Development of the CENTURION Jet Fuel Aircraft Engines at TAE

25th April 2003, Friedrichshafen, Germany

Thielert Group

The Thielert group has been developing and manufacturing components for high performance engines, as well as special parts with complex geometries made from high-quality super alloys for various applications.

Our engineers are developing solutions to optimize internal combustion engines for the racing-, prototyping- and the aircraft industry.

We specialize in manufacturing, design, analysis, R&D, prototyping and testing. We work with our customers from the initial concept through to production.

www.Thielert.com

CENTURION
Built by TAE

TAE
THIELERT AIRCRAFT ENGINES

Company Structure

Thielert AG

Thielert Motoren GmbH
Hamburg

Thielert Aircraft Engines GmbH
Lichtenstein

High-Performance Engines, Components and Engine Management Systems, Manufacturing of Prototype- and Race Cars

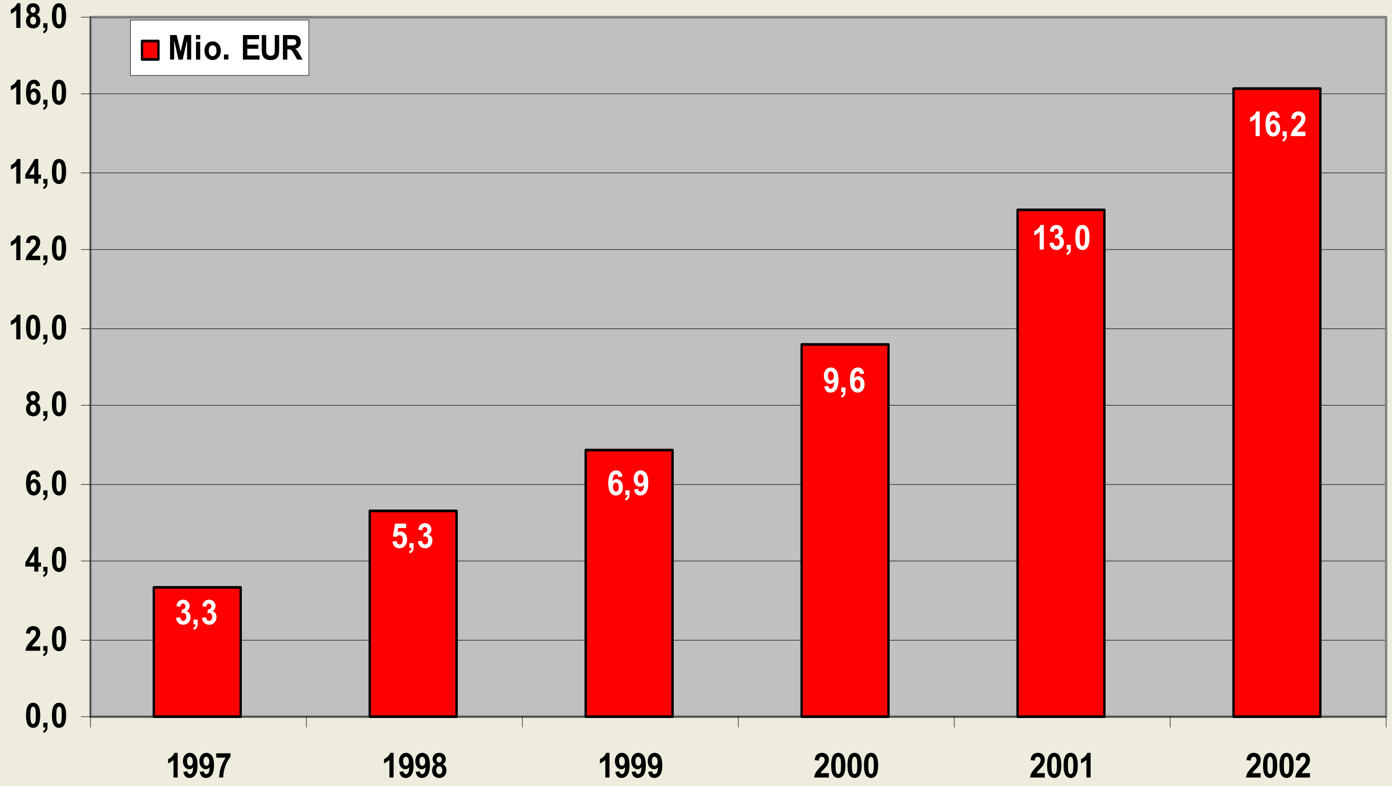
Manufacturing of components and parts with complex geometries

Design Organisation
according to JAR-21 Subpart JA

Production Organisation
according to JAR-21 Subpart G

Aircraft Engines according to JAR-E
Engine installation acc. to JAR-23

Turnover



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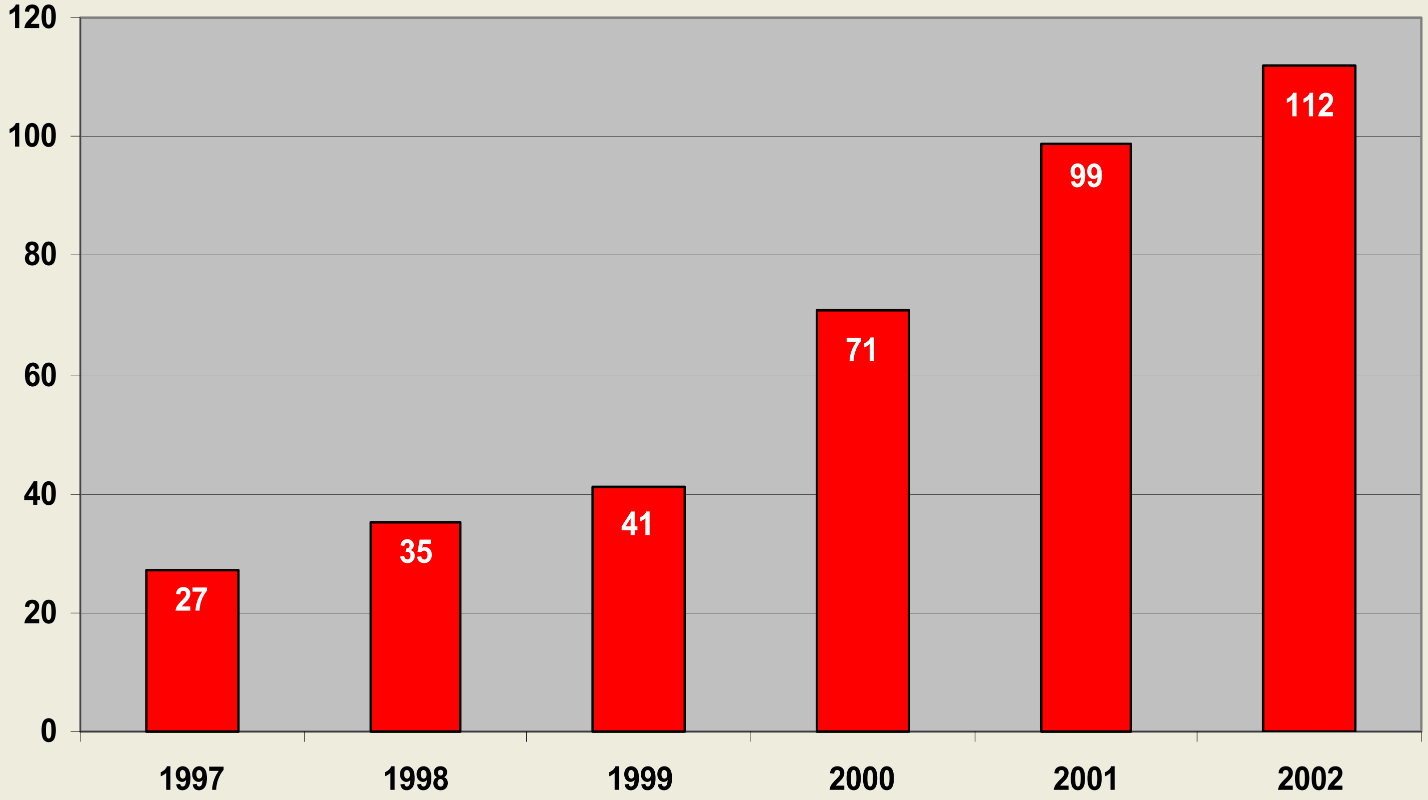
Employees



Founded 1989 as a One-Man-Company.

Competency has increased steadily due to very low employee turnover.

Company Profile

Aviation:

- Production of jet fuel aircraft engines
- Production of precision components for the aviation industry (including engine components and structural parts)
- Development and production of aircraft electronics assemblies (Digital engine control units)

Automotive (Prototypes, pilot lots, motor racing):

- Production of engine components (including high-performance cam-and crank shafts)
- Development and production of electronic assemblies (Engine control units, control software)
- Engineering Services (including test facilities, optimisation of engine concepts)

Current List of Customers

Automotive

- Bugatti Engineering GmbH, Wolfsburg
- DaimlerChrysler AG, Untertürkheim
- Dr. Ing. h.c. F. Porsche AG, Stuttgart
- Porsche Motorsport, Santa Ana, California (USA)
- Salzgitter Antriebstechnik GmbH & Co. KG, Crimmitschau
- Toyota Racing Development USA Inc., Costa Mesa (USA)
- TWR Group, Leafield (England)
- Volkswagen AG, Wolfsburg

Current List of Customers

Aviation

- OEM agreements with (excerpt):
  - Superior Air Parts Inc., Dallas (USA)
  - Diamond Aircraft Ind. GmbH, Wiener Neustadt (Austria)
  - EADS Airbus GmbH, Varel (Germany)

- Dealer agreements (excerpt):
  - Piper Germany AG, Calden (Germany)
  - Rheinland Air Service, Mönchengladbach (Germany)
  - Meridian, Bournemouth (England)
  - Air Alpha, Odense (Denmark)
  - Pilatus Maintenance, Stans (Switzerland)

Thielert Aircraft Engines

- Founded in 1999 to adapt diesel engines for General Aviation
- Certified design and production organization for aircraft engines and system partner for components
- Over 86 employees and high tech CNC turning-milling center
- Serial production of CENTURION 1.7 since 2002

Milestones of TAE

2000

- Construction of plant in Saxony, start of production

2001

- Type certificate for TAE 110 (first jet fuel piston engine since world war II)
- Approval as design organization according to JAR-21 JA
- Approval as production organization according to JAR-21 G, JAR-22 H

2002

- Type certificate for TAE 125 (CENTURION 1.7)
- Supplemental type certificates for Cessna 172 N and P
- Jet fuel aircraft: Diamond DA40 and DA42, Cessna 172, Piper PA28

2003

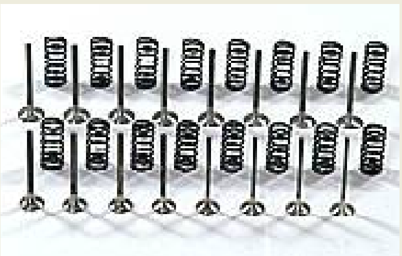
- Serial production CENTURION 1.7, design and certification CENTURION 4.0, extension of plant

Manufacturing

Manufacturing

Manufacturing of Components

Assembled camshafts with concave radii



Steel or Titanium valves

- Our machinery is dedicated to the production of prototype and small production runs
- Our manufacturing spectrum covers the following:
  - billet and forged crankshafts
  - billet, forged and assembled camshafts
  - billet and forged connecting rods
  - splined shafts and gears
  - 5-axis manufacturing of crankcases and cylinder heads
  - 5-axis CNC head porting
- Shortest production times through in-house manufacturing

Billet crankshaft with splines and involute gears

Modification of combustion chambers and head porting

CENTURION
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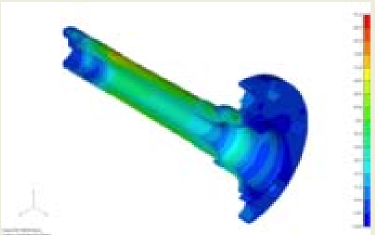
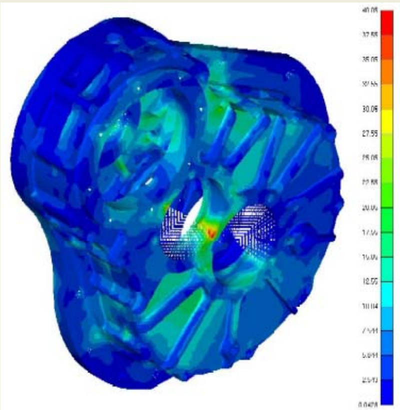
THIELERT AIRCRAFT ENGINES

Manufacturing

Quality Assurance





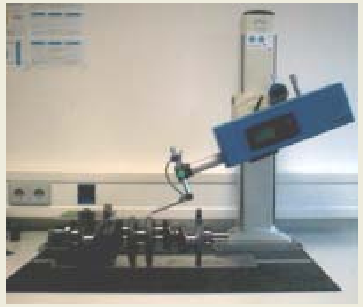
Process Control

- Exact definition and survey of production.
- Permanent process controlling.
- Camshafts, crankshafts and gearwheels are 100%:
  - geometrical measured
  - checked with Barkhausen noise based non-desructive testing for studying grinding burns, hardness changes and heat treatment problems
  - checked with magnetic particle inspection bench for detection of longitudinal and transverse defects
- FME Analysis

Quality Assurance

Traceability

- Perfect documentation for reliability of production process.
- Survey and quality control for all suppliers via own audits.
- Perfect documentation of material flow
- Traceability „to molten mass“



Quality Assurance

ADCOLE 1200 SH
Orbital crank- and camshaft measuring machine, max. length of workpiece : 965 mm

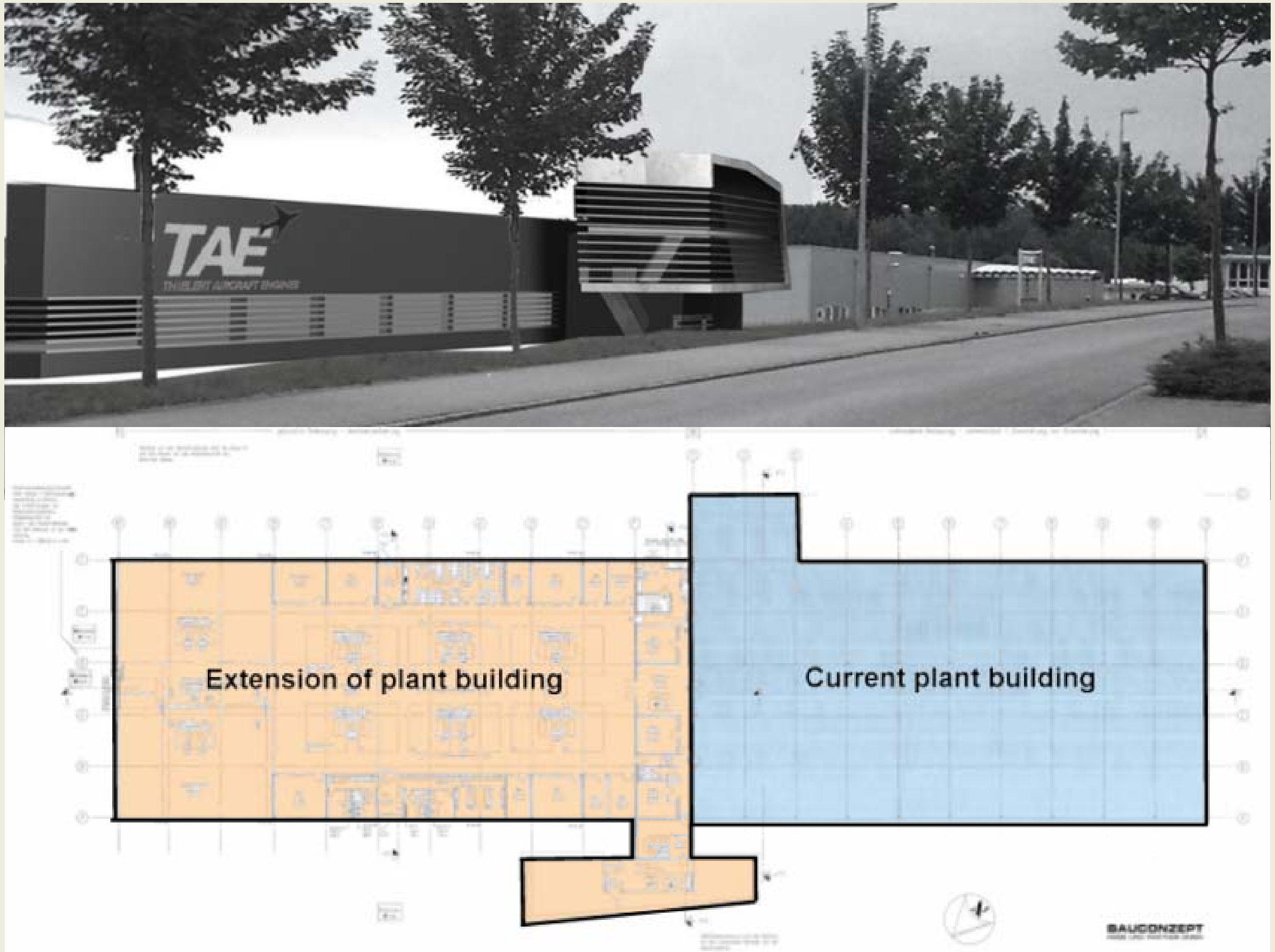
Coordinate Measuring Machine Zeiss Prismo 7
Measuring with Zeiss VAST technology, scanning of surfaces, measuring cam contours, digitalizing of free-form surfaces

Zeiss Contura
Coordinate measuring machine 700x1000x600 VAST

Zeiss Vista
Coordinate measuring machine 400x500x350

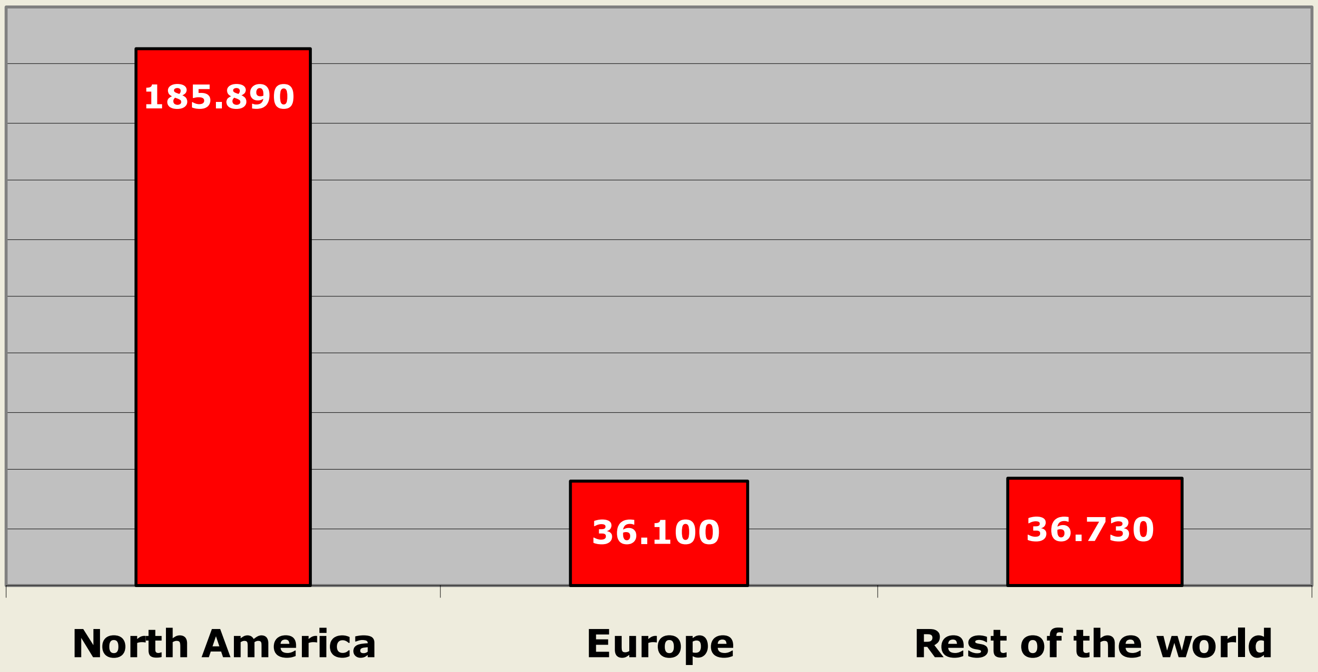
2 x Wolpert Testor 971/250
Hardness testing according to Vickers, Brinell and Rockwell

Plant extension



Our Business: GA Aircraft

Fleet worldwide



Source: GAMA Statistical Databook 2002

GA Aircraft Fleet

- Spectrum of GA aircraft fleet:
  - Single-Engine to 2 t MTOM
  - Multi-Engine to 5,7 t MTOM
- Share of piston engine aircraft: 78 per Cent
- Average age of this fleet: approx. 31 years*

Typical Example: Cessna 172

- Year: 1972
- Airframe Time: 5,560h
- Engine S.M.O.H.: 1,582h

Source: Internet

* Source: GAMA Statistical Databook 2002, LBA

Reverse of GA Aircraft

- High asset and operational cost for aircraft
- High training cost
- Immense operational workload for the pilot
- Intensive and long maintenance, repair and overhaul

Caused by

Out-of-date
parts and engine technology

Background of Diesel Technology

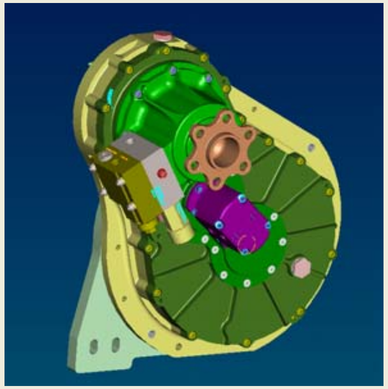
- Air is compressed in the combustion chamber without fuel
- Air temp rises above the flashpoint of the mixture
- Fuel is then added, mixes with the air and combusts spontaneously
- Power is controlled by the amount of fuel
    - Quality controlled
- There is no throttle valve – intake fully open

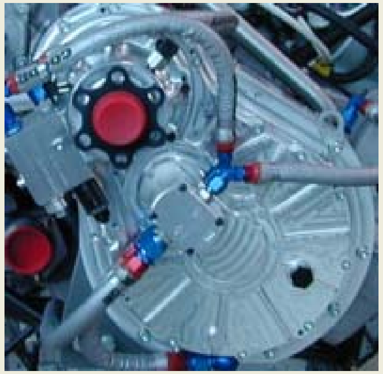
Advantages of Diesel

- Fuel takes time to mix and combust. This limits RPM.
- Diesels operate at extremely high compression ratios thus having better efficiency
- No detonation
  - Limit for boost is the engine´s structure
- Diesels do not usually operate at the stoichiometric ratio. The engine does not depend on oxygen. That means high power output in high altitudes.

Design and Development

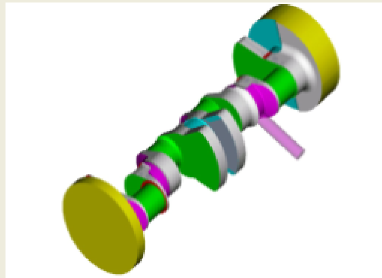
Development of mechanical systems





Gear of Centurion 1.7

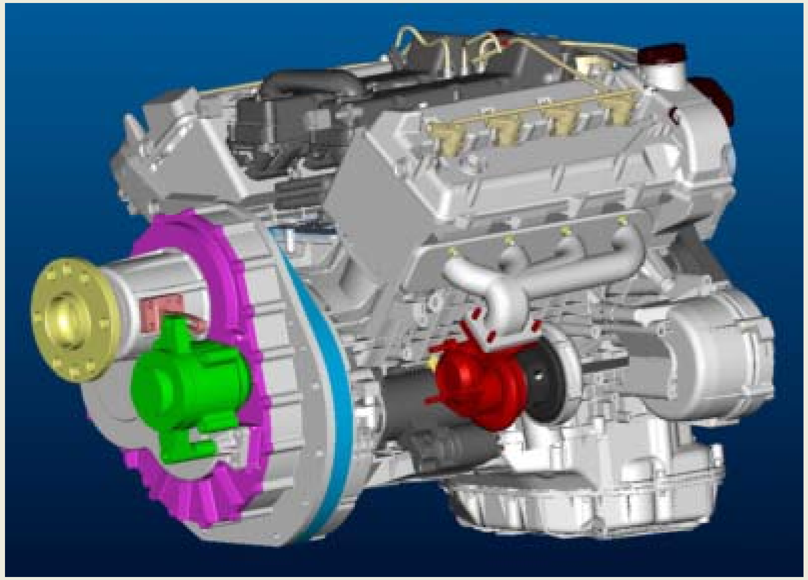
- Our design department is equipped with 10 3-D CAD/CAM workstations using the latest version of Pro/ENGINEER 2001 and Catia V5
- Any component is designed as a 3-D model used to derive
  - Drawings for manufacturing
  - CNC-programs for our manufacturing machines
  - Nominal values for our coordinate measuring machines
- Useable prototype and development parts can be designed and manufactured within days. Time consuming subcontract manufacturing is not necessary.

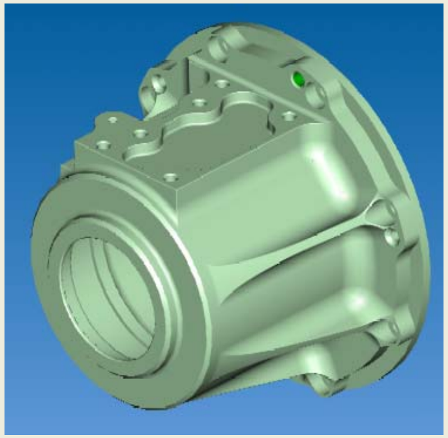


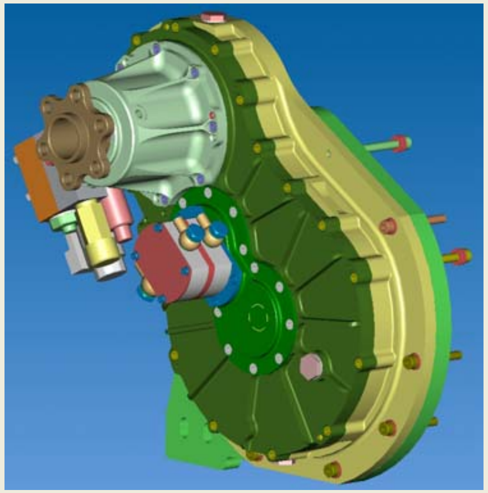
Manufacturing simulation of a billet crankshaft inside the 3-D model

Reverse engineering of scanned inlet and exhaust ports

Computer Aided Design







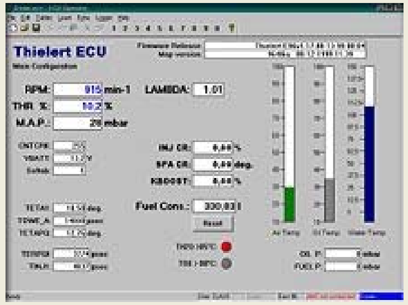
Design and Development

Thielert ECU for
Lotus Elise Turbo
with internal Datalogger

Ignition- und injection
wiring loom
Porsche GT 2

Development of electronic systems

- Our electronics department follows aircraft certified processes
- The hardware development of our engine management system and the display follow Aircraft Standard DO 160
- The software development periphery meets all requirements of Aircraft Standard DO178B and is certified for the development of aircraft control systems
- The development of wiring looms incl. the integration of the car's wiring loom and the definition of the interfaces is performed in-house.
- Manufacturing of prototype-nature wiring looms is carried out in-house, production of series production wiring looms is organised and coordinated by our engineers.

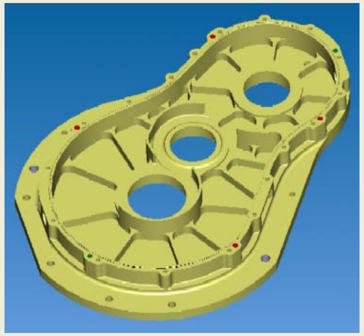
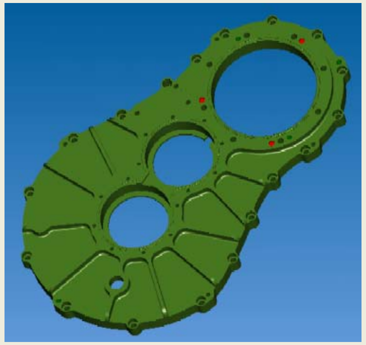
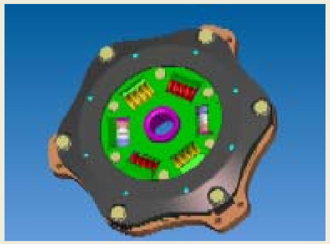


Thielert ECU Operator Software
Windows-based

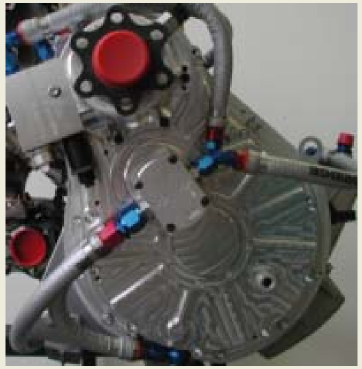
Board layout of complex
electronic components

Gearbox and Clutch

Development

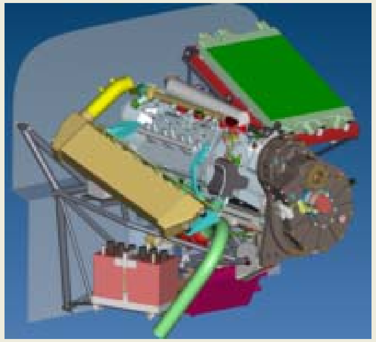




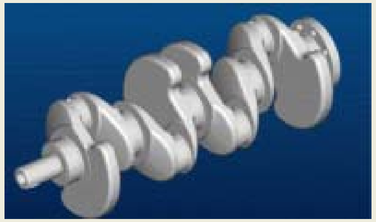
- Limitation of max. load
- Torsional vibration damper within clutch
- gear wheel from high quality steel
- Electronical constant speed control for hydraulic prop setting
- Special oil distribution system
- Compact design



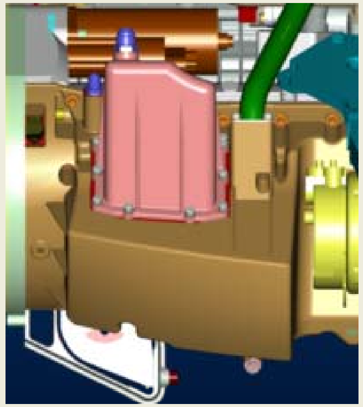

Engine Components & Periphery

Development according to aviation standards





- Crankshaft
- Oil system incl. system for separation of blow by from crank case
- Coolant system: first water cooling in this market segment
- Exhaust system: exhaust manifold, modification turbo charger, intercooler



CENTURION
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Direct Injection

State-of-the-Art Diesel Injection Technology

- High efficiency, high power output, low noise level

Development

- Adaption of high pressure pump for jet fuel
- Electronic control for aviation
- Rail pressure is controlled
  - Enables control over injection volume as well as duration
  - Improves combustion efficiency and power
- Rail pressure of 1,350 bar (19,500 psi)

Centurion Built by TAE

FADEC – the Electronic Engine Control

TAE THIELERT AIRCRAFT ENGINES

- Full Authority Digital Engine Control
- Redundant without mechanical backup system
- Developed and certified according to DO160 and DO178
- Meets lightning protection and EMC (150 V/m) requirements

FADEC - Opportunities

- Redundancy of two ECU*-Mainboards
- Health levels: the ECUs check each others health; automatic switch to the healthier one if problems occur
- Single lever control
- Engine control via sensors (e.g. temperature of water, oil, air, revs, rail pressure etc.)
- Automatic pre flight checks
- Control of hot and cold starts
- Event log – all relevant engine data are logged and saved. Therefore ease of maintenance and engine setting.

* ECU = Engine Control Unit

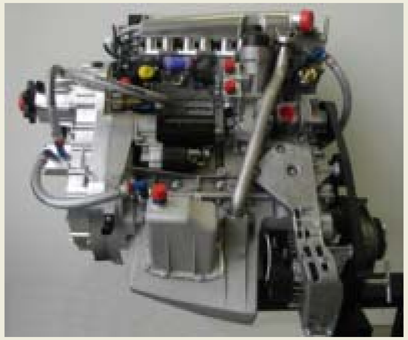
Aircraft Engine
CENTURION 1.7

CENTURION 1.7 – the Idea

- Based on existing automotive engine
  - High development standards
  - Benefits from large R&D budgets of the automotive industry
  - Reliable and safe base product
- Diesel engine with direct injection and turbo charger
- Electronic engine control

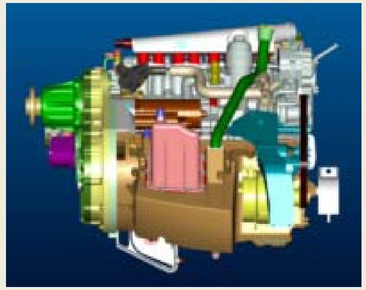
Before:

After:



CENTURION 1.7 – the Product

- Certified jet fuel engine for General aviation singles and twins (JAA type certification for jet fuel and diesel according to JAR-E)
- 1,7 l 4-cylinder inline engine with common rail, direct injection, turbo charger and liquid cooling
- 99 kW (135 hp) take off and max. power at 6.000 ft altitude
- 93 kW (125 hp) power at 12.000 ft altitude
- 72 kW (97 hp) cruise power at best economy point at 17.500 ft (service ceiling)
- Integrated redundant electronical engine and prop management
- Single lever control
- Cruise consumption of 17,5 l Diesel
- Cost reduction of 70 per cent



OEM – Diamond Aircraft

Comparison of Performance

- Lycoming O-320 und CENTURION 1.7 in Cessna 172 R:

	Climb Rate O-320	Climb Rate Centurion 1.7	Power O-320	Power Centurion 1.7
Sealevel	740 ft/min	630 ft/min	160 hp	135 hp
2.000 ft	635 ft/min	630 ft/min	147 hp	135 hp
4.000 ft	530 ft/min	630 ft/min	136 hp	135 hp
6.000 ft	426 ft/min	600 ft/min	128 hp	133 hp
8.000 ft	321 ft/min	510 ft/min	119 hp	129 hp
10.000 ft	175 ft/min	450 ft/min	112 hp	122 hp
12.000 ft	84 ft/min	370 ft/min	100 hp	119 hp
14.000 ft	0 ft/min	290 ft/min	91 hp	112 hp

Comparison of Consumption

- Consumption of Lycoming avgas engines and CENTURION 1.7 in different aircraft
- *Fast** cruise at 10.000 ft with 225 km/h (122 KTAS):

	Lycoming	Centurion
Diamond DA40	27,3 l/h (7.2 gal)	**15,5 l/h (4.1 gal)**
Cessna 172	30,3 l/h (8 gal)	24 l/h (6.3 gal)

* We have chosen a fast cruise to point out the performance of modern aircraft with modern propulsion. This explains the consumption of C172 with Centurion. Same Cessna flown with Centurion on best economy point takes 17,5 lph at 118 KTAS.

Comparison of Cost

- Operative cost of Lycoming avgas engines and CENTURION 1.7 in different aircraft.*
- Cost per hour at 10.000 ft with 225 km/h (122 KTAS):

	Lycoming 1,65 EUR AVGAS	Centurion 0,90 EUR Diesel
Diamond DA40	45,05 EUR	**13,95 EUR**
Cessna 172	49,99 EUR	21,60 EUR

* Based on German fuel prices.

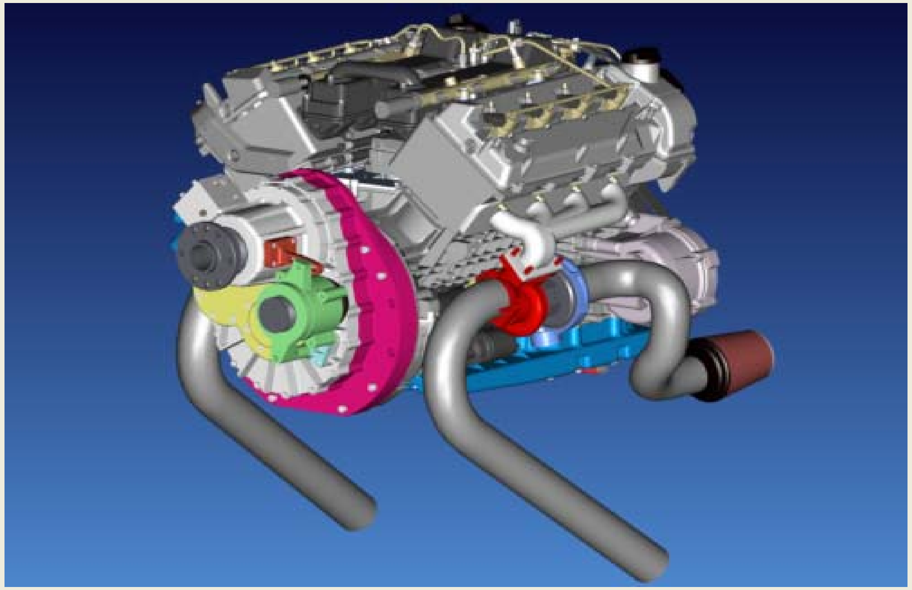
Advantages of CENTURION 1.7

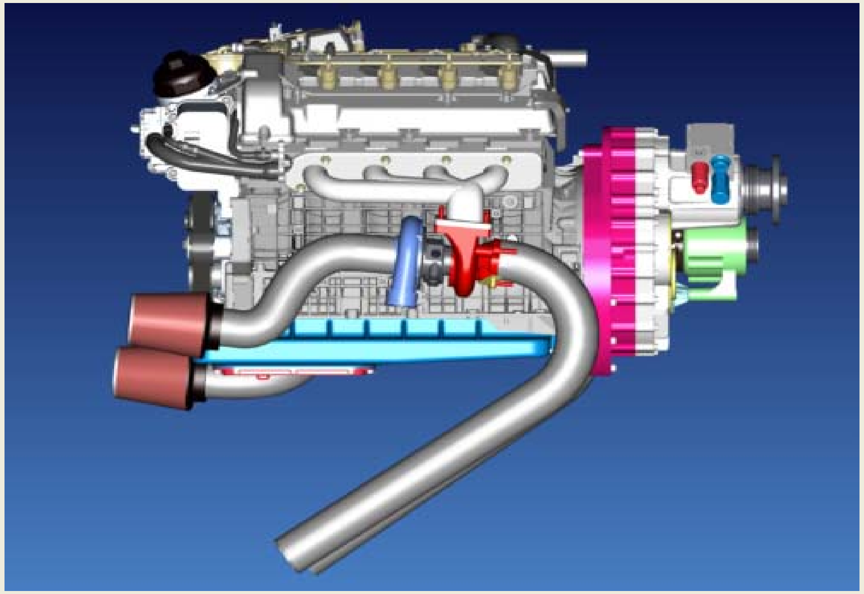
- Modern technology
- Worldwide availability of diesel and jet fuel
- Cost reduction to 70 per cent possible
- Electronic engine and prop management with single lever
- Simple operation
- Automatic pre flight check
- Safety through event log
- Strong take of performance
- Excellent climb to 13.500 ft altitude
- Longer range

Aircraft Engine
CENTURION 4.0

- Jet fuel aircraft engine for 1- and 2-mots
- V8-Turbo engine with 4.0 l engine swept volume and 310 HP take off power
- Fuel consumption 29.5 lph jet fuel (compared to 51 lph leaded Avgas of competitor´s engine)
- Running costs reduced by 70%
- Dry weight incl. gear box: 283,5 kg
- Planned sales: 120 units in 2004, then 600 units per year

CENTURION 4.0
The Development



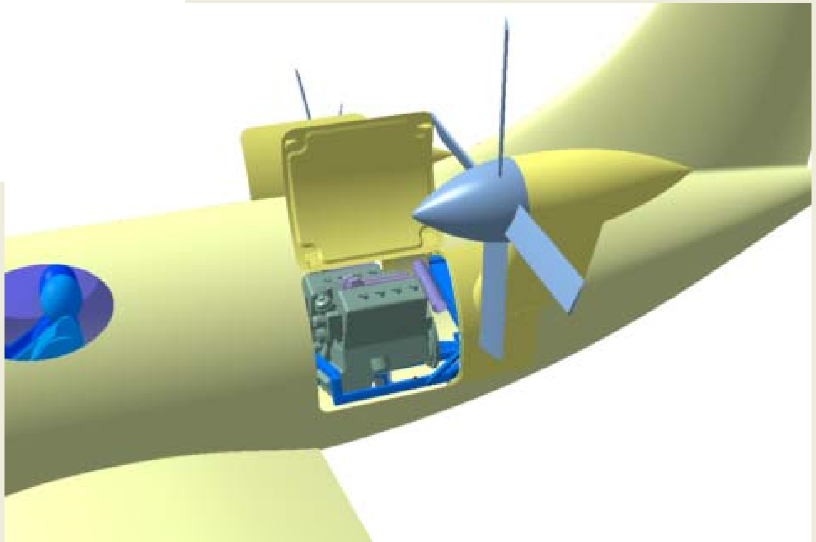


CENTURION 4.0
Technical Data

- Type of engine: 8-Cylinders, V-arrangment
  DOHC, 4 valves per cylinder
  75° V-angle
  direct injection
  common rail System
  twin turbo charged
  liquid cooled
- Swept volume: 3996 cm³
- Take off and max. power at 8.000 ft: 228 kW (310 hp)
- Recommended cruise power: 186 kW (250 hp)
- Torque: 946 Nm (at propeller)
- Take off prop RPM: 2.300 rpm
- Fuel Consumption at best economy point:
  25 liters/hr Diesel/Jet Fuel
- Specific Fuel Consumption (BEP): 208 g/kWh (153 g/hph)
- Dimension (w x d x h): 693 x 1037 x 667 mm (30,7 x 31,3 x 23,2 in)

CENTURION 4.0 in TT62

The TT62 from High Performance Aircraft GmbH is a 5-seat twin in the 2.5 t range.



After development, testing and certification the aircraft will be available in 2005.

CENTURION 4.0 in TT62

HPA TT62

▪ Cabin:	pressurized cabin with 5 seats
▪ Engine:	2 CENTURION 4.0
▪ Propeller:	4-blade, full feathering 1.700 mm diameter, constant speed, 2,300 rpm
▪ Max. Take off mass:	2,550 kg

Expected Performance

▪ Climb rate with MTOW at SL:	1,800 ft/min
▪ Cruise speed at 20,000 ft:	240 kts
▪ Max. operation speeds:	Vmo = 250 kcas
▪ Consumption at cruise speed:	50 liter/hr Jet Fuel/Diesel
▪ Range standard tanks:	1,700 nm

Aircraft vs. Car

A business trip from Falkenfels to Rostock*

	Car (Alfa Romeo 156 1.9l)	Car and Airline München-Rostock	Conventional business aircraft (Aerostar 601P)	**Business aircraft in future (HPA TT 62)**
Dis-tance	751 km	175 km Auto und Flug	595 km	**595 km**
Time	5:46 Std.	ca. 4 Std.	2:28 Std.	**ca. 2 Std.**
Consum-ption	79 l Super	17 l Super und Flug	237 l AVGAS	**158 l Jet Fuel/Diesel**
Cost	89,27 EUR	469 EUR	331,20 EUR	**142,20 EUR**

* Based on German fuel prices.

Advantages of Jet Fuel Engines

- Modern Technology
- Availability of fuel
- Low consumption, lower fuel price
- Electronic engine and prop management with single lever control
- Low workload for pilot
- Automatic pre flight check
- Safety because of event log
- Strong take off power
- Excellent climb performance
- Ease of maintenance
- Longer range

- **Cost Effectiveness**
- **Comfort**
- **Safety**
- **Performance**

Summary

- CENTURION are state-of-the-art turbo jet fuel engines
- Advantages: cost effectiveness, comfort, safety, performance
- Single lever control: the pilot is his own flight guest.
  (lever for load, mixture, revs, prop settings etc. no longer necessary), automatic checks
- Reduction of operating cost to 70 per cent
- Jet fuel (kerosene) and diesel usable in any mixture ration: over 99,5 per cent of delivered aviation fuel worldwide.
- Most important development achievements: electronic engine management FADEC, gearbow with torsional damper, adaption of fuel system for jet fuel