Robust and Corrected Coefficients for the ROtor-Body-INteraction (ROBIN) Geometry

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1 Introduction

The ROBIN body is a VTOL fuselage shape [1, 5, 4, 3] defined by the intersection of multiple sets of analytic equations. This shape is very useful as a benchmark for rotorcraft aerodynamics research, but the formulae, if implemented as published, will generate floating point errors during computation, and even if those are fixed, the coefficients will not recreate a usable shape. While subsequent authors have presented corrections [5, 4], none have reported all that are required to generate the proper shape. This Technical Note serves as a notice of correct and clarified formulae and coefficients suitable for automatic calculation. It also provides a link to a public repository for a program which generates a correct triangular mesh surface of the ROBIN body [2], otherwise unavailable online. Note that our aim is simply to *allow* generation of the shape as used in previous research using formulae as close as possible to those previously published, alleviating any modeling burden on future researchers, and not to change the intent of the original coefficients, or create a new or different shape.

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2 Method and Proposed Changes

In proper form, the superellipse function used to define the ROBIN body is

$$y = r\sin\theta \quad , \quad z = r\cos\theta + Z0 \tag{1}$$

where

$$r = \left(\frac{\left(\frac{HW}{4}\right)^N}{|\frac{H}{2}\sin\theta|^N + |\frac{W}{2}\cos\theta|^N} \right)^{\frac{1}{N}} \qquad \theta \in [0, 2\pi]. \tag{2}$$

and H, W, N, and $Z0$ are height (z), width (y), elliptical power, and camber line coefficients, respectively. Each of these coefficients varies along the length (x) of the body according to

$$F(x) = C_6 + C_7 \left[C_1 + C_2 \left(\frac{x + C_3}{C_4} \right)^{C_5} \right]^{\frac{1}{C_8}} \tag{3}$$

with appropriate parameters $C_{1\to 8}$. Original [1] and subsequent [5] papers confusingly point to different equations for N and $Z0$. In addition, all previous authors omit the absolute value modifiers on sine and cosine in Eq. (2); these easily prevent floating point errors when an otherwise negative number is raised to a non-integer power, though their inclusion could be circumvented with extra algorithmic logic. All subsequent corrections involve the coefficients.

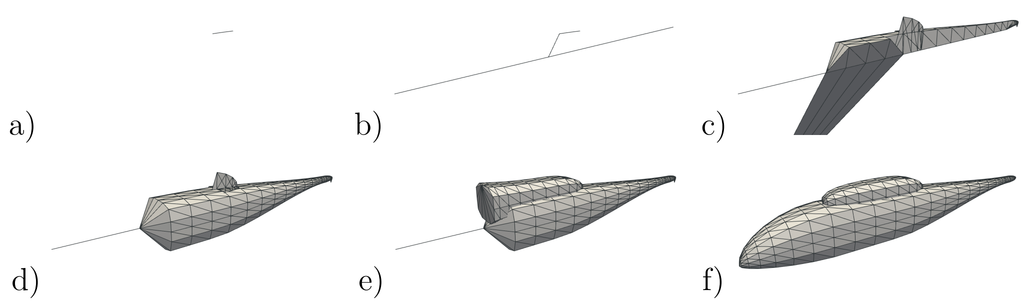

Figure 1: Fuselage and pylon generated by the following: a) Ref. [1] as written; b) Ref. [1] with absolute values around sine and cosine and converting NaN to 0; c) Ref. [5] converting NaN to 0; d) Ref. [5] with sine and NaN fixes; e) Ref. [4] with fixes from Ref. [5] and sine and NaN; f) present work.

Tables 1 and 2 present our proposed coefficients, with changes from the original [1] in bold, accounting for all corrections listed below.

When applied using the full Eq. (3) in an automatic system, the original coefficients result in frequent floating point errors, which prevent obtaining the correct values for r and $Z0$ and thus y and z. Previous authors had made corrections to alleviate some of these errors, but not all (see Fig. 1).

- Two obvious typographic errors in the original [1] — $Z0$ in the second body segment and N on the pylon aft — were caught by later authors [5, 4], but no author reported both.

- Phelps & Berry [5] noted that sections with C_1 representing the constant value were raised to the power of $\frac{1}{C_8} = \frac{1}{0}$ and then multiplied by $C_7 = 0$. They subsequently report using $C_7 = C_8 = 1$ to correct this.

Incorporating the corrections from subsequent authors still does not allow creation of the correct shape. Here we describe further changes to the coefficients that needed to be made.

- Denominators C_4 for H and W for the front section of both the fuselage and pylon, as well as $Z0$ for the front of the fuselage, had the wrong sign and created incorrect results (see Figs. 1e-f).

- In cases where $C_2 = 0$, C_4 was changed from 0 to 1 to prevent division by zero.

While the above corrections were necessary to generate a valid shape, the original coefficients generated a tall pylon that did not appear to match the model used in those experiments [1, 5]. We thus use coefficients C_7 for H and W from Mineck and Gorton (2000) [4]. Figure 2 shows both original ($C_{7,H} = 0.2$, $C_{7,W} = 0.172$) and updated ($C_{7,H} = 0.145$, $C_{7,W} = 0.166$) pylon shapes.

A final change reported in the coefficients in Tables 1 and 2 represents a preference for simplicity and is not required for correctness. Coefficient sets that were intended to produce a constant value over the interval placed the constant value in C_1, inside the brackets in Eq. 3. In order to avoid floating point errors, this requires also setting $C_4 = C_7 = C_8 = 1$. Alternatively, if that constant value were assigned to C_6, outside the brackets, one only needs to set $C_4 = C_8 = 1$ to achieve the desired result.

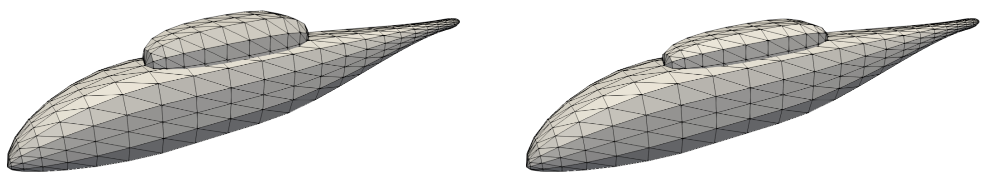

Figure 2: Pylon using original coefficients [1, 5] (left), pylon from Mineck and Gorton (2000) [4] (right).

Portable C++ code using these formulae and coefficients is provided at the following Github link: `https://github.com/Applied-Scientific-Research/robin-surface-mesh` [2]. The compiled program generates a triangular mesh with a user-specified number of nodes across the length and circumference of the fuselage and pylon.

3 Conclusion

This Technical Note contains corrected coefficients and robust formulae for easy reproduction of the ROBIN body, a well-studied but erratically documented geometry useful for studies of rotary-wing aerodynamics. The equations are now easily translatable to a computer algorithm, and an open-source program which recreates the surface geometry has been created. We hope that future research projects will not be led astray by past inconsistencies in the reporting of the body coefficients and formulae.

References

[1] C. E. Freeman and R. E. Mineck. Fuselage Surface Pressure Measurements of a Helicoptor Wind-Tunnel Model with a 3.15 Meter Diameter Single Rotor. Technical Report NASA TM-80051, March 1979.

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[3] R. E. Mineck. Application of an Unstructured Grid Navier-Stokes Solver to a Generic Helicopter Body. Technical Report NASA TM-1999-209510, August 1999.

[4] R. E. Mineck and S. A. Gorton. Steady and Periodic Pressure Measurements on a Generic Helicopter Fuselage Model in the Presence of a Rotor. Technical Report NASA/TM-2000-210286, June 2000.

[5] A. E. Phelps, III and J. D. Berry. Description of the U.S. Army Small-Scale 2-Meter Rotor Test System. Technical Report NASA TM-87762, February 1987.

Table 1: Coefficients for the fuselage; changes are in **bold**

Function	x	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
H	[0.0, 0.4]	1.0	-1.0	-0.4	**-0.4**	1.8	0.0	0.25	1.8
W		1.0	-1.0	-0.4	**-0.4**	2.0	0.0	0.25	2.0
$Z0$		1.0	-1.0	-0.4	**-0.4**	1.8	-0.08	0.08	1.8
N		2.0	3.0	0.0	0.4	1.0	0.0	1.0	1.0
H	[0.4, 0.8]	**0.0**	0.0	0.0	**1.0**	0.0	**0.25**	0.0	**1.0**
W		**0.0**	0.0	0.0	**1.0**	0.0	**0.25**	0.0	**1.0**
$Z0$		**0.0**	0.0	0.0	**1.0**	0.0	0.0	0.0	**1.0**
N		**0.0**	0.0	0.0	**1.0**	0.0	**5.0**	0.0	**1.0**
H	[0.8, 1.9]	1.0	-1.0	-0.8	1.1	1.5	0.05	0.2	0.6
W		1.0	-1.0	-0.8	1.1	1.5	0.05	0.2	0.6
$Z0$		1.0	-1.0	-0.8	1.1	1.5	0.04	-0.04	0.6
N		5.0	-3.0	-0.8	1.1	1.0	0.0	**1.0**	**1.0**
H	[1.9, 2.0]	1.0	-1.0	-1.9	0.1	2.0	0.0	0.05	2.0
W		1.0	-1.0	-1.9	0.1	2.0	0.0	0.05	2.0
$Z0$		**0.0**	0.0	0.0	**1.0**	0.0	**0.04**	0.0	**1.0**
N		**0.0**	0.0	0.0	**1.0**	0.0	**2.0**	0.0	**1.0**

Table 2: Coefficients for the pylon; changes are in **bold**

Function	x	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
H	[0.4, 0.8]	1.0	-1.0	-0.8	**-0.4**	3.0	0.0	**0.145**	3.0
W		1.0	-1.0	-0.8	**-0.4**	3.0	0.0	**0.166**	3.0
$Z0$		**0.0**	0.0	0.0	**1.0**	0.0	**0.125**	0.0	**1.0**
N		**0.0**	0.0	0.0	**1.0**	0.0	**5.0**	0.0	**1.0**
H	[0.8, 1.018]	1.0	-1.0	-0.8	0.218	2.0	0.0	**0.145**	2.0
W		1.0	-1.0	-0.8	0.218	2.0	0.0	**0.166**	2.0
$Z0$		1.0	-1.0	-0.8	1.1	1.5	0.065	0.06	0.6
N		**0.0**	0.0	0.0	**1.0**	0.0	**5.0**	0.0	**1.0**