

RApid Blade-Vortex Interaction Tool (RABIT) User's Manual - Version 1.0

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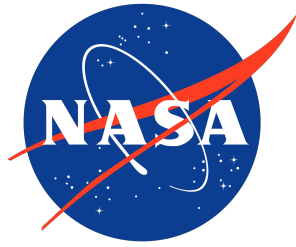
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Abstract

Identifying and reducing rotorcraft noise is essential to urban air mobility (UAM). Blade-vortex interaction (BVI) can be a major contributor to rotary-wing vehicle noise, particularly during flight phases where a close and nearly parallel interaction occurs between a rotor blade and a strong tip vortex. These interactions often happen during the descent and landing phases of flight when the vehicle is near the ground and therefore, near people. Reducing public noise exposure requires fast BVI estimations to rapidly assess the acoustic signature of rotary-wing vehicles. The RAPid Blade-Interaction Tool (RABIT) is a fast, user-friendly, stand-alone computer program/application that predicts BVI strength and location using a prescribed wake model and a simple blade motion model. It also determines blade and wake intersection timing and location and provides visualizations to support conceptual design, rotor placement, and rotor-wake interaction assessments. This manual outlines the background of the RABIT tool, theory, validation cases, installation process, interface, output files, and example applications.

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Nomenclature

A	Rotor disk area (ft ²)
C_T	Coefficient of thrust, $\frac{T}{\rho A(\Omega R^2)}$
F	Blade loading (lb/(ft·s))
N_b	Number of blades
R	Rotor radius (ft)
T	Thrust (lb)
TOL	Tolerance factor (%)
V_b	Local blade velocity (ft/s)
V_∞	Forward flight velocity (ft/s)
X	Streamwise coordinate relative to rotor 1 hub center, positive forward flight direction (ft)
Y	Lateral coordinate relative to rotor 1 hub center, positive port direction (ft)
Z	Vertical coordinate relative to rotor 1 hub center, positive up direction (ft)
c	Blade mean chord (ft)
$c_{l\alpha}$	2D lift curve slope (1/rad)
h	Blade-vortex vertical miss distance (ft)
r	Spanwise radial position (ft)
α_{TPP}	Rotor tip-path-plane angle, positive nose up (deg)
β_0	Rotor coning angle, positive blades up (deg)
γ	Blade-vortex interaction angle (deg)
Γ	Vortex strength (ft ² /s), $\Gamma = 2\Omega R c \frac{C_T}{\sigma}$
$\bar{\Gamma}_s$	Vortex strength factor, $\frac{\Gamma}{2\pi h V_b}$
χ	Wake skew angle (deg)
$\bar{I}$	BVI Impulse factor
λ_0	Inflow ratio
λ_i	Inflow (ft/s)
μ	Advance ratio, $\frac{V_\infty}{\Omega R}$
ρ	Air density (slug/ft ³)
σ	Rotor solidity, $\frac{N_b c}{\pi R}$
ψ	Azimuth angle (deg)
ψ_b	Blade azimuth angle of BVI interaction (deg)
ψ_s	Azimuth angle of blade that generated vortex (deg)
ψ_w	Vortex wake age (deg)
Ω	Rotor angular speed (rad/s)

1 Introduction

Rapid Blade-Interaction Tool (RABIT) is an educational tool designed to assist engineers in quickly identifying blade-vortex interaction (BVI) occurrences for various vehicle configurations. RABIT provides the framework for users to create and analyze rotorcraft configurations with various blade geometries, while featuring a user-friendly interface that maximizes accessibility to engineers of all educational backgrounds. This manual is designed to familiarize the user with the background, theory, interface, function, and output of the RABIT application.

1.1 Background

The emergence of the urban air mobility (UAM) market has brought rotary-wing noise reduction to the forefront of civil rotorcraft applications, as minimizing environmental intrusion is a critical element to more widespread usage of UAM vehicles [1, 2]. Noise sources generated by the rotor blades are often categorized as being either loading, thickness, or high speed impulsive noise. Loading noise can be separated into steady and unsteady sources. Unsteady sources can be further subdivided into deterministic sources and non-deterministic sources. Non-deterministic sources are considered “broadband”, which have a random nature; whereas deterministic sources are not random [1]. BVI noise is generally an unsteady but deterministic component of loading noise (see Fig. 1). Thickness noise is related to blade geometry and blade motion, but not aerodynamics, so it is not considered here. High speed impulsive noise is related to shock waves in the flow field which are generated by blade sections traveling near the speed of sound. High speed impulsive noise sources are not considered here because rotors on most UAM vehicles do not operate such that the blade tips approach the speed of sound.

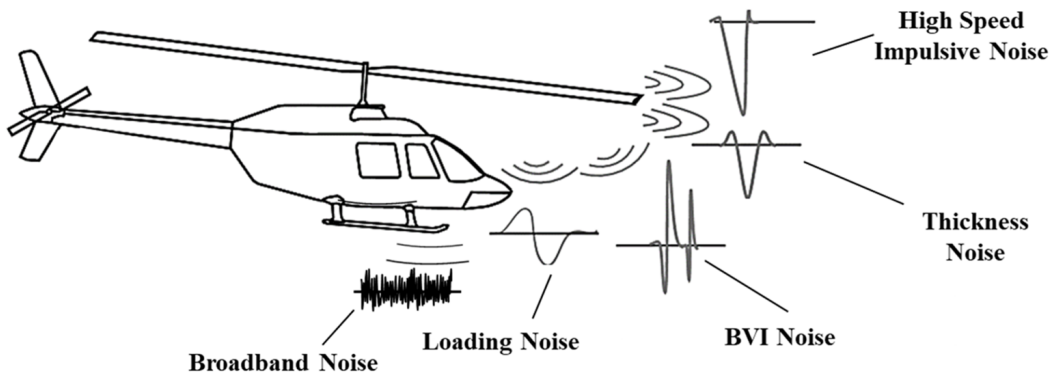


Figure 1: Examples of Rotorcraft Noise Sources [1].

One of the primary contributors to noise during landing is BVI noise, which arises from an aerodynamic condition in which a tip vortex impinges on a rotor blade, see Fig. 2 for a parallel BVI. A BVI event may result from interaction with a vortex shed by the same blade or with vortices generated by other blades. This interaction could cause an impulse in blade loading which results in a pressure wave

being emitted. The amplitude of this pressure wave will be related to the amplitude of the impulse of the interaction (more specifically, to the time rate of change of the blade loading) [3]. Under certain conditions, these events can accumulate and increase the noise related to vehicle operations and have adverse effects on continued operations in a community. Four different types of BVI geometric scenarios are identified based on the intersection angle between the vortex and the blade: parallel, perpendicular, oblique, and orthogonal [4]. The most intense form of BVI noise can occur when the BVI geometry is “parallel”, where the interaction angle between the blade and vortex is 0 degrees.

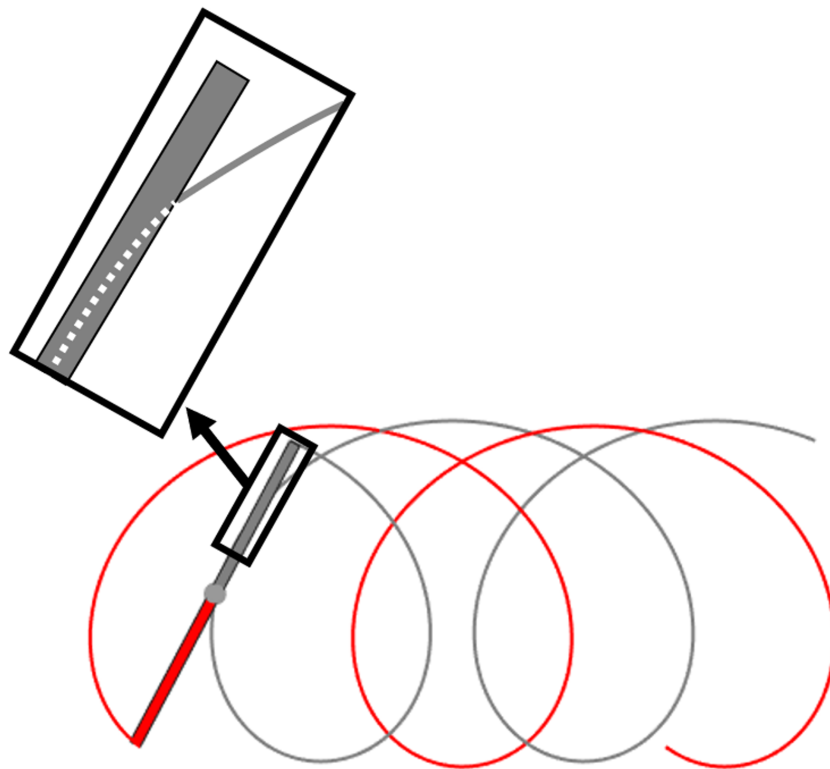


Figure 2: Visual of a parallel BVI occurrence.

The NASA Advanced Air Mobility (AAM) Toolchain is a suite of codes used in the evaluation of noise and performance of rotary wing vehicles. The current toolchain workflow that enables the prediction of rotor noise includes calculating loads from Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics II (CAMRAD II) [5] to feed into the ANOPP2 Aeroacoustic Rotor Noise (AARON) tool [6]. ANOPP2 is a NASA aircraft noise prediction framework, while AARON is the rotorcraft-focused module within ANOPP2 that provides aeroacoustic rotor noise modeling. Due to the computationally expensive and time-consuming nature of these programs, a rapid and lower fidelity tool is desired. Thus, the Rapid BVI Tool (RABIT) was created.

RABIT enables engineers to quickly design and simulate the location and charac-

teristics of BVI and blade overlap for a variety of UAM configurations, including single, multi, and coaxial rotors. RABIT is not a general acoustic prediction tool, but instead utilizes vortex and wake parameters to visualize and predict BVI geometry and the resultant unsteady aerodynamics on the blade. The tool utilizes a Beddoes' prescribed wake model [7], and then computes variables such as vertical miss distance and BVI angle between the vortex and the blade to calculate an impulse factor that visualizes the BVI geometry for a given rotorcraft. The goal of this tool is to help engineers quickly locate and predict BVI potential noise source locations to better understand which rotorcraft configurations and blade designs are amenable to rotorcraft noise reduction.

1.2 Development History

In 1995, Sim and George developed a program based on Beddoes' prescribed wake model to resolve BVI events. This program introduced a novel method for evaluating and quantifying BVI noise in terms of blade loading by simulating the blade tip vortex trajectory to predict various factors that influence BVI noise [7, 8].

Building upon this foundation, Schatzman (2018) predicted and visualized blade crossing locations and the BVI impulse factor for both single and coaxial rotors, validating the approach against Sim and George's single rotor blade data [2]. This early code, initially named RABBIT (RAPid Blade and Blade-vortex Interaction Timer), lacked a graphical user interface (GUI). In 2022, Weist and Schatzman further compared RABBIT to CAMRAD II and AARON for various configurations including the Quiet Single Main Rotor (QSMR), Side-by-Side, and Quadrotor models. These efforts demonstrated the capability of RABBIT as a robust prediction tool for visualizing BVI geometry across multiple parameters [9]. Subsequently, in 2024, Schatzman and Holly enhanced the software by introducing a user-friendly GUI, improving overall robustness, and expanding its geometry modeling capabilities [10].

In 2025, the tool was rebranded as the Rapid BVI Tool (RABIT). Accompanying this name change was a newly designed logo by Isabelle Pichay (Fig. 3), which aesthetically aligns with the tool's function while playfully nodding to its namesake. The design incorporates a vortex motif that seamlessly transitions into rabbit ears mimicking rotor blades, symbolizing the tool's reliance on vortex and wake parameters to predict BVI geometry. A final stylized blade swoops downward to form the rabbit's neck, completing the silhouette. The finalized design was subsequently vectorized using Adobe Illustrator (v 29.7.1).



Figure 3: RABIT logo designed by Isabelle Pichay.

2 Theory

The theory section provides a brief summary of the research behind BVI aerodynamics and the basic RABIT algorithm. Beddoes' prescribed wake model is explained and concepts such as blade loading, impulse factor, and BVI angle are introduced. RABIT capabilities and assumptions are as follows:

Rotor/Blade Geometry

- Blades modeled as rectangular prisms (only airfoil thickness modeled)
- Variation in rotor and blade counts, blade spacing, and coning and shaft tilt angles

Wake Model

- Beddoes' Wake Model (prescribed wake)
- Wakes do not interact with each other (each rotor acts independently)
- Wakes from other rotors can hit all rotors and will identify potential BVI occurrences

Blade Loading Model

- Wake skew angle and induced velocity calculated from momentum theory
- Vortex strength calculated from momentum theory and Helmholtz's theorem
- BVI intensity calculated by using Sim and George's rotor blade loading prediction scheme

2.1 Wake Model

RABIT was designed as a tool for rapid BVI prediction, and as such, utilizes low fidelity calculation methods to improve computational speed, thus the Beddoes' prescribed wake model is implemented [7]. The Beddoes' wake model is a prescribed wake model that calculates tip vortex geometries. In general, a free wake model computes the distorted wake geometry resulting from the induced velocity of every wake element in the system. This method can be computationally expensive.

Beddoes' prescribed wake model is a simplified wake geometry model that provides an assumption for the inflow distribution across a rotor disk and conditional vortex displacement equations for the X, Y, and Z locations using simple parametric equations provided in Eqs. 1 through 3.

$$\frac{x_{tip}}{R} = x'_{tip} = \cos \Psi + \mu \psi_w \quad (1)$$

$$\frac{y_{tip}}{R} = y'_{tip} = \sin \Psi \quad (2)$$

$$\frac{z_{tip}}{R} = z'_{tip} = -\mu_z \psi_w + \int_0^{\psi_w} \lambda d\psi_b \quad (3)$$

Depending on rotational direction, Ψ is defined as $\Psi = \psi_b - \psi_w$ for counter-clockwise rotation and $\Psi = \psi_b + \psi_w$ for clockwise rotation. Figure 4 depicts rotational direction for an (a) clockwise and (b) counter-clockwise rotor within RABIT.

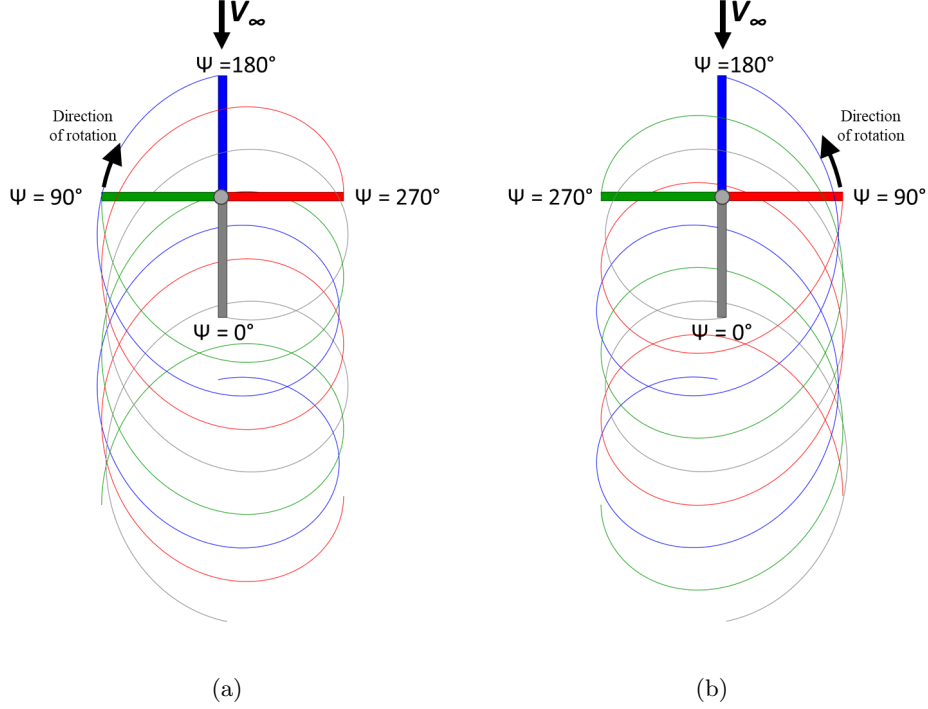


Figure 4: Rotational direction for (a) clockwise and (b) counter-clockwise rotors.

The vertical displacement of the wake (z'_{tip}) is dependent on the location of the wake and is split into three conditions for the parameter $\int_0^{\psi_w} \lambda d\psi_b$ within the vertical displacement equation; conditions are as follows:

Condition 1: The vortex element has not traveled outside of the rotor disk area, or $x'_{tip} < -\cos \Psi$, see Eq. 4.

$$\int_0^{\psi_w} \lambda d\psi_b = -\lambda_0 \left(1 + \chi \left(\cos \Psi + \frac{1}{2} \mu \psi_w - |y'_{tip}|^3 \right) \right) \psi_w \quad (4)$$

Condition 2: The vortex element is outside and downstream of the rotor disk, $\cos \Psi > 0$, see Eq. 5.

$$\int_0^{\psi_w} \lambda d\psi_b = -2\lambda_0 (1 - \chi |y'_{tip}|^3) \psi_w \quad (5)$$

Condition 3: If neither condition is true, then the element spent some time within the disk and downstream of the disk, $\cos \Psi < 0$ and $x'_{tip} > -\cos(\Psi)$, see Eq. 6.

$$\int_0^{\psi_w} \lambda d\psi_b = -2\lambda_0 x'_{tip} \frac{(1 - \chi |y'_{tip}|^3)}{\mu_x} \quad (6)$$

where,

$$\mu_x = \frac{V_\infty \cos \alpha_{TPP}}{\Omega R} \quad (7)$$

To summarize, Beddoes' prescribed wake model uses a simplifying assumption for inflow distribution across the disk, and induced velocities are approximated [8, 11]. A visual representation of each condition is shown in Fig. 5 for a vortex on one of the blades of a UH-1D rotor.

To begin calculating the wake, RABIT reads in a desired V_{tip} , α_{TPP} , μ , and C_T and solves Eq. 8. This momentum theory uniform inflow equation is iteratively solved for inflow (λ_i) which can subsequently be used in the Beddoes' prescribed wake model for calculating rotor downwash and vortex geometry.

$$\frac{C_T}{2\lambda_i} = \sqrt{(\mu_z + \lambda_i)^2 + \mu_x^2} \quad (8)$$

2.2 BVI Intensity

In 1995, Sim and George [8] developed a program using Beddoes' prescribed wake model to resolve BVI events using a new method to quantify BVI noise in terms of blade loading (F). In this model, the wake that is released from the tip of the blade is used to predict a variety of important BVI parameters using radius (R), advance ratio (μ), wake skew angle (χ), inflow (λ_0), blade position (ψ_b), and wake age (ψ_w). Furthermore, important geometric properties include 2D lift curve slope ($c_{l\alpha}$), and chord (c). Major BVI noise contributors can be summarized into the blade airfoil aerodynamic factors, vortex strength factor ($\bar{\Gamma}_s$), BVI Impulse factor ($\bar{I}$), and BVI impulse function as shown in Eqs. 9 and 10. RABIT follows the same method and approach used by Sim and George when developing a scheme for aerodynamic load prediction, and a full explanation of this method and how it is implemented can be found in [8].

$$F = (c_{l\alpha} c) \left(\frac{1}{2} \rho V_b^2 \right) \left(\frac{\Gamma}{2\pi V_b h} \right) (\bar{I}) \left(\frac{1 - (\bar{I} \frac{(\Psi_b - \Psi_s)}{\Omega})^2}{(1 + (\bar{I} \frac{(\Psi_b - \Psi_s)}{\Omega})^2)^2} \right) \quad (9)$$

$$\bar{I} = \left(\frac{V_b \cos(\gamma)}{h} \right) \quad (10)$$

For the current implementation of RABIT, the vortex strength (Γ) is determined using momentum theory in conjunction with Helmholtz's theorem, as expressed in Eq. 11. It should be noted that this formulation is derived for a rotor operating in hover; however, it is applied here as a simplifying assumption.

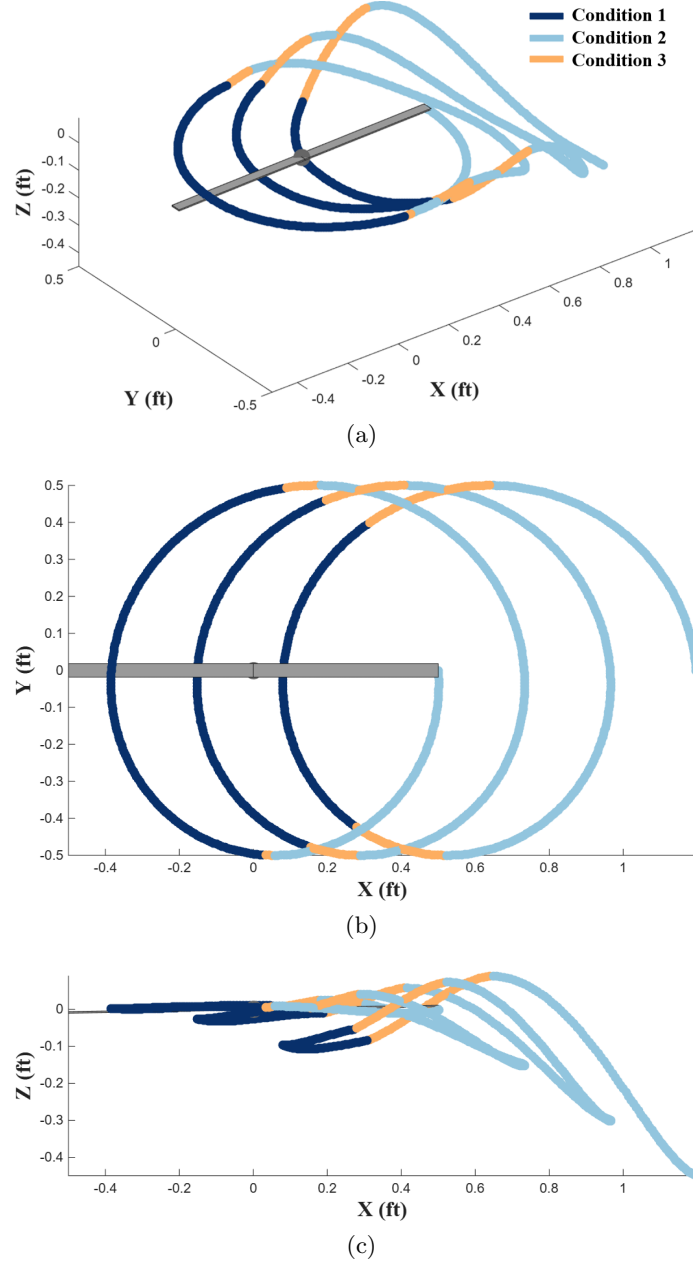


Figure 5: Beddoes' prescribed wake model for a single blade of a UH-1D rotor for an (a) isometric view, (b) top, and (c) side view. Center of rotor hub is located at $(X, Y, Z) = (0, 0, 0)$, where the forward flight is in the $-X$ direction.

$$\Gamma = 2\Omega R c \frac{C_T}{\sigma} \quad (11)$$

To better visualize some of the key components in BVI noise prediction, the translating blade velocity (V_b), vertical miss distance (h), BVI angle (γ), and vortex wake age (ψ_w), are depicted in Fig. 6.

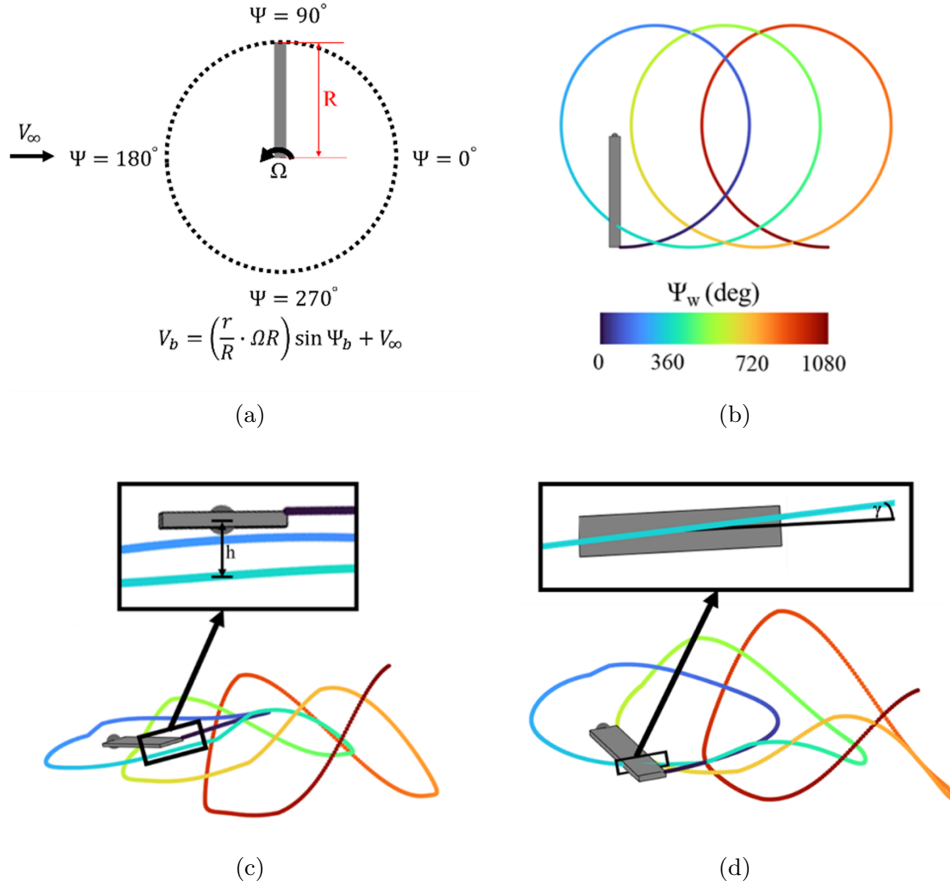


Figure 6: Visualization of important BVI metrics for (a) translating blade velocity (V_b), (b) vortex wake age (ψ_w), (c) vertical miss distance (h), and (d) BVI angle (h).

2.3 Multi-Rotor BVI Identification Capability

RABIT extends the single rotor BVI model developed by Sim and George to multi-rotor configurations. This extension enables RABIT to identify BVI events between a blade and vortices generated by itself, other blades on the same rotor, or blades on different rotors. That is, RABIT can examine both inter- and intra-rotor BVI events.

Figure 7 illustrates the inter-rotor interaction capability for a tandem rotor configuration. In the scenario shown, a tip vortex from blade 1 of rotor 1 (front

rotor) convects downstream and interacts with blade 1 of rotor 2, resulting in a BVI event on this blade of the aft rotor. The visualization highlights the rotor wake geometry as well as the ability of RABIT to detect inter-rotor interactions.

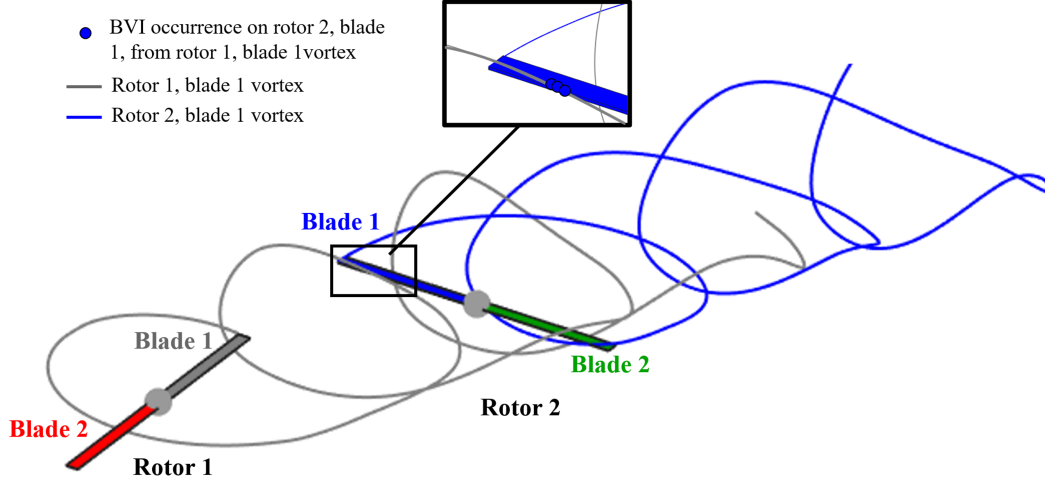


Figure 7: Example of RABIT detecting a BVI event on rotor 2 resulting from a vortex shed by rotor 1, demonstrating cross-rotor interaction capability.

3 Validation and Comparison

To highlight the capabilities and limitations of RABIT, several comparison and validation studies are performed. Historical wake geometry data from Beddoes and Landgrebe from a model-scale UH-1D rotor is used to validate the usage of the Beddoes’ prescribed wake within RABIT. Because limited experimental wake geometry data is available, the RABIT wake geometry is compared against CAMRAD II’s free wake geometry for several additional flight conditions using a full-scale UH-1D rotor. Finally, a BVI intensity comparison between RABIT and CAMRAD II is performed to highlight the ability of RABIT to capture BVI locations and intensities relative to a mid-fidelity tool. Model and full-scale UH-1D rotor geometry specifications are provided in Table 1.

	Model-scale	Full-scale
Number of blades	2	2
Radius (ft)	0.5	24.0
Chord (ft), constant	0.0364	1.7500
Rotor solidity	0.0464	0.0464
Twist	N/A	N/A
Airfoil, constant	NACA0012	NACA0012

Table 1: Model and full-scale UH-1D rotor geometry specifications.

3.1 RABIT versus Beddoes’ Wake Validation

The RABIT Beddoes’ prescribed wake algorithm is validated using results from Beddoes and Landgrebe for both a low and a high advance ratio flight condition of a model-scale UH-1D rotor [7, 11]. Results are compared in the non-dimensional Z direction for a wake age from 0 to 900 degrees for the vertical distortion of the vortex. This comparison is performed for only the vertical component (Z) due to the complexity of the algorithm compared to the vortex element in the X and Y plane. RABIT uses Beddoes’ exact algorithm, which should result in minimal differences between the results for RABIT and the results from Beddoes. Results for this comparison are shown relative to the blade tip-path-plane as was provided by Beddoes and Landgrebe, therefore tip-path-plane distortions are not seen within results [7, 11].

Wake validation between results from both Beddoes and RABIT is shown in Fig. 8 for the model-scale UH-1D rotor at blade locations of (a) 0, (b) 90, (c) 180, and (d) 270 degrees for a low speed advance ratio case of $V_\infty = 1.23$ ft/s, $C_T/\sigma = 0.078$, $\mu = 0.074$, RPM = 318, and $\alpha_{TPP} = -2.8^\circ$. Minimal differences are seen between resultant wake locations for all blade locations for this low advance ratio flight condition.

The validation for a high advance ratio is shown in Fig. 9 for a flight condition of $V_\infty = 3.16$ ft/s, $C_T/\sigma = 0.078$, $\mu = 0.19$, RPM = 318, and $\alpha_{TPP} = -6.3^\circ$. Similarly, minimal differences are observed between the two methods regarding resultant wake locations across all blade azimuths for the high advance ratio flight condition.

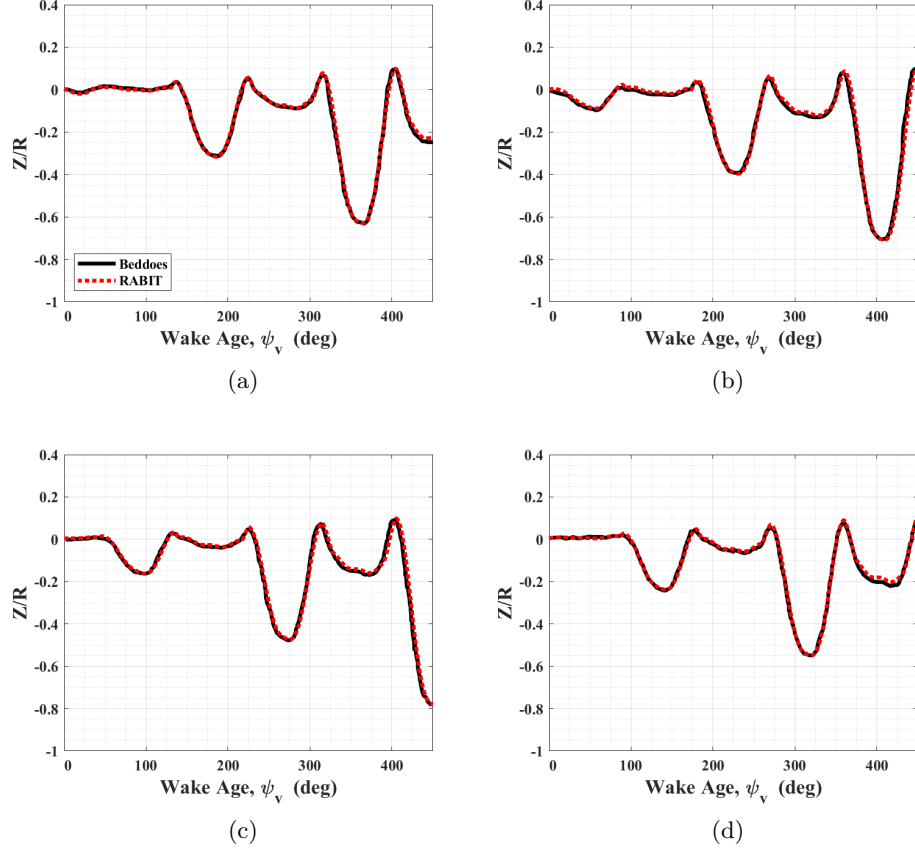


Figure 8: Vertical distortion of vortex from RABIT, validated against Beddoes' prescribed wake model for a model-scale UH-1D rotor for a low advance ratio flight condition for blade locations at (a) 0, (b) 90, (c) 180, and (d) 270 degrees in the rotor tip-path-plane ($V_\infty = 1.23$ ft/s, $C_T/\sigma = 0.078$, $\mu = 0.074$, RPM = 318, and $\alpha_{TPP} = -2.8^\circ$).

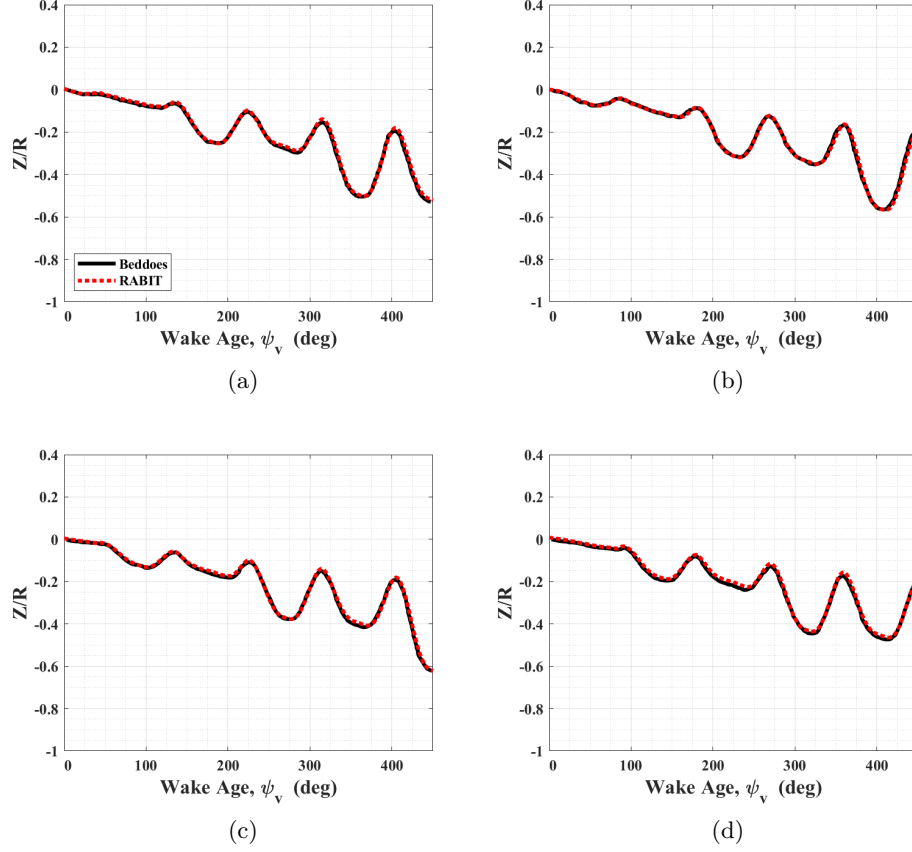


Figure 9: Vertical distortion of vortex from RABIT, validated against Beddoes' prescribed wake model for a model-scale UH-1D rotor for a high advance ratio flight condition for blade locations at (a) 0, (b) 90, (c) 180, and (d) 270 degrees in the rotor tip-path-plane ($V_\infty = 3.16$ ft/s, $C_T/\sigma = 0.078$, $\mu = 0.19$, RPM = 318, and $\alpha_{TPP} = -6.3^\circ$).

3.2 RABIT versus CAMRAD II Wake Comparison

Because differences in wake geometry modeling between RABIT and CAMRAD II directly affect BVI location and intensity predictions, a wake geometry comparison is first performed across a sweep of advance ratios. A full-scale UH-1D rotor is simulated in CAMRAD II using a free wake and in RABIT (Beddoes' prescribed wake) for a range of advance ratios [5, 7]. Results for this comparison are shown relative to the hub plane and therefore blade tip-path-plane and coning angle are seen within results. Blade locations at 0, 90, 180, and 270 degrees are provided.

A low advance ratio case is shown in Fig. 10 for a flight condition of $V_\infty = 40$ ft/s, $C_T/\sigma = 0.1076$, $\mu = 0.05$, RPM = 318, $\alpha_{TPP} = -3.27^\circ$, and $\beta_0 = 0^\circ$. A similar wake skew angle is seen for all blade locations when comparing RABIT to CAMRAD II, though some differences are observed. In general, the locations of the troughs in the wake geometry (where the geometry coordinate experiences a rapid decrease then increase) are captured, but the magnitude of the change is not. Both the RABIT results and the CAMRAD II free wake results show similar patterns in the location where the vertical displacement of the wake changes; however, the CAMRAD II results show a significantly larger variation in the vertical displacement of the wake at these locations.

A low advance ratio for a positive α_{TPP} case is shown in Fig. 11 for a flight condition of $V_\infty = 84$ ft/s, $C_T/\sigma = 0.0700$, $\mu = 0.106$, RPM = 318, $\alpha_{TPP} = 5.33^\circ$, and $\beta_0 = 0^\circ$. A similar wake skew angle is seen for all blade locations when comparing RABIT to CAMRAD II, though some differences are observed. In general, the locations of the troughs in the wake geometry are captured between RABIT and CAMRAD II, but the magnitude is not well captured for all troughs.

A medium advance ratio case is shown in Fig. 12 for a flight condition of $V_\infty = 120$ ft/s, $C_T/\sigma = 0.0698$, $\mu = 0.15$, RPM = 318, $\alpha_{TPP} = -2.66^\circ$, and $\beta_0 = 0^\circ$. RABIT is able to capture a similar wake geometry to that of CAMRAD II compared to the low advance ratio case for all wake locations shown. As with the low advance ratio case, both the RABIT results and the CAMRAD II free wake results show similar patterns in the location where the vertical displacement of the wake changes. Unlike the very low advance ratio case, the variation of vertical displacement from both methods is of similar magnitude.

A higher advance ratio case is shown in Fig. 13 for a flight condition of $V_\infty = 180$ ft/s, $C_T/\sigma = 0.099$, $\mu = 0.225$, RPM = 318, $\alpha_{TPP} = -2.51^\circ$, and $\beta_0 = 0^\circ$. As advance ratio increases, it is seen that wake skew angle decreases for both RABIT and CAMRAD II. Differences between RABIT and CAMRAD II are minimal, though larger differences are seen at the "dips" of the wake geometry (that is, where there is a rapid decrease then increase in the vertical location of the wake geometry).

Furthermore, the RABIT and CAMRAD II wake geometries are compared in an isometric view (see Fig. 14). For all cases, it is seen that the older the wake age the more the wake geometries between RABIT and CAMRAD II begin to differ. This is more clearly seen in the 3D isometric view.

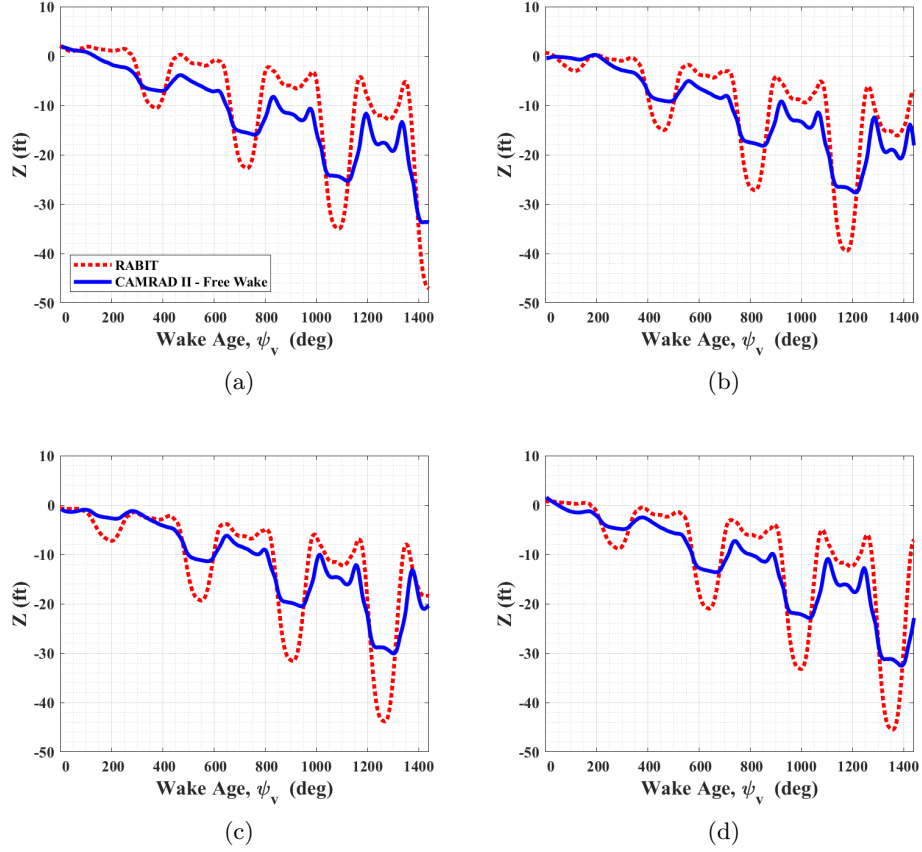


Figure 10: Vertical distortion of vortex comparison between RABIT (Beddoes' prescribed wake model) and CAMRAD II (free wake) for a full-scale UH-1D rotor for blade locations at (a) 0, (b) 90, (c) 180, and (d) 270 degrees in the hub plane ($V_\infty = 40$ ft/s, $C_T/\sigma = 0.1076$, $\mu = 0.05$, RPM = 318, $\alpha_{TPP} = -3.27^\circ$, and $\beta_0 = 0^\circ$).

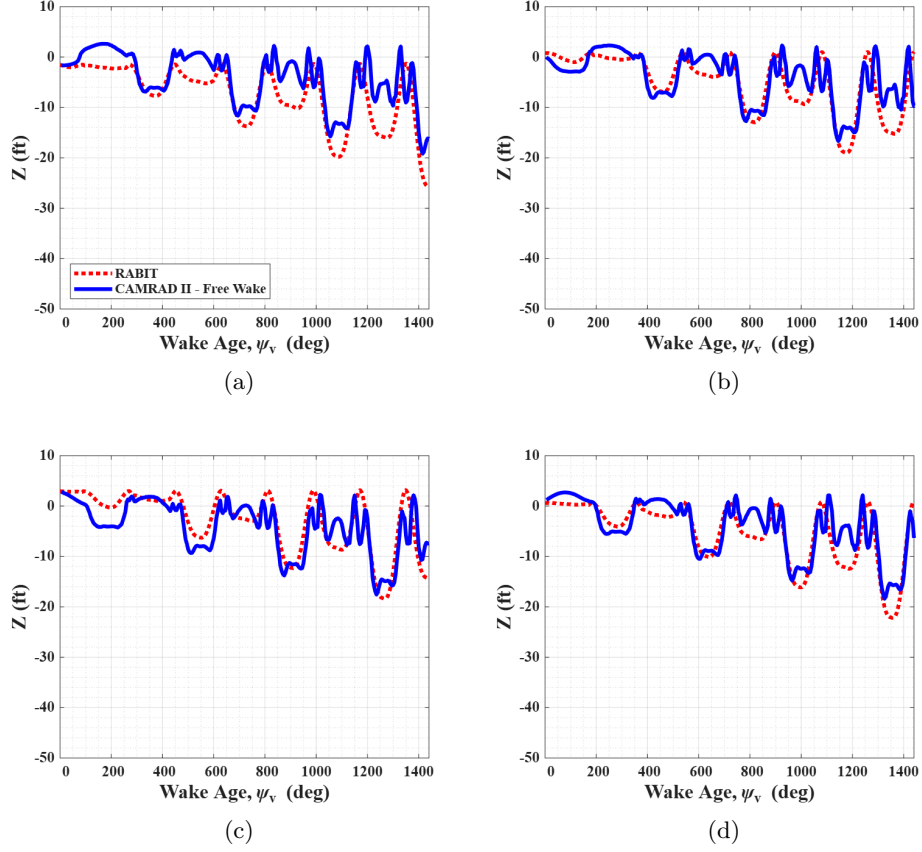


Figure 11: Vertical distortion of vortex comparison between RABIT (Beddoes' prescribed wake model) and CAMRAD II (free wake) for a UH-1D rotor for blade locations at (a) 0, (b) 90, (c) 180, and (d) 270 degrees in the hub plane ($V_\infty = 84$ ft/s, $C_T/\sigma = 0.0700$, $\mu = 0.106$, RPM = 318, $\alpha_{TPP} = 5.33^\circ$, and $\beta_0 = 0^\circ$).

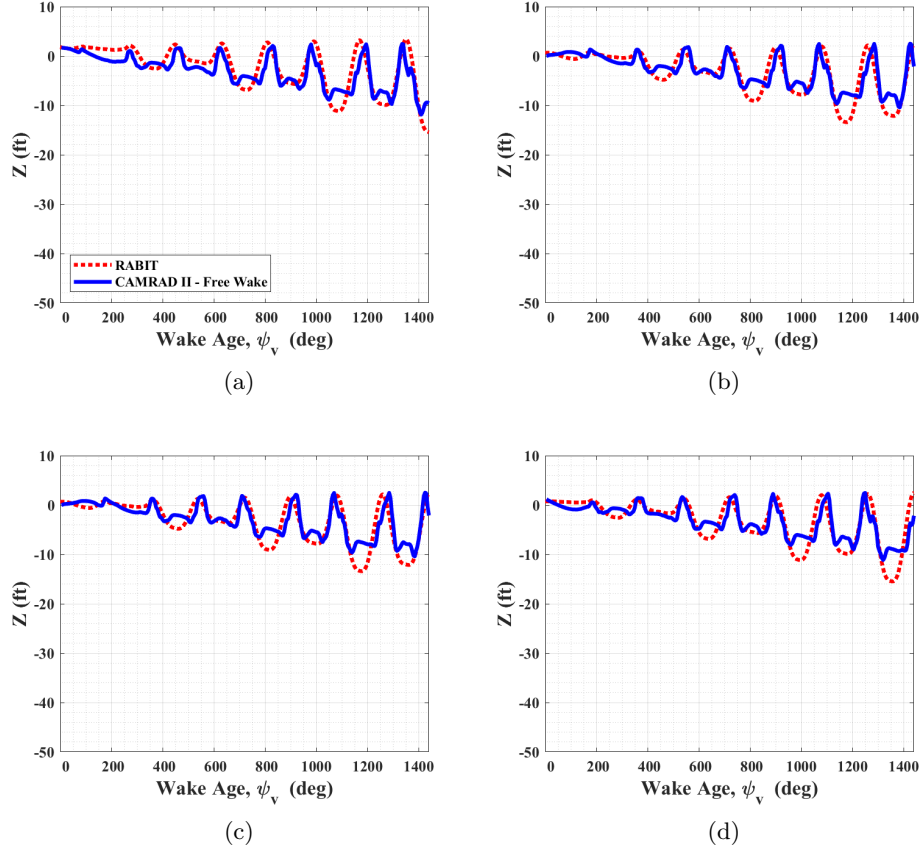


Figure 12: Vertical distortion of vortex comparison between RABIT (Beddoes' prescribed wake model) and CAMRAD II (free wake) for a UH-1D rotor for blade locations at (a) 0, (b) 90, (c) 180, and (d) 270 degrees in the hub plane ($V_\infty = 120$ ft/s, $C_T/\sigma = 0.0698$, $\mu = 0.15$, RPM = 318, $\alpha_{TPP} = -2.66^\circ$, and $\beta_0 = 0^\circ$).

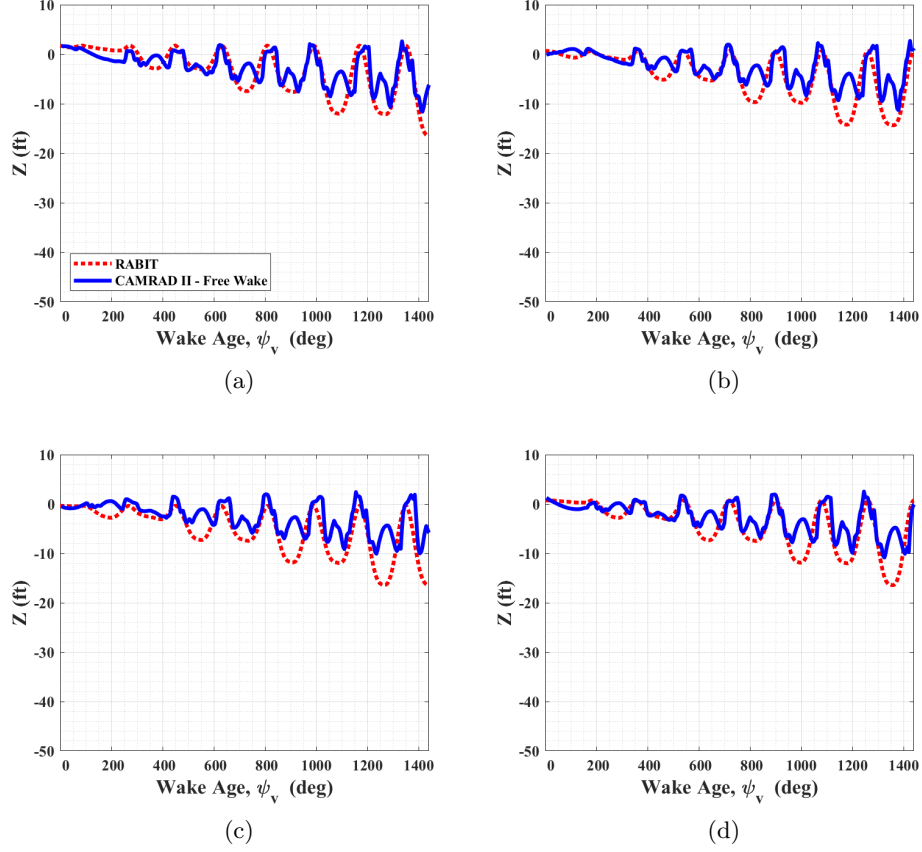


Figure 13: Vertical distortion of vortex comparison between RABIT (Beddoes' prescribed wake model) and CAMRAD II (free wake) for a full-scale UH-1D rotor for blade locations at (a) 0, (b) 90, (c) 180, and (d) 270 degrees in the hub plane ($V_\infty = 180$ ft/s, $C_T/\sigma = 0.099$, $\mu = 0.225$, RPM = 318, $\alpha_{TPP} = -2.51^\circ$, and $\beta_0 = 0^\circ$).

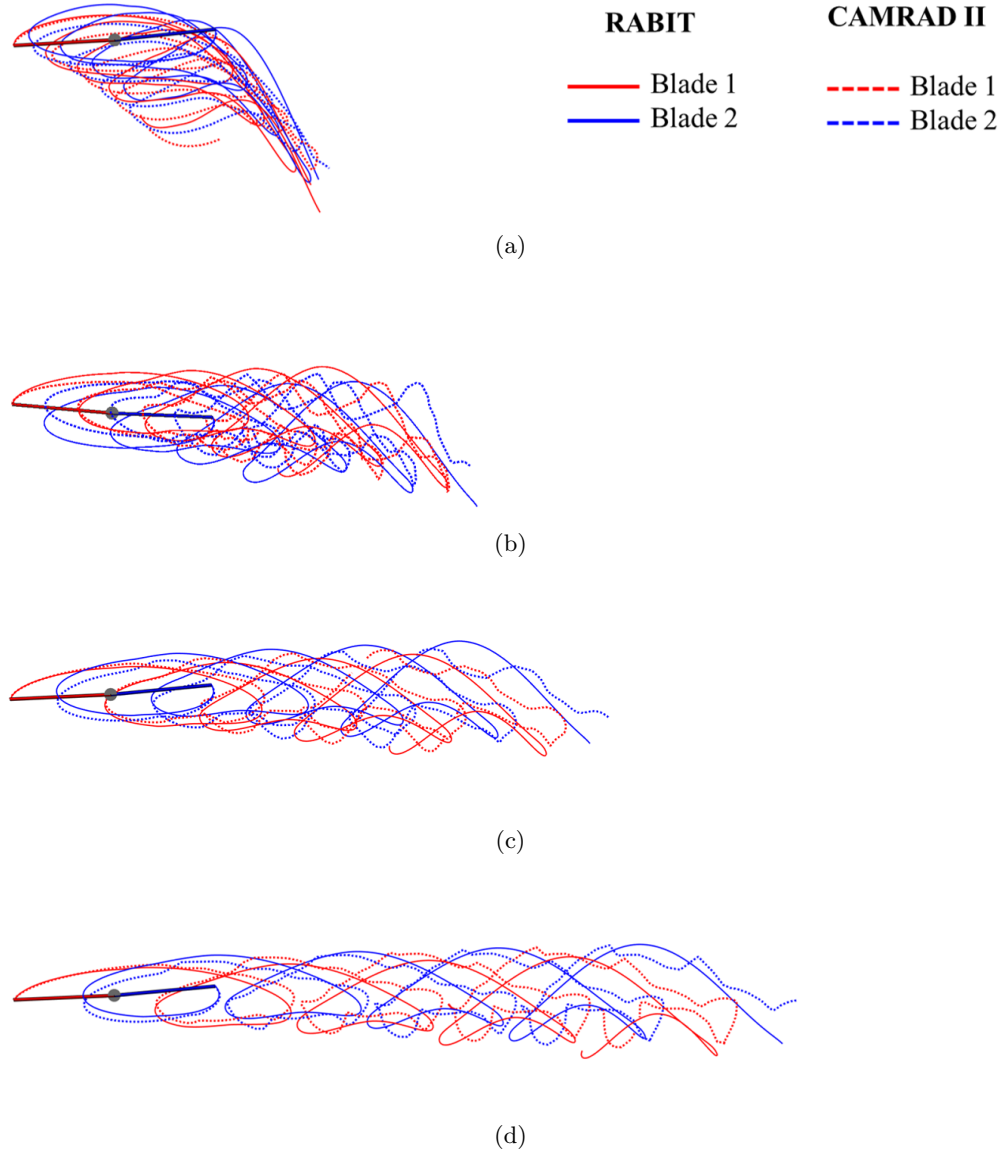


Figure 14: RABIT and CAMRAD II wake geometries compared in a isometric view for a full-scale UH-1D rotor for the following flight conditions: (a) ($V_\infty = 40$ ft/s, $C_T/\sigma = 0.1076$, $\mu = 0.05$, RPM = 318, $\alpha_{TPP} = -3.27^\circ$, and $\beta_0 = 0^\circ$), (b) ($V_\infty = 84$ ft/s, $C_T/\sigma = 0.0700$, $\mu = 0.106$, RPM = 318, $\alpha_{TPP} = 5.33^\circ$, and $\beta_0 = 0^\circ$), (c) ($V_\infty = 120$ ft/s, $C_T/\sigma = 0.0698$, $\mu = 0.15$, RPM = 318, $\alpha_{TPP} = -2.66^\circ$, and $\beta_0 = 0^\circ$), and (d) ($V_\infty = 180$ ft/s, $C_T/\sigma = 0.099$, $\mu = 0.225$, RPM = 318, $\alpha_{TPP} = -2.51^\circ$, and $\beta_0 = 0^\circ$).

3.3 RABIT versus CAMRAD II BVI Intensity Comparison

As previously noted, larger differences in wake geometry between RABIT and CAMRAD II result in greater discrepancies in the identification of BVI location and intensity. To compare BVI intensity between RABIT and CAMRAD II, three flight conditions are evaluated. The first derivative of the CAMRAD II rotor Z-force, $(\frac{\partial F_z}{\partial t})$, is used to highlight BVI timing and intensity, as rapid variations in vertical loading are indicative of a BVI event. Because RABIT does not compute rotor loads, blade loading F is used instead; a rapid transition from negative to positive blade loading denotes a BVI occurrence. For both methods, a more rapid change in loading corresponds to a higher BVI intensity.

For consistency across the three cases, the maximum and minimum blade-loading limits are set to -1000 and 1000 lb/(ft·s). The RABIT tolerance factor for all cases presented in this BVI intensity assessment is set to 100%.

Figure 15 presents a comparison of BVI intensity between the CAMRAD II derivative of vertical loading and the RABIT blade-loading change for a full-scale UH-1D rotor at $V_\infty = 40$ ft/s, $C_T = 0.00234$, $\mu = 0.05$, RPM = 318, $\alpha_{TPP} = -6.38^\circ$, and $\beta_0 = 0^\circ$ for a tolerance of 100%. Under this condition, both CAMRAD II and RABIT indicate minimal BVI activity.

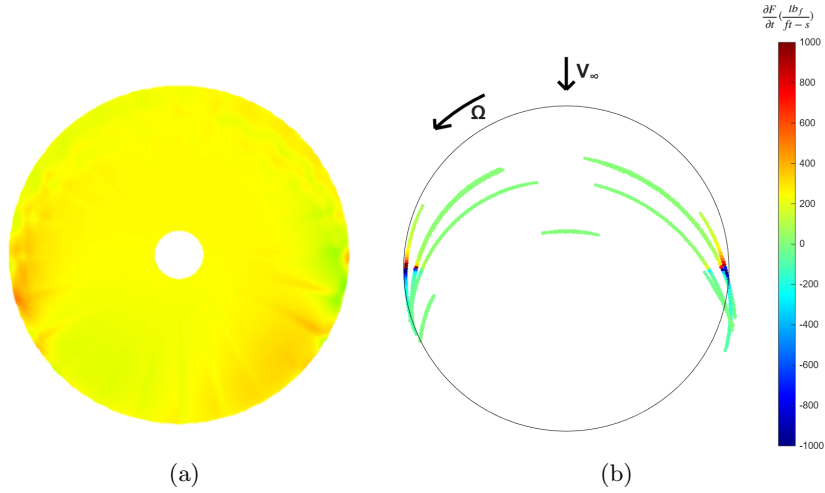


Figure 15: BVI intensity comparison between (a) CAMRAD II derivative of vertical loading and (b) change in blade loading from RABIT for a UH-1D rotor ($V_\infty = 40$ ft/s, $C_T = 0.00234$, $\mu = 0.05$, RPM = 318, $\alpha_{TPP} = -6.38^\circ$, $\beta_0 = 0^\circ$, and TOL = 100%).

A more intense BVI condition is shown in Fig. 16, at $V_\infty = 141$ ft/s, $C_T = 0.0058$, $\mu = 0.177$, RPM = 318, $\alpha_{TPP} = 2.61^\circ$, and $\beta_0 = 0^\circ$ for a tolerance of 100%. Results from both CAMRAD II and RABIT reveal BVI occurrences on the advancing and retreating sides of the rotor. RABIT does not capture all BVI occurrences, particularly toward the rear of the rotor.

Finally, Fig. 17 illustrates a high-intensity BVI condition at $V_\infty = 180$ ft/s, $C_T = 0.00584$, $\mu = 0.225$, RPM = 318, $\alpha_{TPP} = 2.18^\circ$, and $\beta_0 = 0^\circ$ for a tolerance of 100%. For this case, CAMRAD II and RABIT each identify multiple BVI occurrences.

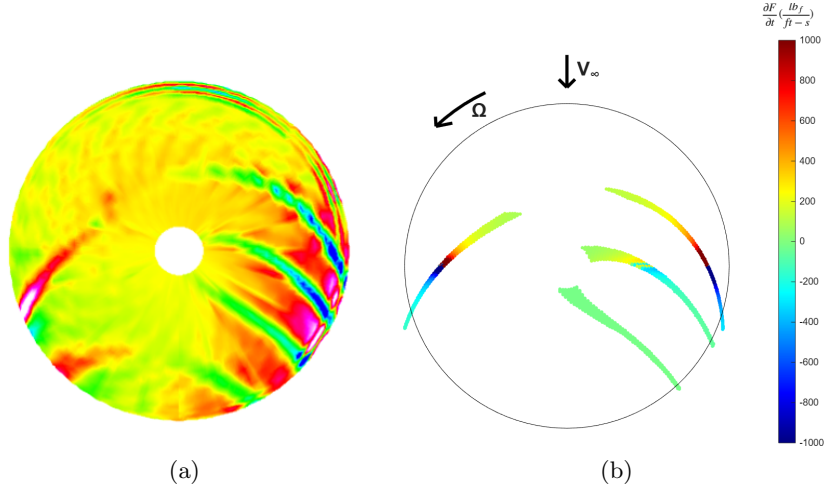


Figure 16: BVI intensity comparison between (a) CAMRAD II derivative of vertical loading and (b) change in blade loading from RABIT for a UH-1D rotor ($V_\infty = 141$ ft/s, $C_T = 0.0058$, $\mu = 0.177$, RPM = 318, $\alpha_{TPP} = 2.61^\circ$, $\beta_0 = 0^\circ$, and TOL = 100%).

The highest-intensity BVI occurrence is shown on the advancing side of the blade where a change from red to blue is observed within RABIT and CAMRAD II.

Overall, RABIT demonstrates consistent capability in identifying strong BVI events across all flight conditions evaluated in this study, in comparison with CAMRAD II, although some differences in predicted intensity are identified. Notably, RABIT captures the higher-intensity BVI occurrences with good fidelity relative to CAMRAD II.

3.3.1 RABIT Tolerance Study versus CAMRAD II

Due to wake geometry differences between RABIT and CAMRAD II, a tolerance study within RABIT is performed. It was suggested by Sim and George [8] to use a vortex core of 0.5% of the chord. Based on this suggestion, a tolerance factor is implemented to allow the specification of how close a vortex must be to the blade to be considered an “interaction” event. Specifying a tolerance (TOL) creates volume around the blade, in percent chord, within which a vortex is considered as an “interaction” candidate, see Fig. 18.

The RABIT tolerance study is performed for the UH-1D rotor for a condition of $V_\infty = 180$ ft/s, $C_T = 0.00584$, $\mu = 0.225$, RPM = 318, $\alpha_{TPP} = 2.18^\circ$, and $\beta_0 = 0^\circ$ for tolerance factors from 1% to 150%, see Fig. 19. Rotor conditions are the same as shown in Fig. 17 in order to ensure BVI locations are captured. This study is performed to highlight the needed tolerance setting to capture BVI occurrences on a rotor disk. In general, a tolerance factor above 50% is recommended, as it enables RABIT to capture strong BVI events while avoiding excessive computational cost associated with identifying weaker interactions.

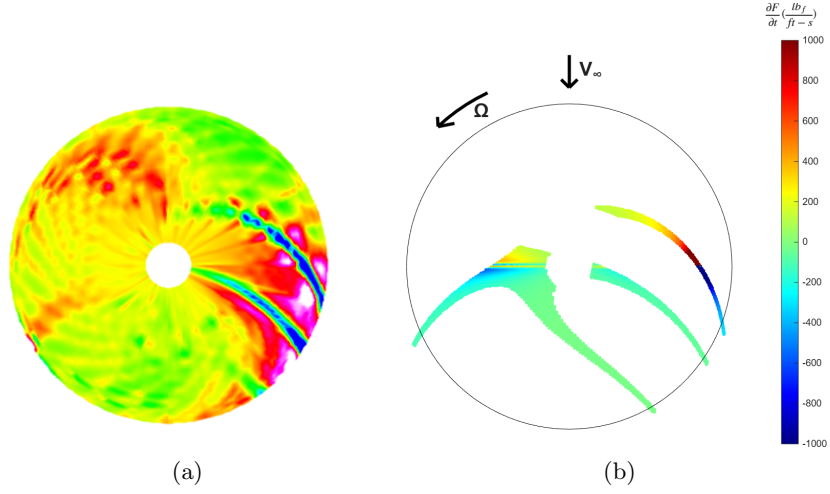


Figure 17: BVI intensity comparison between (a) CAMRAD II derivative of vertical loading and (b) change in blade loading from RABIT for a UH-1D rotor ($V_\infty = 180$ ft/s, $C_T = 0.00584$, $\mu = 0.225$, RPM = 318, $\alpha_{TPP} = 2.18^\circ$, $\beta_0 = 0^\circ$, and TOL = 100%).

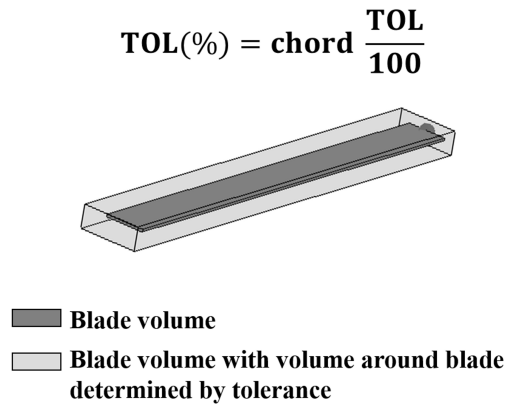


Figure 18: RABIT tolerance factor graphical representation and equation.

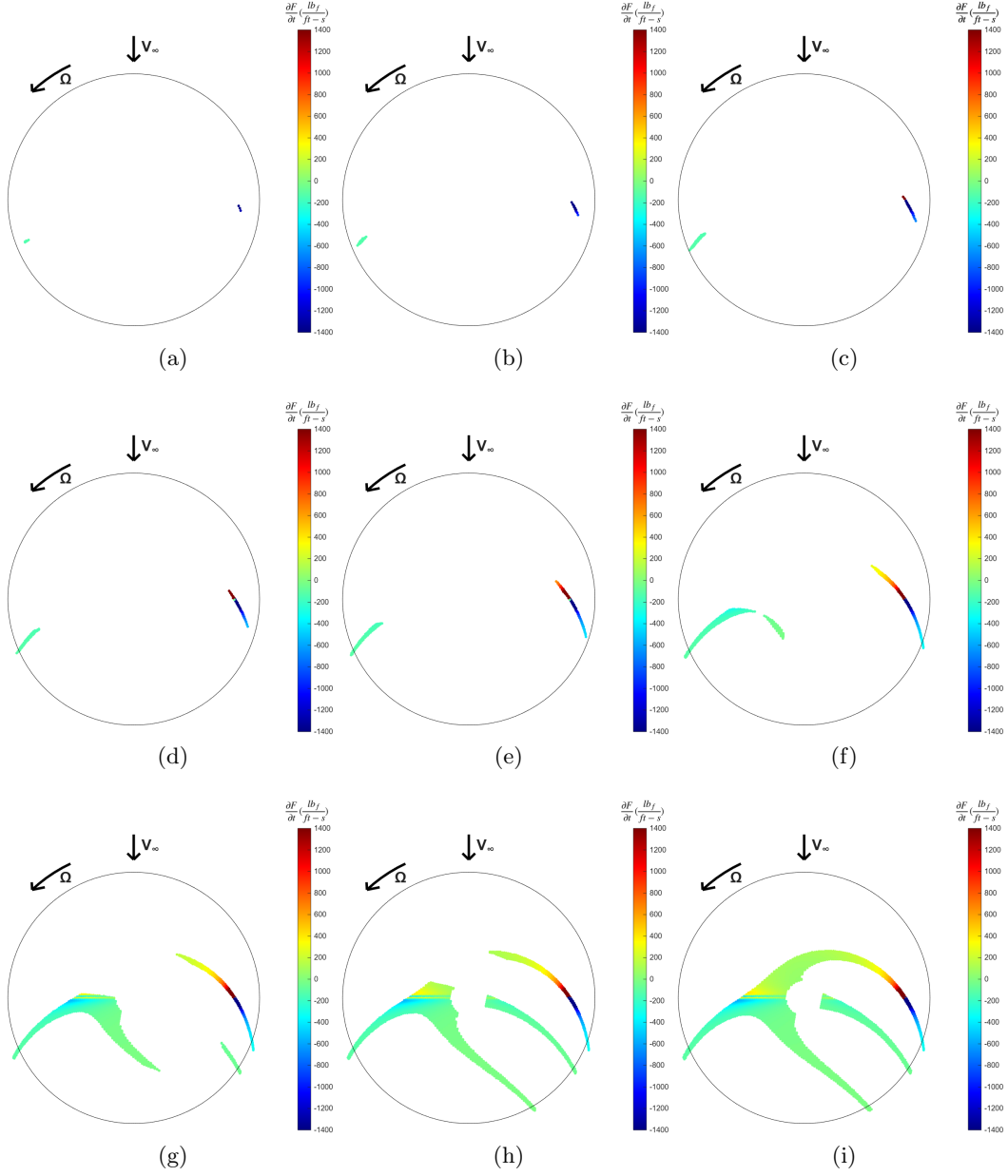


Figure 19: RABIT tolerance factor study for (a) TOL = 1, (b) 5, (c) 10, (d) 15, (e) 25, (f) 50, (g) 75, (h) 100, and (i) 150% for a UH-1D rotor ($V_\infty = 180$ ft/s, $C_T = 0.00584$, $\mu = 0.225$, RPM = 318, $\alpha_{TPP} = 2.18^\circ$, and $\beta_0 = 0^\circ$).

4 Getting Started

This section provides the essential steps needed to begin running RABIT. The installation instructions explain how to download the standalone application from the NASA Software Distribution Catalog and how the installer automatically manages the required MATLAB Runtime dependency. The RABIT graphical user interface is then introduced, and its layout, navigation structure, and all adjustable input parameters—including rotor geometry settings, flight condition controls, auxiliary buttons, and animation features—are described. Users are shown how to configure a rotorcraft, preview its geometry, run a full analysis, and interpret the resulting BVI animations. The chapter concludes by outlining the various output files RABIT generates, such as vehicle description tables, BVI intensity plots, interaction logs, and blade-overlap data for coaxial rotors. Together, these sections prepare users to operate the tool and understand the outputs produced by their simulations.

4.1 Installation Guide

The Installation Guide presents the necessary steps to install RABIT as a standalone computer application. Although RABIT was created using MATLAB App Designer, MATLAB itself is **not** required to run the application. Currently, RABIT is compatible only with Windows 11.

1. **Verify Internet Connectivity:** Ensure your system is connected to an active internet network before initiating the download.
2. **Access NASA Software Directory:** Navigate to the NASA Software Distribution Catalog at software.nasa.gov and search for **RABIT**.
3. **Download and Launch:** Download the installation package, extract the zip contents, and run the executable file titled **RABIT**. The step-by-step setup screens you will encounter during this process are shown in Figs. 20 through 28.

Note on MATLAB Runtime: RABIT requires the MATLAB Runtime (R2024a) engine to execute. If this third-party dependency is not already detected on your system, the installer will automatically prompt and handle the MATLAB Runtime installation for you during setup.

4.2 User Interface Overview

The User Interface Overview provides descriptions of all adjustable parameters in the RABIT Graphical User Interface (GUI) and demonstrates the various tools to be used inside the application. This section also explains the output files that are generated by the prediction analysis and describes the various plots and tables the users could choose to populate. Currently, all units used within RABIT are in English units.



Figure 20: Installer splash screen.

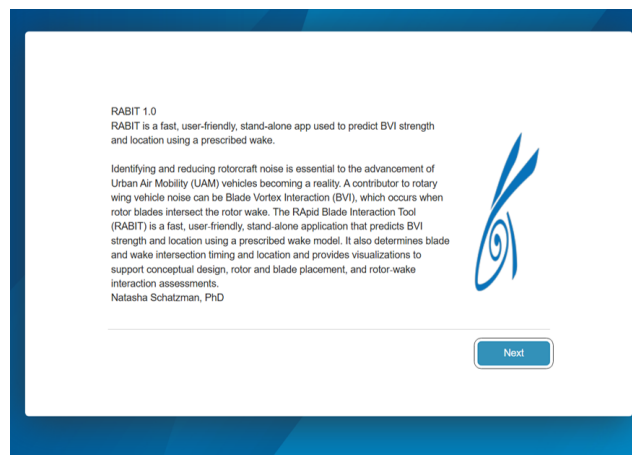


Figure 21: License agreement.

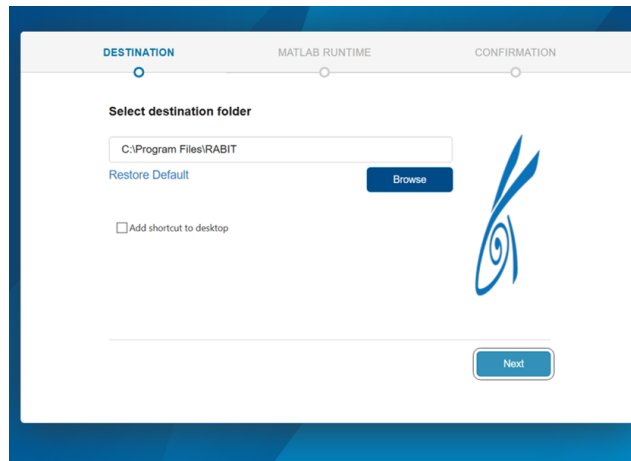


Figure 22: Destination folder.

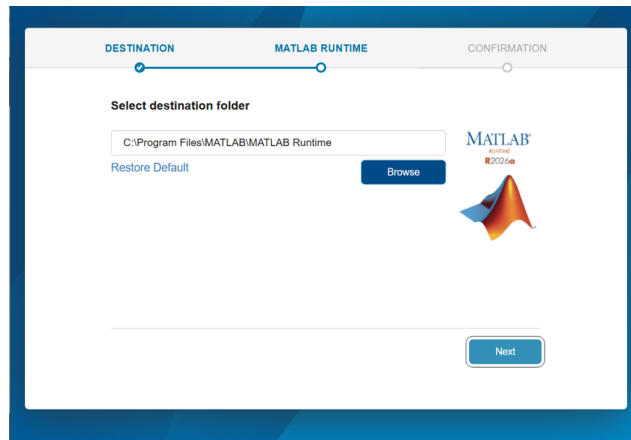


Figure 23: MATLAB Runtime.

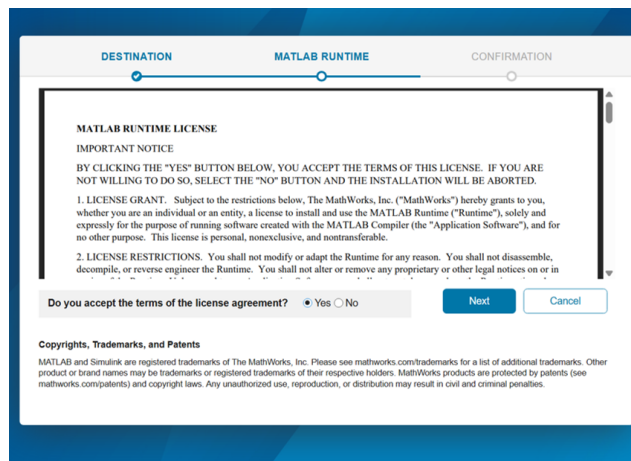


Figure 24: Confirmation.

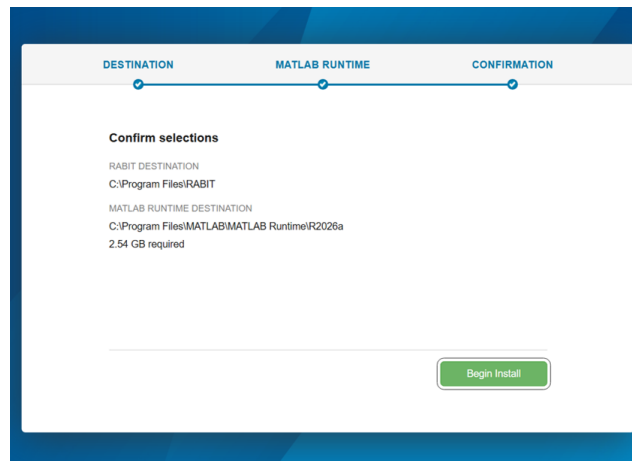


Figure 25: Installing.

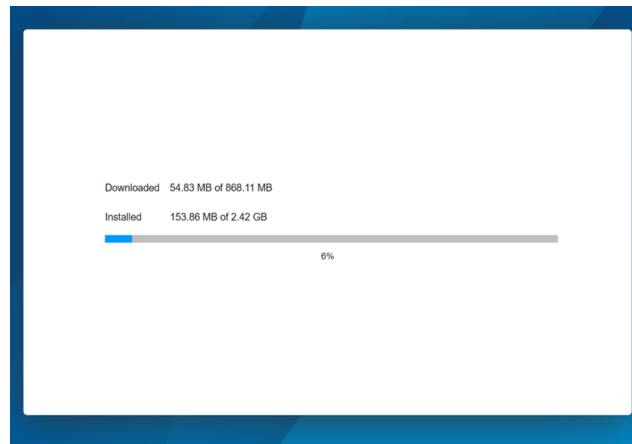


Figure 26: Setup progress.

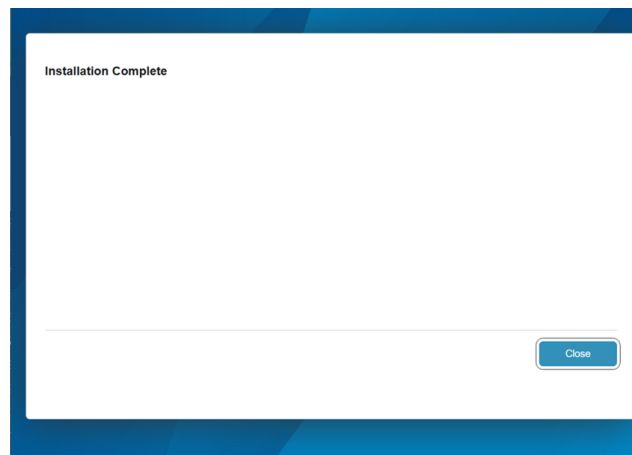


Figure 27: Installation complete.



Figure 28: Opening screen.

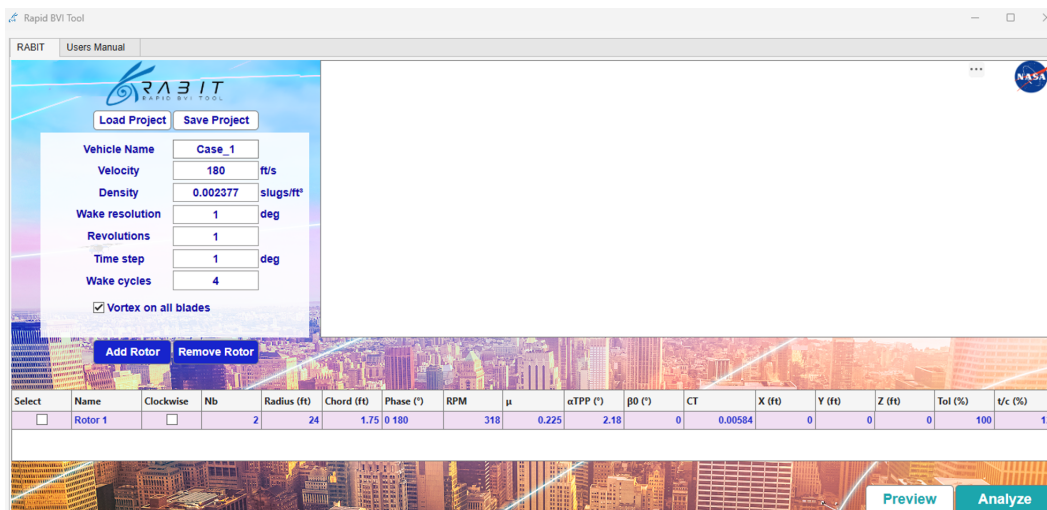


Figure 29: RABIT home application window.

The RABIT GUI has two main tabs: “RABIT” and “User’s Manual”. These are located in a gray bar along the top-left corner of the display and allow navigation through the application window, see Fig. 29. The GUI automatically opens to the “RABIT” window, which is the main workspace for users. The “User’s Manual” window provides access to the User’s Manual.

4.2.1 Input Parameters

The home screen is the main workspace and is where the user inputs their rotorcraft characteristics and runs the simulation. There are several input fields, including simulation and flight condition controls, blade controls, auxiliary input, and animation controls.

Hovering the cursor over a specific interface element displays an informational pop-up dialog box with an extended definition. These definitions are also provided in the following sections for simulation and flight condition controls, blade controls, auxiliary input. An example of the informational pop-up dialog box is shown in Fig. 30.

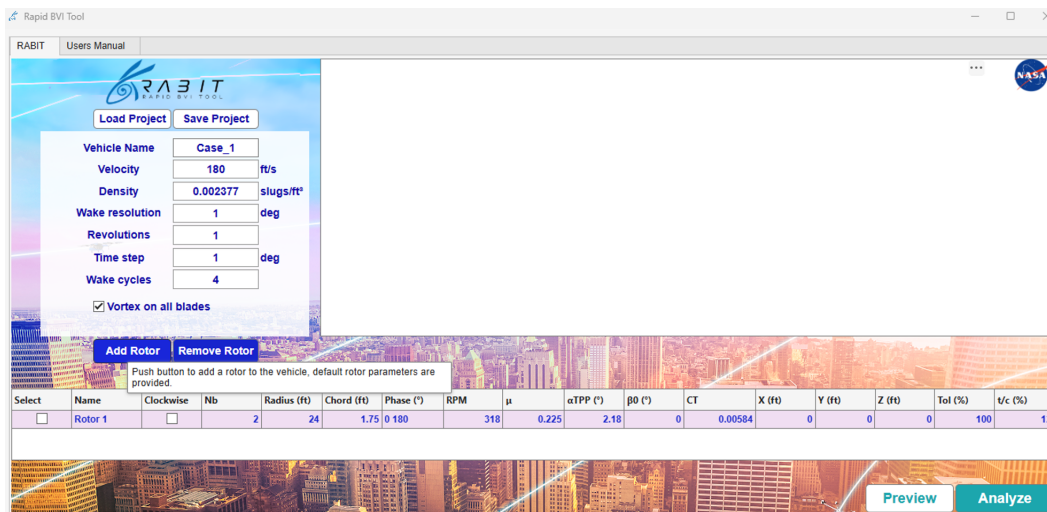


Figure 30: Example of informational pop-up dialog box for “Add Rotor” button.

4.2.2 Simulation and Flight Condition Controls

The simulation and flight condition controls are featured in the rectangular box on the left side of the screen, see Fig. 31.

- **Vehicle Name** allows the users to change the name of the files outputted. When the configuration is analyzed, all output files are stored in a folder with the same name as the vehicle being examined.
- **Velocity** sets the forward flight velocity of the rotorcraft in ft/s and is fixed to the X-axis and parallel to the ground. The default value is 80 ft/s. Input must be positive.

- **Density** sets the fluid medium density through which the blades are rotating. The default value is 0.002377 slugs/ft³ which is the density of air at sea level under standard conditions). Input range is limited to densities similar to those on Earth, ranging from 0.00045 - 0.0030 slugs /ft³.
- **Wake resolution** sets the resolution of the wake model in degrees. Lower resolutions decrease computation time but generate a lower-fidelity wake model that is coarser due to the larger time steps and longer (in length) wake elements. It is recommended to keep the default setting of 1 degree in order to ensure adequate modeling related to the Beddoes' prescribed wake model. Input must be between 0.25 and 15 degrees.
- **Revolutions** controls the number of full rotations of the rotor(s) in the simulation, based on the rotor with lowest RPM value. The default and recommended value is 1. Input must be between 0.1 and 10.
- **Time step** is the resolution of the time step in degrees, which controls the speed of the simulation video. It is recommended to keep the default value of 1 degree. Input is limited between 0.1 and 15.
- **Wake cycles** is the number of wake rotations. At this time, the user must choose a wake cycle value large enough to ensure potential BVI interactions are captured. The higher the number of wake cycles, the longer the simulation takes to run. The default value is 4. The minimum input is 1 cycle, which is 360 degrees.
- **Vortex on all blades** controls the number of vortices pictured in the simulation. When checked, there is a vortex depicted on each blade; when unchecked, there is only a vortex depicted on the first blade. The default position is that the "Vortex on all blades is checked" (turned on).

Vehicle Name	Case_1	
Velocity	180	ft/s
Density	0.002377	slugs/ft³
Wake resolution	1	deg
Revolutions	1	
Time step	1	deg
Wake cycles	4	
☒ Vortex on all blades		

Figure 31: Default simulation and flight condition controls.

4.2.3 Rotor Properties

The second input field, located along the bottom of the screen, controls the blade geometry in a table format, see Fig. 32. All inputs can be altered by double-clicking on the respective text boxes. All lengths are measured in feet. There is a slider bar below the input field to allow the user to access all parameters without running RABIT in full screen.

- **Name** allows the user to change the label for each rotor in the configuration.
- **Clockwise** specifies the direction of rotation for each rotor. Checking the box causes the rotor to spin clockwise (when viewed looking down on the rotor from above). Leaving the box unchecked, by default, causes rotors to spin counterclockwise (when viewed looking down on the rotor from above). See Fig. 4 visualization of rotor rotational direction.
- **Nb** is the number of blades per rotor. Altering this field requires a corresponding alteration in the **Phase** field.
- **Radius** controls the radius of the blades on the rotor.
- **Chord** controls the chord length of the rotor blades. Blade taper, sweep and droop are not available at this time.
- **Phase** controls the spacing between the blades by specifying the phase angle in degrees that a particular blade will be located in. There must be one phase input per blade, and the inputs should be separated by one space (i.e., there should be four phase angles for a rotor with four blades). Both equal and unequal phasing are supported.
- **RPM** controls the revolutions per minute of the rotor.
- μ is the advance ratio of the rotor, which is $\frac{\text{forward flight speed}}{\text{blade tip speed}}$. This can be automatically calculated from the V_∞ and RPM. Only μ values between 0.005 and 0.30 are permitted. It is important to note that V_∞ is fixed to the X-axis and parallel to the ground.
- α_{TPP} is the rotor tip path angle of attack in degrees, positive nose up. Only α_{TPP} values between -90 and 90 degrees are permitted.
- β_0 controls the coning angle of the blades in degrees (positive blades up). Only β_0 values between -90 and 90 degrees are permitted.
- C_T sets the rotor coefficient of thrust. Only C_T values between 0.001 and 1 are permitted.
- **X, Y, and Z** sets the position of the rotor in space. By default, when a second rotor is added it is placed 54 feet away from the first rotor in the Y-direction (to the right of the first rotor).

- Tol controls the BVI hit tolerance as a percentage of chord. It is calculated by using the input value as a percentage of the chord and creates a volume around the blade. Ex: An input of 5 with a chord of 1.25 ft creates a volume around the original blade that adds 0.0625 ft to the radius, chord, and thickness. This volume is searched for vortices that are candidates for blade-vortex interactions. The greater the tolerance, the greater the number of possible interaction locations.
- t/c refers to the maximum thickness of the airfoil as a percentage of chord length.

Select	Name	Clockwise	Nb	Radius (ft)	Chord (ft)	Phase (°)	RPM	μ	α_{TPP} (°)	β_0 (°)	CT	X (ft)	Y (ft)	Z (ft)	Tol (%)	t/c (%)
☐	Rotor 1	☐	2	24	1.75	0.180	318	0.225	2.18	0	0.00584	0	0	0	100	12

Figure 32: Blade geometry and settings.

4.3 Modeling Capabilities

Users may customize the vehicle by varying the (a) number of rotors on the vehicle, (b) placement, location, and orientation of each rotor, (c) radius and rotation direction of each rotor, (d) number of blades on each rotor and the spacing of those blades, (e) coning angle of the blades on each rotor, (e) airfoil tables used for aerodynamics, and the (f) airfoil maximum thickness ratio, see Fig. 33 for visual representation.

Unconventional rotors can be used as well that have various rotor radius, chord, or coning angle, see Figs. 34 through 36. To simulate specific blades of the same rotor with varying properties, the user must overlap multiple rotors and align the phasing of each blade to appear as if the combination is simply one rotor. For example, if the user has a rotor with four blades and only wants to increase the chord of one blade, then they must have one rotor with three blades stacked on top of another rotor with just one blade. This is done by changing the number of blades in the controls panel and then assigning each blade a corresponding phase angle. Finally, the chord can be increased on the rotor with just one blade.

4.3.1 Auxiliary Inputs

Additional input fields are provided through buttons and allow the user to interact with the application. These buttons are as follows:

- “Load Project” and “Save Project” work together to allow the user to load in previous configurations without manually adjusting the input. Pressing the “Load Project” button prompts the user to open a saved configuration, while the Save Project button saves all of the information so the vehicle can be easily accessed again later. The “Vehicle Name” is used as the default filename.
- “Add Rotor” adds another rotor into the simulation and creates a corresponding tab in blade geometry control panel. “Remove Rotor” removes the selected rotor from the simulation. To remove a rotor, the “Select” box in the blade control panel must be checked.

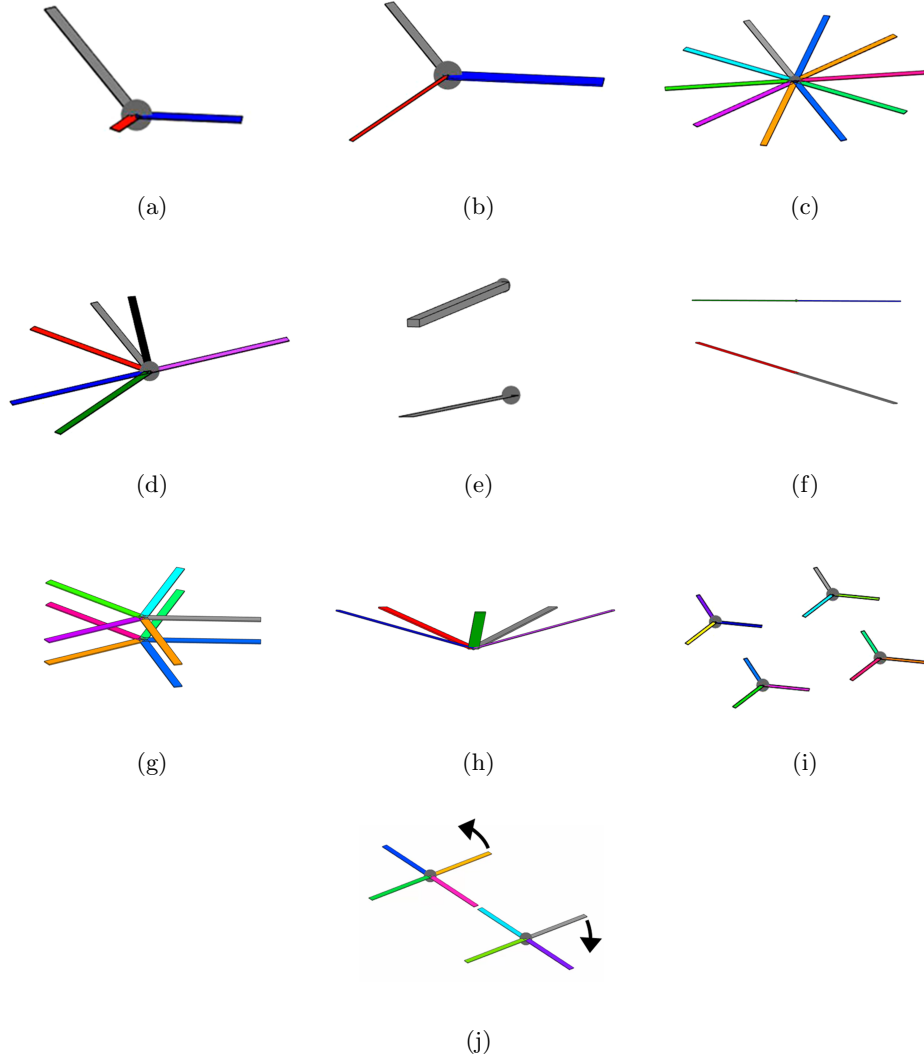


Figure 33: Visual representation of (a) varying radius, (b) varying airfoil, (c) number of blades, (d) unequal phasing, (e) airfoil thickness, (f) tip-path-plane angle, (g) vertical distance, (h) coning angle, (i) multiple rotors, and (j) rotational direction.

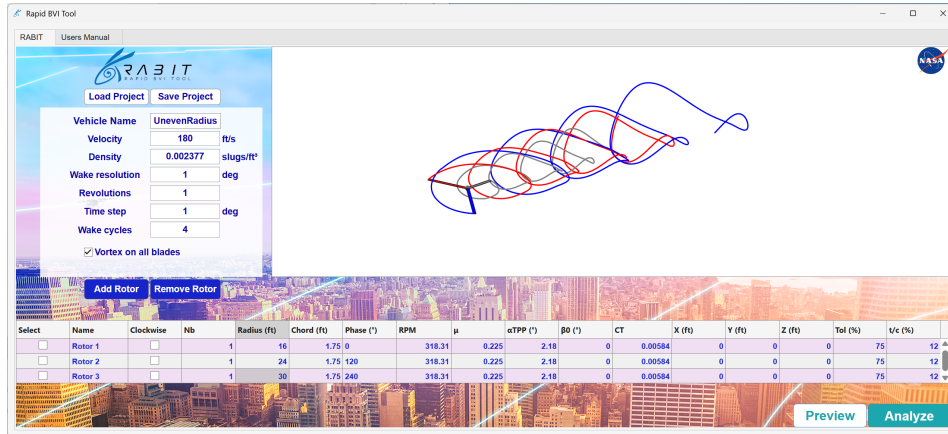


Figure 34: Example of RABIT geometry modeling capabilities for varying radius.

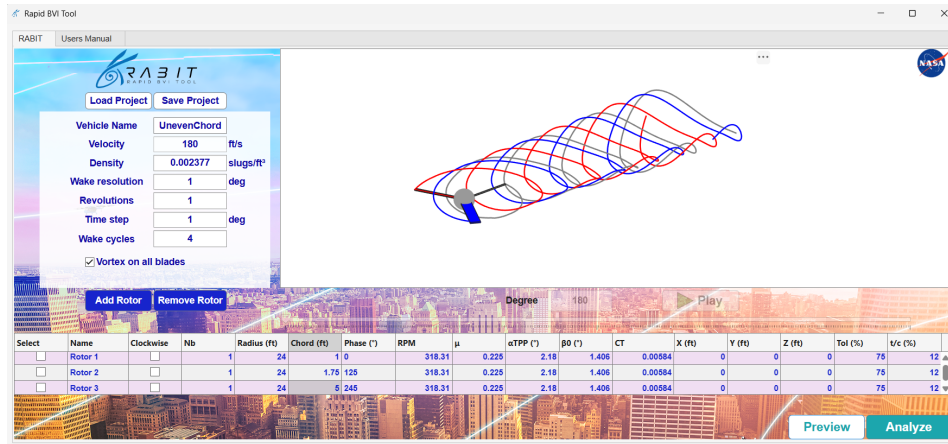


Figure 35: Example of RABIT geometry modeling capabilities for varying chord.

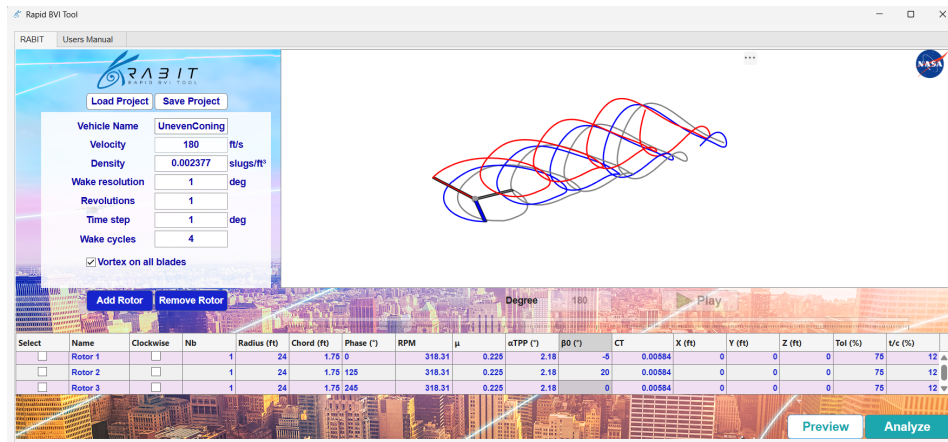


Figure 36: Example of RABIT geometry modeling capabilities for varying coning angle.

- “Preview” allows the user to view the rotor configuration without running a full analysis.
- “Analyze” launches the simulation and triggers a pop-up titled “Analysis Output Files” that allows the user to specify which output files should be generated, and where they should be saved, see Fig. 37. Select the desired output files by checking the boxes directly to their right. Select the directory by clicking on the folder icon next to “Output file location” or by typing the location into the text field. The files are saved in a folder with the same name as the rotorcraft being analyzed. After pressing “Apply”, the simulation runs. Please note, computation time varies depending on the complexity of the rotorcraft and simulation conditions. Once the simulation is complete, the window is redirected to the “RABIT” window where the video animation is displayed.

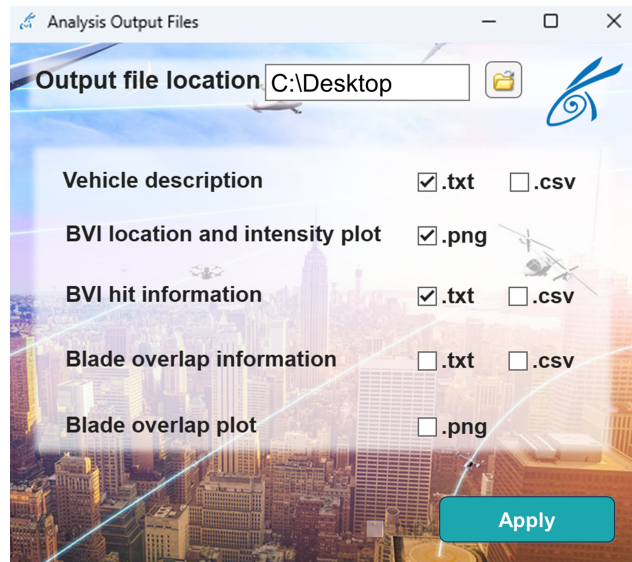


Figure 37: Analysis output file selection window.

4.3.2 Animation Controls

After analyzing the rotorcraft, RABIT generates an animation of the wake geometry, overlaid with the rotors to better visualize the predicted BVI locations. To view the video, press the “Play” button underneath the display field. This starts the animation. The “Degree” counter shows the amount of rotation undergone by the rotor at any given time and is connected to the white slider underneath the “Play” button. Moving the slider changes the orientation of the rotor. Similarly, pressing the right arrow next to Play advances the rotation to the next time step, and pressing the left arrow reduces the rotation to the previous time step. Pressing the stop button pauses the animation. Pressing the restart button next to the degree display resets the animation back to zero degrees of rotation.

The colored points that populate on the animation are the BVI occurrences being displayed in real time. These represent the locations of blade-vortex interactions. The color of each point corresponds to the color of the blade involved in the interaction, so the relationship between the BVI instances and blade geometry can be further analyzed. See Fig. 38 for the start of the animation and Fig. 39 when the animation is paused at 180 degree with BVI occurrences marked.

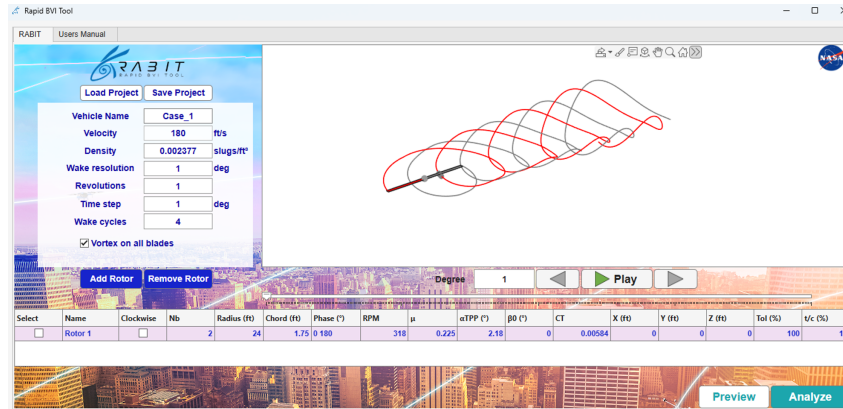


Figure 38: RABIT simulation at 1 degree for default single rotor configuration.

The animation is also interactive, as seen in Fig. 40. Hovering over the display triggers a toolbar to become visible along the top right of the animation, and this allows users to zoom in and out, pan around, rotate the graphic, find coordinates of specific points, highlight areas of interest, and export the animation.

To interact with the image, first select an icon from the toolbar featured in Fig. 40. After selecting, simply click or drag on the image to use the tool. The “home” icon resets the perspective of the animation but does not erase any mark-ups. To completely clear the view, right click on any mark-ups and click “remove”. The user can interact with the animation at any time, as long as the animation is paused. If the purpose of a tool is not clear, hovering over the individual icon provides a text box with information on the function of the tool.

Please note, the animation does not automatically reset if a user starts creating a new configuration after analyzing a previous one. To make edits to a vehicle after

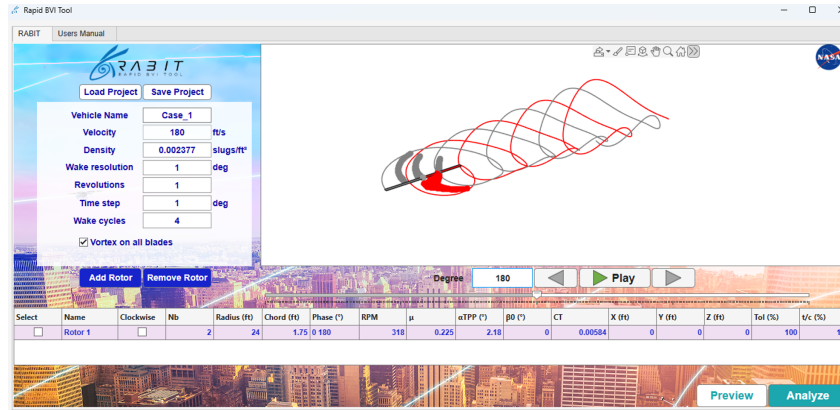


Figure 39: RABIT simulation at 180 degrees video visual with BVI occurrences.

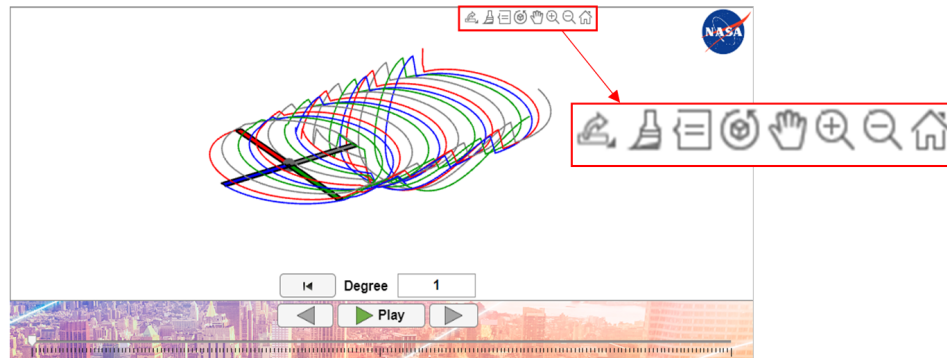


Figure 40: Enlarged view of animation controls toolbar. From left to right: export, highlighter, data point, rotate, pan, zoom in, zoom out, reset view.

pressing “Analyze” and generating an animation, the user must either pause the animation or wait for it to finish, then make the edits and press “Preview”. This resets the visuals so they only show the new configuration. Failing to reset the visuals may result in video lag and out-of-date animations.

4.4 Output Files

In addition to generating a BVI animation, the RABIT application also provides six output files detailing the specifics of the simulation. These are designed to help the user identify the location and relative strength of BVI. The output selection includes ability to select vehicle description, BVI location and intensity plot, BVI interaction information, and blade overlap information and plot (for coaxial rotors only). All outputs are available to export as either a text file “.txt” or a Comma-Separated Values file “.csv” except for the BVI and blade overlap information plots, which are exported as Portable Network Graphic “.png”. When the configuration is analyzed, all output files are stored in a folder with the same name as the vehicle being examined. The folder name and vehicle name must match in order for RABIT to save the output files in the specified location, so users should not rename the folder when specifying the directory location.

4.4.1 Vehicle Description

The vehicle description is a table containing all the input parameters specified for the vehicle being analyzed, with the option to output as a “.txt” or “.csv” file. This includes rotor name (**Rotor_Name**), number of blades (**Blades**), radius (**Radius**), chord (**Chord**), α_{TPP} (**Alpha_Tpp**), coning angle (**Beta_0**), phase (**Phase_M**), location (**Loc_X**, **Loc_Y**, **Loc_Z**), rotation direction (**Rotation**), RPM (**RPM**), μ (**Mu**), tip speed (**Tip_Speed**), C_T (**CT**), V_∞ (**V_inf**), number of revolutions (**Time_revs**), time step (**Time_step**), wake cycles (**Wake_cycles**), and wake resolution (**Wake_res**). Note that all data is tab delimited in the “.txt” file, so the data is not displayed directly aligned under table headings when viewing. At the bottom of the vehicle description file RABIT assumptions are stated.

4.4.2 BVI Information

If a BVI occurrence is identified, a “.png” file is generated, plotting the change in blade loading in terms of the time derivative of the force. ($\frac{\partial F}{\partial t}$). There is one plot for each rotor for the vehicle. An example output of BVI intensity is shown in Fig. 41. The larger the change from negative to positive or positive to negative, the larger the strength of the BVI event.

BVI occurrence information is output to both a “.txt” and “.csv” file and contains time in degrees (**Time_deg**), identification of the rotor (by rotor number) that created the vortex (**Rotor_number_formed**), identification of the blade (by blade number) that created the vortex (**Blade_number_formed**), identification of which rotor (by rotor number) was hit by the vortex (**Rotor_number_hit**), identification of which blade (by blade number) was hit by the vortex (**Blade_number_hit**), radial location of the interaction (**Radius_location**), BVI angle of interaction (**BVI_angle**),

vertical miss distance between the blade and the vortex (**Miss_distance**), wake age (**Wake_age**), change in blade loading for each BVI instance (**dF**), and X (**X_Loc_BVI**), Y (**Y_Loc_BVI**), and Z (**Z_Loc_BVI**) position of BVI location in feet.

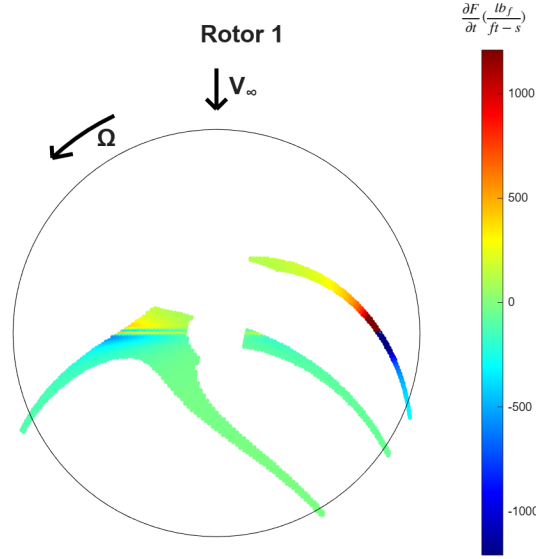


Figure 41: Change in blade loading plot for a single rotor with default rotor inputs.

If no BVI occurrences are identified, a “.txt” file is generated stating: ”There were no recorded BVI interactions for this simulation.” In this case, the only output files generated are the vehicle description and the BVI information file containing this statement.

The video displayed on the RABIT application uses a synchronized color-coding scheme. When a BVI event occurs, a colored marker is placed at the location of the interaction, and the marker color corresponds to the blade that came in contact with a wake field.

4.4.3 Coaxial Rotor Blade Crossing

When running a coaxial rotor configuration, the software automatically generates a blade overlap data table and corresponding plot. The Output Table: Available in both “.txt” and “.csv” formats, this table tracks the time a blade crossing occurs in degrees (**Time_deg_BladeCrossing**), the specific blade numbers for each rotor Rotor 1 (**Rotor1_Blade**) and Rotor 2 (**Rotor2_Blade**), and the physical location of the blade overlap in degrees (**Azimuth_deg**). The Overlap Plot: Saved as a “.png” file, this graph visually maps out where the blades cross paths relative to their azimuth angle. An example of a coaxial rotor blade overlap output figure is shown in Fig. 42. The current version of RABIT only identifies blade overlap for vehicles with two rotors that have the same X and Y location.

The video displayed on the RABIT APP shows when blade overlap occurs by plotting a black square symbol when an upper and lower rotor blade overlap.

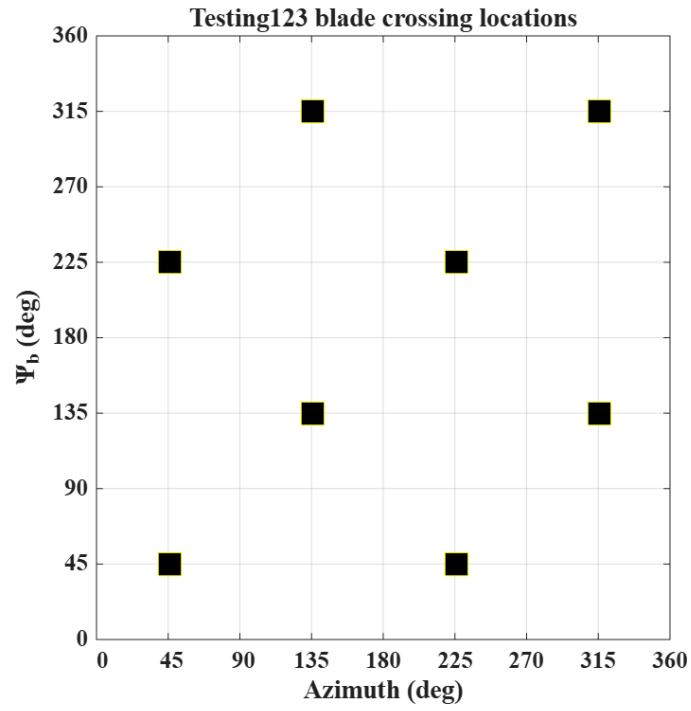


Figure 42: Example blade overlap output plot for a coaxial rotor for one revolution (Upper rotor: 2 blades at 90 and 270 degrees, Lower rotor: 2 blades at 0 and 180 degrees).

5 Example Cases

Example configurations for single, tandem, coaxial, and quad-rotor aircraft are provided. For each configuration, a preview image and the corresponding output figures illustrating BVI-related blade-loading changes and blade overlap (where applicable) are shown; see Figs. 43 through 50. These examples are included to assist new users in becoming familiar with the tool and to facilitate rapid initial setup.

5.1 Single Rotor

An example for a single, two-bladed rotor using the default RABIT settings is provided. The preview for this example single rotor is shown in Fig. 43 along with the change in blade loading shown in Fig. 44.

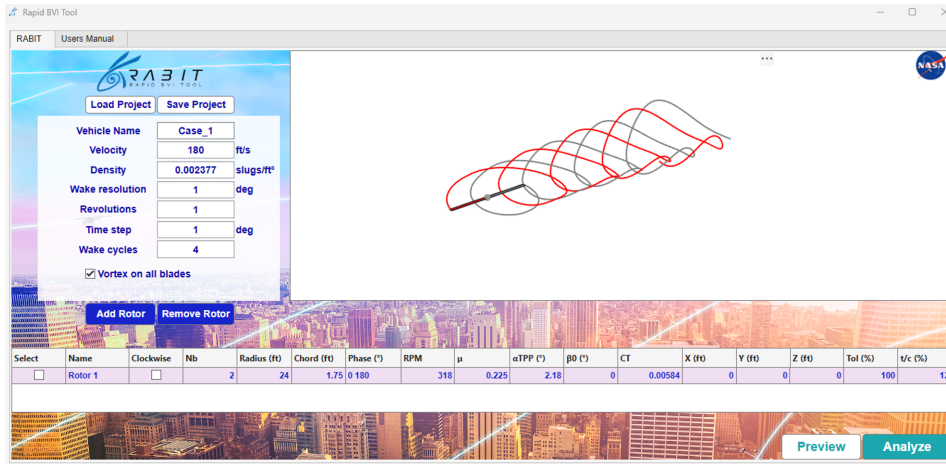


Figure 43: Single rotor example preview.

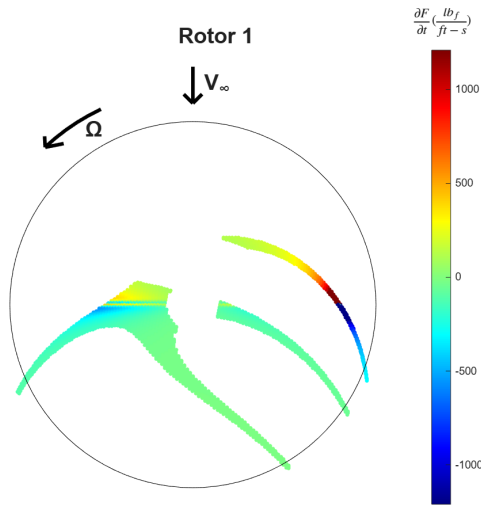


Figure 44: Single rotor example blade loading plot output.

5.2 Tandem Rotor

An example of a tandem rotor configuration is shown in Fig. 45, with the change in blade loading presented in Figs. 46a and 46b. This example demonstrates the capability of RABIT to detect BVI resulting from the wake of an adjacent rotor. In addition, the results on the plot for the aft rotor are mirrored about a vertical plane (the XZ plane) that intersects both hubs, due to the opposite rotational direction of the two rotors.

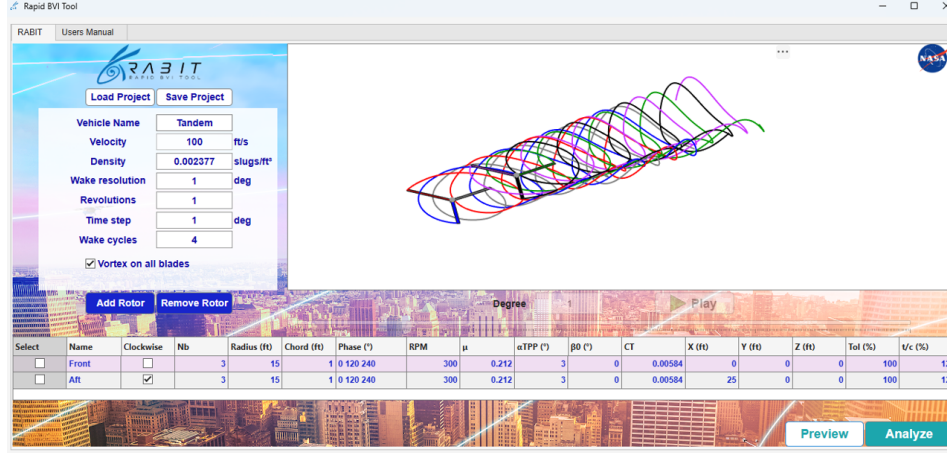


Figure 45: Tandem rotor example preview.

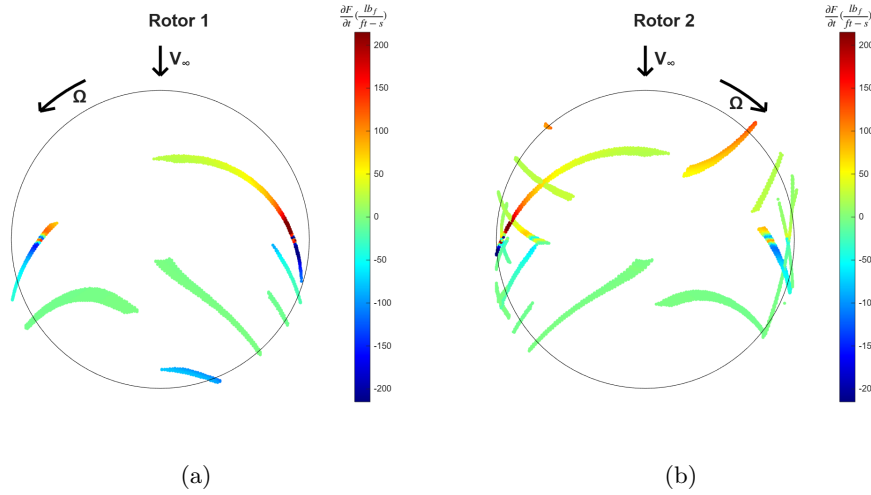


Figure 46: Tandem rotor example blade loading plot output for (a) front rotor and (b) aft rotor.

5.3 Coaxial Rotor

An example of a six-bladed coaxial rotor configuration consisting of three blades on the upper rotor and three blades on the lower rotor is provided. In this configuration, the upper rotor is positioned 5 feet directly above the lower rotor. A preview of the geometry is shown in Fig. 47, and the resulting changes in blade loading are presented in Figs. 48a and 48b. Because this configuration uses a coaxial rotor with blades spinning in opposite directions, blade-overlap events occur; therefore, a corresponding blade-overlap visualization is included in Fig. 49. It is important to note that if the user wants the blade-overlap figure to be included in the output, this option must be selected in the analysis output file section window (see Fig. 37).

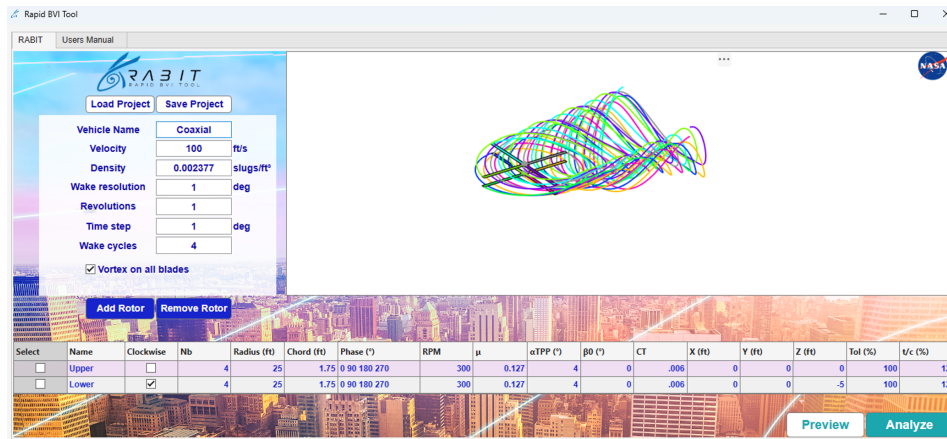


Figure 47: Coaxial rotor example preview.

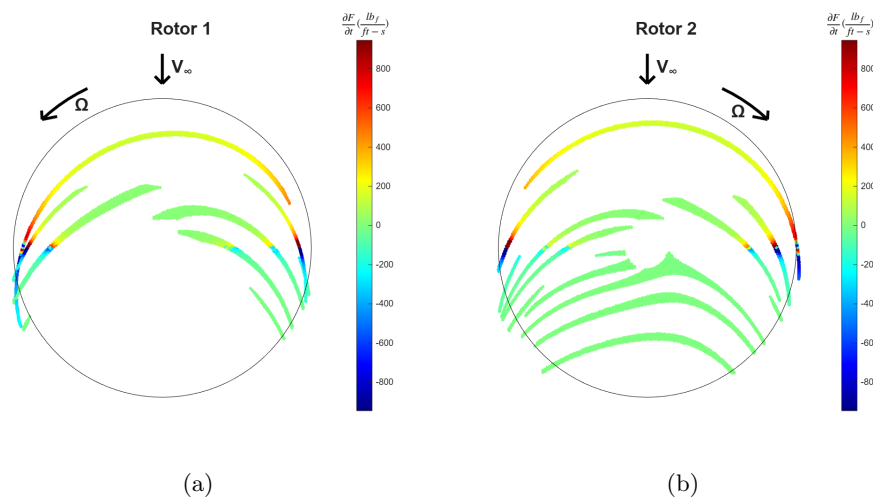


Figure 48: Coaxial rotor example blade loading plot output for (a) upper rotor and (b) lower rotor.

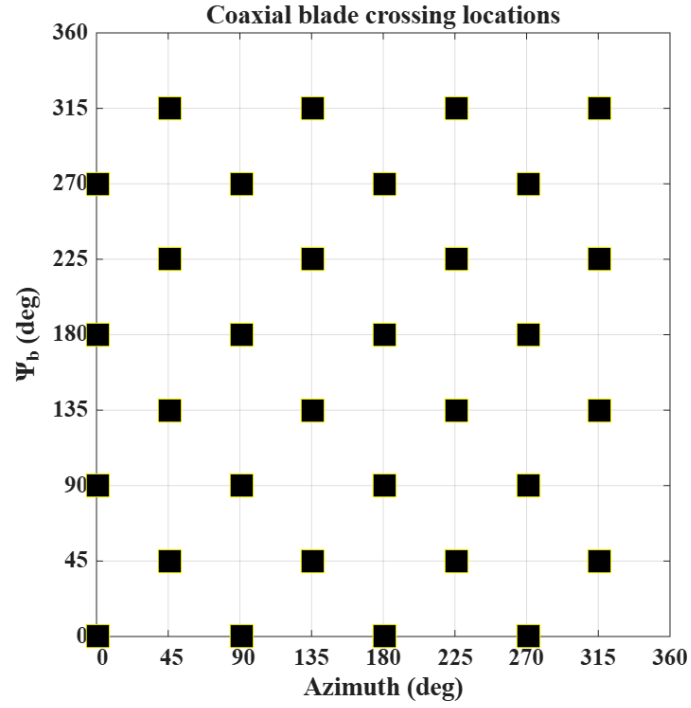


Figure 49: Coaxial rotor example blade overlap.

5.4 Quadrotor

An example of a quadrotor configuration is shown in Fig. 50, with the change in blade loading presented in Figs. 51a through 51d. Similar to the tandem rotor example provided, this example demonstrates the capability of RABIT to detect BVI originating from the wake of an adjacent rotor.

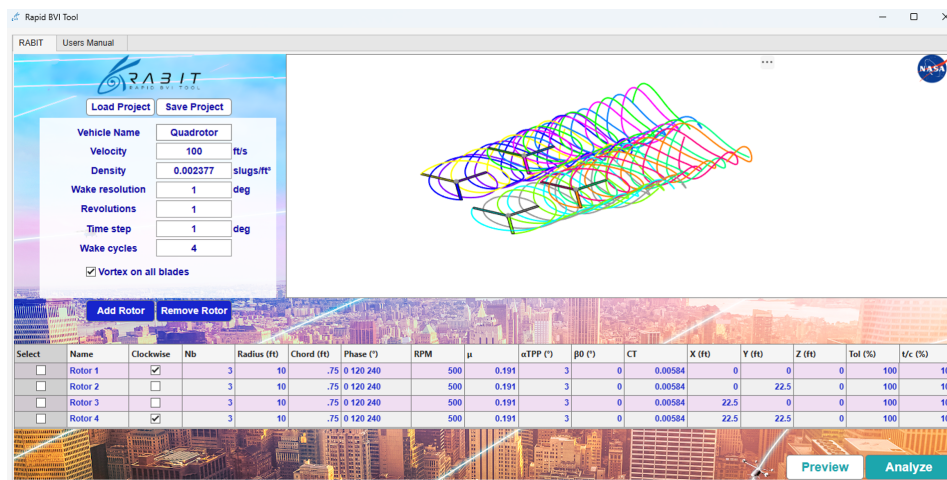


Figure 50: Quadrotor example preview.

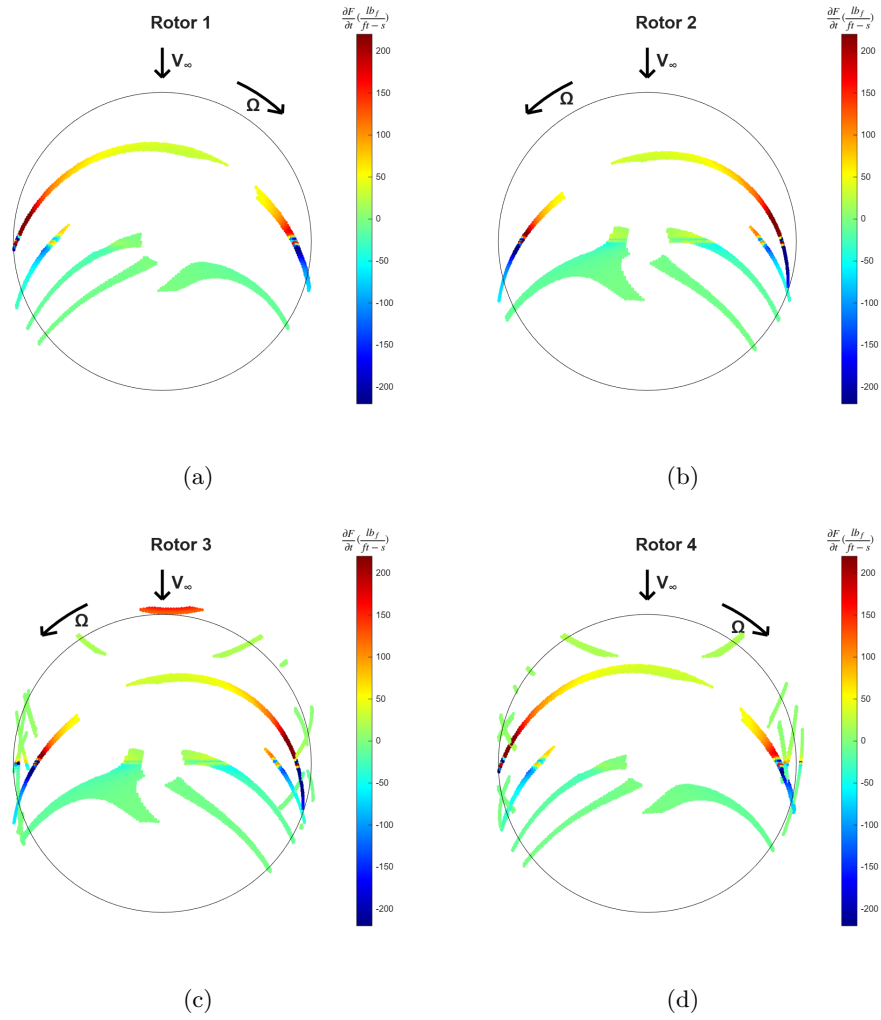


Figure 51: Quadrotor example blade loading plot output for (a) front rotor left (Rotor 1), (b) front rotor right (Rotor 2), (c) aft rotor left (Rotor 3), and (d) aft rotor right (Rotor 4).

6 Conclusion

RABIT is a fast, user-friendly, stand-alone application designed to identify and visualize BVI occurrences across a wide range of rotorcraft configurations, including coaxial rotor blade overlap. Building upon the single-rotor BVI model originally developed by Sim and George, RABIT extends BVI detection to multi-rotor systems. Validation against Beddoes' prescribed wake and comparisons with CAMRAD II free-wake and aerodynamic loading predictions demonstrate that RABIT captures essential wake trends, identifies major BVI events, and highlights strong interaction occurrences despite the inherent simplifications of the prescribed wake approach. These capabilities make RABIT a computationally efficient and effective tool for assessing BVI during early-stage conceptual design.

7 Contact Information

For further information, contact: Dr. Natasha Schatzman at Natasha.Schatzman@NASA.gov.

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14. ABSTRACT Identifying and reducing rotorcraft noise is essential to urban air mobility (UAM). Blade-vortex interaction (BVI) can be a major contributor to rotary-wing vehicle noise, particularly during flight phases where a close and nearly parallel interaction occurs between a rotor blade and a strong tip vortex. These interactions often happen during the descent and landing phases of flight when the vehicle is near the ground and therefore, near people. Reducing public noise exposure requires fast BVI estimations to rapidly assess the acoustic signature of rotary-wing vehicles. The RApid Blade-Interaction Tool (RABIT) is a fast, user-friendly, stand-alone computer program/application that predicts BVI strength and location using a prescribed wake model and a simple blade motion model. It also determines blade and wake intersection timing and location and provides visualizations to support conceptual design, rotor placement, and rotor-wake interaction assessments. This manual outlines the background of the RABIT tool, theory, validation cases, installation process, interface, output files, and example applications.						
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