

# The significance of Shear Stress in Cosmology

## ABSTRACT

*The concept of shear stress forms a fundamental base for meteorology and oceanography, which is the heritage of classical physics. In this paper, we show by well understood physical reasoning that it is also fundamental to cosmology although this link has not been previously recognised. The key physical model is that of the sea surface where two fluids (air and water) of high density contrast interact giving rise to a constant shear stress layer and wave breaking.*

*In cosmology, we show that two analogous, equal and opposite stress layers, due respectively to the formation of galaxies on the large scale and to their destruction by black holes on the small scale, constitute the physical model for the Universe, in which the mean shear stress is zero. The consequences of this condition for the expanding Universe are shown in a simple model. Two comparative images are also presented which illustrate the similarity between stress fields observed in a laboratory experiment and in the cosmos.*

**Keywords:** *Shear stress; net-zero cosmic stress; the evolving Universe*

## 1. INTRODUCTION

The science of meteorology and oceanography is built on stress, in particular on shear stress, the importance of which far outweighs normal stress. My longstanding interest in stress began with a doctoral investigation of the circulation in rectangular basins driven by a wind stress and retarded by a bottom stress, through which a steady-state can be achieved [1]. This idealised model has many hidden secrets. In particular, what proportion of the surface shear stress is the wind stress available to the water, and what proportion is returned to the air by the wave field. This latter proportion may be called the understress [2] in distinction to the bottom stress. Understress quantifies the loss of momentum to the air in addition to the loss of momentum to the bottom of the basin. In many situations the bottom loss is much greater than the surface loss, and also there is an imbalance between wind stress and bottom stress, which is made good by a pressure gradient due to a surface slope on the water surface set up by the side walls of the basin [3]. In an unconfined region however an equilibrium can only be obtained by establishing a zero net stress in which the understress is equal and opposite to the wind stress.

30 This stress balance, which is the subject of this paper, does not seem to have been previously  
31 investigated for the cosmos.

## 32 **2. COSMIC STRESS**

33 In [5], it was shown that an approximate zero net stress occurs in the Newtonian dynamics of  
34 the planetary system [4]. This observational result has stimulated this study in which the  
35 mass of the orbiting body is expressed as an annular density ( $\rho$ ) and the friction between the  
36 orbiting bodies is represented by the Prandtl frictional force [3] used in fluid dynamics.

37 The basic relation in Newton's gravitational model is,

$$38 \quad U^2 = G (M + M_o)/R \quad (1)$$

39 where  $U$  is the orbital velocity,  $G$  is the universal gravitational constant,  $M_o$  is the mass of the  
40 Sun and  $M$  is the planetary mass. In Newton's model, the orbital shear stress,  $\tau_{R\phi} = \rho |u_*| u_*$ ,  
41 where  $R$  is the radial co-ordinate and  $\phi$  is the azimuthal co-ordinate, and  $u_*$  is the friction  
42 velocity, which in Prandtl's frictional model is,

$$43 \quad \rho^{1/2} u_* = - \kappa [G(M_o + M)]^{1/2} d(\rho R)^{1/2}/dR \quad (2)$$

44 where  $\kappa$  is von Karman's constant [5], and in the planetary system,  $M_o \gg M$ , and for the  
45 Universe  $M \gg M_o$  in which  $(GM)^{1/2} / R_o = c$  where  $c$  is the velocity of light and  $R_o$  is the  
46 radius of the Universe.

47 The stress-free condition is  $(\rho R) = \text{constant}$ . The observed planetary data show that  $(\rho R)$  is  
48 almost a constant between the two planetary groups, which correspond with the terrestrial and  
49 the icy planets [5], from which it is concluded that the frictional force, evaluated for a von  
50 Karman's constant of 0.4, as occurs in turbulent measurements on Earth [7] is very small  
51 compared with the force of gravity, in agreement with a Newtonian stress-free gravitational  
52 model.

53 On the other hand, at radii outside of the region of Newtonian dynamics, either at smaller or  
54 larger scales, the friction velocity in Prandtl's frictional model is,

$$55 \quad \rho^{1/2} u_* = - \kappa (G M)^{1/2} R^{1/2} d\rho^{1/2}/dR \quad (3)$$

56 [6]. Here the dynamics, which may be called Einsteinian, is stress-free for  $\rho = \text{constant}$ . At  
57 the junction of the two regions, there is a constant stress layer, similar to that occurring at the

58 sea surface which is maintained by the wave spectrum where wave breaking occurs [7 and 8],  
59 and the two wave properties of phase velocity in the air, and particle velocity in the water  
60 intersect.

61

62 In the Universe at the junction of the two regions of large annular density contrast, the  
63 expressions for the two friction velocities, (2) and (3), show that the orbital shear stress,  $\tau_{R\phi}$   
64 =  $\pm \frac{1}{4} \kappa^2 \rho c^2$ , where the positive sign occurs if the Newtonian dynamics occurs at a smaller  
65 radius than the Einsteinian dynamics and the negative sign occurs if the Newtonian dynamics  
66 occurs at a greater radius [5 and 6]. The mean orbital shear stress within the Newtonian  
67 regime (which is our Universe) is zero, i.e. stress-free. The positive sign corresponds with  
68 the formation of galaxies and the negative sign with their destruction by black holes. This  
69 process is essentially one of chance in which an infinitesimal event, characterized famously  
70 by Ed Lorenz through a single flap of a butterfly's wings in Brazil, which transforms the  
71 climate in Texas [9].

72 Stress is a compounding of such events, and the cosmic stress model is analogous to the  
73 stress model of the circulation in a rectangular basin presented in [3] with the substitution of  
74 the positive orbital shear stress ( $\tau_{R\phi} > 0$ ) for the wind stress, and of the negative orbital stress  
75 ( $\tau_{R\phi} < 0$ ) for the understress, and the absence of bottom stress, although of course the cosmic  
76 physics is somewhat more complex. In particular, the episodes of positive and negative  
77 orbital stress occur throughout time and space.

78 At the black hole interface, the constant stress layer extends outwards over the range ( $R_1 \geq R$   
79  $\geq R_o$ ), and at the galactic interface, the constant stress layer extends inwards over the range  
80 ( $R_1 \leq R \leq R_o$ ); in both instances into the region of Newtonian dynamics. On the assumption  
81 that the mean velocity of the turbulent fluctuations is the velocity of light, it was found that,

$$82 \quad \frac{1}{8} \kappa^2 (\theta + 1)^2 = (\theta - 1)^2 \quad (4)$$

83 where  $\theta = R_1/R_o$  [6]. From which, at the black hole interface, the positive root yields,  $\theta =$   
84 1.32, which is consistent with the dimension of the bright ring observed around the black  
85 hole [6] suggesting that  $\kappa = 0.4$  may be a universal constant, and at the galactic interface, the  
86 negative root yields,  $\theta = 0.75$ , indicating the extent of the band of galactic formation.

87 The significance of cosmic stress for the Universe is discussed in Section 4. These  
88 conclusions follow from the properties of cosmic stress, which are summarized in this  
89 Section, based on results originally presented in [5 and 6].

### 90 **3. OBSERVATIONS OF STRESS**

91 We illustrate this discussion on a laboratory scale in a circular tank of diameter 380 mm in  
92 which wave fields are generated by rotating a transparent disk above an air gap over the  
93 contained water, and then digitally imposing a counter revolution on the imagery to bring the  
94 dominant wave motion to rest, as described in [10], and on the cosmic scale from telescopic  
95 observations in the neighbourhood of a Galaxy [11]. In both situations, the fetch is infinite  
96 so that the turbulent stress fields, which are assumed to arise in their respective constant  
97 stress layers due to velocity shear, can be compared (Figures 1 and 2). A visual inspection  
98 shows the remarkable result that there is a clear similarity between the two fields, indicating  
99 the uniformity of the stress process over the full range of scale from laboratory to cosmic,  
100 which includes the meteorological scale.

101 The laboratory image was selected from the video imagery to show this similarity, however  
102 other images in which the transparent plate was rotated at a different rate and the air gap was  
103 varied gave rise to a waveform very similar to a spiral Galaxy. The inference from these  
104 observations is that shear stress plays a crucial role in cosmology through a galactic  
105 generation mechanism in which the Newtonian dynamics provides the shear, which is  
106 analogous to that produced by the rotating plate in the laboratory rig.

### 107 **4. THE STRESS-FREE MODEL OF THE EVOLVING UNIVERSE**

108 We may extend the stress-free model to a consideration of the evolution of the Universe, with  
109 due regard to the definition of time. The essential property is that there is no acceleration in  
110 a stress-free state. Hence the evolving Universe expands at the homogeneous rate ( $K(t_0)$ )  
111 which, at the radius ( $R$ ), is satisfied by the relation,

$$112 \quad dR/dt_R = K(t_0), \quad 0 \leq t_0 \leq \infty \quad (5)$$

113 where  $t_R$  is the time observed at the radius ( $R$ ), and  $t_0$  is the absolute time observed at the  
114 origin of the Universe ( $R = 0$ ), and  $K(t_0)$  is the observed expansion rate.

115 The observable time ( $t_R$ ) is related to the absolute time ( $t_0$ ) by the expression,  $t_R = t_0 + R/c$ ,  
 116 which takes account of the difference in time between the origin and the radius ( $R$ ). On  
 117 differentiating this relation with respect to  $t_0$  we obtain,

$$118 \quad \frac{dR}{dt_0} = K(t_0) / (1 - K(t_0)/c) \quad (6)$$

119 which is the rate of expansion of the stress-free Universe at  $t = t_0$  in terms of  $K(t_0)$ .  
 120 Alternatively, we may express the rate of expansion in the form,

$$121 \quad \frac{dR}{dt_0} = \beta(t_0) c \quad (7).$$

122 A comparison of the two expressions (6) and (7) for the rate of expansion yields,

$$123 \quad K = \beta c / (1 + \beta) \quad (8)$$

124 from which it is clear that for an expanding Universe ( $\beta > 0$ ), we require,  $K < c$ , which  
 125 satisfies the Einsteinian condition on the primacy of  $c$ . It also shows that the expansion rate  
 126 ( $\beta c$ ) is equal to the velocity of light ( $c$ ) for  $K/c = 1/2$ . This allows for an arbitrary formation  
 127 mechanism for the Universe, provided only that  $K(t_0)$  satisfies the inequality,  $0 \leq \alpha \leq 1/2$ ,  
 128 where  $\alpha = K(t_0)/c$ .

129 There is a growing question, regarding observations of the recession rates of distant Galaxies  
 130 which are greater than the speed of light, see for example,[14]. The above stress-free model  
 131 answers this question, and predicts that receding Galaxies would be observable out to  
 132 recession rates ( $c + K$ ), up to fifty percent greater than the speed of light ( $c$ ).

133 The predictions of the stress-free analysis can also be compared with the observational data  
 134 on the mass and age of the Universe. A simple model is the following. On differentiating the  
 135 defining relation for  $M$  [5], we obtain on the assumption that  $m_0$  is a constant,,

$$136 \quad \frac{dM}{dt_0} = m_0 \frac{dR}{dt_0} \quad (9)$$

137 where  $M$  is the mass and  $R$  is the radius of the Universe, and  $m_0 = c^2/G$ . On now substituting  
 138 for  $dR/dt_0$  from (6), (9) yields,

$$139 \quad \frac{dM}{dt_0} = m_0 K(t_0) / (1 - K(t_0)/c) \quad (10)$$

140 which, on assuming a decaying exponential model for the expansion rate, is easily solved,  
 141 with the boundary condition that  $M(0) = 0$ . The result is,

142 
$$M(t_0) = M_0 [ (1 - \alpha)^{-2} - \exp(-\gamma t_0)(1 - \alpha \exp(-\gamma t_0))^{-2} ] \quad (11)$$

143 where  $\alpha = K_0/c$  in which  $K_0 = K(0)$  where  $t_0 = 0$  is the time at which the expansion begins in  
144 a 'big bang', and  $M_0 = K_0 T m_0$  in which  $T = \gamma^{-1}$  is the time constant for the decaying  
145 expansion rate, which we identify with the Age of the Universe. For  $\gamma t_0 \rightarrow \infty$ , (11) yields,

146 
$$M \rightarrow c T m_0 \alpha / (1 - \alpha)^2 \quad (12)$$

147 in which  $M$  is the mass of the Universe. Observational data indicate that  $M = 1.5 \cdot 10^{53}$  kg  
148 [12],  $T = 13.8 \cdot 10^9$  yr [13] and  $m_0 = 1.35 \cdot 10^{27}$  kg  $m^{-1}$ , and hence from (12),  $\alpha = 0.35$ , which is  
149 70% of the maximum allowable value of  $\alpha = 0.5$ . The result of this simple model is clearly  
150 consistent with the occurrence of a stress-free state following the origin of the Universe.

## 151 **5. CONCLUSION**

152 This paper shows that shear stress, which has a special place in oceanography and  
153 meteorology, is also a seminal force in cosmology, and is possibly 'the missing something in  
154 the cosmological model' sought after in [14]. Eq. (12) shows that the observed mass and age  
155 of the Universe are consistent with the occurrence of a zero net stress environment  
156 throughout the existence of the Universe. This condition was implicit in Newton's  
157 gravitational theory of the planetary system [4], although this may not have been realized at  
158 the time (except by theologians) and subsequently led to a major division in natural  
159 philosophy.

160 Figures 1 and 2 illustrate the importance of shear stress in constant stress layers ranging from  
161 the laboratory to the cosmic. Within the stress layers, there is a balance between positive  
162 and negative stress so that on average a stress-free environmental process occurs, which on  
163 the cosmic scale is responsible for  $K(t_0)$ , and extends from zero to infinite time, consistent  
164 with the eternal nature of the Universe.

## 165 **ACKNOWLEDGEMENTS**

166 I should like to express my deep thanks, in particular, to Professor Kenneth Bowden who  
167 through the works of Joseph Proudman showed me the logical simplicity of dynamical  
168 oceanography. This precept has been followed in this paper. The comments of the  
169 Reviewers, and the continuing support of Charles James on aspects of the paper are also  
170 gratefully acknowledged.

171 **COMPETING INTERESTS**

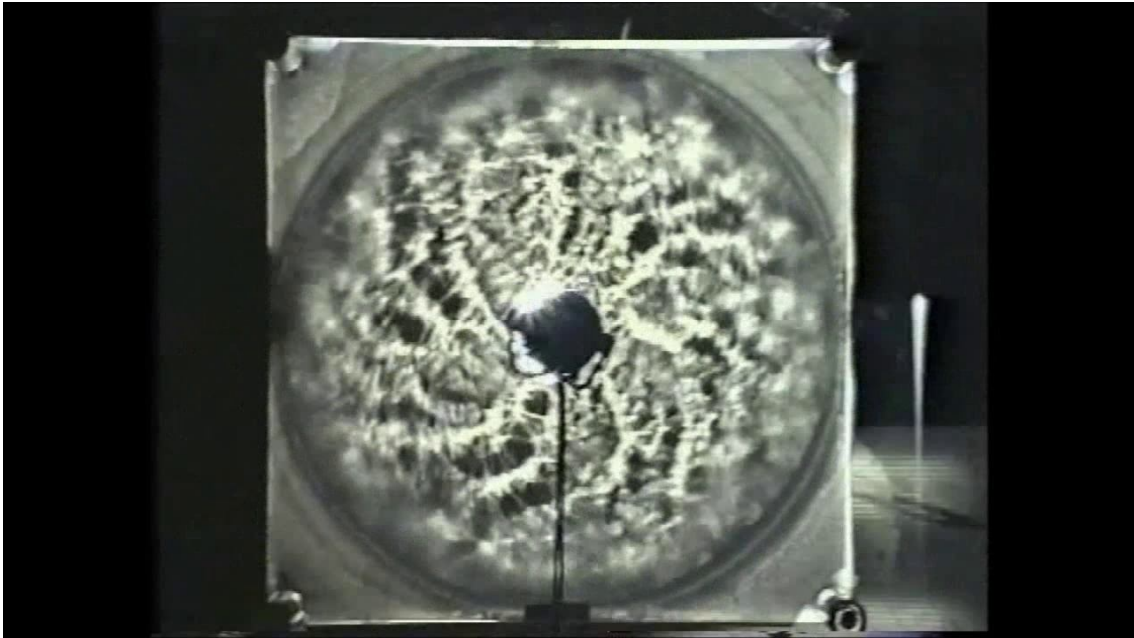
172 Author has declared that no competing interests exist.

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202 Figure 1. Waveforms occurring in a circular tank of diameter 380 mm, in which the  
203 fetch of the wind, generated by a rotating plastic disk at various rotation rates, is  
204 infinite [10].

205



206  
207

208 Figure 2. The chaotic galactic field observed by [11]