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DESIGN OF A SPECIAL TWIN STING SUPPORT SYSTEM FOR FORCE MEASUREMENTS ON A LAUNCH VEHICLE MODEL

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ABSTRACT

Conventionally, launch vehicle models are mounted on sting support systems for overall force / moment measurements in the 1.2m Trisonic wind tunnel of National Trisonic Aerodynamic Facilities (N.T.A.F.), National Aerospace Laboratories (CSIR-NAL), Bengaluru. However, this concept of mounting has always resulted in distorted base of the core and modification/removal of the core nozzle(s). A design concept was required to test the configuration without distorting the vehicle core and to simulate the core nozzles fully, as CFD predictions showed a substantial change in loads in the presence of core and nozzles. The design incorporates a special twin sting support system with an unconventional model assembly, which permits full simulation of the core nozzle. The balance is mounted in the core vehicle and attached to the twin stings through an adaptor .The design features of the special support system and the novel approach in the integration of model to support system is described in this paper.

Key Words: Twin sting support system, FEA, Geometric and dimensional tolerance, support rigidity

NOMENCLATURE

$\sigma_{max.}$	Maximum stress
FEA	Finite Element Analysis
FS	Factor of safety
θ	Angle of model on support, degrees
D	Divergence parameter

1.0 INTRODUCTION

One of the models for force measurements in the 1.2m wind tunnel features a core vehicle with two strap-on rockets is shown in Figure 1. In this configuration, the base of the strap-on boosters extends beyond the base of the core vehicle. Hence, the use of a conventional sting mounted balance in the core vehicle increases the influence of the sting on the flow field around the strap-on boosters, especially in the yaw-plane of the model. Also, in order to accommodate the central sting, most of the components in the base of the core vehicle will have to be modified or removed, resulting in improper geometric scale down of the model for wind tunnel tests. Attempts have been reported in the literature on twin sting support systems, mainly for testing of empennage of civil transport aircraft (Ref. 1). Some efforts are also reported on use of twin-balances mounted on twin strap-on boosters to measure the overall loads on a model featuring a core vehicle with two strap-on boosters. Use of two independent balances within a model can lead to complications in the load path since the system becomes statically indeterminate; the ratio of loads transferred between the two balances may not algebraically lead to the overall loads within the desirable accuracies from force measurements. Also, the calibration of balances becomes complicated. Therefore, in the present effort, a single balance mounted in the core is used to measure overall aerodynamic loads; the twin sting system is designed to accommodate an adaptor which holds the core balance taper in such a way the complete model is metric. Details of the support system design are presented in this paper.

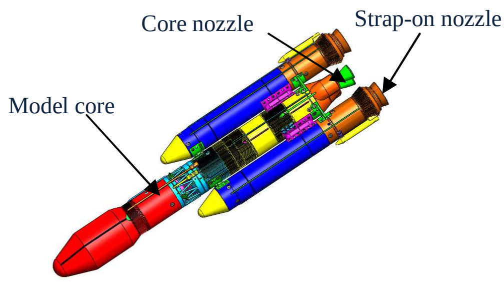

Figure 1. Model with core and strap-on nozzles

2.0 THE TWIN STING SUPPORT SYSTEM

2.1 The Concept for Measurements

The CAD view of the launch vehicle model on a special Twin sting support system is shown in Figure 2 where it is supported along the strap-on boosters for a support free base of the core with the core nozzles being fully simulated for measurement of aerodynamic loads on the launch vehicle model. The support is designed with the concept of two sting arms within the strap-on of the launch vehicle model with gap all around sting and booster. It is important that the loads of the model be completely transferred to the single balance that is housed in the core of the vehicle .The model support scheme has to ensure that no grounding takes place between strap-ons and twin stings where the complete model loads are transferred to the two arms of sting through connectors on either side of it. The design of support was governed by strength requirement for the breakdown loads during starting stopping of the tunnel which is typical in blow-down type wind tunnels at high supersonic mach numbers and the rigidity requirements during measurements to avoid model grounding to sting. A number of iterations in length and diameter of sting were carried out using FEA to achieve the design requirement.

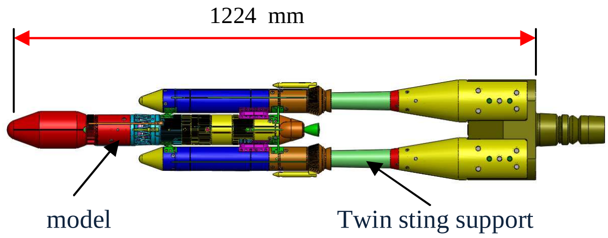

Figure 2. View of model on the twin sting support

2.2 Critical Gap Requirements of Model and The Twin Sting Support

The concept of using twin stings to support the balance meant that 'connectors' were required to link the balance adaptor and sting arms. These connectors had to be optimised as they are in the flow region between core and strap-on's where the deviations had to be minimum for aerodynamic reasons and yet it had to be designed for strength and rigidity. The gap provided around the 'connectors' is 1.5mm and strap-on to the stings has a minimum gap of 2mm with an annular gap of 4mm. The critical gaps between model and support are shown in Figure 3.

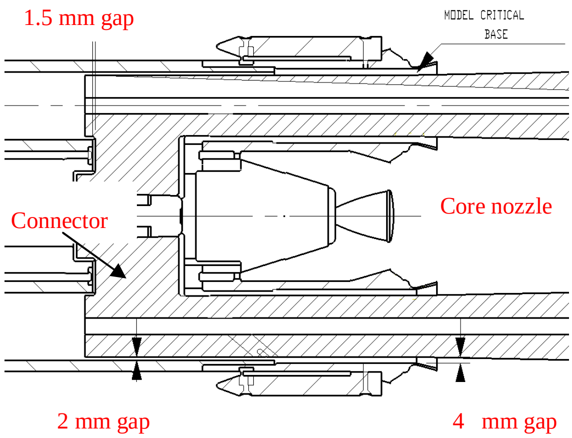

Figure 3. Critical gaps between model and support

2.3 The Support System Features

The upstream sting is made up of MDN-250 maraging steel; it consists of hollow taper balance adapter which houses the Ø1.5" NAL balance. The complete loads of the model via the measuring balance are transferred to the socket of the adaptor and this taper should have a minimum of 95% contact which could be ensured by blue matching .The connectors on either side of the adaptor are rectangular with leading edge radius and is a critically designed for the combined loads as it transfers the large bending and turning moment to the sting arms. The arms are cylindrical which tapers outside the model base for rigidity. The upstream sting has to be made integral with no joints between the balance adaptor, connectors, and sting arms as it is not feasible to provide fasteners in this region. This design also leads to alternate approaches in detailing and process planning for manufacture of the upstream sting for assembly to the downstream support. The stings are mounted in socket of downstream sting. The assembly has to ensure there is no pre-loading of sting arms due to unavoidable deviations during manufacture. Hence, special insitu instructions have been provided on GD&T .The downstream sting, made of Maraging steel is an intermediate structural member between upstream and support. It has a cylindrical socket and a fork at the other end with grooves for balance cables / pressure port cables routing.

The sting also features a mounting block with provision for roll checks, sting flares for aerodynamic flow over the support. A 3D view of the support sting assembly is shown in Figure 4.

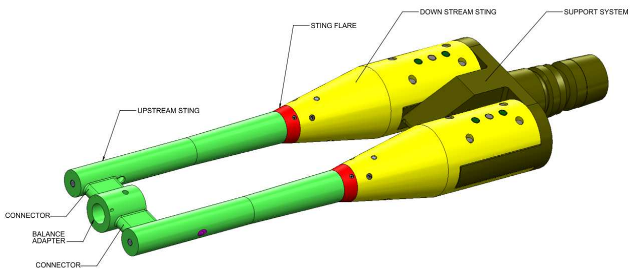

Figure 4. CAD View of the Twin sting support

The maximum shear stress theory is used for stress analysis. A factor of safety (FS) of 2.0 is considered for tunnel start-stop loads based on the yield strength of the material while an FS of 3.0 is considered for maximum steady loads. The sting arms are designed to be manufactured from MDN 250 high strength alloy steel that has guaranteed tensile stress of at least $\sigma_{yield.}$ =170kgf/mm^2 .The material has to be tested to detect any micro defects that could lead to crack propagation especially under dynamic loading conditions. Also, deflection of model –balance-support is limited well within 3° and static divergence checks are carried out as any occurrence would result in catastrophic failure of wind tunnel models supported on stings.

The stress analysis was done using Finite Element Analysis (FEA).CAE based solutions HYPERMESH and OPTISTRUT were utilised. The meshing consisted of 6, 62,438 nodes and 17, 65,624 tetrahedron elements with a Jacobian of 1.00 that had no failed element.

The stress contours on the twin sting are shown in Figures 5 a & b.

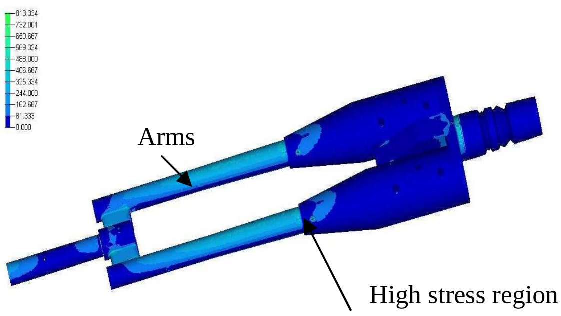

Figure 5 a. The stress contours plot of the sting

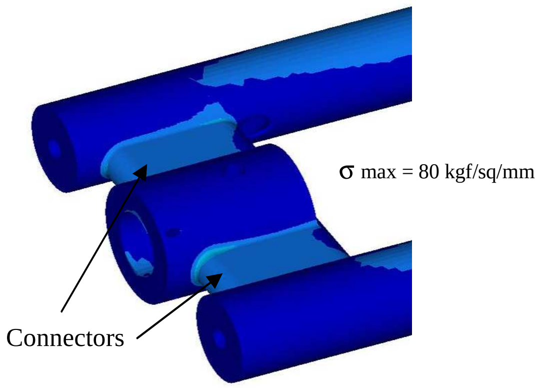

Figure 5b.

The model support deflection was 0.7° which is well within the stipulated value. The gap between the model base and the sting is usually predicted with standard formulation In this case, as it is not a conventional sting the displacement of the support required FEA based solutions where the connectors were also modeled for analysis. The torsion deformation that connectors undergo due to large bending moments from the model is considered for deflection and gap calculations. The displacement of the upstream sting is shown in Figure 6.

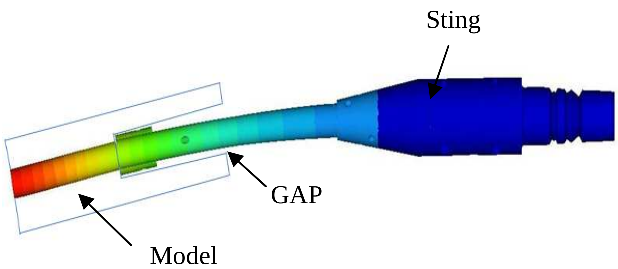

Figure 6. The displacement of the sting

3.0 THE LAUNCH VEHICLE MODEL

The launch vehicle model for measurements as seen in Figure 1 is simulated with all its protrusions as in the configuration where the inter-tank skirting has an open air ratio of more than 95%. The design of novel support system also leads to an unconventional design and assembly of the model, especially where the strap-on is assembled to the core by attachments. These attachment brackets are designed to be fixed after the support is integrated to ensure proper load transfer and concentricity of strap-on over the twin sting arms. The model assembly sequence is also unconventional as it is assembled with the support and integrated to ensure the required gaps between model and support.

4.0 THE INTEGRATION OF MODEL AND SUPPORT

The upstream sub-assembly of the model is mounted on the NAL 1.5" Ø balance and then the strap-on links are fixed to ensure proper load transfer from the joint and uniform concentricity to sting. The detailing to realise the accuracies are incorporated in the drawings. Also, inspection criteria are specified as the stringent gaps requirements would be achieved from different subassemblies. The accuracies that are built in the 1224 mm assembly of model and support are to ensure the control of 1.5 mm gap on length and 2 mm, 4 mm annular gaps after integration. The critical gaps that are required have been shown in Figure 3.

5.0 CONCLUSION

The design of this model and support system particularly highlights the achievement of novel concept for core free base for force/moment measurements for a twin booster launch vehicle model.

It incorporates precision engineering based design that is backed up with stringent geometric and dimensional tolerances (GD&T). The design ensures a 1224 mm model, support assembly results in a minimum of 1.5 mm uniform gap for accurate force/moment measurements.

Finite element analysis (FEA) was extensively used for stress and deflection analysis of the model and support especially at highly stressed corners and for torsion, flexural deflections.

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