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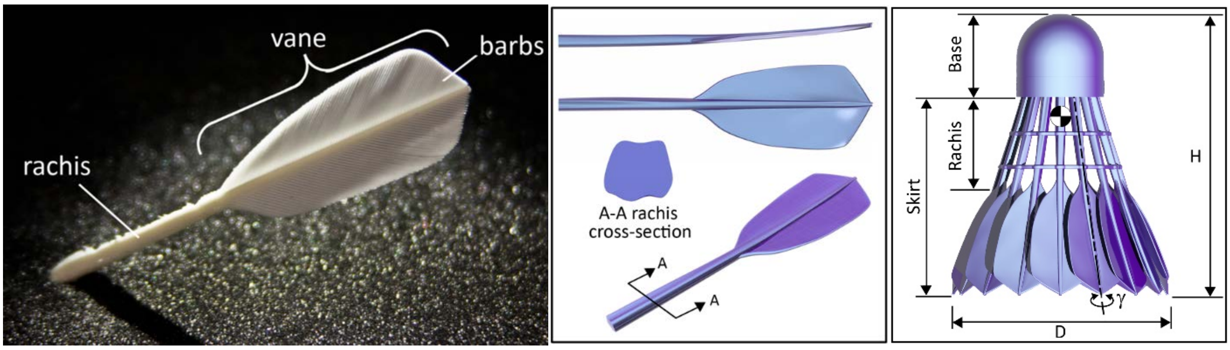
Understanding the influence of the vane in feather shuttlecocks

J.H. Hart, and J.R. Potts
Sheffield Hallam University, Sheffield, UK
john.hart@shu.ac.uk

Abstract

The feather shuttlecock is a unique projectile within the world of sport. It stands apart not only due to its structure, and mass (5~6 g), but because of the range of velocity it operates across. Not only is it recognised as the fastest none ballistic sports projectile (the World record currently stands at 137 m/s), it is also exhibits the largest inflight deceleration. Traditional shuttlecocks are constructed using waterfowl feathers, affixed into a fabric covered cork base. Sixteen feathers are required in construction of the shuttlecock, and these are taken from a specific wing location due to the form. The feathers once cleaned have their rachis and lateral vanes shaped for formation of the shuttlecocks conical skirt, Fig. 1. Synthetic variations of shuttlecocks are readily available however these plastic products are considered inferior to the natural feather. Recreating the unique characteristics, both structurally and aerodynamically that feathers possess has been a long-term goal for manufacturers. However, replicating the delicate forms and properties of these keratin structures, in a synthetic variation has not yet been achieved. The creation of a shuttlecock capable of use in an outdoor environment has also been of interest to the badminton community in recent years, with the goal of increasing participation levels. This has proved a considerable challenge as these delicate projectiles are highly susceptible to air movement; in elite play it is stipulated on court air velocities should not exceed 0.1 m/s.

In response to the above challenges the amount of research being undertaken into shuttlecocks, both aerodynamically and structurally, has increased. The majority of studies undertaken on shuttlecock aerodynamics have however focused either on understanding the shuttlecock as a whole, or been specifically concerned with flow through the rachis. Fewer studies exist where researchers have attempted to understand the detailed flow behaviours of shuttlecocks, Hart (2018), Kitta (2013), Lin (2014), that would explain the measured performance, or the role the feather vane plays. The computational fluid dynamic research presented herein specifically concentrates on the vane, and includes; consideration of the vane insertion angle (γ), and consideration of the aerodynamic effect of vane damage that may be sustained during play. The overarching methodology applied is outlined below, however detailed description and validation can be found in Hart (2018).



(a) (b) (c)

Fig. 1 (a) Single feather removed from a feather shuttlecock; (b) constructed model of feather geometry revealing rachic complex form and curvature; (c) Final modelled shuttle geometry

Feather shuttlecock geometry in the research presented is based on a readily available Yonex Aerosensa 50. This has been constructed using a combination of scanning and traditional measures. Scanning is required to capture the complex form of the feather rachis, and the thickness and curvature of the feather vanes. The modelled shuttlecock has a height of H = 86 mm and a maximum skirt diameter D = 66 mm (used as the characteristic length in calculation of aerodynamic coefficients). For simulation the shuttlecock is placed in a cylindrical flow domain, with the major rotational axis of shuttlecock and domain aligned.

ANSYS Fluent v19.1 and a scale resolving delayed detached eddy simulation turbulence model is used in solution. Governing equations and turbulence model were solved through non-iterative time advancement. The importance of using scale resolving models in simulation of these bluff bodies in order to understand the detailed time dependent flow behaviours has been previously demonstrated, Hart, et al (2018). Computational grids were hybrid in construction. Earlier research presented used a tetrahedral-hexcore grid, however as grid generation methods have advanced the use of polyhedral grid generation has been adopted. All grids include polyhedral elements layered across the surface of the shuttlecock structure. Polyhedral grid size was approximately 14.8 million elements, which gave comparable solution to earlier 16.9 million element tetrahedral-hexcore grids. This size of grid is comparable to the 21 million elements required in simulation of synthetic shuttlecocks, Hart (2014).

Simulations were conducted over the Reynolds number range (90,000 < Re < 271,000), and results are presented both with and without rotation. Hart (2020) has previously shown rotation reduces measured aerodynamic drag by 4% in simulation. Time averaged drag coefficients for static and rotating baseline shuttlecock simulations are $C_{d\ static} = 0.76$ and $C_{d\ rot} = 0.73$ respectively. Altering the angle of the feather vane $\gamma = \pm 4^o$ alters the measured drag coefficient by $C_d = \pm 8.5\%$. This is attributable to a reduction or increase in air movement between adjacent feather vanes as the proximity of these surfaces is directly influenced by γ. Simulated damage of the feather vanes resulted in an average increase in drag coefficient of 4%. Again this is attributable to increased air flow through the shuttlecock skirt. Although this is only a marginal increase in C_d, the influence upon other aerodynamic coefficients was more pronounced due to the rotational behaviour of the shuttlecock.

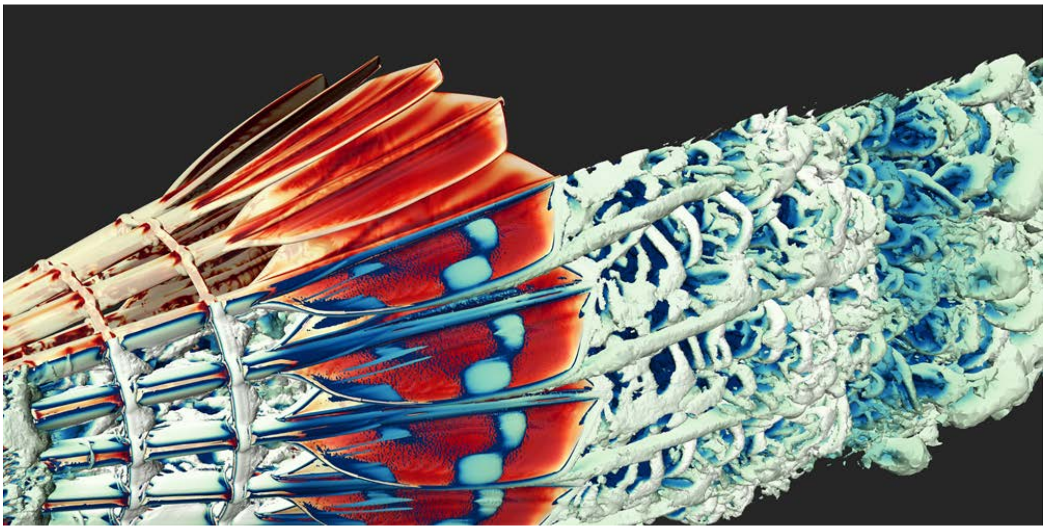


Fig. 2 Detail of resolved flow structure around a feather shuttlecock skirt modelled with SRS DDES turbulence model

Studies investigating the influence of the vane in feather shuttlecocks, are showing the significance this element of the projectile has on performance. Prior publications have clear demonstrated how a restriction, or increase, of air movement through the rachis has a significant influence on aerodynamic coefficients. This work demonstrates the direct additional influences attributable to the vane, with implications for the development of shuttlecock skirts. Work is ongoing to further this knowledge, with preparations for full publication of results.

References

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