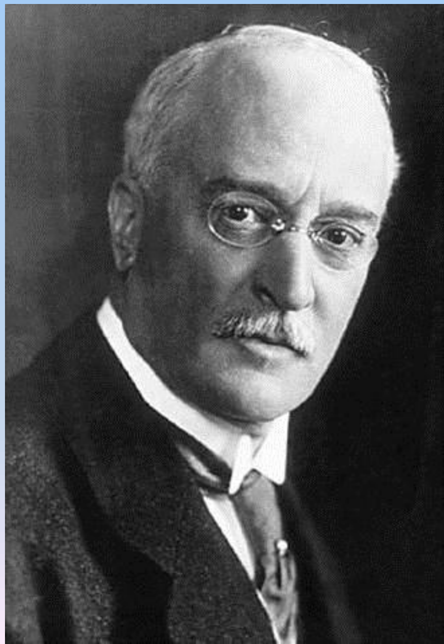
Aircraft Diesel Engines

Why haven’t they been really successful?

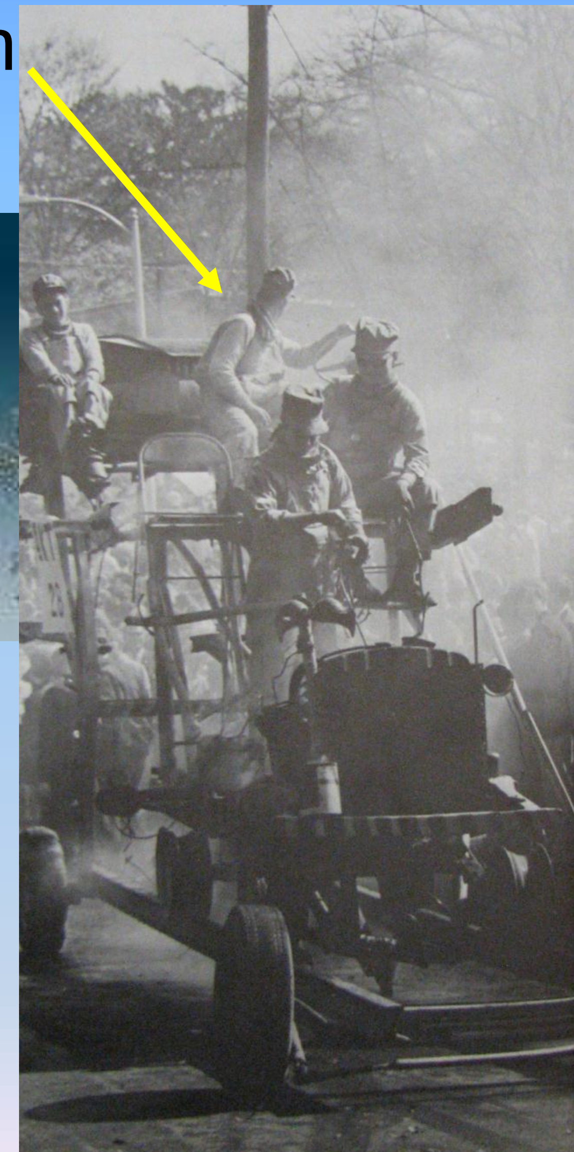
What will the future bring?



May 10, 2012
AEHS Meeting
Pensacola FL
by Bill Brogdon

Some of My History

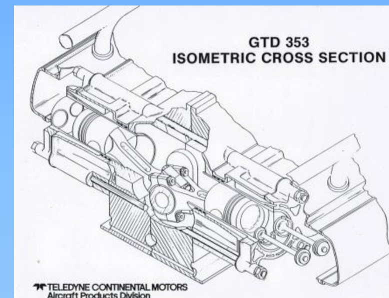
- Rambling Wreck from Georgia Tech
- 1968 B. Mechanical Engineering



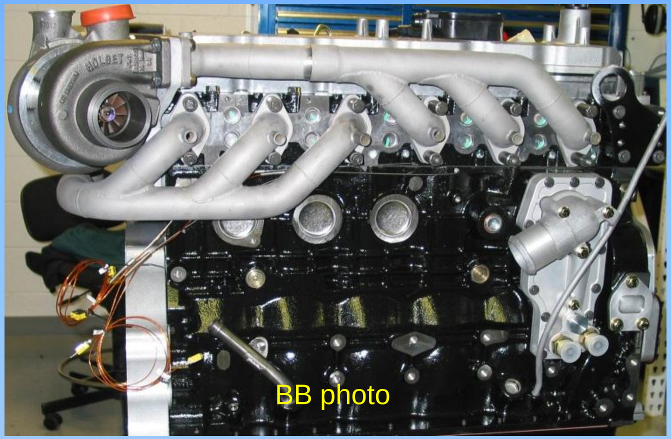
- 1968-76 International Harvester
- Truck engine design and analysis

Teledyne Continental Motors

- 1976-98 & 2007-10
- Design Engineer
  Director Engineering
  Chief Engineer
- Engines
  - TSIOL300 Boeing Condor
  - IOL-200 Voyager
  - TSIOL 550 RAM 414
  - Grob Strato 2C HALE
  - NASA GAP diesel
  - O-200D Skycatcher



Ricardo, Inc.



- 1998-06
- Design Manager
  Chief Engr (Industrial &Other)
- TARDEC- Commercially based FCS engine
- Cummins Mercruiser Diesel marinized ISB
- Design and analysis direction for all engine types and clients
  - Diesel
  - Gasoline
  - Stirling
  - Engine sizes from .5 to 10,000 hp

CMD photo

About This Presentation

- Engine design guy, not a historian, help me where you see I need it
- Airship diesel engines are left out of this presentation, there was never a successful one!
- Also true for helicopters… but some of them are in here… *consistency is for sissies*.
- Some experimental auto conversions are included and some are not.

Aircraft Diesels -- Why?

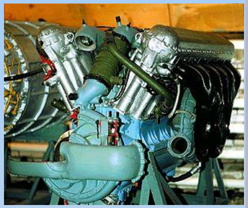
- Fuel economy
  - Cost
  - Range
- Fuel availability
- Fire safety and no CO
- Operational
  - Single lever fueling control
  - Inlet (carb) icing due to fuel evaporation not an issue
- Potentially longer TBO
- The emphasis on each changes over time
- Diesels are now in a rapid phase of development due to trucks and cars; applied to aircraft diesels this will lead to great improvements in “ilities”

Factors in Engine Success

- *Success is serial production of 500 or more engines for aircraft (my definition)*
- Dedicated leaders with drive tempered with patience (temporal and financial)
- Financial (development funding)
- Right place, right time
- Willing aircraft OEM partners
- Regulations and Politics
- Technical
  - Appropriate power
  - Weight
  - Reliability & durability
  - Fit in airplane
  - Good operational features

What Has Been Successful

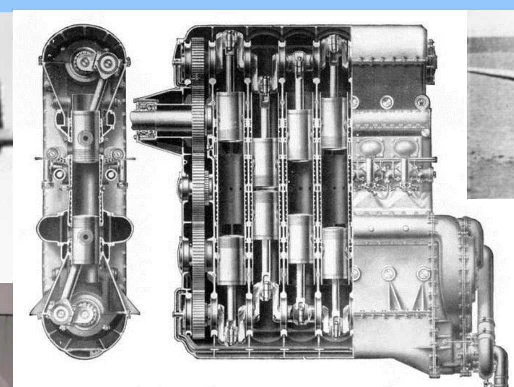
- Junkers Jumo 205 & 207
- Thielert Centurion 1.7 and 2.0
- Charomskiy ACh-30 & M40

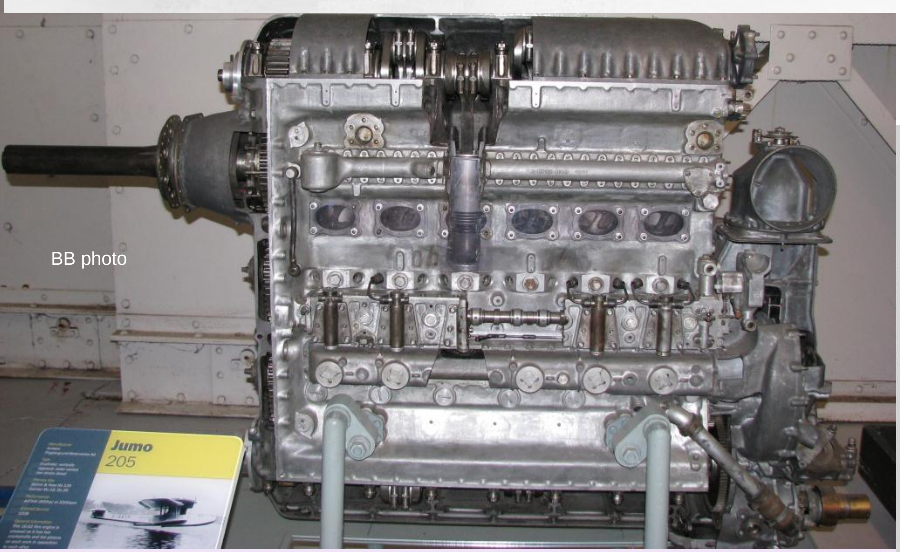


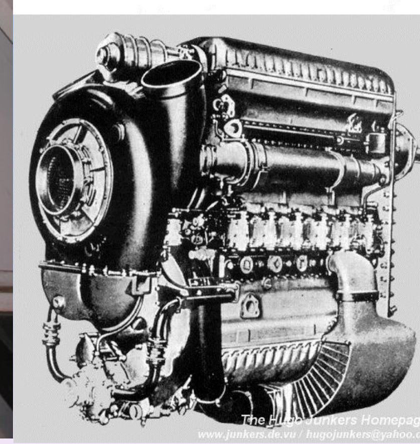
- Potentially, the Austro 2.0

Junkers Jumo 204-207

- Six cylinder opposed piston 600-1000 bhp
- Turbocharged 207 1000 hp operational to 46,000’
- Do18 with 2-205’s flew 5214 miles England to Brazil







BB photo

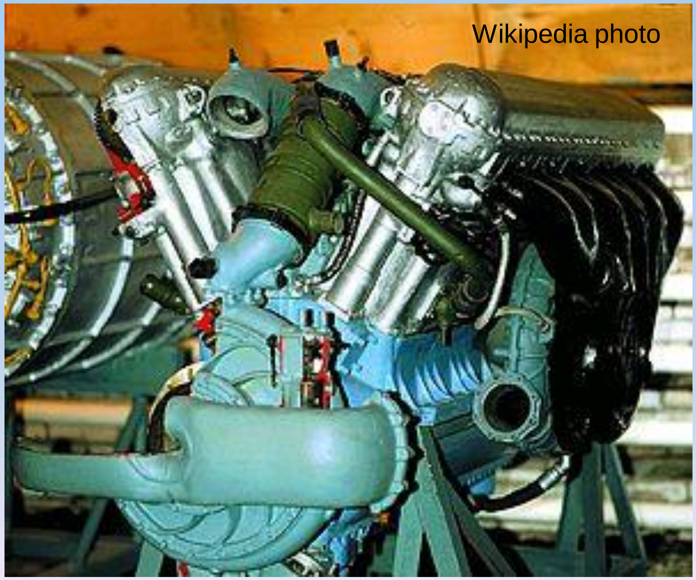
Junkers Jumo 204-207

- Dr. Hugo Junkers started development of OPs in 1913, first flight 1929
- Series production of the 204 began in 1931
- Series production of the 205 began in 1935
- Dr. Junkers was a brilliant engineer, a good leader, and very persistent, did not get along with Nazi's
- Junkers company was financially strong for much of the development period
- WW2 and government funding provided the right place and time
- Although successful, the Junker OPs still did not compare well technically with German SI engines
- Dr. Junkers had the advantage of also running an airplane company, but his engines were used by others too.

Charomskiy ACh-30b & M40

- 61L, V-12, 1500 bhp, liquid cooled, turbocharged, 2800 lb.
- Soviet design for long range bombers
- Development started in early ‘30s
- Initial engines unreliable, troublesome at high altitudes and in cold conditions
- 1526 engines built from 1940-45


Wikipedia photo


Wikipedia photo

Thielert Centurion

- 1.7 and 2.0 L conversions of Mercedes car engines
- Geared, common rail, liquid cooled, 4 cylinder in-line, 135 to 155 bhp
- Centurion diesel engines installed in:
  - Diamond DA40 & 42
  - General Atomics Gray Eagle (nee Predator A)
  - Finch Ecoflyer (Robin DR400)
  - STCs for Cessna 172, 206 & Piper PA28
- 2600 engines produced since 2001

Centurion 4.0

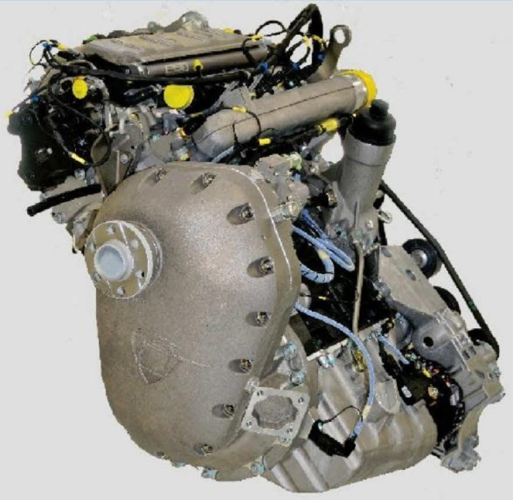
Thielert Centurion

- Frank Thielert started in auto racing components in 1989
- Started Thielert Aircraft Engines in 1999
- Diamond selected the Centurion 1.7 in 2001 for the DA 40 and DA42
- Thielert and Diamond owner Christian Dries are both talented and intense, good for getting started

- Both the Centurion and Austro (next slide) and some other planned engines are automotive based
  - Lifespan of auto engine designs are usually short ~5 years
  - Aircraft engines hang around for 50 years, this makes conformance to automotive type design a real issue

Austro AE300

- 2L, 165 bhp, four cylinder, geared, common rail, 407 lb, conversion of a Mercedes car engine
- To replace Centurion engines in Diamond Airplanes
- Diamond Aircraft formed Austro Engine company
- Diamond has been experimenting with a number of engine options over the years
- Well funded company with dynamic management by Christien Dries



Almost Successful

- Guiberson A-1020
  - 9 cylinder radial, two valve, 340 bhp
  - 1326 produced as a 245 bhp tank engine by Buda
  - Flew in a Stinson Reliant but overtaken by WW2 commitments to tank production
  - Evidently a smooth running, reliable engine

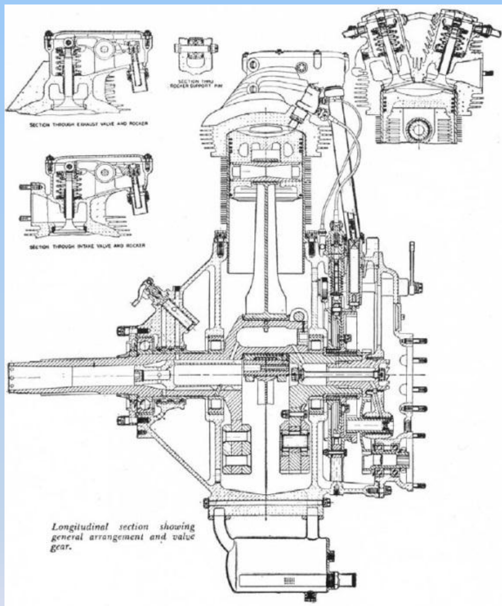
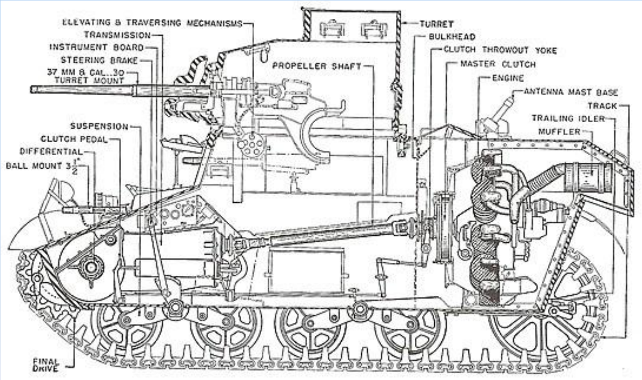


Fig. 27.—Sectional views of Guiberson A-1020.

AEHS Wilkinson Ch. 3



http://wargamers.19.forumer.com/a/m2-light-tank_post1211-20.html

What Wasn't Successful

- Packard DR 980
- Napier Culverin
- BMW-Lanova 114
- KHD 710
- Bristol Phoenix
- Jalbert Loire
- Coatalen
- Clerget
- ZOD 260B
- Godfrey
- Lawrance
- Fiat ANA
- Napier Nomad
- VM (VOKBM)
- McCulloch
- TCM (GPD)
- NASA Compound Cycle
- Garrett 2 stroke
- TCM NASA GAP
- Diesel Air/Gemini
- Merlyn
- Zoche
- CRM
- EcoMotors (OPOC)
- Achates
- Rybinsk DN 200
- SCOMA-Energie
- Engine Corp. of America

Why No Success?

- A failure in either leadership, financing or technical issues

- Packard DR-980 225 hp, 9 cyl. radial, 4 str. 1928
  - Good financing, right place & time, but not enough power
  - Single valve cylinders without exhaust manifold let exhaust into cabin, nauseating but not deadly
  - Said to vibrate badly, unknown if balance, firing impulse, or improper mounting
  - Suffered reliability issues because of a short three year development program, the rush to production is the killer of many engines

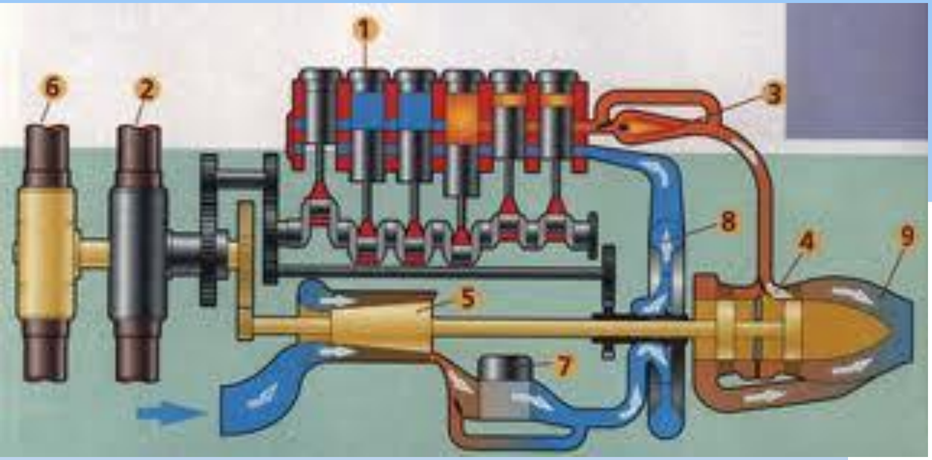

BB photo

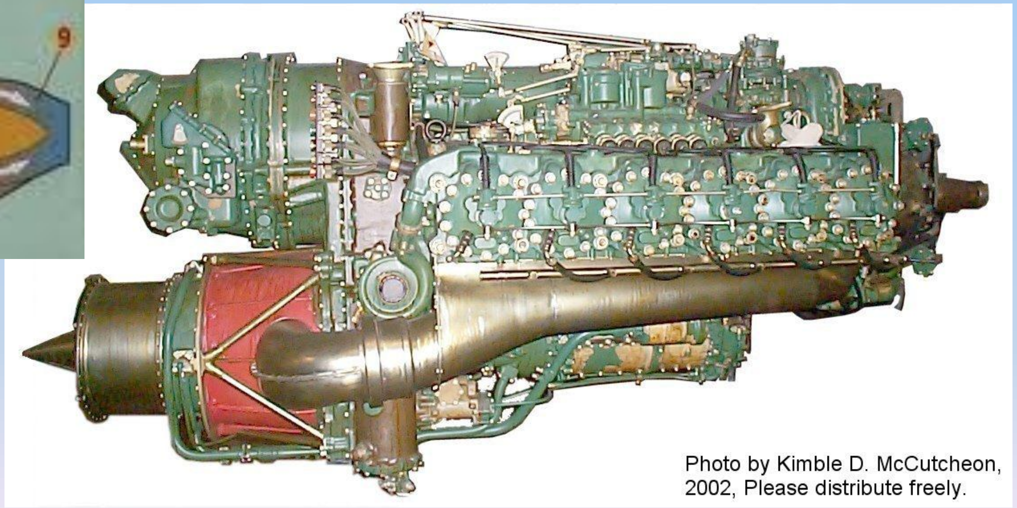

BB photo

Smithsonian 1964

Why No Success?

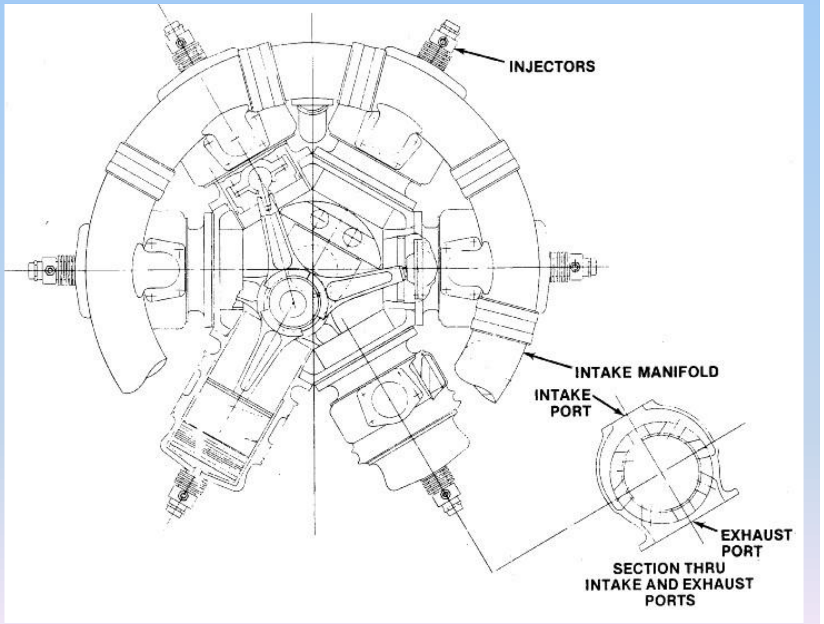
- Napier Nomad 3570 hp, 12 cyl., 2 str, loop scav turbocompound, 1950
  - Overtaken by gas turbines, low fuel costs
  - Very complex, Napier almost never made normal engines

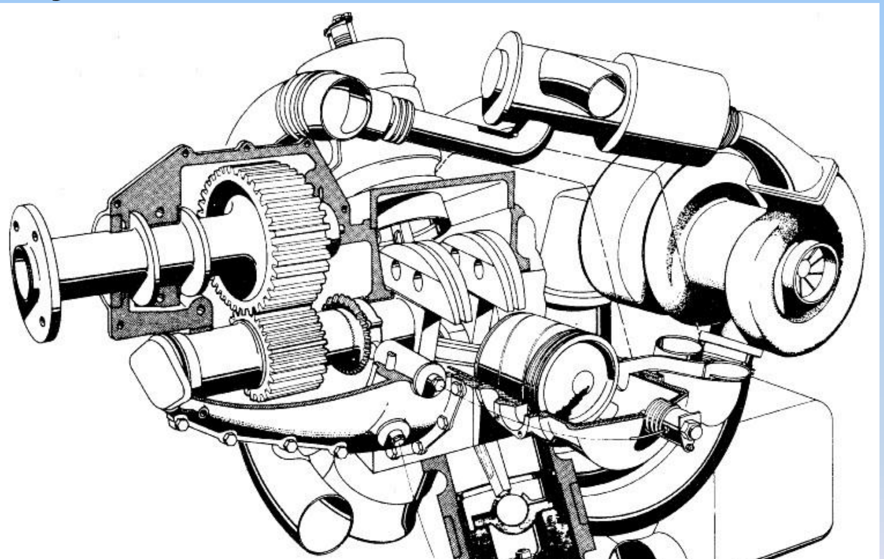




Why No Success?

- TCM General Products Div 400 hp, 6 cyl. radial, 2 str., loop scav., geared, turbocompound, catalytic combustor, VAT, ceramic piston, slipper rods, adiabatic, 1980
  - Right time
  - NASA funded, not well supported by company
  - Too much weird, especially adiabatic



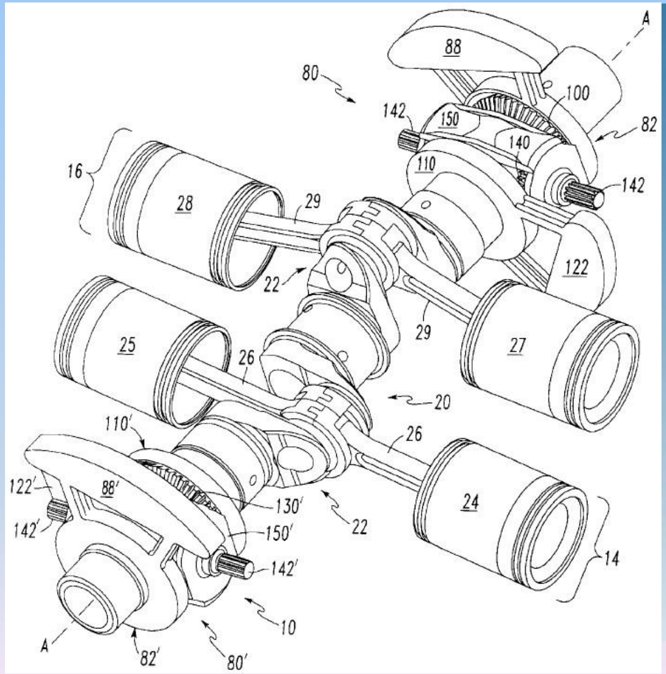


NASA Contractor Report 3260

Teledyne Continental Motors, Inc.
A Teledyne Technologies Company

Why No Success?

- TCM NASA GAP 200 hp, 4 cyl., opposed, 2 stroke, Uniflow, slipper rods,1996
  - Right time, but power too low for diesel market
  - NASA funded, not well supported by company
  - Too much weird, especially balance system
  - Brogdon engine, no good excuse



Success TBD

Engines in Hardware

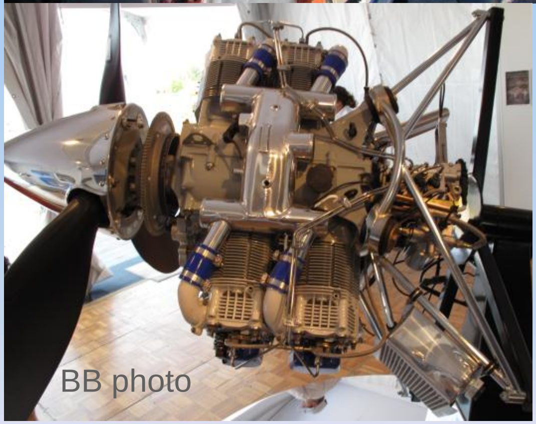
- SMA 305
- Delta Hawk
- Raiklhin
- CMD GF56
- Continental TD 300
- Steyr
- Wilksch
- EPS 180° V8
- Raptor Turbo Diesel

Paper Engines

- TEOS Powertrain Engineering
- CoAxe
- FairDiesel

SMA 305

- 230 bhp, 5L, four cylinder, opposed, air and oil cooled
- Weight competitive with SI
- Renault Sport (Formula 1) designed engine mid 90's
- Less than 100 installed, all STC's
- Tried by many OEM airframers
- Issues (reported to be resolved)
  - Propeller stress (4 cylinder)
  - Vibration (4 cylinder)
  - Charge air and oil cooler sizes
  - Minimum manifold pressure of 60" Hg
- First Reno Diesel Air Racer 2011
- Probable lack of consistent, forceful management



SMA 305

Continental Motors, Inc.

Continental TD 300

- 230 bhp, 5L, four cylinder, four stroke, opposed, air and oil cooled
- Weight competitive with SI
- Design license acquired in 2010
- Currently under development in Mobile AL
- Completed redesign to improve critical altitude, cold temperature starting ability and air cooling characteristics in late 2011.
- Entered FAA certification in Q1 2012
- Will be in rate production in Q1 2013


CMI photo

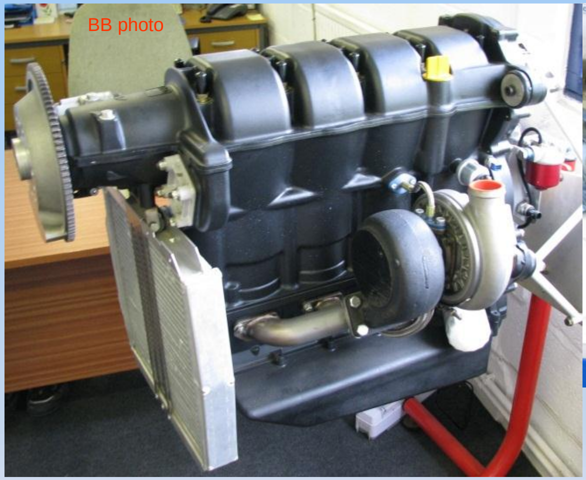

Photo J Ray, CMI

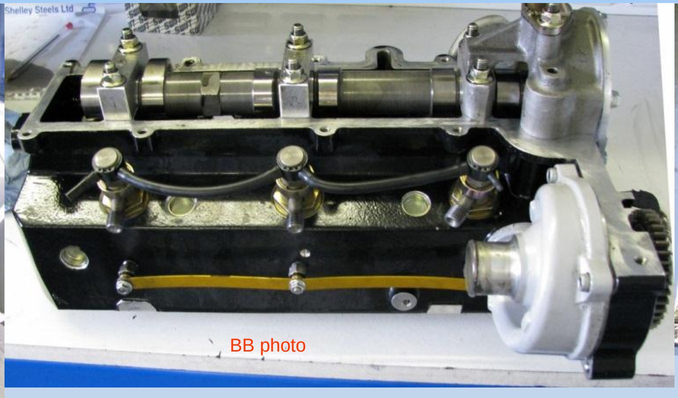
Photo J Ray, CMI

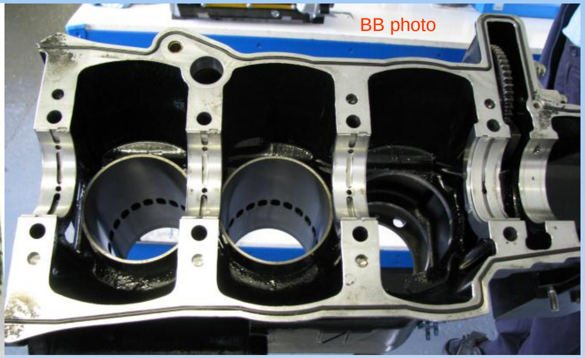
Wilksch Airmotive

WAM

- 130 bhp I3 and 190 bhp I4, inverted, two stroke, uniflow, IDI
- Mark Wilksch started in 1994, flew in 1997
- A pretty good small engine, smooth running, evidently fairly reliable
- 20 are flying, I flew in an RV9 in spring 2010







Raikhlin

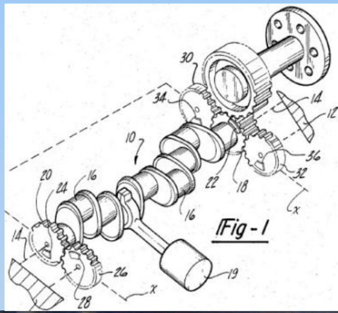
- RED AO3 V12 Aircraft Engine
- 6L, 500 bhp,V12, geared, four stroke
- Almost certainly an auto engine conversion, perhaps Audi? B/S don't match

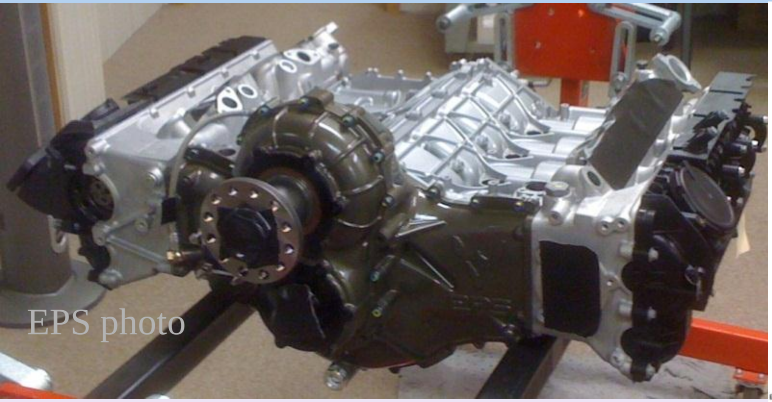
RED website photo

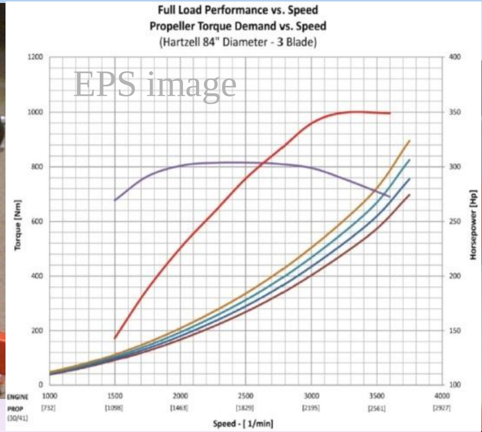
Audi website photo

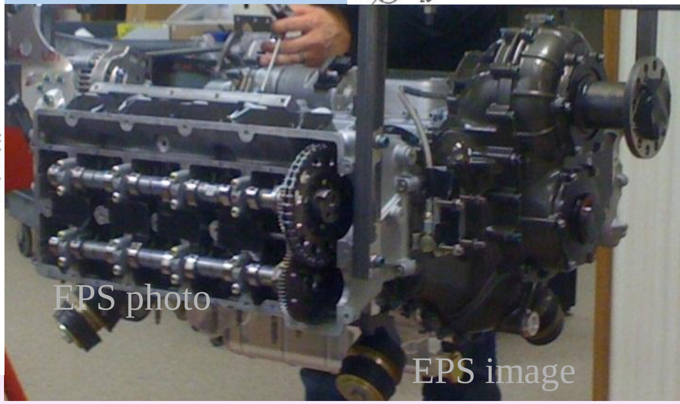
Engineered Propulsion Systems

- Small start up company in New Richmond WI
- Good technology (probably best of current candidates), limited funds but good business plan
- 350 bhp, 8 cylinder, geared,180°V, 4.4L, four stroke
- Running demonstrator (Nov 2011), BMW heads and other components (production will use EPS parts)
- Excellent fuel consumption 214 gm/kW/hr (.35lb/hp/hr)
- Weight competitive









Significant Issues for the Future

- Jet-A specification has no cetane requirement
  - Synthetic Jet-A may have cetane of 20 or less
    - High minimum manifold pressure requirements
    - Starting issue
  - Will the Military force cetane requirements for “one fuel forward”?
  - Current Jet-A cetane as low as 40, this is ok
- Possible required unleaded avgas will benefit diesel
- Uncertain markets
  - Will the BRIC and other emerging nations embrace General Aviation?
  - Will a phase out of 100LL wreck GA in the US?
- Will UAV’s start using significant numbers of diesels or will they go to gas turbines?

What Will Drive A Successful Future Diesel

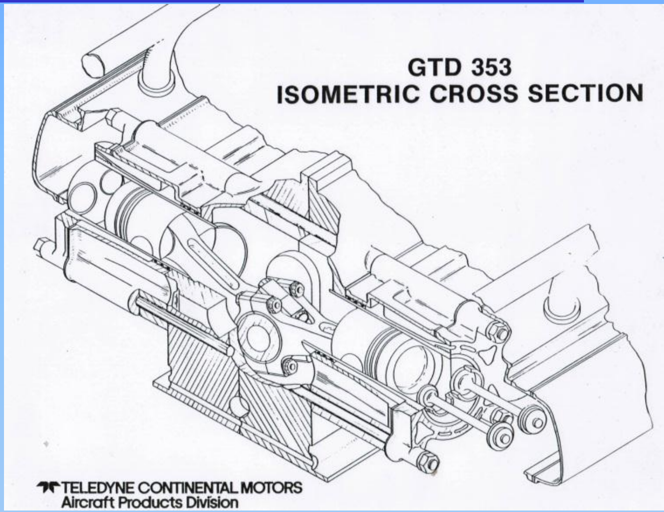
- Emerging Markets
  - Big countries with small road infrastructure
    - China, India, Brazil, Russia
    - Africa
    - SE Asia
  - Phase out or non-availability of 100LL
    - Europe
    - US in 10-15 years
- Appropriate power for airframes
  - Singles for individuals? 250-400 bhp
  - Twins for commercial? 400-1000 bhp
- Strong partnership of engine and airplane manufacturers
- Financial and management strength

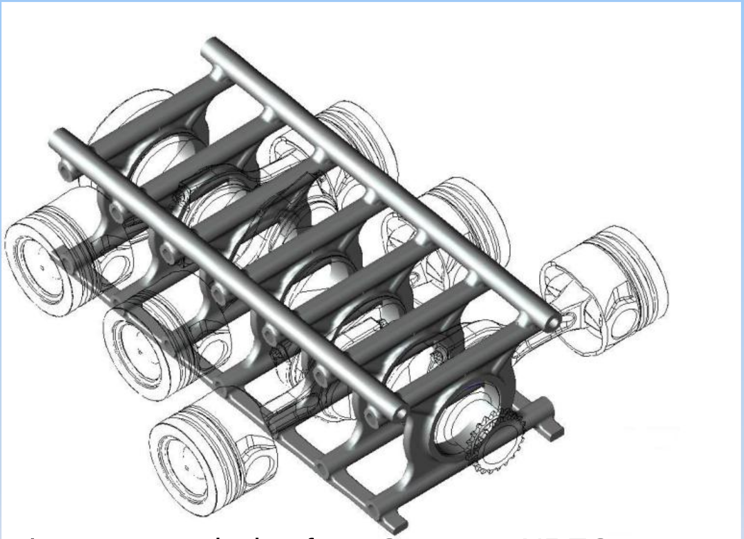
Brogdon's Engine for the Future

- The presumption is that the diesel market will be for GA and UAV
  - ~400 bhp for personal GA (e.g. Cirrus)
  - ~1000 bhp for business GA (e.g. King Air)
  - ~30-400+ for UAV
- Four stroke, not a two stroke
  - Surpassed weight specific outputs of two strokes
  - This is the technology being developed by truck engines
  - Much better durability at high thermal loading
  - Easier turbocharger match
  - No need for starting blower
- Liquid cooled because of high power density
- Direct drive flat 6 for 400 bhp
- Geared flat 12 for 1000 bhp

Brogdon's Favored Engine Construction

- Flat six, 7 main crank, through bolted
- Flat twelve, 7 main crank, fork & blade or side by side rods
- Cylinder barrels screwed into heads to eliminate head gasket
- Steel main bearing saddle
- Overhead four valve, two high camshafts
- Unit pump or unit injector fuel injection





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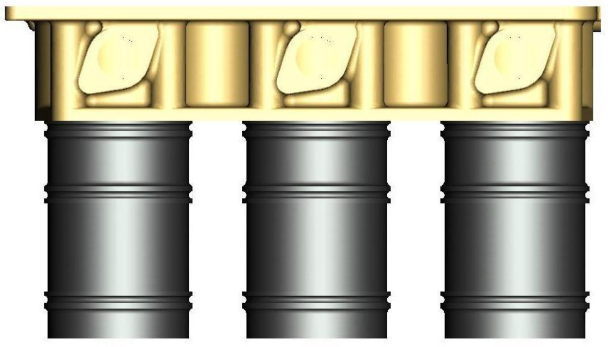
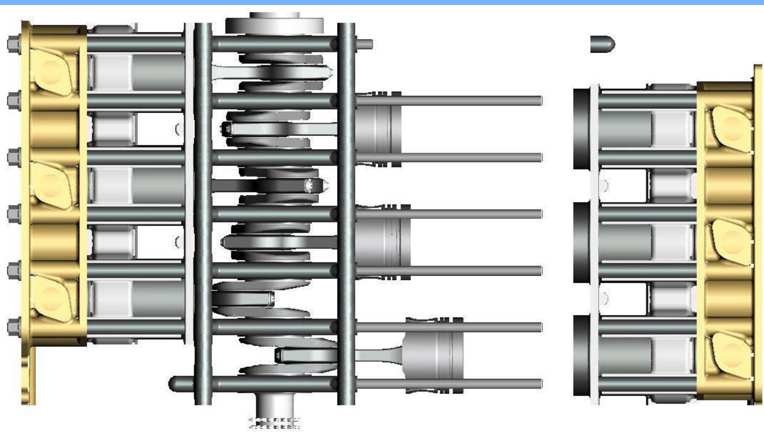
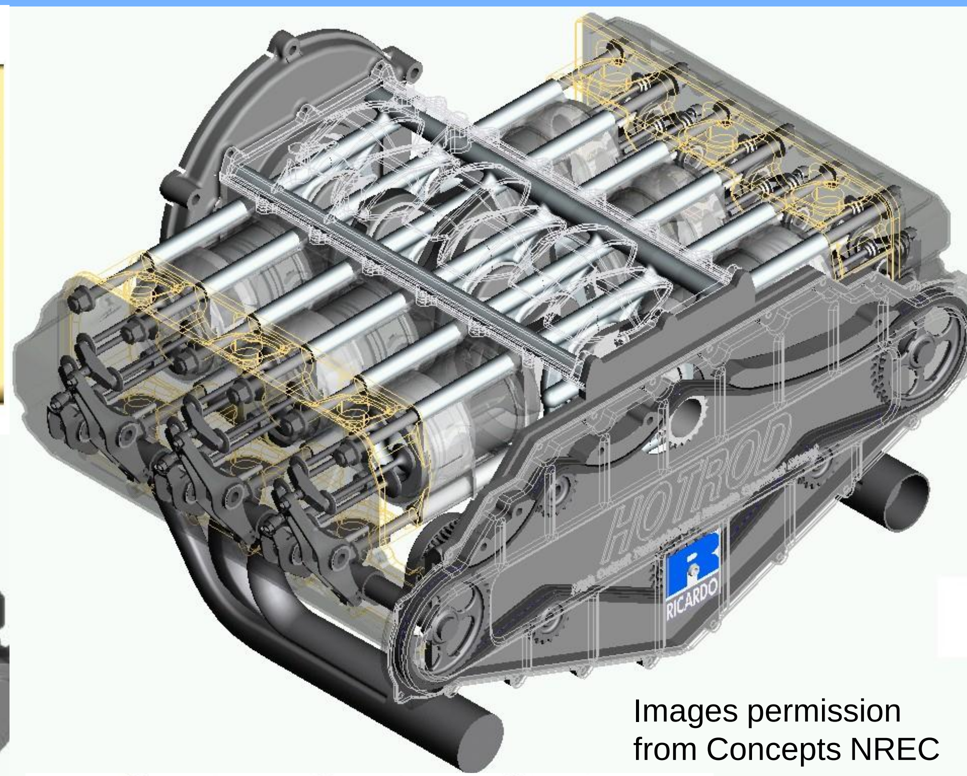


Brogdon’s Favored Engine Construction





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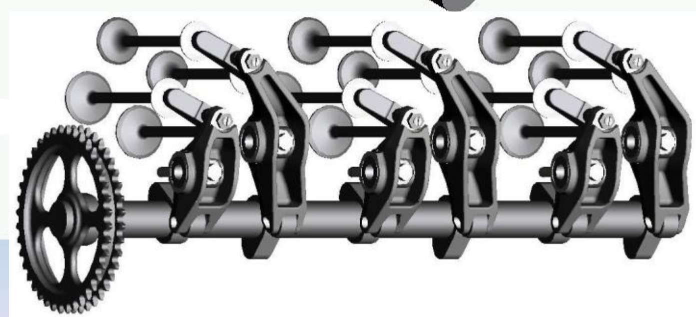
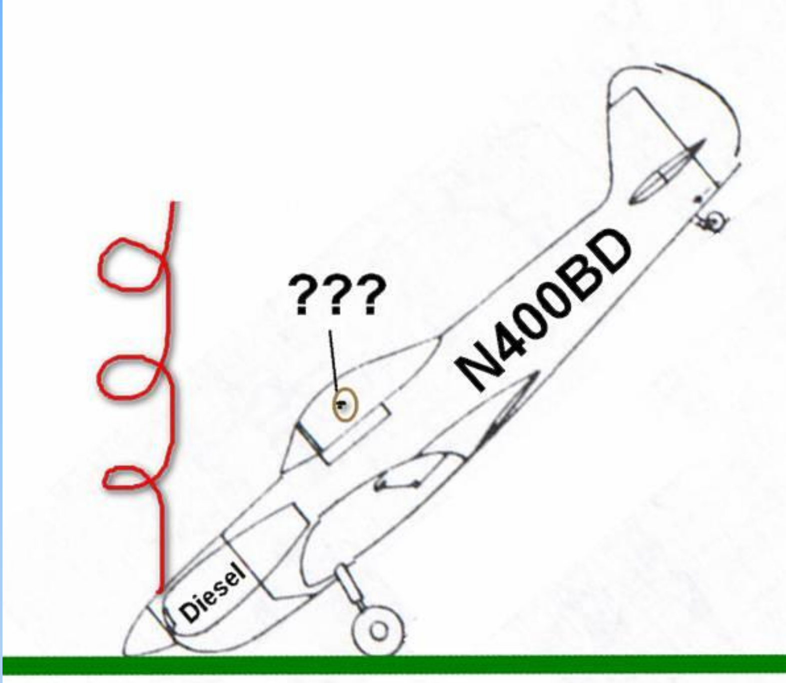


What Probably Won’t Work

- Two strokes (except for low power density)
  - Lubrication of the cylinder above the ports is an unresolvable issue for high power density
  - This includes:
    - Opposed Pistons (especially because of exhaust ports)
      - Achates
      - OPOC
      - DAIR/Gemini
      - CoAxe
      - FairDiesel
    - Loop scavenge
      - Delta Hawk (sorry Dennis)
    - Uniflow
      - WAM works pretty well, but power increase problematic
      - Raptor
- Barrel engines, cam engines, any non-slider crank

Why Haven't Diesels Taken Over?

- Weight, but that's improving quickly
- Other technology that was time appropriate
  - Spark ignition engines in WW2
  - Gas turbines post war
- Market success of SI in General Aviation
  - SI was good enough
- Development costs are very high for any new engine, more so for diesels



Apologies to Dr. Jan Roskam

- Interesting competition-Two pairs of similar designs
  - Air cooled 4 – France vs. US-China
  - Liquid cooled auto conversions – Germany vs. Austria

Discussion