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PRELIMINARY QCGAT PROGRAM TEST RESULTS

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ABSTRACT

NASA Lewis Research Center is conducting a program to demonstrate that large commercial engine technology can be applied to general aviation engines to reduce noise, emissions and fuel consumption and to develop new technology where required. Following a study Phase I, two contractors (AiResearch and AVCO-Lycoming) were selected to design, fabricate, assemble, test and deliver their respective Quiet, Clean General Aviation Turbofan (QCGAT) experimental engines to NASA. The QCGAT engines have now entered the test phase. This paper describes the overall engine program, design, and technology incorporated into the QCGAT egnines. In addition, preliminary engine test results are presented and compared to the technical requirements the engines were designed to meet.

I-9802

IN LATE 1976, NASA initiated an experimental engine program to design, develop and test a Quiet Clean General Aviation Turbofan (QCGAT) engine. The objective of this program is to demonstrate the applicability of available large turbofan engine technology to small general aviation engines in order to obtain significant reductions in noise and pollutant emissions while reducing or maintaining fuel consumption levels. The program has now progressed well into the test phase. This paper presents the significant test results that have been recently obtained and includes an overview of the program.

General aviation aircraft have the potential of more widespread adverse community reaction to noise and pollution than do transport aircraft because general aviation airports are much more numerous and are usually located in relatively small communities where background noise and pollution are low. The noise produced by small turbofan engines can be as annoying as that produced by the large engines. In the past, considerable design and test efforts have been spent on the large commercial turbofans in quieting engines, decreasing emissions and increasing fuel economy. This technology has generally not been tested on general aviation turbofan engines. A technology bridge between these two engine classes was needed and was implemented through the NASA QCGAT experimental engine program.

Following initial studies, as reported in reference (1),* contracts were awarded to the Garrett-AiResearch Company and AVCO-Lycoming Corporation to each design, fabricate, test and deliver to NASA a QCGAT experimental engine and test nacelle. The engines have now entered the test phase. This paper describes the QCGAT program and the major design features of the engines, discusses the progress made and test results to date.

PROPULSION SYSTEM OVERALL DESIGN

A basic requirement to minimize cost for the QCGAT engine program is for the contractors to use an existing core for their engine design. AiResearch chose the core used in the TFE 731-3 executive jet engine. The engine currently produces approximately 16 458 N (3700 lb) of thrust. AVCO-Lycoming selected an uprated

*Numbers in parentheses designate References at end of paper.

version of the LTS 101 core. The basic LTS 101 core with a power turbine has been used primarily in helicopters and would be capable of producing a turbofan engine with approximately 5783 N (1300 lb) of thrust. Based on the contractors' engine core sizes and the preliminary design thrust levels of the QCGAT engines, the contractors synthesized twin-engined executive jet aircraft to provide a basis for assessing propulsion system performance and noise. These aircraft, shown in Fig. 1, appear similar in design but actually are quite different. The AiResearch aircraft pictured is a Learjet 35. For the program, this aircraft was stretched, and uprated aerodynamic characteristics were used - especially in the airport or slow speed regime. The AiResearch QCGAT engine resulted in an aircraft whose takeoff gross weight is 8674 kg (19 122 lb) with a payload carrying capability of 14 passengers, including crew, for 3297 km (1780 n. mi.). This aircraft has a design cruise speed of Mach 0.8 at an altitude of 12 192 m (40 000 ft).

The AVCO-Lycoming aircraft was conceived by the Beech Aircraft Company under an AVCO-Lycoming subcontract. This aircraft is a new design specifically for the QCGAT engine. It weighs 3538 kg (7800 lb) at takeoff and carries six passengers including crew. This executive jet has characteristics similar to the Cessna Citation, cruising at approximately Mach 0.6 at a 10 058-m (33 000-ft) altitude. The maximum payload range is approximately 2778 km (1500 n. mi.).

DESIGN GOALS - The significant difference in aircraft size and weight is a result of a basic QCGAT engine requirement to use existing engine cores and synthesize twin engine aircraft. Consequently, since the FAR Part 36 noise measuring points are flight profile (aerodynamics and engine thrust/airplane gross weight ratio) and aircraft gross weight dependent, each contractor has a different noise goal for their respective engine/aircraft combinations.

Figure 2 shows the NASA QCGAT program noise goals and the preliminary design noise values that each contractor predicted for the FAR Part 36 takeoff, sideline and approach locations. Also shown on the figure are the 1969 and 1977 FAR Part 36 noise requirements. For reference, existing twin executive type jet aircraft and the airbus (A300B) noise levels are shown. The NASA noise goal values for the QCGAT engine program are summarized in Table 1.

Figure 2(a) shows the AVCO-Lycoming takeoff noise goal to be 4.5 EPNdB quieter than the NASA goal. The AiResearch engine is predicted to meet the NASA contract goal at takeoff. Both contractors are using inlet and aft duct acoustic treatment in conjunction with an internal mixer nozzle. For sideline noise, measured at 463 m (0.25 n. mi.), Fig. 2(b) shows both contractors predict noise values quieter than the NASA noise goal. A similar situation exists at the 113-m (370-ft) altitude, 1852 m (1.0 n. mi.) from the runway end approach noise measuring point (Fig. 2(c)). Both of the engine/aircraft configurations are quieter than the goal.

The QCGAT engine emission goals are shown in Table 2. These goals are based on the emission levels established for 1979 EPA standard T1 class (<35 586-N (8000-lb) thrust) engines. The allowable SAE Smoke Number values are determined by the procedure set forth by the United States Environmental Protection Agency (EPA) in the Federal Register, Volume 38, No. 136, July 17, 1973. In 1978, it was decided by the EPA to abandon the emission goals for the T1 class engines. Although new EPA emission standards are being considered, the QCGAT contracts have retained the 1979 goals for demonstration purposes.

The performance goals for the QCGAT program (shown in Table 3) are considerably different for each contractor. Design approach and core size are the major contributors to this difference. The smaller AVCO-Lycoming engine has an uninstalled thrust goal of 7215 N (1622 lb) at takeoff, while the larger AiResearch engine has a thrust goal of 17 513 N (3937 lb). The maximum cruise thrust goals are 2157 N (485 lb) at a flight cruise condition of Mach 0.6, 7620 m (25 000 ft), and 4017 N (903 lb) thrust at Mach 0.8 at 12 192 m (40 000 ft) cruise for each of the engines, respectively.

OVERALL DESIGN - In Fig. 3, a cross section of the AiResearch QCGAT engine is shown with the core and supercharger of their selected model TFE 731-3 basic turbofan engine. The TFE 731-3 is a 16 458-N (3700-lb) thrust turbofan with two spools and a geared fan similar to the arrangement for the QCGAT engine. The TFE 731-3 is currently used in the

Dassault Falcon 50, Learjet 35/36 and others. As modified for QCGAT, it incorporates a new fan similar to the AiResearch ATF3 design (another AiResearch engine), a new reduction gear, combustor and power turbine in conjunction with other associated parts. The major unique QCGAT parts are shaded on the figure.

Figure 4 shows a cutaway view of the AiResearch QCGAT engine in an installed configuration. The mixer nozzle is a key element in reducing takeoff noise and, as model tests have shown (2), can significantly improve performance. A moderate fan tip speed and proper fan rotor-stator spacing are also evident design features for low noise. Acoustic treatment is installed in the inlet and fan exhaust duct. The significant installed performance pretest predictions and characteristics are shown on the insert. A moderate engine bypass ratio and fan pressure ratio are typical designs for the high altitude and Mach number cruise capability of the selected aircraft configuration.

The cross section AVCO-Lycoming QCGAT engine (Fig. 5) is shown with the modified LTS 101 core. The LTS 101, which was certified in 1975, has flown in helicopters of two aircraft manufacturers. An uprated LTS 101 core is being used for the QCGAT program. This uprating includes the addition of a new supercharger stage on the core compressor and increased inlet temperature requiring cooled turbine blades. The new parts unique to QCGAT are a scaled ALF 502 fan, a reduction gear, a combustor and power turbine. These parts are shown as shaded areas on the figure.

Figure 6 shows a cutaway view of the AVCO-Lycoming engine in an installed configuration. The installation is similar to AiResearch, featuring acoustic treatment in the inlet and fan duct and a mixer nozzle designed (3) for both takeoff noise reduction and performance improvement. The significant engine characteristics and pretest performance predictions are shown in the insert in Fig. 6. Of note is the relatively high bypass ratio of 8.5. The fan pressure ratio and tip speed are relatively low, which is customary for high bypass engines. These selected design characteristics are a result of the low noise requirements imposed on the propulsion system. However, the selected engine characteristics are nearly optimum for the aircraft cruise speed selected for this engine-aircraft configuration combination.

PROGRAM SCHEDULE

An overall program schedule is shown in Fig. 7. The AVCO-Lycoming program runs about 6 months longer than the AiResearch program. As of this date, all work except data analysis and final reports have been completed at AiResearch. The engine was recently delivered to NASA Lewis Research Center for further testing. AVCO-Lycoming is in the final months of testing the QCGAT engine. The engine will then be refurbished and shipped to NASA in mid-1979.

TEST RESULTS

Reported herein are the overall test results of both of the QCGAT engines that have been completed to date by each of the contractors. This includes all the AiResearch tests but only part of the AVCO-Lycoming tests. Inasmuch as detailed analyses have not been completed, the results are considered to be preliminary in nature. However, the prospects for significant changes in the information presented are small.

Figure 8 shows the AiResearch and AVCO-Lycoming QCGAT engines installed in their respective company test facilities. To minimize program costs, testing is being accomplished with boiler plate nacelles. However, internal aerodynamic and acoustic characteristics are correctly simulated. The AiResearch engine is shown installed in the outdoor acoustic test facility with a simulated flight inlet while the bellmouth inlet is shown on the AVCO-Lycoming engine installed in an indoor test cell. The flight inlet is used for installed system performance measurements while a bellmouth type inlet is used for correct airflow measurements and basic performance calibration. An additional inlet is being tested in the program, a flight lip, and a simulated flight lip which has aerodynamic flow contours to simulate a particular flight condition. These inlet lips are used to verify for the contract installed engine performance goals and engine/aircraft simulated acoustic test goals.

NOISE - The QCGAT system noise levels in the fully suppressed configuration were predicted for the conditions for which the FAR

Part 36 noise requirements were established; namely takeoff, sideline, and approach. A comparison of predicted engine levels and the QCGAT noise goal levels from Table 1 are shown in Table 4.

For both contractors engines, the QCGAT sideline and approach noise levels are predicted to be quieter than the NASA goals. AiResearch predicts the NASA takeoff noise goal will be met. The AVCO QCGAT predicted takeoff noise is somewhat quieter than the NASA goal. A method of comparing the significance of the predicted noise levels for these engines can be illustrated using noise contours. A noise contour defines an area within which the noise level exceeds a given level. The noise contour is generated for a specific flight path which an aircraft is capable of flying with a particular engine. At each point in the vicinity beneath the flight path, the observer is exposed to a different noise level. The noise signal at each point is weighted based on the frequency content of the signal and integrated with respect to time. The contour is then generated by determining the locus of points where this particular level is heard. The area inside the noise contour can then be compared to other noise contours for similar type engine-aircraft combinations. The predicted AiResearch QCGAT-airframe noise contour area was compared to a TFE 731-3 powered Learjet 35 at an 80 EPNL level. The QCGAT powered aircraft has an 86 percent reduction in exposed area compared to the Learjet 35. The Learjet 35 is considered to be a quiet aircraft meeting the FAR Part 36 1977 guidelines.

A similar comparison was made between the AVCO-Lycoming-Beech engine airframe combination and a Cessna Citation powered by two JT15D engines. The Cessna Citation is considered to be a very quiet aircraft being considerably below the FAR Part 36 1977 noise guidelines (Fig. 2). However, with the AVCO-Lycoming-Beech engine-airplane combination, 92 percent reduction of an 80 EPNL exposure area resulted when compared to the Cessna Citation. Both QCGAT engines are predicted to be considerably quieter than present day quiet engines. Consequently, the QCGAT program should demonstrate that noise need not be a major constraint on the future growth of turbofan powered aircraft in general aviation.

EMISSIONS - The emission goals are shown in Table 5 with the current results for both engines. AVCO-Lycoming engine emission predictions are based on extensive QCGAT combustor hardware component testing which has been done throughout the design and fabrication phases of the QCGAT engine. AVCO combustor tests have shown that with the exception of NO_x, the 1979 EPA emission goals can be met by the reverse flow combustor with airblast fuel injectors. The AVCO engine emission tests are currently being run and the data is not yet available. AiResearch emissions are based on the test of the QCGAT engine with the Concept 1 combustor which was designed using the data from a NASA-sponsored T1 Pollution Reduction Technology Program. With the exception of NO_x and smoke, the AiResearch Concept 1 combustor meets the NASA contract emission goals.

PERFORMANCE - A comparison of the uninstalled and installed sea level thrust goals and the measured thrust performance for both engines is shown in Table 6.

As can be seen, the thrust goals for AiResearch were achieved while AVCO-Lycoming is predicted to be slightly below the goal. AiResearch specific fuel consumption was slightly higher than predicted. It is believed that most of the SFC degradation comes about because the AiResearch fan tip efficiency is not as high as predicted. The AVCO-Lycoming fan hub supercharger stators have a higher than design loss as do the high and low pres sure turbines. However, those discrepancies can be easily remedied by additional component development. These losses are also reflected in the installed performance values. It appears the AiResearch mixer nozzle is mixing and performing as well as predicted. However, analyses are still in progress to determine the possible areas of modification for performance improvement.

Important to the engine's thrust performance was the performance of the fans. These fans are relatively low-pressure ratio designs. The design pressure ratio for each fan was selected at a point between low-pressure ratio required for low noise at takeoff and the higher pressure ratio desired at cruise for improved engine performance. The airflow and bypass ratio were selected for noise and performance at takeoff and cruise, respectively. The AiResearch fan aerodesign point was selected for the Mach 0.8 at 12 192-m (40 000-

ft) cruise condition. The takeoff aerodynamic performance of the AiResearch fan was generally good as seen on Fig. 9. The takeoff airflow and mass averaged fan pressure ratio was generally as good as predicted. Fan efficiency is below predicted values at the tip portion of the fan rotor blades.

A photo and performance of the AVCO-Lycoming fan is shown on the Fig. 10. The fan is a scaled version of the fan in the AVCO-Lycoming ALF 502 engine which is currently flying on the Canadair Aircraft. The full size QCGAT version of the fan was tested at the AVCO facility. The tests included complete mapping and surge line definition. The tests showed that the actual data very closely followed predicted data. The QCGAT fan design point is for an engine operating during a second segment climb aircraft condition with one engine out. The performance data shows flow and pressure ratio were on design for the design fan speed. The 1 percent efficiency degradation is from a lower than expected hub section stator performance which is included in the efficiency rating. This root stator section has been redesigned for a greater recovery. The fan tip section exceeds the design efficiency.

CONCLUSIONS

The QCGAT program goal is to demonstrate experimentally that the design technology developed for a quiet, clean large commercial turbofan engine can be scaled down and used to design and develop a quiet, clean general aviation turbofan engine with at least equal to or improved engine performance. Initial engine test results indicate that the majority of the technical goals laid down for the engines will be met or exceeded. The engines are predicted to be quieter than the stringent noise goals established by NASA for the General Aviation aircraft demonstrator engines of the QCGAT program, which should show that noise need not be a major constraint on the future growth of general aviation aircraft using turbofan engines. The emission goals established for the program were only partially met. However, the demonstrated emissions for these engines are substantially lower than those of current engines. The AiResearch thrust goals of the program were met. However, the fuel consumption was slightly higher than desired because component efficiencies were slightly lower than expected. These loss mechanisms are understood and are correctable with design modifications and further component development which was beyond the scope of this program.

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1. D. L. Bresnahan and G. K. Sievers, "NASA Quiet, Clean General Aviation Turbofan (QCGAT) Program Status." ASME Paper 77-GT-77, Mar. 1977.
2. W. L. Blackmore and C. E. Thompson, "QCGAT Mixer Compound Exhaust System Design and Static Rig Model Test Report." AiResearch Manufacturing Co. of Arizona, AiResearch 21-2861, Proj. FEDD, NASA CR-135386, 1978.
3. J. F. Hurley, L. I'Anson, and C. Wilson, "Design of an Exhaust Mixer Nozzle for the AVCO-Lycoming Quiet, Clean General Aviation Turbofan (QCGAT)." AVCO-Lycoming Div., AVCO Corp., Proj. FEDD, NASA CR-159426, 1978.

Table 1 - QCGAT Noise Goals

Noise	AVCO	AiResearch
Takeoff: 6482 m (3.5 n. mi.) from runway threshold	69.4	73.3
Sideline: 463 m (0.25 n. mi.) sideline	78.4	82.3
Approach: 113 m (370 ft) altitude, 1852 m (1.0 n. mi.) from runway end	83.4	87.3

Table 2 - QCGAT Emission Goals

	EPA parameters			
	CO	UHC	NO_x	Smoke number*
	g/kNs (lb/1000 lb thrust hr-cycle)			
AVCO	0.266 (9.4)	0.045 (1.6)	0.105 (3.7)	45
AiResearch (Concept 1 combustor from NASA T1 Program)	0.266 (9.4)	0.045 (1.6)	0.105 (3.7)	38

*Dimensionless.

Table 3 - QCGAT Performance Goals

	Standard day			
	AVCO*		AiResearch**	
	Thrust, N (lb)	SFC, kg/hr/N (lb/hr/lb)	Thrust, N (lb)	SFC, kg/hr/N (lb/hr/lb)
Takeoff				
1. Uninstalled	7215 (1622)	0.0367 (0.360)	17 513 (3937)	0.0426 (0.418)
2. With ground test nacelle and acoustic treatment	7166 (1611)	0.370 (0.363)	17 31[illegible] (3892)	0.0431 (0.423)
Design Cruise				
1. Uninstalled	2171 (488)	0.0636 (0.624)	3 954 (889)	0.0775 (0.760)
2. With ground test nacelle and acoustic treatment	2157 (485)	0.0640 (0.628)	4 017 (903)	0.0758 (0.744)

*AVCO-Lycoming Cruise is at Mach 0.6, 7620 m (25 000 ft).
**AiResearch Cruise is at Mach 0.8, 12 192 m (40 000 ft).

Table 4

	AiResearch		AVCO-Lycoming	
	Goal	Pre-dicted	Goal	Pre-dicted
Takeoff, EPNdB	73.3	73.3	69.4	65.0
Sideline, EPNdB	82.3	79.0	78.4	71.8
Approach, EPNdB	87.3	83.5	83.4	73.7

Table 5

EPA parameters

	CO	UHC	NO_x	Smoke number
	g/kNs (lb/1000 lb thrust hr-cycle)			
Contract goal	0.266 (9.4)	0.045 (1.6)	0.105 (3.7)	< 45* ≤ 38**
AVCO	0.103 (3.6)	0.011 (0.4)	0.127 (4.5)	18 00
AiResearch	0.289 (8.0)	0.045 (1.6)	0.130 (4.6)	00 42

*Goal for AVCO engine.
**Goal for AiResearch engine.

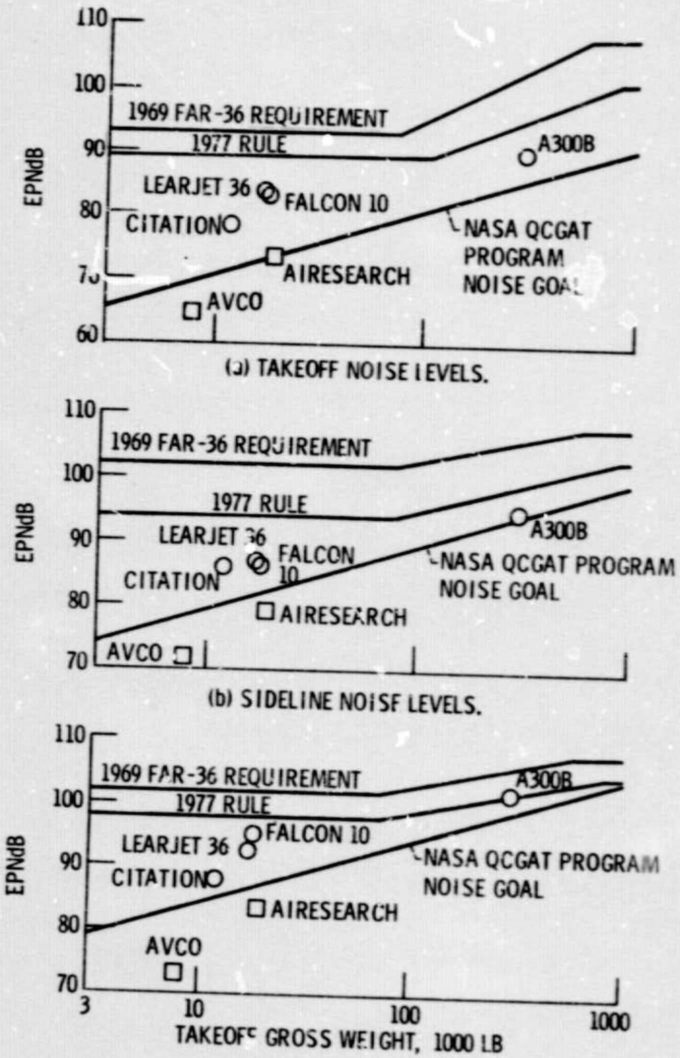
Table 6

	AiResearch		AVCO	
	Goal	Measured	Goal	Predicted
Uninstalled thrust, N (lb)	17 513 (3937)	17.513 (3937)	7215 (1622)	7063 (1588)
Uninstalled SFC, kg/hr/N (lb/hr/lb)	0.0426 (0.418)	0.0456 (0.448)	0.0367 (0.360)	0.0370 (0.363)
Installed thrust, N (lb)	17 312 (3892)	17.312 (3892)	7166 (1611)	6868 (1544)
Installed SFC, kg/hr/N (lb/hr/lb)	0.0431 (0.423)	0.0438 (0.430)	0.0370 (0.363)	0.0371 (0.364)

(a) GATES LEARJET 35 AIRCRAFT, WHICH UTILIZES THE GARRETT AIRESEARCH TFE 731 ENGINE.

(b) AVCO-LYCOMING-BEECH AIRCRAFT.

Figure 1. - QCGAT twin-engine Executive aircraft.



(a) TAKEOFF NOISE LEVELS.

(b) SIDELINE NOISE LEVELS.

(c) APPROACH NOISE LEVELS.

Figure 2. - Estimated noise levels and goals.

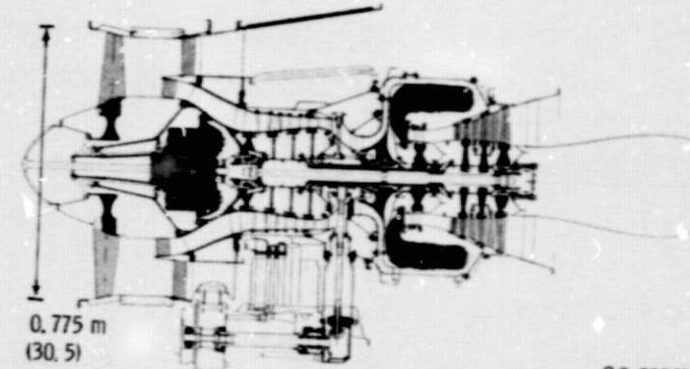


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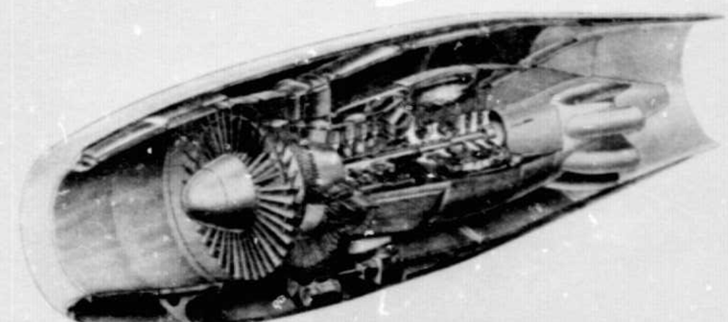
Figure 3. - AiResearch QCGAT engine cross section.



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Takeoff Characteristics	
Airflow, kg/sec (lb/sec)	64 (141)
Bypass ratio	4.2
Fan P/P average	1.45
Fan tip speed, m/sec (ft/sec)	358 (1174)
Thrust, N (lb)	17 370 (3905)
Cruise, M = 0.8 at altitude, m (ft)	12 192 (40 000)
Thrust, N (lb)	4017 (903)

Figure 4. - Installed Garrett AiResearch QCGAT engine.

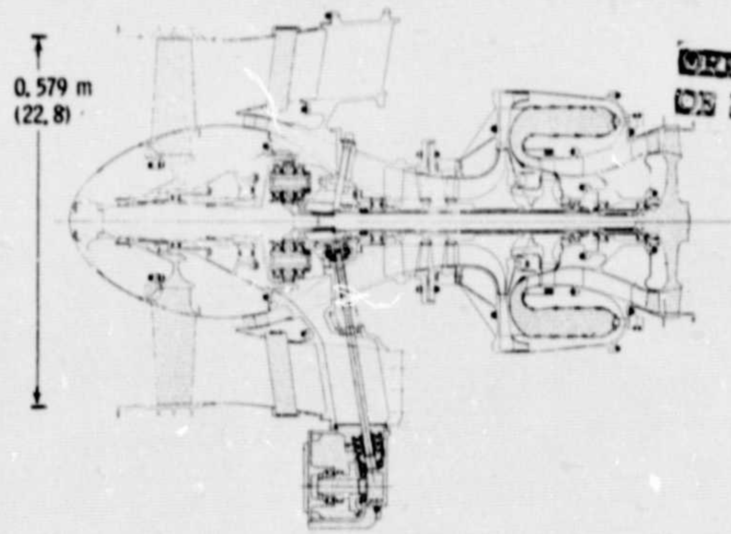
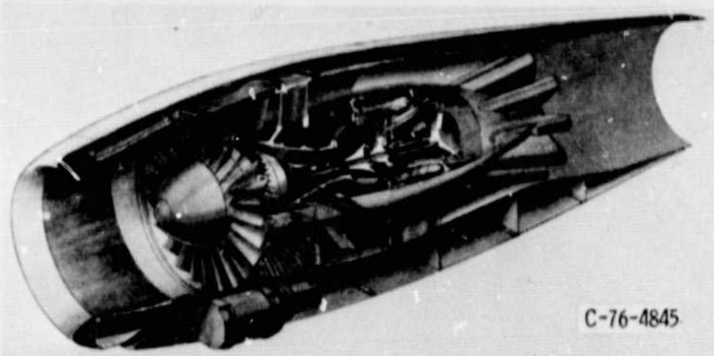


Figure 5. - AVCO-Lycoming QCGAT engine cross section.



Takeoff Characteristics	
Airflow, kg/sec (lb/sec)	32 (70)
Bypass ratio	8.5
Fan P/P average	1.31
Fan tip speed, m/sec (ft/sec)	306 (1005)
Thrust, N (lb)	7068 (1589)
Cruise, M = 0.6 at altitude, m (ft)	7620 (25 000)
Thrust, N (lb)	2077 (467)

Figure 6. - Installed AVCO-Lycoming QCGAT engine.

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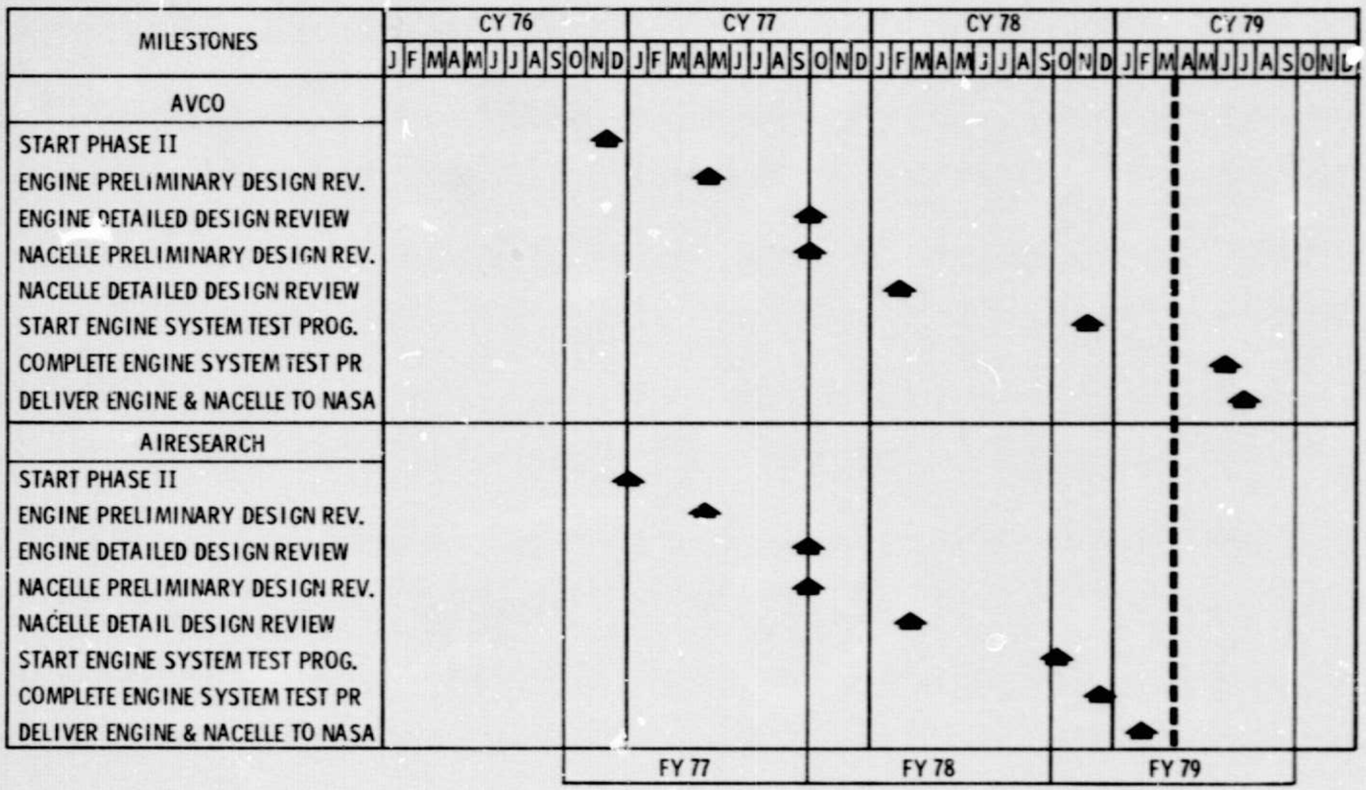
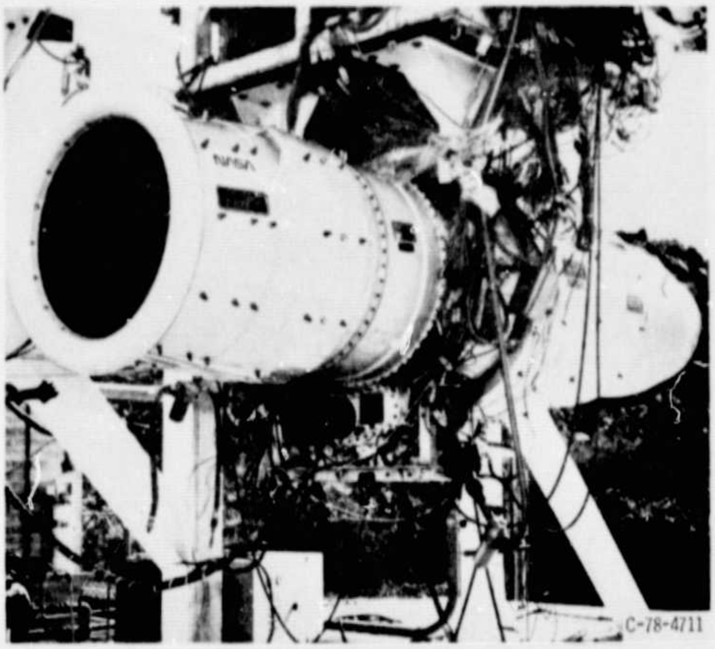
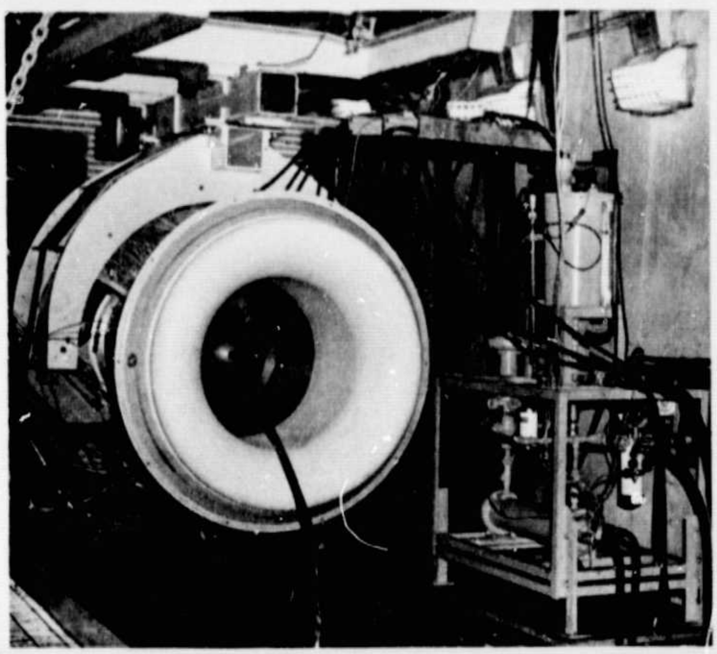


Figure 7. - Overall QCGAT program schedule.

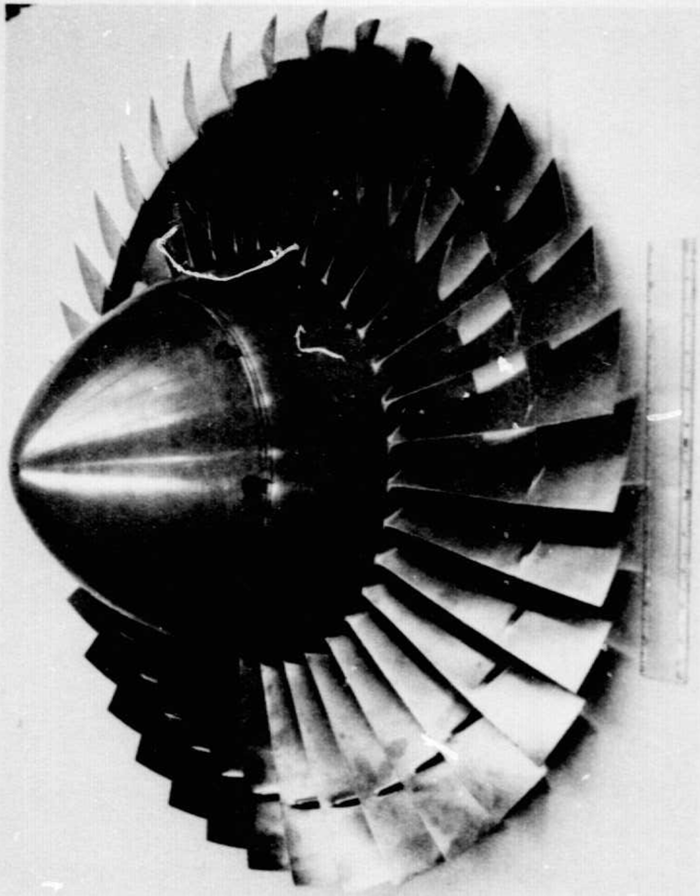


(a) AiRESEARCH ENGINE.



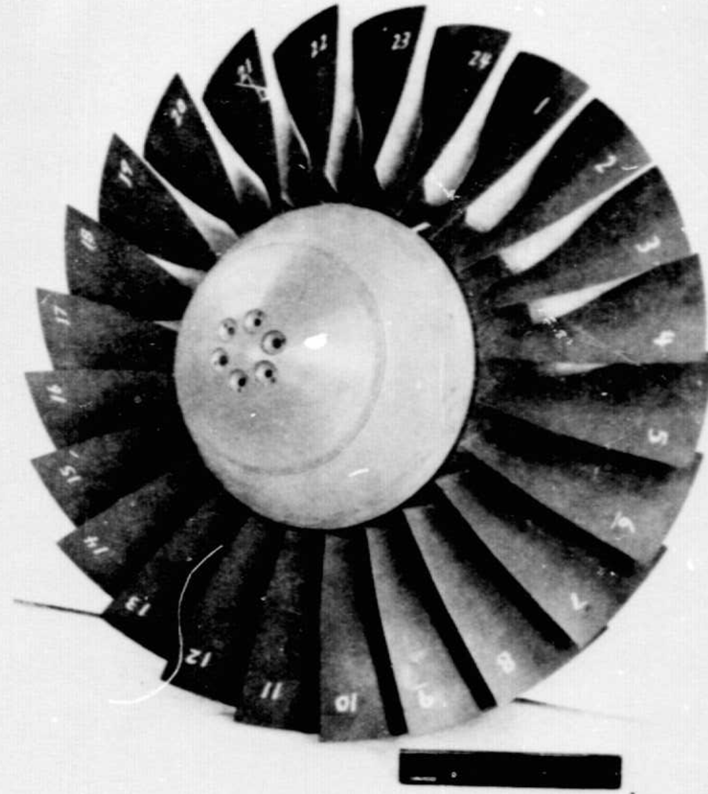
(b) AVCO-LYCOMING ENGINE.

Figure 8. - QCGAT engines installed in test cells.



	Aerodesign (cruise)	Takeoff	
		Predicted	Measured
Corrected flow, kg/sec (lb/sec)	76.9 (169.5)	64.0 (141.0)	64.4 (141.8)
Ave P/P	1.64	1.45	1.45
η average	0.84	0.87	0.78
Tip speed, m/sec (ft/sec)	421 (1381)	358 (1174)	370 (1213)

Figure 9. - AiResearch fan performance.



	Aerodesign		Takeoff	
	Predicted	Measured	Predicted	Measured
Corrected flow, kg/sec (lb/sec)	37.0 (82)	37.0 (82)	32.0 (70)	32.0 (70)
Ave P/P	1.37	1.37	1.31	1.31
η average	0.87	0.86	0.85	0.85
Tip speed, m/sec (ft/sec)	334 (1095)	334 (1095)	306 (1005)	306 (1005)

Figure 10. - AVCO-Lycoming fan performance.