Coexistence of order and chaos in C majorPaul M. Branson,^{1,*} M. Rayson,¹ M. Ghisalberti,² and G. N. Ivey¹¹*Ocean Graduate School, University of Western Australia, Crawley, Western Australia 6009, Australia*²*Department of Infrastructure Engineering, University of Melbourne, Parkville, Victoria 3010, Australia*

(Received 2 February 2018; published 17 October 2018)

This paper is associated with a video winner of a 2017 APS/DFD Gallery of Fluid Motion Award. The original video is available from the Gallery of Fluid Motion, <https://doi.org/10.1103/APS.DFD.2017.GFM.V0053>

DOI: [10.1103/PhysRevFluids.3.100510](https://doi.org/10.1103/PhysRevFluids.3.100510)

Fluid dynamics is a chorus of energy interacting at a range of scales. These interactions can evolve into beautiful ordered patterns or chaotic random processes and frequently involve the superposition of both. Through fluid dynamics experiments it is possible to illuminate such patterns and processes. The transition from the ordered laminar state to the chaotic turbulent state remains one of the fundamental areas of fluid dynamics research. One of the defining characteristics of order (coherent structure) in fluid mechanics is instantaneous phase correlation (of velocity or vorticity) over a connected spatial extent or region [1]. The regions of correlated motion can manifest in a variety of shapes and patterns, for example the waves that grow in the laminae of an unstable boundary layer or the vortices that form around bluff bodies (see Fig. 1). In contrast to the “ordered” motion of waves and vortices, turbulence is characterized by seemingly random, chaotic motions that occur simultaneously across a range of scales and decorrelate rapidly in space and time. This is demonstrated through the turbulent “spots” that burst from the boundary layer (see Fig. 2) and turbulent streaks that encroach from the right on the ordered flow structures present around the bluff mounted cylinder.

The flow features were visualized by illuminating slightly negatively buoyant particles. The negative buoyancy of the particles resulted in them resting on the bottom, while still being easily mobilized by the fluid motion. A commonly applied technique in fluid mechanics to characterize the periodicity of the fluid motion in space or time is Fourier analysis. This technique represents a measured signal as the sum of a finite number of sinusoidal waves with varying frequency, amplitude, and phase. In order to generate the sound heard in the video, the fast Fourier transform (FFT) of each frame of the video was calculated to obtain a spectrogram. The frequencies were averaged into 12 bins of increasing wave number (in units of pixels) and the wave numbers replaced by the frequencies of 12 tones from the C-major chord (comprising the notes C, E, and G), see Fig. 3. The amplitude and phase information for each frequency bin was retained from the images and an inverse Fourier transform performed to reconstruct a sound wave from the mapped spectrogram. This allowed the features and changes of the flow to be both seen and heard.

*Corresponding author: paul.branson@research.uwa.edu.au

Published by the American Physical Society under the terms of the [Creative Commons Attribution 4.0 International](https://creativecommons.org/licenses/by/4.0/) license. Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI.

FIG. 1. “Ordered” Tollmein-Schlichting waves formed in the boundary layer of an oscillatory flow (left). Horseshoe and wake vortices formed around a cylinder (right). The video with these images is available at <https://doi.org/10.1103/APS.DFD.2017.GFM.V0053>

FIG. 2. Turbulent spots bursting from an oscillatory boundary layer during the transition to turbulence (left). Turbulent streaks encroaching on the vortices that form around a bluff mounted cylinder (right). The video with these images is available at <https://doi.org/10.1103/APS.DFD.2017.GFM.V0053>

FIG. 3. Example mappings of the spatial frequency content of the video frames at three time instants to the notes of the C-major chord. The video with these sounds is available at <https://doi.org/10.1103/APS.DFD.2017.GFM.V0053>