VG100: INTRODUCTION TO ENGINEERING

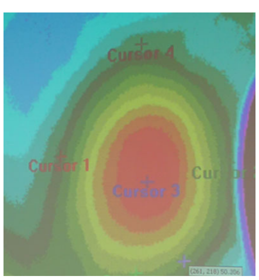
Understanding to Design In Thermo-Fluids

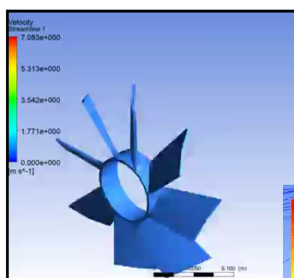
Dr. Qiang Zhang

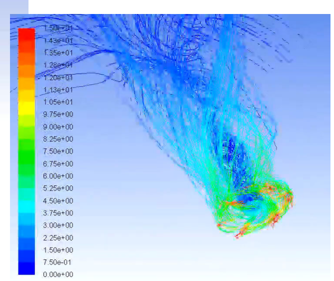
Preview

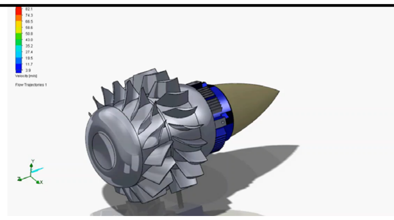
- Core project review
- Propulsion fundamentals
- Micro-Air Vehicle (MAV)
- Unmanned Underwater Vehicle
- Bird flight aerodynamics
- Research in JI Thermo-Fluids Group

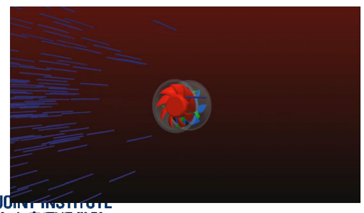
What happened?

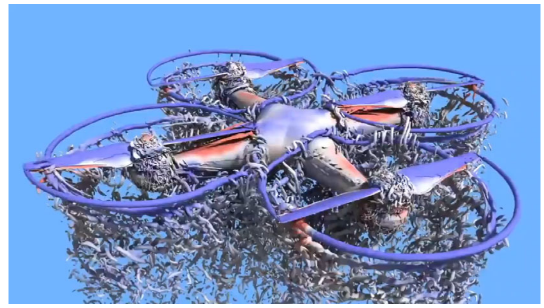












Personal Aircraft

GPPS Forum 18, Alan Epstein
https://gpps.global/gpps-forum-18-movies.html

Propulsion Fundamentals

Energy from combustion is used to deliver a combination of shaft power and high-energy air jet

- Thrust generated by expelling air incoming air rearwards (Newton's 3rd Law) using shaft-driven prop/fan and/or jet

Propulsor and ‘jet’ velocity depends on flight speed

- prop → propfan → turbofan → turbojet → rocket
  - increasing cruise speed

Propel vehicle by *reaction* force

- Mass stored in the vehicle is thrown backwards (all fuel and oxidizer are carried onboard)
- Capture mass and push it backwards (only fuel is carried onboard)

Which is greater?

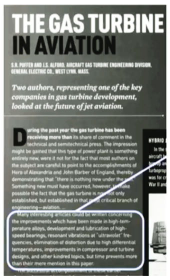
A. The ratio of the propellant mass to total vehicle mass of a rocket

B. The ratio of the fuel mass to total vehicle mass for an airplane

Air-Breathing Propulsion

- Gas turbine engines power every modern aircraft and will for foreseeable future
- Many technical challenges still remain:
  - Multi-Disciplinary: aerodynamics, thermodynamics, heat transfer, combustion, controls, materials, etc.
  - One of most complicated device on earth
- Development time of engine > development time of aircraft
- Vast R&D
- Most exciting / challenging area in aerospace engineering!

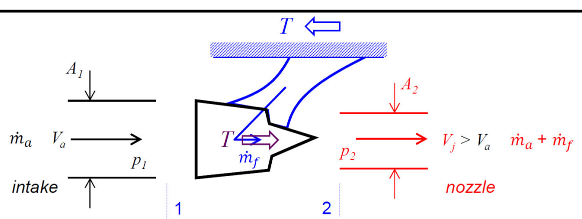
Excerpt from Mechanical Engineering, Dec 1945



Many interesting articles could be written concerning the improvements which have been made in **high-temperature alloys**, development and lubrication of **high-speed bearings**, **resonant vibration** at “ultraviolet” frequencies, elimination of **distortion due to high differential temperatures**, improvements in **compressor and turbine designs**, and other kindred topics, but time prevents more than their mere mention in this paper.

Aircraft Propulsion (air breathing)

- Air is ‘taken in’ by the engine, hence ‘ram air’ drag
- Some of the inlet air is used for fuel combustion
  - Reciprocating or gas turbine engine
  - Energy is captured as shaft power
  - And/or increased enthalpy converted into jet kinetic energy
- Intake air, with exhaust combustion gases, is expelled at a higher velocity than at inlet
  - Exhaust gases: CO_2, H_2O, CO, NO_x, partially-burnt HC
    - Plus SO_x and oxides of any other impurities/additives
- Thrust force = rate of change of momentum of air



A = streamtube area	Subscripts	
p = static pressure	a air	f fuel
V = flow velocity	j jet	
$\dot{m}$ = mass flow rate	1 upstream	2 downstream

Propulsive efficiency

The fraction of the net mechanical output of the engine which is converted into thrust power.

$$\eta_p \equiv \frac{T.V_a}{\Delta KE}$$

Assumptions:

- Fuel flow rate is a small fraction (~2%) of the air flow rate,
- $P_2 = P_1 = P_\infty$, $A_2 = A_1$

$$p_1A_1 - p_2A_2 + T = (\dot{m}_a + \dot{m}_f)V_j - \dot{m}_a V_a$$

Can you derive a simplified equation for propulsive efficiency?

Propulsive efficiency

$$\eta_p \approx \frac{2}{1 + V_j/V_a}$$

The propulsive efficiency is maximum when $V_j = V_a$. Can we?

- Some overspeeding is needed to produce reaction thrust. A 100% propulsive efficiency is impossible.
- The smaller increment of velocity rises across the engine, the higher its propulsive efficiency will be.

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Thermal efficiency

$$\eta_t = \frac{\Delta KE}{\dot{m}_f Q_R}$$

Energy per unit mass of the fuel

Overall efficiency

$$\eta_0 = \eta_t \eta_p$$

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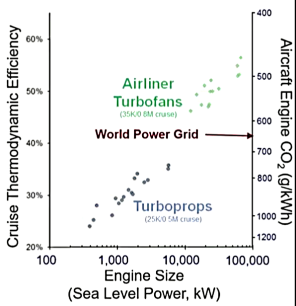
Airliners produce less carbon than the grid!

- The world power grid is less efficient than the existing Turbofan engines.
- The current aeroplane engine is more efficient than the best Combined Cycle Power Plants
- Electrification would require +23% of the world's electricity



GPPS Forum 18, Alan Epstein
https://gpps.global/gpps-forum-18-movies.html

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Micro-Air Vehicle (MAV)

Insect-sized aircraft

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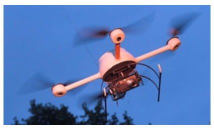
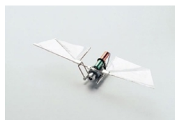
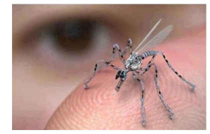




Future Trend

（1）smaller size



（2）Multi-function

T-Hawk MAV

A ducted fan VTOL Micro-UAV developed by Honeywell in 2007.

- Search areas for roadside bombs and inspect targets.
- Deployed at the Fukushima Daiichi Nuclear Power Plant in Japan to provide video and radioactivity readings after the 2011 Tōhoku earthquake and tsunami.

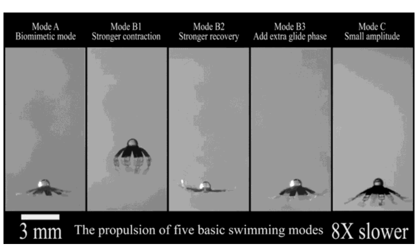
(3) Efficient Green energy Consumption

Unmanned Underwater Vehicle

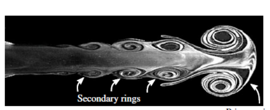
"SoFi," a soft robotic fish that can independently swim alongside real fish in the ocean - *MIT team*

- The robot has two fins on its side that adjust the pitch of the fish for up and down diving. To adjust its position vertically, the robot has an adjustable weight compartment and a "buoyancy control unit" that can change its density by compressing and decompressing air.

Jelly Fish Robot

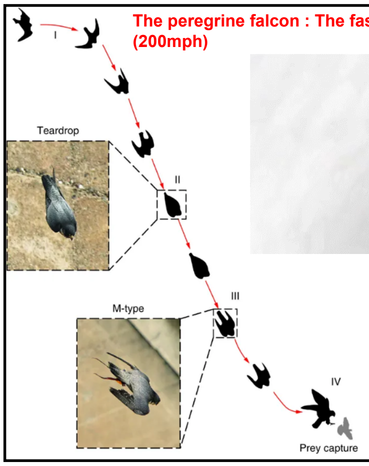


"vortex-enhanced propulsion can yield up to a 50% increase in the propulsive efficiency over a steady jet.

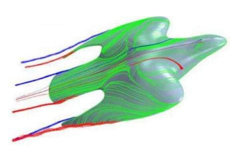


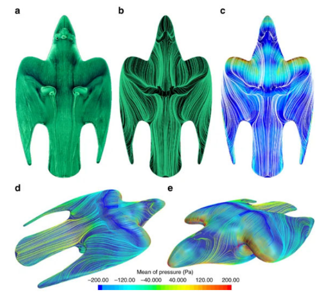
Birds Flight Aerodynamics

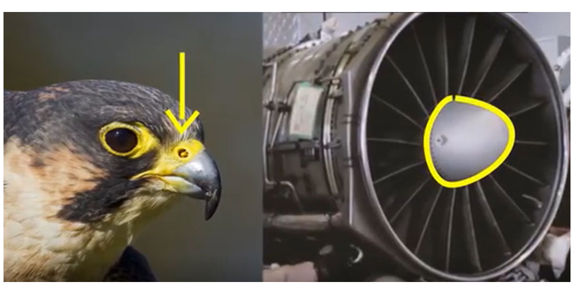
The peregrine falcon : The fastest animal on earth (200mph)



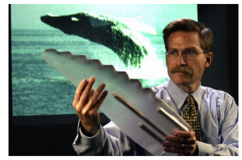
Led by the Chair in Nature-Inspired Sensing and Flow Control for Sustainable Transport, Professor Christoph Bruecker, City's research demonstrates the way in which peregrine falcons perform complex maneuvers to attack their prey.



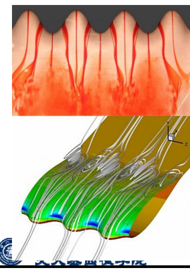




How Does An Owl Fly So Silently?

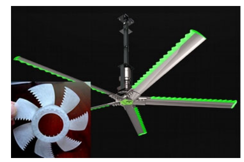


WhalePower's chief science officer and a mechanical engineering professor at Duke University, Laurens Howle, holds a prototype of the company's distinctive, Humpback-inspired airfoil design.



https://www.design-engineering.com/features/whale-of-an-idea/

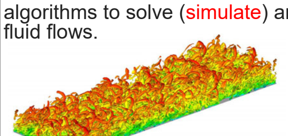
A Whale of an Opportunity



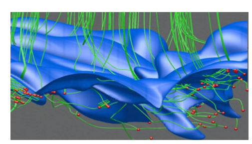
Research in JI Thermo-Fluids Group

Computational Fluid Dynamics

branch of fluid mechanics that uses numerical methods and algorithms to solve (simulate) and analyze problems that involve fluid flows.



The near-wall vortex structure of channel turbulence: instantaneous snapshot of the iso-surface of the second invariant of the velocity gradient, colored with the streamwise velocity.

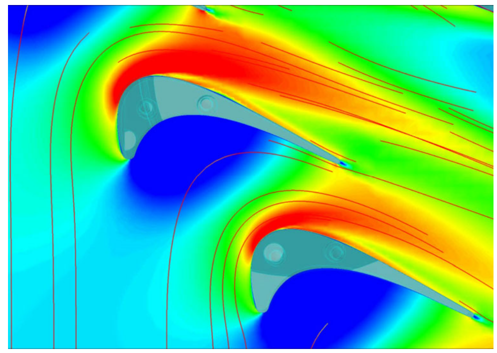


Interaction of the passive scalar isosurface with the streamlines

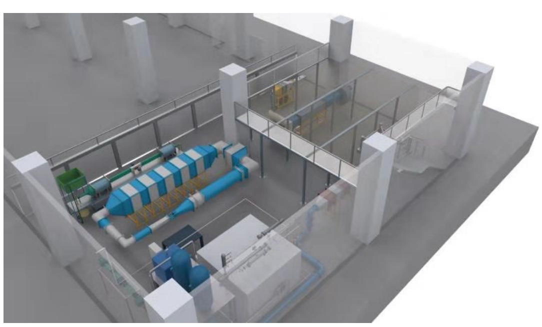
- To analyze/understand the data is more important than simulation itself. Try to find new ideas to extract the physics by data post-processing.

United Innovation Center (UIC) of AeroThermal Technologies for Turbomachinery

Main sponsor: *AECC Commercial Aircraft Engine Co. Ltd.*

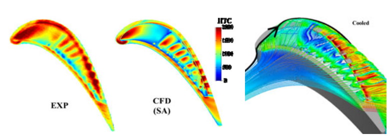


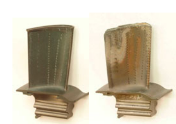
New Thermal Engineering Research Center (under construction)



Gas turbine aerodynamics and cooling techniques

- Novel cooling techniques
- High-speed wind tunnel measurement
- CFD development and validation

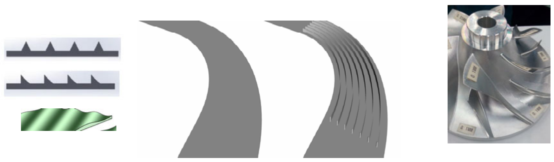


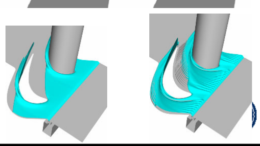


China's 1st Best Paper Award in International Gas Turbine Heat Transfer

Engineering the Surface

- *Explore the new design flexibilities offered by latest advances in*
    - *Additive Manufacturing*
    - *New "Smart" Materials*





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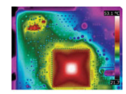
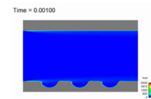
Engineering the Time – Novel Thermal Management Concept

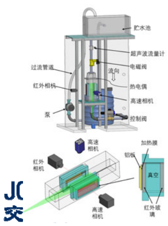
- Explore the thermal management design space in time
- Intelligent scan-cooling (patent)

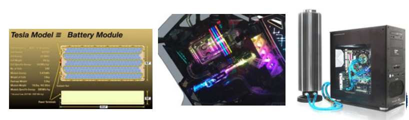
Applications:

- Electronic Cooling
- EV battery Cooling
- Energy Storage









Follow-up Project

- Focus on understanding : what key physical principles are involved ? what new story can you tell? (**not just some fancy design!**)
- Be focused …

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Review

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