Perspicuous Technologies

Engines and Propulsion Systems

Thoughts On Advanced Technology Demonstrator Program Opportunities

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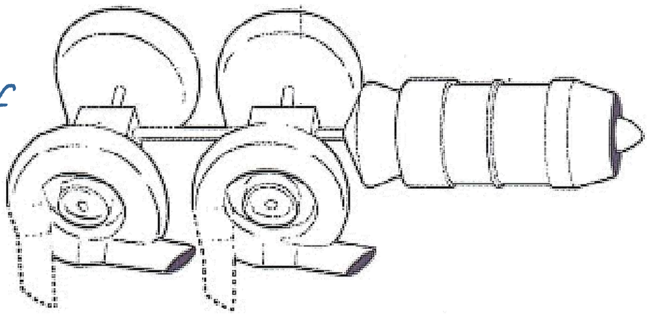
Innovation From The Engine Quarter

In early 1957, Hawker Aircraft's chief designer, Sydney Camm, responsible for the Hawker Hurricane, Typhoon, Hunter, and other famous aircraft, was attending the Paris Air Show. There, he happened to chat with the Hawker representative in France, Gerry Morel, a Frenchman who had been a member of the British SOE during the WWII. Camm mentioned that he was unimpressed with most of the "lift-engine" VTOL schemes being put forward at the time, and Morel told him about Stanley Hooker's Rolls Royce tinkerings based on the "Orpheus" turbojet engine (BE.53). Camm wrote a letter:

Dear Hooker:

What are you doing about vertical take-off engines?

Yours, Sydney



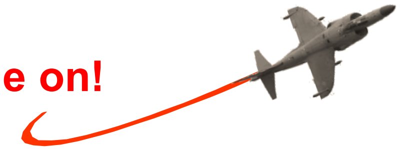
-- and a few days later Camm got back an envelope containing data on the BE.53. He passed it on to his engineering staff, and in due time got back a preliminary sketch of a VTOL aircraft. Some time later, in early March 1957, Camm then gave Hooker a call, starting out with:

"When the devil are you coming to see me?"

"About what?" Hooker replied.

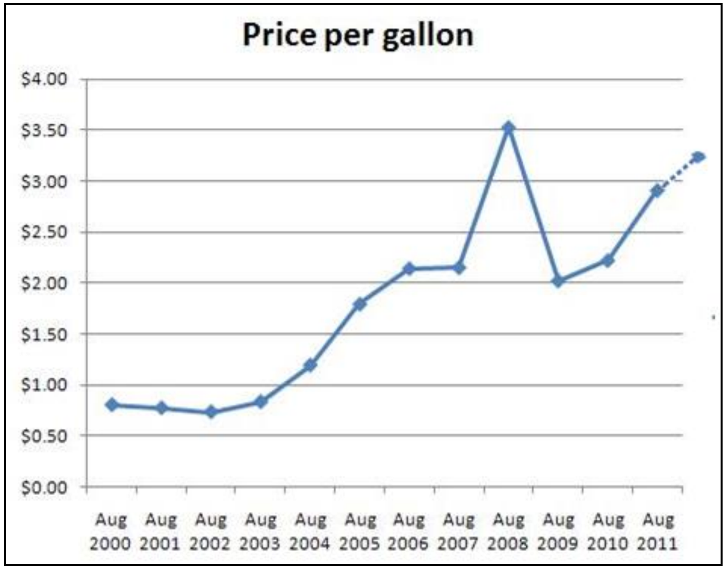
"About this lifting engine of yours, you bloody fool! I've got an aircraft for your BE.53!"

…and game on!



Fuel Costs – Part Of Future Strategy Must Be To Reduce Consumption

- The Department of Defense (DOD) relies heavily on petroleum-based fuel for mobility energy—the energy required for moving and sustaining its forces and weapons platforms for military operations
  - Dependence on foreign oil
  - Projected increases in worldwide demand
  - Rising oil costs
  - Logistics burden associated with moving fuel on the battlefield
- Ongoing need for DOD to reduce its mobility energy demands
- A key approach is more efficient petroleum-based fuel engines, examples:
  - Re-engine B-52 (burns ~3,334 gals per flight hour; after re-engining, 2,218 gals per hour - saving around 24 million gallons of fuel per year)
  - CODOG ships
  - Gas Turbine-Diesel hybrid engines (helicopter)



Jet fuel increased from $0.80 per gallon in 2000, to $1.90 in 2006 to around $3.20 in 2012 (to date)

A Need For New Aviation Engine Development To Better Use Existing Energy Reserves

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- Strong dependency - global economies primarily petroleum based
- Humanity certainly needs the development of new transformational technologies that disrupt the dependency on oil (and other fossil)
- However, sensibly, a balanced strategy is required to:
  - Develop recognized alternative energy – perhaps "greener" such as wind, wave, solar, hydro, geo-thermal etc
  - Find transformational new technologies – nuclear fusion, photosynthetics…or otherwise make science fact out of science fiction because without this, trouble lies ahead unless mankind is headed for a new Neolithic age
  - Make better use of remaining oil reserves
- More efficient and novel aero-engines should be part of the last but unfortunately, they are apparently becalmed in an R&D backwater
- DARPA and ARPA-E largely ignore new hydrocarbon fuelled engine approaches – perhaps appearing insufficiently revolutionary, not transformational or having too little "super-science cachet" or dazzle
- Weakens our ability to secure better use of remaining oil reserves

There Is An Urgent Need To Develop Innovative Novel Engines Seeking The Goal Of Raising Efficiency From 25 To 45%, For Retro-fit Initiatives

What's Going On With Aviation Engine R&D

- ASD (R&E):
  - Future Vertical Lift
- DARPA
  - Biofuels
  - Vulcan – Constant Volume Combustor
  - Falcon - Hypersonics (Schulz)
  - Materials
- ONR (/NAVAIR)
- AATD
  - Advanced small engines/JMR-FVL
- AFRL
  - Motor house – ADVENT
- ARPA-E:
  - Alternative energy
  - Little weight given to petroleum powered engines

Need A New Mandate – Otherwise There Is No Imperative To Initiate A New Generation Of More Novel, Tailored, Efficient Aero-Engines

US Aviation Weakened – DARPA ATD Example

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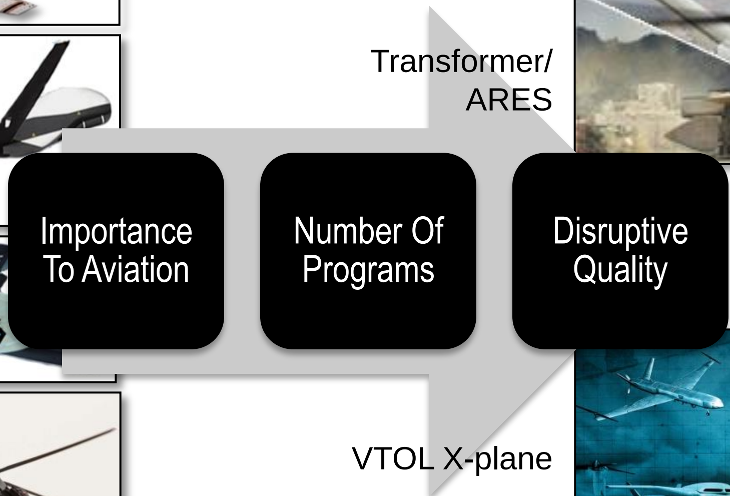
- Hitherto, DARPA-led ATD aircraft platforms have rated large in US national aviation defense efforts:
  - Relevant to the warfighter – however, technically, were often at variance with conventional approaches
  - Covered a wide operational missions spectrum - FW, RW, UAV, Strike, ISR etc
  - More revolutionary than evolutionary – surer path to disruptive capability fielding
- But… aircraft ATDs act as technology “locomotives” – they can pull forward other systems development, including aero-engines

Past





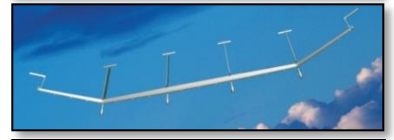


Compare

Present

Hypersonics

Vulture

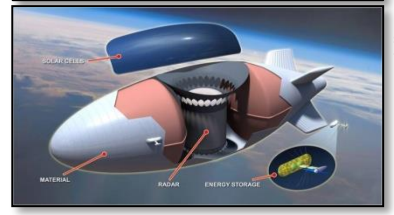


Transformer/ ARES

VTOL X-plane

TERN

ISIS



DARPA – Public Release

Tailored Novel Engine Concepts – Making Better Use Of Fuel Resources

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- Aero-engines that integrate to airframes ..
  - Turbo-diesel Compound Engine
  - Turbo-Shaft/Jet Thrust Hybrid Engine
  - Variable Speed – Optimized Free Power Speed Rotor
  - JMR – Optimized Speed Rotor
  - Hybrid Airship Integrated propulsion System
- Morphing Aircraft, Hypersonics & ISR
- More Novel Technologies

There Is An Opportunity, That Appears To Have Escaped Attention Or Priority, For A Breed Of More Novel And Tailored Aero-Engines - Integrated Into Airframes That Exploit Inherent Efficiencies To Achieve Twice The Range/Endurance For Every Unit Of Fuel Used

Turbo-Diesel Compound Engine

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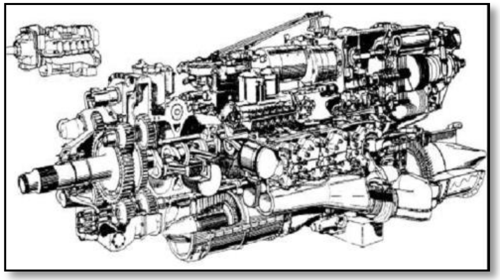
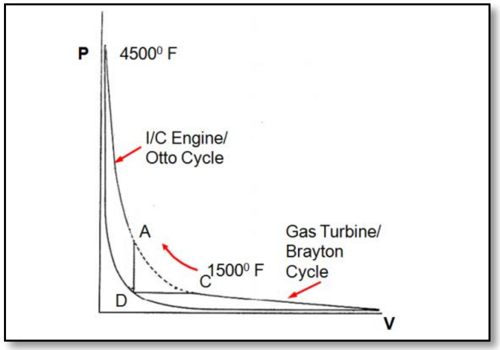
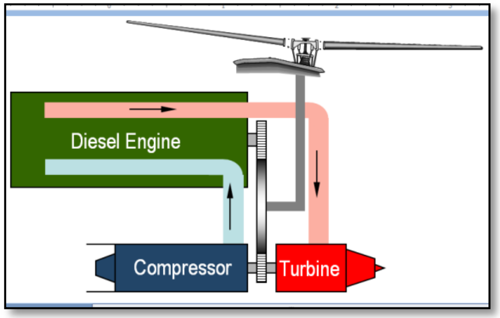
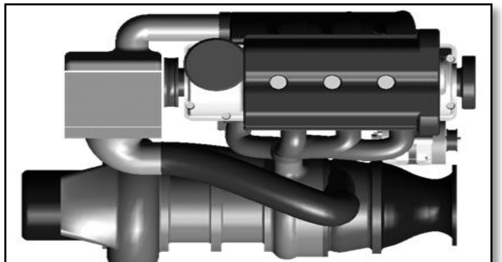
- Helicopters – performance limitations - **range** and **endurance**
- A160 Hummingbird, conceived by Abe Karem planned to use a new development Diesel engine
- Better solution with more capability is the Turbo-Diesel Compound engine:
  - Achieve extreme efficiency improvement (µt =45%) (I/C alone ~ 27%)
  - Power to Weight approaching GT technology standards (3:1)
  - Sfc 0.31 lb/hp. Hr
  - Low lapse rate
- 400 – 3000 hp class for UAV, UGV, manned aircraft and ground vehicles








Courtesy Ricardo

Turbo-Shaft/Jet Thrust Hybrid Engine

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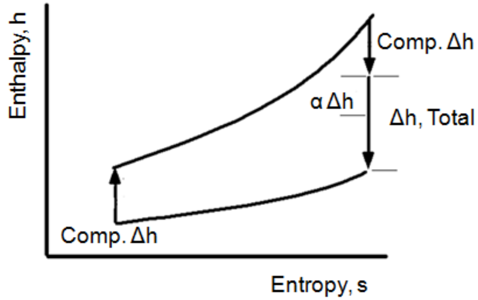
- Helicopters – performance limitations - **speed**
- DARPA DiscRotor required the development of an engine producing:
  - Shaft output power – rotor and prop-fans
  - Jet thrust – vectored counter torque and high speed flight jet thrust
- Armstrong-Siddeley Double Mamba – fixed turbine engines with shaft drive and installed in flight ~20-25% of total thrust
- Opt. shaft versus Jet thrust – depends on speed

$$\mathbf{T = T_p + T_n \; \ldots . where \; T = f(\alpha)}$$

$$\mathbf{\alpha_{optimised} = 1 - (u^2 / \Delta h).\, K_\eta}$$



- Best thrust:
  - For high speed, largest amount of jet thrust (Δh↑)
  - Low speed (hover) all power thru prop shaft

http://www.adl.gatech.edu/classes/propulsion/prop8.html
α is the fraction of the enthalpy drop used to run the power turbine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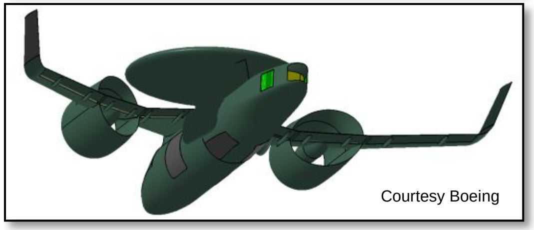
Courtesy Boeing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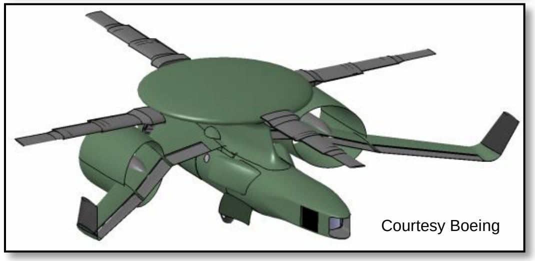
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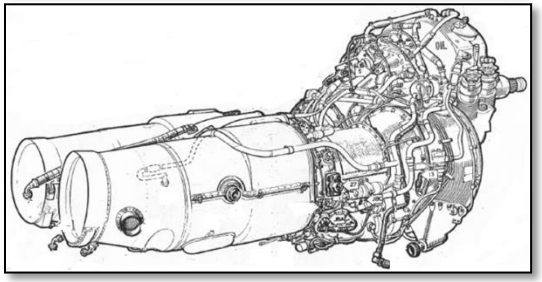


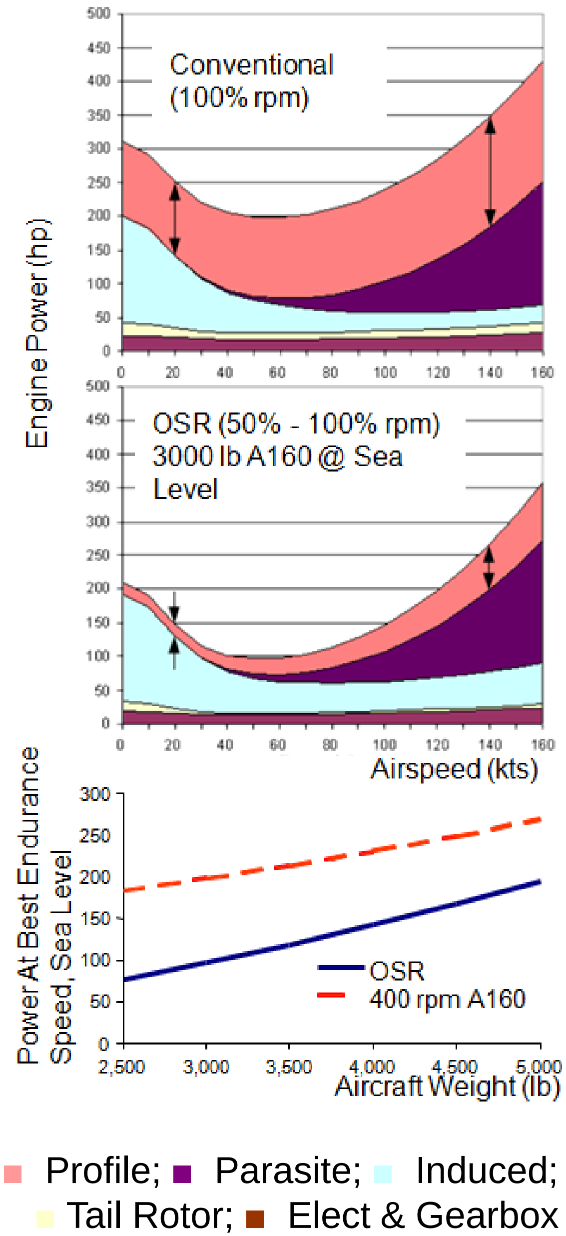
Variable Speed – Optimized Speed Rotor

- A160 designed for extreme long endurance - achieved through a variety of measures, most notably the rotor (OSR) is run at varied rpms that reduce profile drag (v^2)
- A problem is that this requires the turboshaft free turbine to run off design speed incurring an efficiency penalty
- Small rpm changes do not much change in free turbine efficiency (flattish) but at 50% rpm…


Courtesy Boeing

- Options, development of:
  - Variable speed transmission
  - Variable speed free turbine

- **Development of fully variable speed free turbine engine efficiency – JMR?**



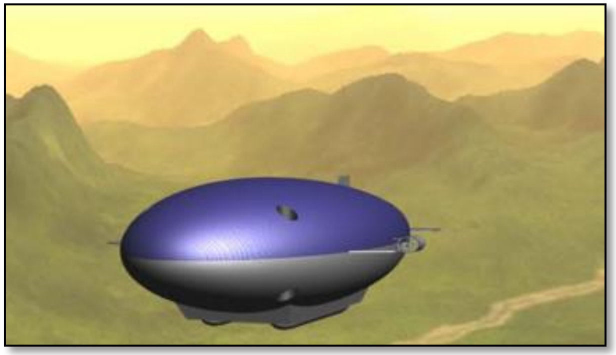
JMR – Optimized Speed Rotor

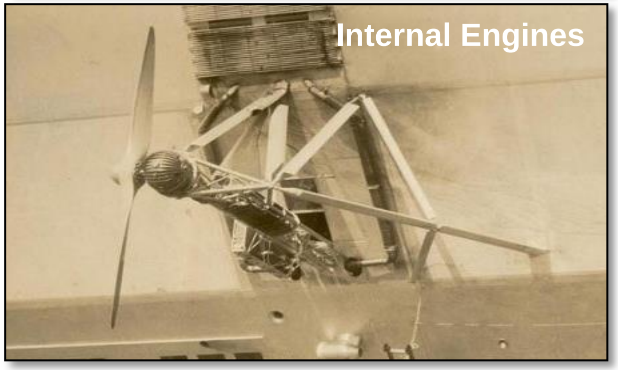
- Aircraft Design is Driven Primarily by:
  - Range & Endurance
  - Payload Requirements
  - Environmental Conditions
  - Basing & TOL Constraints (VTOL, STOVL, STOL)
  - Specific Mission Needs (Survivability, Cargo, Complex Terrain Flt, Weapons Delivery, etc.)
- Key technical drivers:
  - Propulsive Efficiency
  - Weight
  - Fuel Economy
  - Survivability
- Technologies
  - Novel engine
  - Transmissions
  - Distributed drives (electro-mechanical)
  - Variable speed free turbine engine (see previous)/ or transmission

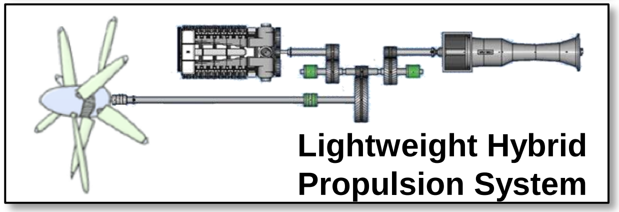
Hybrid Airships

- New technologies – opportunities with rising interest - NDAA 2012 language
- Semi-Rigid or rigid approach to Hybrid Airships allows the development of very capable integrated propulsion-lift-buoyancy systems
  - Propulsion
  - Controlled buoyancy
  - Ballast generation (1lb fuel creates 1.4lb water)
  - Superheating lift (20^0F ↑ produces ~18K lbs lift)*
  - CG and CL active control
  - Maneuver authority – high power demand for maneuver/efficient cruise
  - Survivability
- Internal location opens up design scope for highly efficient propulsion configurations similar to CODOG, CODAG & CODLAG
- Opportunity to be first in this market – creative thinking/small investment – ASD(R&E) customer?

* Hindenburg size LTA







More Novel Technologies

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- Electro-mechanical:
  - Distributed propulsion systems
  - Fuel cell hybrids
- Materials
- Duel-use fuels:
  - H_2 (gas or liquid) + petroleums
  - Fuel cracking
- Pulsed combustors (Vulcan)
- Integrated lightweight airframe-engine structure – UAVs
- Manufacturability
- ….and so on

Summary

Perspicuous Technologies

- There is a sense that aero-engines are a mature technology and that future incremental improvement will be driven mainly by the commercial sector
- Power system primary advanced R&D is shifted to focus on esoteric energy technologies – seemingly ignored are integrated novel airframe-engine technologies that could actually double performance by using oil-based fuels more effectively are not well supported
- There is a place for transformational will-o'-the-wisp solutions (e.g. nuclear fusion) most of which prove to be technically elusive…
- …but need a balanced approach that pursues technologies that can be strongly transformational and will use the oil resources that we still possess more efficiently – advanced tailored novel aero-engines are part of the solution

BACKUP

Engine Technologies - Goals

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Engine	Aero-Application	Size	Weight Class / P/W	Power Class	sfc	TRL		Discussion
						Integrated/	Key Tech	
Turbo-Diesel Compound Engine	Rotorcraft	~ x2 volume est.	~ x2.3 wt of a simple turboshaft/ P/W ~ 3:1	500-3000 hp	0.31 lb/hp.hr	3	3	1950s Napier Nomad used this concept. Achieved sfc of 0.34; P/W around 1:1; 3000 hp turboprop. A new generation with modern technology (rotary diesel) will do much better. Modern turboshaft sfc around 0.5-0.58 and around 40% weight but quickly compensated by twice fuel burn rate
Turbo-Shaft/Jet Thrust Hybrid Engine	High speed FW/ Rotorcraft Hybrids	Similar to existing – say 1.2 with variable nozzle	20-30% penalty est. P/W 2.7:1	500-11000 hp	0.4 lb/hp.hr	3	3	Produces shaft power and jet thrust – rotorcraft application driving rotor shaft in the hover and jet thrust for high speed flight For high speed, largest amount of jet thrust and low speed (hover) all power thru prop shaft. Technical development might involve variable nozzle last stage turbine and jet pipe nozzle scheduling. Otherwise, performance similar to current TS. Payoff, is in efficiency of high speed wing-borne flight.
Variable Speed – Optimized Speed Rotor (OSR)	Helicopters	Similar to existing – say 1.2 with variable GB or PT	20-30% penalty est. P/W 2.7:1	600-700 hp	0.4 lb/hp.hr	3	4	For any Flight Condition, there is a rotor speed that minimizes total power required by finding best compromise between Induced Drag & Profile Drag. Typical helicopters are designed to achieve one rotor speed. Varying rotor speed between 50-100%. At best endurance speed, 30% power reduction , leading to a lower apparent sfc to a propulsion system effectiveness of around 0.4 (A160 example). Weight increase small compared to much lower fuel consumption.
JMR – Optimized Speed Rotor	Rotorcraft - complex transmissions	Similar to existing – say 1.4 with variable Transmission	25-35% penalty est. P/W 2.9:1	500-11000 hp	0.4 lb/hp.hr	4	4/5	As with OSR but addition of further transmission mechanism for forward flight thruster etc
Hybrid Airships	CODOG systems	~ x4 volume est	~ x3 wt	2000-10000 hp	0.29 – 0.5 lb/hp.hr	2	2/5	Hybrid airships need a new power concept – similar to Navy ships CODOG. In cruise flight, diesel only for an sfc ~0.29 at max speed dash diesel + turbo shaft, combined sfc , estimated at ~ 0.47 lb/hp.hr. Development challenge is to achieve aviation weights
Morphing Aircraft, Hypersonics & ISR	FW							Special requirements engines. An example is the RR Pegasus engine that morphs between vertical and horizontal flight modes. ADVENT, is a multi-cycle engine. Engines which are tailored to the aircraft configuration. The payoff for combining a multi-cycle engine with a morphing airframe is that a 100K lb aircraft achieves the range/endurance capability of a 400K aircraft (e.g. B-1)
More Novel Technologies	FW, RW and Fans							Distributed propulsion – and other hybrids

- Δh is the enthalpy drop available, after taking out enough work to run the turbine which runs the compressor and other auxiliary devices
- α is the fraction of the enthalpy drop used to run the power turbine – the quantity to be optimized
- So for $\alpha_{opt} = (1 - u^2/\Delta h).K_\eta$
- At low speed, $\alpha_{opt} \rightarrow 1$, implying that it tends to total Δh, or all the power extracted by the PT
- At high speed, $\alpha_{opt} \rightarrow <1$, implying that tends to less than total Δh, or less power extracted by the PT and more to jet thrust