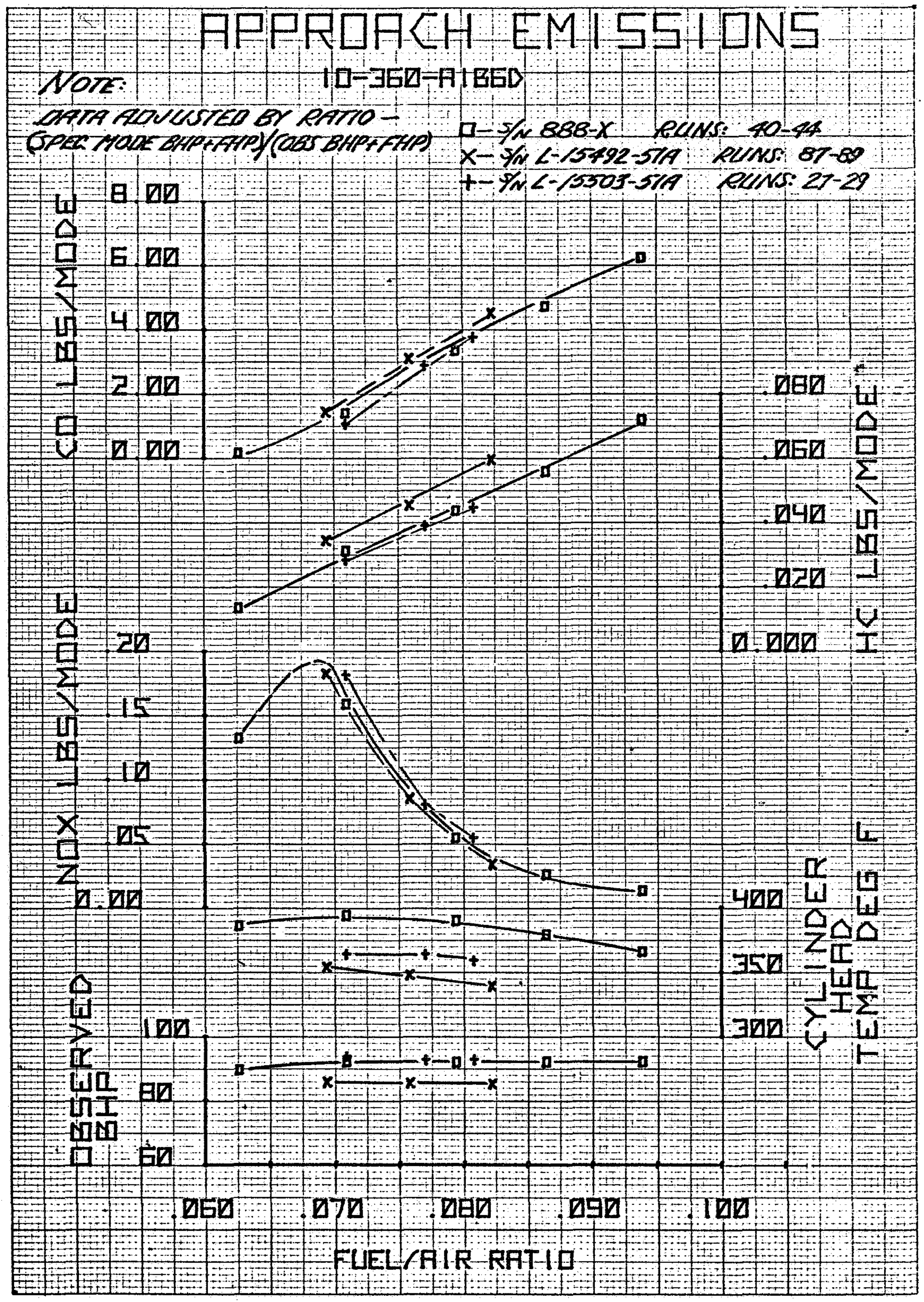
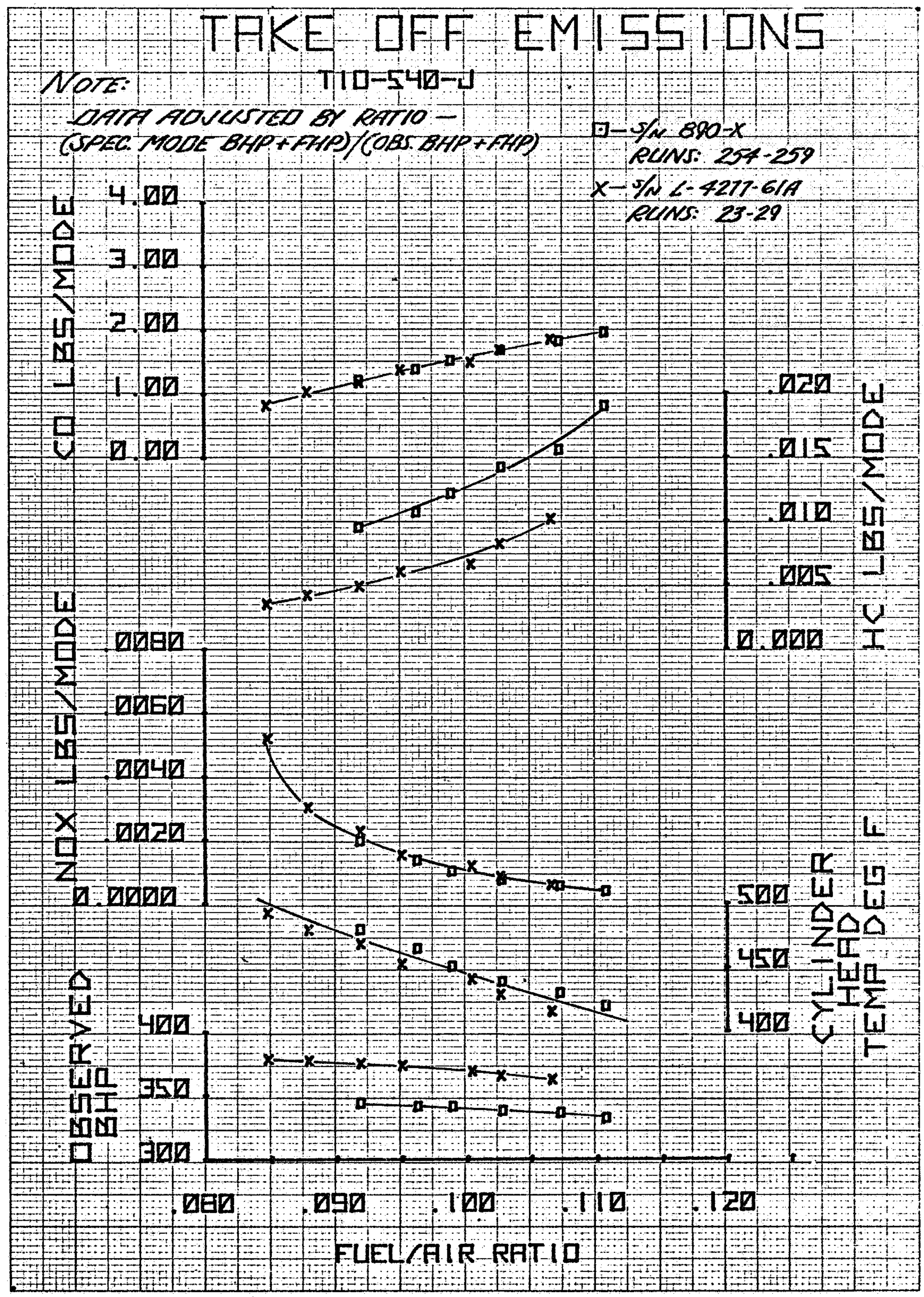
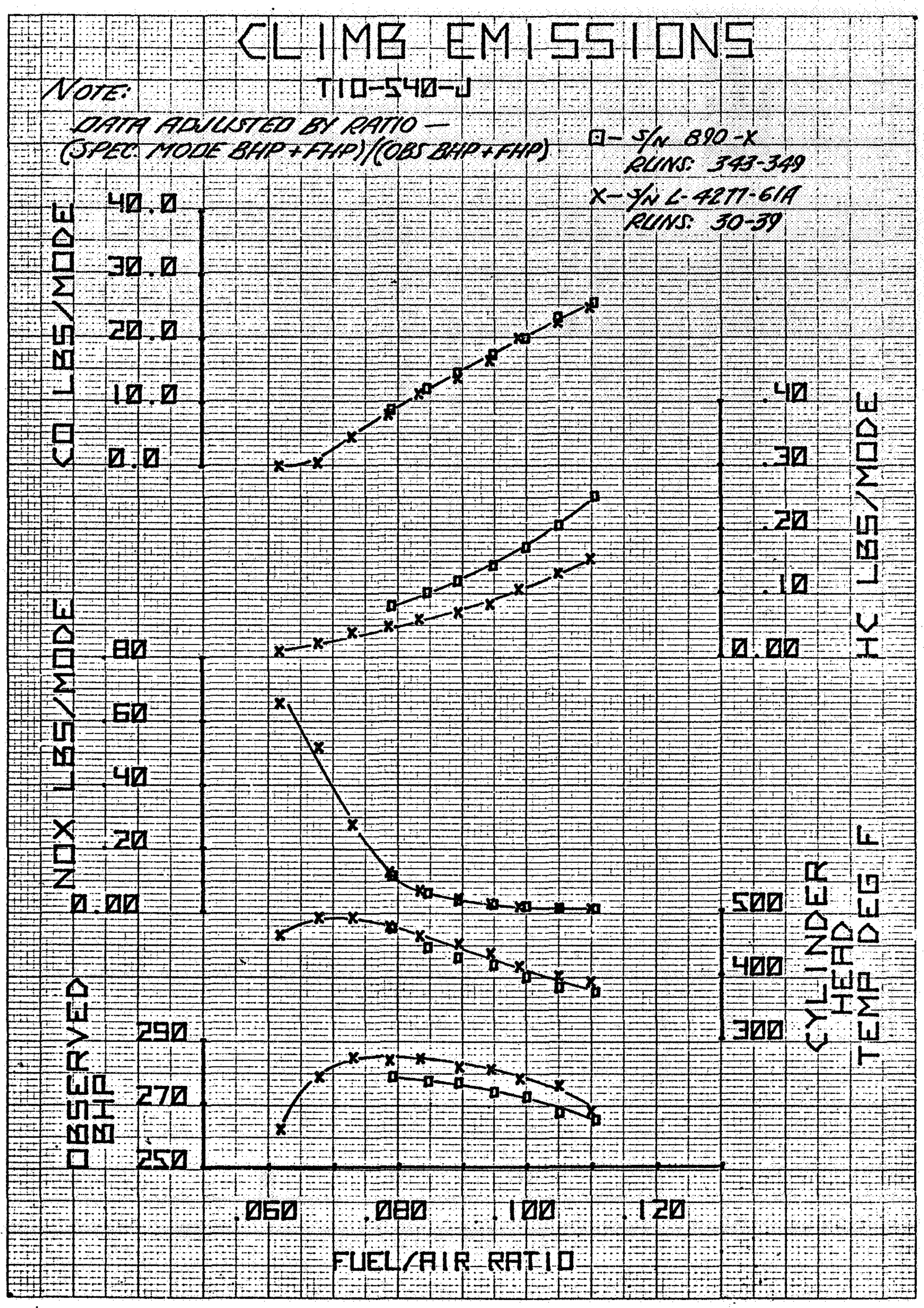

APPROACH EMISSIONS
IO-360-A1B6D
NOTE:
DATA ADJUSTED BY RATIO —
(SPEC MODE BHP+FHP)/(OBS BHP+FHP)
□ — S/N 888-X RUNS: 40-44
X — S/N L-15492-51A RUNS: 87-89
+ — S/N L-15503-51A RUNS: 21-29
CO LBS/MODE
8.00
6.00
4.00
2.00
0.00
HC LBS/MODE
.080
.060
.040
.020
0.000
NOX LBS/MODE
.20
.15
.10
.05
0.00
CYLINDER HEAD TEMP DEG F
400
350
300
OBSERVED BHP
100
80
60
.060
.070
.080
.090
.100
FUEL/AIR RATIO

Figure 7-7



TAKE OFF EMISSIONS
TIO-540-J
NOTE:
DATA ADJUSTED BY RATIO —
(SPEC. MODE BHP+FHP)/(OBS. BHP+FHP)
□— S/N 890-X
RUNS: 254-259
X— S/N L-4217-61A
RUNS: 23-29
CO LBS/MODE
4.00
3.00
2.00
1.00
0.00
HC LBS/MODE
.020
.015
.010
.005
0.000
NOX LBS/MODE
.0080
.0060
.0040
.0020
0.0000
CYLINDER HEAD TEMP DEG F
500
450
400
OBSERVED BHP
400
350
300
.080
.090
.100
.110
.120
FUEL/AIR RATIO

Figure 7-8



CLIMB EMISSIONS
TIO-540-J
NOTE:
DATA ADJUSTED BY RATIO —
(SPEC. MODE BHP + FHP)/(OBS BHP + FHP)
□ – S/N 890-X
RUNS: 343-349
X – S/N L-4271-61A
RUNS: 30-39
CO LBS/MODE
40.0
30.0
20.0
10.0
0.0
HC LBS/MODE
.40
.30
.20
.10
0.00
NOX LBS/MODE
.80
.60
.40
.20
0.00
CYLINDER HEAD TEMP DEG F
500
400
300
OBSERVED BHP
290
270
250
.060
.080
.100
.120
FUEL/AIR RATIO

Figure 7-9

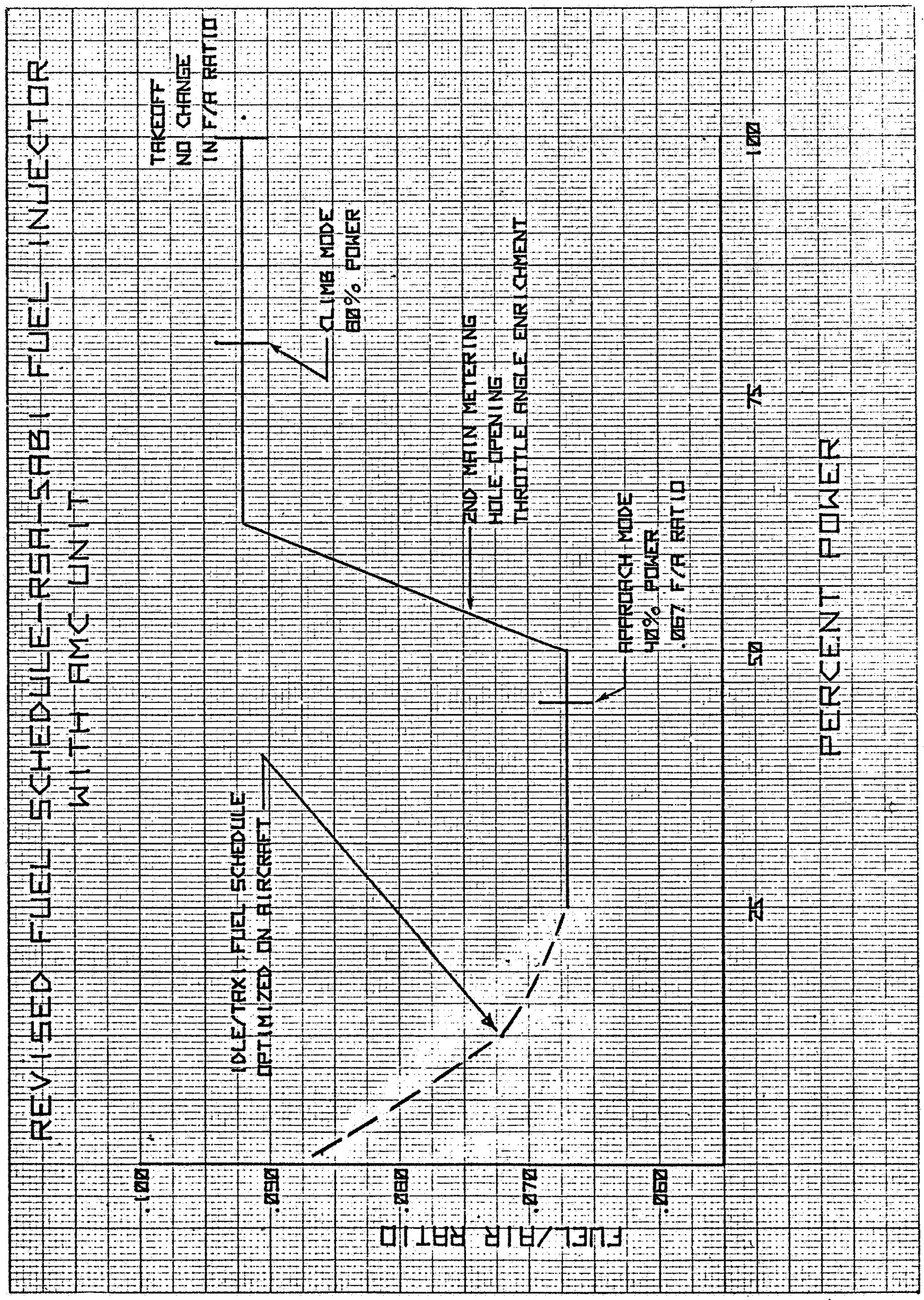

REVISED FUEL SCHEDULE-RSA-5AB1 FUEL INJECTOR
WITH AMC UNIT
TAKEOFF
NO CHANGE
IN F/A RATIO
CLIMB MODE
80% POWER
2ND MAIN METERING
HOLE OPENING
THROTTLE ANGLE ENRICHMENT
APPROACH MODE
40% POWER
.067 F/A RATIO
IDLE/TAX FUEL SCHEDULE
OPTIMIZED ON AIRCRAFT
.100
.090
.080
.070
.060
FUEL/AIR RATIO
25
50
75
100
PERCENT POWER

Figure 7-10

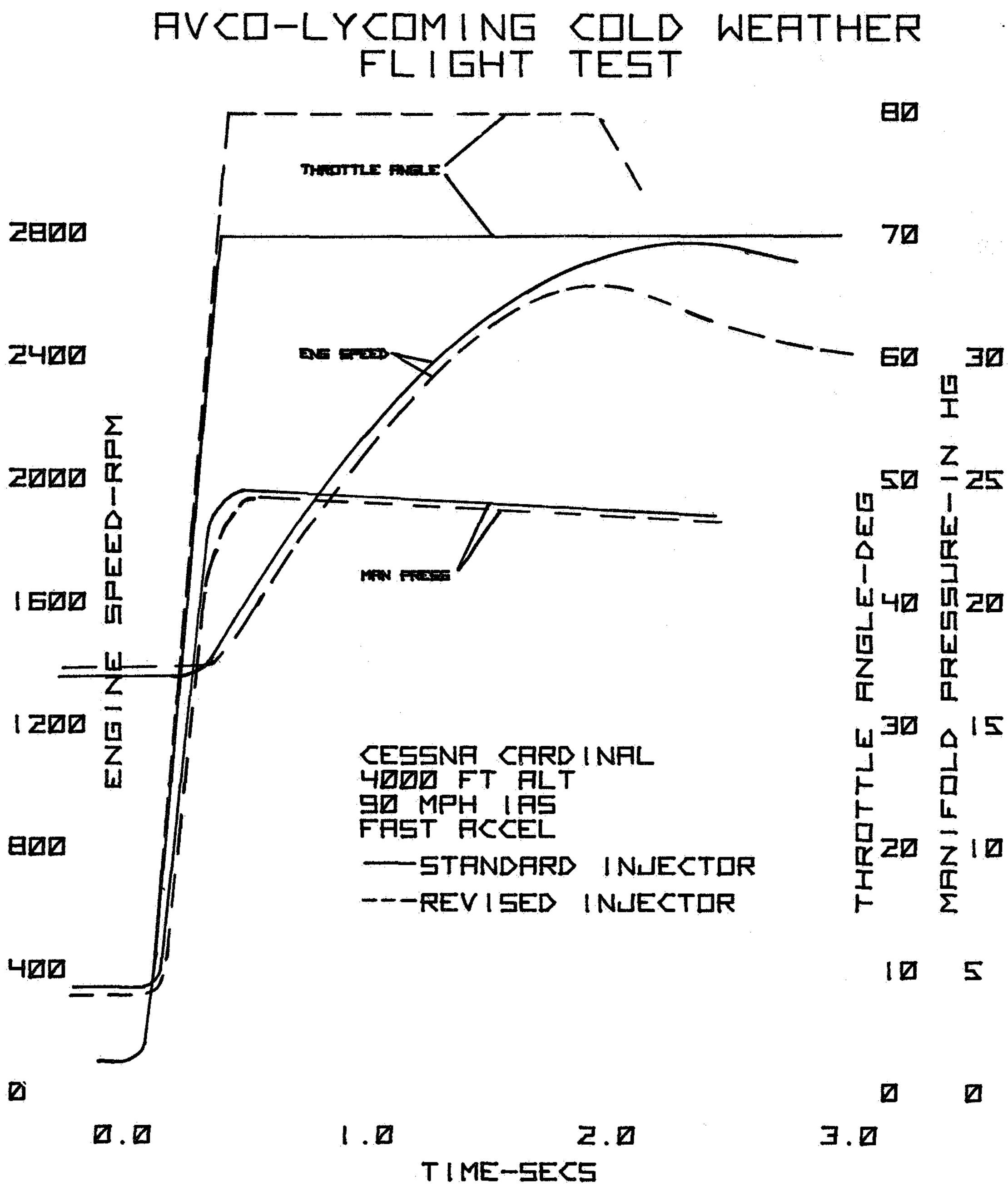

AVCO-LYCOMING COLD WEATHER
FLIGHT TEST
THROTTLE ANGLE
ENG SPEED
MAN PRESS
CESSNA CARDINAL
4000 FT ALT
90 MPH IAS
FAST ACCEL
——STANDARD INJECTOR
---REVISED INJECTOR
ENGINE SPEED-RPM
THROTTLE ANGLE-DEG
MANIFOLD PRESSURE-IN HG
TIME-SECS
0
400
800
1200
1600
2000
2400
2800
0.0
1.0
2.0
3.0
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
30

Figure 7-11

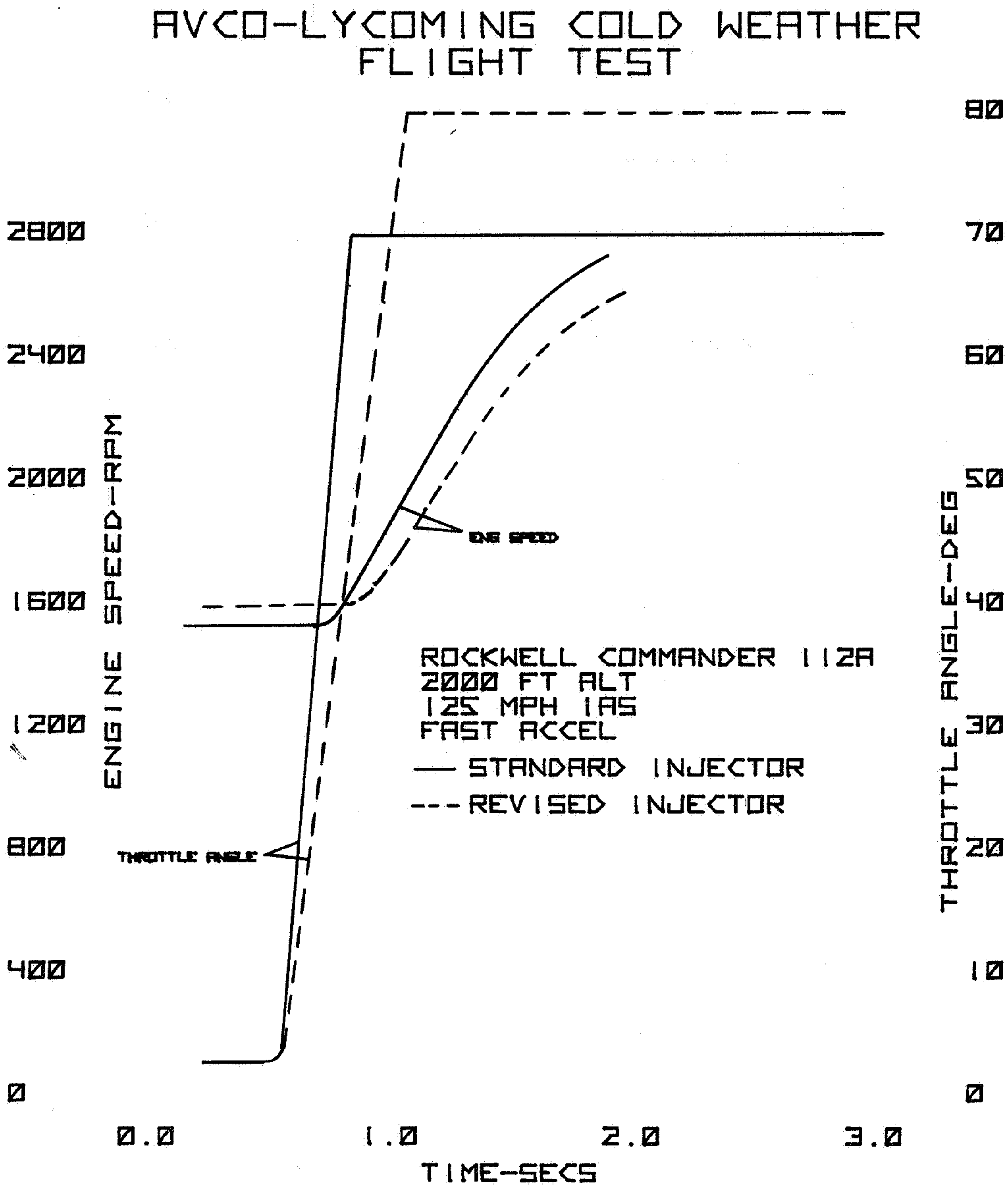

AVCO-LYCOMING COLD WEATHER
FLIGHT TEST
2800
2400
2000
1600
1200
800
400
0
ENGINE SPEED-RPM
80
70
60
50
40
30
20
10
0
THROTTLE ANGLE-DEG
ENG SPEED
THROTTLE ANGLE
ROCKWELL COMMANDER 112A
2000 FT ALT
125 MPH IAS
FAST ACCEL
—— STANDARD INJECTOR
- - - REVISED INJECTOR
0.0
1.0
2.0
3.0
TIME-SECS

Figure 7-12

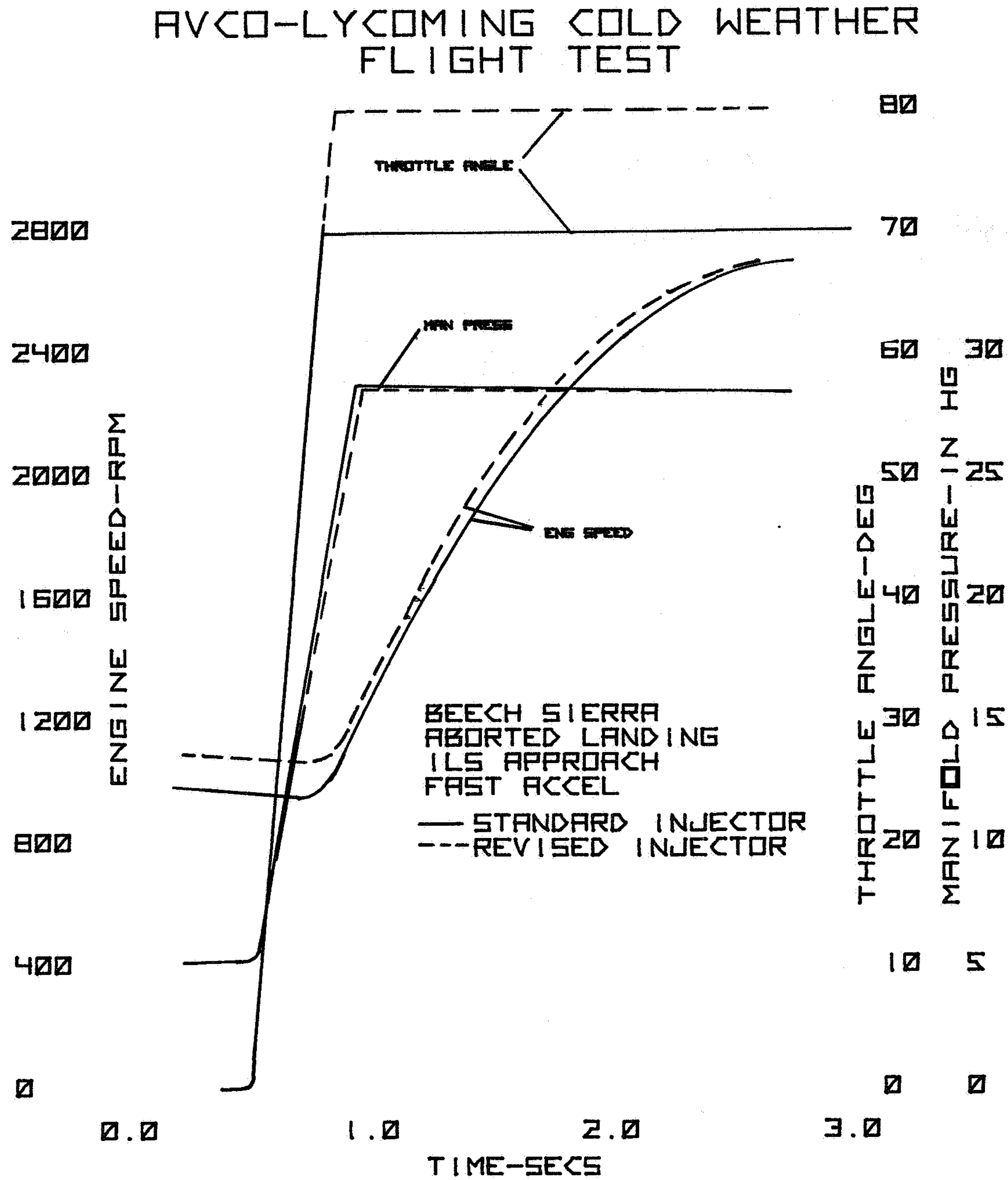
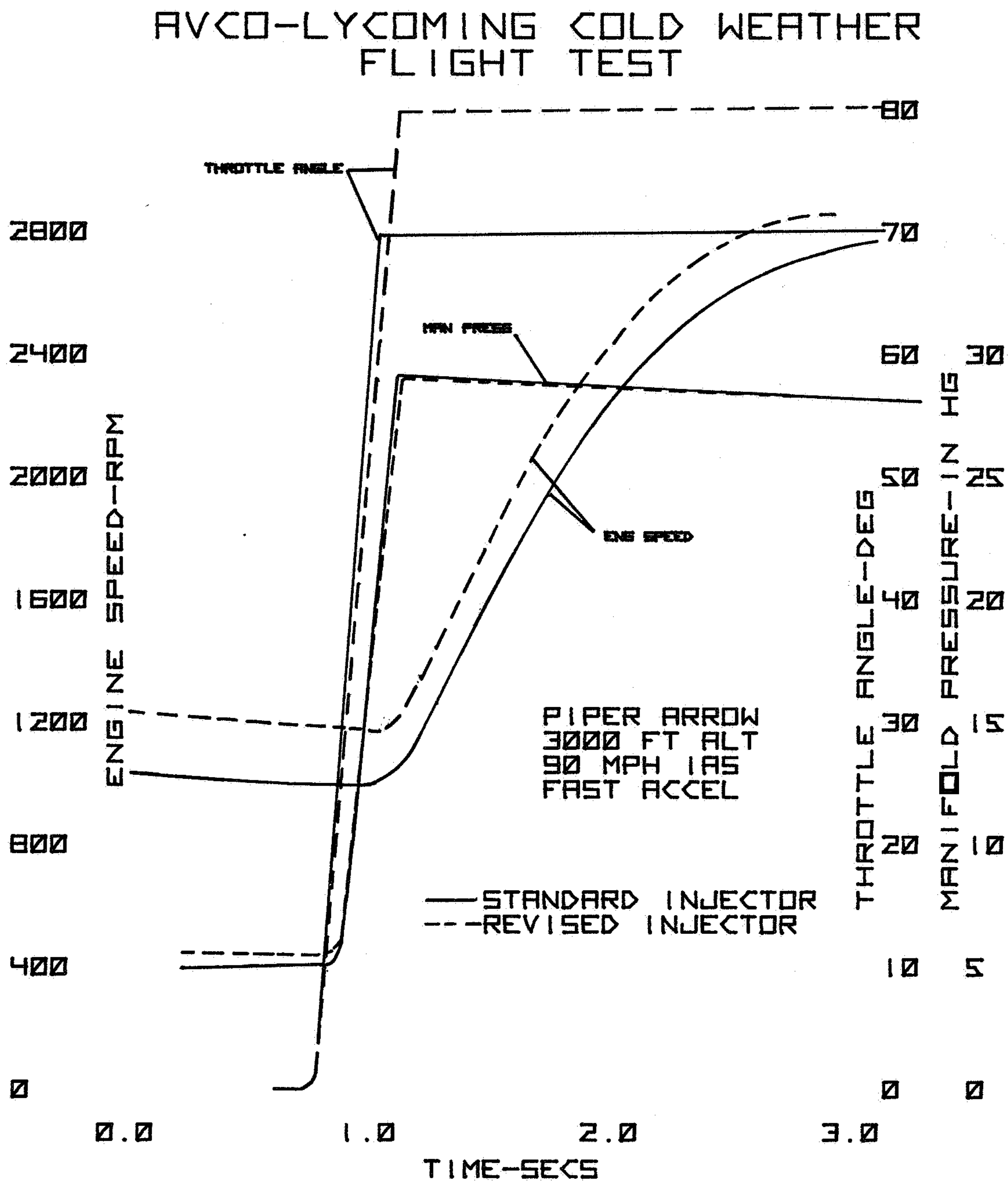

AVCO-LYCOMING COLD WEATHER
FLIGHT TEST
THROTTLE ANGLE
MAN PRESS
ENG SPEED
BEECH SIERRA
ABORTED LANDING
ILS APPROACH
FAST ACCEL
STANDARD INJECTOR
REVISED INJECTOR
ENGINE SPEED-RPM
THROTTLE ANGLE-DEG
MANIFOLD PRESSURE-IN HG
TIME-SECS
0
400
800
1200
1600
2000
2400
2800
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
30
0.0
1.0
2.0
3.0

Figure 7-13



AVCO-LYCOMING COLD WEATHER
FLIGHT TEST
THROTTLE ANGLE
MAN PRESS
ENG SPEED
ENGINE SPEED-RPM
2800
2400
2000
1600
1200
800
400
0
THROTTLE ANGLE-DEG
MANIFOLD PRESSURE-IN HG
80
70
60
50
40
30
20
10
0
30
25
20
15
10
5
0
PIPER ARROW
3000 FT ALT
90 MPH IAS
FAST ACCEL
STANDARD INJECTOR
REVISED INJECTOR
0.0
1.0
2.0
3.0
TIME-SECS

Figure 7-14

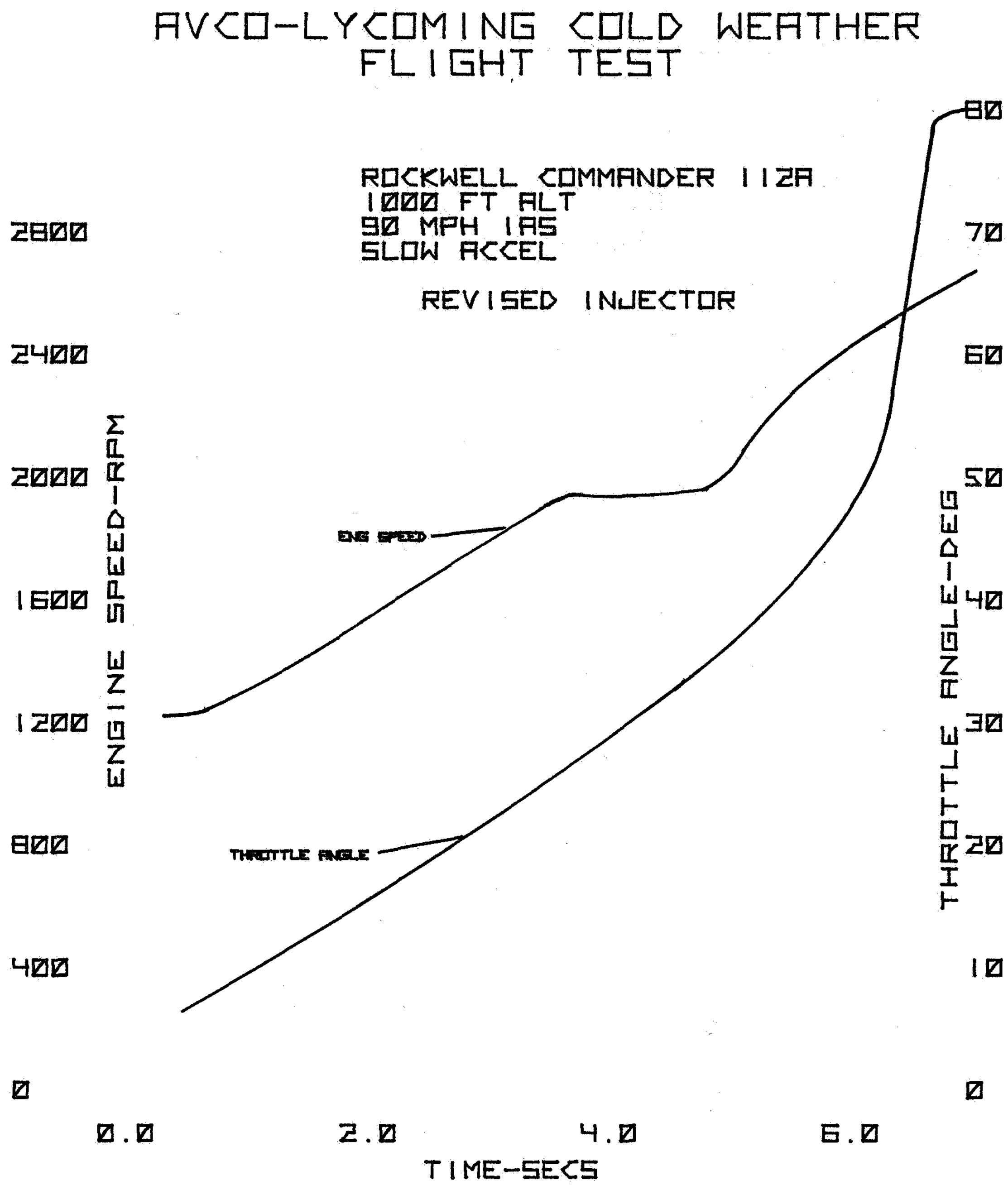

AVCO-LYCOMING COLD WEATHER
FLIGHT TEST
ROCKWELL COMMANDER 112A
1000 FT ALT
90 MPH IAS
SLOW ACCEL
REVISED INJECTOR
ENG SPEED
THROTTLE ANGLE
ENGINE SPEED-RPM
THROTTLE ANGLE-DEG
TIME-SECS
0
400
800
1200
1600
2000
2400
2800
0
10
20
30
40
50
60
70
80
0.0
2.0
4.0
6.0

Figure 7-15

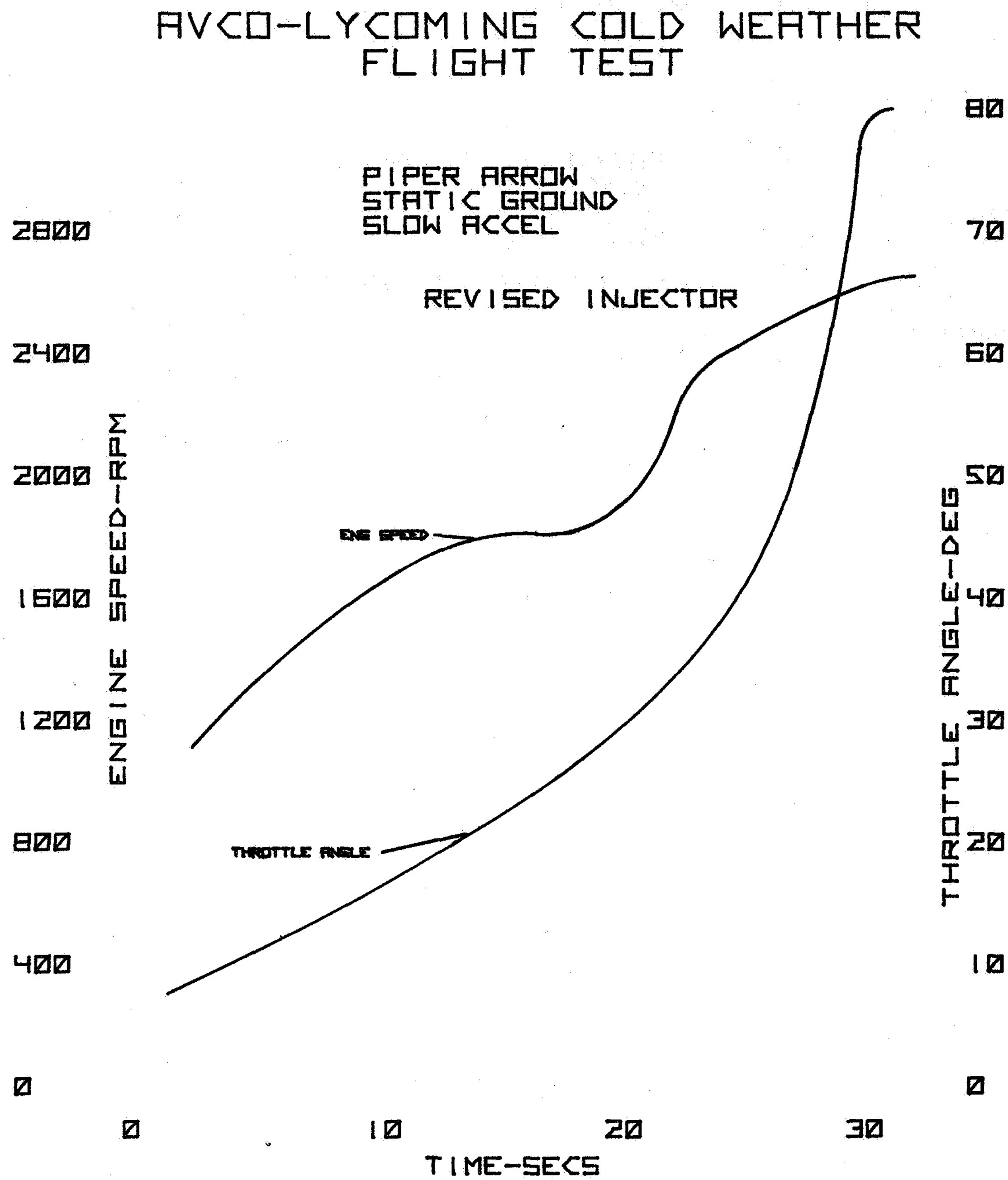

AVCO-LYCOMING COLD WEATHER FLIGHT TEST
PIPER ARROW
STATIC GROUND
SLOW ACCEL
REVISED INJECTOR
ENG SPEED
THROTTLE ANGLE
ENGINE SPEED-RPM
THROTTLE ANGLE-DEG
TIME-SECS
2800
2400
2000
1600
1200
800
400
0
80
70
60
50
40
30
20
10
0
0
10
20
30

Figure 7-16

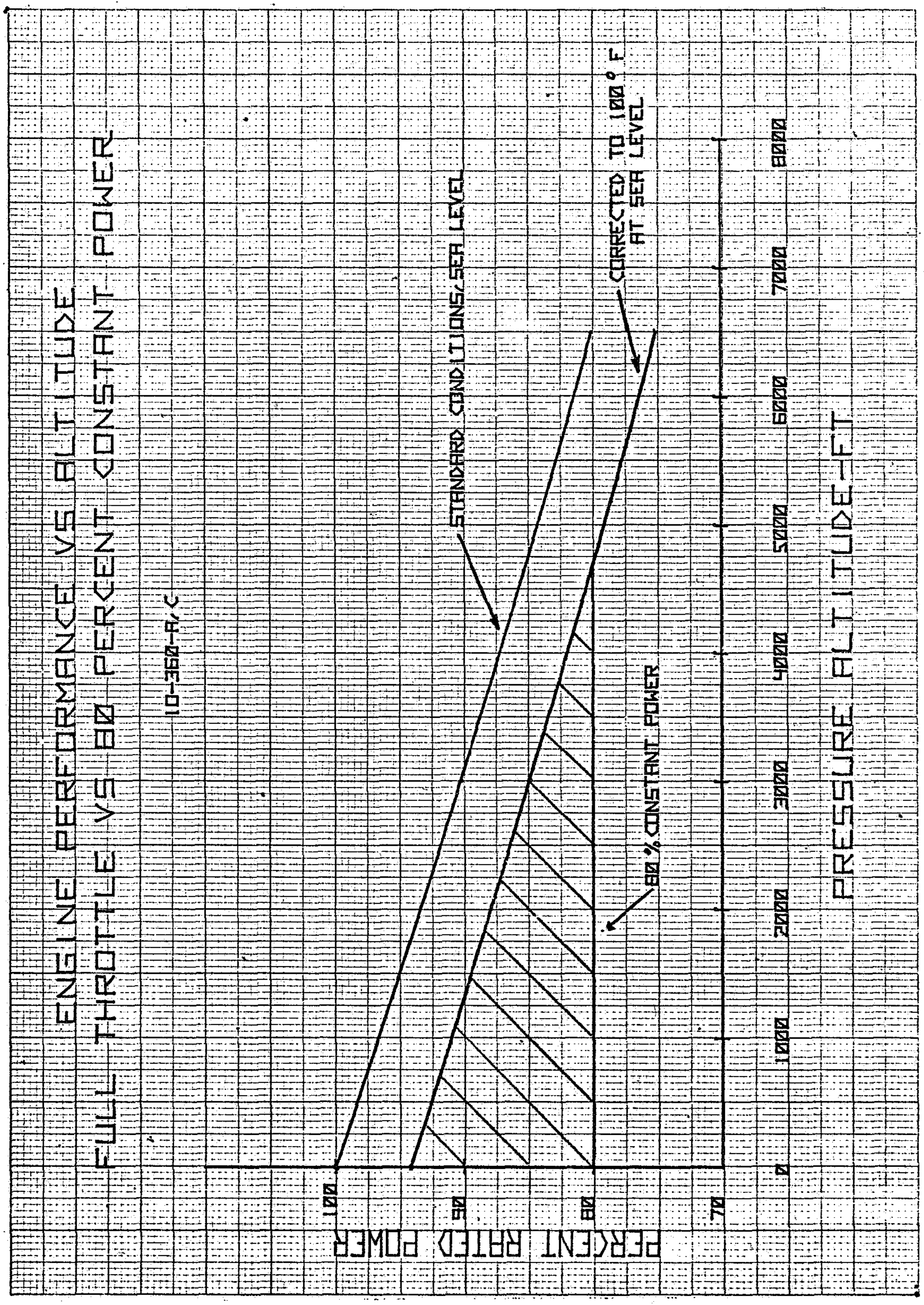

ENGINE PERFORMANCE VS ALTITUDE
FULL THROTTLE VS 80 PERCENT CONSTANT POWER
IO-360-A,C
STANDARD CONDITIONS,SEA LEVEL
CORRECTED TO 100 ° F
AT SEA LEVEL
80 % CONSTANT POWER
PERCENT RATED POWER
100
90
80
70
0
1000
2000
3000
4000
5000
6000
7000
8000
PRESSURE ALTITUDE-FT

Figure 7-17

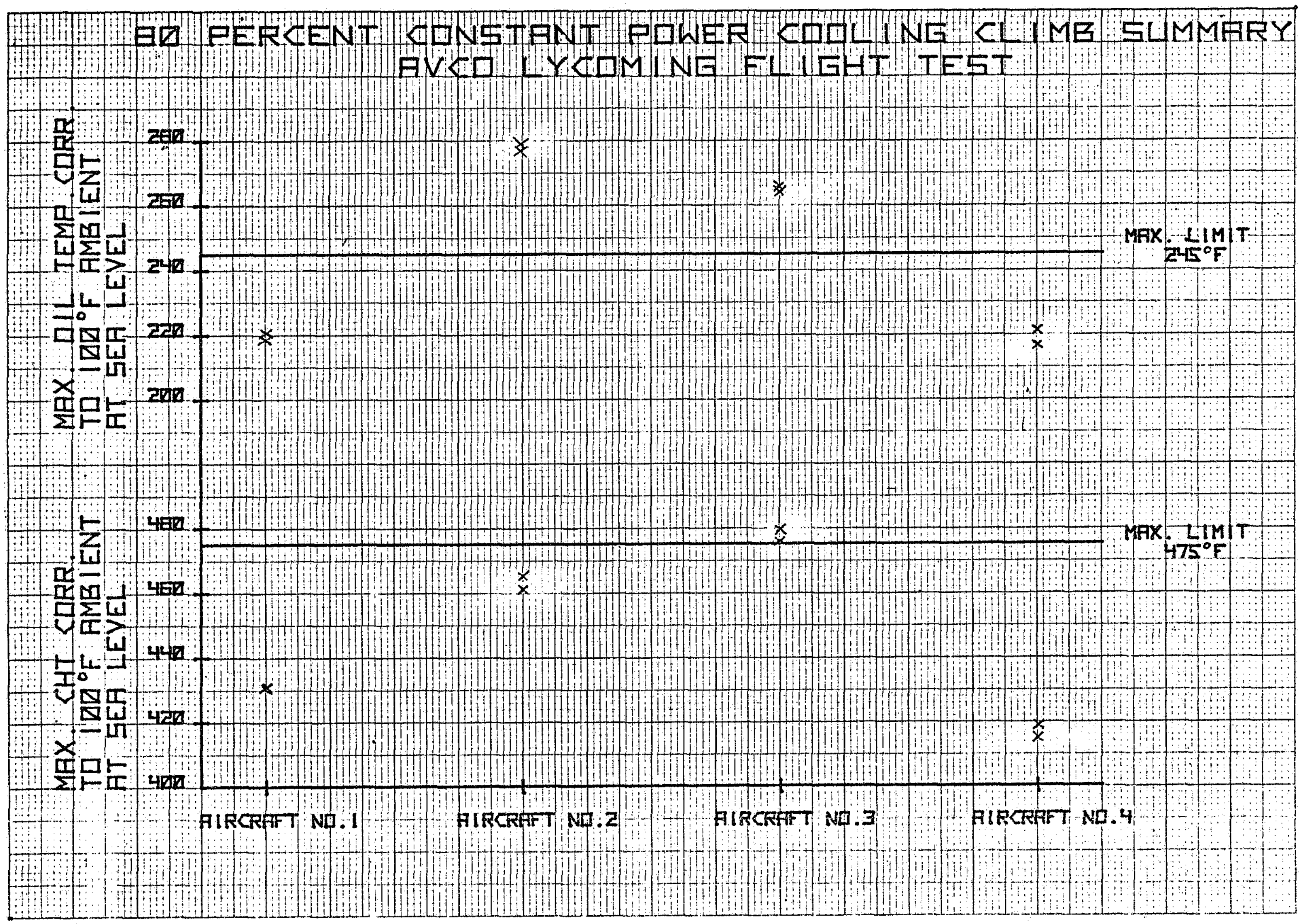

80 PERCENT CONSTANT POWER COOLING CLIMB SUMMARY
AVCO LYCOMING FLIGHT TEST
MAX. OIL TEMP CORR TO 100°F AMBIENT AT SEA LEVEL
280
260
240
220
200
MAX. LIMIT 245°F
MAX. CHT CORR. TO 100°F AMBIENT AT SEA LEVEL
480
460
440
420
400
MAX. LIMIT 475°F
AIRCRAFT NO.1
AIRCRAFT NO.2
AIRCRAFT NO.3
AIRCRAFT NO.4

Figure 7-18

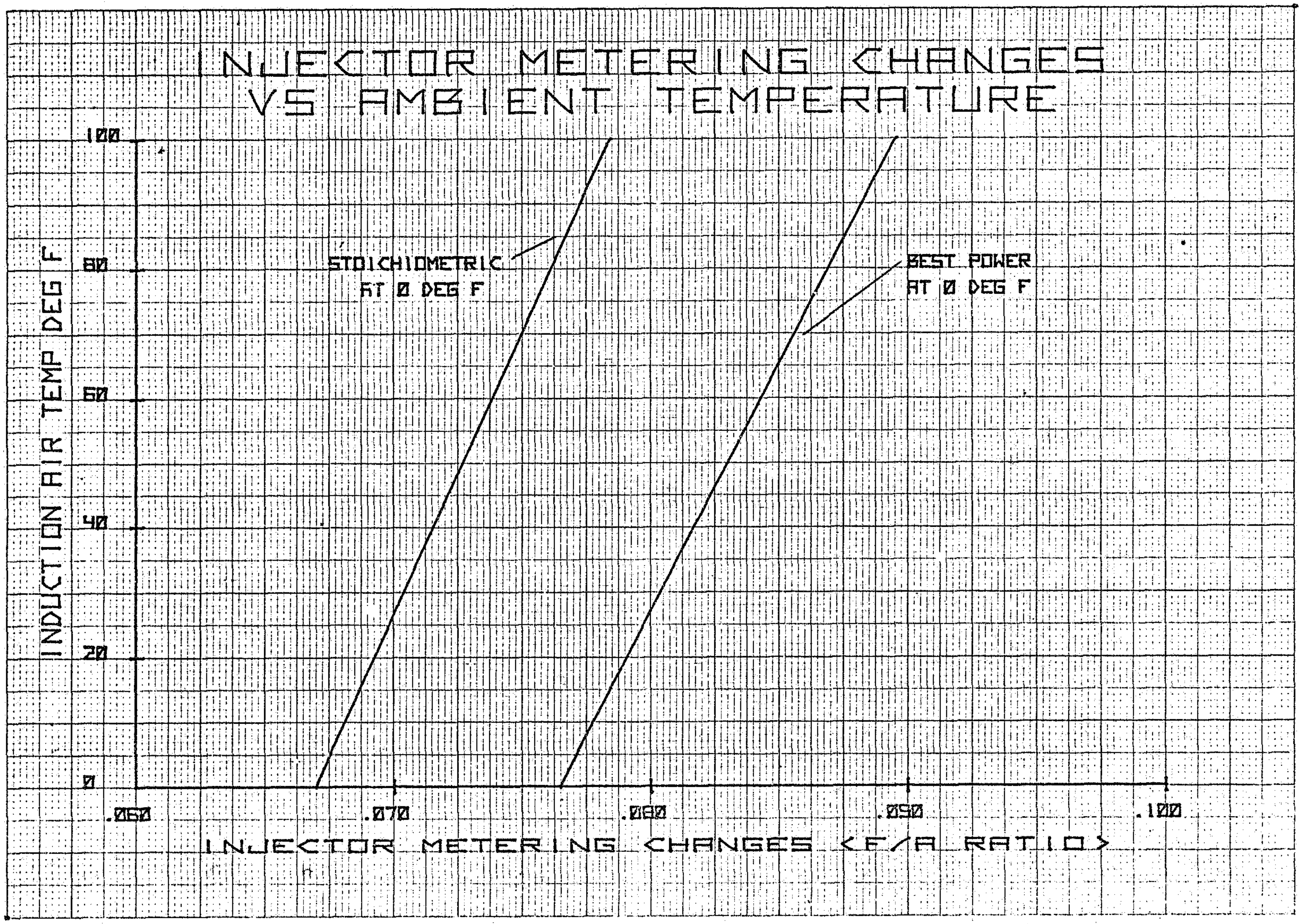

INJECTOR METERING CHANGES
VS AMBIENT TEMPERATURE
INDUCTION AIR TEMP DEG F
100
80
60
40
20
0
.060
.070
.080
.090
.100
INJECTOR METERING CHANGES <F/A RATIO>
STOICHIOMETRIC
AT 0 DEG F
BEST POWER
AT 0 DEG F

Figure 7-19

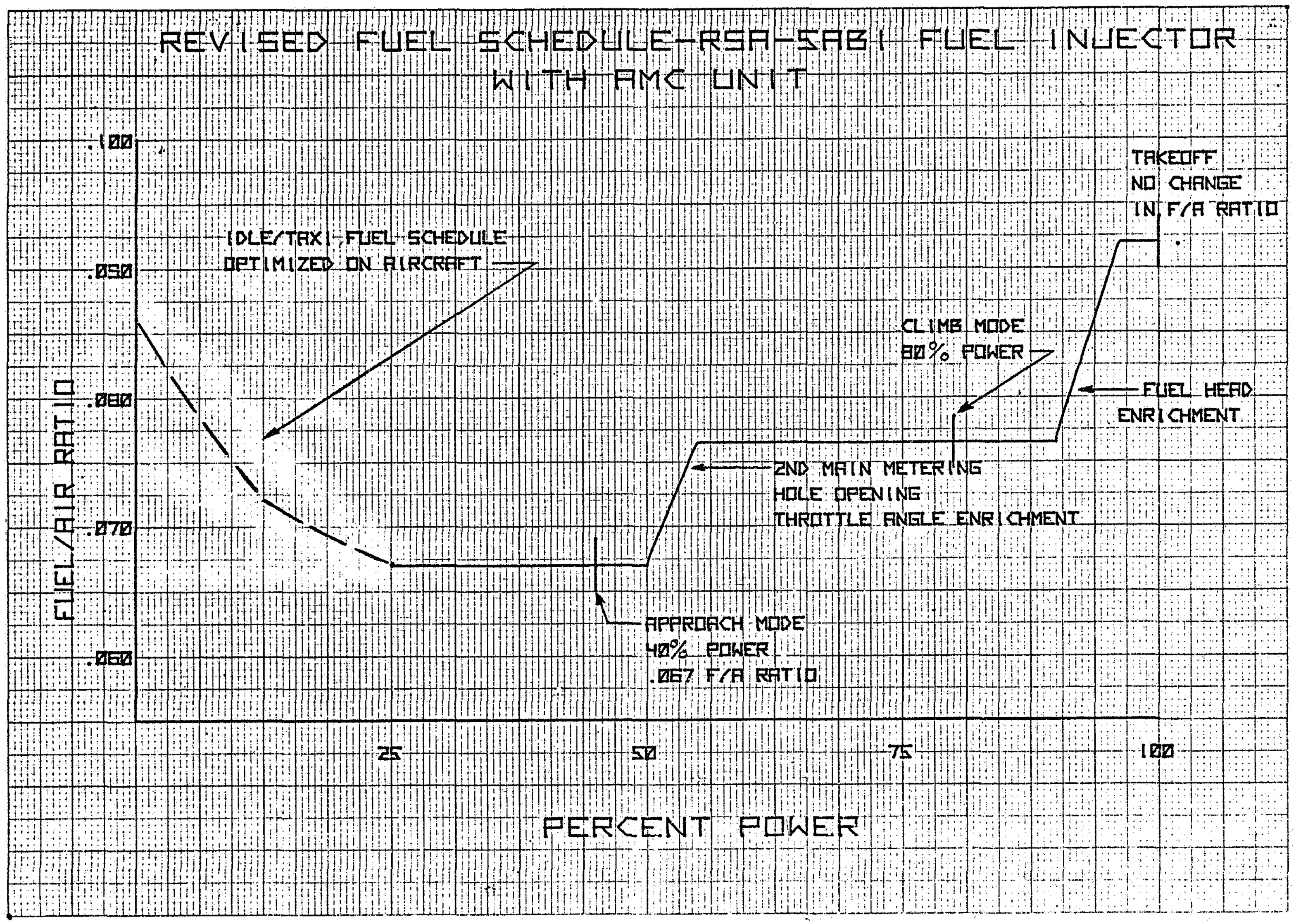

REVISED FUEL SCHEDULE-RSA-5AB1 FUEL INJECTOR
WITH AMC UNIT
.100
.090
.080
.070
.060
FUEL/AIR RATIO
IDLE/TAXI FUEL SCHEDULE
OPTIMIZED ON AIRCRAFT
TAKEOFF
NO CHANGE
IN F/A RATIO
CLIMB MODE
80% POWER
FUEL HEAD
ENRICHMENT
2ND MAIN METERING
HOLE OPENING
THROTTLE ANGLE ENRICHMENT
APPROACH MODE
40% POWER
.067 F/A RATIO
25
50
75
100
PERCENT POWER

Figure 7-20

CO EMISSION PROFILE
IO-360-A1B6D, S/N 888-X

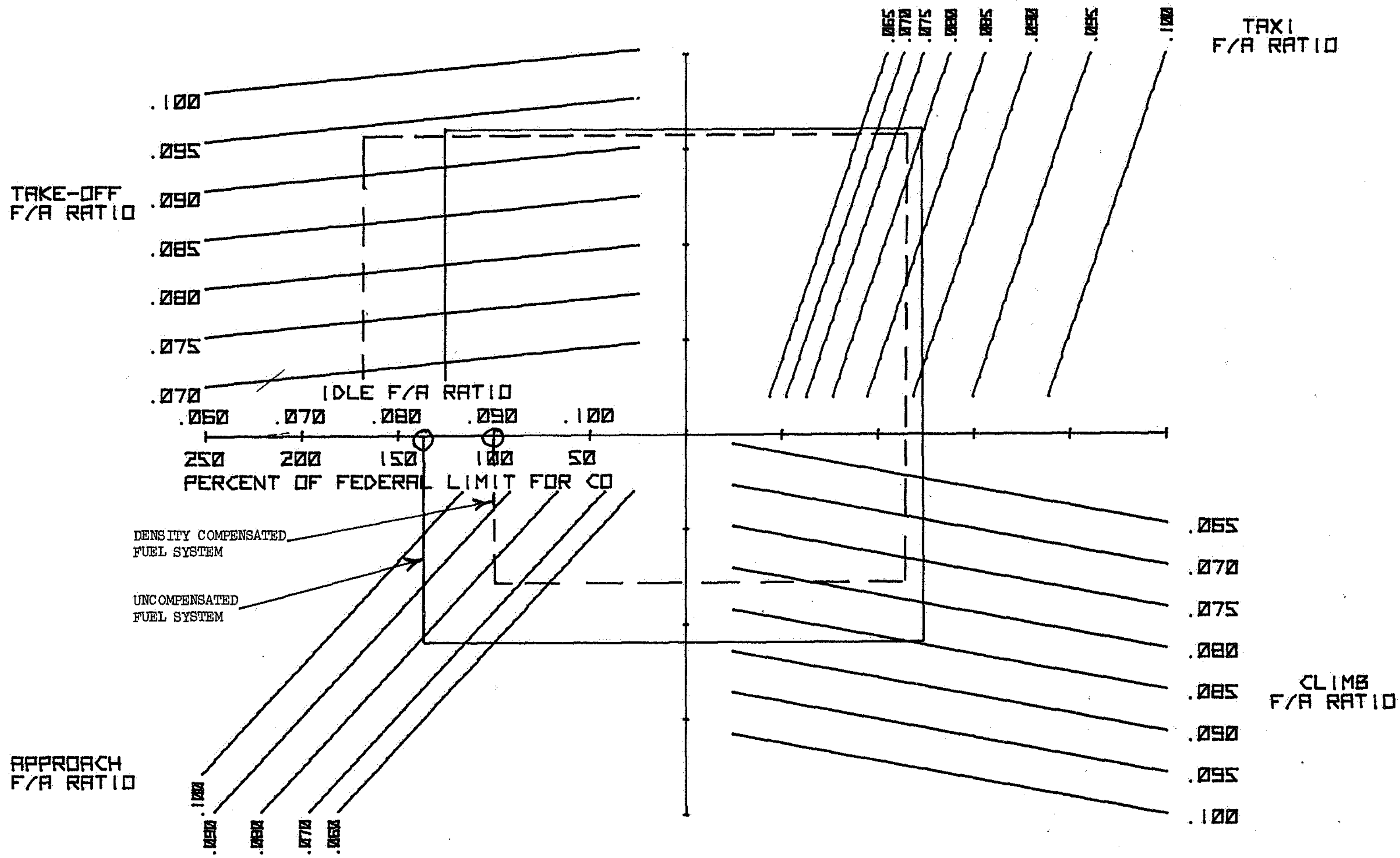


Figure 7-21