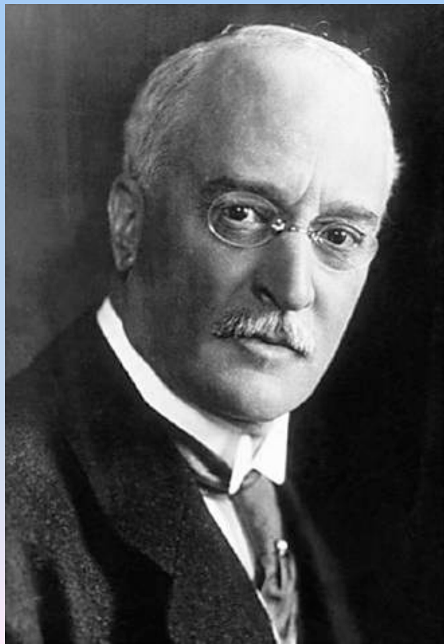
Aircraft Diesel Engines

Why haven't they been really successful?

What will the future bring?

by Bill Brogdon
November 12, 2020

Rudolf Diesel
1858-1913



Some of My History

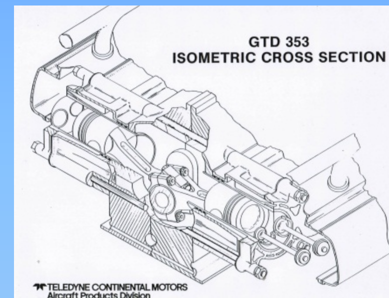
- Rambling Wreck from Georgia Tech
- 1968 B. Mechanical Engineering

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

Teledyne Continental Motors

Teledyne Continental Motors, Inc.

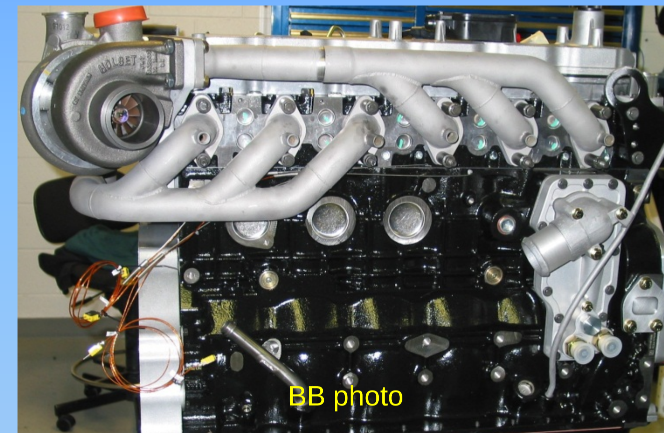
- 1976-98 & 2007-10
- Design Engineer
  Director Engineering
  Chief Engineer
- Engines
  - TSIOL300 Boeing Condor
  - IOL-200 Voyager
  - TSIOL 550 RAM 414
  - Grob Strato 2C HALE
  - NASA GAP diesel
  - O-200D Skycatcher




JCB photo

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 0.5 to 10,000 hp


BB photo


CMD photo

About This Presentation

- Engine design guy, let me know when my jargon is unintelligible
- 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
- SI = spark ignition, CI = compression ignition (diesel)

Aircraft Diesels -- Why?

- Fuel economy
  - Cost
  - Range
- Fuel availability (Jet A available world wide, avgas no)
- Fire safety and no CO
- Operational
  - Single lever fueling control
  - Inlet (carb) icing due to fuel evaporation not an issue
- Potentially longer TBO (time between overhauls)
- The emphasis on each changes over time
- Diesels are now in a rapid phase of development due to trucks and cars; this can be applied to aircraft diesels

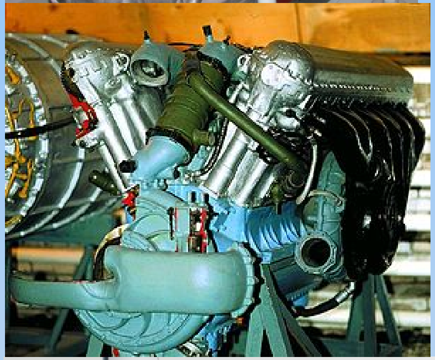
Factors in Engine Success

- *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, availability, maintainability
  - Fit in airplane
  - Good operational features

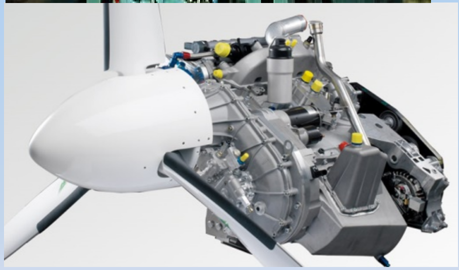
What Has Been Successful

- Junkers Jumo 205 & 207

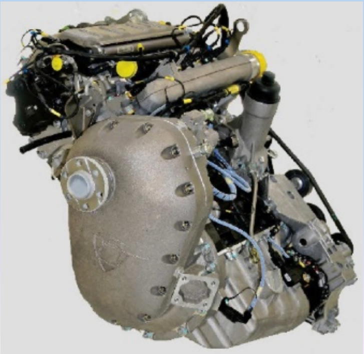
- Charomskiy ACh-30 & M40



- Thielert Centurion 1.7 and 2.0

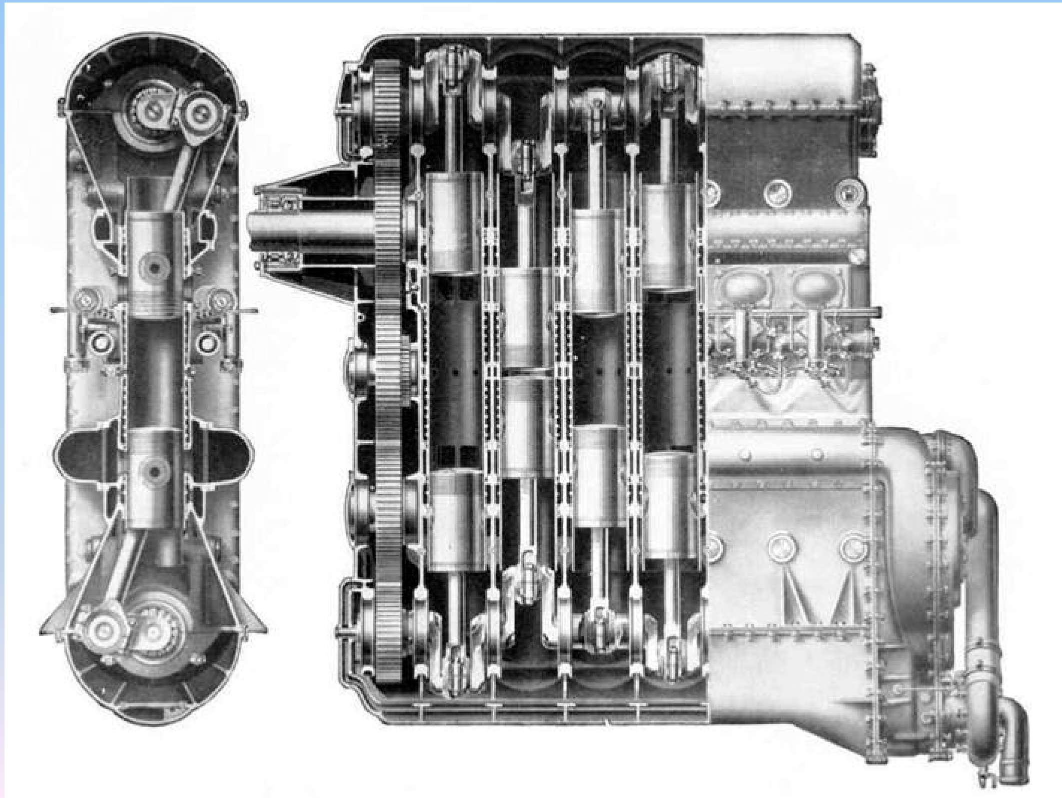


- Austro 300 &330



Junkers Jumo 204-207

- Six cylinder opposed piston (OP) 600-1000 bhp
- Turbocharged 207 1000 hp operational to 46,000’
- Do18 with 2-205’s flew 5214 miles England to Brazil, then a world distance record
- 900 engines produced from 1930’s thru WW II



Do26

Do18

BV 222

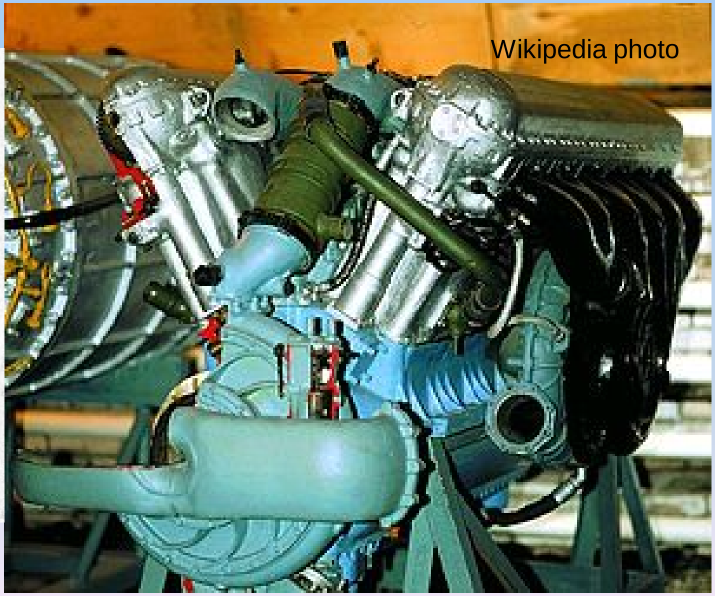
Junkers Jumo 204-207

- 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 & 2.0 L conversions of Mercedes OM 640
- 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
- 3500 engines produced since 2001

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
- Continental Motors, now Continental Aerospace Engineering purchased Thielert in 2013
- 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 certified type design a real issue

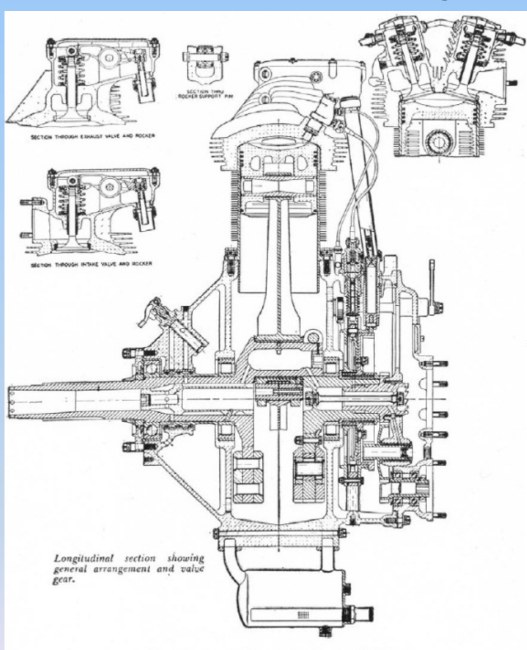
Austro AE300 & 330

- 2L, 165 & 180 bhp, four cylinder, geared, common rail, 410 lb., conversion of an OM640 Mercedes car engine
- Diamond has been experimenting with a number of engine options over the years
- Diamond Aircraft formed Austro Engine company
- To replace Centurion engines in Diamond Airplanes, 1500 engines in service
- Initially a well funded company with dynamic management by Christien Dries
- Financial troubles in the 2008 recession led to acquisition by Chinese company Wanfeng Aviation in December 2017

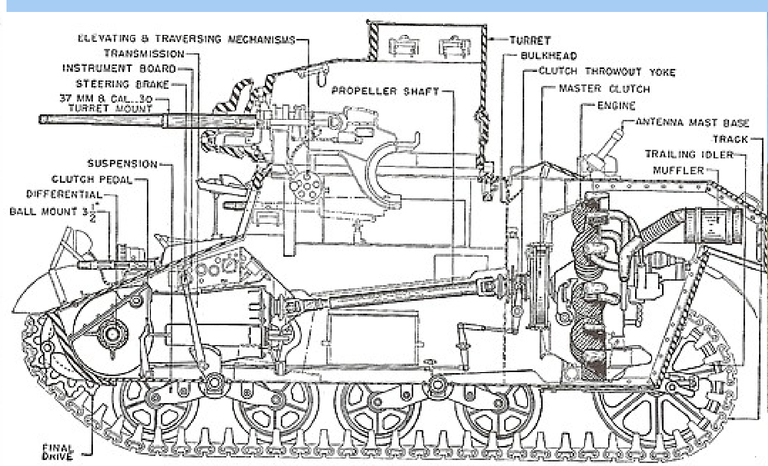
Diamond DA 62

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



AEHS Wilkinson Ch. 3



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

By Kecko - Operational M3,

What Wasn't Successful

- Packard DR 980
- Napier Culverin
- BMW-Lanova 114
- KHD 710
- Bristol Phoenix
- Jalbert Loire
- Coatalen
- Clerget
- ZOD 260B
- Godfrey
- Diesel Jet
- Lawrance
- Fiat ANA
- Napier Nomad
- McCulloch
- TCM (GPD)
- NASA Compound Cycle
- Garrett 2 stroke
- Beardmore
- VM Motori
- 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 leadership, financing or technical issues

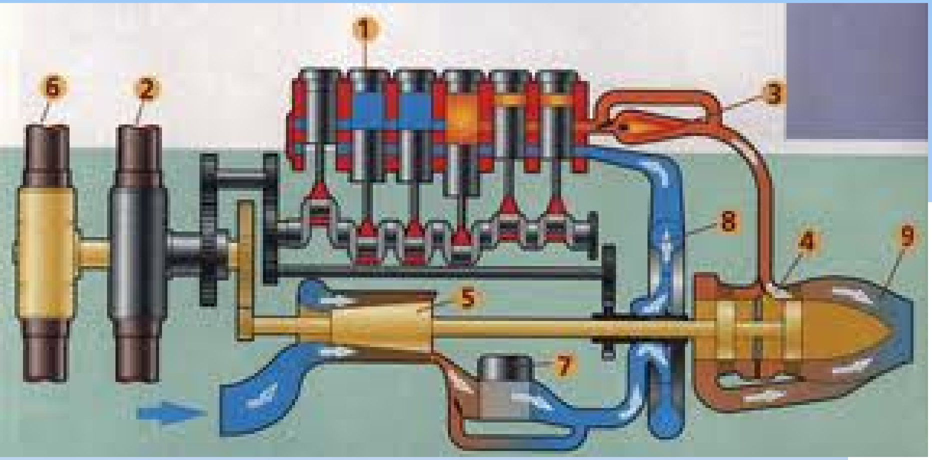
Why No Success?

- Packard DR-980 225 hp, 9 cylinder radial, 4 stroke, 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

Smithsonian 1964

Why No Success?

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



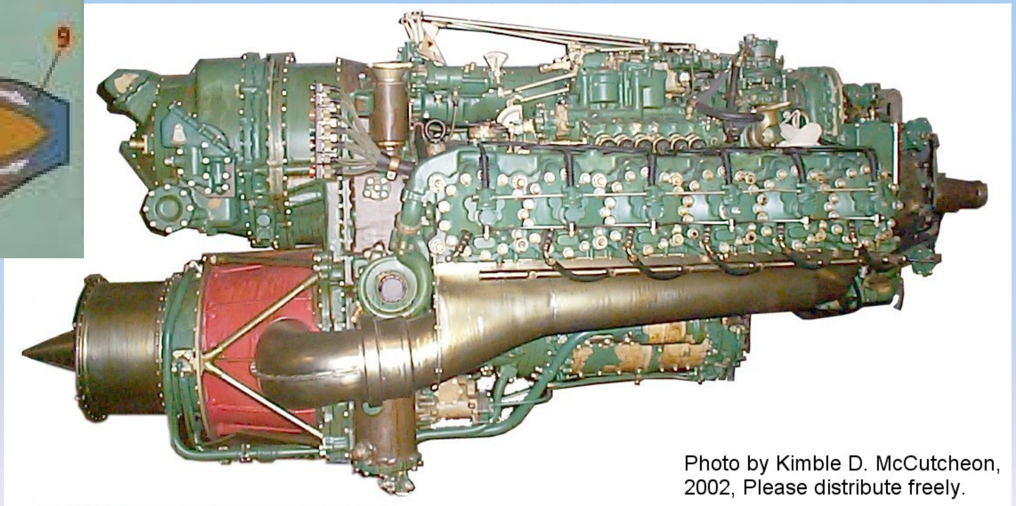
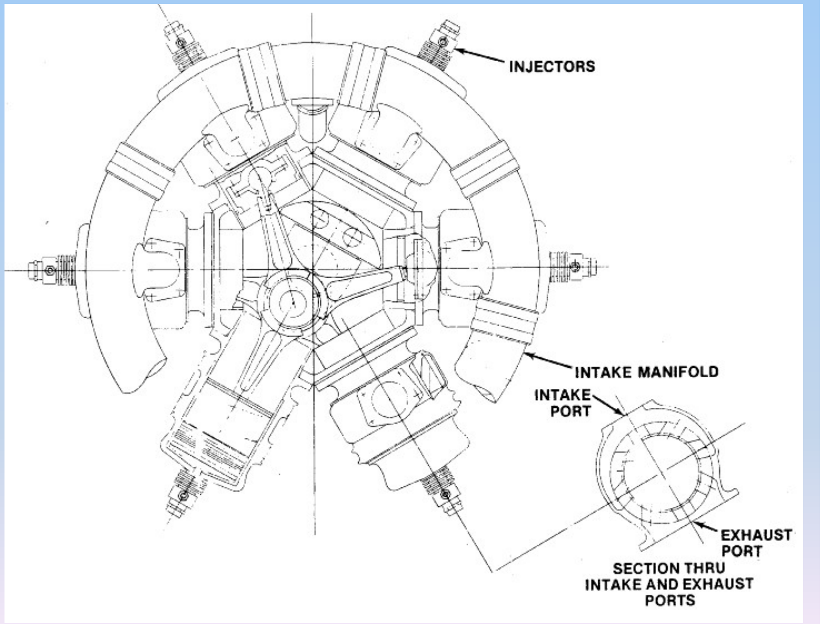
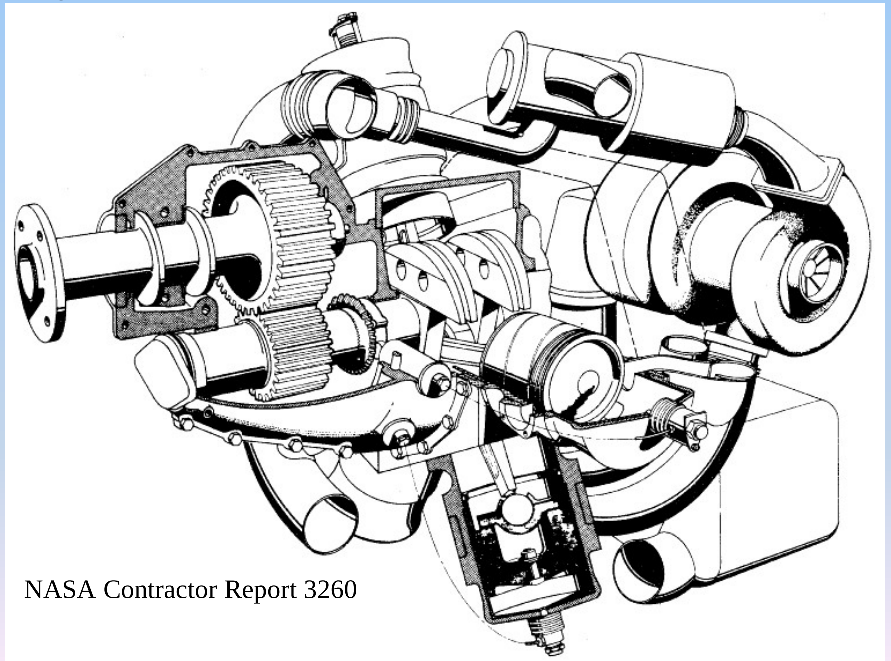


Photo by Kimble D. McCutcheon, 2002, Please distribute freely.

Why No Success?

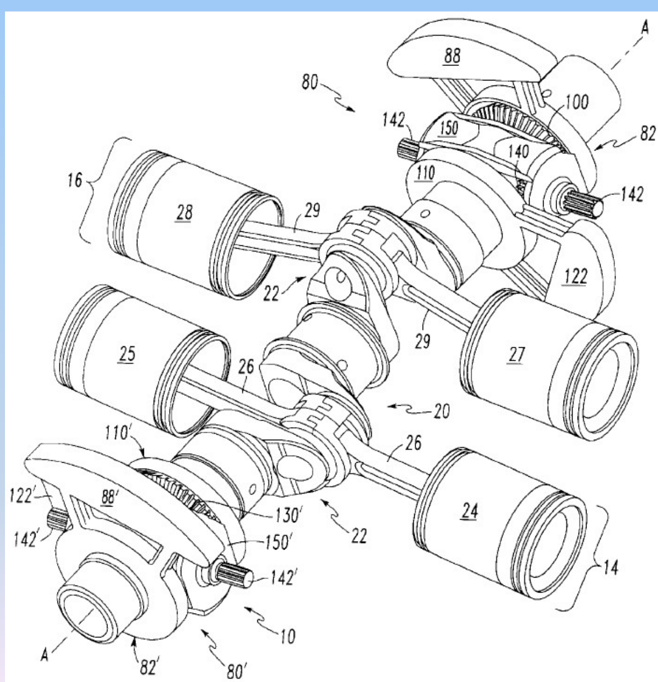
- TCM General Products Div 400 hp, 6 cyl. radial, 2 str., loop scav., geared, turbocompound, catalytic combustor, VAT, ceramic piston, slipper rods, adiabatic, 1980
  - Right time
  - NASA funded, not well supported by company
  - Too much weird, especially adiabatic

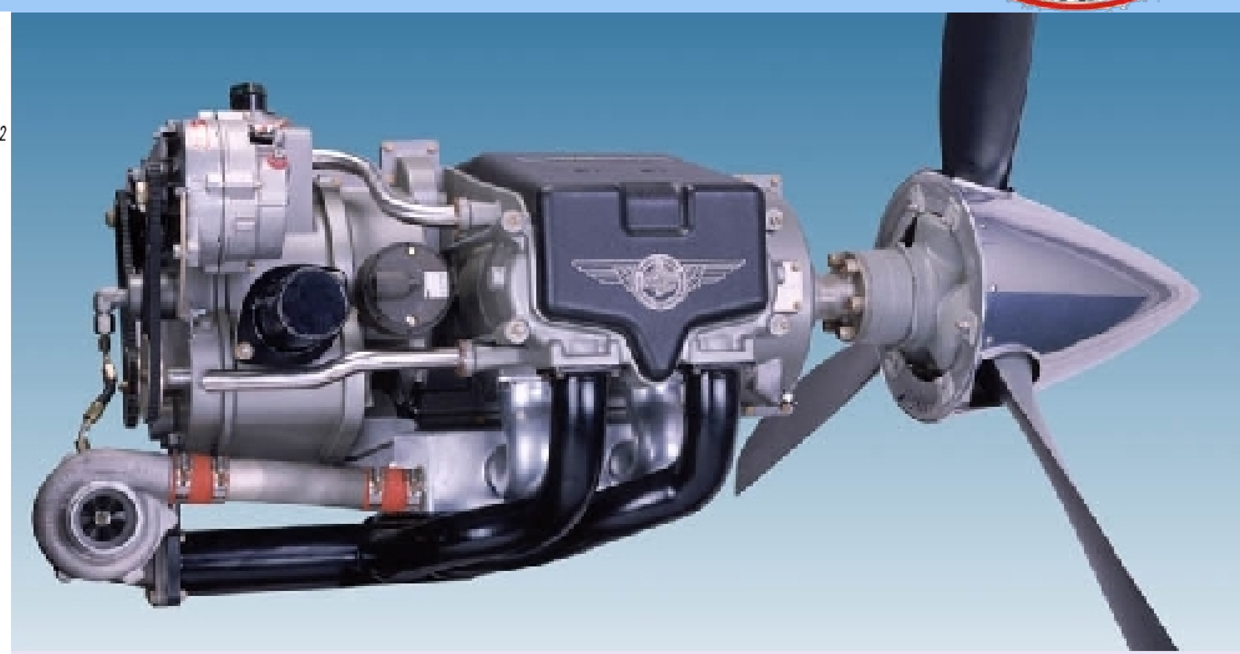




Why No Success?

- 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

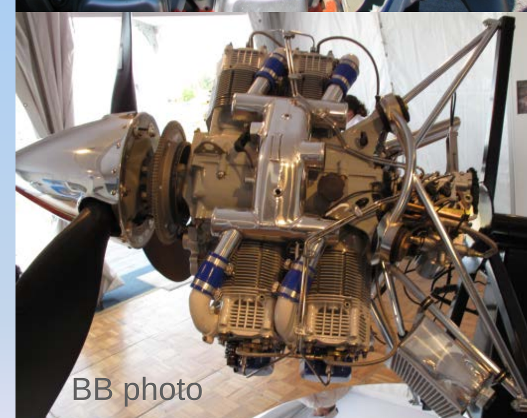
- SMA 305
- Delta Hawk
- Raikhlin
- CMD GF56
- Continental CD-230, 265
- Steyr
- Wilksch
- EPS 180° V8
- Vulcan Turbo Diesel

Paper Engines

- TEOS Powertrain Engineering
- CoAxe
- FairDiesel

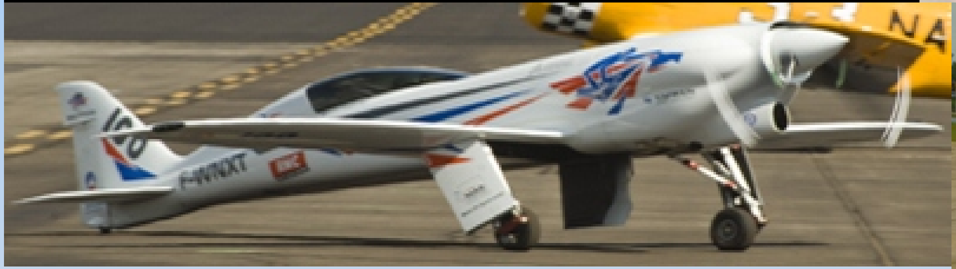
SMA 305

- 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



SAFRAN
SMA

SMA 305



Continental CD-230, 265

- 5L, 4 cylinder, 4 stroke, opposed, air and oil cooled
- 438 lb. weight competitive with SI
- SMA design license from 2010
- 234 bhp@2500 version for airplanes
- 264 bhp@2700 version for helicopters
- Certified but not in serial production

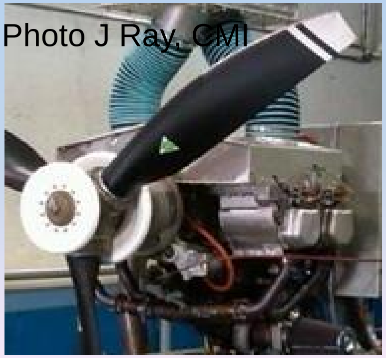
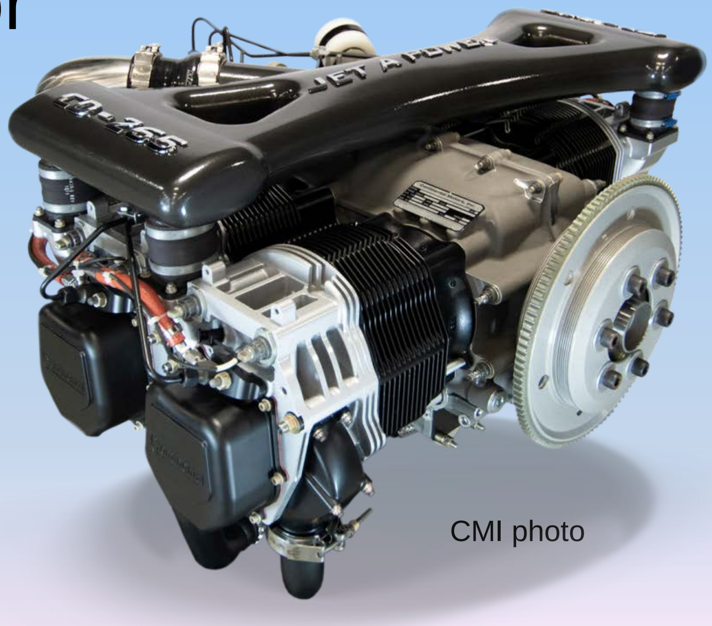


Photo J Ray, CMI

Photo J Ray, CMI

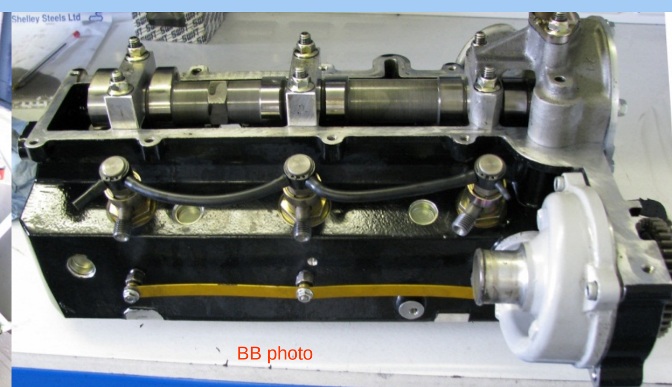


CMI photo

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

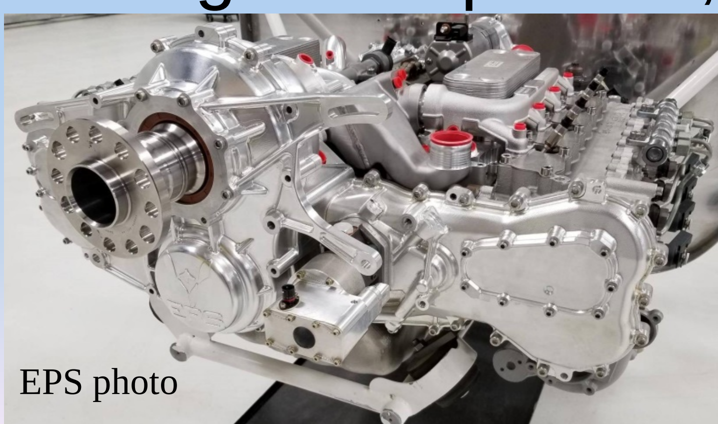


Raikhlin

- RED AO3 V12 Aircraft Engine
- FAA & EASA certification 2014
- 6L, 5-600 bhp,V12, geared, four stroke
- Clean sheet design, not auto derived
- German company, Russian design

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, current engines use EPS parts)
- Excellent fuel consumption 192-207 gm/kW/hr (.32-.34 lb/hp/hr)
- Weight competitive, 650 lbs, supposedly in cert.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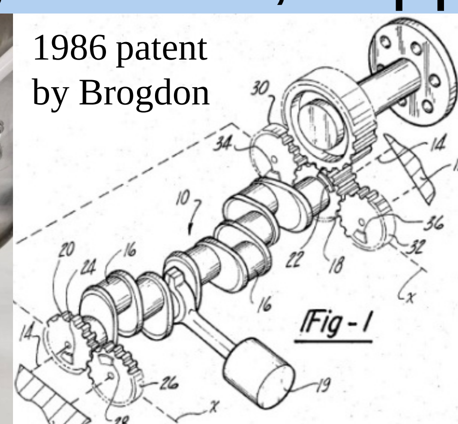
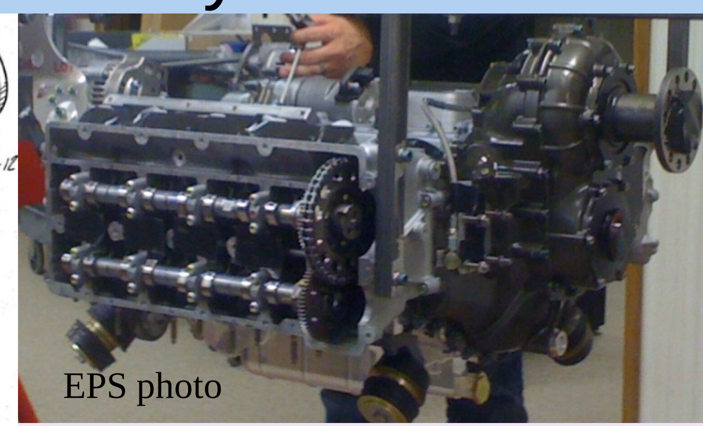


1986 patent by Brogdon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Significant Issues for the Future

- Jet-A specification has no cetane requirement
  - Current Jet-A cetane as low as 40, this is ok
  - 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”?
- 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 avgas 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

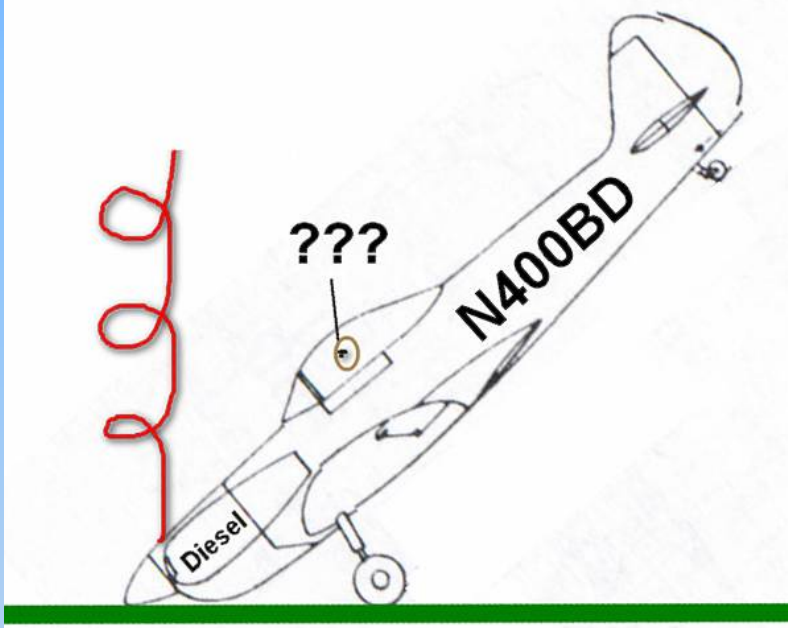
- Emerging Markets
  - Big countries with small road infrastructure
    - Brazil, Russia, India, China (BRIC)
    - Africa
    - SE Asia
  - Phase out or non-availability of 100LL
    - Europe
    - US in 10-15 years
- Appropriate power for airframes
  - Singles for individuals? 250-400 bhp
  - Twins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

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

Discussion

Discussion

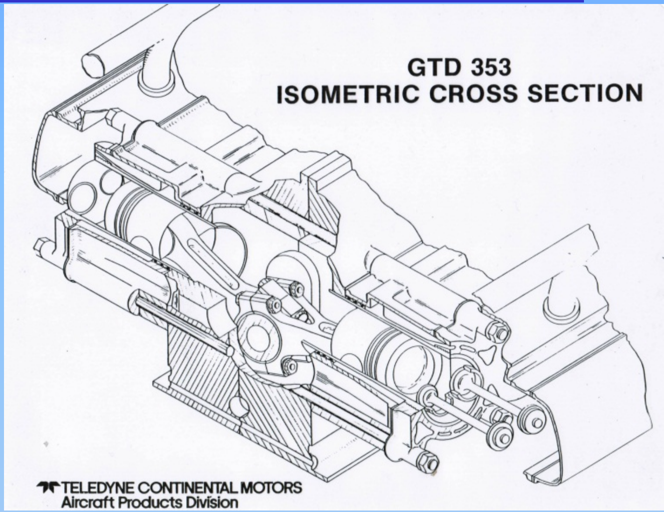
Kalinin K-7

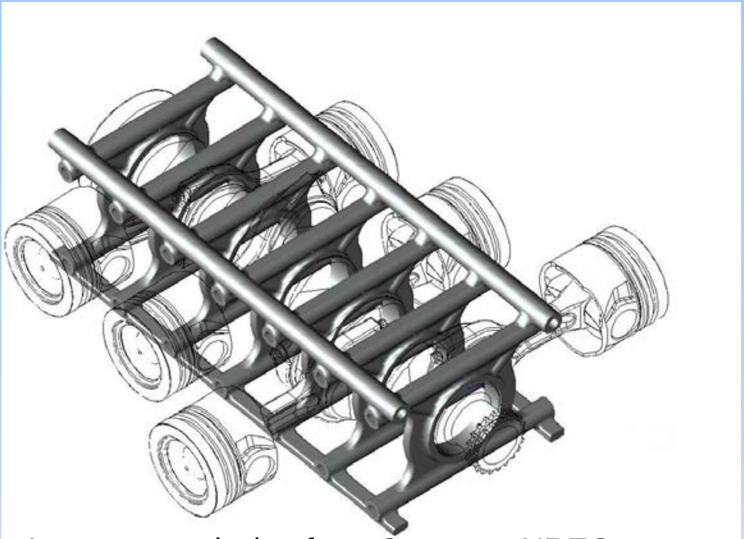

Brogdon’s Engine for the Future

- 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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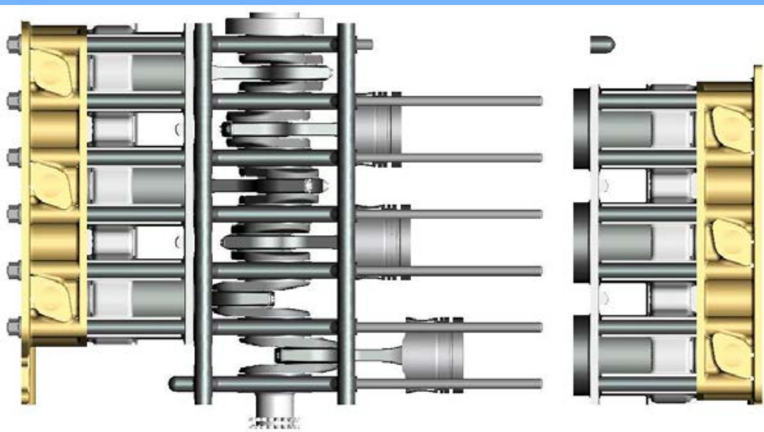
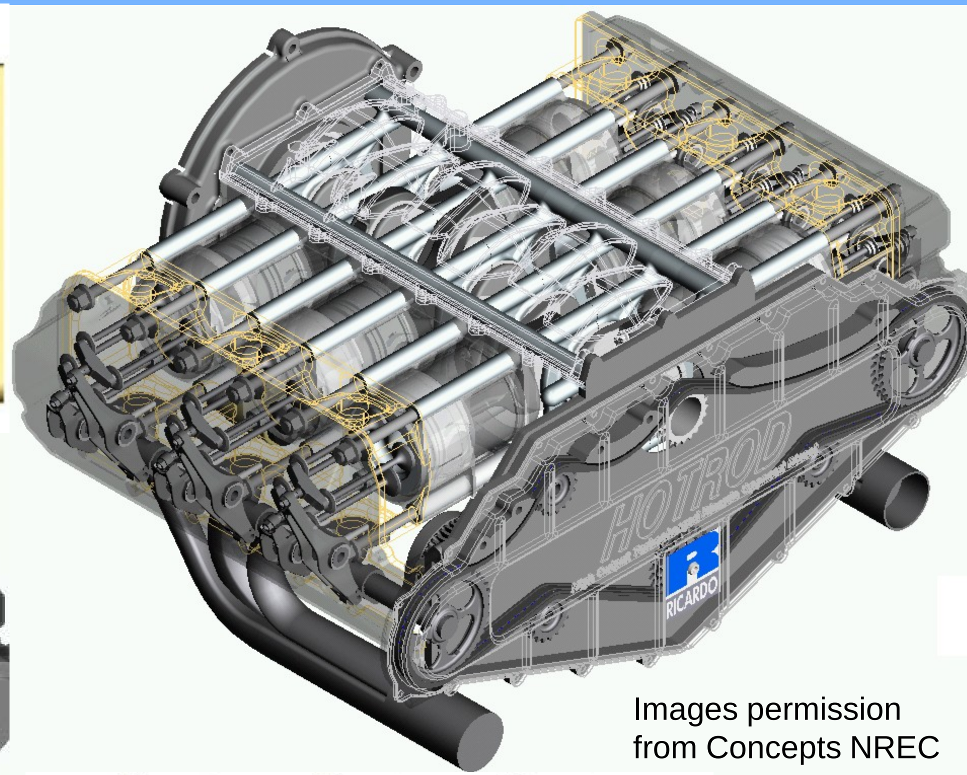
Brogdon’s Favored Engine Construction





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