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COMPUTATIONAL AEROELASTICITY CHALLENGES AND RESOURCES

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TRANSONIC AERODYNAMICS AND FLUTTER

In the past decade there has been much activity in the development of computational methods for the analysis of unsteady transonic aerodynamics about airfoils and wings. The upper left figure illustrates significant features which must be addressed in the treatment of computational transonic unsteady aerodynamics. On the plot of equivalent airspeed versus Mach number, lines of constant altitude are straight lines through the origin with decreasing altitudes represented by steeper slopes. The flight envelope, typically set by the maximum limit speed and a typical flutter boundary curve, characterized by the flutter speed gradually dropping to a minimum in the transonic speed range followed by a rapid upward rise, is shown. The ability to predict this minimum, termed the transonic flutter dip, is of great importance in design, since the flutter boundary must be shown by a combination of analysis and flight test to be outside the flight envelope by a margin of at least 15 percent in equivalent airspeed for military aircraft.

The upper right figure indicates the flow regions for an aircraft on a plot of lift coefficient versus Mach number. Flows which are predominantly attached or separated are designated as type I and III respectively, while mixed attached and separated flows are designated type II. For aeroelastic problems the boundary of the type II flows will be enlarged over that for steady flows since a vibrating airfoil or wing may exhibit alternating attached and separated flow for sensitive conditions. The "picket fence" in the mixed flow region has been added to emphasize the possibility of "nonclassical" aeroelastic effects in this region.

The diagram in the lower left of the figure illustrates the sequence of events occuring in air combat maneuvers. Upon the decision to engage, a maneuver is initiated with the objective of achieving maximum turn rate. This leads, in turn, to pull-up and turn at the structural limit load, decelerating at limit load to the intersection with the maximum lift coefficient curve; holding this "corner" condition until the pointing objective is achieved and completion of engagement and pull-out occurs. These maneuvers, encompassing the complete fight envelope, involve rapid transitions between type I, II, and III flow conditions.

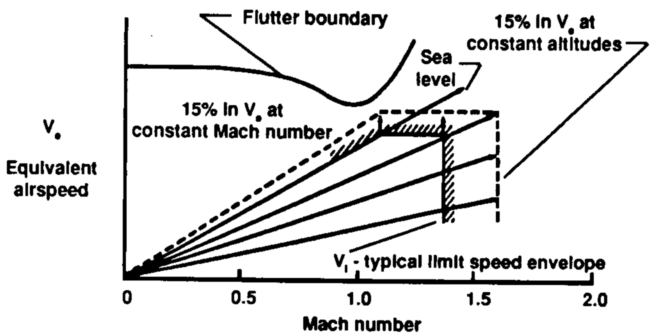
Further features of transonic flutter are illustrated in the lower right diagram. Dynamic pressure at flutter tends to decrease with increasing Mach number to a minimum "critical flutter point" value in the transonic speed range. At subsonic speeds the flow can be reasonably assumed to be attached (type I) at flutter and linear theory is well calibrated for flutter analysis. At transonic speeds the situation is complicated by the onset of flow separation (type II flow) and linear theory must be used with caution. The low damping region indicated in the figure indicates the potential for nonclassical aeroelastic response and instabilities which may be encountered.

References:

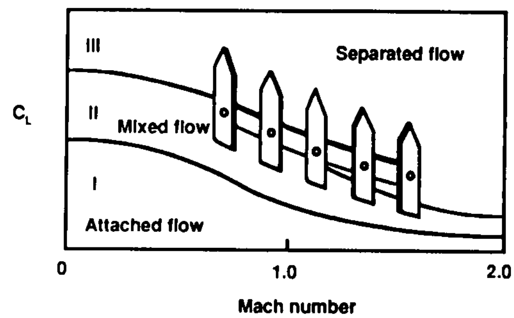
Edwards, J. W.; and Thomas, J. L.: Computational Methods for Unsteady Transonic Flows, AIAA Paper No. 87-0107.

TRANSONIC AERODYNAMICS AND FLUTTER

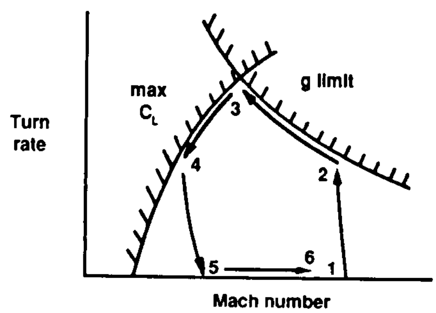
GRAPHICAL REPRESENTATION OF MINIMUM REQUIRED FLUTTER MARGIN



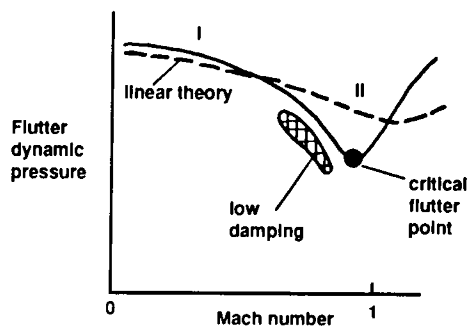
CHARACTERISTICS OF ATTACHED AND SEPARATED FLOW FOR COMPLETE AIRCRAFT



AIR COMBAT DYNAMICS



FEATURES OF TRANSONIC FLUTTER



COMPUTATIONAL AEROELASTICITY CHALLENGES

This figure illustrates several types of aeroelastic response which have been encountered and which offer challenges for computational methods. The four cases illustrate problem areas encountered near the boundaries of aircraft flight envelopes, as operating conditions change from high speed, low angle conditions to lower speed, higher angle conditions. The nonclassical aeroelastic response observed on the DAST ARW-2 wing model (upper left) is a region of high dynamic response at nearly constant Mach number which was encountered at dynamic pressures well below those for which flutter was predicted. The motion is of the limit-amplitude type and the response is believed to be associated with flow separation and reattachment over the supercritical wing (type II flow).

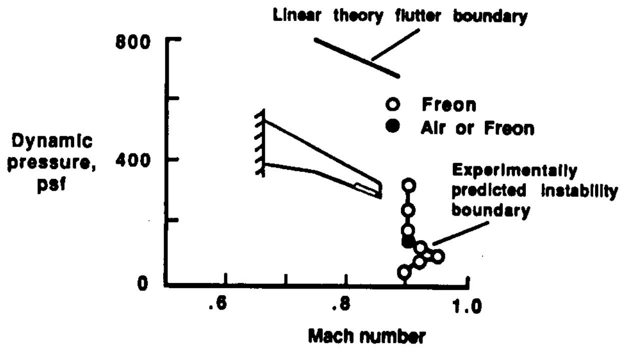
The upper right figure illustrates wing/store limited amplitude oscillations experienced by modern, high performance aircraft under various loading and maneuvering conditions at transonic Mach numbers. Such oscillations can result in limitations on vehicle performance. The conditions for which this response occurs appear to be near the onset of type II mixed flow. The response typically increases for maneuvering flight conditions.

Dynamic vortex-structure interactions causing wing oscillations have been observed on a bomber type aircraft for high wing sweep conditions during wind-up turn maneuvers (lower left). The flow involves the interaction of the wing vortex system with the first wing bending mode and occurs over a wide Mach number range (0.6 - 0.95) at angles of attack of 7 - 9 degrees.

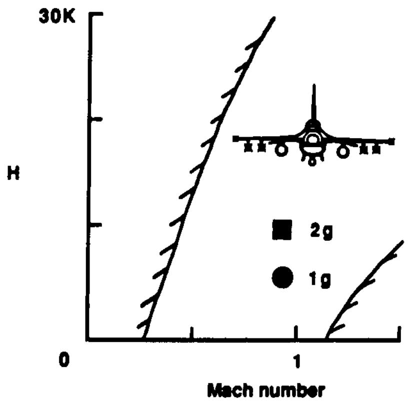
At higher angles, interaction of forebody and wing vortex systems with aft vehicle components results in vortex-induced buffet loads, illustrated in the lower right figure. The figure shows the operating conditions for which tail buffet may occur on a high performance fighter. Buffet of horizontal tails can occur at intermediate angles of attack and is a result of the vortex system encountering the horizontal tail lifting surface. As angle of attack increases, the location of vortex bursting moves upstream in the wake. Loss of lift is associated with the burst location reaching the vicinity of the aircraft, and vertical tail surfaces located in such regions can experience severe dynamic loads.

COMPUTATIONAL AEROELASTICITY CHALLENGES

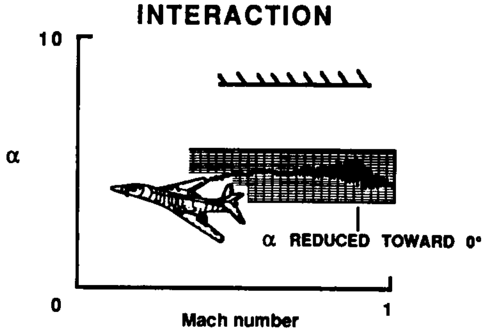
NOVEL SHOCK-INDUCED INSTABILITIES



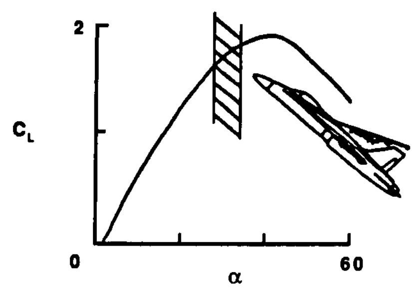
WING/STORE LIMITED AMPLITUDE FLUTTER



DYNAMIC VORTEX-STRUCTURE INTERACTION



VORTEX-INDUCED BUFFET LOADS



COMPUTER RESOURCE REQUIREMENTS FOR FLUTTER ANALYSIS

This table indicates the computer resources required to perform a flutter analysis of a complete aircraft configuration at one Mach number. Time-marching transient aeroelastic response calculations are used to determine the flutter condition. This involves, on average, four response calculations: two to calculate steady flow field conditions and two transient responses bracketing the flutter speed. Modal frequency and damping estimates from the responses are determined and the flutter speed interpolated from the damping estimates. Calculations have been performed for a complete aircraft configuration with a transonic small disturbance (TSD) potential code using 750,000 grid points. The calculation of one flutter point for this case on the CDC VPS-32 computer would require 2.3 CPU hours. Estimates of similar calculations using the full Navier-Stokes equations would require 77.8 CPU hours. Conditions for this estimate are a Reynolds number of 10 million, 7 million grid points and an assumed computational speed of 100 million floating point operations per second (MFLOPS).

References:

Whitlow, Woodrow, Jr.: Computational Unsteady Aerodynamics for Aeroelastic Analysis, NASA TM 100523, December 1987.

COMPUTER RESOURCE REQUIREMENTS TO DETERMINE FLUTTER POINT AT A SPECIFIED MACH NUMBER

(4000 TIME STEPS PER FLUTTER POINT)

CONFIGURATION	FLOW MODEL	GRID POINTS	CPU HOURS (VPS-32)
COMPLETE AIRCRAFT	TSD	0.75M	2.3*
COMPLETE AIRCRAFT	FULL NAVIER-STOKES (RE = 10 MILLION)	7.00M	77.8**

*BASED ON ACTUAL CASES

**ASSUMES COMPUTATIONAL SPEED OF 100 MFLOPS

COMPUTER RESOURCE REQUIREMENTS FOR COMPLETE FLUTTER BOUNDARY

This table summarizes computational requirements for flutter calculations of a wing/body/canard configuration on the CDC VPS-32 computer operating at 100 MFLOPS and on the NAS CRAY II computer operating at 250 MFLOPS. Again, four response calculations per flutter point are assumed. It is assumed that ten flutter points will be calculated to define the flutter boundary versus Mach number. The left hand column indicates the difficulty of the flowfield calculation as defined in figure 1; type I for attached flows, type II for mixed (alternately separated and attached) flows and type III for fully separated flows. The second column indicates the fluid dynamic equation level needed to accurately model the flow physics of the problem. Note that two-dimensional strip boundary layer models are assumed for interactive viscous-inviscid calculations for the potential and Euler equation methods. It is anticipated that potential equation models will be adequate for flutter calculations of type I attached flow conditions and may also be quite useful for some type II mixed flow cases. Full potential equation codes will require about 50 percent more computer resources than TSD methods due to the necessity of conforming, moving grids, among other considerations. Euler equation methods should also be adequate for these conditions and, in addition, be able to treat more difficult type III fully separated flows. Euler equation methods are estimated to require approximately twice the resources of TSD methods. The full Navier-Stokes equations, which should only be required for type II and III flows require approximately 30 times the resources of the Euler equations (at a Reynolds number of 100 million).

WING/BODY/CANARD CONFIGURATION
10 MACH NUMBERS (40 CASES) PER ANALYSIS

$$\text{TIME} = (\text{GRID PTS}) \times \frac{\text{OPS}}{(\text{GRID PTS} \times \text{ITER})} \times (\text{ITER})/(\frac{\text{OPS}}{\text{SEC}})$$

FLOW REGION	FLOW MODEL	VPS-32 (100 MFLOPS)	NAS (250 MFLOPS)
I, MAYBE II	TSD WITH 2-D STRIP BOUNDARY LAYER	30 HOURS	12 HOURS
I, MAYBE II	POTENTIAL WITH 2-D STRIP BOUNDARY LAYER	45 HOURS	18 HOURS
I, II, MAYBE III	EULER WITH 2-D STRIP BOUNDARY LAYER	65 HOURS	26 HOURS
II, III	NAVIER-STOKES (RE = 10^8)	1611 HOURS	644 HOURS

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