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BECK'S COLUMN AS THE UGLY DUCKLING

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1. KOITER'S ARTICLE

Some years ago the first author (Y.S.) received an e-mail message from a graduate student in Germany that there was in Europe a group of scientists who do not believe in the existence of follower forces. Later a letter from Denmark notified us about Koiter's article entitled "Unrealistic follower forces" [1].

It was interesting for us to know that the elimination of follower forces proposed by Koiter, on the advice of Isaac Elishakoff, took place about half a century after Beck's column, a cantilevered column subjected to a follower force, was born in 1952. Since Professor W. T. Koiter was one of the top-most scientists in the field of applied mechanics and Professor Isaac Elishakoff is one of the most active scientists, the storm of their criticism that follower forces are unrealistic, and that the papers on the effect of follower forces should not be accepted for publication, has had far-reaching consequences in the society of applied mechanics. The magnitude of the storm, and to what extent the storm was bitter to scientists who were interested in the concept of follower forces, can be understood easily from Bolotin's confession [2]: "I met many people arguing about this subject." "The arguments resulted in a temporary personal break of the friendship." "I am not at all a partisan of follower forces. It seems that since 1961 when I had published my book, I never returned to the topic."

However, in our opinion, their criticism is only partly correct, in the sense that many purely would-be academic/theoretical papers on the effect of follower forces not relevant to science and engineering have been published. But it is partly wrong, in the sense that the concept of follower forces is important in order to understand some types of dynamic instability of structures subjected to follower non-conservative loadings, while Koiter said that follower forces are unrealistic in general. It is true that there have been published a vast body of papers dealing with the concept of so-called follower forces which are nothing but purely mathematical exercises having no relevance with physical reality. In such papers, even though follower forces do exist, the mathematical models accommodated with the follower forces—modified versions of Beck's columns—are unrealistic or have no physical reality. Some of them are unduly simplified [3], and some are artificially complicated. It is noticed that these unrealistic models are prone to yield, eventually, a new, paradoxical or

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unrealistic conclusion or both (one of such examples is described in reference [4]). This could be a reason why unrealistic models have been loved by some prospective researchers.

If we understand correctly, the only thing that Koiter wanted to say was that purely theoretical papers on the effect of follower force should be omitted from publication. After reading Koiter's article, the first author (Y.S.) sent letters, together with some papers on his experimental works, to Professor P. E. Doak, the Editor-in-Chief of the *Journal of Sound and Vibration*, in September 1996. Reading Professor Doak's reply to the letters, we were much impressed by his fair attitude to the topic. Professor P. E. Doak said that, "I wonder why some experts in structural stability theory, like Professor Koiter, are not aware of your work, and that of Feldt *et al.* (1969) and Wood *et al.* (1969)." Following Professor Doak's invitation, we wrote a short article entitled "Realistic Follower Forces" [5], and later a survey paper entitled "Dynamic Stability of Columns Subjected to Follower Loads: A Survey" [6].

2. WHY COULD BECK'S COLUMN BE THE UGLY DUCKLING?

The concept of follower forces is realistic and important to explain dynamic stability of some types of non-conservative elastic systems, for example, bending flutter of slender missiles under an end rocket thrust (an example of a concentrated follower force), and vibrations and noise due to a dry frictional force (a possible example of a distributed follower force). Also it is noted that the investigations into the effect of follower non-conservative forces has triggered the splendid development of the theory of structural dynamic stability. The only reason why Beck's column could be "the ugly duckling" might be due to the fact that only a small number of papers dealing with experimental verification of the effect of follower forces have been published. What is the reason for this?

There may be a number of reasons why only a small number of experimental investigations into the effect of follower forces has been done so far. One reason would be that it is not easy to realize a follower non-conservative force in a laboratory to observe dynamic instability due to the non-conservativeness of the force. This would be especially the case for the scientists who were mainly involved with structural statics. There have been published some papers in which vain efforts were made to try to produce a follower non-conservative force by static ways of loading.

The most convincing other reason could be attributed to the fact that computers have come into the laboratories, and scientists work on keyboards rather than on experimental set-ups for a larger number of papers. As long as a scientist needs to work on a new experimental set-up to complete one paper, it will take at least 3 years or so in the shortest, normally 10 years or so. Whereas smart scientists symbiotic with computers and mathematics can write up several papers in 1 year to get a prompt promotion and possibly success in the academic society. If this kind of situation is a fact in these decades, then a prospective scientist will take the shortest course for his academic success by being free from experiment. It was some two or three decades ago that an experimental validation of a doctoral dissertation work was required for a doctoral candidate to get the doctor of engineering degree, while lately only computational simulation and/or mathematical exercises may be enough to compile the doctoral dissertation for the Ph.D. degree or even the Doctor of Engineering degree.

3. THEORY AND EXPERIMENT

If we talk about the importance and necessity of experiments on the effect of follower forces, we can go back to the early 1960s, when the English version of Bolotin's book on the

subject was published in 1963 [7]. It is very interesting to read again at this time the last chapter of his book entitled "Concluding Remarks. Suggested Direction for Future Research". Bolotin wrote that "There is no doubt that "follower" force can have a definite effect on jet and rocket installations, turbines, etc. It is felt that the principal lines along which future research in this field should be directed must aim, not at increasing the number of purely academic problems solved, but at providing an answer to the question of the degree to which "follower" forces can satisfactorily represent actual forces encountered in practice. Here experimental investigations are of prime importance."

In a way, the recent discussion on purely theoretical work on follower forces, initiated by Koiter, is similar to the discussions on theoretical hydrodynamics about 80 years ago. These discussions are described in the recent book *Fluid Dynamics for Physicists* by T. E. Faber [8]. Faber tells that Lord Rayleigh, in his review of Sir Horace Lamb's fourth edition of *Hydrodynamics* in 1916 wrote "During the last few years much work has been done in connection with artificial flight. We may hope that before long this may be coordinated and brought into closer relation with theoretical hydrodynamics. In the meantime one can hardly deny that much of the latter science is out of touch with reality."

It is interesting to note that the above citation of Lord Rayleigh fits the present state of the concept of follower forces, if "artificial flight" is replaced by "experimental verifications of the effect of follower forces", and "theoretical hydrodynamics" is replaced by "purely theoretical dynamic stability of structures subjected to follower forces".

As to the necessity of co-ordination between theory and experiment for the steady and sound progress of the theory of non-conservative problems of elastic stability, it is interesting to read R. A. Caflisch's foreword to Sir Horace Lamb's *Hydrodynamics*, the sixth edition published in 1932 and reprinted in 1993 [9];

"In his 1916 review of *Hydrodynamics*, Rayleigh concluded with a call for more coordination between theory and experimental results, stating that "one can scarcely deny that much of theoretical hydrodynamics is out of touch with reality"".

In the following years from the early 1920s and onwards the standard in hydrodynamics research was raised significantly, in the sense that it became customary to verify theoretical results by experiment. This trend was initiated in particular through the works of G. I. Taylor at Cambridge and L. Prandtl at Goettingen. Nowadays no fluid dynamics journal will publish any work without any connection to physical reality.

4. CONCLUDING REMARKS

If we turn over the cover of the book *Andersen's Fairy Tales*, we may find a tale called "The Ugly Duckling". The tale [10] reads that "I believe he will be very strong, and I don't doubt but he will make his way in the world." "He felt quite glad of all the misery and tribulation he had gone through; he was the better able to appreciate his good fortune now, and all the beauty which greeted him."

REFERENCES

1. W. T. KOITER 1996 *Journal of Sound and Vibration* **194**, 636–638. Unrealistic follower forces.
2. V. V. BOLOTIN 1999 *Applied Mechanics Reviews* **52**, R1-R9. Dynamic instabilities in mechanics of structures.
3. Y. SUGIYAMA, K. KASHIMA and H. KAWAGOE 1976 *Journal of Sound and Vibration* **45**, 237–247. On an unduly simplified model in the non-conservative problems of elastic stability.

4. M. A. LANGTHJEM and Y. SUGIYAMA 1999 *Journal of Sound and Vibration* **226**, 1–23. Optimum shape design against flutter of a cantilevered column with an end-mass of finite size subjected to a non-conservative load.
5. Y. SUGIYAMA, M. A. LANGTHJEM and B.-J. RYU 1999 *Journal of Sound and Vibration* **225**, 779–782. Realistic follower forces.
6. M. A. LANGTHJEM and Y. SUGIYAMA 2000 *Journal of Sound and Vibration* **238**, 809–851. Dynamic stability of columns subjected to follower loads: a survey.
7. V. V. BOLOTIN 1963 *Nonconservative Problems of the Theory of Elastic Stability*. New York: Pergamon Press, 315.
8. T. E. FABER 1995 *Fluid Dynamics for Physicists*, Cambridge: Cambridge University Press, 161.
9. SIR HORACE LAMB 1932 (reprinted in 1993) *Hydrodynamics*. Cambridge: Cambridge University Press, sixth edition.
10. HANS CHRISTIAN ANDERSEN 1993 *Andersen's fairy tales*. Hertfordshire: England: Wordsworth Editions Limited, 386-394.