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Comment

An appreciation of the 1939 paper "On an experimentally observed phenomenon on vortex rings ..." by Carl-Heinz Krutzsch*

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Many people working in the field of vortex ring dynamics will have heard of the paper on vortex rings published by Carl-Heinz Krutzsch in 1939 in Annalen der Physik. However, few will have read it in detail since it is written in highly technical German, which is well beyond what many of us learned in German classes. As such, it seemed well worth while to us to take the trouble to translate and re-publish the paper in English. We are very grateful to Professor Ulrich Eckern, the current Editor in Chief of Annalen, for permission to publish this translation in the same journal where it originally appeared.

Why then do we feel that this paper, now over 70 years old, is still worth reading? The first thing we notice, of course, is the subject matter. Vortex rings have been a subject of great fascination to fluid dynamicists for a very long time, dating back to Reynolds in 1876 [1] or even earlier to Rogers in 1858 [2], the founder of MIT. This initial interest is in part due to Lord Kelvin's idea that such rings were a model of atoms [3] (at the time Lord Kelvin was Sir William Thomson). Like many subjects in fluid mechanics, it is one where interest in the community has been up and down, but it is one in which there has always been interest. They are visually stunning phenomena, which can capture even lay peoples' interest. From a scientific perspective they pose many interesting and theoretically challenging questions. This paper was perhaps the first to study wave motion on the vortex core and to attempt to describe the initial roll-up of the fluid exiting the gun.

A quick search in recent literature highlights the importance of vortex rings in the natural and manufactured world, ranging from fish swimming [4] and inter-fish communication [5] to insect flight [6] to manufactured jet propulsion [7] or robotics problems [8]. The beauty, complexity and universality of vortex rings is perhaps best summarized in the oft-quoted words of the late Phillip Saffman (1981) [9]:

> "One particular motion exemplifies the whole range of problems of vortex motion and is also a commonly known phenomenon, namely the vortex ring... Their formation is a problem of vortex sheet dynamics, the steady state is a problem of existence, their duration is a problem of stability, and if there are several we have a problem of vortex interactions."

The second thing we would like to highlight from the Krutzsch paper is the exceptionally fine quality of the photographs. As with any good scientific paper, the high quality images convey much of the information in the article, which we believe gave rise to its interest by the scientific community despite any challenges

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associated with language. Given the time at which, and technology with which they were taken these images are quite outstanding. We have taken many photographs of vortex rings with equipment Krutzsch could not even dream of having (e.g. [10,11]). Ours are no better, and often perhaps inferior. Krutzsch used some clever tricks such as dropping a mirror behind a ring so that it can be photographed in motion. We recently employed this very technique to produce the pictures published in [11]. When reading the paper, the amount of work, patience and effort on Krutzsch's part to obtain these high quality images and data is evident. It is our hope that the translation of the techniques and apparatus used by Krutzsch will aid others as it aided us, and it certainly might make a good place to start for any young graduate student looking for inspiration.

It is interesting to look at the history of citations of this paper, which according to the ISI Web of Science totals 38 as of December 2010. This is by no means an impressive number in terms of impact, but what is interesting is the timeline associated with the citations.

No citations took place until 1952 (perhaps a reflection of the fact that this paper was published right at the onset of World War II) and was on rings forming at the exit of a shock tube [12]. The next couple of decades were quiet with a resurgence of citations in the 1970s in papers by Tony Maxworthy [13,14], Sallet and Widmayer [15] and Liess and Didden [16], which brought this paper to the attention of the vortex dynamics community. Philip Saffman [17], inspired by the high quality images provided by Krutzsch begins his paper on the number of waves on unstable vortex rings with the statement "The instability of vortex rings formed by pushing fluid out of a tube was convincingly demonstrated by Krutzsch (1939) who presents remarkable pictures of the phenomena and gives quantitative data". Citations picked up again in the late 1980s and 1990s, e.g. Shariff and Leonard [18]. The early 2000s were once again calm with citations picking up from 2005-2010, including two experimental papers by our research group at the University of Oregon [10, 11].

This lack of early citations along with the lack and reappearance of citations over recent decades perhaps demonstrates that this article was well ahead of its time. In fact, reading the text carefully shows that the author himself struggled in interpreting many of his own observations. He provides detailed descriptions and explanations of some of the complexities associated with vortex rings. Some of these, while clever and insightful given knowledge at the time, are incompatible with our current day understanding of vortex rings, while others seem right on. Regardless of today's theoretical views, his eloquent descriptions of phenomena we still struggle with today, are an inspiration and reminder that modern technology does not override good common scientific sense.

There is an interesting parallel to this paper in the thesis work of Maurice Couette in Paris about 1890. Couette was the first to study the flow of fluids between concentric cylinders. His brilliant work led to the celebrated theoretical and experimental work by Geoffrey Taylor in 1923 and decades of papers and conferences following in what is now called Couette-Taylor flow. Both Krutzsch and Couette did very important doctoral theses, significant even to this day. Both went on to long careers in teaching, but published nothing else of note.

Translator's note: We use the term "Kelvin waves" on vortex rings even though there are much more complicated instabilities than simple bending waves, such as have been studied by Widnall and Sullivan [19] and others.

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