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**Tan et al.**

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(54) **APPARATUS WITH A CONTROLLABLE SURFACE FOR UNDERWATER BOUNDARY FLOW**

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(52) **U.S. Cl.**  
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(58) **Field of Classification Search**  
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(56) **References Cited**

U.S. PATENT DOCUMENTS

6,002,184 A \* 12/1999 Delson ..... H02K 23/00 341/20  
6,024,119 A 2/2000 Kirschner  
(Continued)

OTHER PUBLICATIONS

Besse, Nadine, et al.: "Flexible Haptic Display With 768 Independently Controllable Shape Memory Polymers Taxels," IEEE, Transducers 2017, Kaohsiung, Taiwan, Jun. 18-22, 2017, pp. 323-326.  
(Continued)

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(57) **ABSTRACT**

An apparatus including a controllable fluid-contacting surface is provided. In another aspect, the present apparatus includes a flexible membrane and multiple actuators each having an output shaft or activation member coupled to a water-contacting membrane, with the shafts extending in a direction offset from the nominal outer surface of the membrane. A further aspect of the present apparatus includes an underwater vessel including a propulsion source, a flexible  
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