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A numerical study on the wind effect on train overhead conductor cables

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SUMMARY:
This work examines the wind induced loads on various train overhead conductor cables and analyses the impact of wind angle and wind speed on the aerodynamic forces on the cables. The study was conducted using computational fluid dynamics (CFD) method, validated using wind tunnel experiments, where 6 common contact wires and 6 twisted conductor cables were considered. It was found that under perpendicular wind, the drag coefficients for the cables range from 0.77 to 1.11, where cables with similar diameters and geometrical form were shown to have similar values of drag coefficients (less than 3% difference). Additionally, the value of drag coefficient decreases as much as 98% with the change in wind angle from 90º (perpendicular) to 5º on all cables, which was due to the reduction of the wake and the stagnation regions. The drag coefficients were also observed to change (approximately 10% decrease) with increasing wind speed from 5 m/s to 35 m/s. The findings presented in this research provide a fundamental insight into the wind induced loads on various conductor cables.

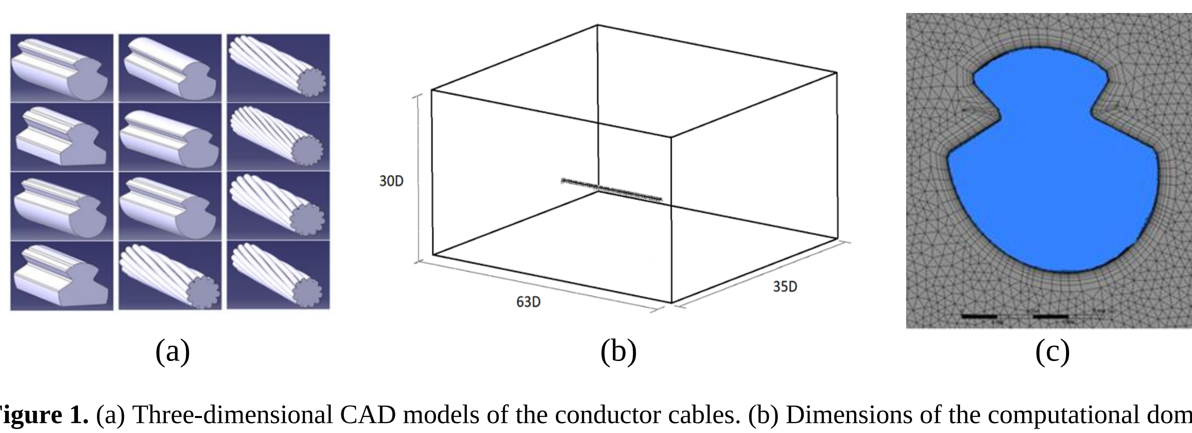
Keywords: Computational fluid dynamics, conductor cables, aerodynamic force, train overhead lines.

1. INTRODUCTION

The aerodynamic forces generated from flow over cables can contribute significantly to the structural loads for train Overhead Line Equipment (OLE) installations. The method of assessment currently uses the drag coefficient of conductor cables as a key input to OLE structure and foundation design. Wind loads on conductors are typically determined for adjacent span to the structure for up to 8 different wind directions. BS EN 50119:2020 (2020) clause 6.2.4.3 recommends that a drag factor of 1.0 is used to determine wind loadings for all conductors, regardless of the geometry. In fact, the drag coefficients for various components used in the UK are listed in ECP34 (1977). There, the conductor cables were typically assumed to be similar with circular cylinder and the methodology which the results were obtained is unknown. Further guidance is whilst available in EN 1991-1-4 (2005), it uses the term force coefficient and lacks clear justifications. In general, all these techniques assume a single value that is independent of wind angle. While some studies had been conducted on the flow over cables such as transmission cables (Shan et. Al., 1992, Mara & Hong, 2013), the geometrical configuration of cables can vary widely and the analysis on the flow over conductor cables is still lacking. Therefore, as part of the wider Network Rail Cost Effective Electrification programme of work, the aim of this study is to improve understanding of wind induced loads on OLE structures by investigating the aerodynamic forces on various conductor cables in order to inform future design parameters for OLE installations.

2. COMPUTATIONAL METHODS AND MODELS

A rectangular computational domain with the conductor cables placed within was created for this study. The domain has a length of 35D in the stream-wise direction, 30D in the vertical direction and approximately 63D in the span-wise direction; the dimensions of the domain were chosen such that the streamwise length is sufficient for the generation of downstream wake and blockage area effects can be neglected. A total of 12 conductor cables were considered based on the profiles of the conductors in BS EN 50149:2012 (2012), as shown in figure 1(a), which includes six common contact wires (AC-107 mm^2 new, AC-107 mm^2 worn, AC-120 mm^2 new, AC-120 mm^2 worn, BF-107 mm^2 and BF-120 mm^2) and six common twisted conductor cables (19/3.25-150 mm^2 (Hornet), 19/4.22-270 mm^2 (Cockroach), 37/378-400 mm^2 (Centipede), AL7 263, AL7 167, BzII 65 mm^2). The contact wires AC-107 mm2 worn and AC-120 mm2 worn are wires presented in worn condition with the wear of 33% of the cross-sectional area of AC-120 mm^2 new and AC-107 mm^2 new respectively. A short section of each conductor was modelled in uniform flow conditions. The Reynolds Averaged Navier Stokes (RANS) modelling approach with the k-ω SST turbulence model was used for the simulations. The method has been validated using both wind tunnel experiments and high-fidelity CFD technique LES—results are not shown here. A uniform wind speed of V_{ref} was used as the reference velocity at the inlet, while the top, bottom, sides and outlet of the domain was set with pressure outlet with zero pressure boundary condition. A no-slip boundary condition was applied to the surface of the conductor cables. Figure 1(c) shows an illustration of the computational mesh generated for the simulations. On the surface of the conductors, 10 layers of structured cells were created to resolve the flows near the walls, while the mesh around the conductor cables were refined by two refinement regions so that the flow characteristics are well captured, resulting in a total of approximately 9 million cells for each of the conductors shown in figure 1(c).



(a) (b) (c)

Figure 1. (a) Three-dimensional CAD models of the conductor cables. (b) Dimensions of the computational domain (c) Illustration of the computational mesh generated near the surface.

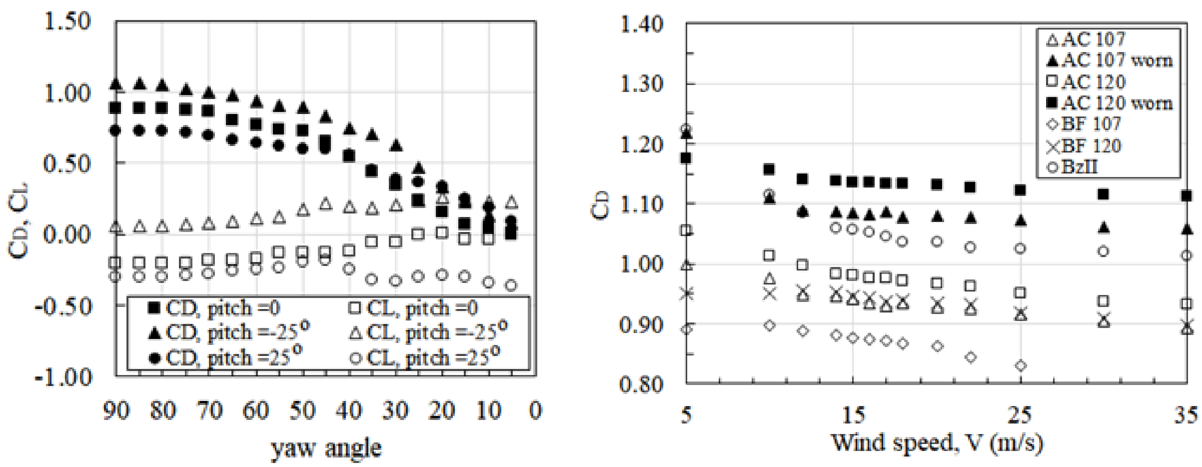
3. RESULTS & DISCUSSIONS

The numerically obtained aerodynamic forces on the cables are presented in table 1, where the drag coefficients of the cables at the reference velocity of 35m/s range from 0.77 to 1.11. It can be observed that the cable with the smallest diameter, BzII 65 mm^2 has a drag force of 7.11 N per unit length and drag coefficient of 1.0, while the cable with the largest diameter, 37/378-400 mm^2 (Centipede) has a drag force of 16.08 N per unit length and drag coefficient of 0.9. Cables with similar diameters and geometrical form show similar values of drag force and drag coefficients, e.g., the 19/3.25-150 mm^2 (Hornet) and AL7 167, with diameters of 16.25 mm and 16.8 mm respectively, have drag forces of 8.42 N and 8.28 N respectively, and drag coefficients of 0.77, and the 19/4.22-270 mm2 (Cockroach) and AL7 263, with diameters of 21.1 mm and 21.0 mm respectively, have the drag forces of 11.44 N and 11.34 N respectively, and drag coefficients of 0.8. For the comparison of wear conditions for contact wires, it can be observed that the increase in wear decreases the force on the cable, from 7.41 N to 5.96 N for AC-107 mm^2 new and AC-107 mm^2 worn respectively, and from 8.29 N to 8.07 N for AC-120 mm^2 new and AC-120 mm^2 worn respectively. However, despite the decrease in force, due to the decrease in projected area, the value of C_D increases with wear. Additionally, it was also shown that all the contact wires show a downwards force, as indicated by the negative values of C_L. This was due to the geometry of the contact wires, where a region of high pressure is concentrated on top of the front groove on all the contact wires, thus resulting in the downwards force.

Table 1. Force (per unit length of 1 m) and aerodynamic coefficients of the conductor cables in comparison with relevant documentation.

Conductor		Drag force (N)	C_D	Lift force (N)	C_L
Contact wire	AC-107 mm^2 new	7.41	0.89	-0.18	-0.19
	AC-107 mm^2 worn	5.96	1.06	-0.23	-0.25
	AC-120 mm^2 new	8.29	0.93	-0.23	-0.23
	AC-120 mm^2 worn	8.07	1.11	-0.27	-0.27
	BF-107 mm^2	5.91	0.77	-0.32	-0.37
	BF-120 mm^2	7.36	0.90	-0.18	-0.20
Conductor cable	19/3.25-150 mm^2 (Hornet)	8.42	0.77	0	0
	19/4.22-270 mm^2 (Cockroach)	11.44	0.80	0	0
	37/378-400 mm^2 (Centipede)	16.08	0.90	0	0
	AL7 263	11.34	0.80	0	0
	AL7 167	8.68	0.77	0	0
	BzII 65 mm^2	7.11	1.00	0	0

The impact of wind angles on all conductor cables were examined, where the inflow angle was simulated with yaw angles from 90º (perpendicular to the conductor cables) to 5º, in 5º increments. Due to the non-symmetrical cross section, three pitch angles were considered, 0º, -25º and 25º for contact wires. A general trend can be observed for all 3 pitch angles, where the value of C_D decreases with the decrease in yaw angle from 90º to 5º (as shown in figure 2(a) for the contact wire AC-107 mm^2 new). This was due to the wake region formed behind the cables being shifted sideways with the change in inflow yaw angle, thus reducing the pressure difference between the front and back of the cable in the perpendicular direction, resulting in the decrease in the value of aerodynamic drag, C_D. All wires in new condition shows the highest value of C_D at the pitch angle of -25º, while the lowest at the pitch angle of 25º, while wires with worn condition shows the highest value of C_D at the pitch angle of 25º. On the contrary, when the pitch angle is 0º or 25º, the magnitude of lift (negative value of C_L) is greater compared to the pitch angle of -25º for all contact wires. The impact of wind speed on the drag forces on the conductors subjected to various wind speeds are illustrated in figure 2(b). Generally, the values of C_D are higher at lower wind speeds, ranging between 0.9 to 1.17 at the lowest wind speed of 5 m/s, and gradually decreases with the increase in wind speed, with the value of C_D ranging between 0.77 to 0.93 at the highest wind speed of 35 m/s. Overall, the contact wires with smaller diameters, such as the AC-107 mm^2 and BF-107 mm^2, have lower drag coefficients in comparison with the contact wires with larger diameters such as the AC-120 mm^2. Additionally, wires with similar diameters such as AC-107 mm^2 and BF-120 mm^2 show very similar trends of drag coefficient.



(a) (b)

Figure 2. (a) Plot of force coefficients at different yaw and pitch angle on the cable, AC-107 mm^2 new. (b) Dimensions of the computational domain.

4. CONCLUSIONS

This work investigates the wind induced loads on 12 conductor cables and examines the impact of wind angle and wind speed on the aerodynamic drag and lift on the conductor cables. The following conclusions were made:

- The drag coefficients of the conductor cables at the perpendicular wind speed of 35 m/s ranges from 0.77 to 1.11, where cables with very similar diameters and geometrical form were shown to have similar values of drag force and drag coefficients.
- The value of C_D decreases as much as 98% with the change in wind angle from 90º to 5º on all cables, due to the wake region behind the cables shifting sideways.
- The value of C_D for the cables were observed to change with wind speed, but generally lower that the recommended drag factor as outlined in the design standards.

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