**CONFIGURATIONS OF THE GRAF–BOKLEV (V-STYLE) SKI JUMPER MODEL AND AERODYNAMIC PARAMETERS IN A WIND TUNNEL**

DOI: 10.2478/v10038-009-0012-4

Jerzy Maryniak¹, Edyta Ładyżyńska-Kozdra²*, Sławomir Tomczak³

¹ The Polish Air Force Academy, Dęblin, Poland
² Faculty of Mechatronics, Warsaw University of Technology, Warsaw, Poland
³ Faculty of Mechanical, Power and Aeronautical Engineering, Warsaw University of Technology, Warsaw, Poland

**ABSTRACT**

The paper discusses the results of wind tunnel tests for different angular configurations ($\varphi_1$ and $\varphi_2$) of a V-style (Graf–Boklev style) ski jumper model. The range of tested angles of attack was $\alpha = -10, 20, 30, 40$ (deg), depending on a configuration. The configurations of the Graf–Boklev style ski jumper model were compared with the classic parallel style of ski jumping with the ski-opening angle $\lambda = 0$. K1 as a configuration for the parallel style of ski jumping was used as the reference configuration for other configurations with different ski-opening angles, i.e., $\lambda = 0, 15, 25, 45$ (deg). The results obtained have been presented graphically as aerodynamic parameters within a specific angle of attack.

**Key words:** ski jumping, Graf–Boklev configuration, V-style, aerodynamic characteristics

---

**Introduction**

Ski jumper model tests for the parallel style (Dae-scher technique) were carried out in a balance wind tunnel in the Institute of Aeronautics and Applied Mechanics of the Warsaw University of Technology in 1971 [1–3] and 1990 [4]. On the basis of those tests mathematical models were developed and various studies of the dynamics of a ski jumper in flight were performed [1, 2, 5–8]. The present study was carried out with a V-style (Graf–Boklev technique) ski jumper model (ski jumper + skis) [3, 4, 8–10]. The V-style of ski jumping so commonly used nowadays was first demonstrated by Polish ski jumper Mirosław Graf [10].

The V-style allows performing longer and safer ski jumps in different angular configurations and at different ski-opening angles.

The present study was aimed to examine the behavior of a ski-jumper in different configurations and to determine the impact of configuration test model parameters on aerodynamic characteristics.

Particular configurations were marked as $K_i \lambda \nu$ (Tab. 1, Fig. 1, Fig. 2), where $i$ denoted the ski jumper configuration number with the following angles: configuration angle $\varphi_1 = 10, 20, 30$ (deg) and $\varphi_2 = 0, 10, 20, 30$ (deg); ski-opening angle $\lambda = 0, 15, 25, 45$ (deg); angle of roll $\nu = 0, 15, 30$ (deg). For example, $K_4 \_25 \_15$ was a configuration with the following angular values: $\varphi_1 = 20$ (deg), $\varphi_2 = 0$ (deg), $\lambda = 25$ (deg), $\nu = 15$ (deg). When the ski-opening angle $\lambda$ amounted to 0 or the angle of roll $\nu$ to 0, these values were not taken into consideration.

**Table 1. Ski jumper test model angular configurations**

| Configuration | $\varphi_1$ (deg) | $\varphi_2$ (deg) | $\lambda$ (deg) | $\nu$ (deg) | $\alpha$ (deg) |
|---------------|------------------|------------------|----------------|-------------|---------------|
| K1 $\lambda$  | 10               | 0                | 0, 15, 25, 45   | 0, 15, 30   | –10 – 40      |
| K2 $\lambda$  | 10               | 10               | 15, 25, 45      | 0, 15, 30   | –10 – 40      |
| K3 $\lambda$  | 10               | 20               | 15, 25, 45      | 0, 15, 30   | –10 – 40      |
| K4 $\lambda$  | 20               | 0                | 15, 25, 45      | 0, 15, 30   | –10 – 40      |
| K5 $\lambda$  | 20               | 20               | 15, 25, 45      | 0, 15, 30   | –10 – 40      |
| K6 $\lambda$  | 30               | 0                | 15, 25, 45      | 0, 15, 30   | –10 – 40      |
| K7 $\lambda$  | 30               | 30               | 15, 25, 45      | 0, 15, 30   | –10 – 40      |

$\varphi_1, \varphi_2$ – configuration angles, $\lambda$ – ski-opening angle, $\nu$ – angle of roll, $\alpha$ – angle of attack

In configuration K1, a parallel ski jumping style was used with $\lambda = 0$ (deg). Since the parallel style used to be the most common ski jumping technique, K1 was regarded as the reference configuration.

The angles of attack $\alpha$ (Fig. 2), depending on the ski jumper configuration, ranged from $-10$ (deg) to $40$ (deg).
**HUMAN MOVEMENT**

J. Maryniak, E. Ładyżyńska-Kozdraś, S. Tomczak, Effects of ski jumper configurations

**Material and methods**

Wind tunnel model ski jumper tests

The aerodynamic model ski jumper tests were carried out in Wind Tunnel 1 of the Department of Aerodynamics in the Institute of Aeronautics and Applied Mechanics of the Warsaw University of Technology (Fig. 3). The wind tunnel was equipped with an aerodynamic balance designed by Prof. C. Witoszyński. The measurement methods were taken from Litwińczuk et al. [11] and Tomczak, Maryniak [12].

The test section of the wind tunnel was connected to a PC with data processing software for measurement of the lift ($P_z$), drag ($P_x$) and pitching moment ($M_a$) (Fig. 2). Tests were carried out for different configurations of the
ski jumper model (ski jumper + skis) in the full range of angles of attack $\alpha$ (Fig. 4) \[1–9, 10, 12–14\]. The configurations of the ski jumper model change during particular stages of a ski jump: stage 1 – take off – skis parallel followed by a quick opening and formation of the V-shape and proper angle of attack $\alpha$; stage 2 – V-style flight, maintaining the most favorable lift-to-drag ratio and proper angle of attack $\alpha$; stage 3 – landing approach, moving from the V-formation to the parallel technique; stage 4 – touch down, proper landing (telemark, or safe landing if the critical landing point is crossed).

Figure 4. Ski jump stages

Results

Defining dimensionless aerodynamic coefficients

The study was aimed to determine dimensionless aerodynamic coefficients of the lift ($C_z$), drag ($C_x$) and pitching moment ($C_{ma}$) within the angle of attack $\alpha$ for a given ski jumper configuration ($\varphi_1, \varphi_2$), ski-opening angle ($\lambda$) and angle of roll ($\nu$). The coefficients of the lift ($C_z$) and drag ($C_x$) were used to determine the lift-to-drag ratio $K$, which could be physically interpreted as the distance covered by a gliding object (sailplane, bird, ski jumper) in windless weather:

$$K (\alpha, \varphi_1, \varphi_2, \lambda, \nu) = \frac{C_z (\alpha, \varphi_1, \varphi_2, \lambda, \nu)}{C_x (\alpha, \varphi_1, \varphi_2, \lambda, \nu)} \quad (1)$$

The aerodynamic balance was used to determine first the drag ($P_x$), lift ($P_z$) and pitching moment ($M_a$), and then their dimensionless aerodynamic coefficients:

$$P_x = \frac{1}{2} \rho V_0^2 C_x (\alpha, \varphi_1, \varphi_2, \lambda, \nu),$$
$$C_x = C_x (\alpha, \varphi_1, \varphi_2, \lambda, \nu) = \frac{P_x}{\frac{1}{2} \rho V_0^2} \quad (2)$$

$$P_z = \frac{1}{2} \rho V_0^2 C_z (\alpha, \varphi_1, \varphi_2, \lambda, \nu),$$
$$C_z = C_z (\alpha, \varphi_1, \varphi_2, \lambda, \nu) = \frac{P_z}{\frac{1}{2} \rho V_0^2} \quad (3)$$

$$M_a = \frac{1}{2} \rho S V_0^2 C_{ma} (\alpha, \varphi_1, \varphi_2, \lambda, \nu),$$
$$C_{ma} = C_{ma} (\alpha, \varphi_1, \varphi_2, \lambda, \nu) = \frac{M_a}{\frac{1}{2} \rho S V_0^2} \quad (4)$$

$V_0$ – airflow velocity ($V_0 = 30$ m/s for wind tunnel tests),
$S$ – surface area of ski jumper model skis ($S = 0.034739$ m$^2$),
$l$ – ski length ($l = 0.705$ m),
$\rho$ – air density ($\rho = 1.225$ kg/m$^3$).

Figures 5–11 present selected test results.
Figure 7. Changes of dimensionless aerodynamic coefficients of the drag ($C_x$), lift ($C_z$), pitching moment ($C_{ma}$) and lift-to-drag ratio ($C_z/C_x$) within angle of attack $\alpha$ for configuration K1 ($\phi_1 = 10$ (deg), $\phi_2 = 0$ (deg), $\lambda = 0, 15, 25, 45$ (deg), $\nu = 0$ (deg)).

Figure 8. Changes of the lift-to-drag ratio ($C_z/C_x$) within angle of attack $-10 \leq \alpha \leq 40$ (deg), and a visual representation of the ski jumper test model (ski jumper + skis) for configuration K1_450 ($\phi_1 = 10$ (deg), $\phi_2 = 0$ (deg), $\lambda = 45$ (deg), $\nu = 0$ (deg)).
Figure 9. Changes of dimensionless aerodynamic coefficients of the drag ($C_x$), lift ($C_z$), pitching moment ($C_{ma}$) and lift-to-drag ratio ($C_z/C_x$) within angle of attack $\alpha$ for configuration K6 ($\varphi_1 = 30$ (deg), $\varphi_2 = 0$ (deg), $\lambda = 0, 15, 25, 45$ (deg), $\nu = 0$ (deg)).

Figure 10. Changes of the lift-to-drag ratio ($C_z/C_x$) within angle of attack $\alpha$, and a visual representation of the ski jumper test model (ski jumper + skis) for configuration K7_450 ($\varphi_1 = 30$ (deg), $\varphi_2 = 30$ (deg), $\lambda = 45$ (deg), $\nu = 0$ (deg)).
Conclusions

The above study is the first such comprehensive ski wind tunnel research in professional literature. The wind tunnel tests of configuration K1 for the parallel style of ski jumping were performed to obtain reference values for the V-style configurations: for K1_0 $C_{z_{\text{max}}} (\alpha) = 1.16$ with $\alpha = 40$ (deg), and lift-to-drag ratio $K_{\text{max}} (\alpha) = 1.08$ with $\alpha = 21$ (deg) (Fig. 5). Configuration K1_450 featured the highest coefficient of the lift and lift-to-drag ratio, for $C_{z_{\text{max}}} (\alpha) = 1.53$ with $\alpha = 40$ (deg), and $K_{\text{max}} (\alpha) = 1.58$ with $\alpha = 10$ (deg) (Fig. 7, 8, 11). It should be emphasized that an excessive angle of roll $\nu$ reduces the measured aerodynamic parameters (Fig. 11). The jumping distance is also considerably influenced by changes of the angle of attack ($\alpha$) during particular stages of the jump (Fig. 8, 10).

Acknowledgements

Research financed from the 2008–2010 research fund. Project O N501 003534.

References

1. Luhtanen P., Pulli M., Ski-jumping champion exploits ballistics and aerodynamics. Griffin the SAAB-SCANIA, Linköping, 1989.

2. Maryniak J., Longitudinal stability of a ski jumper in flight [in Polish]. NIT – Nauka Innowacje Technika, 2003, 1, 5–11.

3. Maryniak J., Krasnowski B., Longitudinal stability of a ski jumper. In: Proceeding of the 1st Polish Symposium “System, Modeling, Control” [in Polish]. PTC, Łódź 1974, 195–209.

4. Maryniak J., Static and dynamic investigations of human motion. In: Proceedings of the Congress Mechanics of Biological Solids. Bulgarian Academy of Sciences, Sofia 1977, 151–174.

5. Maryniak J., Direct numerical simulation of ski jumps. In: Proceedings of the 7th Symposium on Simulation of Dynamic Processes [in Polish]. Wydzial Elektryczny, Politechnika Warszawska, Warszawa 1993, 255–264.

6. Maryniak J., Dynamics of a ski jumper in flight: direct numerical simulation [in Polish]. NIT – Nauka Innowacje Technika, 2003, 2, 41–51.

7. Maryniak J., Ski jumps – take-off, flight stability, aerodynamics of a ski jumper in V-style configuration [in Polish]. NIT – Nauka Innowacje Technika, 2004, 1, 31–40.

8. Maryniak J., Tomczak A., Dziubiński A., Machu M., Aerodynamic tests of a ski jumper model [in Polish]. DOR-253/2002, ZNB Dynamiki Obiektów Ruchomych, Politechnika Warszawska, Warszawa 2002.

9. Maryniak J., Wołek A., The effects of ski jumper’s posture of the flight trajectory [in Polish]. Zeszyty Naukowe AWF we Wrocławiu, 1991, 53, 129–137.

10. Maryniak J., Dynamic theory of moving objects [in Polish]. Prace Naukowe Politechniki Warszawskiej. Mechanika. Politechnika Warszawska, Warszawa 1976, 32.

11. Litwińczuk M., Selerowicz W., Skrzyński S., Tarnogrodzki A., Lab exercises in fluid mechanics [in Polish]. Politechnika Warszawska, Warszawa 1991.
12. Tomczak A., Maryniak J., Aerodynamic tests of the V-style ski jumper model. In: Maryniak J. (ed.), Mechanics in aviation [in Polish]. Polskie Towarzystwo Mechaniki Teoretycznej i Stosowanej, Warszawa 2002, 493–509.

13. Maryniak J., Leśniewska A., Mathematical modeling of dynamics of ski jumper in flight by using the Boltzmann–Hamel equations [in Russian]. *Biomechanika*, 1978, 7, 10–16.

14. Maryniak J., Krasnowski B., Balance and longitudinal stability of a ski jumper in flight [in Polish]. *Mechanika Teoretyczna i Stosowana*, 1974, 2(3), 351–373.