

## Honoring Charles Steele

**Submission ID** 3003163

**Submission Type** Symposia

**Topic** Other

**Status** Submitted

**Submitter** Sunil Puria

**Affiliation** Harvard Medical School, Mass. Eye & Ear Infirmary

**Participant(s)** Sunil Puria (Chair), Elizabeth Olson (Co-chair), Kelly Steele (Presenter), Elizabeth Olson (Presenter), Sunil Puria (Presenter), Anthony Ricci (Presenter), Yanli Wang (Presenter), Renata Sisto (Presenter), Karl Grosh (Presenter)

### SUBMISSION DETAILS

**Session Description** In this special symposium, we plan to honor the lifetime contributions by Prof. Charles Steele to the field of Cochlear and Middle Ear mechanics.

Charles R. “Chuck” Steele, professor emeritus of mechanical engineering and of aeronautics and astronautics at Stanford University, contributed significantly to cochlear and middle ear mechanics, died Dec. 9, 2021 in Redwood City, CA. He was 88. Steele’s first paper on the cochlea was published in 1974 and many of his subsequent works on the topic are still cited today. In total, it is estimated Steele published some 100 journal articles, five review articles and numerous abstracts in conference proceedings, while delivering guest lectures around the world. As an editor, he was perhaps even more influential, becoming editor-in-chief of the International Journal of Solids and Structures. As teacher, Steele was similarly admired. He taught plates and shell structures, differential geometry and the mechanics of hearing to graduate students. He mentored more than 70 doctoral students through their dissertations and maintained contact with many of them throughout their careers. Professional recognition followed these accomplishments. He was elected a fellow of American Society of Mechanical Engineers in 1980 and the American Academy of Mechanics in 1985. In 1995, he became a member of the National Academy of Engineering. In 1988, the National Institutes of Health bestowed the Claude Pepper Award upon Steele for his work in hearing. In 2014, he was given the lifetime achievement award at the Mechanics of Hearing meeting in Greece.

Each session will be 15 mins. The target audience is the general Inner Ear and Middle Ear group of ARO attendees.

**Presenter Diversity** Good gender balance (4 female, 3 male), diversity (3 Asian), very junior (post doc) to senior journalist (Kelly Steele)

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**Signature** Sunil Puria

## Honoring Charles Steele

### Charles Steele – the “Mad” Scientist

**Submission ID** 3003163

**Submission Type** Symposia

**Topic** Other

**Status** Submitted

**Submitter** Kelly Steele

**Affiliation** Widow of Charles Steele

**Participant(s)** Sunil Puria (Chair), Elizabeth Olson (Co-chair), Kelly Steele (Presenter), Elizabeth Olson (Presenter), Sunil Puria (Presenter), Anthony Ricci (Presenter), Yanli Wang (Presenter), Renata Sisto (Presenter), Karl Grosh (Presenter)

### SUBMISSION DETAILS

**Individual Abstract** George Springer, longtime colleague of Charles and former chair of Stanford Aeronautics and Aerospace Department says Charles is a “mad” scientist- which best describes him in many ways. Charles is not a “normal” scientist. He is a musician who plays French Horn professionally. He is an avid opera fan who would tell you everything about an opera with sparking eyes. He is a multilingual who had worked on Russian, German, Chinese, Spanish, Swedish, Portuguese and delivered speeches with native language in different countries. He is a birder who would walk into woods, hear bird calling and tell you what kind of bird it is. He kept a schedule of going to gym every morning at 5:30 and going to work at his office till before the Pandemic closedown at Stanford. He practically worked till the last moments of his life by advising students, writing papers and collaborating with his colleagues and partners worldwide. I’d love to share more personal aspects of Charles life with everyone at the Symposium.

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\* Presenting Author

First Name	Last Name	Affiliation
Kelly *	Steele *	Widow of Charles Steele

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**Signature** kelly zhang steele

## Honoring Charles Steele

Charles Steele's entrance into cochlear mechanics: JASA papers from the 1970s through 1980

**Submission ID** 3003163

**Submission Type** Symposia

**Topic** Other

**Status** Submitted

**Submitter** Elizabeth Olson

**Affiliation** Columbia University

**Participant(s)** Sunil Puria (Chair), Elizabeth Olson (Co-chair), Kelly Steele (Presenter), Elizabeth Olson (Presenter), Sunil Puria (Presenter), Anthony Ricci (Presenter), Yanli Wang (Presenter), Renata Sisto (Presenter), Karl Grosh (Presenter)

### SUBMISSION DETAILS

**Individual Abstract** My presentation will review the Steele and Steele + Taber papers published in the Journal of the Acoustical Society of America during the 1970s and through 1980. These papers described the basic physics of the cochlea, showing how the cochlear traveling wave and passive tuning emerged from known physical properties. Charles Steele's pre-cochlear-amplifier work remains central to our current understanding of cochlear mechanics.

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\* Presenting Author

First Name	Last Name	Affiliation
Elizabeth *	Olson *	Columbia University

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**Signature** Elizabeth S. Olson

## Honoring Charles Steele

### From Rockets to Plant Growth, Charles Steele Leaves His Positive Impact

**Submission ID** 3003163

**Submission Type** Symposia

**Topic** Other

**Status** Submitted

**Submitter** Karl Grosh

**Affiliation** University of Michigan

**Participant(s)** Sunil Puria (Chair), Elizabeth Olson (Co-chair), Kelly Steele (Presenter), Elizabeth Olson (Presenter), Sunil Puria (Presenter), Anthony Ricci (Presenter), Yanli Wang (Presenter), Renata Sisto (Presenter), Karl Grosh (Presenter)

#### SUBMISSION DETAILS

**Individual Abstract** I first came to know Charles in his role as a member of the Applied Mechanics faculty while I was a student at Stanford, and have been lucky to have him as a colleague in cochlear mechanics for many years. Charles taught a canonical sequence of classes on the mechanics of plates and shells. I will recount a delightful spring term I spent learning shell theory from Charles, who always brought a human view of the material he covered. The Applied Mechanics community was tight-knit back in the 1990's, and I enjoyed interacting with Charles's students and learning of the diversity of topics his group covered. Charles made an impact in four different areas: the analysis of shells as structural elements, bone remodeling and density estimation, cochlear mechanics, and plant morphogenesis, an amazing breadth of study. Charles's work has been recognized in many ways; one was the 1999 ASME Koiter medal. In his acceptance presentation for that award, he lucidly described some of his work on the influence of shell buckling in plant morphogenesis, and I will endeavor to summarize his work with P. B. Green, J. Dumais, and other colleagues in this area. Finally, I wanted to recognize Charles's incredible service to the community as editor of the influential International Journal of Solids and Structures (Editor in Chief from 1985-2005!). With his passing, we have lost a giant in the field and a role model for how engineers can make an impact in biology.

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\* Presenting Author

First Name	Last Name	Affiliation
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Karl *	Grosh *	University of Michigan
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**Signature** Karl Grosh

## Honoring Charles Steele

### How the Analytical Wkb Approach to 3d Cochlear Models by Charles Steele is Still the Basis for Our Understanding of Cochlear Mechanics

**Submission ID** 3003163

**Submission Type** Symposia

**Topic** Other

**Status** Submitted

**Submitter** Renata Sisto

**Affiliation** INAIL Research

**Participant(s)** Sunil Puria (Chair), Elizabeth Olson (Co-chair), Kelly Steele (Presenter), Elizabeth Olson (Presenter), Sunil Puria (Presenter), Anthony Ricci (Presenter), Yanli Wang (Presenter), Renata Sisto (Presenter), Karl Grosh (Presenter)

#### SUBMISSION DETAILS

**Individual Abstract** Although numerical models may be more efficient for including realistic details of the Organ of Corti in cochlea models, the analytical approach to cochlear mechanics still prevails whenever a deeper intuitive understanding of the most relevant phenomena is required. Charles Steele used his uncommon mathematical skill to elaborate cochlear model in terms of the most relevant physical phenomena and their equations. His 3d WKB models are probably still the best way to fully describe the cochlear phenomenology in terms of fluid field dynamics and fluid-structure interaction. In this presentation we will show how the most relevant aspects of the cochlear hydrodynamics had already been taken into account by Steele's WKB solutions, developed in the 70's, and propose our interpretation.

The complete approach to the 3d hydrodynamics of the cochlea permits the correct understanding of an important short-wave effect, which we name the "fluid focusing effect". This effect is related to the flux conservation of an incompressible fluid, and becomes relevant in the "peak region", where the traveling wave (TW) wavelength is shorter than the cochlear duct height,  $H$ . In this region, only a layer of thickness comparable to wavelength of fluid is involved in the TW dynamics and in the energy exchange between structure and fluid. Charles took this phenomenon into account by defining an effective mass of the system reduced by a factor of order of the ratio between  $H$  and the wavelength of the traveling wave in the short-wave region. Following Shera et al. (2005), we describe this effect as a boost to the differential pressure, driving the BM motion, produced by a geometrical shape factor.

In the 3d fluid field equations developed by Charles, the effect of viscosity in the peak region is also analytically taken into account. Without the damping effect of viscosity, which in the peak region is also proportional to the local wavenumber, it is quite difficult to get the stabilization of the response that permits to get both a high peak gain and a rapid decay of the response immediately after the peak. Recently, we showed how the pressure focusing and viscous damping effects can be included

in a correction to the 1d transmission line admittance. Charles had understood the importance of geometrical and viscous effects from the beginning of his activity. Based on this ansatz, he was also able to give accurate estimates of the power balance in the traveling wave propagation.

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First Name	Last Name	Affiliation
Renata *	Sisto *	INAIL Research
Arturo	Moleti	Physics Dept., University of Roma Tor Vergata

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**Signature** Renata Sisto

## Honoring Charles Steele

Charles Steele's contributions to numerical solutions for shells of revolution

<b>Submission ID</b>	3003163
<b>Submission Type</b>	Symposia
<b>Topic</b>	Other
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<b>Submitter</b>	Sunil Puria
<b>Affiliation</b>	Harvard Medical School, Mass. Eye & Ear Infirmary
<b>Participant(s)</b>	Sunil Puria (Chair), Elizabeth Olson (Co-chair), Kelly Steele (Presenter), Elizabeth Olson (Presenter), Sunil Puria (Presenter), Anthony Ricci (Presenter), Yanli Wang (Presenter), Renata Sisto (Presenter), Karl Grosh (Presenter)

### SUBMISSION DETAILS

**Individual Abstract** Charles Steele was a gentle soul and I miss his calm demeanor. We started working together when I moved to the Bay Area in 1997. Charles contributed to many fields but in our field, he was known for cochlear mechanics. We co-advised many trainees together and shared a flourishing lab. As he learned more about the middle ear, he said 'who knew that the middle ear was so interesting.' He was driven by curiosity. When I get stuck on a problem, I often think about how Charles would address this. But fortunately for us, he left us with many breadcrumbs to follow in the scientific literature. In addition to the 3D WKB approach, one of the computational approaches he developed is the FAST4 method and its application to the organ of Corti. This approach used axisymmetric shells of revolution and allowed calculations at multiple length scales from the nano-meter dimension tip links to the mm scale fluid spaces. This was an alternative finite-element modeling approach but one that was far more efficient. He would boast that he could compute organ of Corti responses in a matter of seconds on his laptop while standard finite-element approaches took days for the same problem. I will attempt to summarize a few of his papers in this area (Steele and Shad, 1995; Steele et al. 2009). He was my primary collaborator at Stanford, but he mentored all of us in the Mechanical Engineering Department. Just a few weeks before he passed away, he provided constructive feedback on a paper we co-authored. How amazing! He gave us hope that as we ourselves get older, we can do good science late into life.

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\* Presenting Author

First Name	Last Name	Affiliation
Sunil *	Puria *	Harvard Medical School, Mass. Eye & Ear Infirmary

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**Signature** Sunil Puria

## Honoring Charles Steele

Emeritus Professor Charles Steele

**Submission ID** 3003163

**Submission Type** Symposia

**Topic** Other

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**Submitter** Anthony Ricci

**Affiliation** Stanford University

**Participant(s)** Sunil Puria (Chair), Elizabeth Olson (Co-chair), Kelly Steele (Presenter), Elizabeth Olson (Presenter), Sunil Puria (Presenter), Anthony Ricci (Presenter), Yanli Wang (Presenter), Renata Sisto (Presenter), Karl Grosh (Presenter)

### SUBMISSION DETAILS

**Individual Abstract** I knew of Charles's work since I was graduate student, but I did not get to know Charles until 2006 when I moved to Stanford. At that time, Charles had emeritus status, something I never realized until years later because his work ethic, his enthusiasm for science and for mentoring and his productivity were unmatched. During the past several years, Charles was a regular member of our lab meetings and journal clubs and regardless of the topic had information and insight and a unique perspective. You always felt good after talking with Charles. I will present on several recent projects with Charles that highlight his creativity, his ability to simplify difficult questions and his diversity. Examples include calculating diffusion coefficients for dyes within the lipid bilayer, estimating pressure drops across cochleostomies, and estimating fluid flow around sensory hair bundles.

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First Name	Last Name	Affiliation
Anthony *	Ricci *	Stanford University

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**Signature** A Ricci

## Honoring Charles Steele

### Mentoring the Love of Life beyond WKB and Finite Element Modeling of the Cochlea

<b>Submission ID</b>	3003163
<b>Submission Type</b>	Symposia
<b>Topic</b>	Other
<b>Status</b>	Submitted
<b>Submitter</b>	Yanli Wang
<b>Affiliation</b>	Harvard Medical School, Massachusetts General Hospital
<b>Participant(s)</b>	Sunil Puria (Chair), Elizabeth Olson (Co-chair), Kelly Steele (Presenter), Elizabeth Olson (Presenter), Sunil Puria (Presenter), Anthony Ricci (Presenter), Yanli Wang (Presenter), Renata Sisto (Presenter), Karl Grosh (Presenter)

#### SUBMISSION DETAILS

**Individual Abstract** Charles not only made cochlear mechanics fascinating and beautiful for me, but also filled my world with wonder and warmth. I was Charles' last PhD student working with him from 2013 to 2018. Our first work investigates the energy flow in the cochlea based on a 3D WKB model of the mouse cochlea. Charles always had the magic to make the equations and symbols dance in front of my eyes. Charles' curious and patient eyes can inspire the dullest soul. My second project was an experimental project investigating the in situ motion of individual inner hair cell stereocilia. For an engineering student, learning wet lab experiments from ground zero wasn't easy. Charles' encouragement was paramount, not to mention the support of quick hands-on finite element models here and there in parallel with the experiments, for example, the investigation on the effect of the holes on the pressure drop in the cochlea. Long after I graduated, it was still fun to pick up the phone and talk about my newest model with Charles, not to mention the road trip he and his wife took me on to visit relatives and friends, and the cultural gems in Germany. A true mentor like Charles doesn't just teach engineering and science with clarity, passion, and beauty, but also embodies the groundedness and spaciousness in front of difficulties, the wisdom of staying true and humble, and a deep love to the world, to the people, and to the earth. There is nothing more humbling than Charles' humbleness and loving presence. The impact of a PhD advisor on their students can be a lifelong fortune, and I definitely consider myself one of the most fortunate to be under Charles' wings of wisdom and love. This heart is forever changed to be warmer, more patient, and more loving. Thank you Charles.

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First Name	Last Name	Affiliation
Yanli *	Wang *	Harvard Medical School, Massachusetts General Hospital

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**Signature** Yanli Wang