Optimization of Wing Tip Store Modeling

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Abstract

IN present three-dimensional flutter investigations of aircraft with external stores, the stores are often approximated by flat plates to reduce the cost and complexity of the analyses. In this Synoptic, the doublet lattice and kernel function methods are utilized to investigate the validity of this flat-plate approximation in comparison to store models of other geometries for an F-5 wing with tip-mounted launcher/store combination. Various cross sections are found that show improved results with only a moderate increase in model complexity and thus computer cost.

Contents

When stores such as missiles are added to the wings of an airplane, the vibrational and aerodynamic characteristics of the aircraft will be changed. In particular, the flutter speed may be adversely affected because of the inertial, elastic, and aerodynamic coupling between the wing and stores. This makes theoretical aeroelastic analysis essential for the flutter evaluation of this type of aircraft configuration.

Several recent studies have considered the effects of store aerodynamics on unsteady wing airloads with emphasis placed on wings with missiles. For example, Dusto[1] presented a higher-order panel method to compute detailed steady and unsteady flows about an F-5 wing with and without underwing and wing tip stores. Experimental results for the same configurations were obtained by Tijdeman et al. at NLR.[2]

For practical applications of flutter analyses, the stores are most commonly modeled as flat plates when computing the aerodynamic loads on oscillating wing/body combinations. This simplification for reasons of complexity and cost, however, tends to reduce the accuracy of the results. The studies discussed here are conducted to evaluate various other models for stores, such as end plates and flat-plate/end-plate combinations, in comparison to the present flat-plate models. This is done using the doublet lattice method (DLM) code H7WC by Giesing et al.[3] and the kernel function method (KFM) code ANKF by Cunningham.[4] The DLM as incorporated in H7WC calculates lift distributions on surfaces in steady and oscillatory motion, even in the case of nonplanar configurations, at only subsonic speeds. The KFM as used in ANKF can also be applied to the supersonic and, with limitations, the transonic flow regime. It is investigated whether the quality of the aerodynamic results can be improved by the new approximate models without paying the high price for very detailed modeling. Results are computed for an F-5 wing with a tip-mounted store (Fig. 1a) to be able to compare them to experimental results[2] as well as the computational results obtained for very detailed store models by higher-order panel methods[1] and by other doublet lattice methods.

Geometrically, the wing and launcher were modeled as flat plates and the missile was simplified without fins as (see examples in Fig. 1c): 1) a flat plate for accuracy evaluation (model 1), 2) an end plate (model 2), 3) various flat-plate/end-plate combinations (models 3-20), 4) an octagonal cylinder (model 21), and 5) an axisymmetric slender body (model 22, DLM only).

The DLM flat-plate model is shown in Fig. 1b. The KFM models looked similar to the DLM models with slight differences in the outboard section of the wing.

For both DLM and KFM, the flow was chosen to be symmetric about the centerline of the aircraft and the Mach number was assumed to be uniformly distributed over the wing surface. Flight speeds were covered in the range $M=0.6$–1.35, with an oscillation frequency of the wing of 20 Hz. In all cases, the wing was oscillated about a near-zero mean angle of incidence. For simplicity, it was assumed that the lower and upper surfaces of the wing have the same Mach number distributions.

Before analyzing the characteristics of the various tip-store models, the clean wing was evaluated at $M=0.6$ and 20 Hz. The unsteady lift coefficient distributions from DLM and KFM agree well, but are 10–30% higher than the experimental results,[2] possibly due to viscous effects.

The 22 models mentioned previously were investigated for Mach numbers $M=0.6$, 0.7, 0.8, and 0.9 by use of the doublet lattice code. Plots of the unsteady lift coefficient distributions for $M=0.6$ at 20 Hz are given in Fig. 2a. All DLM results are again higher than the experimental data. The best results are those for models 2, 19, and 22. The presently widely used flat plate (model 1) shows a higher distribution than the best end-plate models. The cylindrical slender body (model 22) shows the lowest loads in the tip region. All other models present increased loads in this area. For the higher Mach numbers, the cylindrical slender-body model again shows results closest to the experimental data, together with the end-plate models 2 and 19. Even though the slender-body and end-plate models show the best comparison for all cases, none of the models give totally adequate results when compared to the experimental data. This is probably due to the failure of the lifting surface theory to predict flows with shock waves or flow separation. Thus, the significance of the differences among the various lifting surface idealizations seems somewhat reduced.

To verify the advantage of the end-plate configurations, four models were then tested by the kernel function code: the flat plate (1), two end plates (2, 19), and a combination (4). Here, the octagonal cylinder model was not used due to the high associated analysis cost and the slender-body cylinder model could not be accommodated by the ANKF code. The four models were evaluated at the same Mach numbers and frequency as in the DLM. At $M=0.6$, all four models show lift distributions similar to those for the DLM, except in the tip region where the drop in lift coefficient occurs closer to the wing tip (Fig. 2b). The two end-plate models (2, 19) show the best lift distributions compared to the experimental results. At the higher Mach numbers, the differences between the numerical and experimental lift results from the midsection to the tip section were broadened. The lift distributions for the models with the best comparison (2, 19) show slightly larger values in the tip region compared to the DLM. Again, the

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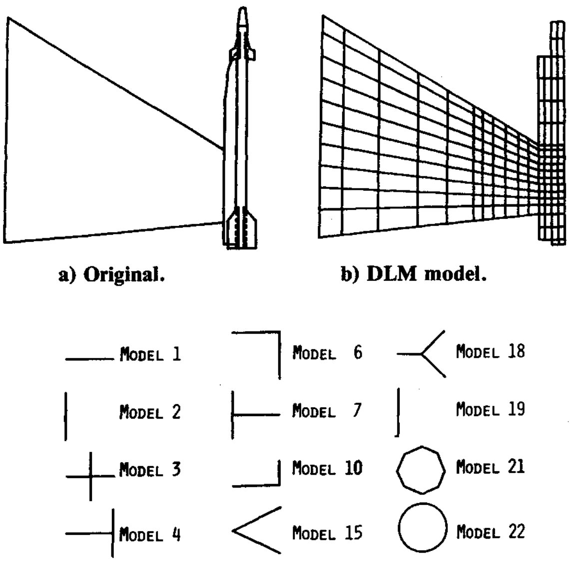
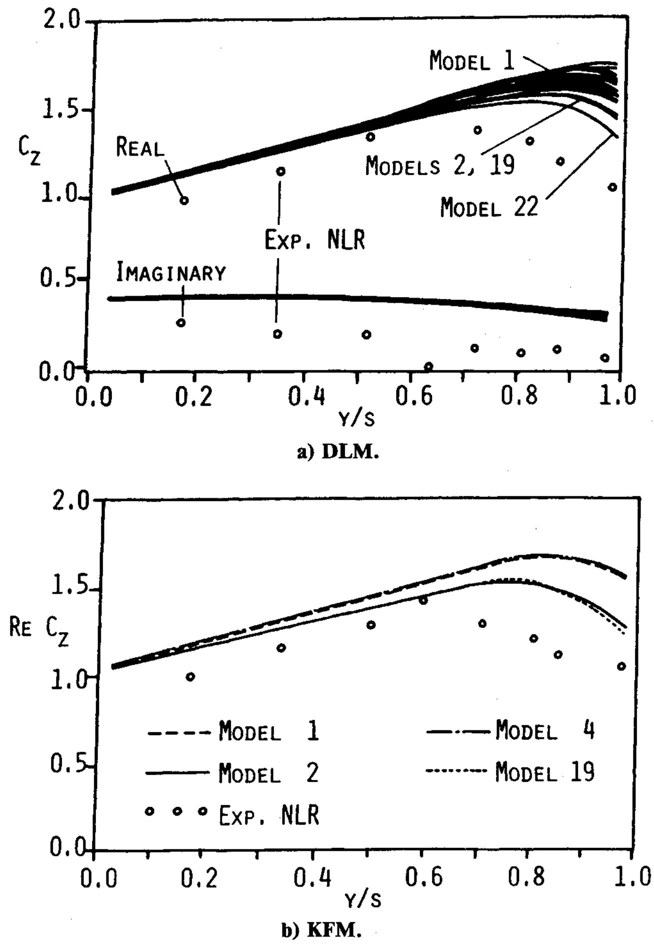


a) Original. b) DLM model.

c) Store cross sections.

Fig. 1 Configuration of F-5 wing with store.



a) DLM.

b) KFM.

Fig. 2 Unsteady lift coefficient distributions ($M=0.6$, $f=20$ Hz).

bumps in the "sub"-transonic experimental pressure distributions could not be obtained numerically. The four models were also analyzed in the supersonic regime for $M=1.1$ and 1.35. The end-plate models, again, gave lift distributions closest to the experimental results.[2]

Finally, a comparison was conducted of the distributions of the unsteady pressure coefficients in chordwise direction at 35, 72, and 98% of the semispan for $M=0.8$ among the flat-plate model (1), the end-plate models (2, 19), the results of Dusto's detailed model,[1] and the experimental data.[2] Both KFM and DLM show good agreement with the results of Dusto and fairly good agreement with the experimental data.

In evaluating the missile models, it was found that the analysis cost for the end-plate and slender-body models was less than that for the other configurations (with the exception of the flat-plate model), while at the same time these models showed the best agreement with experimental results.

Conclusions

In conclusion, calculations of the aerodynamic characteristics of an F-5 wing with and without a wing tip missile were carried out by a doublet lattice code and a kernel function code. The unsteady lift distributions in the spanwise direction and the unsteady pressure distributions in the chordwise direction were computed for the wing with a tip-mounted launcher and a missile without fins. The results indicate that, for subsonic flow, the slender-body and end-plate models yield the best comparison to experimental data. For supersonic flow, results for the slender-body model cannot be computed. Here, the same end-plate models showed the best comparison. Thus, in almost all cases, representation of the tip store as an end plate gives aerodynamic results closer to experimental data than using the present flat-plate models. However, it is apparent that the differences among the various models are, over most of the span, smaller than the overall differences between the numerical and the experimental results. This seems to be due to the limitations of the theories presently used to predict the nonlinearities of transonic shock flow and flow separation. Thus, for these codes, the significance of which tip store model to use is reduced.

Therefore, it is recommended that the modeling be extended into the nonlinear transonic regime by use of a transonic CFD code such as XTRAN3S. Also, flutter analyses should be performed to evaluate how the found differences in pressure and lift distributions for the various models affect the actual flutter speeds.

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References

[1]Dusto, A. R., "Aerodynamic Analysis of a Fighter Aircraft with Higher Order Paneling Methods," AFWAL-TR-80-3115, Nov. 1980.

[2]Tijdeman, H., van Nunen, J. W. G., Kraan, A. N., Persoon, A. J., and Poestkoke, R., "Transonic Wind Tunnel Tests on an Oscillating Wing with External Stores, Parts I-IV," AFFDL-TR-78-194, 1978-1979.

[3]Giesing, J. P., Kalman, T. P., and Rodden, W. P., "Subsonic Unsteady Aerodynamics for General Configurations," Pt. I, Vols. I-II, AFFDL-TR-71-5, Nov. 1971.

[4]Cunningham, A. M. Jr., "A Steady and Oscillatory Kernel Function Method for Interfering Surfaces in Subsonic, Transonic, and Supersonic Flow," NASA CR-144895, Sept. 1976.