Preface

Aeroelasticity deals with the dynamics of an elastic structure in airflow with primary focus on the endemic instability of the structure called “flutter” that occurs at high enough speed. This book presents the “continuum theory” in contrast to extant literature that is largely computational; where typically one starts with the basic continuum model, a partial differential equation usually highly nonlinear but omitting the all important boundary conditions and disregarding the question of existence of solution; going immediately to the discretized approximation; presenting charts and figures for a confluence of numerical values for the parameters and conclusions drawn from them.

Here we stay with the basic continuum model theory until the very end, where constructive methods are developed for calculating physical quantities of interest, such as the flutter speed. Indeed this is considered “mission impossible” because it is nonlinear and complex.

As in any scientific discipline, continuum theory provides answers to “what if” questions which numerical codes cannot. It makes possible precise definitions—such as what is “flutter speed.” Physical phenomena—such as transonic dip, for example—can be captured by simple closed-form formulae. And above all it can help develop intuition based on a better understanding of the phenomena of interest. As with any mathematical theory it enables a degree of generality and qualitative conclusions, increasing insight.

But the use of continuum models comes with a price: it requires a high level of abstract mathematics. For a precise statement of the problem, however, the language of modern analysis—developed in the latter half of the twentieth century—abstract functional analysis, in particular, the theory of boundary value problems of partial differential equations, is unavoidable. Indeed the aeroelastic problem, the structure dynamics in normal air flow-formulates as a nonlinear convolution/evolution equation in a Hilbert space.

On the other hand the numerical range of the physical parameters plays an important role in being able to generate constructive solutions otherwise impossible from the mathematics alone. What we do is indeed applied mathematics in the sense that we use mathematics to solve today's engineering problems addressed to engineers as well as mathematicians.

And now for some points of view, points of departure, of this book closer to the subject matter. Aeroelasticity is concerned with the stability of the structure in air flow. The air flow per se is of less interest. Thus we are not concerned, for example, whether there are shocks in the flow or not, in itself a controversial matter. The faith of the aeroelasticians in shocks, it turns out, is not substantiated by the mathematical theory (2D or 3D flow). It may be heresy to the clan but shocks may exist that do not affect the stability (or rather the instability) of the structure. Another and more significant view concerns the interaction between Lagrangian structure dynamics and Eulerian fluid dynamics, often the most mysterious part of computational work.

Here we take the simple engineering input–output point of view where the velocity of the structure is the input and the pressure jump across the structure is the output. The input–output relation is the integral equation of Possio that does not get any mention in as recent a work as [17] which features partial differential equations. The Possio Integral Equation can be looked as an illustration of the Duhamel principle and we make systematic use of it—linear and nonlinear—throughout the book. We show that flutter speed is simply the smallest speed at which the structure becomes unstable; it is a Hopf bifurcation point determined completely by the linearized model about the steady state. In turn this means incidentally that the control for extending the flutter speed need not be nonlinear, contrary to current wisdom.

The mathematical style of the book is largely imitated/borrowed from that of R.E. Mayer [14], and Chorin–Marsden [4] where they claim to "Present basic ideas in a mathematically attractive manner (which does not mean 'fully rigorous')." In this sense although we use abstract functional analysis, we try to reduce the abstraction and sacrifice mathematical generality, preferring to emphasize constructive solutions and basic ideas rather than get lost in Sobolev spaces and weak solutions. Quoting another pioneer in this style: "I shall not be guilty of artificially complicating simple matters. A phenomenon that sometimes occurs in mathematical writing." Tricomi in his book *Integral Equation*, 1957 [11].

We should caution that there are many problems that mathematical theory cannot currently answer especially in viscous flow and as a result also in aeroelasticity. We invoke the Prandtl boundary layer theory, for example, with this caveat.

We should also note a price to be paid for mixing the abstract with the concrete, saying too much or too little at either end.