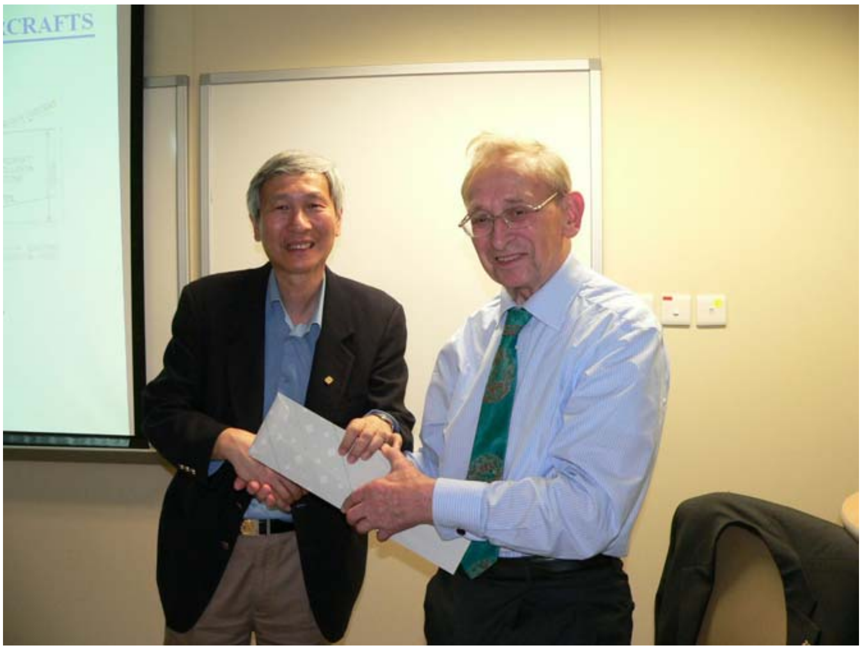
BSE CPD Lecture –
The Silent Flight of the Owl on 2 December 2009

Organized by the Department of Building Services Engineering, a CPD lecture delivered by Professor Geoffrey M. Lilley on ***The Silent Flight of the Owl*** was held on 2 December 2009 (Wednesday).

Professor Geoffrey M. Lilley is a Professor Emeritus of the University of Southampton of UK. His main research has been in the structure of turbulent flows and the generation of noise from turbulence. In recent years he has attempted to model dark matter in the Universe based on the concepts of fluid dynamics.



Souvenir presentation to Professor Geoffrey M. Lilley by Professor. W.K. Chow

The owl in all probability developed the ability to fly silently about 20 million years ago, at least at frequencies exceeding 2kHz, which is the range of maximum hearing sensitivity of its prey typically, voles and mice. The fossil record shows owls were flying along with pterosaurs from about 75 million years ago. This remarkable achievement, not attached to any other species of bird, resulted from changes to its wing feathers close to the wing leading and trailing edges and on its wing upper surface, and the feathers around its legs and thighs. With this special hush-kit the owl has perfected the catchment of its food daily for the survival of its family, since the prey are unaware of its approach before they are caught in its large talons. This is performed mainly at night in poor light in the depths of a forest, for the owl does not need to see its prey, for their capture can be by sound recognition alone.

In the talk, Professor Lilley discussed the details of the owl's hush-kit and explained the aerodynamics associated with the changes to its feathers and how this leads to a suppression of the sound generated and radiated from the owl's wing and undercarriage.

Professor Lilley concluded the talk with a discussion on how 'Owl' Technology can help us on the quest to reduce Commercial Aircraft Noise at take-off and on the approach to landing at major airports throughout the world.

CPD lecture by Professor Lilley

Powerpoint file of the CPD lecture

THE SIILENT FLIGHT OF THE OWL
(with applications of Owl Technology to the design of future quiet commercial aircraft)

Lecture at Department of Building Services Engineering

Hong Kong Polytechnic University, 2nd December 2009

Professor Geoffrey M. Lilley
School of Engineering Sciences
University of Southampton

PRESENTATION OUTLINE

INTRODUCTION

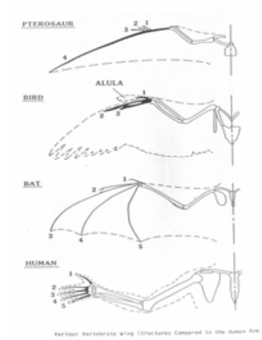
A wise old Owl sat in an oak,
The more it saw the less he spoke,
The less he spoke the more he heard,
Why can't we all be like that wise old bird!
Anon

Sir James Lighthill showed in his pioneering work in Fluid Dynamics and Wave Motion that Nature has been responsible for the development of many creatures over millions of years whose successful evolution has depended on finding solutions to many intricate problems in Fluid Dynamics and Wave Motion.

We ignore what Nature has done by ignorance and arrogance!

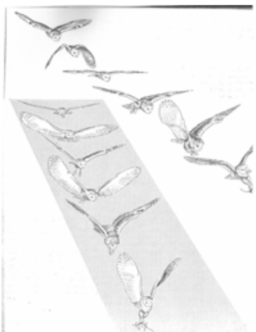
THE ORIGIN OF OWLS

- ***Paleocene***, 50-70 million years ago, England and France covered with sub-tropical forests. Fossils show Owl existed.
- ***Miocene***, 10-30 million years ago, climate cooler. Presence of more owls. Pleistocene, the Great Ice Age, ended 10,000 years ago. Fossils of Great Grey Owl found in Rumania.
- Owl population expands from evolution of rodents, comprising, voles, hamsters, rats and mice. Proliferation of flowering plants provided food for insects, bats and birds and seed dispersion and pollination. Glut of red berries around 20 million years ago enticed the rodents, providing a food supply for hawks and owls.
- ***Hawks*** dominated diurnal and Owls nocturnal scene.



THE OWL'S VISION AND HEARING

- The vision and hearing act in unison. The asymmetric positioning of the ears gives pinpoint accuracy of sound sources.
- The eyes face forwards and are fixed in sockets to provide a wide angle of binocular stereoscopic vision.
- The head of the Owl can rotate through 360deg. The Owl is able to see in near darkness.
- The Owl uses visual and bi-aural sound location to search for prey around dusk and at night.
- (Left) : Flapping flight at night.
- (Right) : Gliding flight at day.



THE CHARACTERISTICS OF PREY

- The prey are typically voles and mice. Their squeals and squeaks are in the frequency range 3-6kHz, which also includes the rustling of leaves by the prey.
- The prey, typically mice and voles, have trumpet shaped ears and their hearing is acute between 2-20kHz.
- The Owl's bi-aural sound location system has a maximum sensitivity between 3-6kHz. The Owl's self-noise (aerodynamic noise) must be well below 3-6kHz to avoid interference with its bi-aural sound location system.
- The Owl's self-noise must not exceed 2kHz if it is to avoid detection by its prey.

THE SPECIFICATION OF OWL'S HUSH-KIT

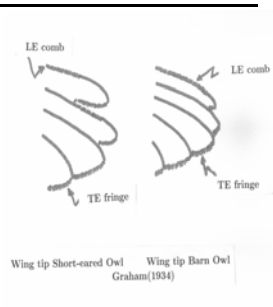
- Kroeger et al.(1972) noise measurements ‘Florida Barred Owl’ (*strix varia alleni*) confirmed Owl not easily detectable by the human ear beyond a distance of 3m.
- The prey, however, hear nothing below 2kHz and do not detect the approach of the Owl until it is grabbed by the Owls' talons.
- Once prey are detected and recognized at dusk or in the night the Owl launches itself from its perch, 6-10m up in a tree, often with eyes closed at night.
- With its head kept focused on the prey the Owl glides or flaps its wings flying down its steep trajectory.
- It raises its head as its enormous talons clasp the prey.

THE OWL'S FLIGHT TRAJECTORY

- The steep flight trajectory of about 24^0, is unique to the Owl.
- The speed on the approach is typically 8m/s(18mph or 16kn.)
- The Lift Coefficient, $C_L = 1$. At the low flight Reynolds number of 1.5×10^5 we would expect laminar flow separation close to the leading edge with $C_L < 0.6$, followed by wing stall.
- The Owl would be unable to fly stably along this steep trajectory with a normal aircraft wing at this low Reynolds number.

THE OWL'S SPECIAL WING

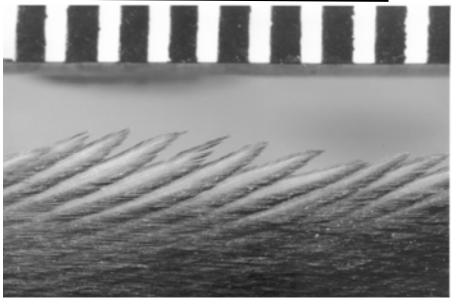
- In order to create a well resolved image of its prey in its brain prior to launch and to follow its movements during its steep trajectory the Owl must fly stably with its wing's horizontal.
- It requires a special wing to prevent the laminar boundary layer flow separation flow and the following stall. It must achieve $C_L = 1$ The Owl's dynamic $C_{Lmax} = 1.4$.
- The Owl accomplishes the above specification using a comb with equi-spaced teeth along the leading edge of its number 10 of its primary feathers. Each tooth generates a longitudinal or streamwise vortex.
- The upper surface boundary layer is attached and appears as an array of longitudinal vortices over the complete wing.



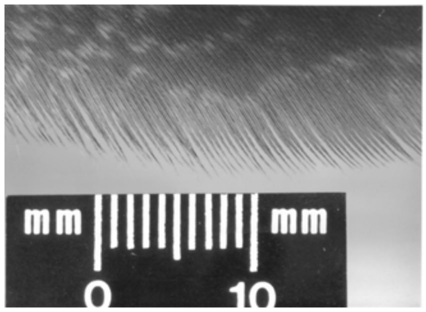
FLOW OVER WING LEADING EDGE COMB

- The non-dimensional spanwise spacing of the teeth of the leading-edge comb equals a value $z^* = u_\tau\, \Delta z/\nu = 18$ which is near the optimum spacing for maximum drag reduction.
- The Owl has demonstrated that it is possible to achieve stable gliding and flapping flight at and near the stall through a highly unconventional boundary layer passive control mechanism.
- Kroeger et al(1972) found that when the leading edge comb from the primary feathers is removed the Owl can no longer fly along a steep trajectory as a horizontal stable platform. Its flight is stalled and it quickly falls to the ground. Without the comb it is as noisy in its flight as all other birds.

LEADING EDGE COMB



TRAILING EDGE FRINGE



THE FEATHERS OF THE OWL'S WING

Lt.Cmdr. Graham(1932) described the differences between the feathers of the Owl and all other British birds, (apart from the Nightjar) :

✈ ***The Leading-Edge Comb:*** A stiff comb-like structure exists on feathers that function as a leading edge. The largest teeth are 4.0mm in length and 0.75mm apart.

✈ ***The Trailing-Edge Fringe:*** Along the trailing-edge of the main wing and each primary feather exists a fringe. Its length is 5.0mm on large owls.

✈ ***Downy Upper Surface:*** Parts of feathers covered with fine short, fluffy down.

CHARACTERISTICS OF OWL'S FLIGHT

The Florida Barred Owl in the trials conducted by Kroeger et al(1972) had the following geometric characteristics:

$$Mass(m) = 0.69kg \qquad Weight(W) = mg = 6.9N$$

$$MeanChord = 0.23m \qquad Span = 0.97m \qquad WingArea(S) = 0.225m^2$$

$$WingLoading = W/S = 30.5N/m^2 \qquad Speed(V) = 7.2m/s$$

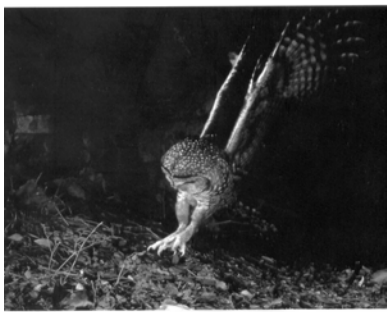
$$L/D = 5 \qquad Lcos\theta + Dsin\theta = W \qquad Flightangle(\theta) = 24\deg$$

$$C_L = \frac{2 \times mg/S}{1.225 \times V^2(1 + (D/L)tan\theta)} = 0.97$$

$$ReynoldsNumber = 1.5 \times 10^5 \qquad C_L = 1 \qquad AspectRatio = 4.2$$

FLIGHT OF SNOWY OWL

CRUNCH AND CAPTURE



FLOW OVER TRAILING EDGE

- ✈ **BROOKS** and **HODGSON(1981)** showed experimentally that the dominant noise source from a wing was at the T.E. The noise intensity was proportional to V^5. Their results appeared to be in agreement with the T.E. scattering theories of HOWE(1978) and **FFOWCS WILLIAMS** and **HALL(1970).** The characteristic length and velocity for the radiated noise were the displacement thickness and average turbulent velocity at the T.E.
- ✈ The fringe at the T.E. provides smooth mixing between the upper and lower surface boundary layers and avoids the discontinuity in the flow at the T.E. of a normal wing, and therefore eliminates the scattering. The intensity $I \sim V^6$.
- ✈ Experiments in Germany confirm that a brush (hairbrush in patent) fitted as an extension to a standard wing reduces the radiated noise by about 7dB.

CALCULATED AND MEASURED NOISE

- **The non-dimensional peak frequency :**

$$St \equiv \frac{f_{peak}\bar{c}}{V} = \frac{1.7}{2\pi}\frac{u}{V}\frac{\bar{c}}{\delta_1}$$

- **The far-field radiated flyover noise intensity :**

$$I(Watts/m^2) = K\left(\frac{WVM^2}{C_L H^2}\right) \qquad NdB = 10log_{10}\left(\frac{I}{I_{ref}}\right)$$

where $Iref = 10^{-12}Watts/m^2$ **and the flow constant** $K \sim 5.5 \times 10^{-7}$ **equals** $(\frac{1.7}{\pi^3}(\frac{u}{V})^5(\frac{\delta}{\delta_1})_{TE})$**.**

- **The noise measurements of Kroeger et al(1972): Measured** $f_p = 120Hz$ **in agreement with the estimated value.**

Height m	Estimated Ndb	Measured NdB	Noise Reduction Δ NdB
9.75	20	14	6
1	40	33	7

NOISE FROM BIRDS, GLIDERS AND AIRCRAFT

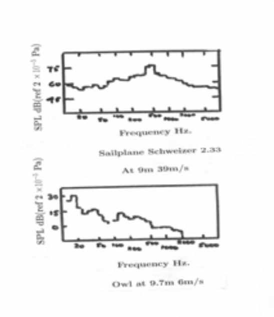
- **The Owl, with a fringe, shows a noise reduction of $6-7dB$ compared with a bird of comparable mass and flying at the same height and speed. (Note: A noise reduction of 7dB is equivalent to reducing the noise by a factor of 5. $(7 = 10log_{10}5)$. An impressive result.)**
- **If we assume the BROOKS and HODGSON(1981) model, with $I \sim V_\infty^5$, can be extended to include the effects of tip vortices and changes in lift coefficient, it follows that the sound intensity from birds, clean glider and clean aircraft with flaps and undercarriage up is equal to**

$$I \sim \left(\frac{WVM^2}{C_L H^2}\right)$$

for the *same technology*. **$W = mg$ is the weight of the bird or aircraft and $M = V/c$, the Mach number. The correlation is satisfactory, within 10dB, over a mass range from $1kg.$ to $400,000kg.$**

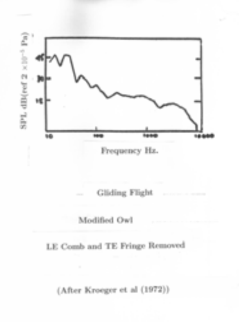
OVERALL NOISE OF AIRCRAFT AND OWL

- The comparison between the extrapolated results for the glider and aircraft noise show the Owl is quieter than the glider by about 10dB - the result of a change in technology.
- Comparisons between the calculated and measured noise from gliders have been found acceptable. The same formulation when applied to aircraft shows higher noise levels mainly as a result of protuberances, and especially the undercarriage noise, when the aircraft is in a landing configuration.



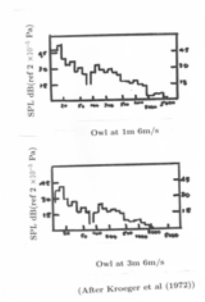
POWER SPECTRUM FOR OWL'S NOISE

- The Barn Owl uses both visual and bi-aural sound location to search out prey. Maximum sensitivity of sound location between 3-6 kHz. Head-width prevents Owl from using sound location system at lower frequencies, since the wavelength is then greater than skull dimensions.
- Mouse squeaks and squeals and the rustling of leaves are in the frequency range 3-6kHz. Mice and voles have good frequency response in the frequency range 2-6kHz and hence would hear the approach of an owl from its perch at 3-6m above the ground but for the existence of its `hush-kit'.
- The noise spectrum obtained by Kroeger et al. show Owl's noise spectrum similar to that of a clean glider near the spectrum peak. This is followed by a decay of f^{-2}.



OWL'S NOISE CHARACTERISTICS

- Noise spectrum from a glider continues its decay to well beyond 2-3kHz. That of the Owl falls rapidly to almost zero beyond 2kHz.
- Noise spectrum of Owl has a double peak in the low frequencies at 17Hz and 120Hz. The Strouhal number corresponding to the upper peak appears to be comparable with that of the glider. The lower peak appears to be generated by the Owl's head.
- Kroeger et al.'s overall sound measurements suggest trailing-edge scattering mechanism eliminated by the `fringe' at the Owl's trailing-edge. The result is the power law is changed from V^5 to V^6, a substantial noise reduction at the low flight speed of the Owl. But a reduction in the overall sound power does not result in a change in the spectrum at the decay beyond the peak.



QUIET OWL ABOVE 2kHz

- The presence of the compliant, downy, fluffy surface on the wings and legs of the Owl has an important impact on the spectrum of the turbulent boundary layer kinetic energy fluctuations at frequencies above 2kHz. The conjecture is that the fine fibres of the down feathers extract energy from the quasi-turbulent flow over the wing upper surface and provide a bypass dissipation mechanism at a decade in frequency below the normal viscous dissipation in the Kolmogoroff range of eddy scales.
- When the comb is removed from the L.E. of the Owl's wing the boundary layer is no longer attached to the upper surface of the wing and hence the turbulent vortices are no longer in contact with the down feathers. In this case of the unsteady flight of the Owl the dissipation reverts to that of normal viscous dissipation and the noise spectrum becomes similar to that of all birds, gliders and aircraft.

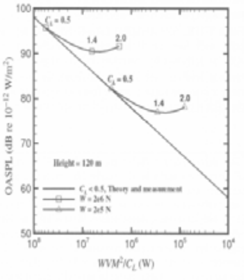
THE OWL'S `HUSH-KIT' ABOVE 2kHz

- The Owl would not be silent in this frequency range above 2kHz. were it not for the compliant surface formed from velvety, downy, fluffy, fibrous material, whose fibres are of slightly greater length than the scale of Kolmogoroff eddies.
- Bypass dissipation is then made possible at a lower frequency by absorption of turbulent energy by the compliant surface, as opposed to normal viscous dissipation at higher frequencies. (Analogy with long-chain molecules in water.)
- ***The Owl ensures that all noise generation at frequencies greater than 2kHz is reduced effectively to zero.***

A LASTING STARE

CONCLUSIONS I

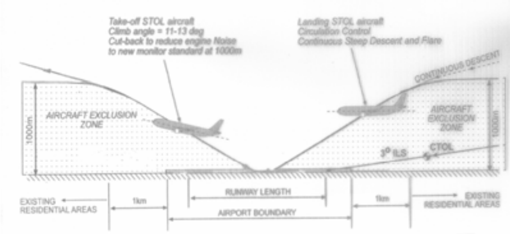
- The Owl has developed a strategy to catch prey by its Silent Flight. It is the only creature or vehicle that can fly silently, at least at frequencies greater than 2kHz.
- It uses a steep descent at high lift and slow speed which would be impossible, if its wing feathers were the same as all other birds flying at a Reynolds number of 1.5×10^5.
- The Owl's wing has modifications to its primary feathers. At the wing LE the teeth of its comb act as a line of vortex generators. The resulting array of streamwise vortices over the complete wing, eliminates laminar separation from the LE and allows the Owl to fly by flapping or gliding stably at high lift similar to a glider flying at a much higher Reynolds number, above 10^6.



CONCLUSIONS II

- The Owl however would remain as noisy as all other birds, and would be heard by prey as it swooped down from its perch.
- The fringe at the Owl's TE eliminates the scattering mechanism, which is the main source of noise from all birds and aircraft with undercarriage retracted. The Owl with its fringe is therefore less noisy than all other birds. However it would still be heard by prey since its radiated noise is broadband with an upper limit greater than 6kHz. Prey have acute hearing, but with a lower limit of 2kHz.
- The Owl's down feathers on its wing upper surface and around its legs acts as a compliant boundary layer and eliminate the generation of all sound above 2kHz. The prey do not recognize the approach of the Owl until captured by its giant talons.

FLIGHT TRAJECTORY FOR FUTURE AIRCRAFTS



FLIGHT TRAJECTORY AT TAKE-OFF AND LANDING

FOR FUTURE QUIET AIRCRAFT(Lilley 2005)

CONCLUSIONS III

- The success of the Owl in reducing not only the intensity of its radiated noise, but eliminating all noise above 2kHz using the bypass dissipation mechanism, is referred to as `Owl Technology'. Of course the Owl is not concerned about its poor aerodynamic efficiency associated with its small L/D ratio.
- 'Owl Technology' is proposed as a means to assist in reducing the noise of commercial aircraft, so that in future aircraft will not be heard by residents living at 1-2km beyond airports. (Increasing height by a factor of 10 leads to a noise reduction of 20dB. But reduction of speed and steeper approach involves change from CTOL to STOL and Circulation Control.)
- All residents should be removed from areas closer to the airport and the land re-used for factories and other non-noise sensitive occupations such as sound-proofed hotels and offices. An airport is a noisy environment!!!

ANY QUESTIONS???

NOTES (Preamble)

- It is an enormous pleasure to be back in Hong Kong since I have not been back for over ten years at the invitation of Professor Grafton Hui and Professor Frank So.

NOTES

- Nature provides the rocks, earth, water and oxygen for all life on earth.
- Nature also provides the food for all animals and human beings to live.
- However all birds are noisy and as they approach prey they are recognized and the prey may easily escape.
- The exception is the OWL who has survived for over 20 million years, since its flight is silent and prey are not aware of its approach before being grabbed by its sharp talons.
- In this lecture we will examine the OWL's hush-kit and finally explore if we can use OWL Technology in the design of new aircraft that can take-off and approach landing without being heard above the ambient noise in residential areas close to major airports.

Notes

- Those of us engaged on aircraft noise reduction, and I started on this quest over 60 years ago, have found that aircraft noise reduction, for no loss in aircraft performance, is almost like striving for perpetual motion. In many ways it is more difficult than planning for flight to the Moon or designing nuclear weapons.
- The reduction of aircraft engine noise has been pursued with success for many years and this is the major source of noise at take-off.
- However on the approach to landing, with the required low flight speed, and low altitude, the airframe noise from the wing and undercarriage needs to be reduced, and since the sources of airframe noise are common to all flying vehicles, including birds, it is natural for us to study Owl Technology.
- The question to be asked is how and why Nature was able to change the feathers of all owls to enable the OWL to fly silently, at least with respect to its prey and as observed by humans situated in close proximity to owls in flight.