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ANALYSIS OF THE POSSIBILITY OF INCREASING STING STIFFNESS IN THE T-38 WIND TUNNEL

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Preliminary notes
Wind tunnel model and sting deflections during experiment in the T-38 wind tunnel have a significant influence on the measurement quality. It is necessary to reduce deflections due to higher accuracy of measurements achievement. High quality stainless steel is already widely used in the T-38 wind tunnel so there is no possibility for further influence to sting stress and deflection level. Based on the great number of performed experiments it is established that sting deflection can be reduced by increasing the sting stiffness. In this paper different material combinations with maraging stainless steel, which is base material for sting manufacturing, are considered. It is necessary to select combination of materials which produces the biggest required stiffness and allowed level of stress in critical sections of the sting.

Keywords: *combined sting, composite sting, deflection, stress, wind tunnel*

Analiza mogućnosti povećanja krutosti držača modela u aerotunelu T-38

Prethodno priopćenje
Aerotunelski model i deformacije držača modela tokom eksperimenata u aerotunelu T-38 imaju značajan utjecaj na točnost mjerenja. Radi dobivanja visoke točnosti mjerenja poželjno je da deformacije budu što manje. Mogućnost da se uporabom visokokvalitetnog čelika za izradu držača modela utječe na razinu naprezanja i deformacija je iscrpljena time što se u aerotunelu T-38 koriste visoko kvalitetni maraging čelici. Na osnovu velikog broja provedenih eksperimenata utvrđeno je da je postizanje manjih deformacija moguće povećanjem krutosti držača modela. U ovom radu se razmatraju kombinacije različitih materijala s maraging čelikom koji je osnovni materijal za izradu držača modela. Neophodno je odabrati kombinaciju materijala koja daje najveću zahtijevanu krutost i dopuštenu razinu naprezanja u kritičnim presjecima držača modela.

Ključne riječi: *aerotunel, deformacije, kombinirani držač, kompozitni držač, naprezanje*

1 Introduction

High stiffness of sting is necessary for model testing at high Mach numbers and high angles of attack in the blowdown T-38 wind tunnel [1]. Maximum Mach number in the T-38 wind tunnel test section is 4 and maximum model angle of attack is 19°. Large transient loads during starting and stopping wind tunnel runs on high Mach numbers is common characteristic of blowdown wind tunnels [2 ÷ 5]. All experimental equipment for the measurements in such wind tunnels has to be designed for huge transient loads.

In the wind tunnel test section model is supported by sting which is cantilevered forward from a support sector into the oncoming airflow, Fig. 1.

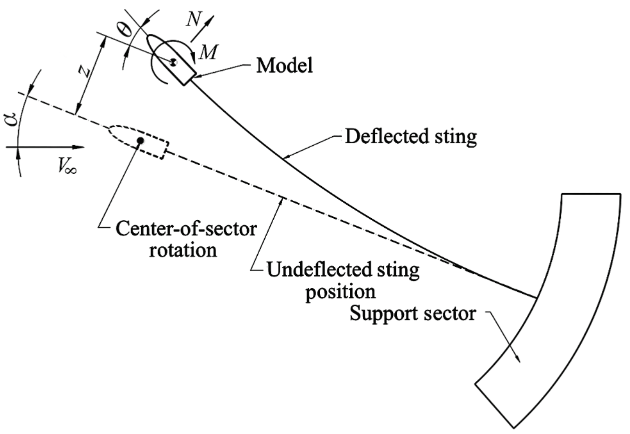

Figure 1 Sting deflections

Sting deflection is caused by bending moments due to aerodynamic force and moments and it is inversely proportional to product of the sting material modulus of elasticity E, and sting cross section area moment of inertia I, otherwise stiffness EI. Sting deflection is shown in Fig. 1 where: V_∞ is free-stream velocity, α is pitch angle of sting, Z is sting deflection, θ is rotational deflection of sting, N is aerodynamic normal force and M is aerodynamic pitching moment.

Size of the wind tunnel model and other necessary components for experiments are limited by testing conditions in the wind tunnel test section. A sting size is defined by the size and geometry of the wind tunnel model rear part and aerodynamic requirements. A sting diameter has to be twice smaller than wind tunnel model base diameter, length of sting straight part has to be five times wind tunnel model base diameter. These conditions are important for minimizing influence of sting on aerodynamic flow field around rear part of the model. As sting dimensions are limited by mentioned conditions, one possibility for reducing sting deflection and slope during wind tunnel experiment is to increase sting stiffness. Sting stiffness can be increased by selection material with high modulus of elasticity.

Base material of most stings which are in use in the T-38 wind tunnel is high quality stainless steel Armco13-8Mo with modulus of elasticity 195 GPa [6]. The main goal of this research is to show how the combination of stainless steel Armco13-8Mo with other materials with high modulus of elasticity can increase sting stiffness. Characteristics of the materials which can be used for sting manufacture are given in Tab. 1.

The selection of material for sting manufacture depends on several factors:

- Sting geometry.

- Maximum values of aerodynamic forces and moments which are generated on a model during wind tunnel test runs.
- Sting allowable deflection and slope.

Table 1 Characteristics of the materials of sting

Material	Module of elasticity E / GPa	Tensile strength R_m / MPa	Density ρ / kg/m^3
Titanium alloy	110	1200	4700
Nickel super alloy	200	1230	8200
Steel alloy	187 ÷ 210	1460	7850
Armco13-8Mo	195	1482	7760
Tungsten	410	1550	19400

Sting geometry and connection with internal wind tunnel balance require high precision during manufacture (grinding, drilling in assembly, thread production, etc.). Using materials with high values of modulus of elasticity for sting manufacture mostly causes high hardness of these materials, which makes it difficult for machining.

To overcome these technological problems and to use mechanical characteristics of the selected materials, it was selected that the sting has to be manufactured by combination of several different materials and that type of sting is called composite or combined.

2 Sting with increased stiffness

2.1 Sting produced by maraging stainless steel

For the manufacturing of all main parts built in the T-38 wind tunnel high quality maraging stainless steel Armco13-8Mo is adopted. Manufacture process which is used for stainless steel Armco13-8Mo makes it ideal for using in applications where tensile strength and corrosion resistance, which is a consequence of stress, are required. Scopes of applications of high quality stainless steel Armco13-8Mo are aeronautics, nuclear power plants, aircraft landing gears, high performance driving shafts and petrochemical industry where high tensile strength and corrosion resistance, which is a consequence of stress, are required.

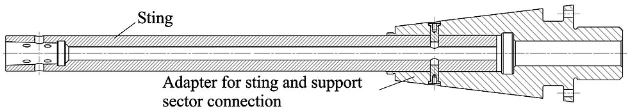

Figure 2 43 mm diameter sting

One possibility for increasing sting stiffness is to embed core with high modulus of elasticity inside of sting and provide a new sting with higher stiffness without losing toughness.

Starting geometry for analysis and application proposed combined sting solution was existing stainless steel Armco 13-8Mo sting Fig. 2.

2.2 Carbide metal core sting

Sting cylindrical part was manufactured as separate part of the sting so it was suitable for building carbide metal core with high modulus of elasticity inside the existing sting Fig. 3.

Alloy 90WC-10Co [7] wide wall tube, Fig. 4, which is built inside the existing sting Fig. 4, was obtained by the method of powder metallurgy, cold isostatic pressing of elemental powders of tungsten carbide and cobalt.

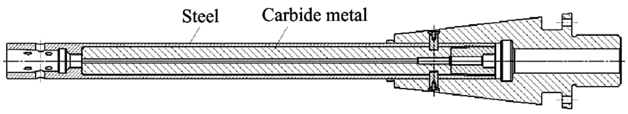

Figure 3 Combined sting

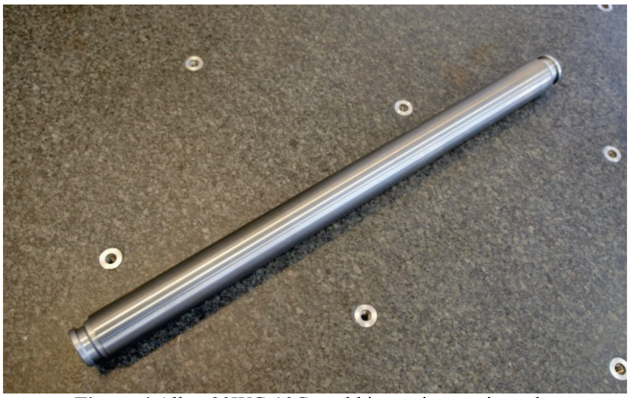

Figure 4 Alloy 90WC-10Co cold isostatic pressing tube

The chemical composition of cold isostatic pressing tube was examined by X-ray fluorescence spectrometry method and Vickers hardness method. Results of chemical analysis are given in Tab. 2 and mechanical characteristics are given in Tab. 3

Table 2 The chemical composition of cold isostatic pressing tube

Chemical composition 90WC-10Co / mas. %				
Co	Fe	Cr	Nb	Ta
10,2	0,2	0,1	≤0,01	0,5

Table 3 Mechanical characteristic of alloy 90WC-10Co

Hardness HRC	Density ρ / kg/m^3	Compressive strength R_{mc} / MPa	Module of elasticity E / GPa
76	14500	2080	5,52

2.3 Sting with covering made of composite fibre

Another possibility for increasing sting stiffness is usage of covering made of composite fibre [8]. Characteristics of the high modular unidirectional carbon fibre M40J which is used in manufacture of composite sting are given in Tab. 4.

Table 4 Characteristics of the high modular unidirectional carbon fibre M40J

Fibre type	Tensile strength R_m / MPa	Module of elasticity E / GPa	Elongation ε / %	Density ρ / kg/m^3
M40J	4410	377	1.2	1770

However, beside these characteristics of high modular unidirectional carbon fibre given in Tab. 4, their total mechanical characteristics are also influenced by resin which is used as binder. Depending on percentage of resin, different values for tensile strength and modulus of elasticity of composite can be achieved. For the determination of the basic mechanical characteristics of unidirectional composite with minimum percentage of resin, a sample with 20 % resin was made. Based on the results obtained in testing of sample of unidirectional composite M40J (tensile strength equal to 1740 MPa and module of elasticity equal to 250 GPa) design and calculation of sting with cladding made of composite fibre started.

The composite sting is manufactured from unidirectional composite with minimum 20 % resin. Starting geometry for analysis and application of proposed composite sting solution was existing stainless steel Armco 13-8Mo sting of diameter 43 mm, Fig. 1.

Stiffness of all assembly is increased by covering of cylindrical part of the sting made of composite fibre as shown in Fig. 5.

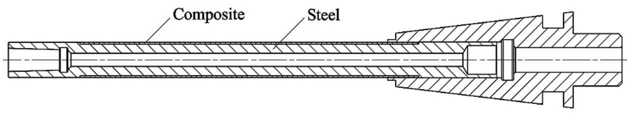

Figure 5 43 mm diameter composite sting

Thickness of the composite fibre cover is 2 mm over the sting diameter. Unidirectional fibres are placed in layers in the direction of the sting longitudinal axis; the last layer is inclined at 45° to the longitudinal axis of the sting. After covering with composite fibres, the sting was heat treated in an autoclave at temperature of 70 °C. The composite sting is finished off by machine processing on a lathe to achieve the required tolerances and sting surface quality, Fig. 6.

Figure 6 Composite sting

3 Structural analysis of the sting with increased stiffness

Contribution of the carbide metal core and covering made from composite fibre to the sting stiffness is determined by comparisons of elastic characteristics of the composite and combined stings with existing stainless steel sting.

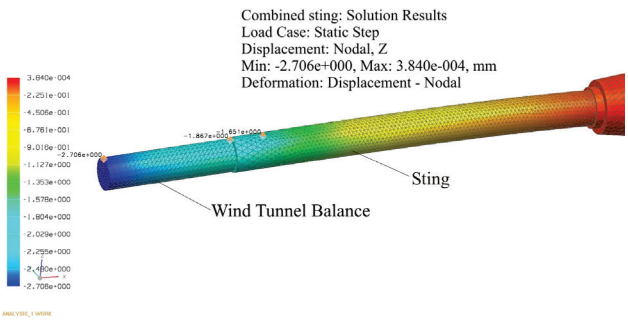

Figure 7 Simulation of the combined sting deflection and slope

Finite element simulation of load was performed using software package NASTRAN NX for these comparisons [9, 10]. In wind tunnel experiment aerodynamic load is measured with six-component wind tunnel balance located internal to the model. The model is attached to the balance, and the balance is attached to the end of the sting. Both the sting and the balance are deflected under aerodynamic and inertial loads. In the simulation of load, deflection and slope were calculated for maximum stationary load F = 2206 N. Deflection and slope were calculated at the sting cross-section where the wind tunnel balance is joined to the sting. Results of the simulation are shown in Figs. 7 and 8, and Tab. 5.

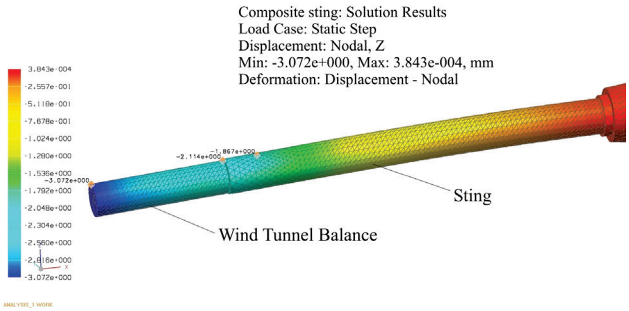

Figure 8 Simulation of the composite sting deflection and slope

Table 5 The stings deflection and slope

Maximum load F = 2206 N	Combine sting	Composite sting	Stainless steel sting
Sting deflection / mm	1,65	1,867	2,258
Sting slope / °	0,29	0,334	0,41

Analysis of data from Tab. 5 shows that carbide metal core sting has the smallest deflection and slope in comparison to stainless steel sting and composite sting.

4 Experimental verification

Experimental verification was performed in laboratory conditions in the calibration room of the T-38 wind tunnel. Laboratory measurements included measurement of deflections and slopes for all three stings. Measurements were performed with standard procedure which has to be done before testing in the wind tunnel test section [11]. The_stings were mounted on calibration rig, loads were applied and deflections and slopes were measured in referent point.

Figure 9 Sting deflection and slope measurement

4.1 High stiffness sting laboratory measurement

Set up for the high stiffness sting deflection and slope measurements is shown in Fig. 9. Slope was measured with precise optical level Carl Zeiss and deflection was measured with comparator. Load was applied by dead weights on pan which was connected to calibration ring. Deflection was measured at the sting cross-section where the wind tunnel balance was jointed to the sting. Slope was measured at the wind tunnel balance body. Measurement covered three sting configurations: stainless steel, carbide metal core sting and composite sting.

Results obtained in the measurements with the stainless steel sting are shown in Tab. 6. Results obtained in the measurements with the carbide metal core sting and composite sting are shown in Tab. 7 and Tab 8.

Table 6 Stainless steel sting deflection and slope

Dead weight / kg	Force daN	Stainless steel sting			
		Sting deflection / mm		Sting slope / °	
		Load	Unload	Load	Unload
0	0	0,00	0,00	0,000	0,010
45	44,127	0,57	0,60	0,108	0,116
90	88,254	1,15	1,20	0,225	0,225
135	132,381	1,74	1,78	0,300	0,310
280	176,508	2,33	2,36	0,400	0,400
225	220,635	2,91	2,91	0,500	0,500

Table 7 Carbide metal core sting deflection and slope

Dead weight / kg	Force / daN	Carbide metal core sting			
		Sting deflection / mm		Sting slope / °	
		Load	Unload	Load	Unload
0	0	0,00	0,00	0,000	0,010
45	44,127	0,52	0,56	0,080	0,090
90	88,254	0,98	1,02	0,158	0,158
135	132,381	1,38	1,43	0,225	0,225
280	176,508	1,78	1,80	0,280	0,280
225	220,635	2,18	2,18	0,350	0,350

Table 8 Composite sting deflection and slope

Dead weight / kg	Force / daN	Composite sting			
		Sting deflection / mm		Sting slope / °	
		Load	Unload	Load	Unload
0	0	0,00	0,05	0,00	0,000
45	44,127	0,68	0,75	0,10	0,108
90	88,254	1,28	1,36	0,20	0,200
135	132,381	1,89	1,96	0,30	0,300
280	176,508	2,51	2,55	0,39	0,390
225	220,635	3,13	3,13	0,49	0,490

Results obtained in these measurements show that carbide metal core sting has the smallest deflection and slope.

5 Conclusion

Based on the results obtained through these investigations of three sting configurations, the following conclusions can be defined:

- Based material for sting has to be high quality maraging steel Armco 13-8Mo in spite of other selected material for combined sting.
- From materials considered at the beginning of this paper, research was performed with available material which gave promising results at starting research phases.
- Result achieved at the end of research showed that the most convenient solution would be the sting with combination of maraging steel Armco 13-8Mo and wide wall carbide metal tube alloy 90WC-10Co inserted.
- Combination of maraging steel Armco 13-8Mo and carbide metal alloy 90WC-10Co showed the best characteristics and smallest deflection and slope for given external load.
- For a testing of the wind tunnel models at high Mach numbers and high angles of attack combined sting composed from maraging steel Armco 13-8Mo and carbide metal alloy 90WC-10Co has to be used.

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