

Technique for Smoothing Free-Flight Oscillation Data

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Introduction

RESULTS obtained using existing data reduction methods,^{1,2} to analyze short sections of free-flight data may be influenced by curve fitting bias due to data scatter and by effects of flow unsteadiness and optical distortion. Hence such results could be enhanced when combined with data fairing process which is able to preserve the complete nonlinear nature of the observed angular motion.

A "phasing" difference between raw free-flight angular data and tricyclic curve fits was observed by Jaffe.³ Subsequently, noticing that the "phasing" was of a periodic nature, it was suggested⁴ that the residual angle data contain individual motion components due to nonlinearities in the force system acting on the model. Further, it is reasonable to expect that these components of motion have forms similar to the basic motion and may therefore also be approximated by tricycles. Residuals of the basic tricyclic solution may thus be fitted with another tricycle and the process repeated until the final residuals are randomly distributed. Superposition of the individual tricyclic components yields a smooth curve through the data points. The purpose of this Note is to introduce a smoothing technique based on these concepts.

Outline of the Technique

A FORTRAN IV program was written to systematically implement the smoothing procedure in conjunction with a conventional data reduction method. Figure 1 depicts a flow diagram of the program which comprises three separate computational loops, denoted STEPS 1, 2, and 3. The STEP 1 loop is essentially the same as the standard data reduction program⁴ in which the measured data (in orthogonal coordinates ψ, θ_z, X, Y, Z , where ψ and θ_z are the horizontal and

vertical plane angles) are transformed to non-rolling coordinates β_1, α_1, X_m and fitted with the tricyclic equation¹ to obtain the basic linear solution. In STEP 2, residuals of the first tricycle are fitted with another tricycle and the process repeated as long as desired. After each pass a set of coordinates $\beta_{cj}, \alpha_{cj}, X_c, j=1,2,\dots,n$ are generated at intervals Δx from the fitted coefficients. The smoothed data set β, α, X_c is then found as the sum of the first tricycle and those determined in STEP 2, so that

$$\beta + i\alpha = \sum_{j=1}^n (\beta_{cj} + i\alpha_{cj})$$

This data set is segmented and analyzed in STEP 3, following conventional data reduction procedure. The SETUP routines determine initial conditions required to start the curve-fitting routine and perform functions required in each loop.

When the reading errors are small, or the nonlinear effects pronounced, the program executes the complete procedure automatically and requires only a fraction of 1 min computing time on an IBM 360 model 65 computer to complete the smoothing. Cases with larger data scatter do not present any problems since it has always been found possible to reach convergence of the tricyclic fit to the residuals by using a suitable external Prony input. Unlike methods by which short portions of a flight are smoothed consecutively, this technique has the advantage of smoothing the data set as a whole, thereby ensuring that the observed motion is accurately reconstructed in the faired curve.

Results

The smoothing technique has been applied to oscillation data from wind tunnel free-flight tests of different model configurations, including sharp 10° cones, blunt 60° cones⁴ and a slender missile, where the reading errors ranged from 1-5% of the maximum angle. Between three and six tricyclic components were determined in each case, depending on the magnitude of the reading errors. Some results from the analysis of the blunt cone data are summarized here.

Figure 2 contains the α - β plot of data from a blunt cone test (JPL Run 22).³ The circles are the measured data points (aeroballistic angles) and the solid line represents the smoothed data obtained by superimposing four tricyclic components on the primary tricyclic solution. The RMS deviation between the data and smooth curve was 0.25° as compared with 0.83° in the case of the original tricyclic fit. Residual angles of the primary tricyclic fit are shown with the smoothed residuals in Fig. 3.

The smoothed data were segmented into intervals ranging in length from one to three oscillation cycles. As was expected, the quasi-linear pitching moment slope ($C_{m\alpha}$) data indicated a smooth variation with the mean-square resultant angle. There was some deterioration in the correlation of data

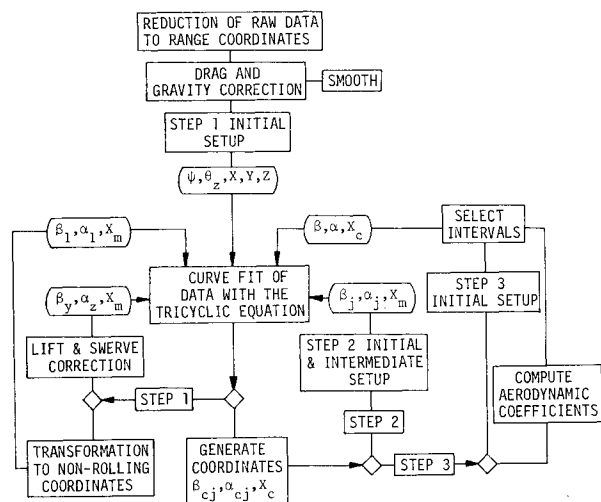


Fig. 1 Computer flow diagram.

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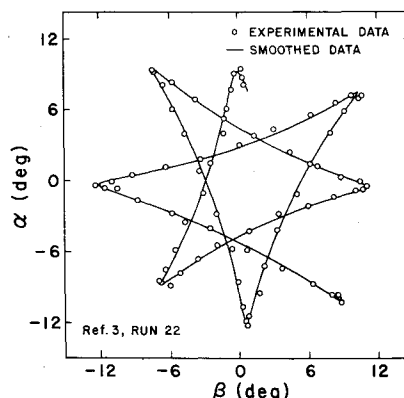


Fig. 2 Smoothing of 60° -cone free-flight data obtained in a wind tunnel.

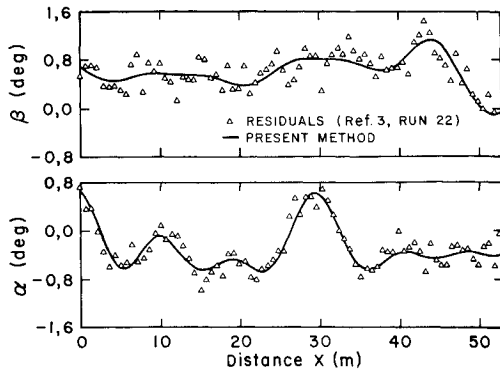


Fig. 3 Smoothed residuals of a tricyclic fit to free-flight data.

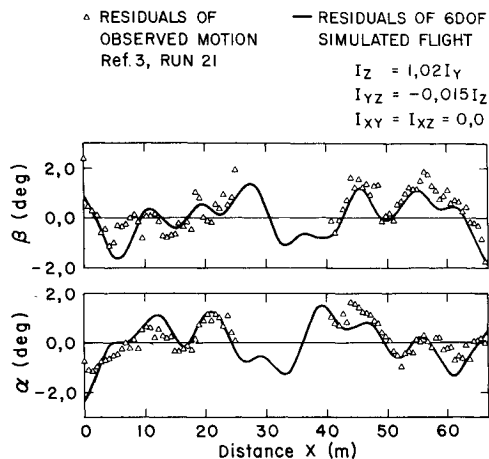


Fig. 4 Comparison of residuals of observed and simulated flight.

from shorter intervals, due primarily to optical distortion and asymmetries. The feasibility of obtaining local $C_{m\alpha}$ values from curve fits of very short intervals ($1/6$ wavelength and shorter) of the smoothed data could be established in the case of the missile. However, in the case of the blunt cone flights this was not possible as the local waveform variations were too small in relation to the reading errors.

Identification of the Tricyclic Components

It is unlikely that the additional motion constants introduced by tricyclic components of the motion have any tractable physical significance, as each individual component may be the concomitant of more than one nonlinearity and could contain contributions due to experimental deviations. Nevertheless, a study was made to establish whether they could be identified as effects due to individual nonlinearities. The method used was to compare tricyclic components of the observed residual motion with known components obtained in

the same way by curve-fitting a six-degree-of-freedom (6DOF) simulation of the observed motion.

A 6DOF simulation of one of the blunt cone flights (JPL Run 21) was generated using a bi-cubic pitching moment derived from the wind tunnel data³ and a mass asymmetry as defined in Fig. 4 where I_z is the moment of inertia about the Z-axis and I_{yz} the product with respect to Y- and Z-axes.⁵ When comparing individual tricyclic components of the observed residual motion with their simulated counterparts, there appeared to be good agreement between components of corresponding frequencies in the two cases. This indicates a direct connection between the tricyclic components and the nonlinearities which produced them.

Further, in comparing residuals obtained from a first tricyclic fit of the observed and simulated motions in Fig. 4 the agreement is satisfactory, indicating that the "phasing" can be accounted for in this case by a combination of the effects of nonlinear aerodynamics and a mass asymmetry consisting mainly of an I_{yz} term of the order of one percent of I_z . This possibility was investigated by Jaffe³ though nothing conclusive could be determined. While the agreement obtained here by postulating a possible mass distribution does not actually prove that this is the explanation of the "phasing," it is evident that the causative factor is manifested as the effect due to an I_{yz} term. This is in agreement with observations by Yelmgren et al.⁶ who suggested that the "phasing" could possibly be explained by an aerodynamic acceleration coupling derivative which has the form of an "apparent product of inertia."

Conclusions

A technique based on superposition of tricyclic solutions has been proposed for smoothing free-flight angular motion. When incorporated into a conventional tricyclic data reduction program, the method is convenient to use and does not require a separate smoothing routine. Tricyclic motion components determined in the smoothing process can be related to effects of individual nonlinearities on the motion.

References

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