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Design of a Novel Aerodynamically Efficient Motorcycle

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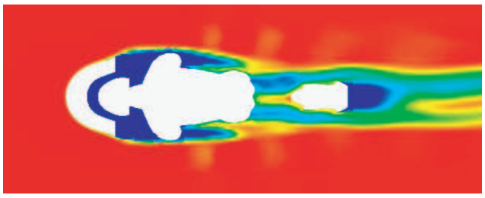
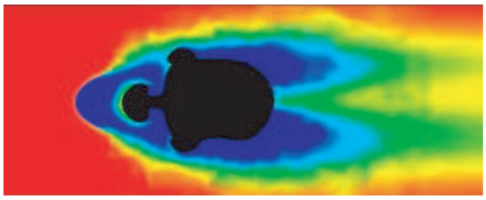
Abstract

Recently a novel aerodynamically efficient motorcycle known as the ECOSSE Spirit (ES1) was designed and patented [1]. Initial computational fluid dynamics (CFD) analysis estimates the ES1's drag-area coefficient at $0.16m^2$ - a 54% improvement over a conventional sports machine (such as the Yamaha R1), which translates into a 30% increase in top speed for a given fixed engine power. Or alternatively, 170bhp performance with a 78bhp engine; see Figure 1. Since the initial design of the ES1 was approached from an aerodynamic perspective, Imperial College London has been working with Spirit Motorcycle Technology on improving the overall dynamics and performance of the vehicle. This paper addresses the parameters that affect the lateral dynamics of the vehicle, which is one of the many aspects in motorcycle design.



(a) ES1 CFD calculation top view

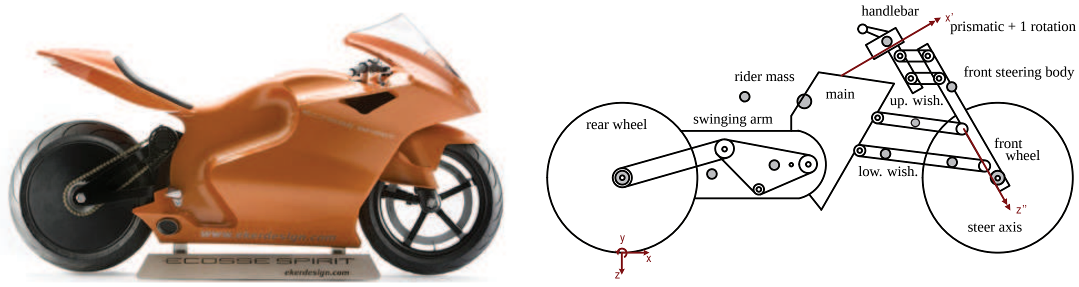


(b) Yamaha R1 CFD calculation top view

Figure 1. Plots comparing air velocity CFD calculations between the ES1 and the Yamaha R1. The ordering red-yellow-green-blue depicts the relative air velocity from low to high respectively. Plot (a) shows the air flow around the ES1-rider combination. The computed aerodynamic drag-area coefficient with the rider in the prone position is $C_dA = 0.16m^2$. Plot (b) shows the air flow around the Yamaha R1-rider combination. The computed aerodynamic drag-area coefficient with the rider in the prone position is $C_dA = 0.35m^2$. These results were obtained from Spirit Motorcycle Technology.

In order to capture the dynamics of the ES1, nonlinear and linearized mathematical models of the vehicle were computed using the multi-body package VehicleSim [2]. The rigid body model is shown in Figure 2 and further details are given in Chapter 6 of [3]. Root-loci and Nyquist diagrams of the linearized vehicle under constant speed and lean [4], as well as acceleration and braking [5], are used to determine the stability bounds on various design parameters.

The vehicle parameters considered are related to the tires, the lower wishbone flexibility, the rear swinging arm flexibility, a proposed introduction of a front lateral flexibility and changes in the aerodynamic properties. The effect of each component is individually analyzed by comparing stability changes due to variations of a single parameter in an otherwise rigid vehicle. The results



(a) ES1 side view (b) ES1 multi-body diagram

Figure 2. Diagrams comparing the side view of the ES1 with the multi-body model programmed in VehicleSim [2]. Picture (a) was obtained from Spirit Motorcycle Technology and shows the right side view of the ES1 motorcycle. Diagram (b) shows the multi-body arrangement of the ES1. Shaded circles represent the body masses, white circles represent ball joints, while concentric circles show hinge joints with rotational freedoms along an axis pointing out of the page. The motorcycle is fitted with Pacejka Magic Formulae tires [6].

show that high friction tires are required, a deliberate introduction of a front lateral flexibility is ill-advised, the rear swinging arm and the front lower wishbone flexibilities should be made as stiff as economically possible and a passive mechanical network involving an inerter [7] is needed to stabilize the accelerating machine. Finally, the effects on the lateral dynamics due to changes in aerodynamics and vehicle loading are investigated. The weave mode becomes more unstable when rear wheel loading increases, or a higher aerodynamic center of pressure, and the wobble mode destabilizes when front wheel loading increases. The observed trends are compared with several results in the literature [4, 8, 9], and similarities as well as differences are highlighted.

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