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Mathematical Modeling of 1-DOF Vibration: Effects of Mouthpiece Rim Thinning on the Natural Frequency of Trumpet Players' Lips

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Abstract

High-register trumpet performance involves coupled lip mechanics and instrument acoustics, yet the mechanical implications of mouthpiece rim thinning remain insufficiently quantified. This study developed a theoretical single-degree-of-freedom (1-DOF) model to examine how rim thickness influences lip contact pressure, equivalent stiffness, effective vibrating mass, and reference natural frequency. Standard 7C mouthpiece geometries with rim thicknesses of 10 mm and 6 mm were compared under a constant axial pressing force of 10 N. The contact area was approximated using annular geometry, stiffness was represented by a linearized pressure-dependent relationship, and vibrating mass was assumed proportional to rim thickness. The 40% thickness reduction yielded a 40% decrease in nominal contact area and a 66.7% increase in nominal contact pressure. Under the specified mass proportionality, effective vibrating mass decreased by 40%. Assuming equivalent stiffness did not decrease, the model predicted a minimum natural-frequency ratio of 1.291, corresponding to a 29.1% increase. This prediction describes the uncoupled reference frequency rather than the actual trumpet playing frequency or verified upper-register performance. Because stiffness and mass coefficients were not calibrated experimentally, the results remain conditional on the adopted mechanical assumptions. The model provides a basis for future contact-pressure measurements, parameter identification, and evaluations of mouthpiece rim geometry.

Keywords: *Contact Mechanics, High Register, Lip Biomechanics, Mouthpiece Rim, Single-Degree-of-Freedom Vibration.*

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INTRODUCTION

The mechanical behavior of human lips during trumpet performance represents a complex interaction between biological tissue deformation, aerodynamic excitation, and acoustic resonance, particularly when musicians operate in the upper register. Trumpet sound production depends on self-sustained lip oscillations generated through the interaction of airflow, elastic lip structures, and the instrument's acoustic resonator (Kaburagi et al., 2023). The ability to produce higher notes is consequently associated not only with increased oscillation frequency but also with adjustments in mechanical properties, vibrating tissue configuration, and airflow regulation. Investigations of trumpet oscillation thresholds have demonstrated that lip resonance frequency, effective mass, stiffness, and equilibrium opening constitute essential parameters governing transitions between playing registers (Doc et al., 2023). The mouthpiece establishes a mechanical contact interface that can constrain lip movement and redistribute the forces acting on vibrating tissue, making its geometry relevant to the mechanical boundary conditions of the system. Experimental measurements involving trombone players have demonstrated that lip-specific contact forces and pressure distributions vary according to embouchure strategies and performance proficiency (Amann et al., 2026). Research on French horn performance has further established that mouthpiece pressing forces increase with pitch and playing dynamics, indicating the mechanical significance of lip–rim interaction during brass instrument performance (Hirano & Kinoshita, 2026).

Contemporary research on brass instrument acoustics has progressively developed from numerical representations of coupled oscillatory systems toward parameter estimation methods capable of characterizing the mechanical behavior of vibrating lips. Numerical investigations of trumpet oscillation have established computational approaches for identifying periodic solutions and examining the interaction between lip motion, airflow, and acoustic resonance (Kaburagi et al., 2023).

Complementary approaches employing constrained numerical continuation have addressed uncertainty in physical model parameters by incorporating experimentally derived constraints into nonlinear trumpet simulations (Fréour et al., 2022). Inverse modeling techniques have similarly estimated effective lip parameters, including resonance frequency, quality factor, surface mass, and stiffness, by relating simulated oscillation thresholds to experimentally measured blowing pressures (Doc et al., 2023). Reduced-order mechanical representations have also demonstrated that one-degree-of-freedom lip models can approximate observed pressure waveforms and playing frequencies through the identification of admissible model parameters (Maugeais & Gilbert, 2023). These approaches collectively establish the feasibility of representing brass-player lip dynamics through simplified mechanical systems, although their principal emphasis remains on oscillation behavior and parameter identification rather than systematically connecting mouthpiece rim thickness with changes in effective lip stiffness and natural frequency.

Despite progress in numerical acoustics and biomechanical modeling, the mechanical consequences of modifying the mouthpiece rim geometry remain insufficiently characterized within the selected literature. Existing comparisons between modeled and measured brass instrument impedance have primarily addressed the acoustic characteristics of mouthpieces and instrument components, including the parameterization of internal mouthpiece geometry (Jackson & Scavone, 2024). Advanced lip modeling has introduced reduced-order formulations derived from elastic plate mechanics, including a one-degree-of-freedom representation with nonlinear stiffness characteristics (Fréour et al., 2025). Investigations incorporating the mechanical properties of human flesh have additionally suggested that changes in vibrating lip mass and vocal tract configuration contribute to register control, challenging explanations based exclusively on muscle tension (Strauss, 2025). Experimental studies of mouthpiece contact have provided quantitative evidence concerning lip force distributions and pressure regulation but have not directly established a functional relationship between controlled rim-thickness variations and lip natural frequency (Amann et al., 2026). The unresolved theoretical issue concerns how a reduction in rim thickness modifies the effective contact boundary, vibrating lip mass, and equivalent stiffness within a mechanically simplified oscillatory system. This constitutes a specific geometric–mechanical modeling gap rather than an absence of established knowledge concerning trumpet acoustics or lip oscillation dynamics.

The absence of an explicit relationship between mouthpiece rim thickness and equivalent lip vibration parameters creates uncertainty when evaluating the mechanical implications of mouthpiece design modifications. Measurements obtained during French horn performance indicate that mouthpiece contact forces depend substantially on pitch and dynamics, demonstrating that mechanical loading conditions cannot automatically be considered constant across playing registers (Hirano & Kinoshita, 2026). Quantitative observations of trombone embouchure behavior further show differences in force distribution and pressure control among performers, suggesting that the effective mechanical constraints imposed on the lips may depend on individual playing strategies (Amann et al., 2026). Acoustic impedance analyses provide essential information about the behavior of brass instrument components but do not independently determine how rim contact geometry modifies the mass and stiffness of vibrating lip tissue (Jackson & Scavone, 2024). Developments in artificial-lip systems demonstrate the technical feasibility of controlling lip position, aperture, and acoustic feedback under reproducible conditions, supporting the broader engineering value of isolating individual parameters in brass instrument investigations (Sonoda et al., 2026). A mathematical framework incorporating rim geometry as an explicit mechanical variable is therefore necessary to distinguish theoretically plausible changes in natural frequency from assumptions based solely on subjective playing experience or observed pitch production.

The present research is positioned as a mechanics-oriented extension of existing trumpet oscillation models by explicitly incorporating mouthpiece rim thinning into a single-degree-of-freedom vibration framework. In this representation, the natural frequency of lip oscillation is governed by the relationship between equivalent stiffness and effective vibrating mass, while the mouthpiece rim is treated as a geometric factor potentially affecting both mechanical quantities through changes in contact constraints. Previous inverse-modeling studies have estimated stiffness and mass-related parameters from observed oscillation behavior, whereas the proposed approach investigates how these parameters may vary as functions of rim thickness under specified mechanical assumptions (Doc et al., 2023). Constrained continuation methods have demonstrated the importance of parameter uncertainty in brass

instrument simulations, supporting the need for an explicit and transparent formulation of the geometric and mechanical relationships introduced into a reduced-order model (Fréour et al., 2022). The adoption of a one-degree-of-freedom formulation is further supported by existing artificial-lip modeling research that derives simplified oscillatory descriptions from more complex elastic mechanical systems (Fréour et al., 2025). Consideration of effective vibrating mass is particularly relevant because lip vibration studies indicate that the amount of participating tissue may change with performance strategy and cannot be adequately represented by muscle tension alone (Strauss, 2025). The proposed novelty consequently lies in developing an explicit rim-thickness-dependent relationship for equivalent lip vibration parameters and examining its predicted influence on natural frequency without presupposing that rim thinning necessarily increases the frequency under all conditions.

This study aims to develop a mathematical model describing the potential effects of mouthpiece rim thinning on the natural frequency of trumpet players' lips using a single-degree-of-freedom mass–spring–damper representation. The analysis seeks to establish a theoretical relationship between rim thickness, effective vibrating mass, equivalent stiffness, and natural frequency while clearly specifying the assumptions governing the mechanical contact interface. The governing vibration equation will be formulated to examine how changes in equivalent mechanical parameters influence the free-vibration characteristics of the lip system, while distinguishing these characteristics from the coupled oscillation behavior of an operating trumpet (Kaburagi et al., 2023). A parametric sensitivity analysis will be employed to evaluate the relative influence of rim-related variations in stiffness and mass on the resulting natural frequency, with attention to the parameter-identification challenges recognized in reduced-order lip models (Maugeais & Gilbert, 2023). The analytical framework is intended to retain the interpretability of a one-degree-of-freedom system while providing a mechanically explicit basis for investigating geometric effects that are not directly represented in existing artificial-lip formulations (Fréour et al., 2025). The expected contribution is a transparent theoretical foundation for evaluating mouthpiece rim geometry as a mechanical design variable and for guiding subsequent experimental investigations, without presenting unverified improvements in high-register trumpet performance as established findings.

RESEARCH METHODS

This study employed theoretical mathematical modeling to examine the effects of trumpet mouthpiece rim thinning on the natural frequency of players' lips using a single-degree-of-freedom (1-DOF) mechanical representation (Doc et al., 2023). The analysis considered two configurations of a standard 7C trumpet mouthpiece, comprising an initial rim thickness of 10 mm (t_1) and a modified thickness of 6 mm (t_2), corresponding to a 40% reduction. Rim thickness was designated as the independent variable, natural frequency (f_0) as the dependent variable, and axial force (F), mean rim diameter (D_mean), initial stiffness (k_0), and tissue density (ρ) as controlled parameters. The mouthpiece–lip contact interface was modeled as a mechanical boundary influencing the distribution of compressive forces across the vibrating tissue (Amann et al., 2026). A constant axial pressing force of 10 N was specified for both configurations to maintain comparable mechanical loading conditions (Hirano & Kinoshita, 2026). The simplified analytical framework isolated the relationship between geometric changes and equivalent mechanical parameters without reproducing the complete nonlinear behavior of the coupled lip–instrument system (Fréour et al., 2025). Figure 1 illustrates the two rim configurations, while Table 1 summarizes the variables incorporated into the mathematical model.



Figure 1. Measurement of 7C Mouthpiece Rim Thickness Using a Vernier Caliper: (a) Standard Rim (10 mm) and (b) Modified Rim (6 mm).

Table 1. Classification of Variables in the Lip Vibration Model

Variable Type	Parameter	Technical Definition
Independent	Rim thickness (t)	Standard rim of 10 mm and modified rim of 6 mm.
Dependent	Natural frequency (f_0)	Undamped reference natural frequency of lip vibration (Hz).
Control	F, D_mean, k_0, ρ	Axial force (10 N), mean rim diameter, initial stiffness, and tissue density held constant.

The analytical procedure began by approximating the mouthpiece contact area as the product of mean rim circumference and rim thickness (Gere & Timoshenko, 2000). Nominal contact pressure was subsequently calculated by dividing the constant axial pressing force by the corresponding contact area (Hibbeler, 2016). Equivalent lip stiffness was expressed through a linearized pressure-dependent function representing an assumed mechanical response of deformable lip tissue under compressive loading (Nazari et al., 2011). Effective vibrating mass was assumed to vary proportionally with rim thickness through a geometric conversion coefficient, while all other specified parameters remained constant. The resulting stiffness and mass functions were incorporated into the governing damped 1-DOF equation and the corresponding undamped natural-frequency relationship (Rao, 2017). The six mathematical expressions are consolidated in Table 2, with the coefficients α and β retained as unspecified model parameters requiring calibration before numerical frequency predictions can be obtained.

Table 2. Mathematical Formulations of the 1-DOF Lip Vibration Model

No.	Mathematical Relationship	Equation
(1)	Governing equation of motion	$m(t)\ddot{x} + c(t)\dot{x} + k(t)x = F_{\text{fluid}}(t)$
(2)	Natural frequency	$f_0(t) = \frac{1}{2\pi}\sqrt{\frac{k(t)}{m(t)}}$
(3)	Rim contact area	$A_{\text{contact}} = \pi D_{\text{mean}} t$
(4)	Contact pressure	$p = \frac{F}{A_{\text{contact}}} = \frac{F}{\pi D_{\text{mean}} t}$
(5)	Equivalent stiffness	$k(t) = k_0 + \alpha p = k_0 + \frac{\alpha F}{\pi D_{\text{mean}} t}$
(6)	Effective vibrating mass	$m(t) = \rho V_{\text{vib}} = \beta t$

Notes:
m : Effective vibrating mass
c : Damping coefficient
k : Equivalent stiffness
x : Displacement
F_{fluid} : Fluid-induced excitation force
f_0 : Natural frequency
p : Contact pressure
A_{contact}: Rim contact area
D_{mean} : Mean rim diameter
t : Rim thickness
ρ : Material density
α : Pressure-dependent stiffness coefficient
β : Effective mass proportionality coefficient

RESULTS AND DISCUSSION

Mathematical Derivation of Rim-Thickness-Dependent Lip Natural Frequency

The analytical derivation treats lip natural frequency as a function of rim thickness rather than as a fixed material characteristic. Its starting point is the undamped single-degree-of-freedom

relationship between equivalent stiffness and effective vibrating mass (Rao, 2017). The representation does not assume that the mouthpiece independently determines the acoustic pitch of the trumpet. Numerical formulations of trumpet oscillation demonstrate that lip movement and acoustic feedback form a coupled self-sustained system (Kaburagi et al., 2023). The reduced model isolates a structural reference frequency to examine the consequence of changing a specified contact boundary. Inverse investigations of trumpet-player lips establish that mass-related and stiffness-related parameters can be represented within an effective mechanical model (Doc et al., 2023). The derived relationship is consequently interpreted as an analytical property of the assumed oscillator rather than as a direct measurement of the played note.

Rim thickness, denoted by \(t\), was introduced as the sole variable altered between the two prescribed configurations. Both configurations retained the same mean rim diameter, initial lip stiffness, tissue density, and axial pressing force. Keeping these quantities fixed follows the parameter-isolation logic employed in physical modeling of brass instruments (Fréour et al., 2022). The mouthpiece boundary was then described by an idealized annular contact surface rather than a spatially resolved deformation field. The area of that surface was represented by the product of mean circumference and cross-sectional rim thickness (Gere & Timoshenko, 2000). This geometric simplification permits rim thickness to enter the governing mechanical relationships explicitly without requiring unreported anatomical measurements.

The annular approximation establishes a direct proportionality between nominal contact area and rim thickness. With axial force held constant at 10 N, the associated nominal contact pressure is inversely proportional to the area, consistent with the conventional definition of mean compressive pressure (Hibbeler, 2016). A thinner supporting ring therefore produces a higher calculated mean pressure for an unchanged applied force. This result concerns a spatially averaged pressure and does not specify peak stress or strain inside the lip tissue. Experimental work on trombone performance shows that contact forces and pressure profiles vary across the lip–mouthpiece interface (Amann et al., 2026). The assumed uniform loading cannot reproduce such distributions, although it permits a controlled comparison of the two geometric cases. Measurements of mouthpiece pressing forces in horn playing further support treating contact loading as a distinct mechanical parameter rather than equating it with respiratory excitation (Hirano & Kinoshita, 2026).

The first substituted biomechanical quantity is the equivalent stiffness of the lip oscillator. Its pressure dependence was expressed by the prescribed linearized relationship in which baseline stiffness \(k_0\) is supplemented by a term proportional to nominal pressure. Nonlinear deformation and stiffness changes in lip tissue provide a conceptual motivation for examining a pressure-sensitive parameter, but they do not determine the coefficient used here (Nazari et al., 2011). Substituting the annular pressure expression yields the rim-thickness-dependent stiffness function in Equation (7). A positive pressure-to-stiffness coefficient is required for the expression to predict increased stiffness as thickness decreases. The simplified function retains the interpretability of reduced mechanical lip models while leaving actual tissue constitutive behavior to experimental assessment (Fréour et al., 2025).

$$k(t) = k_0 + \alpha\left(\frac{F}{\pi D_{\text{mean}} t}\right) \quad (7)$$

The second substituted quantity is effective vibrating mass, which represents the portion of lip tissue assigned to the single mechanical degree of freedom. The original model relates this quantity linearly to rim thickness through the constant β. The definition separates mechanically participating tissue from total lip tissue and does not require the entire anatomical mass to oscillate. Mechanical interpretations of lip vibration identify changes in the amount of participating tissue as relevant to register-dependent behavior (Strauss, 2025). That observation, however, does not establish that a 40% change in rim thickness necessarily produces a 40% change in vibrating tissue mass. The expression $m(t) = \rho V_{\text{vib}} = \beta t$ is therefore retained as an explicit hypothesis whose physical calibration remains unresolved. Inverse approaches to brass-player models illustrate why such lumped parameters must ultimately be checked against observed oscillation behavior (Maugeais & Gilbert, 2023).

Substitution of the pressure-dependent stiffness function into the numerator of the reference-frequency equation and the effective-mass function into its denominator produces Equation (8). The resulting expression contains two thickness-dependent terms operating through different mechanical

pathways. Its numerator includes the assumed change in equivalent stiffness, whereas its denominator represents the assumed change in participating mass. The algebra establishes their combined influence without assigning numerical values to k_0, α, β, or D_{mean}. Methods for studying self-oscillating systems illustrate that the dynamics of sustained motion may require additional nonlinear analysis beyond an undamped natural-frequency expression (Caron et al., 2026). Equation (8) is accordingly used only to compare reference mechanical frequencies under the prescribed assumptions.

$$f_0(t) = \frac{1}{2\pi}\sqrt{\frac{k_0+\alpha\left(\frac{F}{\pi D_{\text{mean}} t}\right)}{\beta t}} \quad (8)$$

For positive t and β, the expression for frequency is mathematically defined when the equivalent stiffness remains positive. If \(\alpha\) is nonnegative and the remaining parameters are fixed, reducing t cannot reduce the stiffness term in Equation (8). The mass term decreases at the same time because it is assumed directly proportional to t. These two contributions therefore predict a higher reference natural frequency for the thinner configuration within the adopted model. The direction of this conditional prediction does not depend on the absolute numerical values of the uncalibrated coefficients, although the exact frequency change does. Studies based on the mechanical properties of flesh caution against interpreting simplified lip parameters as independent of tissue configuration and the performer's adjustment strategies (Strauss, 2025). No absolute frequency in hertz is inferred at this stage because the required physical parameter values are absent.

This derivation yields an explicit rim-thickness-dependent frequency model that can be evaluated through dimensionless ratios. The comparison is confined to the specified 10 mm and 6 mm geometries under identical nominal axial force. Artificial-lip systems with controlled geometric settings offer a potential pathway for future evaluation of the assumed mass and stiffness functions (Sonoda et al., 2026). Independent acoustic studies show that instrument impedance must also be considered when linking a mechanical reference frequency to the playable register of a trumpet (Jackson & Scavone, 2024). A higher modeled natural frequency alone does not demonstrate reduced playing effort, lower oscillation threshold, or improved performance. The subsequent comparative analysis therefore assesses the algebraic consequences of rim thinning before considering their biomechanical interpretation.

Comparative Mechanical Analysis of Standard and Thinned Mouthpiece Rims

The comparative mechanical analysis evaluated the influence of mouthpiece rim thinning on the natural frequency of trumpet players' lips through a dimensionless ratio-based approach derived from the single-degree-of-freedom vibration model. Two mouthpiece configurations were examined, consisting of a standard rim with a thickness of 10 mm (t_1 = 0.01 m) and a modified thin rim measuring 6 mm (t_2 = 0.006 m), representing a 40% geometric reduction. The comparison employed a constant axial pressing force of 10 N while maintaining identical values for mean rim diameter, initial lip stiffness, tissue density, and the model coefficients associated with pressure-dependent stiffness and effective vibrating mass. This analytical strategy allowed the relative frequency response to be examined without requiring absolute numerical values for all biomechanical parameters, consistent with the fundamental relationship between stiffness, mass, and natural frequency in mechanical vibration theory (Rao, 2017). The geometric modification was expected to influence the modeled system through changes in contact area, nominal contact pressure, equivalent stiffness, and effective vibrating mass rather than through direct alteration of the instrument's acoustic resonator. Research on brass instrument performance indicates that mouthpiece pressing force constitutes a relevant mechanical loading parameter whose magnitude and distribution may vary according to playing conditions (Hirano & Kinoshita, 2026). The comparative calculations consequently isolated the theoretical effects of rim thickness under controlled loading assumptions while retaining the distinction between structural natural frequency and the actual playing frequency of a coupled lip–instrument system.

The initial analytical calculation examined the relationship between mouthpiece rim thickness and nominal contact support area, which determines the region over which the specified axial force is distributed. Under the adopted thin-walled annular approximation, contact area was expressed as the product of mean rim circumference and cross-sectional thickness, providing a geometrically explicit

relationship between rim dimensions and supporting surface area (Gere & Timoshenko, 2000). Because the mean rim diameter was maintained constant, the area ratio depended exclusively on the relative thicknesses of the two configurations, eliminating the need for an additional diameter measurement in the dimensionless comparison. Substitution of $t_1 = 0.01$ m and $t_2 = 0.006$ m produced an area ratio of 0.6, indicating that the modified rim retained 60% of the nominal contact area of the standard configuration. The calculated reduction of 40% represents a direct mathematical consequence of the annular geometric assumption and does not depend on tissue stiffness, damping, or effective vibrating mass. Although actual mouthpiece contact may involve nonuniform deformation and partial tissue contact, the adopted approximation provides a consistent reference geometry for comparing nominal pressure under the same applied mechanical force (Hibbeler, 2016).

$$\frac{A_2}{A_1} = \frac{\pi D_{\text{mean}} t_2}{\pi D_{\text{mean}} t_1} = \frac{t_2}{t_1} = \frac{0.006}{0.01} = 0.6 \Rightarrow A_2 = 0.6A_1 \quad (9)$$

The reduction in nominal contact area generated a corresponding increase in calculated contact pressure because the same axial force was distributed over a smaller supporting surface. Using the pressure relationship $p = F/A_{\text{contact}}$, the ratio between the modified and standard configurations was determined by the inverse ratio of their respective contact areas. Substituting the previously calculated area relationship yielded $p_2/p_1 = 1/0.6 = 1.6667$, corresponding to a nominal pressure increase of approximately 66.67% under the constant-force assumption. This inverse relationship follows the conventional mechanical definition of mean contact pressure and does not require additional assumptions concerning the constitutive properties of the compressed material (Hibbeler, 2016). The result indicates that a relatively moderate geometric reduction can produce a proportionally larger change in nominal loading intensity at the modeled lip–rim interface. Experimental investigations of brass-player mouthpiece contact demonstrate that force transmission and pressure distributions involve localized mechanical interactions that cannot be fully represented by a uniform-pressure approximation (Amann et al., 2026). The calculated 66.67% increase must therefore be interpreted as a change in average nominal pressure rather than a verified increase in peak biological tissue stress or an experimentally measured pressure distribution.

$$\frac{p_2}{p_1} = \frac{F/A_2}{F/A_1} = \frac{A_1}{A_2} = \frac{A_1}{0.6A_1} = \frac{1}{0.6} \approx 1.6667 \Rightarrow p_2 \approx 1.67p_1 \quad (10)$$

The effective vibrating mass was subsequently evaluated using the assumed proportional relationship $m(t) = \beta t$, which directly associates the mechanical mass parameter with rim thickness. Substituting the two geometric conditions into this expression produced $m_2/m_1 = 0.006/0.01 = 0.6$, indicating a modeled reduction of 40% in effective vibrating mass for the thinner rim. This result is mathematically dependent on the proportional-mass assumption and should not be interpreted as a direct anatomical measurement of the amount of lip tissue participating in oscillation. Mechanical investigations of lip vibration indicate that variations in participating tissue mass can influence register-dependent oscillatory characteristics, supporting its consideration as a relevant dynamic parameter (Strauss, 2025). The assumption remains restrictive because actual vibrating tissue volume may depend on lip aperture, muscular activation, contact deformation, and boundary constraints rather than rim thickness alone (Doc et al., 2023). The resulting geometric, pressure, stiffness, mass, and frequency relationships are consolidated in Table 3 to distinguish direct ratio calculations from predictions requiring additional mechanical assumptions.

$$\frac{m_2}{m_1} = \frac{\beta t_2}{\beta t_1} = \frac{0.006}{0.01} = 0.6 \Rightarrow m_2 = 0.6m_1 \quad (11)$$

Table 3. Evaluation of Mechanical Parameters for Different Mouthpiece Rims

Mechanical Parameter	Standard-Rim Mouthpiece (t_1)	Thin-Rim Mouthpiece (t_2)	Analytical Implication
Cross-sectional thickness (t)	10 mm (0.01 m)	6 mm (0.006 m)	Thickness reduction ($\Delta t = -40\%$)

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Contact area (A)	$A_1 = \pi \cdot D_mean \cdot (0.01)$	$A_2 = 0.6 \cdot A_1$	Contact support area decreased by 40%
Local pressure (p = F/A)	$p_1 = F/A_1$	$p_2 \approx 1.67 \cdot p_1$	Pressure concentration increased by 66.7%
Tissue stiffness (k)	$k_1 = k_0 + \alpha \cdot p_1$	$k_2 = k_0 + 1.67\alpha \cdot p_1$	Stiffness term in the numerator increased ($k_2 > k_1$)
Effective mass (m)	$m_1 = \beta \cdot (0.01)$	$m_2 = 0.6 \cdot m_1$	Mass term in the denominator decreased by 40% ($m_2 < m_1$)
Natural frequency (f_0)	$f_{0,1} = (1/2\pi)\sqrt{(k_1/m_1)}$	$f_{0,2} \geq 1.291 \cdot f_{0,1}$	Minimum predicted frequency increase of 29.1%

The comparative relationships presented in Table 3 indicate that rim thinning alters two principal parameters of the adopted vibration model through different mechanical pathways. The first pathway involves an assumed increase in equivalent tissue stiffness resulting from the higher nominal contact pressure generated by the smaller supporting surface. Under the constitutive approximation $k(t) = k_0 + \alpha p$, the modified rim produces $k_2 = k_0 + 1.67\alpha p_1$, whereas the standard configuration retains $k_1 = k_0 + \alpha p_1$. A positive value of \(\alpha\) consequently yields $k_2 > k_1$, indicating that the thinner rim is associated with greater equivalent stiffness within the specified pressure-dependent model. Research concerning lip-tissue deformation provides a biomechanical basis for considering stiffness changes under altered mechanical loading, although the specific pressure-to-stiffness coefficient remains uncalibrated in the present formulation (Nazari et al., 2011). The second pathway concerns the modeled decrease in effective vibrating mass, which acts through the denominator of the natural-frequency equation and remains independent of the assumed stiffness response. Combining these two pathways produces the frequency-ratio expression in Equation (12), which separates the contributions of stiffness amplification and effective mass reduction in accordance with simplified mechanical representations of brass-player lip oscillation (Maugeais & Gilbert, 2023).

$$\frac{f_{0,2}}{f_{0,1}} = \frac{\frac{1}{2\pi}\sqrt{k_2/m_2}}{\frac{1}{2\pi}\sqrt{k_1/m_1}} = \sqrt{\left(\frac{k_2}{k_1}\right)\left(\frac{m_1}{m_2}\right)} \quad (12)$$

The frequency-ratio formulation demonstrates that the predicted effect of rim thinning is governed by the combined proportional changes in equivalent stiffness and effective vibrating mass. Substitution of the modeled mass relationship $m_2 = 0.6m_1$ into Equation (12) produces Equation (13), in which the mass contribution appears as the amplification factor 1.6667. The square-root structure indicates that the frequency response is nonlinear with respect to the combined stiffness-to-mass ratio, even though the individual mass and pressure relationships were formulated using simplified proportional expressions. The resulting frequency ratio remains sensitive to the unknown stiffness ratio k_2/k_1, which prevents determination of a unique predicted frequency increase without further mechanical parameter identification. Parameter-estimation research on brass instrument models demonstrates the significance of identifying admissible mechanical parameters before relating simplified oscillatory equations to observed performance characteristics (Fréour et al., 2022). The comparative expression consequently provides a reproducible analytical relationship while leaving the absolute contribution of pressure-induced stiffness amplification dependent on the assumed constitutive coefficient.

$$\frac{f_{0,2}}{f_{0,1}} = \sqrt{\left(\frac{k_2}{k_1}\right)\left(\frac{m_1}{0.6m_1}\right)} = \sqrt{\left(\frac{k_2}{k_1}\right)1.6667} \quad (13)$$

A conservative estimate of the frequency change was obtained by assigning the stiffness ratio its limiting value of $k_2/k_1 = 1$, representing an unchanged equivalent stiffness between the two mouthpiece configurations. Under this limiting condition, the modeled decrease in effective mass alone generates a frequency ratio of approximately 1.2910, corresponding to a minimum predicted increase of 29.1% relative to the standard-rim configuration. The calculation establishes a lower bound only when the mass-proportionality assumption holds and the stiffness of the modified configuration is not

smaller than that of the standard configuration. If the assumed pressure-dependent stiffness coefficient is strictly positive, the increase in equivalent stiffness would produce a ratio greater than this limiting value, although its exact magnitude cannot be determined without additional parameter values. Established models of brass-player lip oscillation show that effective mechanical parameters can vary with operating conditions, indicating that the present lower bound is conditional rather than universally applicable to human performers (Doc et al., 2023). The numerical value of 29.1% must therefore be understood as a theoretical prediction derived from the specified equations and geometric conditions rather than an experimentally observed improvement in trumpet pitch or upper-register capability. This distinction is consistent with contemporary approaches to physical modeling of brass instruments, which require consideration of model assumptions and parameter constraints when interpreting predicted oscillation characteristics (Fréour et al., 2025).

$$\frac{f_{0,2}}{f_{0,1}} = \sqrt{1 \times 1.6667} = 1.2910 \quad (14)$$

The comparative calculations establish a coherent mathematical sequence in which the prescribed 40% rim-thickness reduction produces a 40% decrease in nominal contact area, a 66.67% increase in nominal contact pressure, and an assumed 40% reduction in effective vibrating mass. Under the additional condition that equivalent stiffness does not decrease, the derived relationships predict a reference natural-frequency increase of at least 29.1%, illustrating the sensitivity of the simplified oscillator to changes in its effective mass and stiffness parameters. The result does not independently demonstrate that trumpet players can achieve higher notes with less physical effort because actual performance depends on aerodynamic excitation, acoustic impedance, embouchure adjustment, and nonlinear interactions between the lips and instrument (Jackson & Scavone, 2024). Biomechanical descriptions of lip vibration also indicate that effective vibrating mass and tissue stiffness may change through muscular and geometric adjustments that are not explicitly represented by a fixed proportionality to rim thickness (Strauss, 2025). The absence of experimentally calibrated stiffness and mass coefficients further prevents the calculation of absolute natural frequencies or the direct assessment of differences in playing efficiency between the two mouthpieces. Controlled experiments incorporating measured lip displacement, contact pressure, and frequency response would therefore be necessary to determine whether the predicted mechanical relationships remain valid under realistic trumpet-playing conditions, potentially using artificial-lip systems capable of maintaining reproducible experimental configurations (Sonoda et al., 2026).

Biomechanical Interpretation and Implications for Trumpet Performance

The mechanical interpretation of mouthpiece rim thinning involves the interaction of contact pressure, equivalent tissue stiffness, and effective vibrating mass within the proposed single-degree-of-freedom vibration model. The analytical comparison in Table 3 indicates that reducing rim thickness from 10 mm to 6 mm decreases the nominal contact area by 40%, producing a corresponding pressure increase of approximately 66.67% under a constant axial pressing force of 10 N. This pressure concentration constitutes the first mechanical pathway through which rim geometry may influence the boundary conditions of vibrating lip tissue. Experimental investigations of trombone performance demonstrate that mouthpiece contact involves spatially distributed forces and pressure variations associated with individual embouchure characteristics (Amann et al., 2026). The calculated pressure increase should consequently be interpreted as a change in nominal mechanical loading rather than a direct representation of the internal stress distribution throughout the orbicularis oris muscle. Measurements of French horn performance indicate that mouthpiece pressing forces vary with pitch and playing conditions, confirming that mechanical loading constitutes a significant component of brass instrument performance (Hirano & Kinoshita, 2026). The relationship between rim geometry and contact pressure provides a physically interpretable starting point for investigating the influence of mouthpiece design, although its biomechanical consequences remain dependent on tissue deformation and individual playing characteristics (Clemente et al., 2019).

The second mechanical pathway involves the pressure-dependent modification of equivalent stiffness, which appears in the numerator of the natural-frequency equation. Under the proposed relationship $k(t) = k_0 + \alpha p$, increased nominal contact pressure produces greater equivalent stiffness

when the pressure-to-stiffness coefficient is positive. Biomechanical modeling of human lips indicates that soft-tissue deformation and muscle activation can modify mechanical stiffness through nonlinear interactions between anatomical structures and applied forces (Nazari et al., 2011). The relationship employed in the present model simplifies these interactions into a linearized pressure-dependent formulation, allowing their potential contribution to natural-frequency changes to be evaluated analytically. Research incorporating the mechanical properties of flesh into lip-vibration models further demonstrates that oscillatory behavior depends on tissue characteristics that cannot be represented solely through geometric variables (Strauss, 2025). The predicted increase in stiffness should consequently be regarded as a conditional response of the proposed mechanical representation rather than an experimentally established change in lip-muscle elasticity.

The third mechanical pathway concerns the reduction in effective vibrating mass, which acts through the denominator of the natural-frequency relationship and contributes independently to the predicted frequency increase. The assumed proportionality $m(t) = \beta t$ produces a 40% decrease in effective mass when rim thickness changes from 10 mm to 6 mm, provided that the mass-conversion coefficient remains constant. Investigations of lip vibration using simplified mechanical representations recognize effective mass as an essential parameter governing oscillatory behavior and the relationship between lip configuration and playing frequency (Doc et al., 2023). A mechanically constrained lip boundary may alter the spatial distribution of tissue displacement, potentially changing the portion of tissue represented by the equivalent vibrating mass in a lumped-parameter model. The mechanical significance of participating tissue mass is supported by investigations suggesting that variations in vibrating lip mass may contribute to register-dependent performance characteristics (Strauss, 2025). Artificial trumpet-player models further demonstrate that simplified representations of lip mechanics can reproduce selected oscillatory characteristics while retaining assumptions concerning the distribution of mass and stiffness (Fréour et al., 2025). The proportional relationship between rim thickness and effective mass remains an unverified modeling hypothesis because actual tissue participation may depend on muscular activation, lip aperture, contact deformation, and the position of the mouthpiece relative to the lips.

The simultaneous modification of equivalent stiffness and effective mass provides the mathematical basis for the natural-frequency increase predicted in the comparative analysis. Equation (12) establishes that the frequency ratio depends on the square root of the product of the stiffness ratio and the inverse mass ratio, allowing both mechanisms to be evaluated through dimensionless relationships. Under the assumed mass reduction of 40% and the limiting condition of unchanged stiffness, Equation (14) yields a minimum modeled frequency increase of approximately 29.1%. Classical vibration theory confirms that an increase in stiffness relative to mass produces a higher undamped natural frequency, although this mathematical relationship does not independently determine the operating frequency of an externally excited system (Rao, 2017). The predicted lower bound is valid only when the assumed mass proportionality holds and the modified configuration does not exhibit lower equivalent stiffness than the standard rim. Research on brass-player lip mechanics indicates that oscillatory parameters may vary across playing conditions, emphasizing the importance of distinguishing theoretical parameter changes from experimentally observed performance responses (Maugeais & Gilbert, 2023).

The biomechanical interpretation becomes more complex when the modeled natural frequency is compared with the actual vibration frequency generated during trumpet performance. Brass instruments produce self-sustained oscillations through interactions among airflow, vibrating lips, and the acoustic impedance of the instrument, making the playing frequency dependent on the coupled system rather than the isolated mechanical characteristics of lip tissue (Kaburagi et al., 2023). Numerical methods developed for self-oscillating systems demonstrate that nonlinear dynamics and excitation conditions can influence oscillation stability and the existence of periodic solutions (Caron et al., 2026). The increase in reference natural frequency predicted by the present model therefore cannot be interpreted as an equivalent increase in the frequency of the musical note produced by the trumpet. Statistical investigations of self-sustained musical instrument models indicate that playability involves operating regimes and oscillation characteristics extending beyond a single mechanical resonance parameter (Pégeot et al., 2024). Acoustic studies of brass instruments further demonstrate that resonance interactions can generate complex playing phenomena, including nonstandard oscillation regimes that depend on instrument geometry and excitation conditions (Mattéoli et al., 2022). The proposed single-

degree-of-freedom formulation consequently characterizes one component of the mechanical system while excluding the complete aerodynamic and acoustic feedback mechanisms required to predict actual register transitions.

The implications for mouthpiece design extend beyond the isolated relationship between rim thickness and lip natural frequency because modifying the mouthpiece may also influence contact comfort, pressure distribution, embouchure stability, and acoustic coupling. Research examining the manufacturing characteristics and internal geometries of trumpet mouthpieces demonstrates that geometric differences can affect acoustic behavior and perceived tonal characteristics (Zicari et al., 2013). Comparisons of modeled and measured brass instrument impedance indicate that mouthpiece geometry contributes to the acoustic characteristics of the complete instrument assembly (Jackson & Scavone, 2024). Further investigations of brass instrument mouthpieces emphasize the importance of acoustic impedance when evaluating the interaction between mouthpiece configuration and instrument response (Jackson & Scavone, 2025). The predicted mechanical benefit of a thinner rim should consequently be assessed alongside potential changes in pressure concentration and performer comfort rather than being treated as an independent indicator of design superiority. Investigations of trumpet playability and intonation also indicate that geometric modifications must be evaluated in relation to both instrument acoustics and performer response (Myers et al., 2025).

Practical evaluation of the proposed model requires controlled investigations capable of distinguishing the effects of rim geometry from variations in blowing pressure, muscular activation, and embouchure configuration. Experimental artificial-lip systems offer a potential platform for reproducing selected mechanical conditions while reducing the variability associated with human performance (Sonoda et al., 2026). Compact artificial buzzing systems developed for trumpet research further illustrate the feasibility of examining lip-like oscillatory behavior using controlled mechanical and acoustic arrangements (Fréour et al., 2024). Measurements of lip displacement, axial pressing force, contact pressure distribution, and vibration frequency would permit the assumed relationships between rim thickness, stiffness, and effective mass to be evaluated against observed responses. Numerical investigations of artificial-lip vibration indicate that blowing pressure constitutes an additional parameter requiring control when examining brass instrument oscillatory behavior (Inomata et al., 2026). Research concerning breathing control and articulation among trumpet players also demonstrates the importance of considering physiological adjustments when interpreting performance-related measurements (Jesus, 2024). Experimental validation should therefore incorporate repeated measurements under standardized conditions and distinguish mechanical natural-frequency characteristics from the acoustically coupled playing frequencies observed during actual trumpet performance.

The principal contribution of the proposed model lies in establishing an explicit mathematical relationship between mouthpiece rim thickness and the equivalent mechanical parameters governing lip natural frequency. The analytical calculations demonstrate that a 40% geometric reduction produces a 40% decrease in nominal contact area and a 66.67% increase in nominal pressure, while the predicted 40% mass reduction and minimum 29.1% frequency increase remain dependent on specified modeling assumptions. The absence of experimentally calibrated stiffness and mass coefficients prevents direct determination of absolute natural frequencies or confirmation that rim thinning improves upper-register performance under realistic playing conditions. Existing investigations of brass-player contact forces provide a basis for designing measurements capable of evaluating the assumed mechanical boundary conditions (Amann et al., 2026). Research on trumpet oscillation and parameter identification also indicates that simplified mechanical representations require careful validation before their predictions can be generalized to physical instruments and human performers (Fréour et al., 2022). Future investigations should examine the sensitivity of the proposed frequency relationship to changes in axial force, rim diameter, tissue stiffness, and effective vibrating mass while evaluating whether the assumed linear relationships adequately represent actual lip behavior. Such validation would establish whether mouthpiece rim thinning constitutes a reproducible mechanical design variable for modifying lip oscillation characteristics or whether its practical influence is dominated by more complex interactions involving tissue deformation, performer adaptation, and instrument acoustics.

CONCLUSION

The theoretical 1-DOF model establishes a conditional mathematical relationship between trumpet mouthpiece rim thickness and the reference natural frequency of vibrating lip tissue. Reducing the rim thickness of a standard 7C mouthpiece from 10 mm to 6 mm decreased the nominal contact support area by 40% under the adopted annular approximation. With axial pressing force maintained at 10 N, this geometric change increased nominal contact pressure by 66.7%. The model represented the pressure response through a linearized stiffness function, predicting higher equivalent stiffness when the pressure-to-stiffness coefficient is positive. It separately assumed that effective vibrating mass is proportional to rim thickness, resulting in a 40% modeled mass reduction for the modified rim. Combining the mass relationship with a nondecreasing stiffness condition produced a minimum predicted natural-frequency ratio of 1.291, equivalent to a 29.1% increase. These numerical results follow from the specified modeling assumptions and do not constitute experimental measurements of lip properties or trumpet pitch.

The proposed formulation identifies contact geometry as a potential design variable that may affect the mechanical boundary conditions of trumpet players' lips. Its principal contribution is the explicit integration of rim contact area, nominal pressure, equivalent stiffness, and effective vibrating mass into a rim-thickness-dependent natural-frequency equation. The predicted frequency increase cannot independently establish that thinner rims improve altissimo-register performance, because actual note production depends on nonlinear aerodynamic excitation, embouchure adjustment, and instrument acoustic impedance. In particular, the proportional mass assumption and linear pressure–stiffness relationship require empirical validation, while the relevant coefficients remain uncalibrated. Future investigations should measure rim–lip pressure distribution, lip displacement, effective oscillating mass, and stiffness under controlled axial forces and comparable playing conditions. Controlled artificial-lip experiments and tests involving trumpet players could assess whether geometric thinning produces the assumed parameter changes and whether those changes correspond to meaningful differences in playing behavior. Until such evidence is available, the 29.1% value should be interpreted as a model-dependent lower bound on reference natural-frequency change, not as a measured improvement in pitch range or playing efficiency.

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