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A model for waterski jumping revisited

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1. Introduction

As compared to alpine ski jumping, covered by a large scientific literature, waterski jumping is so far only studied in a chapter of a book (Durey 1997) dedicated to the physics of sport. One of the main differences between alpine ski and waterski jumping, is the fact that the waterskier has to intercept the jump ramp at the end of an acceleration phase, during which hydrodynamic forces come into play, while gravity acceleration and air drag mainly influence the flight phase. Between both phases is a short time interval on the jump ramp. The reader is referred to the International Waterski and Wakeboard Federation website for further details on waterski jumping.

The objective of this study is to improve several aspects from the previous model, and especially : (i) acceleration phase as modelled for slalom waterskiing, (ii) account of the skier posture during the flight phase, as considered for alpine ski. Nevertheless, any loss of energy at the ramp, due to friction or through the shock absorption inside the waterskier body is neglected.

2. Method

The flight phase is determined by the skier speed at the ramp (V_J), the ramp height H , the skier mass m and body position. V_J is in turn determined through the acceleration phase on the water, adapted from a recently published model about slalom waterskiing (Lance 2024). It depends on the skier mass, hydrodynamic parameters, but also on other parameters chosen by the skier : the boat speed V_B and the acceleration start point towards the jump ramp.

2.1 Acceleration phase

For the detailed modelling of the acceleration phase, the reader is referred to Lance (2024). Only the main adaptations are here listed :

- The rope length is taken equal to 23 m
- The water lift coefficient considered for slalom waterskiing is multiplied by 3, in account of the larger surface of the two jump waterskis

- The roll angle characterizing the skier edge position is kept constant from a chosen start point and up to the jump ramp.

2.2 Flight phase

Specialized literature about alpine ski jumping models the air drag and uplift forces, depending on the square of the skier speed and on the body position (Müller 2002). This posture is characterized by three main angles, that have been studied in wind tunnel measurements for alpine ski jumping (Seo 2004). Posture angles are customized for the purpose of waterski jumping :

- While the leaning angle γ has to be minimized (legs and body aligned with the skis) in order to improve the performance, the heels of the waterskier are not free, as in alpine ski. Therefore the leaning angle is found higher than for alpine ski and equal to 35° .
- An angle between the skis $\lambda \sim 30^\circ$ is found to favor the performance and the safety of the alpine jump. Waterski jumpers currently adopt the same “V-position” and the angle λ is kept unchanged.
- Finally the pitch angle θ made by the skis, measured from the horizontal plane, is considered equal to 25° , based upon observations of the waterski jumps.

Air drag and lift forces are calculated during the flight phase, according to the polynomial expressions of Seo. Once the waterskier intercepts the ramp, at the end of the acceleration phase, there is a significant velocity contribution outwards of the boat direction, that justifies to model the flight phase as a motion of a point on a hemisphere, whose center is the rope fixation point in the moving boat.

3. Results and discussion

3.1 Examples

The Figure 1 shows a top view of 3 simulated jumps during competitions : a beginner (A), an intermediate level (B) and a pro waterskier (C), whose data are given at Table 1.

Table 1. Simulated waterskiers and their data

Skier	m (kg)	V_B (km/h)	H (m)	Start point
A	54	54	1.50	Boat channel
B	83	57	1.65	3/4 th cut
C	80	57	1.80	Full cut

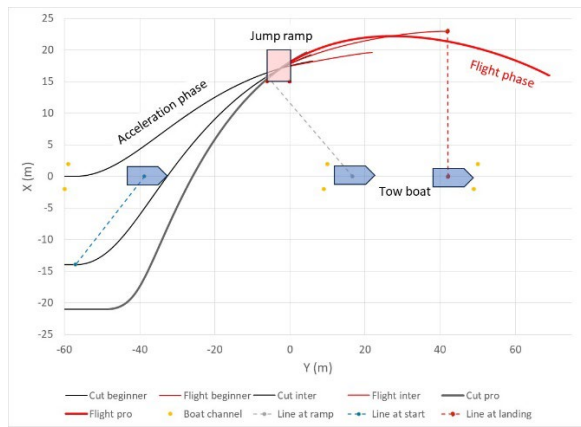


Figure 1. Top view of simulated jumps for 3 waterskiers. Black lines refer to the acceleration phase and red lines to the flight phase

The intermediate skier is assumed to start the acceleration, standing -14 m far away from the boat channel and -57 meters from the jump ramp (top level). It is found that a roll angle of 21° allows to reach the ramp and to achieve a jump length of 41 meters. The top view shows the rope between the skier and the boat at three specific phases : the acceleration start, the contact with the ramp and the landing. The beginner starts from the boat channel, what results in a jump of 22 meters. Finally, the pro starts the acceleration phase farther on the right hand side and later than the intermediate skier, what results in a jump of 69 meters (the world best performance is currently 77.4 m). Jump length of the 3 simulations can be reproduced with an appropriate set of values for the edge angle and the start point.

3.2 Acceleration phase

Simulating the acceleration of a waterskiier starting far away on the right hand side of the boat channel and going towards the jump ramp, it comes out that :

- The maximum speed is located approximately at the level of the ramp (15 m from the boat channel) and rises up to two times V_B , in agreement with values reported by Durey. Such a speed makes possible that the skier lands ahead of the boat, despite the air drag force.
- Lighter weight waterskiier have logically a higher acceleration, but they do not really benefit from this asset.
- Indeed, light waterskiiers are submitted to much higher relative rope tension as compared to heavier ones. Peak values obtained by skiers lighter than 80 kg can exceed 5 BW (body weight), what is in the practice the limit sustainable (Lance 2024). Heavier skiers have

thus a mass asset, ranging between 0.5 up to 0.9 BW / 10 kg.

- The jump speed V_J , of utmost importance for the jump performance, depends on two main parameters : the boat speed (proportional dependance with V_B) and the acceleration start point. The jump speed V_J is found to be 1.3 up to 1.6 times V_B , when the waterskiier starts the cut from the boat channel, while V_J can be multiplied from 1.6 to 2.1 V_B , when the waterskiier starts the cut from the extreme right hand side, but the price to pay is a higher rope load during the acceleration.

3.3 Flight phase

Simulations were performed, that show that the jump length is increased with higher V_J , by roughly 0.5 to 1 meter per km/h, in agreement with the values reported by Durey.

Finally, the jump length is increased with the ramp height, from 1 to 2.5 meters for every 15 cm height step, depending on V_J and on the prior acceleration. Nevertheless the skier has to withstand the push from the ramp (established from the time interval on the ramp and its height), which is somewhat higher for a higher ramp height, going from 2.5 BW for $H = 1.5$ m, up to 3 BW for $H = 1.8$ m.

4. Conclusions

A model for waterski jumping has been developed and implemented on an EXCEL worksheet. Simulations show that it can reproduce the jump performances, from the beginner up to the pro skier. Unfortunately it was not yet validated against measurements, especially the acceleration start point and the rope tension. The model could also be improved by an analysis of the air drag and lift forces, through wind tunnel measurements, considering specific waterski equipment and posture.

Conflict of Interest Statement

This summary presents no conflict of interest.

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