Chapter 8

The destabilization paradox in continuous circulatory systems

The greatest theoretical interest is evidently centered in the unique effect of damping in the presence of pseudo-gyroscopic forces, and in particular, in the differences in the results for systems with slight damping which then becomes zero and systems in which damping is absent from the start ... These interesting aspects require further study ... for obtaining further, more definite, results.

V. V. Bolotin [75]

In 1952, Ziegler [622] when investigating the stability of a double pendulum subjected to a follower load, reached the unexpected conclusion that the flutter threshold of the nonconservative system with negligibly small damping is significantly lower than it is in the ideal (undamped) case. In 1956, Bottema [81] was the first who understood the Ziegler effect as a *structural instability* (in the sense of dynamical systems theory) by linking it to the Whitney umbrella singularity that (as was established in 1971 by Arnold [17]) generically exists on the boundary of the domain of the asymptotic stability of a general finite-dimensional dissipative system depending on at least three parameters.

This phenomenon, which we now know as the Ziegler–Bottema destabilization paradox, was subsequently observed in many nonconservative systems of solid and fluid mechanics, both finite-dimensional and continuous [312]. The well-known examples of the destabilization paradox in continuous systems of fluid dynamics are the enlargement of the domain of *baroclinic instability* due to friction in the Ekman boundary layer observed by Holopainen in 1961 and described by Romea in 1977 [228,334,501,563], and the enhancement of the *modulational instability* of the Stokes waves with dissipation found by Bridges and Dias in 2007 [90,303]. The destabilizing effect of damping is important in nonconservative problems of fluid-structure interaction such as *aircraft flutter* [452] and stability of pipes conveying fluids [85,513,556], as well as in solid mechanics, e.g., in the dynamics of large space structures [224] and in the optimization of slender structures with respect to stability criteria [355].

The analytical description of the destabilization paradox was recognized as one of the main theoretical challenges in nonconservative stability theory [75]. However, de-