9. FLIGHT TEST SUMMARY OF MODIFIED FUEL SYSTEMS

Bruce G. Barrett

Cessna Aircraft Company
Wichita, Kansas

INTRODUCTION

During the spring and summer of 1976, Cessna Aircraft Company, in cooperation with Teledyne Continental Motors, flight evaluated two different aircraft designs, each with two modified fuel control systems. Each aircraft was evaluated in a given series of defined ground and flight conditions while quantitative and qualitative observations were made. During this program, some ten flights were completed, and a total of about 13 hours of engine run time was accumulated by the two airplanes. This report will briefly summarize the results of these evaluations with emphasis on the operational and safety aspects.

DISCUSSION

The first aircraft involved was the Cessna Model 150 (fig. 9-1). This is a single-engine training aircraft powered by the TCM O-200-A normally aspirated, carbureted engine. Instrumentation was supplied in the test aircraft to read engine rpm, manifold pressure, and various operating temperatures, as well as the important atmospheric parameters. In addition, the pilot monitored the general functional behavior of the engine.

The test profile is summarized in figure 9-2. The idle and taxi conditions simulate typical ground operations with this class airplane. The takeoff condition, as defined here, is analogous to the condition for engine cooling called out in the Federal airworthiness requirements. The climb condition, though not necessarily completely representative of the operation of a low power airplane, was included, originally, to allow evaluation of the effect of leaner mixtures at lower power settings on engine operating temperatures. The descent phase was investigated, both with partial power applied and with power completely off, followed by simulated go-arounds to evaluate engine response characteristics. Finally, the landing phase was used to evaluate the typical touch-and-go operations so prevalent to the training class airplane.

The two fuel systems evaluated in this airplane resulted from engine test stand data developed by TCM. The case I system simply results from use of today's lean limit production carburetors. The leaner case II system represented the ground test "safety limit" mixture strength found by TCM in their test cell runs. This safety limit was defined by engine temperatures at the higher powers and by acceleration characteristics of the engine in the lower power range.

The results of the testing on the Model 150 indicated that the case I system pretty well defined the leanest system acceptable. With the case I carburetor, all flight conditions were found acceptable. The case II carburetor, however, was another story. In the airplane, engine operation could not be sustained below approximately 1700 rpm. At this rpm, the engine began overheating rapidly during ground operation. The airplane was not considered at all airworthy in this configuration, and no flights were made with the case II carburetor.

The second aircraft involved was the Cessna T337 (fig. 9-3). This twin-engine airplane is powered by two TCM TSIO-360-C turbocharged, fuel injected engines. The engines are in tandem at either end of the fuselage. The front engine was used here to evaluate the modified fuel systems, while the rear engine was left in the standard configuration. Instrumentation was supplied to read front engine power parameters and operating temperatures, to record throttle position and manifold pressure, and to read appropriate atmospheric variables. In addition, the pilot monitored the behavior of the front engine from purely a functional standpoint.

The test profile is summarized in figure 9-4 for this airplane. Again, the idle and taxi conditions represent typical ground operations. The emergency, or single engine, climb condition represents the most severe condition with respect to FAA engine cooling requirements for this airplane. The normal climb represents a typical cruise climb used in this airplane conducted at a speed in excess of that for best climb performance. The descent phase was investigated in a way to stimulate typical instrument approach conditions, as well as with the power back to idle. In addition, two speed ranges were evaluated and, as with the smaller airplane, go-arounds were simulated following all descents. Finally, the landing phase included touch-and-go operations to observe engine response characteristics.

The case I fuel system was intended to represent the leanest fuel system using today's components which might result from using a full rich mixture for all operations with no supplement with an auxiliary fuel pump. However, the system actually tested was somewhat leaner than intended at maximum continuous power. The case II system represented the "safety limit" fuel mixtures established by TCM during their ground test stand runs, as described previously for the Model 150 tests.

The approximate relationship of the case I and case II fuel flows with those actually used in the present production airplane is shown in figure 9-5 for the various test conditions. As can be seen, the fuel flows actually specified for operation of the airplane in the form of operating limitations and instructions are consistently richer than either of the modified systems.

The results of the case I (as flown) and case II testing indicated both fuel systems to be unacceptable in several areas. In the idle and taxi ranges, some subtle engine roughness was evident with both fuel systems. With the tested case I system, response characteristics were probably marginally acceptable. The case II system, however, was noticeably slower to accelerate. In addition, while no specific measurements were made, the pilot's opinion was that engine starts, particularly with the case II system, were slightly more difficult.

The emergency climb condition was unacceptable as flown with the case I system because of engine overheating due to the lower than planned fuel flow. This is illustrated in figure 9-6 where the tested case I system produced engine temperatures near the limit immediately after the test was started. The case II system being leaner still was not evaluated in this condition. Cruise climbs at a comfortable airspeed higher than the maximum performance speed and with power set to 80 percent of maximum continuous were somewhat better, but even here, with the tested case I system, engine temperatures would be expected to exceed their limits in ISA + 40° F ambient temperatures due to the significantly lower fuel flows as compared to production (fig. 9-5). With the case II system, observed engine temperatures rapidly exceeded allowable limits. In addition, some subtle engine roughness was evident in this condition with the case II system.

The approach conditions evaluated revealed the tested case I system characteristics to be generally marginally acceptable, with the exception of some minor engine stumble on some simulated go-arounds. However, the case II system exhibited unacceptably slow "spool up" of power, as illustrated in figure 9-7, where, on a missed approach, almost twice as much time was necessary to obtain full power as is needed with the present production airplane. In addition, very rapid throttle advancement (throttle snaps) tended to cause the engine to die almost every time. Stumble or hesitation was always evident on the case II system on simulated go-arounds.

The operational acceptability of an airplane, with respect to the subject under question, falls into two major areas - safety and function.

Of prime importance, of course, are the safety aspects. Any system must be tolerant of mishandling to some degree as long as real

people are operating the system. A broad range of pilot knowledge and skill must be accommodated. Such things as "jamming" in of a throttle should not kill the engine. Engine power must always be available rapidly to salvage a bad approach or in the event an intruder on a runway necessitates an aborted landing. The engine installation must provide adequate margins with respect to its temperature limitations to accommodate all potential use of the airplane. Finally, the engine installation, with all of its supporting systems, must be as reliable and foolproof as possible.

Functionally, the engine package must tolerate widely varying atmospheric conditions. Wintertime operations, with the resulting leaner mixtures, must be contrasted against summer operations, with the resulting higher operating engine temperatures. Engine roughness or hesitation will not be tolerated, and rightly so, by the majority of pilots, no matter how subdued, due to the three-dimensional nature of flight.

These comments, then, and others similar, can form a basis for judging the acceptability of the various fuel systems flown in this early evaluation. It was found that with the present Cessna Model 150 the case I fuel system represents, essentially, the leanest acceptable fuel system. The case II system, being unairworthy in this airplane, was completely unacceptable from either safety or functional standpoints.

For the Cessna Model T337, neither the case I (as flown) nor the case II systems were acceptable. However, an analysis does indicate that the case I fuel system with the slightly richer mixtures originally intended might be expected to be marginally acceptable. It is possible that some further leaning could be tolerated for the power approach case and, with an attendant penalty in climb performance, for the cruise climb case, if a higher airspeed can be accepted. However, it should be noted that many pilots will be uncomfortable if any tendency toward roughness is evident in this case, even if airworthiness is not compromised. In the T337, the case II fuel system was found unacceptable from both functional and safety viewpoints.

CONCLUSIONS

While some improvements in exhaust emissions control can be achieved through mixture control on some airplanes, the tests on these two airplanes indicated several important points:

1. Ground tests of the engine alone were not able to predict acceptable limiting lean mixture settings for the flight envelopes of the Cessna Models 150 and T337.

2. The lean limits established today for the Cessna Models 150 and T337 approximately represent the leanest mixtures tolerable from safety and/or functional viewpoints.

3. Further leaning, beyond today's lean limits, for the Cessna Models 150 and T337 for the purpose of emissions control, must be accompanied by potentially extensive development and recertification flight testing to eliminate the safety and/or functional limitations found in this test series.

4. Each airplane design/engine combination must be evaluated in an individual effort to develop acceptable lean limiting mixtures and identify the areas where gains in emissions area are feasible for that airplane.

DISCUSSION

Q - D. Tripp: Does figure 9-7 show the response under approach conditions?
A - B. Barrett: This was the response as recorded during one of our aborted landing approaches. That is correct.

Q - D. Tripp: I'm not a pilot, but do you normally have the throttle all the way closed during approach?
A - B. Barrett: This particular one was a power off landing approach.

Q - D. Tripp: Is that the normal condition?
A - B. Barrett: Yes. It is a normal condition. It may not be completely normal for this particular airplane. This was the extreme case we saw as far as the power response goes. And I might add, I mentioned earlier that no matter how fast or how slow you brought the throttle in, it always stumbles to some degree or other with this particular fuel system.

COMMENT - L. Helms: I've heard that this is the normal condition in the student training film.

A - B. Barrett: Yes, in the case of the Cessna 150 it would be completely normal.

Q - D. Tripp: It was shown that under idle conditions, the condition when the throttle was shoved forward all the way, the engine stumbled, fell off in rpm, and did not respond as it did for the normal carbureted fuel-air ratio condition. Is that a safety problem? What condition would that represent as a safety problem when you are at idle and you shove the throttle forward very rapidly and it stumbled? I can't conceive why that would be a safety problem.
A - C. Price: There was an air worthiness directive, about 2 years ago, directed toward 0-320 engines, I believe in the Cherokee, for that very same reason. Power off approach and aborted landing or for some reason power would be applied and the engine would hang. Sometimes it would come out of it, but it's not very instinctive for a pilot to pull his power back off and try to clear an engine and then try to put power back on. So if he jams it forward and it hangs, he's in trouble.

Q - D. Tripp: Is that a safety problem?
A - L. Helms: Yes. Take the specific example at idle when the throttle is moved forward and the engine coughs and sputters. Consider the environment, a twin engine airplane under a freezing rain or very close to that temperature. The pilot does not know whether he has ice in the carburetor or whether he has ice in the induction system. Therefore, the FAA has properly said, and we agree with them 100 percent, no coughs and no sputters because that's the only way the pilot can be sure he has an absolutely clean carburetor. I'd like to make

another comment on the example he used on rate of climb. If we had looked at it it would have said, "Is the rate of climb of the aircraft good enough to where it would not have created the danger problem?" We talked about the horsepower rating and the rate of climb so now if we reduce the rate of climb slightly so there is no danger problem, we have now put ourselves back over onto the other side of the EPA problem where noise limitations are a function of rate of climb. Therefore, by reducing the rate of climb we got ourselves out of a problem on emissions and put ourselves in a problem on noise. The 84 PNdB allowed on climb is a direct function of the rate of climb. So we can't automatically make these adjustments and get out of our emissions because we can no longer meet the noise requirements.

Q - G. Kittredge: You made the comment that each engine/aircraft combination really has to be considered as a special case and you investigated two examples very thoroughly. Could you estimate for your company how many different combinations of aircraft and engines you would have to deal with?

A - B. Barrett: In my division of my company it's on the order of 25 separate and distinct engine and airframe combinations. In the other division across town it must be approximately a dozen.

COMMENT - L. Helms: For GAMA, there are 64 different aircraft and 407 different engines. Potentially, this gives you an order of magnitude of the problem.

Q - D. Page: You indicated that you were going over limits on your cooling efficiency. Was this a single engine climb condition, and what recovery efficiency are you getting on your particular installation in the 337?

A - B. Barrett: Yes, it was single engine climb, and I think we're running somewhere on the order of 3 to 3 1/2 inches ΔP on cooling air, but I'm not positive on that.

Q - D. Page: What is the percentage of recovery? - I'm trying to establish whether this is the most available at that air speed.

A - F. Monts: I think normally we'll see a dynamic recovery of about 0.75 to 0.8 for the single engine climb speed of just over 100 miles an hour. That's a little over 5 inches of water. You can put the cowl flap open and gain a bit more which for this particular installation is about as good as our industry does at the moment. We have to show single engine climb all the way to approximately 20 000 feet.

Q - B. Houtman: Would you specifically describe what the hardware changes were made in going from the baseline to case 1 and then again to case 2 to achieve the configuration you used?

A - B. Rezy: What we did on the engine was to take a standard fuel injection system and set up the fuel metering system with a particular pump and throttle body. We cut a throttle plate cam, such that we

could control the cases 1 and 2 to those conditions. We also had a modified fuel pump pressure to hold it there. It took our fuel lab well over a month to develop each one just to be able to hold it there. When we finally got it in the airplane it wasn't really what it should have been on case 1.

Q - E. Kempke: It's been said that the case 1 that was flown missed the target slightly on the fuel-air ratio. But in listening to the presentation there was a strong impression left that if the case 1 had made the fuel-air ratio it was extremely marginal. Is that the impression that one should come away with?
A - B. Barrett: Yes.

Q - E. Kempke: Is the case 1 not the lean limit of a production fuel injection system?
A - B. Barrett: The case 1 as flown is, in fact, the engine manufacturer's lean limit, the bottom line of the engine spec. On this particular airplane we have, in effect, established a lean limit for the installation that is richer than the lean limit demanded by the engine manufacturer.

Q - D. Tripp: I still have a question on that approach at closed throttle, and maybe someone from EPA could comment on this, too. Since the EPA LTO cycle specifies 40 percent power on approach, somehow there seems to be an anomaly here in that we're saying for the test procedure use 40 percent power. However, you're saying the way these planes are frequently flown is with a closed throttle. What's the explanation for it?
A - B. Barrett: The 40 percent power is reasonable, if you want to assign a reasonable specification for conducting your emissions testing. It is probably a reasonable simulation of an approach in many of the larger airplanes. But there's nothing that says the pilot is going to fly every approach that way. It's difficult particularly in the final stages of approach to be much lower in power than the 40 percent.

COMMENT - H. Nay: The approach is 6 minutes. In the traffic pattern in the approach to the airport, in that 6 minutes, 40 percent is not an unrepresentative power condition. The point is that in the final stages of approach, and this goes for high performance airplanes to some extent as well as low performance airplanes, you go to completely closed throttle. From that point when the cow walks out in the grass strip, a jet taxis out in front of you, or you have a foulup of some sort, you've got to have immediate power from closed throttle to 40 percent power or higher. That's an absolutely essential safety requirement as the FAA people pointed out.

COMMENT - F. Monts: I think the facts are being confused about the 40 percent approach power used in the EPA cycle. Whatever metering system is devised to meet the emissions limit, it must also work from a cold

throttle position. The complete flight envelope of the airplane and not just the EPA LTO emission cycle must be considered.

Q - D. Tripp: I was just wondering how 40 percent was arrived at?
A - B. Barrett: It's a good average.

COMMENT - G. Banerian: I realize that the controls being used are designed to be a minimum fixed and simple type. It seems to be that in both the Avco-Lycoming and TCM controllers a simple override feature could be incorporated such that in a transient mode it would automatically go to a rich condition. The other flight tests reported earlier did not have a cylinder head heating problem but Cesana's tests did indicate a cooling problem.

COMMENT - B. Barrett: That's an indication, too, of the individuality of each and every installation.

COMMENT - B. Rezy: TCM will discuss tomorrow possible ways of improving engine transient response between steady-state leaned conditions. One example of items which will be evaluated is the use of an accelerator pump.

Q - G. Banerian: Maybe I didn't notice it, but I was anxious to see a comparison of NAFEC data with the data taken at the contractors facilities and also the O-320 work done at Lewis. Are there some baseline emission data we can compare? I didn't see that comparison today.
A - E. Becker: The plots I had up were for the TSIO-360 tests at both NAFEC. The data lined up, there were no significant differences.

COMMENT - L. Helms: We haven't found any differences.

Q - G. Banerian: Have the differences that have been reported been in the idle mode?
A - E. Becker: Most of it is due to large scatter in fuel-air ratios. As NASA-Lewis pointed out earlier, the significance of temperature and humidity effects on hydrocarbons are also quite pronounced in the idle/taxi modes.

COMMENT - G. Banerian: We can then conclude that the measuring methods, even though they are different, at the various sites are sufficiently similar in results.

Q - T. Cackette: Both Avco and TCM data show that there is a fairly large difference in CO, due to the lean and rich production limits, which implies that there is a large fuel-air ratio difference on the production items. Could TCM or Bendix comment on what the causes of the large production tolerances are and possibly if they are anticipating taking any action to reduce those as a method of controlling emissions?

A - B. Rezy: You have to understand that both engine companies ran these tests differently. Lycoming ran full production rich limits and lean limits. TCM ran as baseline, the average fuel flow between the rich and the lean limit. That's why you see those differences.

COMMENT - S. Jedrziewski: Speaking for AVCO, our production limits are of the order of 7 percent of fuel flow right now. These limits are based on just manufacturing tolerances, reproducibility, airflow sensing, etc. We are engaged in programs trying to reduce these limits. At the present time we don't know how much they can be reduced.

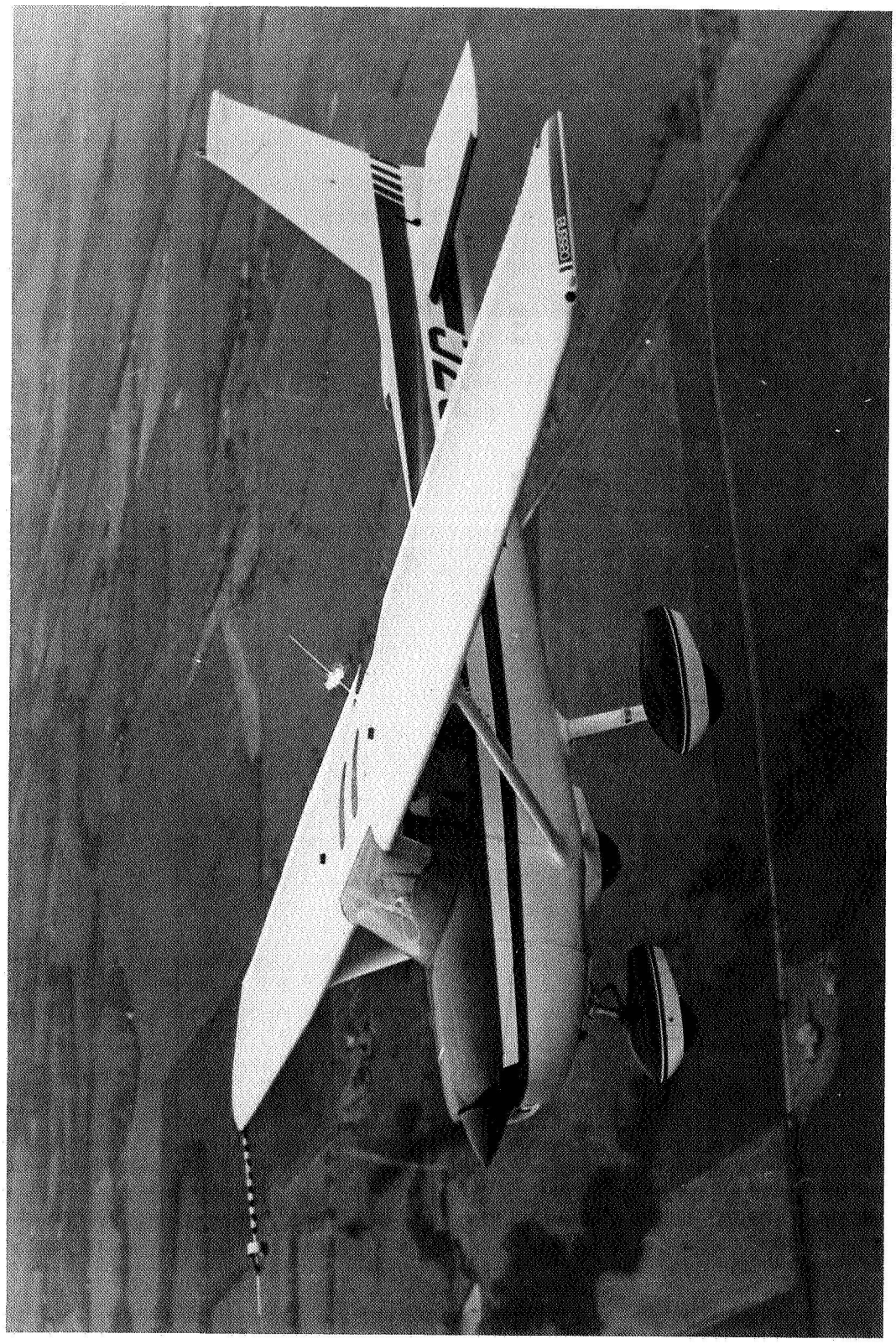

Figure 9-1

FLIGHT TEST PROFILE
CESSNA MODEL 150

FLIGHT CONDITION					
Idle (600 rpm)	Taxi (1200 rpm)	Takeoff (Full Throttle, Best Rate of Climb Speed)	Climb (80% Power, Best Rate of Climb Speed)	Descent	Landing (Power Off)
Fuel Flow: % Leaner Than Production Lean Limit					
Case I					
0%	0%	0%	0%	0%	0%
Case II (Test Stand "Safety Limit")					
5%	19%	3%	3%	8.5%	5%

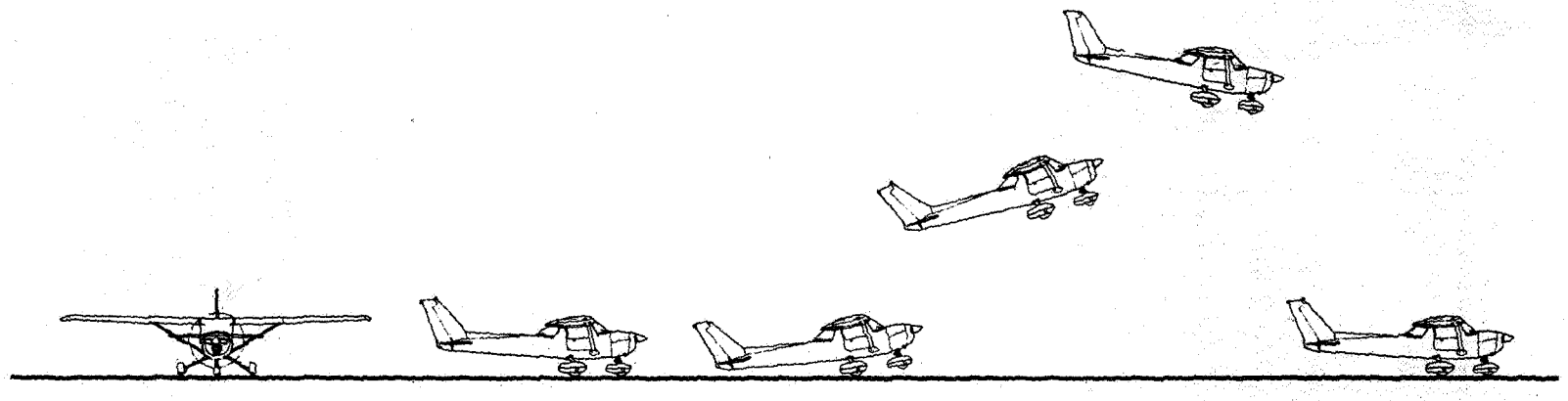

Figure 9-2

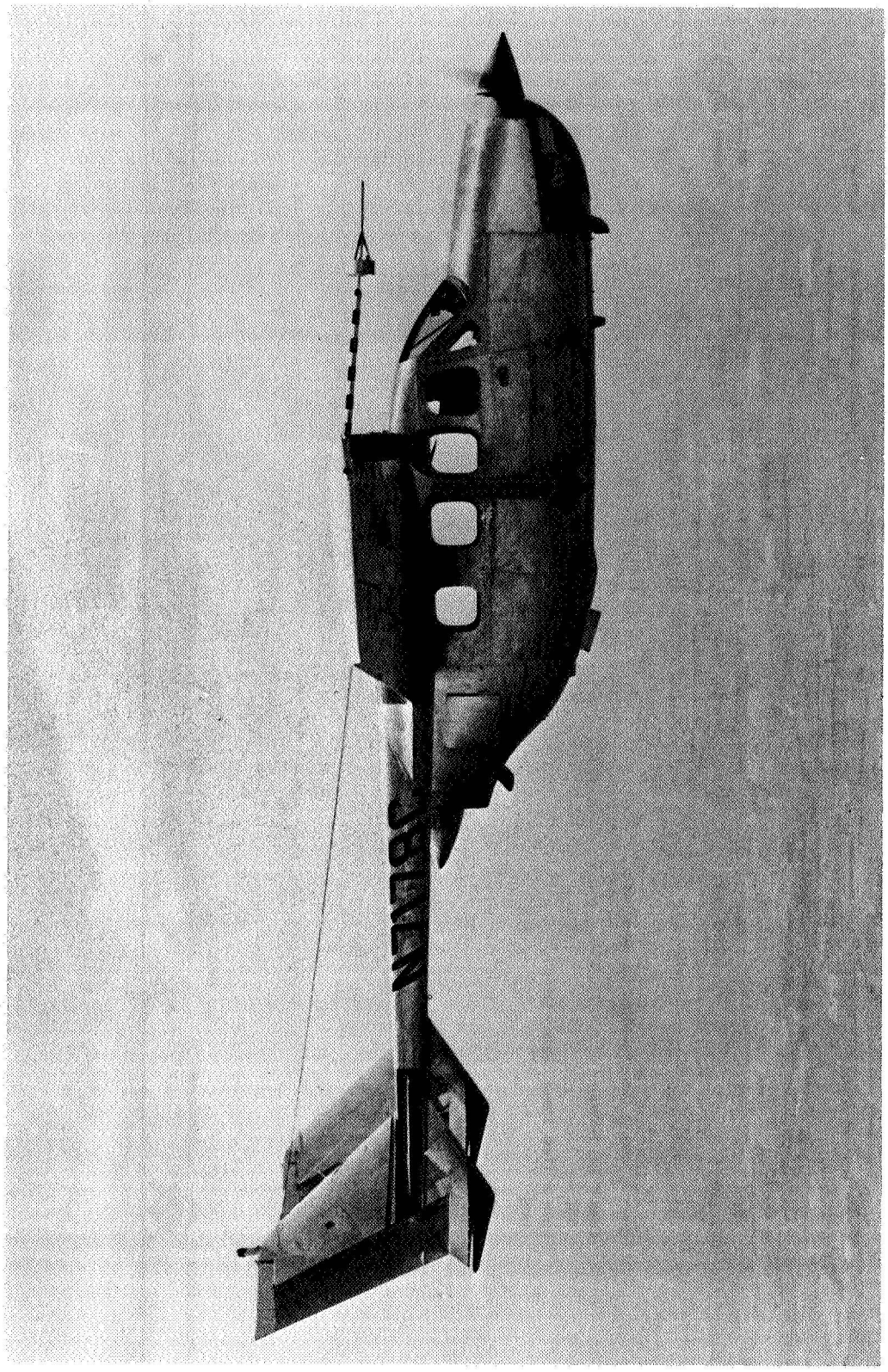

Figure 9-3

FLIGHT TEST PROFILE
CESSNA MODEL T337

FLIGHT CONDITION	Idle (600 rpm)	Taxi (1200 rpm)	Emergency Climb (Single Engine, Max. Power, Best Single Engine Rate of Climb Speed)	Normal Climb (Twin Engine, 80% Power, Rec. Cruise Climb Speed)	Descent (40% Power)	Landing (Power Off)
Fuel Flow: % Leaner Than Specified for Pilot Today.						
Case I (As Flown)	0%	6%	7%	9%	6%	0%
Case II (Test Stand "Safety Limit")	14%	21%	14%	19%	20%	14%

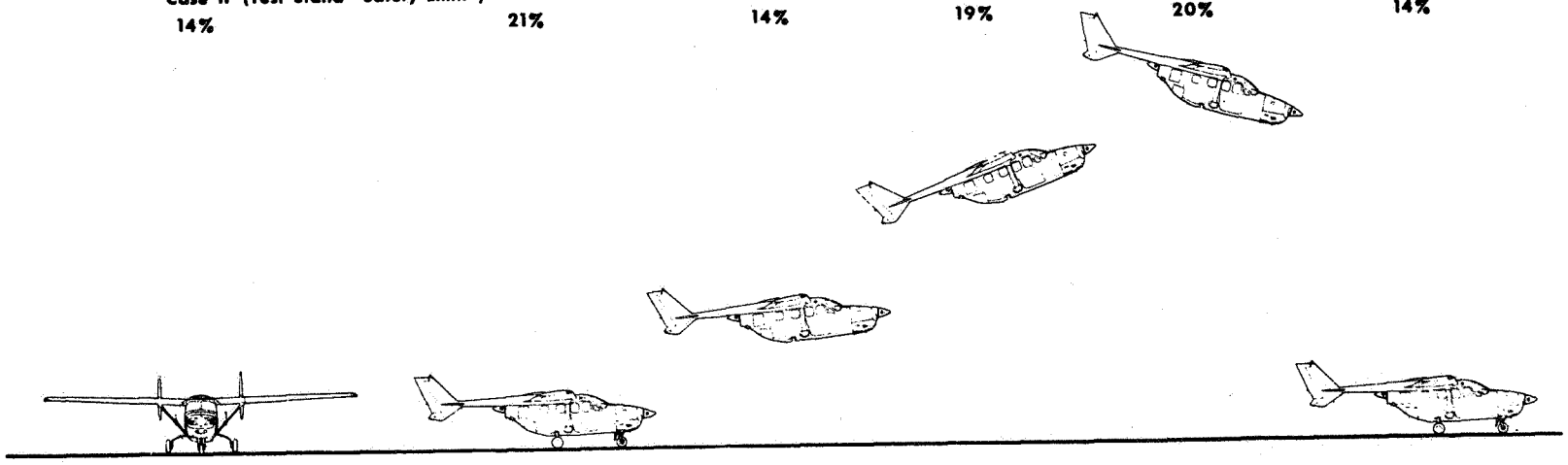

Figure 9-4

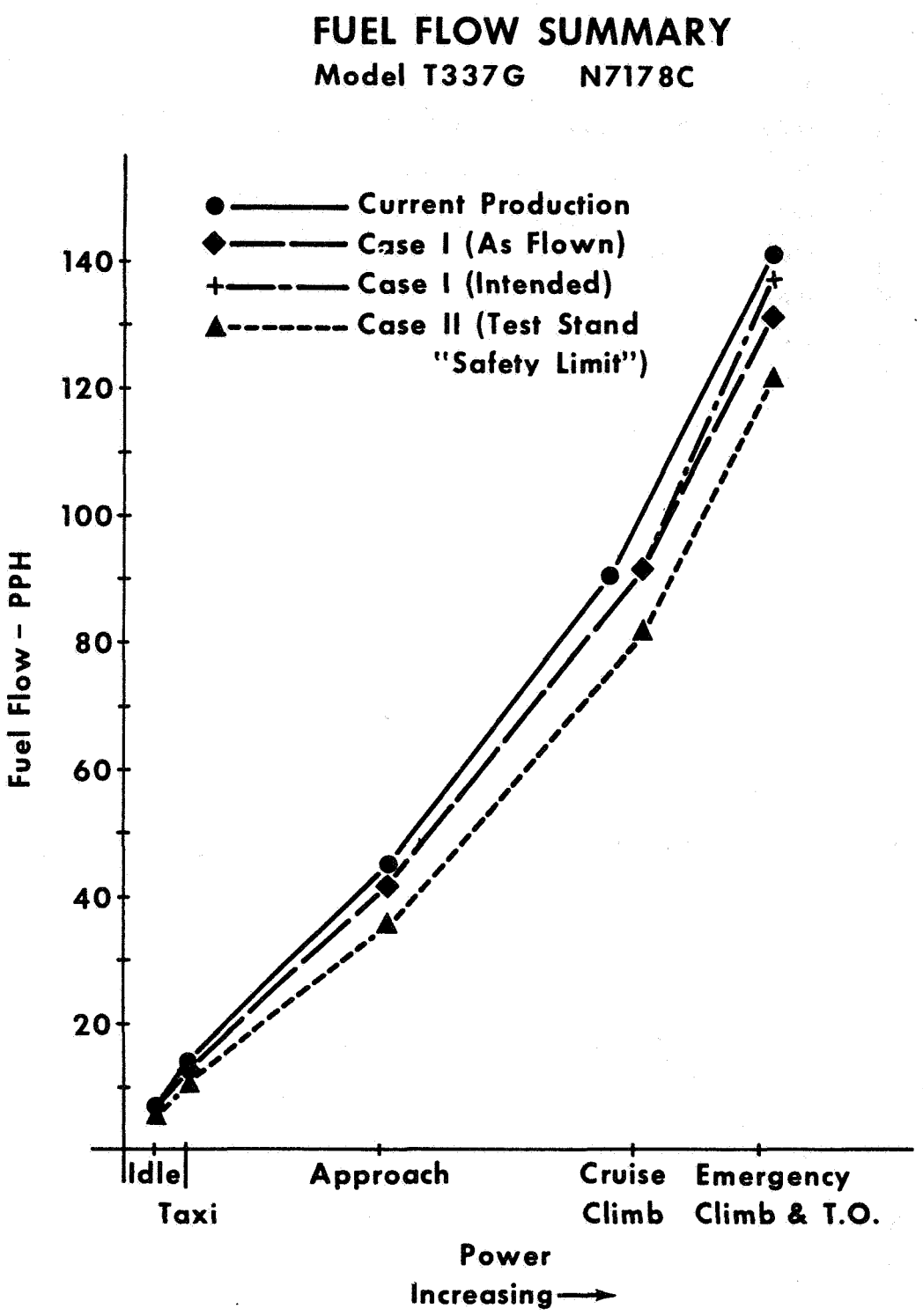
FUEL FLOW SUMMARY
Model T337G N7178C
Current Production
Case I (As Flown)
Case I (Intended)
Case II (Test Stand "Safety Limit")
Fuel Flow - PPH
140
120
100
80
60
40
20
Idle
Taxi
Approach
Cruise Climb
Emergency Climb & T.O.
Power Increasing

Figure 9-5

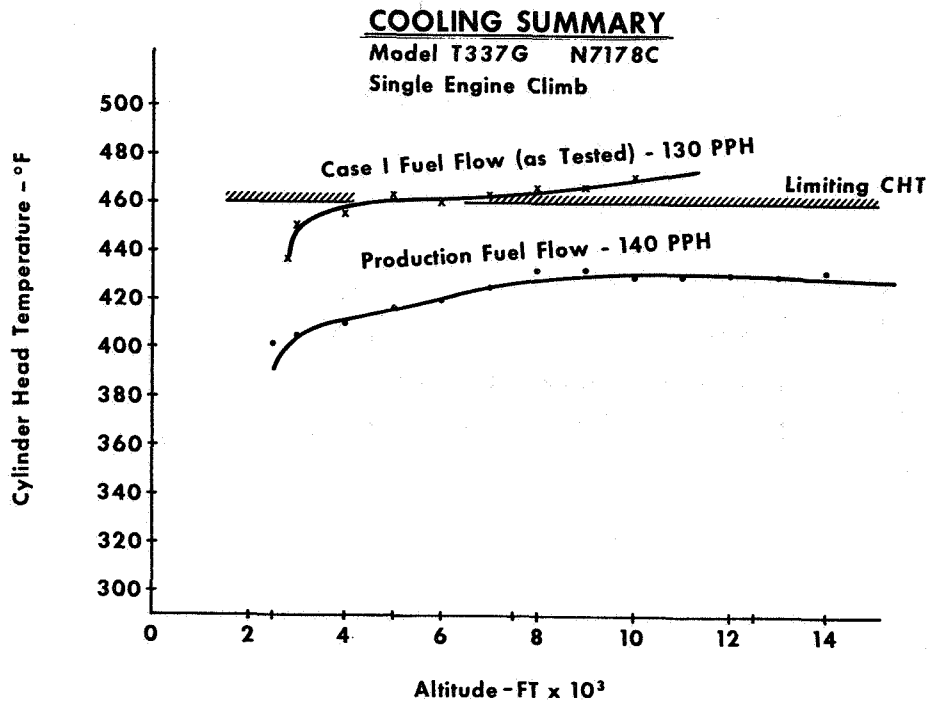

Figure 9-6

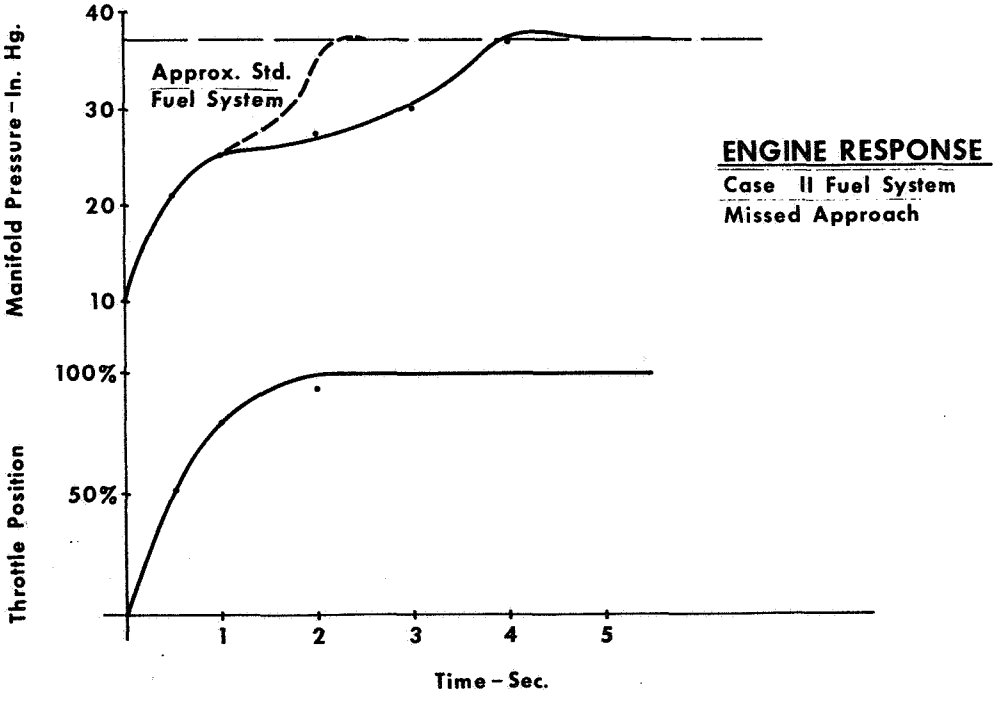

Figure 9-7