Engineering Notes

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Gun Tunnel Free-Flight Model Test Calculation

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Introduction

THE free-flight testing system[1-3] developed for a gun tunnel[4] allows 6-component measurements without the influence of a sting and without interferences between the aerodynamic forces and moments. The technique is shown schematically in Fig. 1. Before the test the model must be fixed to a magnetic adapter. On starting tunnel operation the magnetic linkage between the model and its adapter is solved (model dropping-technique). During the short time interval needed to establish the flow in the test section a long-pull magnet retracts the adapter out of the flow region.

The acceleration impacted to the model by the aerodynamic forces amounts during the testing time (approximately 30 to 40 msec) to values of 30 to 50 times that of gravity. Thus the trajectory of the model depends mainly on its aerodynamic properties. The registration system of this free-flight trajectory is based on a pulsating light source inside the free-flying model—energy transfer is done wireless by the aid of radio frequency—and on a light sensitive film fixed to the cylindrical inner wall of the test section of the tunnel. The light-pulse repetition frequency is kept constant. The light of the flash lamp is split between three beams making angles of 120° with each other by an optical system consisting of three apertures and three lenses to focus the light on to the film. In this way three points on the film originate synchronously from every single light pulse, and during the model flight in the test section three traces of points are produced on the film (see Fig. 2). More details of the basic technique are given in Refs. 1-3. The film used is AVIPHOT PAN 30, polyester base, 126 mm × 30 m, 21 DIN from Agfa Gevaert.

Position and Attitude of the Model

From the film coordinates x_{f_i} and y_{f_i} $(i=1,2,3)$ of the unrolled film (see Fig. 2) one gets the coordinates x_i, y_i, and z_i of the registrated light points in a geodesic system of axes the origin of which is related to the test section. Considering a set of three points, a plan surface is spanned (see Fig. 3) because of the geometrical arrangement of the optical system inside the model, which is performed in such a way that the direction of the light beam (which creates point P_1) falls in the direction of the axes z_b of a fixed model coordinate system. One gets the distances A_1, A_2 and A_3 using the known distances between the points P_1 P_2 and P_3 (from their coordinates in the geodesic systems of axes) and the cosine equations.

To get the coordinates of the point M, where the light beams originate, one compares the coordinates of the points P_1, P_2, and P_3 in a fixed model coordinate system with those in a geodesic system of axis using a transformation matrix.[5] Both coordinate systems have the same origin, the light source.

The coordinates of the new geodesic system of axes are:

$$x_{g_i}=x_i-x_M \quad y_{g_i}=y_i-y_M \quad z_{g_i}=z_i-z_M \tag{1}$$

We then have coordinates of the same light points in the fixed model coordinate system because of the previously mentioned geometrical arrangement inside the model (see Fig. 3)

$$x_{b_1}=0 \qquad x_{b_2}=0 \qquad x_{b_3}=0$$

$$y_{b_1}=0 \qquad y_{b_2}=A_2\cos 30° \qquad y_{b_3}=-A_3\cos 30°$$

$$z_{b_1}=A_1 \qquad z_{b_2}=-A_2\sin 30 \qquad z_{b_3}=-A_3\sin 30°$$

Using the transformation matrix of Ref. 5 results in expressions for the coordinates in the geodesic system of axes as functions of the coordinates in the fixed model coordinate system and the Euler angles. With these and the known coordinates, the coordinates of the point M in the geodesic system of axes (the origin of which is related to the test section) may be calculated. The position of the model is given by

$$x_M=\frac{x_1/A_1+x_2/A_2+x_3/A_3}{1/A_1+1/A_2+1/A_3}$$

$$y_M=\frac{y_1/A_1+y_2/A_2+y_3/A_3}{1/A_1+1/A_2+1/A_3}$$

$$z_M=\frac{z_1/A_1+z_2/A_2+z_3/A_3}{1/A_1+1/A_2+1/A_3} \tag{3}$$

To obtain the attitude of the model (yaw angle ψ, pitching angle θ, and angle of roll Φ) the same equations are used. In a similar way, comparing the coordinates of the points P_i in a fixed model coordinate system with the coordinates in an aerodynamic coordinate system the angle-of-attack α and the angle of sideslip β may be obtained. This calculation is only needed for the x_a-coordinates, which in the aerodynamic coordinate system are identical with those in the geodesic coordinate system.

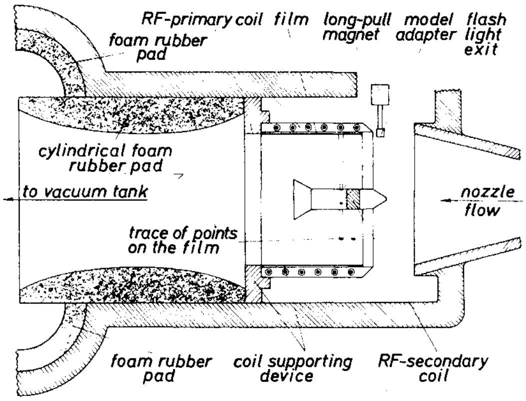

Fig. 1 Gun tunnel equipment for free-flight testing.

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Index categories: Aircraft Testing (Including Component Wind Tunnel Testing); Supersonic and Hypersonic Flow.

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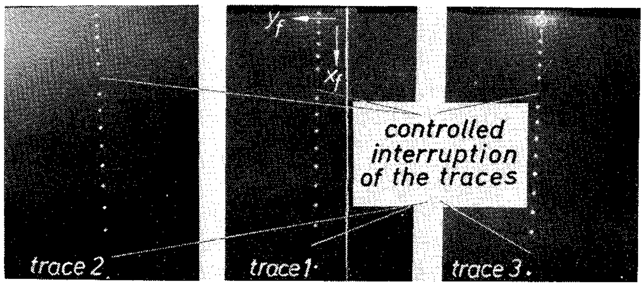

Fig. 2. Parts of the unrolled film with the three traces of points.

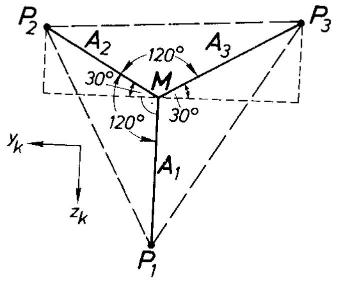

Fig. 3 Plan surface spanned in space by three belonging points.

Aerodynamic Forces and Moments

Positions and attitudes and the fixed time interval are known. The velocity of the model is obtained from the coordinates of two locations, and from three locations the three components of the acceleration may be calculated. Knowing the mass of the model, aerodynamic forces may then be calculated. The moments are calculated in standard fashion using the moments of inertia of the model.

Another approach to obtain the acceleration of the model is to compute the function of time-dependent model-location, for example by a Guass-Approximation, and then take the second derivative. This method may lead to a better accuracy to avoid statistical computing and reading errors.

The acceleration expressed by the different model locations is

$$a = \frac{(s_3 - s_2) - (s_2 - s_1)}{\Delta t^2} \tag{4}$$

Newton's equation for the differences in model location

$$s_3 - 2s_2 + s_1 = \frac{F}{m} \Delta t^2 \tag{5}$$

These differences have to be large compared with the reading error of the coordinates of the light points on the film. For example, for an accuracy of $\pm$ 0.05 mm and a largest permissible error of $\pm 1\%$ the differences have to be $s_3 - 2s_2 + s_1 = 20$ mm. Thus from the previous formula we have the postulation: aerodynamic forces F: to be large; model mass-- m: to be low; time interval Δt: to be large. The last demand contradicts the requirement for redundancy.

Aerodynamic forces for a specific model and specific flow conditions are fixed to the same order of magnitude. The only way to get sufficiently large differences is to lower the model mass which sometimes is not possible. To overcome this problem, the Gauss-Approximation may be applied. In this case the time interval Δt is comparable to the half of the registrated testing time; that means, s_1 is the coordinate of the first registrated point, s_3 is the coordinate of the last point or the preceding one, depending on whether there is a straight number of registrated points or not, s_2 is the point between s_1 and s_3.

To get optimal test results the time required for the model in passing through the registrating section should be equal to the time of fully established flow in this section. The length of this registrating test section is fixed by the dimension of the films and there exists a clear relationship between this length, the testing time and the acceleration:

$$s = \int\int a \, dt^2 = \int\int \frac{F}{m} dt^2 = \frac{F}{m} t^2 \tag{6}$$

(assuming that during one test the aerodynamic forces are almost constant).

For this case the highest accuracy ever possible (related to reading errors) can be calculated. For optimum conditions, the time interval Δt is not only half the registrated testing time but half the running time of the tunnel. With this the differences in model location are

$$s_3 - 2s_2 + s_1 = \frac{F}{m} \frac{t^2}{4} = \frac{s}{4} \tag{7}$$

For a registration length of the film of 120 mm and a reading error of 0.05 mm the possible evaluation error amounts to 2/3%.

On the other hand, because the length of the flight path and the testing time are fixed, there is also a fixed value for F/m. That means the weight of the model depends on the aerodynamic forces, mainly on the drag. For values of $F/m < s/t^2$ the registration time of the model flight is partially out of the testing time. So we have the postulation

$$F/m \geq s/t^2 \tag{8}$$

where the limiting value is identical with the optimum conditions.

References

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Flux of Cosmic Ray Heavy Nuclei Enders behind Low Shielding

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FOR manned space flights, especially in lengthy missions, the consideration of cosmic ray heavy nuclei is necessary. The phenomenon of the light flashes, which were for the first time seen by the Apollo astronauts, emphasized the particular importance of these particles which can deposit large amounts of energy near their path through matter.

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Index category: Space Medicine.

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