Western Museum of Flight
Garrett Propulsion Engine & Auxiliary Power – Historical Overview
March 16, 2013

From Turbochargers to Afterburners

Cliff Garrett – Creating A Major Company – “Out of Thin Air”
About Me!

Background........

✓ Native New Yorker
  Graduate of NYU College of Engineering with BAE in 1957

✓ Joined {
  \textit{Douglas El Segundo} Division – Aero Thermo Group
  Specialized in Engine/ Airframe Integration and Air Induction Systems
  M.S. Aerospace Engineering from USC in 1963

✓ Joined \textit{Ryan Aeronautical} in 1965
  Integration of GE1 (GE J97) and Compass Arrow High Altitude RPV
  Director of Advanced Design – YQM98A “Compass Cope” High Altitude Long Endurance (HALE) RPV

✓ Joined \textit{Garrett AiResearch} Government Relations Office in Dayton Ohio in 1976
  Head Military Propulsion Sales, Garrett Engines in Phoenix in 1980
  VP-Sales, Garrett Engines in Phoenix
  VP-North American Sales, Garrett Corp. Los Angeles
  VP-New Business Development, AlliedSignal

✓ Retired 1998
Under Cliff Garrett’s leadership, the company and its divisions were responsible for many "firsts" in the aviation/space industry, including:

- the first all-aluminum aircraft inter-cooler on the B-17,
- the first volume production of cabin pressure regulators in 1941,
- the first light aircraft turboprop engine and,
- the first gas turbine APU on passenger jets.

John Clifford Garrett created the "Aircraft Tool & Supply Company" in Southern California during the mid-1930s. He was a pioneer in turbo-supercharging technology and envisioned his company as a major contender in turbine propulsion engines.
Garrett Business Principles

• Invest to become the market leader - #1 in selected businesses

• Create businesses with high “cost of entry” – fewer competitors

• Technology driven – “Maybe not the cheapest – but definitely the best”

• Systems Oriented – build what we “bolt on to”

• Powerful Sales & Service Organizations – the “Customer’s voice”
  ✓ Government Relations – Prime Contracts
  ✓ Field Sales – Check on Competitiveness

• Hire and retain the best people – salaries, benefits, working conditions
The heritage of the turbo business began in 1936 when young Cliff Garrett formed his company in a tiny, one-room office in Los Angeles. Over time, the turbocharging business spun off to establish itself as a serious player in the engine boosting industry. Garrett product is produced by over 6,000 employees and serves the leading global engine and vehicle manufacturers, including Audi, BMW, DaimlerChrysler, DDC, Fiat, Ford, International Truck Co, Peugeot, Renault, Saab and Volkswagen.

www.turbobygarrett.com/turbobygarrett/garrett_history
### Turbocharger Technologies Were Key To Major Businesses

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**How Turbocharging Works**

**Turbo Dynamics**

![Diagram]
Businesses of Garrett AiResearch
Worldwide Sales/Service/Support

Torrance California
- Environmental Control Systems
- Electrical Power Generation
- Electro-Mechanical Actuation
- Automotive Turbochargers

Phoenix Arizona
- Propulsion & APU Systems
- Pneumatic Systems
- Airline Services/Support

Tucson Arizona
- Electronic Control Systems
- Cabin Pressure Control Systems
Today’s Talk is About Propulsion Engines & Auxiliary Power Units

**Propulsion Engine Markets:**
- Replacing older Pratt, GE, and Rolls Royce Engines for Business Aviation
- Newer, General Aviation Turboprop Aircraft
- Expanding market for feeder airline, 19-passenger commuters
- Turbofan Jet Commuters (Lycoming-Powered BAE 146, Canadair Challenger)
- Primary Flight Trainers

**Auxiliary Power Unit (APU) Markets:**
- Ground Carts – Aircraft power, Heating & Cooling, Engine Starting
- Commercial Transports Operating at Remote Fields
- Military Transports

**Helicopter Engine Markets:**
- US Army Light Helicopter (Garrett & Allison)
- Utility and Light Attack “Huey” & Marine “Cobra” (Lycoming)
- Chinook Heavy Lift (Lycoming)
The International Gas Turbine Institute,
Historical Perspective on Aircraft Engine Companies:

AlliedSignal Engines.

Phoenix, Arizona

J-P. Frignac
June 9, 1999
1945 to 1960 Building a Strong Expertise in Small Gas Turbine Engines

- 1945-1946: first APU, Project A, the “Black Box”, was designed and built.
- 1948, the GTC 43/44, the first Garrett successful gas turbine enters production.
- 1952, the gas turbine facility is moved to Phoenix.
For more than 50 years, Honeywell Auxiliary Power Units (APU) have delivered highly reliable electrical and pneumatic power for a wide range of business, regional and commercial aircraft applications.

APUs Provide:
- Starting power for main engines
- Pneumatic power for environmental control systems
- Drive power for other pneumatic and hydraulic systems
- Backup electrical and pneumatic power for in-flight operations
- Electric and pneumatic power for ground operations

Honeywell GTCP660 - 4, 4A, 4B

20 Basic Models Installed In Over 150 Applications
APU Models Fit Broad Applications

131-9 Series
The original 131-9D was designed specifically for the Boeing MD-90 airplane. The 131-9A was introduced in January, 1998 for Airbus’ A320 series aircraft

331-200 Series
In-flight operation of the 331-200 series APU allows two-engine commercial aircraft to fly extended ranges because the APU provides back-up electrical power during flight in the unlikely event of a main engine failure. The 331-200 is also the first electronically controlled APU.

331-500 Series
The first application of the 331-500 was the Boeing 777 aircraft, where it’s highly reliable in-flight operability allows extended twin engine operations (ETOPS) of that aircraft

85 Series
The first APU to be installed in an aircraft was a Boeing 727, in 1963. An aerospace industry landmark, the 30,000th production unit was delivered in 1996.

RE220
The RE220 demonstrates Honeywell’s advances in aircraft system integration by being the first general aviation APU to communicate with the aircraft’s maintenance data acquisition unit

660 Series
The 660 is the largest Honeywell APU installed on a commercial aircraft. The 660 was specifically designed to start the massive engines used on the Boeing 747
TURBOPROP PROPULSION PROGRAMS
A Strong Market Need for Gas Turbine Aircraft Engines Emerged

- Piston engines were topping out in power and power to weight ratio.
- Gas turbine engines opportunities were identified for:
  - helicopters
  - fixed wing aircraft.

Garrett Lineage
“Model 331”, the first Garrett aircraft engine

- Dual purpose core:
  - Generator set
  - 400 shp Turboshaft helicopter engine
- 1959, design initiated and first contract for GTCP331 received from U.S. Army.
- Light weight, rugged, low cost design:
  - single-shaft design, dual centrifugal compressor, reverse flow combustor, three stage axial flow turbine, each wheel made from identical integral casting.

Garrett Lineage
The beginning of a large family of TPE331’s, ranging from 500hp to 1,500hp

- “fixed-shaft” configuration (single-shaft running at constant speed.)
- single scoop inlet, up or down.
- integral power and accessory gearbox, providing two optional propeller speeds and direction of rotation
- dual stage centrifugal compressor driven by three stage axial turbine.
- reverse flow combustor
# Garrett TPE 331 Turboprop Powered Aircraft

![Garrett TPE 331 Turboprop Engine](image)

## Aircraft Models

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<td>Marsh S-2F3AT Turbo Tracker</td>
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<td>Models 680/690/840/960/1000</td>
<td>Conroy Stolifter</td>
<td>Mitsubishi MU-2</td>
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<td>Antonov An-38</td>
<td>de Havilland Dove</td>
<td>North American Rockwell OV-10 Bronco</td>
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<td>Ayres Thrush</td>
<td>Dornier Do 228</td>
<td>PAC Fletcher</td>
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<tr>
<td>BAe Jetstream 31/32</td>
<td>Epic Escape[6]</td>
<td>Pilatus/Fairchild PC-6C Turbo-Porter</td>
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<td>BAe Jetstream 41</td>
<td>Fairchild Swearingen Metroliner</td>
<td>Piper Cheyenne 400</td>
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<td>Beech Model 18</td>
<td>FMA IA 58 Pucará</td>
<td>RUAG Do 228NG</td>
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<td>Beech King Air B100</td>
<td>General Atomics MQ-9 Reaper</td>
<td>Short SC.7 Skyvan</td>
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<td>Grumman Ag Cat</td>
<td>Short Tucano</td>
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<td>Cessna 441 Conquest II</td>
<td>Grumman S-2 Tracker</td>
<td>Swearingen Merlin</td>
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<tr>
<td>Cessna Skymaster</td>
<td>Handley Page Jetstream</td>
<td>Volpar Model 4000</td>
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> Over 13,000 Engines Delivered – Over 92 Million Flight Hours
Families of Garrett TPE 331 Powered Aircraft

- Mitsubishi MU-2
- Rockwell Turbo Commander
- Cessna Conquest II
- Beechcraft King Air
Piper Cheyenne 400 With Garrett TPE 331-14 Engines
Garrett Powered 19 Passenger Commuters

Swearingen Metro

BAE Jetstream 41

Dornier 228
TURBOFAN PROPULSION PROGRAMS
The next family of aircraft engines

In the mid 60’s:
- The Turbofan engine provided better take-off thrust, a major reduction in fuel consumption and lower noise to transport aircraft.
- First generation business jets were powered by noisy, fuel thirsty turbojets or aft-fans.
- It was the right time for Garrett to develop a modern engine for this market: the TFE 731 turbofan engine.
The TFE 731 genesis

- Garret had just developed and qualified a two spool APU for the DC10, the TSCP 700.
- The TSCP core was adapted to the Turbofan concept. The 2,710 lb thrust TFE 731-1 was born on paper. Its first intended application: the Swearingen SA-28T delta-wing business jet.
1. Nacelle
2. Fan
3. Low pressure compressor
4. High pressure compressor
5. Combustion chamber
6. High pressure turbine
7. Low pressure turbine
8. Core nozzle
9. Fan

A. Low pressure spool
B. High pressure spool
C. Stationary components
The TFE 731 innovative design

- Front mounted single stage fan gear driven by the LP spool provided low fuel consumption and low noise.
- A small HP spool, single stage HP turbine driving a single stage centrifugal HP compressor and the accessory gearbox, provided easy battery starts.
- A full authority single channel electronic fuel control

Garrett Lineage
The TFE 731-2, the first of a large family

- Potential applications identify the need to increase the take-off thrust to 3,500 lb
- The GTCP 660-4 (Boeing 747 APU) four-stage compressor is adopted to meet the thrust requirement in May 1969.
- The TFE 731-2 is born. It is ordered by Learjet and Dassault in June 1969, it runs in September 1970, and is certified in August 1972. Production begins in September 1972
Garrett Model TFE 731 Turbofan Applications

TFE731-2
AIDC AT-3
CASA C-101
Dassault Falcon 10
FMA IA 63 Pampa
Hongdu JL-8
Learjet 31
Learjet 35/Learjet C-21

TFE731-3
Boeing Skyfox
British Aerospace 125 -700
Cessna Citation III
Cessna Citation VI
Dassault Falcon 50
Dassault Falcon 20 (retrofit)
Learjet 55
Lockheed 731 Jetstar/Jetstar II
IAI 1124 Westwind I
Hawker HS125 series

TFE731-4
Aero L-139 (prototype only)
Cessna Citation VII

TFE731-5
Hawker 800/850XP
TFE731-20
Learjet 40
Learjet 45
TFE731-40
Gulfstream G100/150 Astra SPX)
C-38 Courier
FMA IA 63 Pampa

TFE731-1100
Lockheed 731 Jetstar/Jetstar II
IAI 1124A Westwind II

TFE731: It is probably the only engine in civil service today that did not start as a military or airline engine

1. Over 11000 Engines
2. 100+ Million Flight Hours
3. Over 40 Aircraft Applications
# Families of Garrett TFE731 Powered Aircraft

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<th>Gulfstream</th>
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<td>Aero L-139 Proto.</td>
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<td>900XP</td>
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Garrett and GE team to provide an engine between TFE 731 & CF34

- Early 1980’s Garrett identify a market need for this size engine and studies engine concepts
- 1983, GE wins the MTDE turboshaft technology demonstrator competition with its GE27.
- GE 27 core size matches the turbofan engine cycle identified by Garrett.
- 1987, Garrett and GE create a joint company, CFE, to develop the CFE738 next generation business aircraft engine. GE is responsible for the core and Garrett the LP spool.

6000 POUNDS THRUST

Garrett Lineage
Key Dates in the CFE738 Development

- May 1988, full scale development begins.
- December 1993, TFE738-1 receives its FAA Type Certificate.
- Dassault selected the CFE738 to power its new Falcon 2000 business jet:
  - Aircraft production began in early 1995.
MILITARY PROPULSION PROGRAMS
TFE 731 Military Derivatives

Collaboration With Volvo & Republic of China AIDC

TFE 1042/ F125 - Afterburning

F124 Non-Afterburning
TFE1042 was a major technology Step for AlliedSignal

- Started as JV with Volvo to convert TFE731 into low bypass engine
- Ended as JV with AIDC (ROC)
- New Centerline similar to larger modern fighter engines
- Axi-centrifugal core, non-variable multistage fan
- Bypass ratio < 1.0
TFE1042 Provides Production Base for New Product Line

- Over 1 Million in Service Hours
- Powers IDF Air Defense Fighter (ROC)
- Basis of F124 and F125 Engines being proposed for advanced trainers and other
- Unique Privately Financed Military Engine
F109, Garret wins the Air Force Next Generation Trainer engine

- 1979-1981, TFE76 demonstrator program, combining T76 core with TFE 731 technology.
- 1982, the Air Force selects the Garrett powered Fairchild T46A. The engine is designated F109.
- The F109 was fully qualified by the Air Force, including the new ENSIP Program, in 1987. Unfortunately, the T46A program was canceled in 1986 because of airframe cost issues.
- The F109 supplied its core to the T800 engine.

Garrett Lineage
The One That Got Away ...
USAF Next Generation Trainer – T46

Fairchild Republic T-46 Primary Trainer

Garrett F109-GA-100
The T800, Garrett entry in the turboshaft market

- 1982, the Army announces its LHX program
- October 1984 Garrett and Allison team up and created LHTEC to enter the Army competition
- Allison brings helicopter engine know how and the ATDE 850 shp technology demonstrator.
- LHTEC selected, in 1985, for competitive full scale development phase, was the ultimate winner in 1988.
UNMANNED MILITARY PROGRAMS
Ryan Selects Garrett ATF-3 From Business Aviation
Rockwell Series 60 Sabreliner Business Jet

Unique Configuration:
Three shaft axial-flow engine
Single Stage Low Pressure Fan, 5 stage intermediate pressure axial compressor and single stage centrifugal compressor.
Overall Pressure Ratio 26:1

Maximum Thrust at Takeoff = 5440 lbs.

Performance Advantages:
Slim Profile
High Altitude Capability
Low IR Turbofan Design
Low Fuel Burn
The Garrett ATF-3 Flies 24-hours At 55,000 feet - Unrefueled

Ryan YQM98A “Compass Cope”

Low IR Signature
  • Twin Tail
  • ATF3 Turbofan
Low RCS
  • Fuselage Cross-section
Dual Analog FCS
  • Digital Monitoring Radar Altimeter
Dual Command/Control
  • MCGS
  • UHF Backup

EAFB 1974 Flight Test
Northrop Selects Garrett ATF-3 For Stealth Test Bed
Tacit Blue

The US Air Force, Defense Advanced Research Projects Agency, and Northrop Corp. teamed up for the TACIT BLUE Technology Demonstration Program from 1978 to 1985. TACIT BLUE validated a number of innovative stealth technology advances. Most notably, it was the first aircraft to demonstrate a low radar cross section using curved surfaces.

The men responsible for the design of the Tacit Blue, Irv Walland (aerodynamist), Steve Smith (program manager) and John Cashen (electromagnetist)
Continued Corporate Evolution 90’s:

- 1992, Allied-Signal becomes “AlliedSignal”
- 1993, “AlliedSignal Engines” is created combining both Aircraft engines and Power Systems.
- 1995, Lycoming Turbine Engines is merged into “AlliedSignal Engines”.
Lycoming and AlliedSignal were a perfect fit

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<td>Regional Airlines</td>
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Lycoming Lineage

Junkers Design Team

Technology Core

NACA, German, Wright Field, etc.
T53 First Lycoming Product

- Activity started in Williamsport, PA in 1951
- Won First Air Force Contract in July of 1952
- 600 HP Axial/Centrifugal Compressor Technology Engine
- First Flight in Kaman HOK-1 Helicopter in 1956

Lycoming Lineage
T53 Grew to Power UH-1 “Huey” and Marine Cobra Helicopters

- T53-L-13 (1400HP)
- T53-L-703 (1800HP)
- More than 19,000 built making it the world’s most successful helicopter turbine
- T53-L-701 Powered Mohawk OV-1 observation aircraft
Lycoming T-53 Applications

• Over 19,000 Engines Built
• Worlds Most Successful Helicopter Engine

Bell UH-1 “Huey”

Grumman OV-1 “Mohawk”
Larger T55 Rapidly Followed T53

- Air Force Contract
  Released in April 1954
- 2,200 HP
- Upgraded since to over 5,000 HP
- Powers all versions of the CH47 “Chinook” Twin Rotor Army Heavy Lift Helicopter

Lycoming Lineage
Almost 1200 Built
Turbofan variant of T55 Started Shortly After

- PLF1A, 4,320 lb thrust began in 1961, using geared fan
- Used in A9 aircraft loser to current A10
- Resulted in 7,500 lb thrust ALF502 and LF507 engine used in Bae 146 and Canadair Challenger

Lycoming Lineage
Lycoming ALF-502 Applications

BAE-146
Transport

Northrop A-9
The LTS101 a Logical addition to the Lycoming family of Turboshaft Engines

- 1968 Lycoming R&D Program for low cost shaft engine
- Early 70’s full scale development
- 1975 Certification, 650-750 Hp
- Applications
  - Aerospatiale AS350
  - MBB/KHI BK117
  - Coast Guard HH-65A
  - Bell 222
- 1,650 Engines in Service
- 6 million hours

LTS 101
Lycoming Lineage
Lycoming LTS-101 Applications

Bell 222

Aerospatiale HH-65A Dolphin
AlliedSignal Engines Today

A Full Range of Aircraft Engines

- Business Jets
  - AS900
  - CFE738
  - TFE731

- Fighters & Trainers
  - F125
  - F124
  - TFE1042

- Commuter & Utility
  - CTP800
  - TPE331

- Regional Jets
  - AS900
  - LTS101

- Helicopters
  - CTS800
  - T800
  - T55
  - T53