TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 67, Issue Special I, February, 2024

RESEARCH ON IMPROVING THE FUNCTIONAL CHARACTETISTICS OF THE DOUBLE BAS BOW

Balázs DEÉ, Dan LEORDEAN

Abstract: *The aim of this paper is to develop a novel type of double bass bow that allows for precise center of gravity adjustments according to the user's preferences both before and during performances. The article introduces five different design variations aimed at achieving this balance adjustment. Calculations were conducted to determine the forces acting on the bow rod, and all design variants underwent Finite Element Analysis (FEA) testing. These tests looked at eight different materials, including ABS, Nylon, Carbon Fiber, Aluminum Alloy, 2x Steel Alloys, Copper Alloy, and Brass. The study findings point to the 7075-T6 aluminum alloy variant as the most optimal choice due to its favorable weight, elastic properties, and mechanical strength. Two types of weight adjustment elements were devised to enable precise bow weight customization. Considering these comprehensive results, a prototype of the bow was manufactured, demonstrating the innovative method for center of gravity adjustment during performances.*

Key words: *Double bass bow, CAD, FEA, Aluminum 7075-T6*

1. INTRODUCTION

Like in other industries, there is ongoing research and development in the musical instrument industry aimed at enhancing instruments and their accessories. In the realm of stringed instruments, particularly the double bass, there is continuous experimentation in bow shape and design due to the absence of a standardized form. Various types of double bass bows exist, each with its unique variations.

The bow serves as the tool for producing sound from the double bass. To achieve this, resin is applied to the bow's strings, allowing it to adhere to the strings and produce sound.

Double bass resin differs from that used on other stringed instruments as it possesses a softer and stickier texture [1]. This distinction is essential because the double bass strings are notably thicker than those on other stringed instruments, rendering sound production more challenging. Figure 1 provides an illustration of double bass resin [2].

There are two primary types of double bass bows: the French bow and the German bow [2].

2. METHODS

To achieve an optimal shape for the double bass bow, several constructive variants will be developed and the tensile force acting in the bow is calculated.

2.1 Variant 1

For the first variant (figure 1), the groove was placed in the upper part of the arch. The groove is 3.5 mm wide and 3.25 mm high and extends from the end of the bow to the beginning of the bow head. The dimensions of the groove do not change along the length of the string.

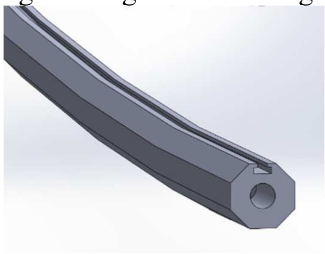

Fig. 1. Variant 1 - hexagonal section with a "T" groove.

2.2 Variant 2

For the second variant (figure 2), the groove was placed on both sides of the bow wand. It runs from the end of the bow to the beginning of the head of the bow. The groove is 3.5 mm wide and 3.25 mm high. The advantage of this variant is that because there is a groove on each side of the profile of the bow, the weight distribution and center of gravity of the bow can be adjusted more precisely.

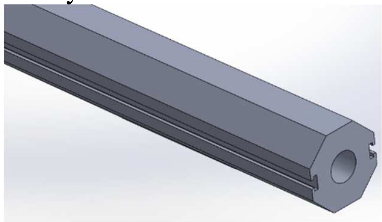

Fig. 2. Variant 2 - hexagonal section with 2 horizontal "T" grooves.

2.3 Variant 3

For the third option (figure 3), a swallowtail groove is proposed at the top of the bow. The groove extends from the end of the bow to the beginning of the head of the bow. The two sides of the groove form an angle of 120 degrees to prevent the balancing elements from falling out of the bow.

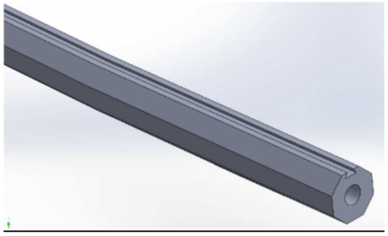

Fig. 3. Version 3 hexagonal section with a dovetail groove.

2.4 Variant 4

In the fourth variant (figure 4), a swallowtail groove is proposed on each side of the wand profile. Both sides of the groove form an angle of 120 degrees. The advantage of this variant is that by having a groove on both sides, the weight of the bow can be adjusted more precisely, and the shape is not complex.

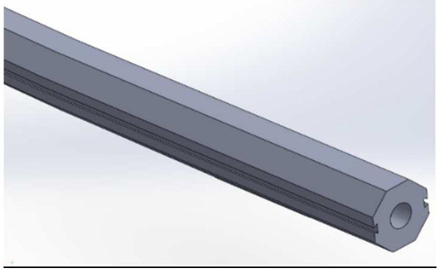

Fig. 4. Variant 4 hexagonal section with 2 horizontal dovetail grooves.

2.5 Variant 5

A swallowtail pattern with a 5-degree angle and a notch at the end of the swallowtail on both sides of the arc has been proposed for this variant (figure 5). The 5 degrees are necessary to keep the balancing elements in the arc. The groove runs from the end of the bow to the head of the bow.

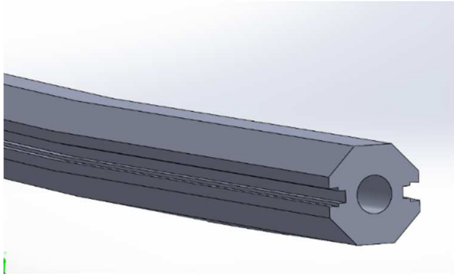

Fig. 5. Variant 5 - hexagonal section with 2 grooves in the form of unique horizontally.

2.6 Calculation of the tensile force

In order to be able to execute the FEA it is necessary to calculate the bending force in the bow [3].

$$d_2 = \sqrt{\frac{F}{\pi \cdot \psi_h \cdot \psi_m \cdot p_a}} \text{[mm]} \quad (1)$$

$$(d)^2 = \frac{F}{\pi \cdot \psi_h \cdot \psi_m \cdot p_a} \text{[mm]} \quad (2)$$

$$F = (d_2)^2 \cdot \pi \cdot \Psi_h \cdot \psi_m \cdot p_a \quad (3)$$

The geometry of the metric thread is shown in the figure below.

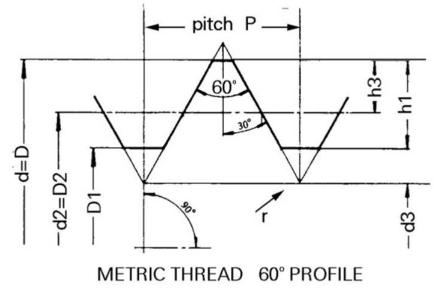

Fig 6. - Metric thread. [4]

Input data

d- outside diameter of the screw; d=4 [mm]
D-outer diameter of the nut; D=4 [mm]
P- thread pitch; P=0,7 [mm]
d2- the diameter of the bolt; d2=3,545 [mm]
D2- average diameter of the nut
D2=d2=d-0.6495-P=3,545 [mm] (4)

d1- inside diameter of the screw

D1- inside diameter of the nut

$$D1=d1=d-1.0825*P=3{,}242[mm] \quad (4)$$

d3- minimum screw thread diameter

$$d3=d-1.2268*P=3{,}141\ [mm] \quad (5)$$

H- profile height

$$H=\frac{\sqrt{3}}{2}\cdot P=0{,}866025404\cdot P \quad (6)$$

R- the radius of the profile connection to the bottom of the screw thread

$$R=H/6=0.144337567*P \quad (7)$$

H1- useful thread height

$$H1=5/8*H=0{,}541265877*P=0.379\ [mm] \quad (8)$$

ac-play at the bottom of the nut thread

$$a_c \approx \frac{H}{16} \quad (9)$$

ψ_h-the coefficient of the coil height

$$\psi_h=\frac{H_1}{P} (10)$$

ψ_m-the coefficient of the thread length of the pulp

$$\psi_m=\frac{m}{d_2}=\frac{P\cdot z}{d_2} (11)$$

m-length of the nut thread

z- number of turns

p_a-tension of admissible

steel $p_a=7\ldots13$

d= 4 [mm]

d2= 3.545 [mm]

d3= 3.141 [mm]

D1= 3.242 [mm]

h3= 0.429[mm]

H1= 0.379[mm]

Coefficient of coil height:

$$\psi_h=\frac{H_1}{P}=\frac{0{,}379}{0{,}7}=0{,}54 \quad (12)$$

Coefficient of nut thread length:

$$\psi_m=\frac{m}{d_2}=\frac{6{,}06}{3{,}545}=1{,}7\ (12)$$

Calculation of the force acting on the double bass bow stick:

$$F=(3{,}545)^2\cdot\pi\cdot0{,}54\cdot1{,}70\cdot1{,}3 \quad (13)$$

cu pa=7 $F=252{,}97\ [N]$

cu pa=13 $F=469.77\ [N]$

$$F=252{,}97\div469{,}77\ [N]$$

$$F=361{,}37\ [N]$$

3. MATERIALS

Several types of materials were used in the analysis to determine the optimal variant. The 3D models of the proposed construction variants were tested with the same types of constraints and loads using SOLIDWORKS software. The following lines present the materials used during the test, describing the material properties. Most of the materials were taken from the SOLIDWORKS material library.

ALUMINIUM 7075-T6 (SN)

Elastic Modular: 7.2e+10 [$N/m2$]

Poisson modulus: 0.33

Mass Density: 2810 kg/m^3

Tensile Strenght: 57000000 [N/m^2]

Yield Strenght: 505000000 [N/m^2]

HMCF FABRIC CARBON

Elastic Modular: 8.5e+10 [N/m^2]

Poisson modulus: 0.49

Mass Density: 1600 kg/m^3

Tensile Strenght: 350.000.000 [N/m^2]

Yield Strenght: 440.000.000 [N/m^2]

ABS filament [5]

Elastic Modular: 2.030.000.000 [N/m^2]

Poisson modulus: 0.4

Mass Density: 1100 kg/m^3

Tensile Strenght: 30.000.000 [N/m^2]

Yield Strenght: 44.000.000 [N/m^2]

NYLON 6/10

Elastic Modular: 8.300.000.000[N/m^2]

Poisson modulus: 0.28

Mass Density: 1400 kg/m^3

Tensile Strenght: 142.559.000 [N/m^2]

Yield Strenght: 139.043.000 [N/m^2]

AISI 1045 STEEL, COLD DRAWN

Elastic Modular: 2.05E+11 [N/m^2]

Poisson modulus: 0.29

Mass Density: 7850 kg/m^3

Tensile Strenght: 625.000.000 [N/m^2]

Yield Strenght: 530.000.000 [N/m^2]

ALLOY STEEL

Elastic Modular: 2.1E+11 [$N/m2$]

Poisson modulus: 0.28

Mass Density: 7700 kg/m^3

Tensile Strength: 123.825.600 [N/m^2]

Yield Strenght: 620.422.000 [N/m^2]

BRASS

Elastic Modular: 1E+11 [N/m^2]

Poisson modulus: 0.33

Mass Density: 8500 kg/m^3

Tensile Strenght: 478413000 [N/m^2]

Yield Strenght: 239689000 [N/m^2]

BERILLYUM COOPER, UNS C17000

Elastic Modular: 1.15E+11 [N/m^2]

Poisson modulus: 0.3

Mass Density: 8260 kg/m^3
Tensile Strenght: 483.000.000 [N/m^2]
Yield Strength: 221.000.000 [N/m^2]

4. RESULTS

Finite Element Analysis (FEA) is the analysis of any simulated physical phenomenon using a numerical technique called Finite Element Method (FEM). FEA analysis was used to reduce the number of physical prototypes, to reduce the number of experiments and to optimize components in the design phase. It saves costs by speeding up the development of a product and improving its quality [6][7][8][9][10].

The virtual bow (figure 7) was modeled with the SolidWork CAD software.

Fig. 7. – 3D model of the bow rod (hexagonal profile).

The following are the steps of the analysis process, which apply to all the construction options. SolidWork Simulation software was used for finite element simulations.

The arch in this test is made of ALUMINIUM 7075-T6, whose weight is 200.37 [g]. Two types of constraints were used, one is "Roller/Sider" and the other is "Fixed Hinge" (figures 8 and 9).

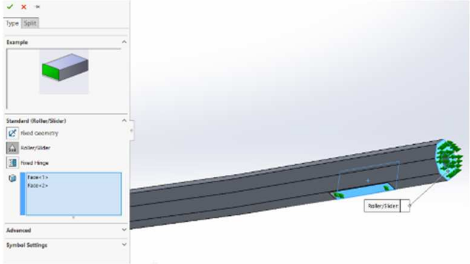

Fig. 8. – Application of constraints - "Roller/Sider" fixing.

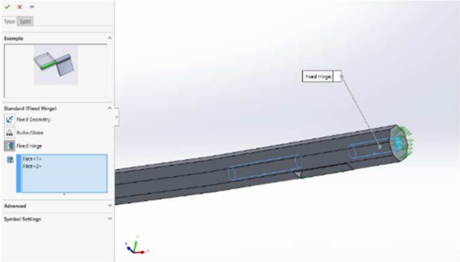

Fig 9. – Applying constraints - "Fixed Hinge" fixing.

The force (figure 10) was placed at the end of the bow to simulate hair stretching, specifically where the hair comes into contact with the bow, which is where the hair is normally fixed.

The force in the bow is the result of the action of the screw-nut mechanism and was calculated based on the axial force calculation relationships in a threaded assembly (13), the resulting force from this calculation being 361.37 [N].

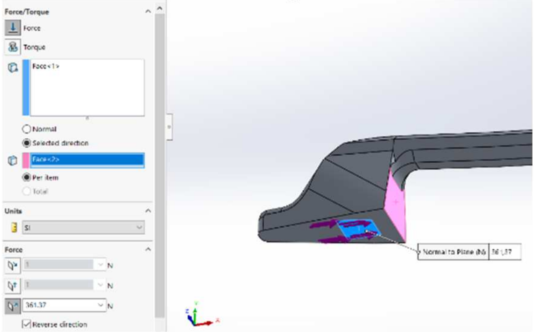

Fig. 10.– Applying force in the pulling direction of the bow hair.

The resulting maximum stress is 136.425 [MPa]. Given that aluminum 7075 has a yield strength of 505 [MPa], it appears that the maximum limit of the material has not been reached (figure 11).

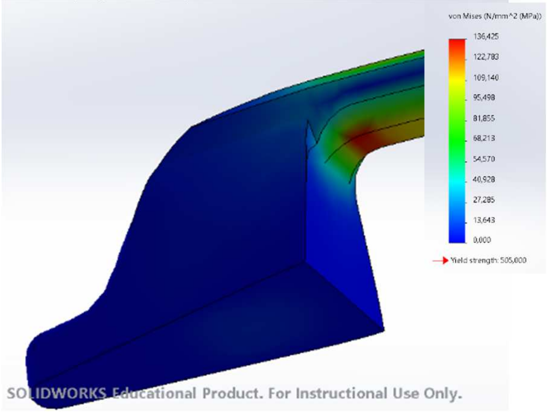

Fig. 11.– Details with the state of von Mises voltages in the most heavily stressed area.

4.1 Simulation results

The results of the finite element analyses are summarized in the tables below. The cells of the tables are marked with 3 colors according to their value, as follows: green color - most favorable situation, yellow color - acceptable situation, and red color - unfavorable situation.

From Table 1 it can be seen that ABS and nylon materials have a favorable weight, but the deformation is unfavorable as it exceeds the accepted 10 mm limit.

FEA tests have shown that the stress exceeds the yield strength of both materials, which makes the design variant unusable.

Table 1

Results of variant 1

Materials used	Weight [g]	Tension max. [MPa]	Deformation [mm]
Al 7075-T6	194.07	140.717	9.13
HCMF Carbon	110.5	140.814	7.716
ABS	75.97	140.51	107.752
Nylon 6/10	96.69	141.027	79.196
AISI 1045 steel	542.16	140.958	3.2006
Alloy Steel	531.8	141.027	3.13
Brass	587.05	140.717	6.573
Beryllium Copper	570.47	140.893	5.716

The materials "AISI 1045 steel, cold drawn", "Alloy Steel", "Brass", "Beryllium Copper, UNS C17000)" are unfavourable because the weight of the resulting spring exceeds 200g. The most favourable material for this variant is Aluminium. Its deformation is acceptable as it does not exceed 10 mm and its maximum stress does not exceed the yield strength of 505 [MPa], its weight is within the prescribed limits as it is less than that of the original profile.

Table 2

Results of variant 2

Materials used	Weight [g]	Tension max. [MPa]	Deformation [mm]
Al 7075-T6	191,55	139,361	8,532
HCMF Carbon	109,07	140,51	7,214
ABS	74,98	139,424	100,704
Nylon 6/10	95,43	139,426	74,009
AISI 1045 steel	535,11	139,403	2,997
Alloy Steel	524,88	139,426	2,925
Brass	579,42	139,361	6,143
Beryllium Copper,	570.47	140.893	5.716

Table 2 shows that ABS and nylon materials have a favorable weight but unfavorable deformation as it exceeds 10 mm. FEA tests have shown that the stress exceeds the yield strength of both materials, making the design variant unusable. The materials "AISI 1045 steel, cold drawn", "Alloy Steel", "Brass", "Beryllium Copper, UNS C17000)" are unfavorable because the weight of the resulting bow is more than 200g. The most favorable material for this variant is Aluminum. Its deformation is acceptable because it does not exceed the deformation of 10 mm, its stress is favorable because it does not exceed the yield strength of 505 [MPa], and its weight is acceptable because it is less than that of the original profile.

Table 3

Results of variant 3

Materials used	Weight [g]	Tension max. [MPa]	Deformation [mm]
Al 7075-T6	193,1	139,363	8,954
HCMF Carbon	111,66	139,74	7,599
ABS	76,76	139,74	106,87
Nylon 6/10	95,43	140,133	77,971
AISI 1045 steel	547,82	140,08	3,157
Alloy Steel	537,35	140,133	3,082
Brass	593,18	139,893	6,472
Beryllium Copper,	576,43	140,08	3,157

The table above (table 3) shows that ABS and nylon materials have a favorable weight, but the deformation is unfavorable as it exceeds 10 mm. FEA tests have shown that the stress exceeds the yield strength of both materials, which makes the design variant unusable.

The materials "AISI 1045 steel, cold drawn", "Alloy Steel", "Brass", "Beryllium Copper, UNS C17000)" are unfavorable because the weight of the resulting bow is more than 200g.

The most favorable material for this variant is Aluminum. Its deformation is acceptable because it does not exceed 10 mm, its stress is favorable because it does not exceed the yield strength of 505 [MPa], and its weight is acceptable because it is less than that of the original profile.

Table 4 indicates that ABS and nylon materials have favorable weights but unfavorable deformation, exceeding 10 mm.

Table 4

Results of variant 4

Materials used	Weight [g]	Tension max. [MPa]	Deformation [mm]
Al 7075-T6	195,48	135,02	8,511
HCMF Carbon	111,3	133,419	7,225
ABS	76,52	134,668	100,454
Nylon 6/10	97,39	135,413	73,83
AISI 1045 steel	546,08	135,329	2,989
Alloy Steel	535,65	135,413	2,918
Brass	591,3	135,02	6,128
Beryllium Copper,	574,6	135,248	5,329

FEA tests have demonstrated that stress levels are more acceptable in nylon, whereas stress exceeds the yield strength in ABS material, rendering them unsuitable for construction. Materials such as "AISI 1045 steel-cold drawn," "Alloy Steel," "Brass," and "Beryllium Copper (UNS C17000)" are unfavorable due to resulting spring weights exceeding 200g.

The most favorable material for this particular variant remains aluminum. Its deformation remains acceptable as it does not exceed 10 mm, stress levels are favorable, not exceeding the yield strength of 505 [MPa], and its weight remains acceptable, falling below that of the original profile.

Table 5

Results of variant 5

Materials used	Weight [g]	Tension max. [MPa]	Deformation [mm]
Al 7075-T6	182,35	137,102	8,56
HCMF Carbon	103,83	134,798	7,245
ABS	71,38	137,195	101,036
Nylon 6/10	90,85	137,327	74,252
AISI 1045 steel	509,41	137,326	3,006
Alloy Steel	499,67	139,094	4,227
Brass	551,59	137,306	6,163
Beryllium Copper,	536,01	137,327	5,359

From Table 5, it can be observed that ABS and nylon materials possess favorable weight characteristics but exhibit unfavorable deformation as it exceeds 10 mm. FEA tests have indicated that stress levels are more acceptable in Nylon; however, the stress surpasses the yield strength in ABS material, rendering them unsuitable for construction. Materials such as "AISI 1045 steel-cold drawn," "Alloy Steel," "Brass," and "Beryllium Copper (UNS C17000)" are deemed unfavorable due to the resulting spring weight exceeding 200g. The most favorable material for this scenario remains Aluminium. Its deformation remains within acceptable limits, not exceeding 10 mm. Moreover, its stress levels are favorable, as they do not surpass the yield strength of 505 [MPa], and its weight is acceptable, falling below that of the original profile.

4.2 Choosing the optimal variant

The aim of this work is to develop a new type of bow for the double bass that allows for balancing by adjusting the center of gravity according to the user's preferences before and during performances.

The analysis of the results in the tables above indicates that the 5th variant is the optimal choice, with Al 7075-T6 as the material that meets all the required conditions. This variant of the double bass bow stick has the lowest weight, at 182.35 g. The stress on this profile is 137.1 MPa, which is favorable as it does not exceed the material's yield strength.

In comparison to the other designed variants, this one exhibits a lower maximum equivalent stress, for example, when compared to variant 1 and variant 3, and it closely matches the stress of the original profile. The deformation is also acceptable, as it is below the required 10 mm.

In conclusion, variant 5 proves to be the optimal choice. While it does have a higher stress level than the original design, its deformation differs only negligibly from the original variant and from the variant with the lowest stress among those analyzed. An important advantage of this variant is its lightweight nature among the variants utilizing aluminum alloy.

5. ASPECTS OF IMPROVING BOW ELEMENTS

5.1 Aspects of balancing the bow

Since the aim of this paper is to develop a new type of bow for the double bass that allows it to be balanced by adjusting the center of gravity before and during performances, this chapter introduces two types of balancing elements (weights) to facilitate center of gravity adjustments in accordance with user preferences. The rationale for bow balancing requirement stems from the fact that each musician and musical genre necessitates distinct weight distributions for the bow. With this solution, musicians no longer need to purchase multiple bows with varying weight distributions, as the weights can be placed in the most suitable position for the their needs and the musical genre.

5.1.1 Variant 1

The dimensions of the balancing variant 1 (figures 12 and 13) have been chosen to fit into the groove in the bow rod. The weight of an aluminium balancing element is 0.4 g.

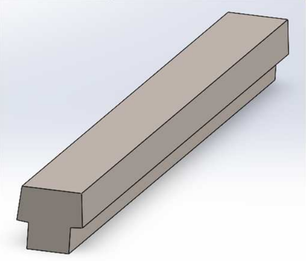

Fig. 12.-Variant 1.

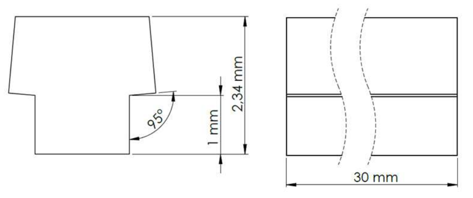

Fig. 13. – Geometry of the balancing variant 1

5.1.2 Variant 2

The dimensions of the balancing variant 2 (figures 14 and 15) are such that the bottom of it fits into the groove and has a small protrusion protruding from the surface of the bow to allow adjustment. The reason for designing this variant is to have a greater weight than that of variant 1 to be placed at a certain point on the bow in order to achieve more accurate balancing. The weight of this balancing element if it were made of aluminum alloy is 1.01 g.

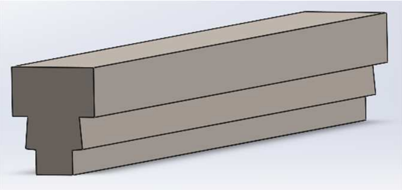

Fig. 14. – Variant 2

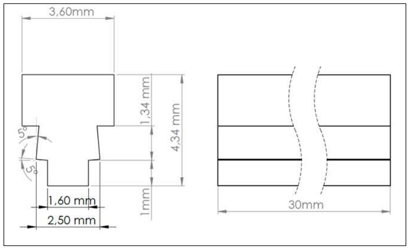

Fig. 15. – Geometry of the balancing variant 2

5.2 Balancing element weights

It was assumed that the balancing elements are made of various materials to allow for several variations in center of gravity adjustment. The table 6 displays the weights of different types of balancing elements constructed from various materials. The third column indicates the weight of each balancing element, while the fourth column denotes the total weight of balancing elements that can be simultaneously inserted into the double bass bow to occupy the two grooves within it. The maximum number of balancing elements that can be accommodated in the double bass bow is 44 pieces.

Table 6

Materials used	Type of balancing element	Weight of an item	Total weight for admissible [g]
Al 7075-T6	Variant 1	0,4	17,6
	Variant 2	1,01	44,44
HCMF Carbon	Variant 1	0,16	7,04
	Variant 2	0,4	17,6
ABS	Variant 1	0,2	8,8
	Variant 2	0,5	22
Nylon 6/10	Variant 1	1,13	49,72
	Variant 2	2,82	124,08
AISI 1045 steel	Variant 1	1,1	48,4
	Variant 2	2,77	121,88
Alloy Steel	Variant 1	1,22	53,68
	Variant 2	3,06	134,64
Brass	Variant 1	1,19	52,36
	Variant 2	2,97	130,68
Beryllium Copper,	Variant 1	0,4	17,6
	Variant 2	1,01	44,44

6. CONCLUSIONS

Stringed instruments have undergone significant changes throughout history. As these instruments have evolved, so have the tools used to play them, including the bow. The content of this paper outlines the history and evolution of these changes. As described in the third chapter, the fifth variant allows for the balancing of the double bass bow by adjusting its center of gravity.

The force acting on the bow stick was calculated, and all construction variants were tested using FEA. These five variants were analyzed using eight types of materials, with aluminum alloy consistently proving to be the optimal choice. This is due to aluminum 7075-T6 having a yield strength of 505 [MPa] and a maximum equivalent stress of only 137.1 [MPa]. The deformation of the spring in the selected variant (5) does not exceed 10 mm and has the lowest weight of all variants in which aluminum 7075-T6 has been used. Two types of balancing elements were developed and manufactured to achieve precise adjustment of the spring's center of gravity. In this context, various materials with different weights were compared.

Considering the above, the goal of the research, which involves balancing the double bass bow by adjusting its center of gravity according to the user's preferences, both before and during performances, thereby reducing weight and increasing reliability, has been successfully achieved.

7. REFERENCES

[1] Farrant, D., *The different darts of a double bass: Anatomy and structure explained*, 2022, https://hellomusictheory.com/learn/ parts-of-the-double-bass/

[2] Cziglényi, A., *Tibay Zoltán (1910-1989) A prágai gordon-iskola hatása munkásságára*, DLA Doktori Értekezés, 2011

[3] Haragâș, S., Pop, D., Buiga, O., *Transmisii cu șuruburi calcul și proiectare*, Todesco, 2013

[4] *ISO Metric Thread Dimensions,* https://international.optimas.com/technical-resources/metric-thread-dimensions/

[5] Toor, R., *Best Heat Resistant Filament Materials for 3D Printing*, 2021, https://www.filamentive.com/heat-resistant-filament-for-3d-printing-guide/

[6] Comșa, DS., *Metoda elementelor finite - curs introductiv*, Cluj-Napoca, 2007

[7] Szabó, B., Babuška, I., *Finite Element Analysis: Method, Verification and Validation*, Wiley & Sons, 2021

[8] Leordean, D., Bâlc, N., *Proiectare industrială. Aplicații PTC Creo-Parametric*, Editura Alma Mater, ISBN 978-606-504-152-3, Cluj-Napoca, 2013

[9] Leordean, D., Vilău, C., Dudescu, MC., *Generation of computational 3D models of human bones based on STL data and CAD software packages*, Applied Sciences, MDPI, Volume 11, Issue 17, 2021

[10] Leordean, D., Ciobanu, T., Rusu, M., *Researches on the design of customized femoral implant*, Modern Technologies in Manufacturing (MTEM 2019), Volume 299, MATEC Web of Conferences, Cluj-Napoca, 2019

CERCETĂRI PRIVIND ÎMBUNĂTĂȚIREA CARACTERISTICILOR FUNCȚIONALE ALE ARCUȘULUI DE CONTRABAS

Rezumat: Scopul lucrării este de a dezvolta un nou tip de arcuș pentru contrabas, care să permită echilibrarea acestuia prin ajustarea centrului de greutate în funcție de preferințele utilizatorului înainte și în timpul interpretării. Articolul prezintă cinci variante constructive care ar putea servi scopului de echilibrare prin reglarea centrului de greutate. De asemenea, a fost calculată forța care acționează asupra tijei arcușului, iar toate variantele constructive au fost testate cu ajutorul FEA. Toate cele cinci propuneri au fost testate luând în considerare opt materiale (ABS, nylon, fibră de carbon, aliaj de aluminiu, două tipuri de aliaje de oțel, aliaj de cupru și alamă). Autorii consideră că varianta din aliaj de aluminiu 7075-T6 este optimă datorită greutății, comportamentului elastic și rezistenței mecanice. Au fost proiectate două tipuri de elemente de reglare a greutății pentru a putea realiza o ajustare precisă arcului. Pe baza rezultateor, a fost realizat un prototip de arcuș cu ajutorul căruia a fost prezentată noua metodă de reglare a centrului de greutate.

Balázs DEÉ, Engineer, Faculty of Industrial Engineering, Robotics and Production Management, TU Cluj-Napoca, Department of Manufacturing Engineering, deebalazs23@gmail.com, Cluj-Napoca, Romania.

Dan LEORDEAN, PhD, Associate Professor, Faculty of Industrial Engineering, Robotics and Production Management, TU of Cluj-Napoca, Department of Manufacturing Engineering, dan.leordean@tcm.utcluj.ro, +40264415653, +40744810091, Cluj-Napoca, Romania.