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NASA QUIET CLEAN GENERAL AVIATION TURBOFAN (QCGAT) PROGRAM STATUS

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ABSTRACT

A two phase program is being conducted by NASA's Lewis Research Center to determine the suitability of large engine technology to reduce noise, emissions and fuel consumption of small turbine engines and develop new technology where required.

In Phase I, six-month study contracts were awarded to three manufacturers of small turbine engines to provide NASA with information required to prescribe the most effective experimental engine program (QCGAT). The results of this study phase showed reduced noise levels for the three engines at takeoff, sideline and approach and emissions predictions that met the 1979 EPA standards for Class T1 engines.

For the second phase, two contractors bid and both were selected to design, fabricate, assemble, test and deliver experimental engines to NASA. The current status of this phase is discussed.

NASA QUIET, CLEAN, GENERAL AVIATION TURBOFAN (QCGAT) PROGRAM STATUS

Introduction

The turbine powered general aviation aircraft fleet size is increasing at a greater rate than the rest of general aviation aircraft. Jet powered general aviation aircraft numbered approximately 1400 in 1974. Annual sales are expected to grow from a current figure of around 200 in 1975 to over 400 within the next ten years.

The airlines serve approximately 500 airports across the nation. General aviation serves these 500 airports plus over 12,000 additional airports that are served exclusively by general aviation. These airports are more apt to be located in relatively small communities where background noise and pollution are low. Therefore, the use of small aircraft has the potential to create a more widespread adverse community reaction to the jet noise and pollution than do transport aircraft.

The small turbine engines used in general aviation and business aircraft generally produce the same type of noise that is produced by the larger commercial and military aircraft engines. However, engine quieting and emission reduction technology and more recently means for improving fuel economy have been directed primarily at the larger engines used in the commercial carriers. It is, therefore, important to determine the suitability of the large engine technology to small turbine engines and develop new technology where required.

Although existing FAR 36 noise restrictions probably can be met by new production aircraft, it is probable that this regulation will be modified to require reduced noise levels for the next generation of aircraft, possibly by as much as 10 PNdB at each of the measuring stations. Also, EPA emissions standards for gas turbine engines of less than 8000 # thrust establish a more stringent set of criteria for all engines manufactured after January 1, 1979 than can be currently met.

A significant portion of the NASA engine noise research program has been conducted with 20" diameter fans which is representative of the size used in general aviation turbofan engines. There are still some uncertainties regarding the applicability and effectiveness of various acoustic suppressor concepts developed for large fan inlet and exit ducts when applied to small engines. It now appears appropriate and timely to resolve some of the uncertainties resulting from large scale component research through the Quiet, Clean General Aviation Turbofan Program.

This systems technology program will provide reference data necessary for establishing feasible approaches and probable limits to emissions and noise reduction of general aviation turbofan engines in time to relieve the effects of the predicted increase in aircraft using this type of engine.

This program seeks to provide the technology for quiet, clean, general aviation turbofan engines. The program goals are to reduce the noise below the present FAR 36 restrictions, reduce the emissions to meet the 1979 EPA standards for the T1 class engines (<36000 N (8000#) thrust) and to improve the fuel consumption.

The program is being conducted in two phases. In the first phase, which was completed in October 1975, six-month study contracts were awarded to three manufacturers of small turbine engines, AiResearch, AVCO-Lycoming and General Electric, to provide NASA with information required to prescribe the most effective experimental engine program. These studies included an assessment of the applicability of existing large turbofan quieting and emission control techniques and how this technology can be scaled and also its applicability to small general aviation turbofan engines.

The second phase is an experimental program that consists of design, fabrication, assembly, ground tests and delivery of experimental turbofan engines to NASA/Lewis. Ground testing to be performed by both contractors and NASA will determine engine performance and effectiveness of the application of noise and pollution technology to general aviation turbofan engines.

Phase I Study Engines

One of the ground rules for the study phase was that each contractor should use an existing well-developed core for the QCGAT engine. Following is a description of each contractor's core engine and the modifications required to develop the QCGAT engine.

AiResearch

The AiResearch Company chose their Model TFE 731 Turbofan Engine (Figure 1) as the basis for the QCGAT studies. This engine, in the 16,500 N (3700#) thrust class, is a two spool geared front fan engine with a medium bypass ratio. The fan is coupled through a planetary gearbox to the low pressure spool which consists of a four stage axial compressor and a three stage axial turbine. The high pressure spool consists of a single stage radial compressor and a single stage axial turbine.

The TFE 731 Turbofan Engine is presently in production in two configurations. The TFE 731-2 (16000 N (3500#) thrust) powers the Dassault Falcon 10 and Learjet 35/36 and the TFE 731-3 (16500 N (3700#) thrust) powers the Lockheed Jetstar and the IAI Westwind 1124.

AiResearch's study was initiated with an assessment of the general aviation aircraft that they felt would realize immediate benefits from the QCGAT Program. Concurrent with the aircraft evaluation, a performance analysis was conducted for a variety of turbofan cycles considered appropriate for those aircraft. Based on the TFE 731 engine core, twelve combinations of fan pressure ratios and cruise bypass ratios were examined. In addition to the performance study, a number of component improvements were examined in an effort to improve the overall engine cycle efficiency and offset any performance loss that might occur due to acoustical treatment.

The components added to the core of this engine for the QCGAT study were new fans designed for lower pressure ratios and low tip speeds, and the combustor from the NASA T1 Pollution Reduction Technology Program. A new low-pressure turbine was designed to extract extra work from the core gas stream and thus obtain a lower jet velocity than with the TFE 731. The extra work obtained was used to drive the larger fans and thus obtain a higher bypass ratio than with the TFE 731. An analysis was made of the exhaust system in an effort to further reduce jet noise. A mixer-compound nozzle was selected for its performance and noise characteristics.

The combustor selected from the NASA T1 Pollution Reduction Technology Program was the airblast combustor which incorporates airblast nozzles through the dome that atomize the fuel into very small droplets promoting complete burning and low levels of HC and CO. It is intended that the nozzle will produce very rapid fuel/air mixing, which would allow off-stoichiometric burning to reduce the rate of NO_x formation.

The thrust of the resulting QCGAT engine is 17490 N (3932#), the fan pressure ratio is 1.492 and the bypass ratio is 4.18. A cross section of the engine is shown in Figure 2.

AVCO-Lycoming

AVCO-Lycoming selected the core of the LTS 101 free-power turbine engine (Figure 3) for the QCGAT studies. Depending on the various design options, the LTS 101 core can provide fan engines having thrust levels in the order to 4500 to 6000N (1000 to 1300#) with growth potential to 9000 N (2000#). The core compressor has a single axial-compressor stage and a single centrifugal stage. The compressor is driven by an uncooled single-stage turbine. A reverse flow annular combustor is wrapped around the turbine section resulting in a short, lightweight engine without compromising frontal area.

The LTS 101 has been flown in helicopters of two aircraft manufacturers and was FAA certificated in 1975.

After reviewing the various possible fan engine configurations, two were selected for further evaluation in this study, one supercharged and one non-supercharged with geared and non-geared versions of each. On the basis of this, a configuration was then selected for the QCGAT Study Phase.

The selected configuration (Figure 4) had a thrust of 5700 N (1289#), fan pressure ratio of 1.35 and a bypass ratio of 6.2. It has a single stage fan with a supercharger that is directly driven by a two-stage turbine. The standard LTS 101 combustor was modified to incorporate emission reduction features resulting from combustor model testing as part of the preliminary design effort. The new combustor configuration has airblast fuel injectors and provision for overboard bleed. In addition, an air partitioning adjustment is included to provide for a leaner primary zone that will reduce the primary zone bulk temperature and NO_x formation rate.

General Electric

To satisfy the requirements of representative turbine-powered general aviation aircraft, General Electric selected a high by-pass ratio (10 to 1) turbofan engine using the T700-GE-700 turboshaft engine as a core. The T 700-GE-700 engine is an advanced technology turboshaft engine designed for advanced helicopter applications. It is rated at 1145 KW (1536 shp). A cross section drawing of the T700 engine is shown in Figure 5. The gas generator is composed of an advanced high pressure ratio axial/centrifugal compressor (5 axial/1 centrifugal stage), a modern straight-through annular combustor with central fuel injection, and a two stage, air-cooled turbine. Power is extracted from the core stream by a two stage free turbine driving a power shaft to the front of the engine.

The T700-GE-700 engine employs turbine temperatures and other technology comparable to that of current large high by-pass engines. It has other characteristics such as relatively high by-pass ratio, simplicity, compactness, and maintainability which make it attractive for use in a small turbofan engine. In addition the T700-GE-700 engine cycle and combustor are compatible with low emissions. The thrust of the fan engine that results from this selection is 9890 N (2224#), which is in the lower portion of the thrust range of current business jet engines.

The fan studied is a scaled version of the QCSEE fixed pitch design. The fan pressure ratio is 1.26 and the bypass ratio is 9.8. The T-700-GE-700 engine low-pressure turbine was used with only minor modifications to the airfoils. The QCGAT combustion system was identical to the T700-GE-700 combustion system, however, sector burning techniques were applied to reduce HC and CO emissions and bring the QCGAT emissions within the EPA standards. The T700 QCGAT engine is shown in Figure 6.

Study Aircraft

Reference aircraft characteristics were used by the three contractors for their noise predictions with the QCGAT engines and for mission evaluation.

AiResearch used a Learjet 35 type aircraft (17,000#TOGW) for the purpose of estimating noise characteristics at the FAR 36 measuring points and determining if the engine cycle was appropriate for a 12,020m (40,000 ft.), M .8 design point.

AVCO-Lycoming used the airplane characteristics of a twin-engine executive aircraft with a TOGW of 6000#. This aircraft had the range, flight speed and altitude capability that is competitive with that of larger fan engine aircraft such as the Cessna Citation and the Falcon 10.

General Electric simulated an aircraft designed to carry the same payload the same distance as an existing turbofan airplane. Because of the improved fuel consumption this resulted in an aircraft 1700# lighter (9800# TOGW) with a 55% increase in passenger miles per pound of fuel.

Conclusions of Study

Comparisons of the characteristics of the QCGAT engines resulting from the Phase I studies are shown in Table I.

The emissions predictions for each of the study engines is shown in Table II. The thrust and time spent at idle, approach, climb and takeoff are the EPA, Class T1 Standard landing and takeoff cycle. All three contractors predicted meeting the 1979 EPA standards with their study engines.

In general, similar methods of engine noise source reduction along with nacelle acoustic treatment were proposed by the three engine contractors. These included by-pass ratios higher than are presently found on the small turbofan engines of general aviation to reduce the core jet velocity and accompanying jet noise; low fan pressure ratio with vane to blade ratios greater than two, low to moderate tip speeds to minimize the propagation of modes out of the inlet, and a large rotor blade to vane spacing to allow blade wake dissipation before impinging on the vanes. Comparisons of these acoustic parameters are given in Table III. Acoustic treatment was also added to the inlet and fan duct walls.

The resulting estimated noise levels for the three engines are shown in Figure 7 compared to existing two-engine business jets for takeoff, sideline and approach.

As a result of this Phase I study, emissions and noise goals were set for the QCGAT engine of Phase II.

The emissions goals for this program are the 1979 EPA Standard for the T1 Class engines ($<$ 36000 N (8000#) thrust) as shown in Table II. The allowable SAE Smoke Number values are determined by the procedures set forth by the United States Environmental Protection Agency in the Federal Register Volume 38, No. 136, July 17, 1973.

The program noise goals for FAR Part 36 takeoff, sideline, and approach locations for QCGAT-powered twin-engine aircraft are shown in Figure 8.

Phase II Experimental Engines

Following the Phase I study, two contractors, AiResearch and AVCO-Lycoming proposed and were selected for Phase II to design, fabricate, assemble, test and deliver experimental engines to NASA.

The AiResearch QCGAT Engine for Phase II is essentially the same as the engine proposed in the Phase I study (Figure 2), differing only in minor component matching changes. These improvements increased the thrust to 17,500 N (3937#).

The AVCO-Lycoming QCGAT Engine (ALF 101) for Phase II is a further modification of the LTS 101 core than the study engine of Phase I and results in an increase of thrust to 7200 N (1622#). The supercharger stage shown on the fan shaft in earlier studies has now been incorporated into the core compressor with the single axial stage as two new axial stages, the bypass ratio has been increased to 8:1 and the turbine inlet temperature has been increased. A cross section of the AVCO QCGAT Engine is shown in Figure 9.

Because of the increased thrust of the proposed engines over the Phase I study engines, each contractor selected a new reference aircraft for his noise predictions and mission evaluation.

AiResearch synthesized a business aircraft, similar to a stretch version of the Learjet Model 35/36 aircraft. The airplane has the capacity for a crew of two and fourteen passengers with a take-off gross weight of 20,170 pounds. The airplane has a supercritical wing and an improved flap configuration that permits a higher wing loading.

AVCO-Lycoming, after consultation with several general aviation aircraft manufacturers, has concentrated its efforts toward a six to eight place general aviation aircraft of 7800 lb DGW powered by two ALF 101 engines of 7200 N (1622 lb) thrust. Such an aircraft will have cruise speed and field operation capability similar to an existing larger fan driven aircraft used in general aviation but the predicted cost of ownership will be lower and its fuel economy will be appreciably better.

Both contractors predict meeting the overall program goals. Each predict meeting the emissions goals. The AiResearch engine is expected to meet the noise goals and the AVCO-Lycoming engine is expected to be several EPNdB below the noise goals.

The relationship of the reference aircraft for the Phase I and Phase II QCGAT engines to the existing general aviation fleet is shown in Figure 10.

This program, to demonstrate the suitability of large engine technology to reduce noise, emissions and fuel consumption of small turbine engines, is now entering its second phase, which is expected to be of two years duration.

TABLE I

QCGAT PHASE I STUDY ENGINES - CHARACTERISTIC

	AIRESEARCH	AVCO	GE
CORE ENGINE	TFE 731-3	LTS-101	T-700
QCGAT ENGINE WEIGHT, Kg (LBS)	384 (855)	120 (265)	225 (500)
THRUST, SLSTO, N (LBS)	17490 (3932)	5700 (1289)	9890 (2224)
THRUST/WEIGHT	5.3	4.9	4.5
TSFC, SLSTO, Kg/HR/N (LB/HR/LB)	.046 (.4498)	.038 (.377)	.034 (.333)
CRUISE CHARACTERISTICS			
THRUST, Kg (LBS)	3950 (888)	1770 (401)	2260 (508)
TSFC, Kg/HR/N (LB/HR/LB)	.078 (.770)	.064 (.631)	.063 (.617)
ALTITUDE, M (ft)	12200 (40K)	7600 (25K)	10700 (35K)
MACH No.	.8	.5	.6
BYPASS RATIO	4.18	6.2	9.8
OVERALL PRESSURE RATIO	15.0	12.5	16.8

ALL PERFORMANCE UNINSTALLED, STD. DAY

TABLE II
ESTIMATED EMISSIONS

	EPA PARAMETERS g/KNs (LB/1,000 LB THRUST HR CYCLE)					
	CO		CxHy		NOx	
1979 EPA STANDARD	.266	(9.4)	.045	(1.6)	.105	(3.7)
AIRESEARCH	.196	(6.9)	.025	(0.9)	.094	(3.3)
AVCO-LYCOMING	.204	(7.2)	.034	(1.2)	.097	(3.4)
GENERAL ELECTRIC (50% SECTOR BURNING @IDLE)	.187	(6.6)	.001	(.1)	.098	(3.5)

TABLE III

ENGINE RELATED ACOUSTIC PARAMETERS

	AIRESEARCH	AVCO	GENERAL ELECTRIC
BYPASS RATIO	4.18	6.2	9.8
FAN PRESSURE RATIO	1.49	1.35	1.26
CORE JET VELOCITY M/SEC (FT/SEC)	323 (1059)	260 (850)	308 (101
FAN STAGE VANE-BLADE RATIO	2.67	2.45	2.0
FAN STAGE ROTOR BLADE-VANE SPACING	2.0	2.3	2.0
FAN TIP SPEED M/SEC (FT/SEC)	352 (1155)	387 (1270)	291 (954

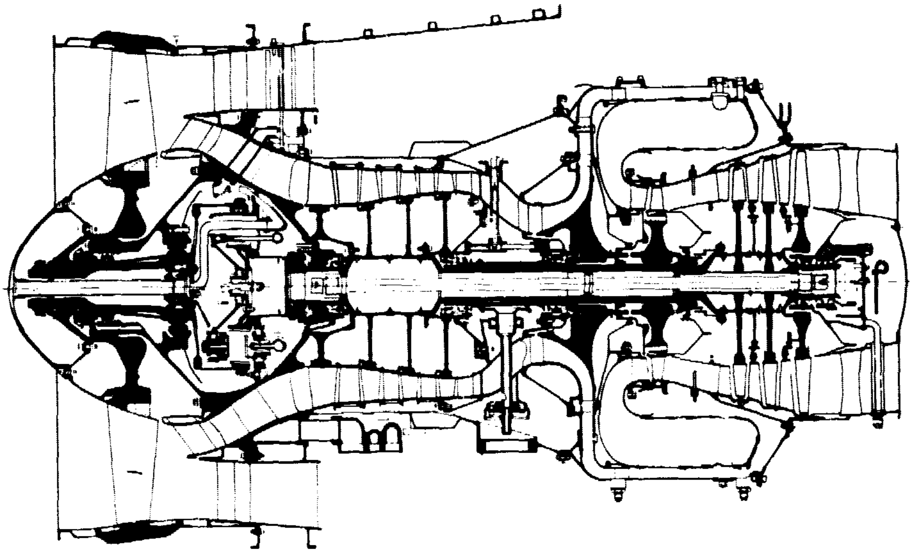


Figure 1. - TFE 731-3 Turbofan engine.

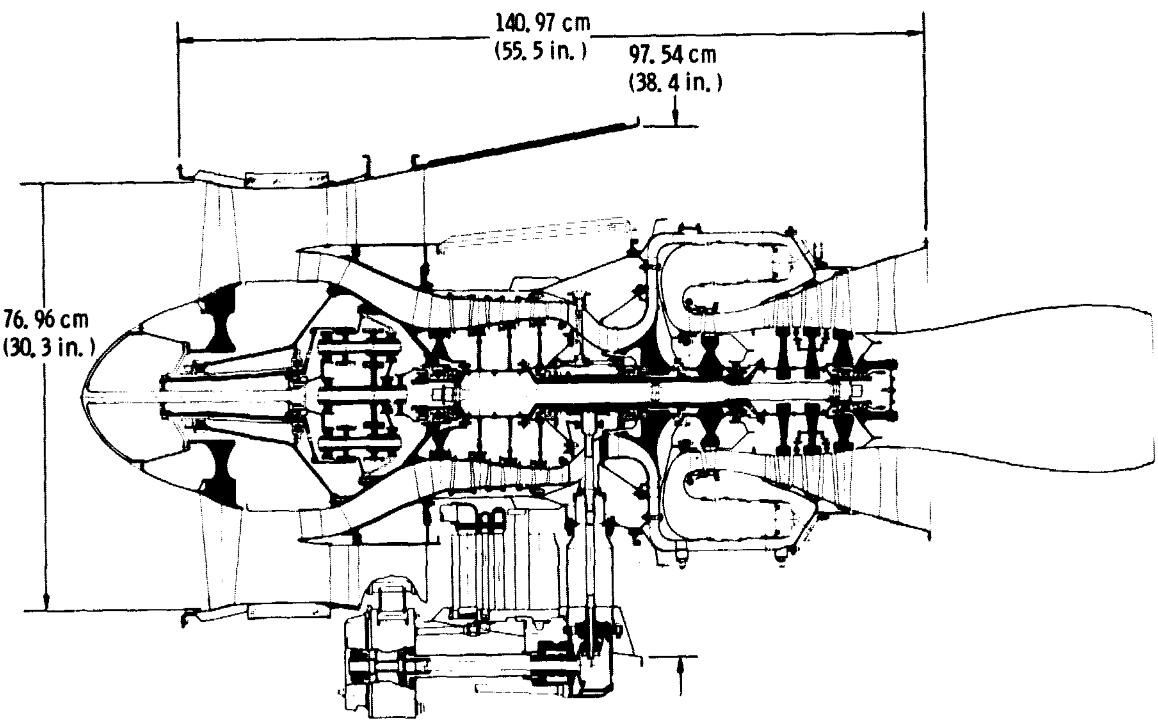


Figure 2. - AiResearch QCGAT engine.

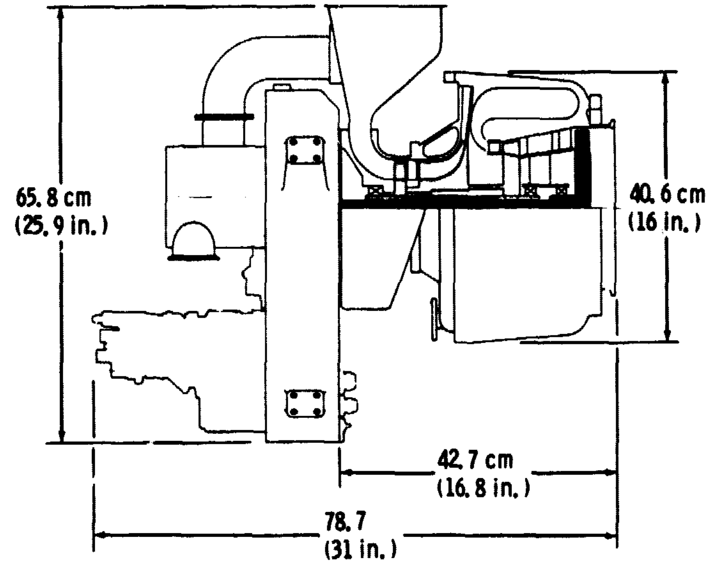


Figure 3. - LTS 101 Turboshaft engine.

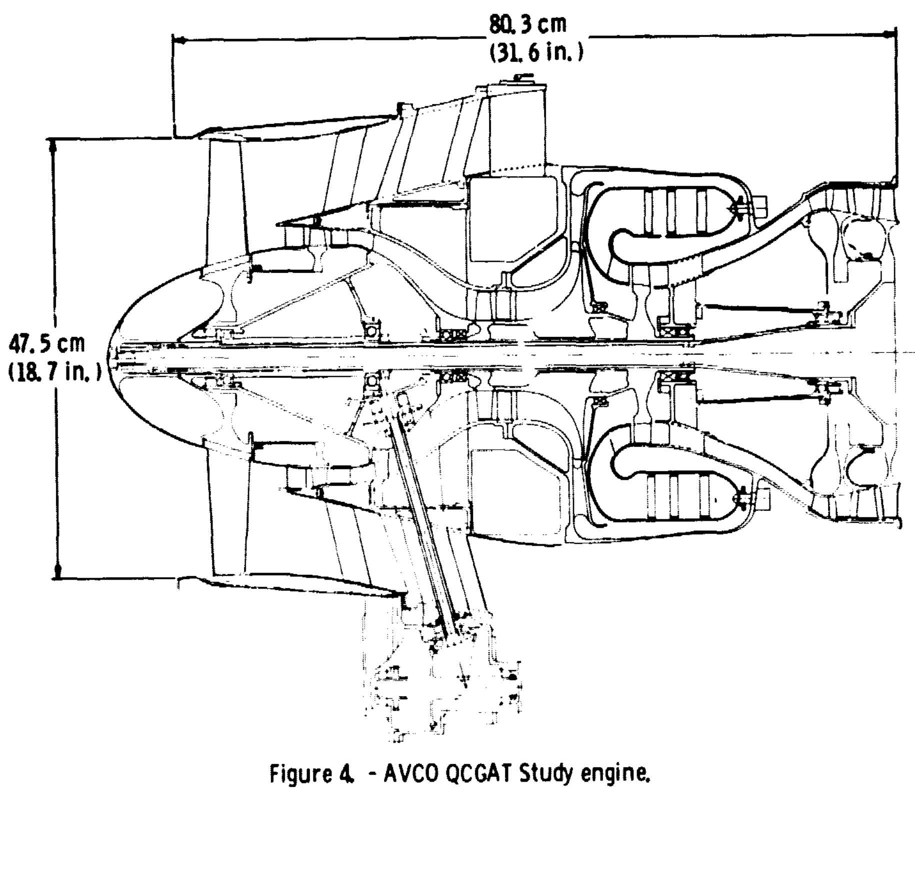


Figure 4. - AVCO QCGAT Study engine.

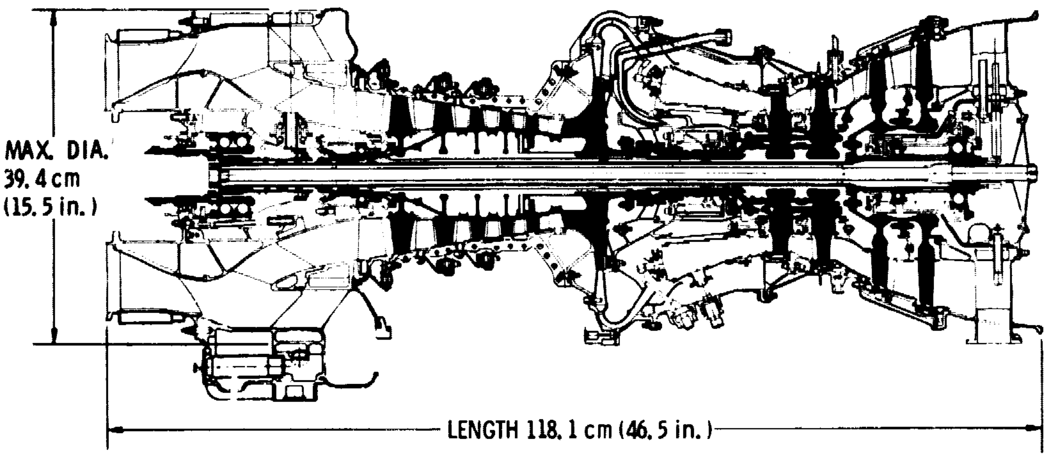


Figure 5. - General Electric T700 engine.

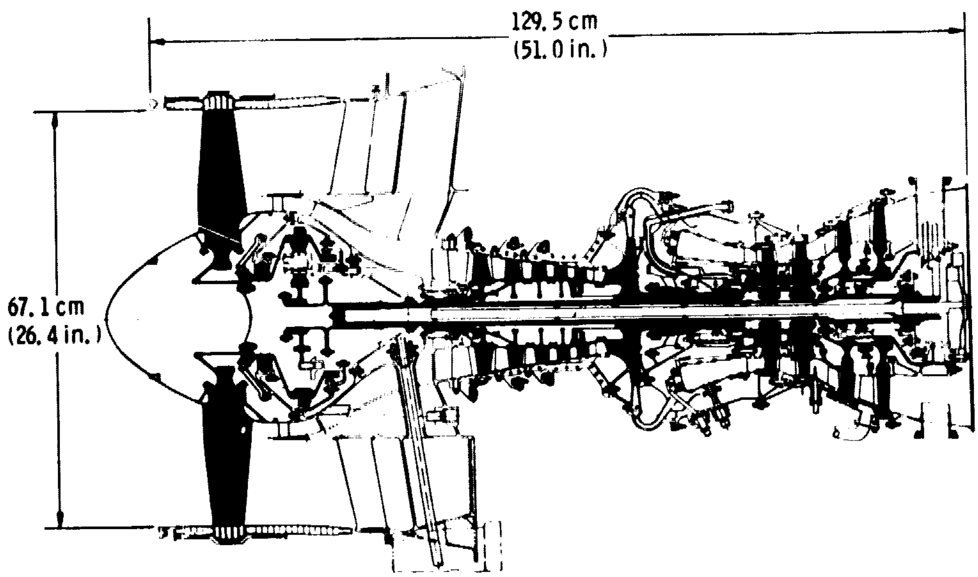


Figure 6. - T700 Quiet clean general aviation turbofan engine.

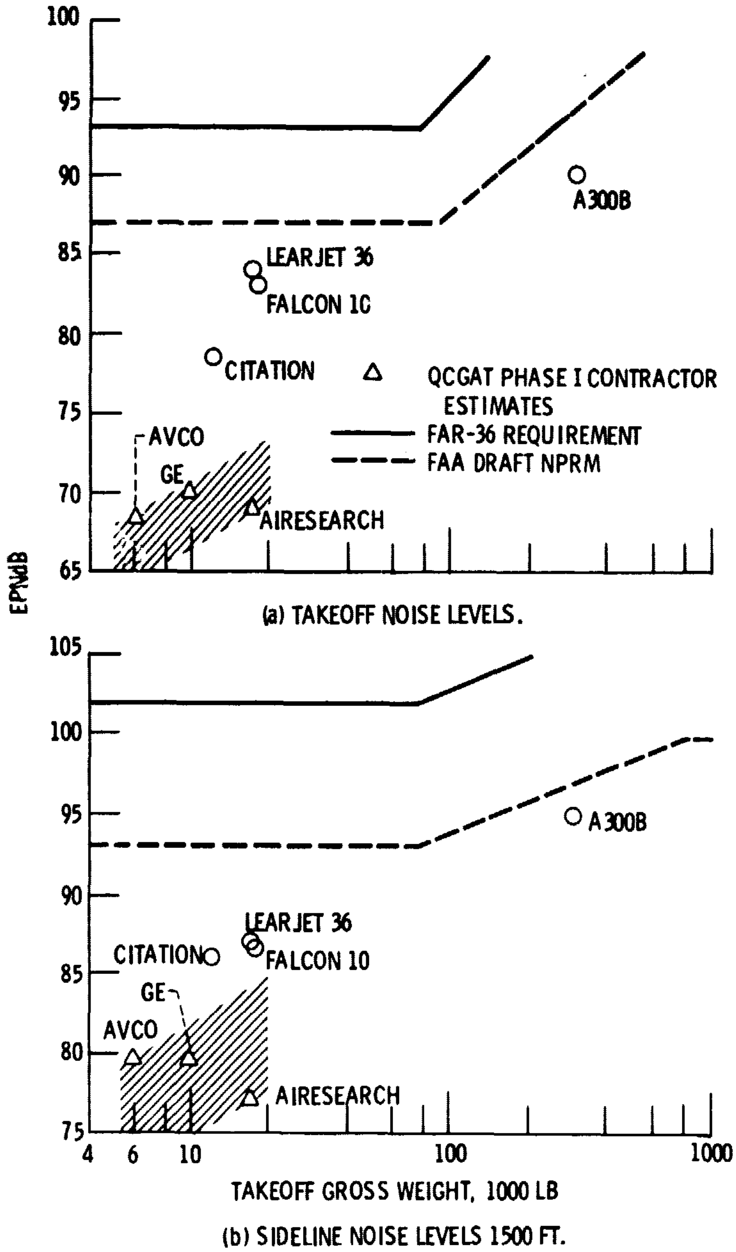
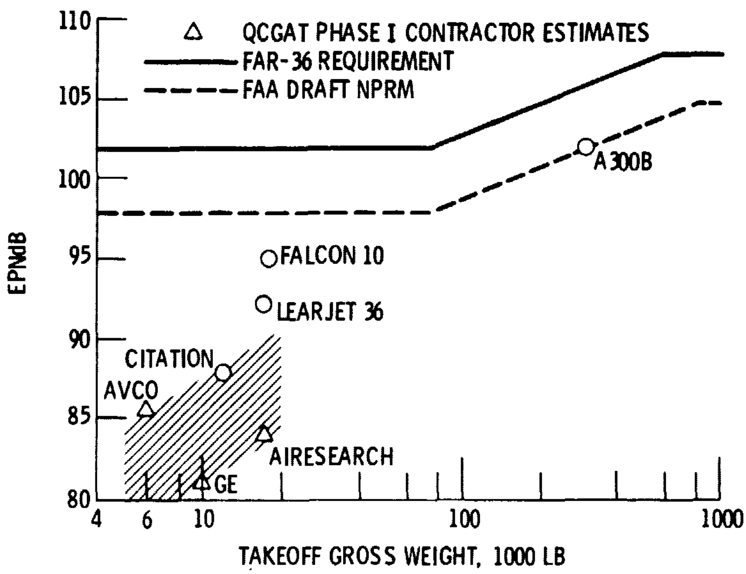


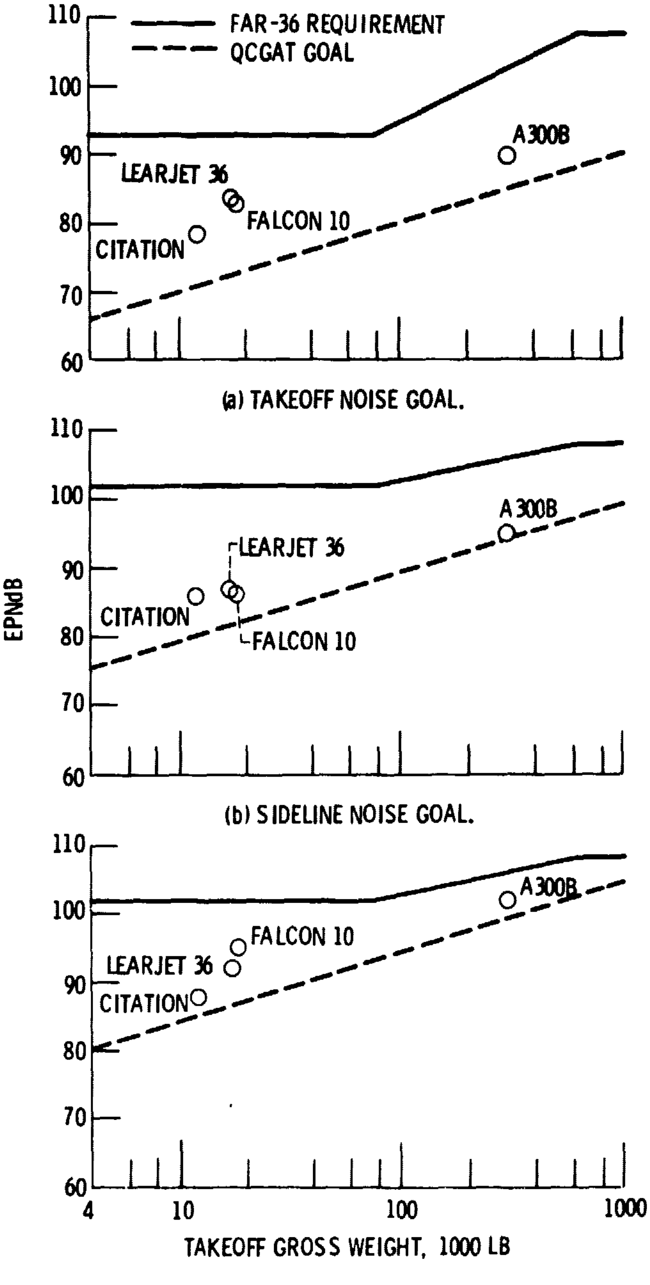
Figure 7. - Estimated noise levels.



(c) APPROACH NOISE LEVELS.

Figure 7. - Concluded.

E-9008



(c) APPROACH NOISE GOAL.

Figure 8. - Program noise goals.

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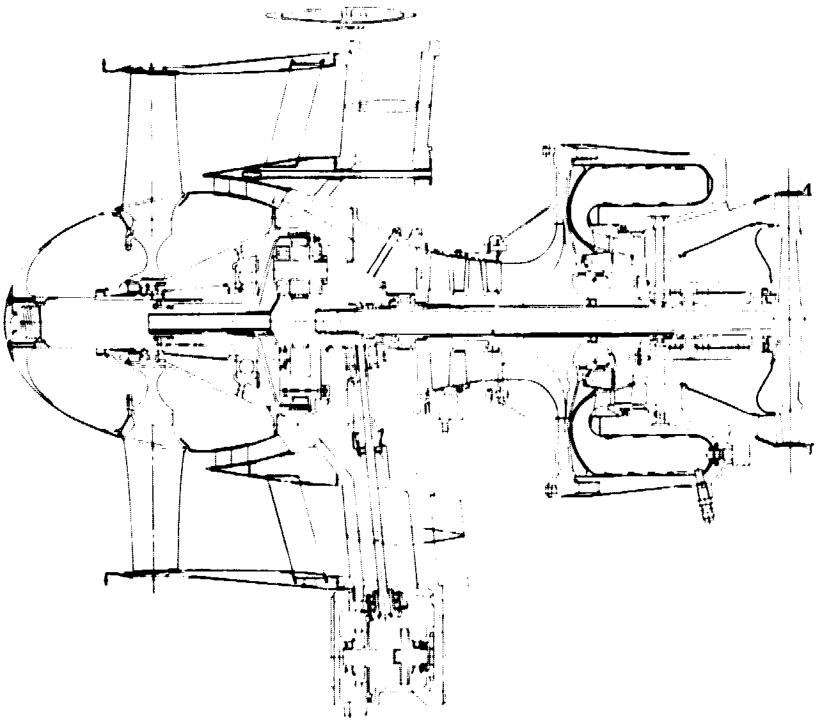

Figure 9. - Lycoming QCGAT engine cross section.

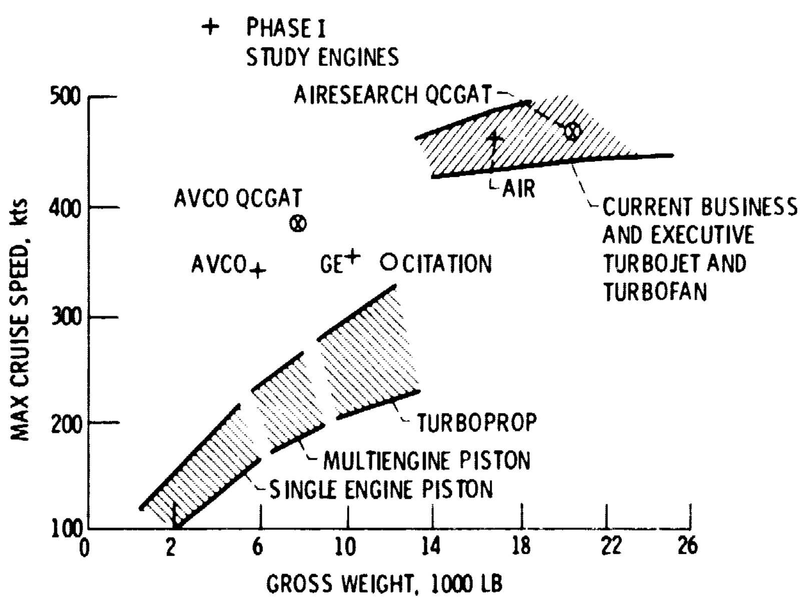

Figure 10. - General aviation aircraft.