UTM
UNIVERSITI TEKNOLOGI MALAYSIA

COMSOL CONFERENCE
2015 KUALA LUMPUR

FLUID FLOW DURING DESCEMET MEMBRANE DETACHMENT

by

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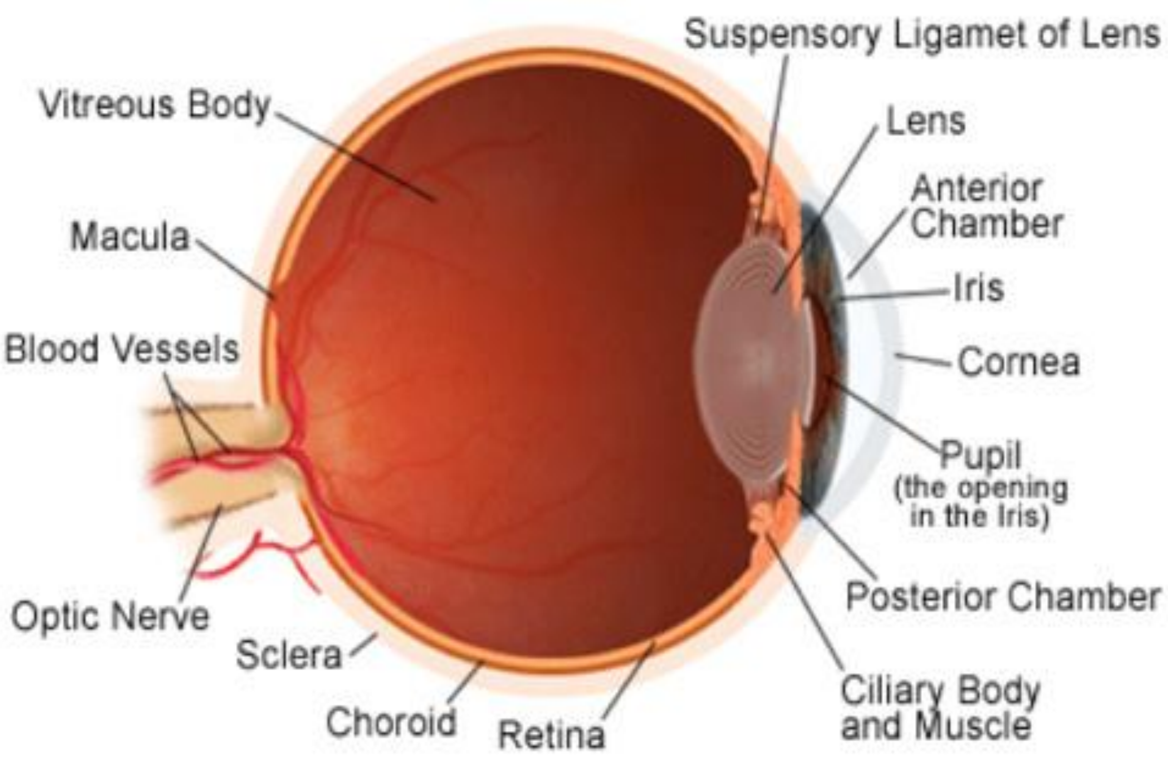
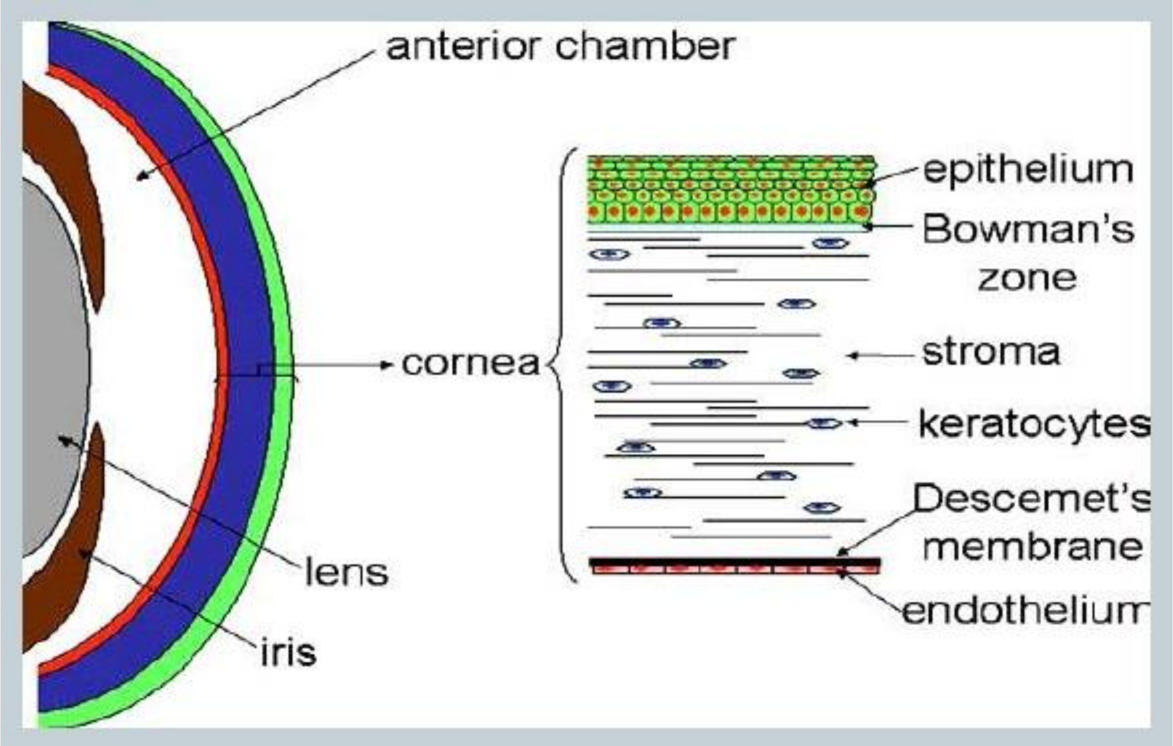
Corneal Structure

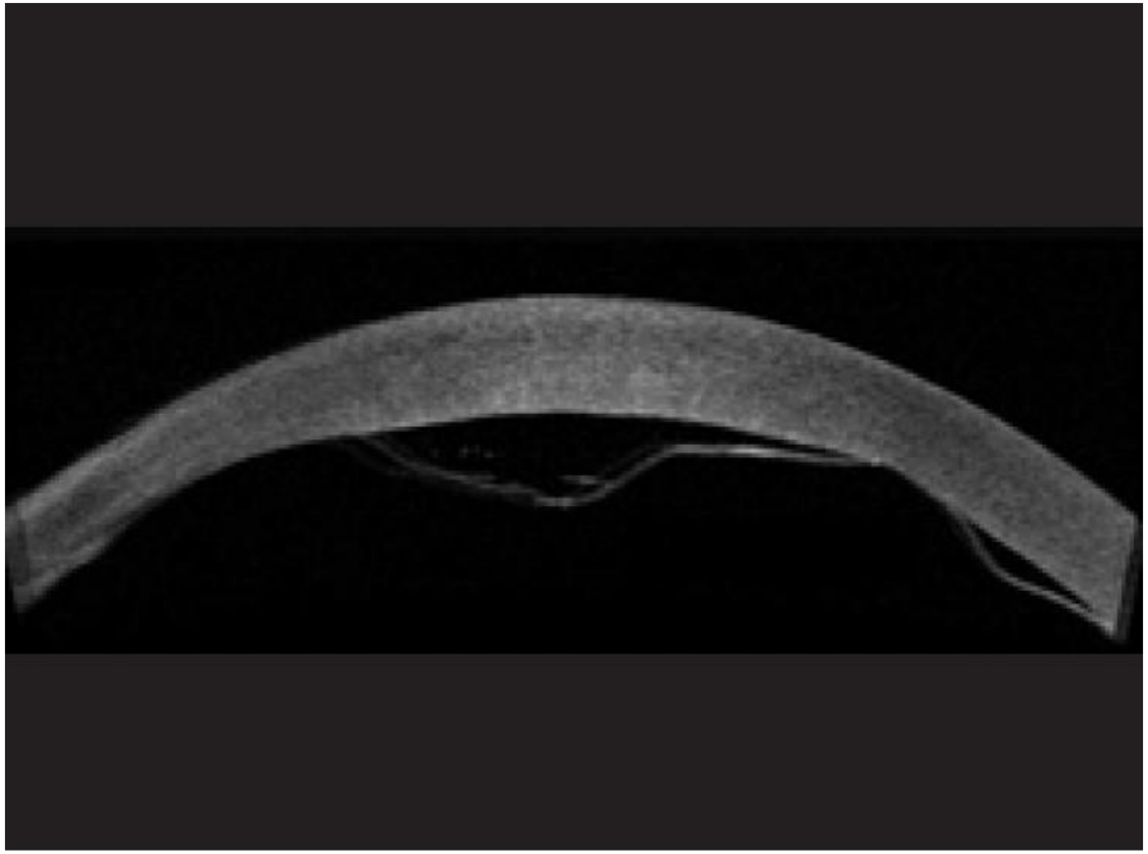


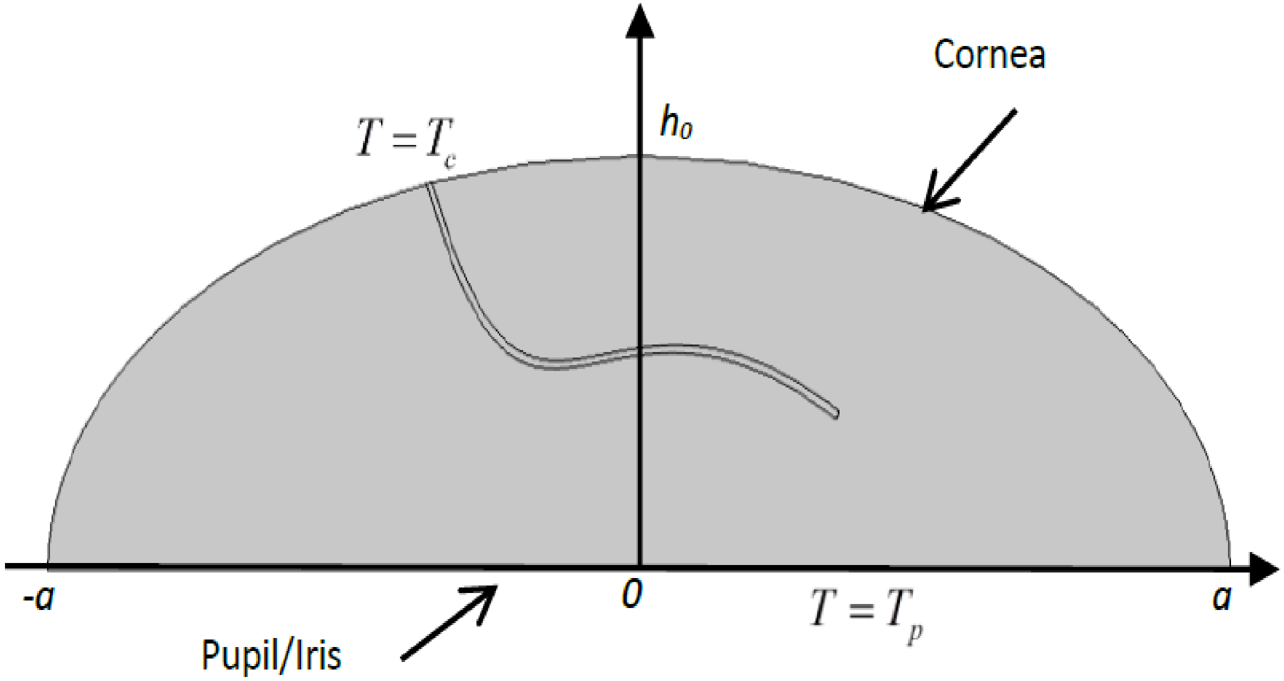


Source : http://weillcornelleye.org/services/corneal_diseases.html

Source : http://www.slideshare.net/AllergyChula/corneal-rejection-1

Descemet Membrane Detachment (DMD)





Source : http://www.ijo.in/article.asp?issn=0301-4738;year=2011;volume=59;issue=4;spage=303;epage=305;aulast=Kothari

Descemet Membrane Detachment (DMD)

1. Canning and associates [1] suggested that even a relatively small temperature difference in anterior chamber (AC) could give rise to the aqueous humour (AH) flow.

2. According to Couch & Baratz [2], a single patient who experienced DMDs in both eyes, one eye was treated surgically , it was noted that the other eye reattached spontaneously after appropriate positioning for the surgical eye.

3. Ismail and associates [3], explained analytically the role of the AH flow driven by the temperature gradient in the AC to the spontaneous DMD attachment.

Assumptions

At the iris

- The temperature is fixed at T_p which is 37 ^{0}C (the human body temperature).

At the Cornea

- The temperature is setted to be T_c , around 35 ^{0}C (as a result of the cornea is cooled by the surrounding air which is estimated to be 24 ^{0}C).

Position of the Patient

- The patient is assumed to be in an upright position so the gravity is acted along the positive *x*-axis as shown in geometry of DMD.

Aqueous Humour

- Similar to the properties of water so AH is Newtonian, viscous and incompressible.

DMD

- A thin and small flap attached onto the anterior surface of the cornea.

To be Realistic

$$h_0 = 2.75mm, \qquad a = 5.5mm.$$

Governing Equations

$$\frac{\partial u}{\partial x}+\frac{\partial w}{\partial z}=0,$$

$$-\frac{\partial p}{\partial x}+\upsilon\rho\left(\frac{\partial^2 u}{\partial z^2}+\frac{\partial^2 u}{\partial x^2}\right)+g\,\rho\left(1-\alpha\left(T-T_c\right)\right)=\rho\left(u\frac{\partial u}{\partial x}+w\frac{\partial u}{\partial z}\right),$$

$$-\frac{\partial p}{\partial z}+\upsilon\rho\left(\frac{\partial^2 w}{\partial z^2}+\frac{\partial^2 w}{\partial x^2}\right)=\rho\left(u\frac{\partial w}{\partial x}+w\frac{\partial w}{\partial z}\right), \qquad (1)$$

$$\frac{k}{\rho C_p}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial z^2}\right)=u\frac{\partial T}{\partial x}+w\frac{\partial T}{\partial z}.$$

Boundary Conditions

$$u(x,z) = w(x,z) = 0, \qquad T = T_p, \qquad z = 0,$$

$$u(x,z) = w(x,z) = 0, \qquad T = T_c, \qquad z = h(x), \qquad (2)$$

$$p = p_a, \quad x = a.$$

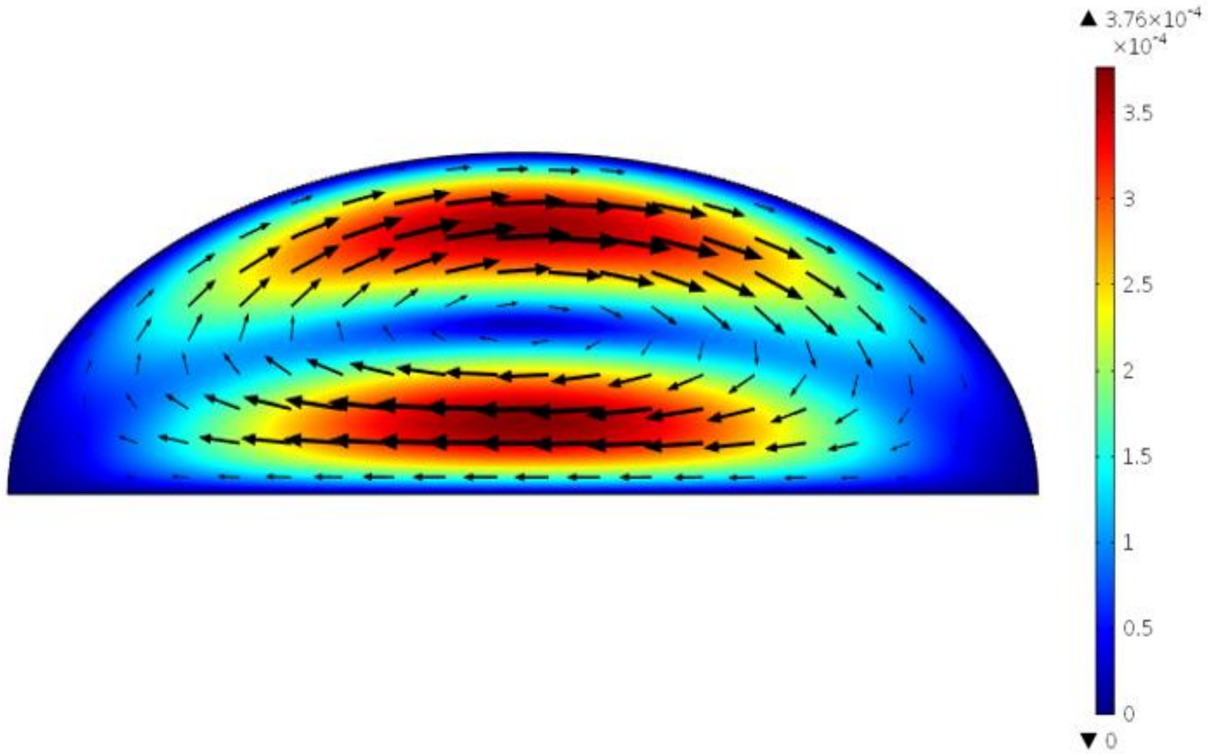
Cont.

υ	the kinematic viscosity	$0.9\times10^{-6}m^2s^{-1}$
ρ	the density	10^3kgm^{-3}
α	the coefficient of linear thermal expansion of the fluid	$3\times10^{-4}K^{-1}$
k	the specific heat	$0.57Wm^{-1}K^{-1}$
C_p	the thermal conductivity	$4200Jkg^{-1}K^{-1}$
g	the gravity	$9.8ms^{-1}$
h_0	a typical depth of the AC	$2.75mm$
T_c	temperature at the cornea	$310.15K$
T_p	temperature at the plane formed by the pupil and the iris	$308.15K$

COMSOL Implementation

- The interface of Laminar Flow and Heat Transfer in Fluids, is applied to study the mechanisms of the fluid flow in DMD.
- The temperature at the pupil/iris is fixed at 37 *Celsius* (the human body temperature), and the temperature at the cornea is assumed to be around 35 *Celsius* as a result of the cornea is cooled by the surrounding air which is estimated to be 24 *Celsius*.
- The gravity, g is acted along the positive x-axis because the patient is assumed to be in an upright position.
- The boundary conditions for velocities, u and w, are all non-slip condition.
- In order to confirm the problem converge, pressure at a point is arbitrary fixed in the model using the point settings.

Verification & Validation

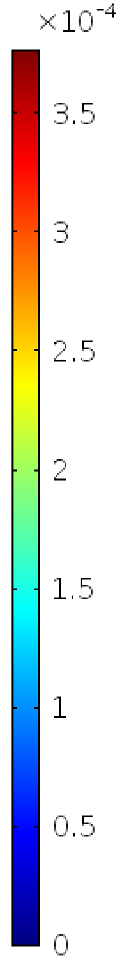


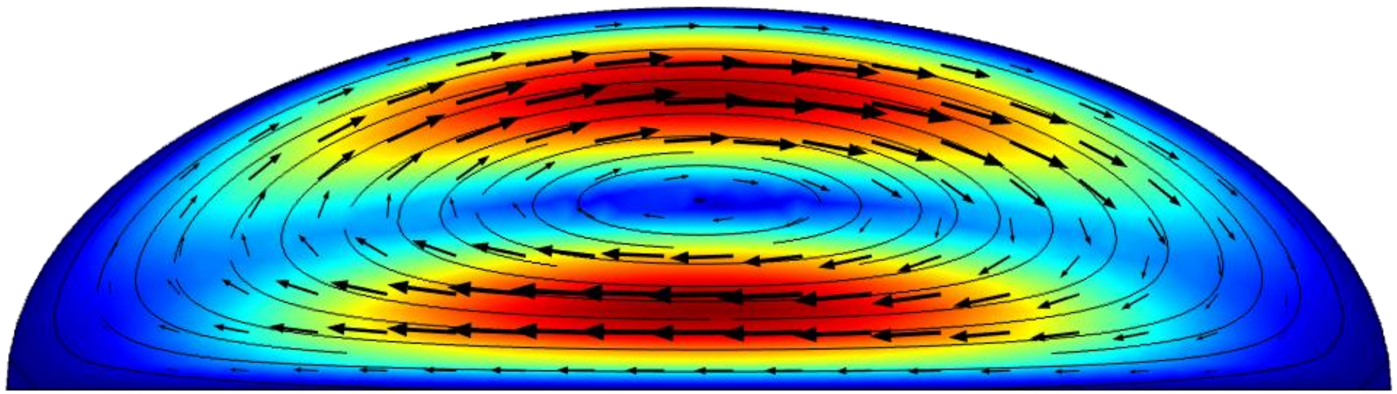
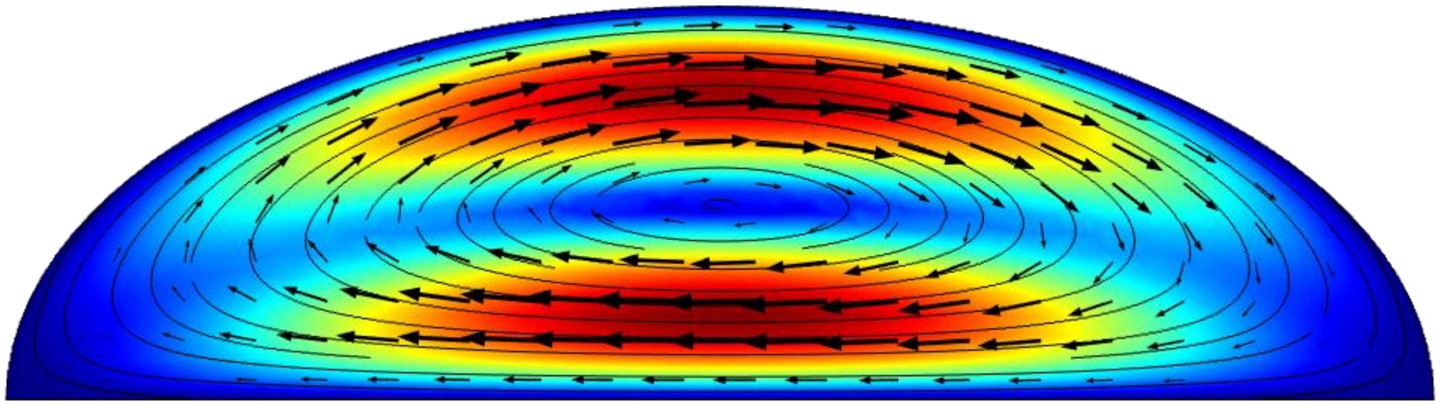
Streamline and countour plot for velocity profile of case without DMD.

- The streamline and contour plot for the fluid flow in the anterior chamber driven by the buoyancy convection without the DMD is plotted and is concur to the streamline plotted by Ismail and associates [3] (see Fig. 3 in [3]).

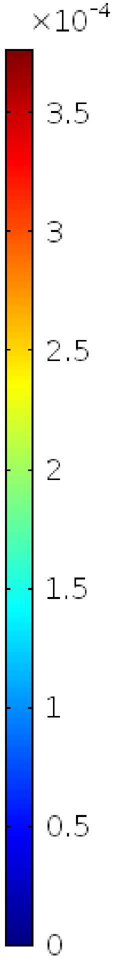
- The maximum flow speed computed in this study is 3.680×10^{-4}[m/s] which exist at position (0, 5.441×10^{-4}) and, Ismail and associates [3], determined analytically that the maximum flow speed exist at (0, 5.811×10^{-4}) with the value 3.962×10^{-4}[m/s].

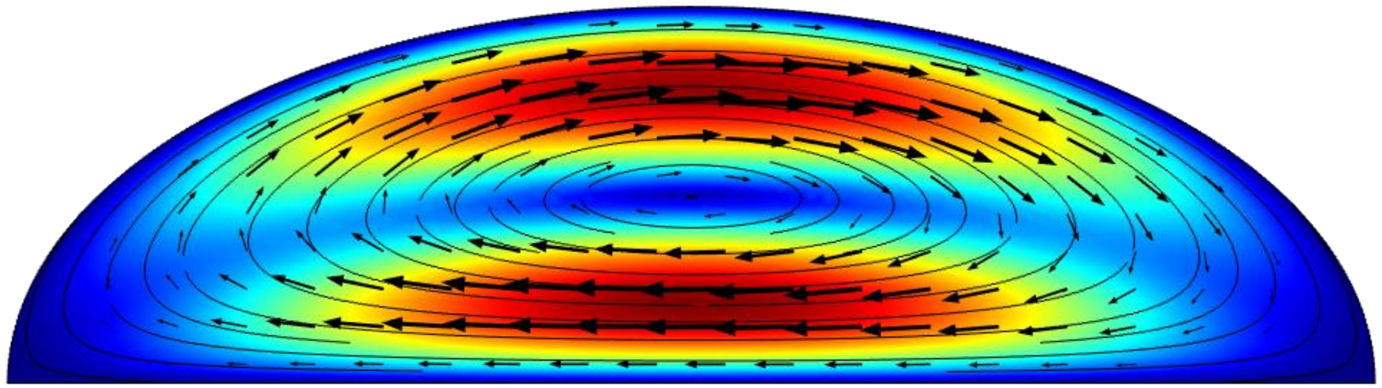
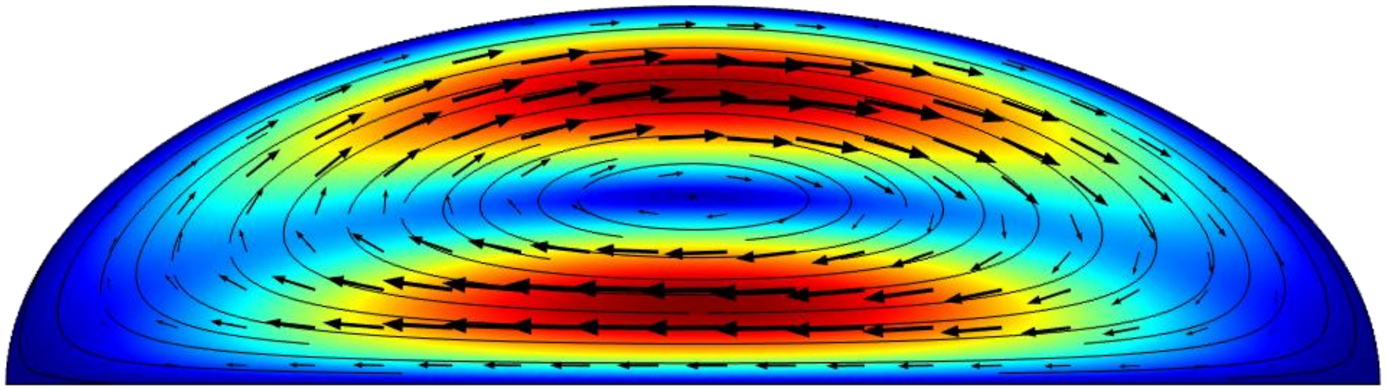
Mesh Test



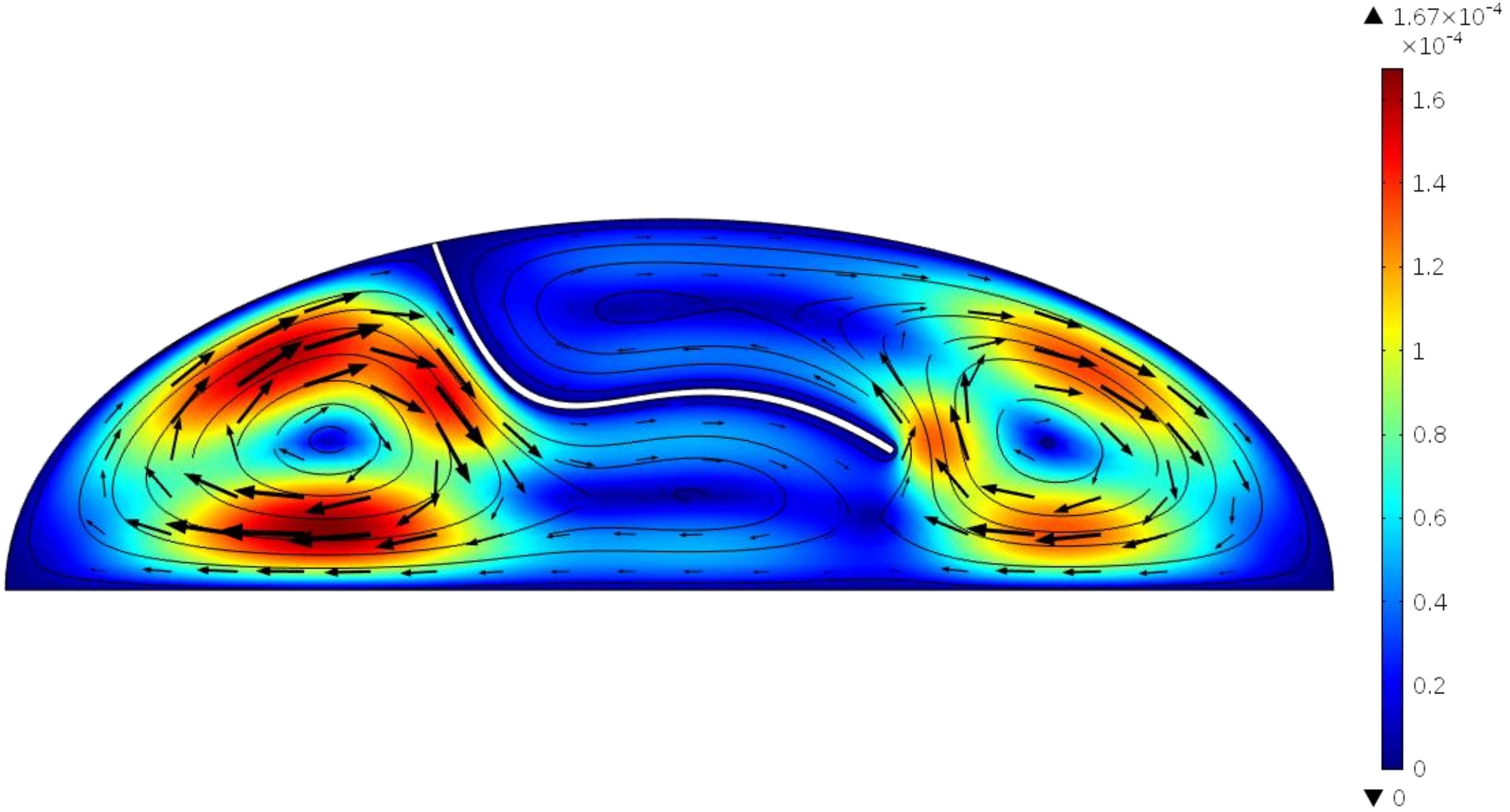
	Number of vertex elements: 3 Number of boundary elements: 94 Number of elements: 1042 Minimum element quality: 0.8865
	Number of vertex elements: 3 Number of boundary elements: 123 Number of elements: 1757 Minimum element quality: 0.8718

Cont.

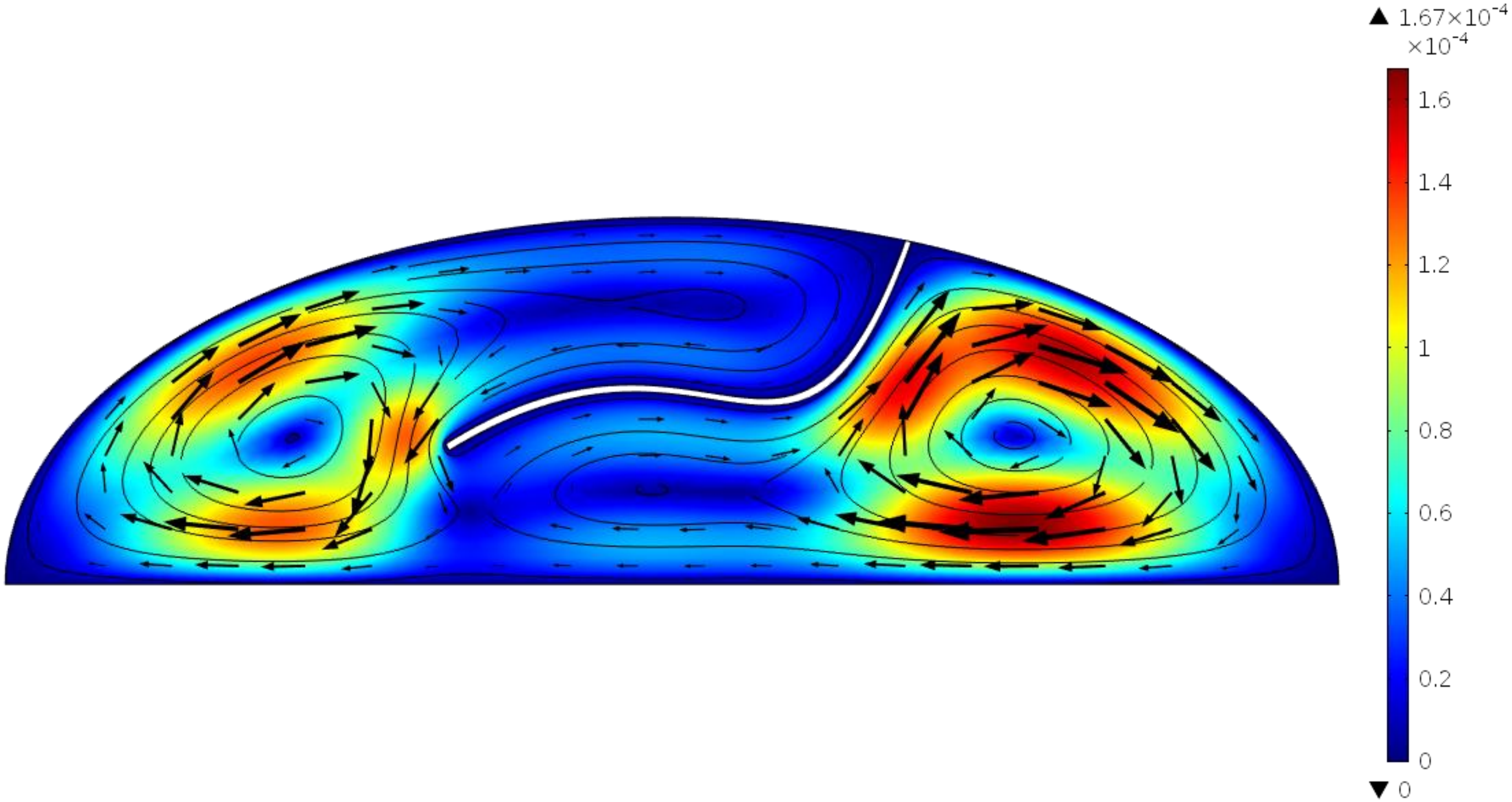


	Number of vertex elements: 3 Number of boundary elements: 181 Number of elements: 3797 Minimum element quality: 0.763
	Number of vertex elements: 3 Number of boundary elements: 234 Number of elements: 6292 Minimum element quality: 0.8629

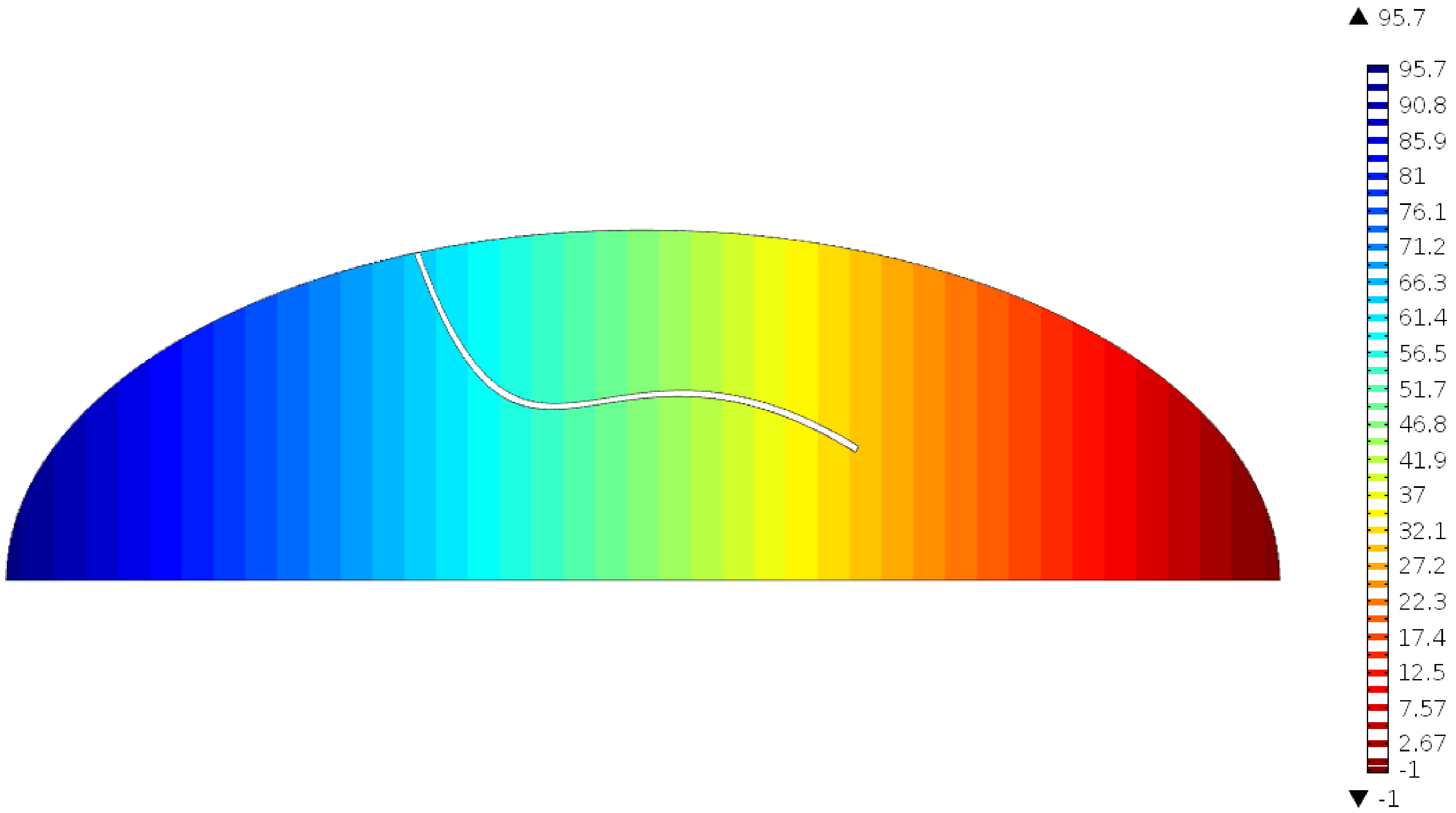
Results & Discussions



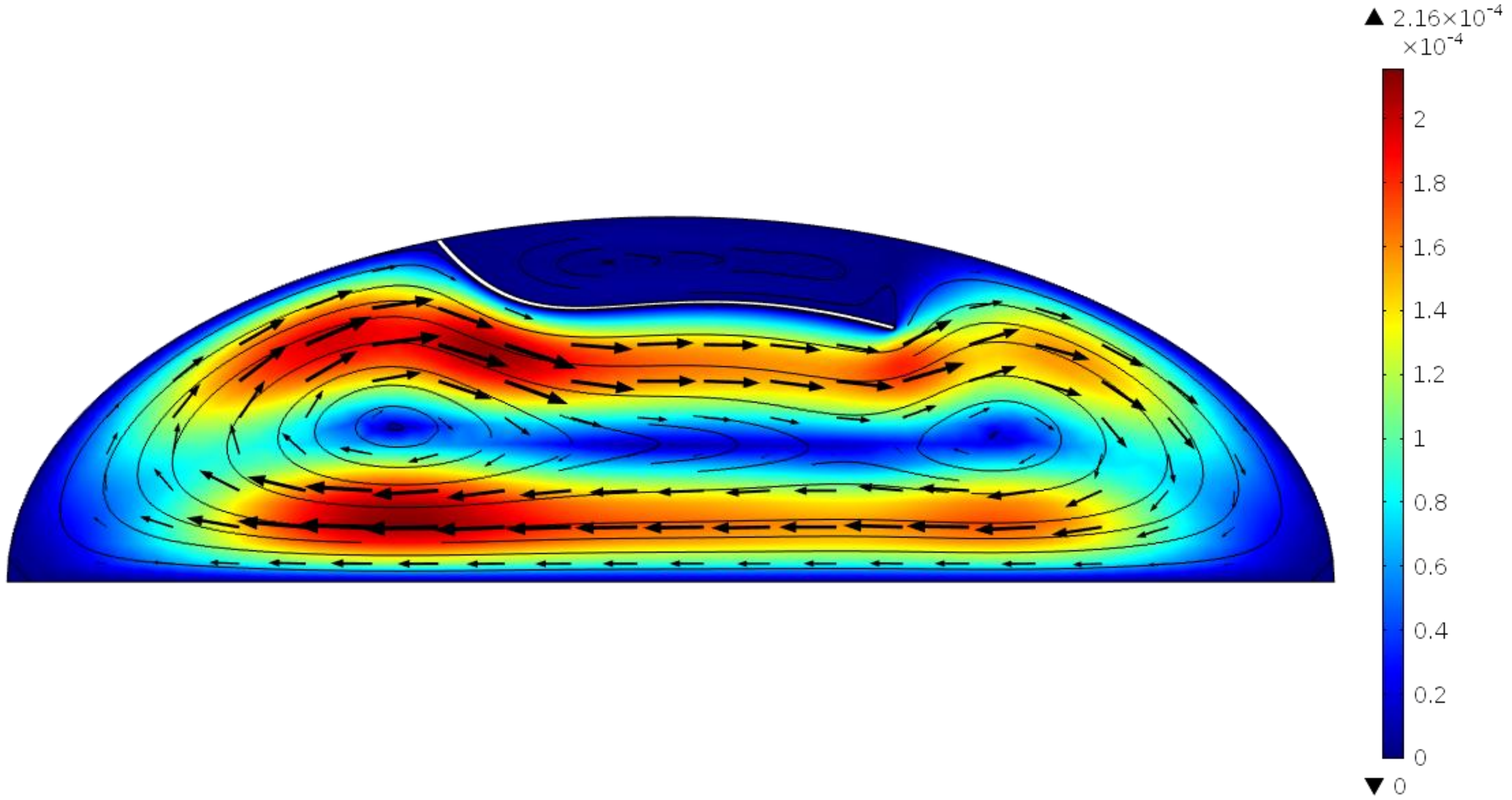
Results & Discussions



Results & Discussions



Results & Discussions



Results & Discussions

- The DMD do affect the fluid flow behavior in the anterior chamber which driven by the temperature difference between the pupil and the cornea.
- Under certain circumstances the DMD may spontaneous reattach, and in some cases the DMD seems likely to become worse.

Conclusion

The behaviour of the AH flow driven by the buoyancy force through the DMD have been studied. COMSOL Multiphysics can effectively be used to simulate the fluid flow in DMD. This is validated when the computed solutions have a great agreement with the theoretical solutions for the case without DMD.

In our opinion, more research have to be done in order to fully understand the behaviour of the AC flow under DMD. The effect of the blinking of the eye may affect the temperature gradient in the AC, therefore will change the fluid flow in the AC. For further research, the effect of the blinking of the human eye have to be considered. Besides that, how will the DMD react to the fluid flow that access on its surface and also how the fluid behaviour change based on the deformation of the DMD?

This will be the next problem we are going to investigate for the aim to full realize the mechanism of the DMD under the effect of fluid flow of AC that driven by temperature gradient.

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References

[1]. C. R. Canning, M. J. Greaney, J. N. Dewynne, and A. D. Fitt, "Fluid flow in the anterior chamber of a human eye," *IMA Journal of Mathematics Applied in Medicine and Biology*., vol. 19, pp. 31-60, 2002.

[2]. S. M. Couch, and K. H. Baratz, "Delayed, bilateral Descemet's membrane detachments with spontaneous resolution: implications for nonsurgical treatment. *Cornea*, vol. 28, 1160-1163, 2009.

[3]. Z. Ismail, A. D. Fitt, and C. P. Please, "A fluid mechanical explanation of the spontaneous reattachment of a previously detached Desecement membrance.," *Mathematical Medicine and Biology*, vol. 30, pp. 339-355, 2013.

THANK YOU