臺灣二 OO 四年國際科學展覽會

科　　別：物理科

作品名稱：雙孔渦流的奧秘

得獎獎項：物理科第二名
　　美國第五十五屆國際科技展覽會正選代表

學　　校：國立臺南第一高級中學

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一、研究動機：

從直徑數公分的小漩渦，到直徑可達 10 公尺的巨型海漩；由 F1~F5 級的龍捲風到輕重度颱風，大自然中有各種渦流。不久之前還有雙眼颱風（杜鵑颱風）經過台灣，颱風出現雙眼時其行進路徑常有不尋常的擺動，行進方向忽而偏北，忽而偏南，擺動的頻率比一般颱風來得頻繁，又其結構紮實，對流旺盛，常造成莫大的災害。研究這個主題主要的目的是嘗試探討此雙渦流運動的起因、其運動方式和可能的控制方法。

二、研究目的：

1. 設計一個能產生流體雙漩渦的裝置以探討漩渦產生的機制。
2. 觀察並研究漩渦的運動情形及轉動趨勢。

三、實驗內容：

1. 不同口徑、位置的雙孔落流流出口所形成漩渦的特點
2. 不同水量所形成漩渦的特點
3. 歸納模型並與實驗值比較

四、研究器材：

1. 水槽（100 cm*50 cm*50 cm）
2. 壓克力片（10cm*4cm）14 片(有些有不同孔徑的圓孔)
3. 透明容器（50cm＊50cm＊50cm）
4. 塞子
5. 海綿
6. 數位攝影機
7. 電腦
8. 訊號放大器（需麵包版兩塊、電線、電阻、可變電阻兩個、積體電路五個）
9. 壓力感測器
10. 三用電表
11. 雙電源供應器
12. 電腦軟體(science work shop 500)
13. 針筒（50ml）
14. 水管
15. 細塑膠軟管
16. 三向閥

17. 氣壓計

五、研究方法：

藉由改變控制變因，觀測紀錄應變變因，探究其變化。

1. 控制變因：
   盛水容器之總截面積
   容器底部出水洞口（單孔、雙孔、大小、在底部的位置）
2. 應變變因：
   漩渦產生時水面高度，漩渦內直徑、外直徑的大小

六、實驗與結果：

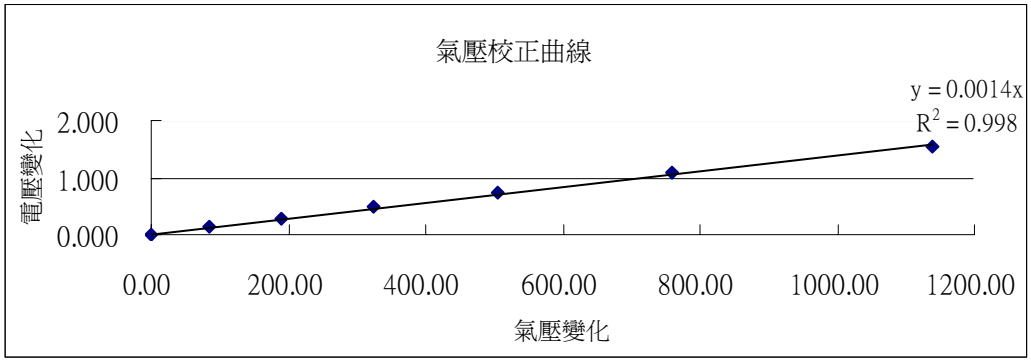
1. 預備實驗--壓力校正曲線

1-1 實驗步驟：

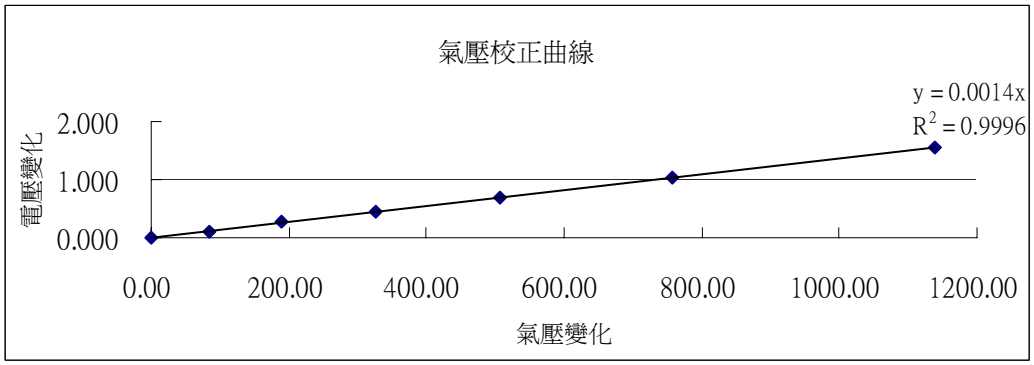
(1) 將壓力感測器之感測端一端接上三向閥並關閉之，並以氣壓計測得目前氣壓為 758.51mmHg；而針筒容積調至 50ml 時以細塑膠軟管與壓力感測器的另一端相接。
(2) 將訊號放大器連接裝設完成的壓力感測器。
(3) 用三用電表測量訊號放大器之工作電壓，調整可影響工作電壓的可變電阻，使訊號放大器工作電壓為 15 伏特。
(4) 將訊號放大器接上雙電源供應器，調整電壓分別為＋15V 及－15V，並接上中性線。
(5) 把三用電表接上感應端，轉到測量為「20V」的測量端。
(6) 打開電源。輕輕壓縮針筒，並同時調整可影響放大倍率的可變電阻，以便能在針筒內的壓力微微改變時，其電壓便有相對大的變化。
(7) 調好放大倍率後,把三用電表接頭換為 science work shop 500 的接頭。
(8) 把針筒歸零（調回 50ml）。
(9) 以 5ml 為間隔變化至針筒內體積為 20ml 測量；每次測量均維持 10 秒，再求其平均值，並重複 4 次。
(10) 測量記錄壓力感測器兩端的電壓。得如附錄之表 1-1 與 1-2 的結果。
(11) 將其畫為折線圖，即為氣壓校正曲線。

1-2 記錄與結果：

(1) 壓力感測器兩端的電壓。如附錄之表 1-1 與 1-2。
(2) 壓力感測器兩端的電壓變化與氣壓變化曲線，如下頁之圖一與圖二



圖一：壓力感測器兩端的電壓隨空氣壓力的變化(一)



圖二：壓力感測器兩端的電壓隨空氣壓力的變化(二)

2. 探討兩孔洞孔徑大小及孔距與雙孔渦流間之關係

2-1 實驗步驟：

(1) 於水槽底部設置 2 孔，孔距固定為 40mm，分別改變兩孔徑之大小。
(2) 定起始水深為 130mm，開始放流。
(3) 以數位攝影機連續攝影，輸入電腦觀察。
(4) 以比例尺的方法分析其產生渦流時的平衡水高及其內直徑、外直徑大小。
(5) 逐次依下表改變兩孔孔徑,分別進行實驗 15 次實驗。

兩孔孔徑變化表(mm)

	A	B	C	D	E
1	(30,30)				
2	(30,25)	(25,25)			
3	(30,20)	(25,20)	(20,20)		
4	(30,15)	(25,15)	(20,15)	(15,15)	
5	(30,10)	(25,10)	(20,10)	(15,10)	(10,10)

(6) 改變兩孔孔距，以 40mm 為間隔，從 40mm 至 200mm，重複（1）到（4）之步驟。
(7) 繪製實驗曲線。

2-2 實驗記錄：

記錄如附錄表 2-1~2-5。整理後為表 3。(其中*號表示未出現渦流)

並繪出其關係圖如下。

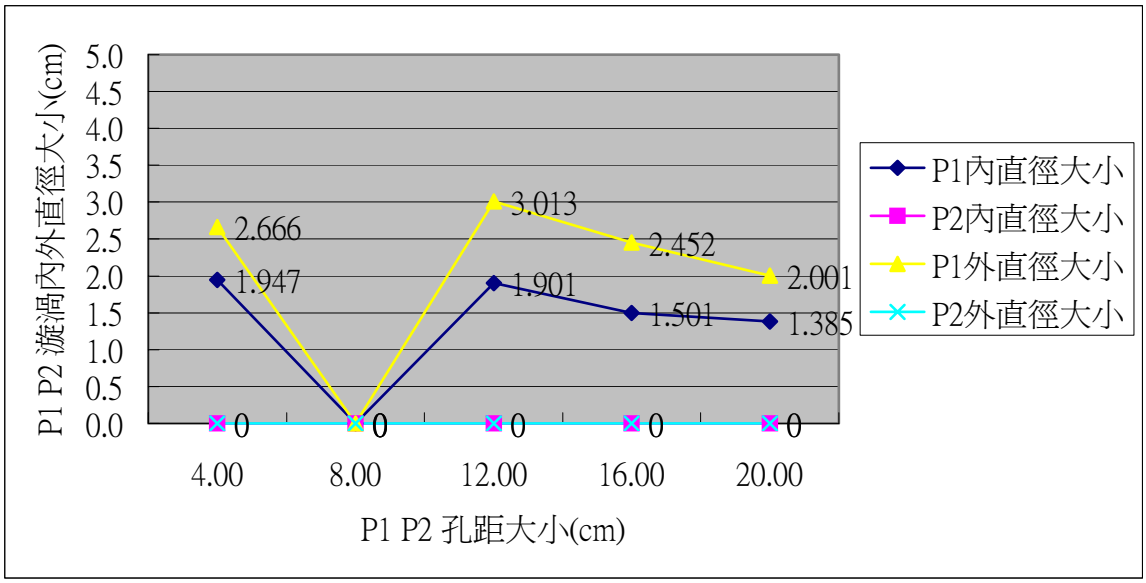


圖 3-1 兩孔徑為 30mm 30mm 時在不同孔距的內外直徑

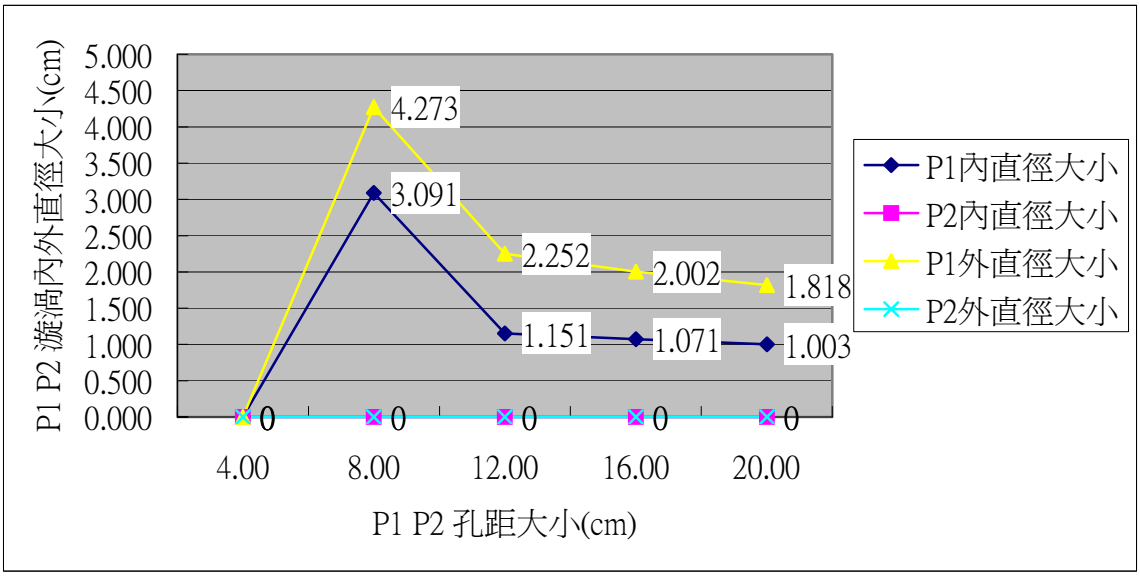


圖 3-2 兩孔徑為 30mm 25mm 時在不同孔距的內外直徑

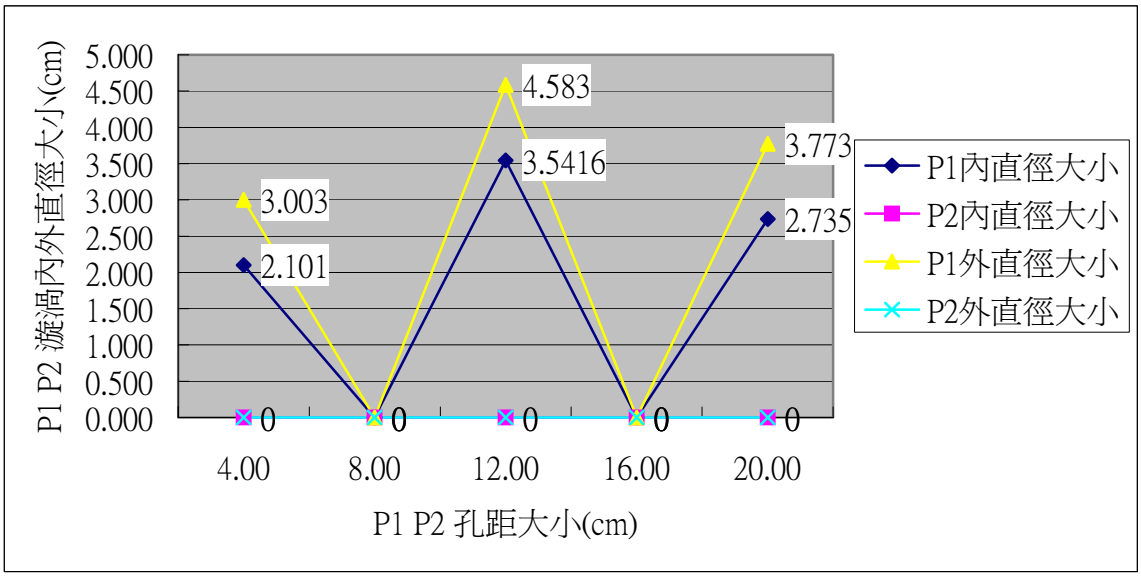


圖 3-3 兩孔徑為 30mm 20mm 時在不同孔距的內外直徑

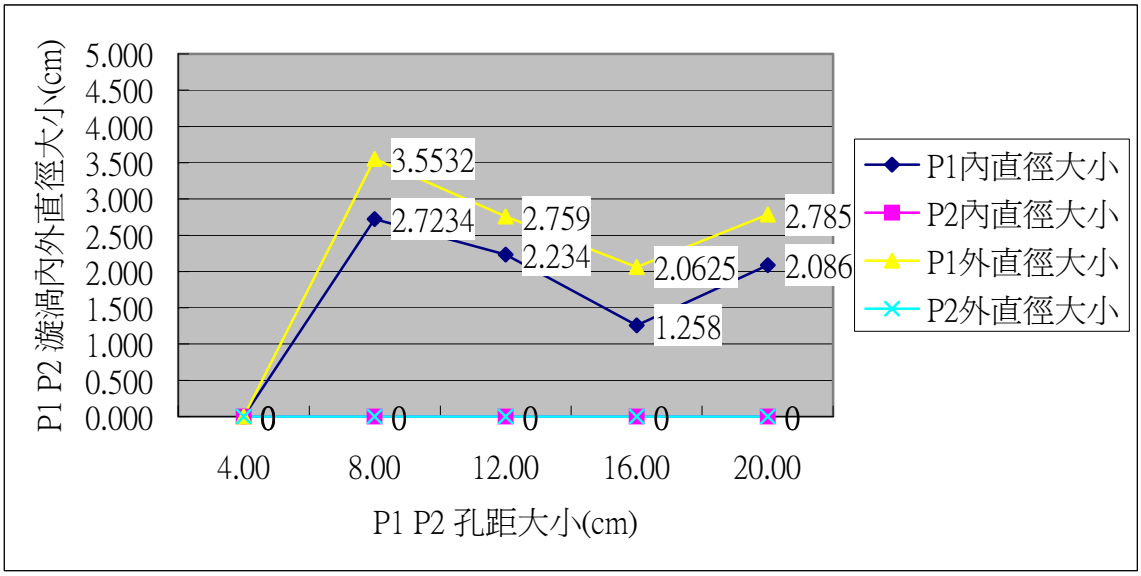


圖 3-4 兩孔徑為 30mm 15mm 時在不同孔距的內外直徑

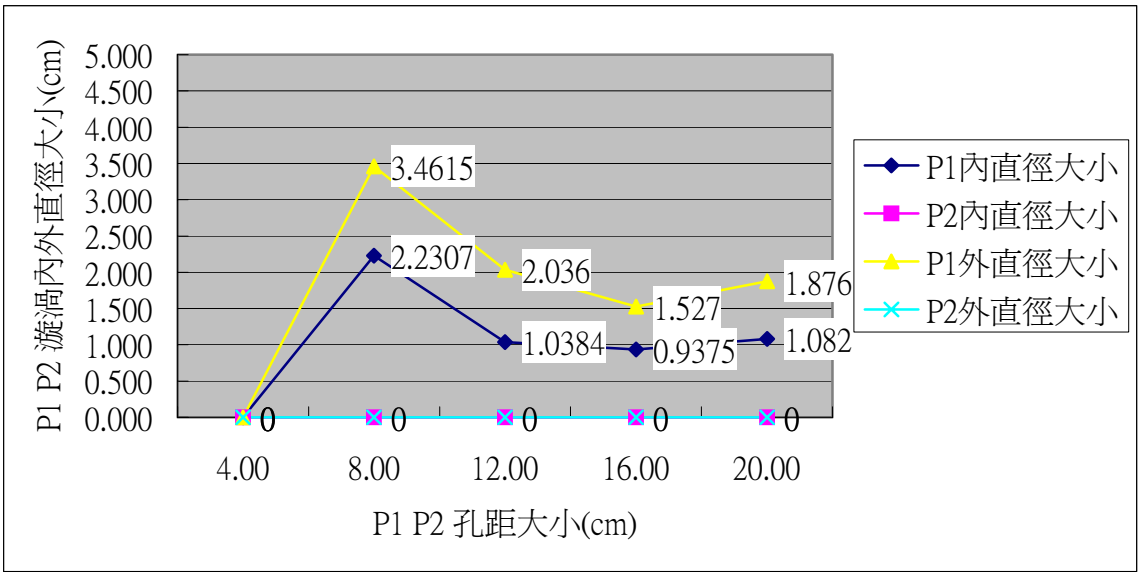


圖 3-5 兩孔徑為 30mm 10mm 時在不同孔距的內外直徑

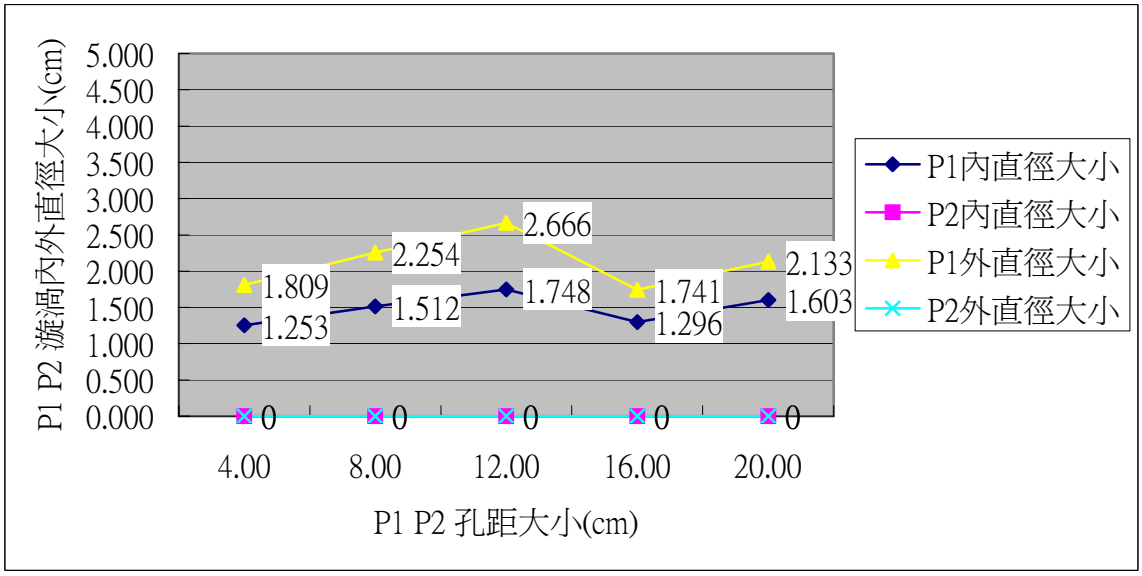


圖 3-6 兩孔徑為 25mm 25mm 時在不同孔距的內外直徑

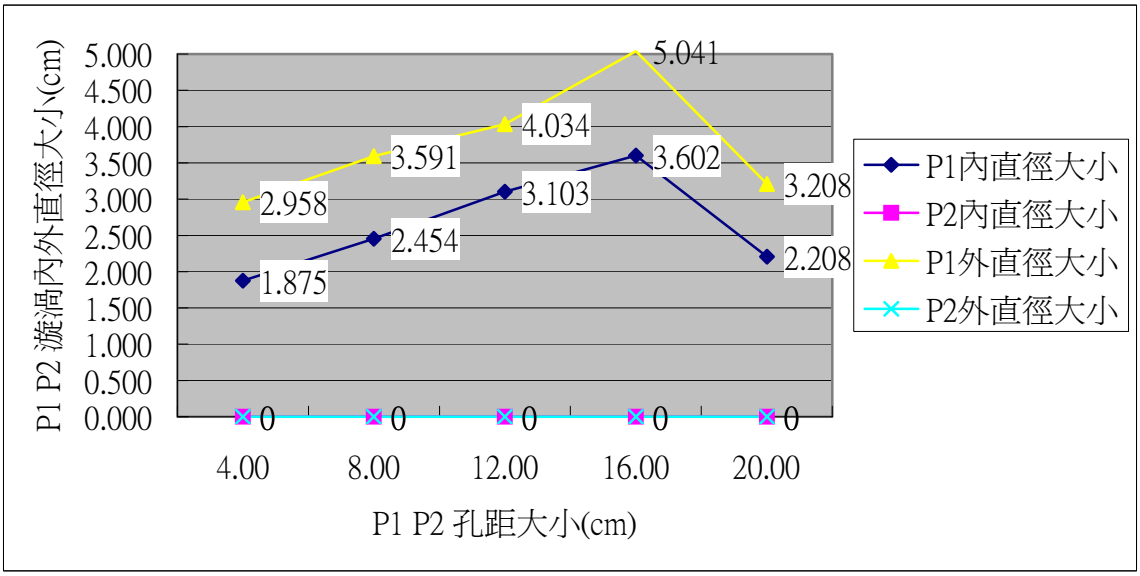


圖 3-7 兩孔徑為 25mm 20mm 時在不同孔距的內外直徑

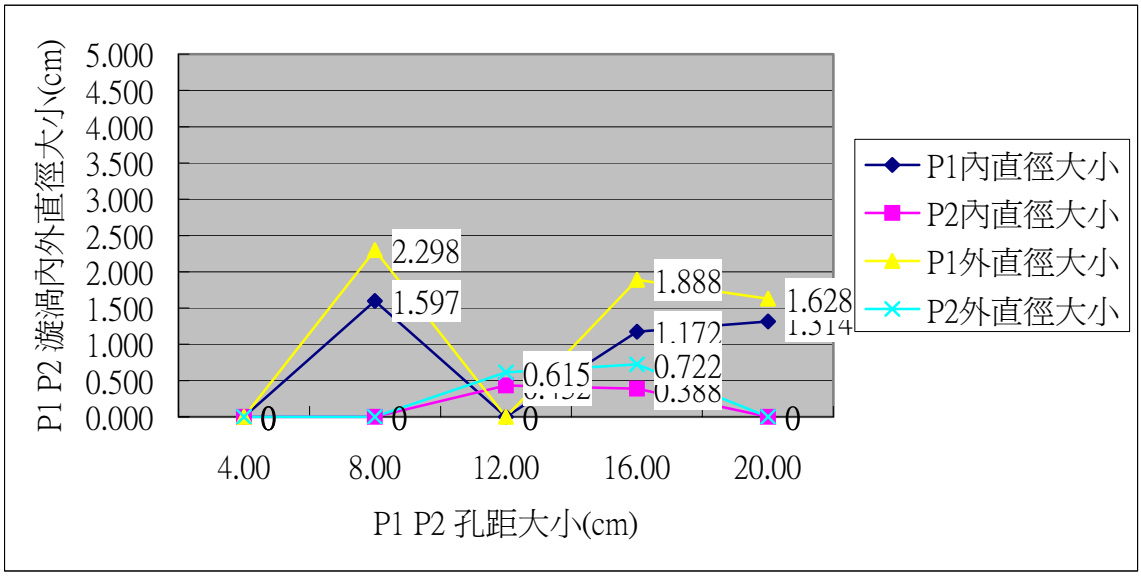


圖 3-8 兩孔徑為 25mm 15mm 時在不同孔距的內外直徑

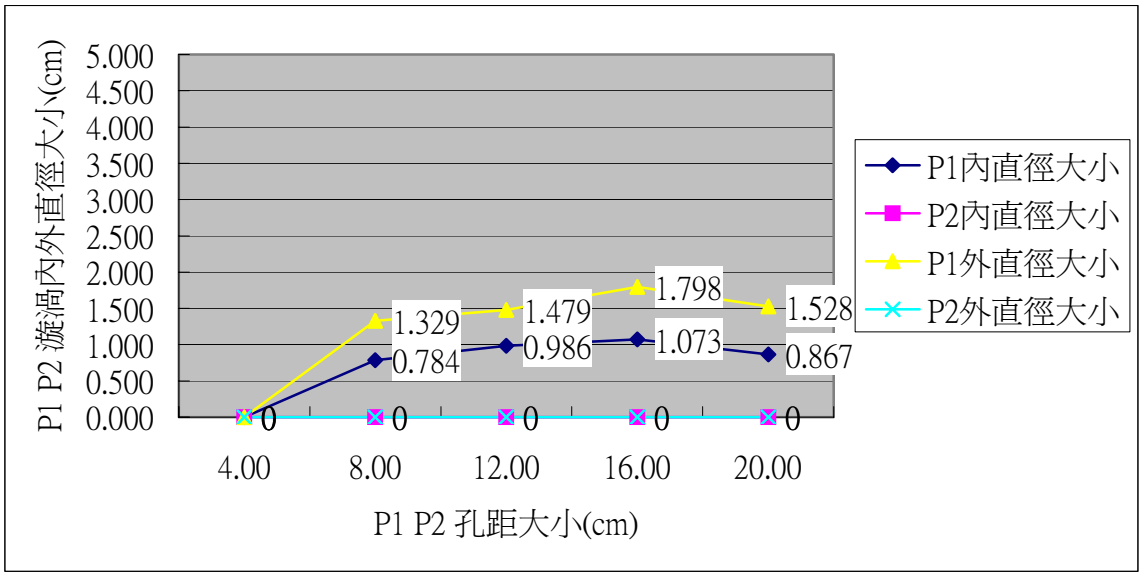


圖 3-9 兩孔徑為 25mm 10mm 時在不同孔距的內外直徑

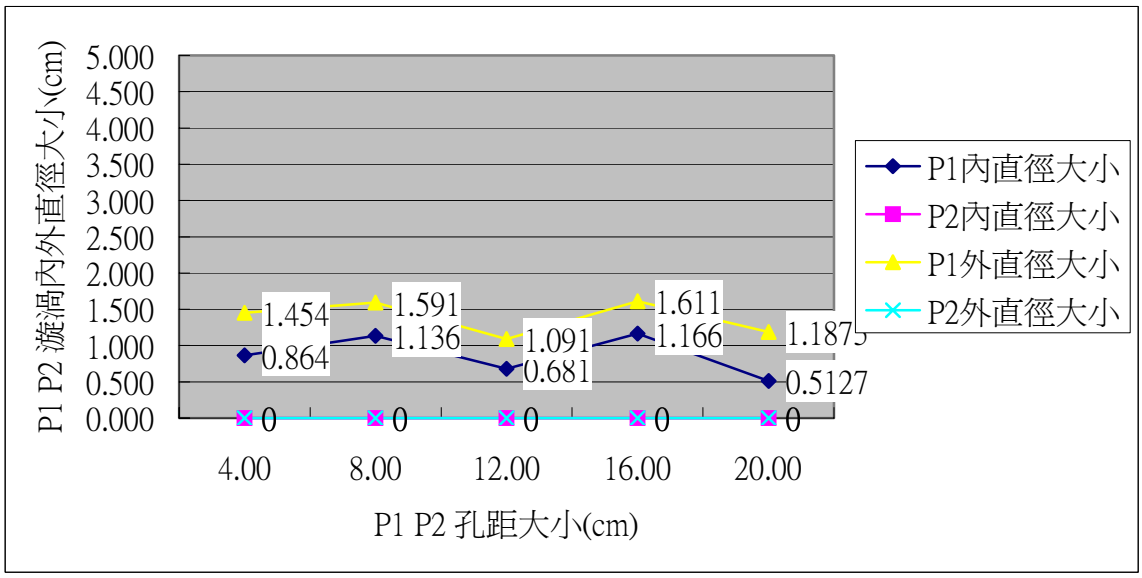


圖 3-10 兩孔徑為 20mm 20mm 時在不同孔距的內外直徑

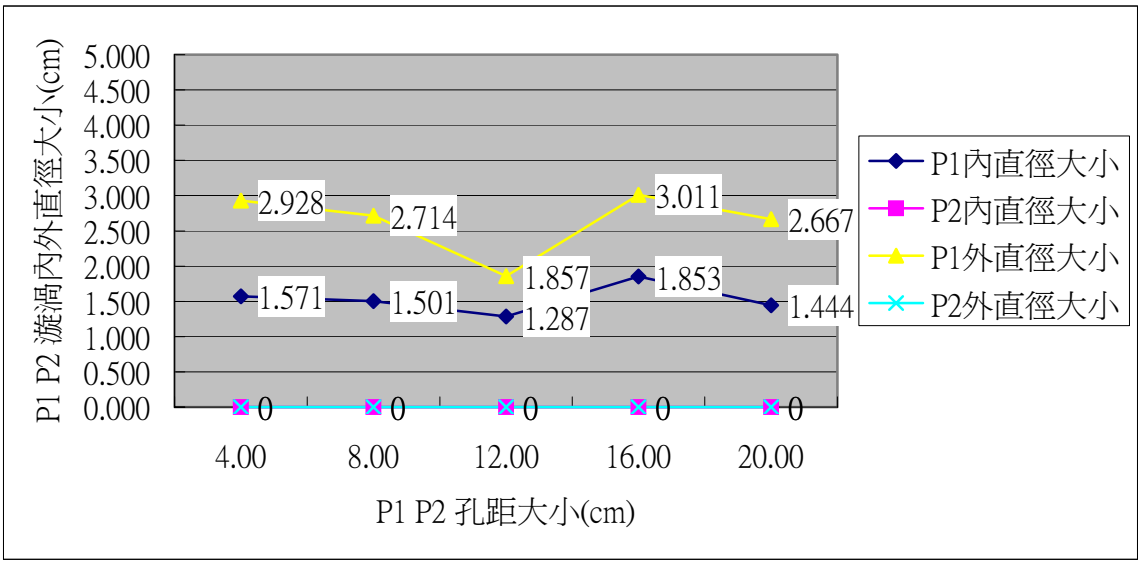


圖 3-11 兩孔徑為 20mm 15mm 時在不同孔距的內外直徑

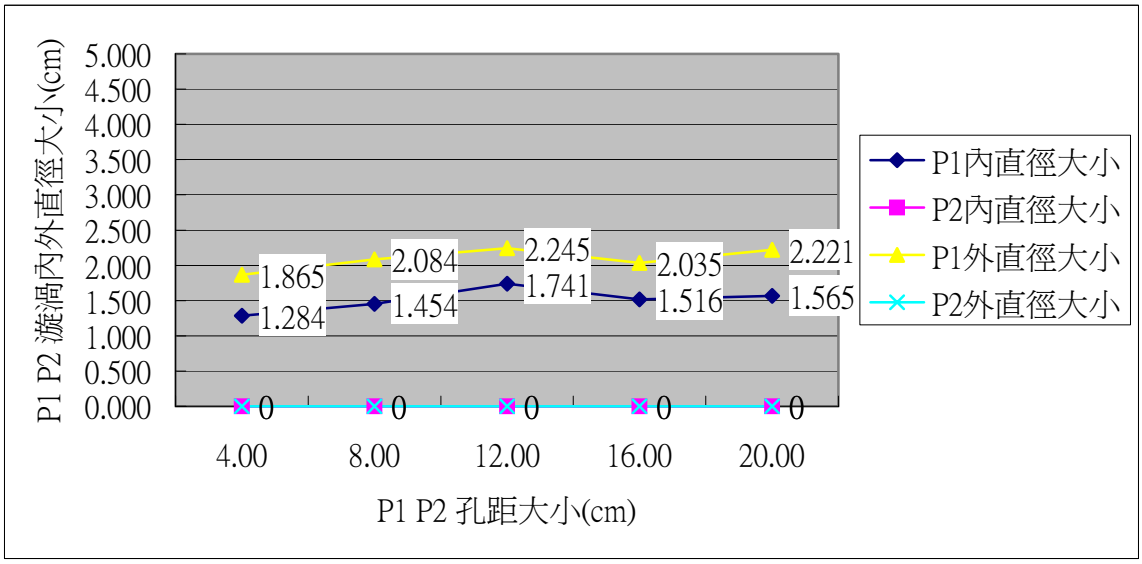


圖 3-12 兩孔徑為 20mm 10mm 時在不同孔距的內外直徑

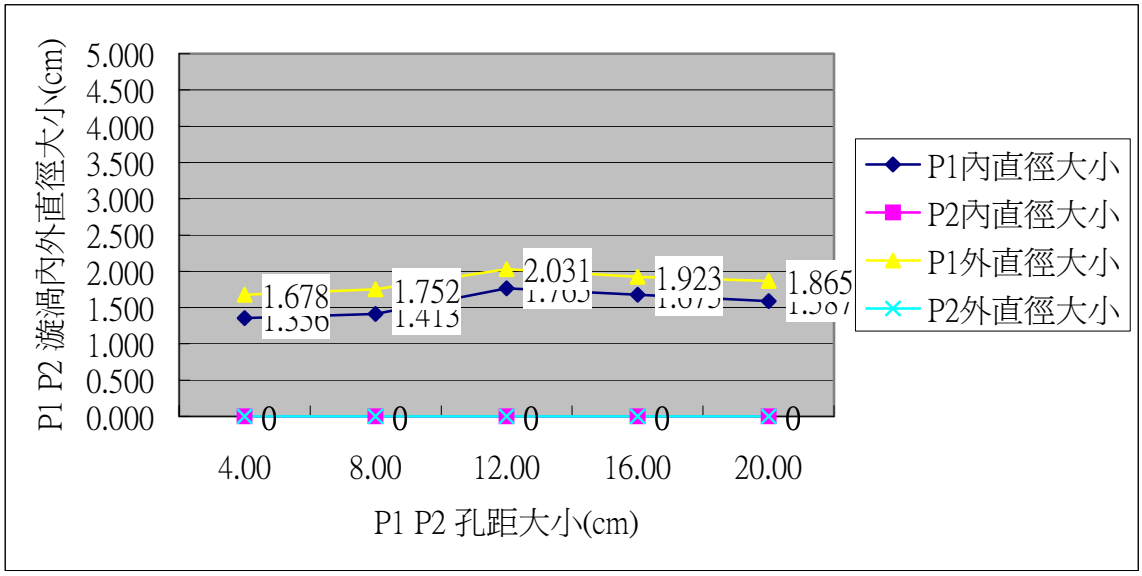


圖 3-13 兩孔徑為 15mm 15mm 時在不同孔距的內外直徑

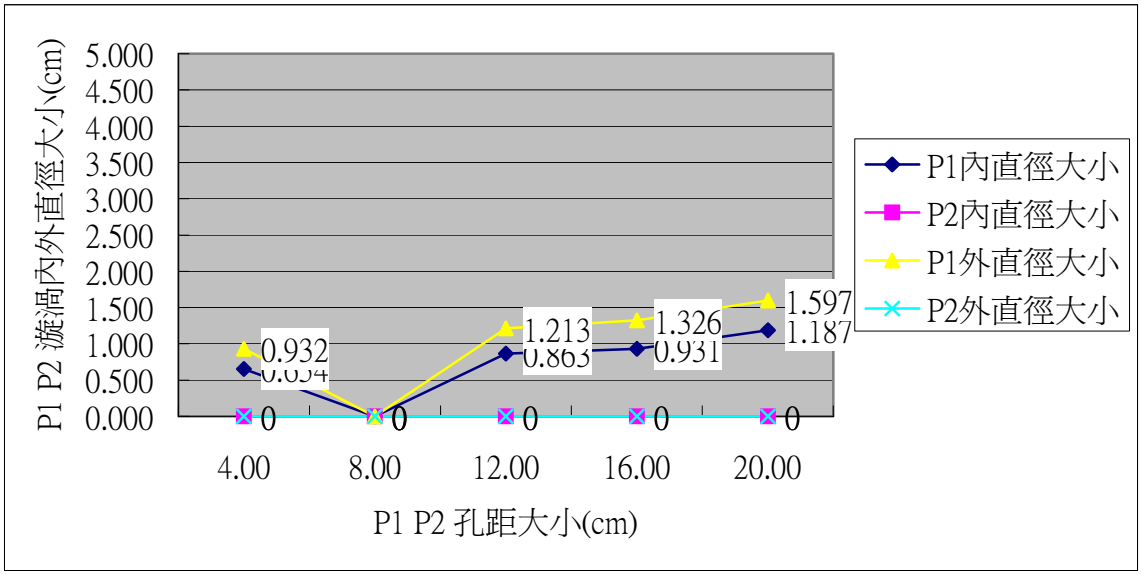


圖 3-14 兩孔徑為 15mm 10mm 時在不同孔距的內外直徑

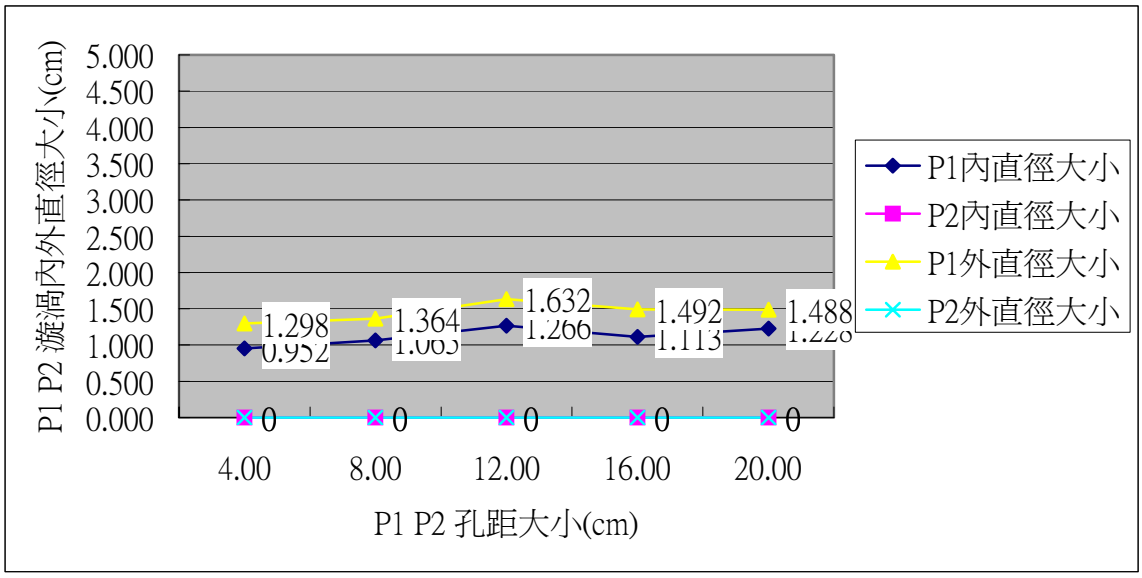
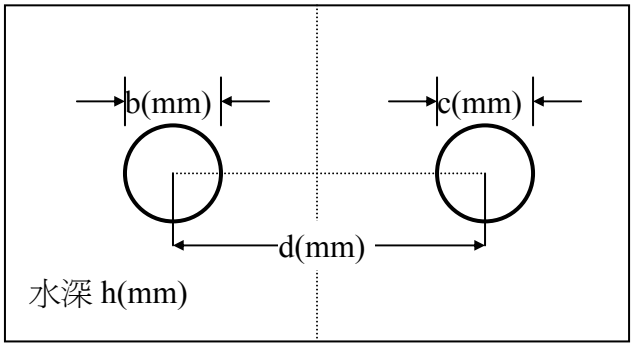


圖 3-15 兩孔徑為 10mm 10mm 時在不同孔距的內外直徑

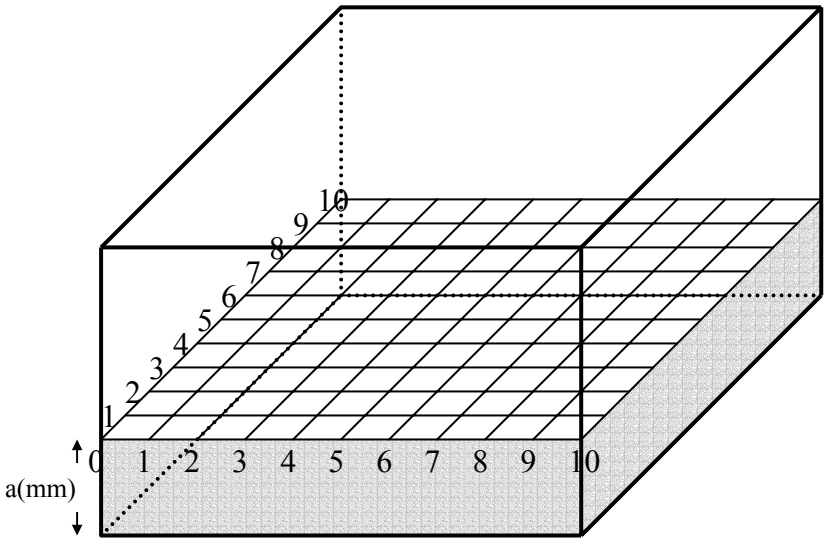
3. 探討渦流中各處之水壓與流速

3-1 實驗步驟：

（1） 如下圖所示，在水槽底部設置 2 孔（P_1,P_2），起始水深 130mm，孔徑 P_1=30mm，P_2=30mm，兩孔孔距為 40mm，使之產生渦流後。



（2） 如下圖所示，在距底部 a(mm)處取一平行底部之底面，並將之坐標化(每 50mm 為一單位)，以壓力感測器測量各點之壓力。



（3） 將測得的壓力值換算所對應的流速大小。

3-2 實驗記錄：

實驗進行中。由於本實驗旋渦所產生的水壓變化量很小，故由壓力感測器所測得的對應值變化量也很小，雖經由訊號放大電路，但得到的變化值幾乎就在測量誤差範圍內，數據的可信度很低。所以本部份的實驗，在結果中並沒有

呈現。我們將在討論中進一步的來說明。

七、討論：

1. 水流

（1） 於實驗過程中其給水裝置供水時所產的水流會影響渦流，而造成些許的誤差，因此在給水裝置中特別以刷子及海綿減低其水流對渦流造成的影響。

（2） 仔細的觀察也發現，從給水側到出水口間的水流流動，仍然對整個水域產生一個「場」，也使得渦流的中心線有微微的偏移。

（3） 整個「場」的影響對靠近給水側的渦流 P_2 比較大，且方向是順流水方向；但對另一個渦流 P_1 則影響就比較不明顯。

（4） 當兩孔距較小時，「場」的影響較大。而兩孔距較大時，又會使 P_2 的位置更靠近給水側，我們可從討論 2. 進一步來說明。

2. 渦流

（1） 渦流內外直徑大致是成比例的。也就是，外直徑愈大，內直徑也就愈大。從側面觀之，每個渦流的形狀大致是一樣的，只是大小有別。

（2） 絕大部份情況下，我們是看不到 P_2 渦流的出現，但從表 3 中，可以知道 P_1=25mm，P_2=15mm，d=120mm 或 d=160mm 以上兩個情況下，P_2 渦流會出現，而且其內外直徑皆很小。這個問題是需要進一步討論的地方。

（3） 不同情況下的渦流大小，其內外直徑的比例是一個可以比較的課題，限於時間關係，我們無法分析之。

3. 渦流大小與孔距間的關係

（1） 從圖 1~圖 15 可以看出，渦流出現的大小，是在某一孔距，並非在最小的 4mm，也不在最大的 20mm。

（2） 我們認為這個應該是兩渦流的偶合，有一個最佳的距離。

4. 兩孔洞孔徑大小與孔距對雙孔渦流間之關係

（1） 從表 2-1 的數據中，我們可以發現，兩孔距為 40mm 時，兩孔徑大小相差過大時，就無法產生渦流。而在孔距為 80mm 以上時，則不管兩孔徑大小，幾乎都會產生渦流。

（2） 整個「場」的影響是順流水方向，也就是對渦流仿佛有一個推的力量。或許可以說，當孔距較遠時，

渦流的中心線雖有微微的偏移，但是兩渦流間的水流亦不致於因此而受到影響，依舊自然的落流。

（3） 但是當孔距較近時，我們試著分析兩孔間的水流。它受到「場」順流水方向的推力，但也受到兩渦流個別的拉力。後者力量在孔徑相差愈大，就愈不平衡而產生影響。當推力與拉力平衡時，就使得水變成好像自由落下般，而沒有渦流的產生。

（4） 有趣的是，孔距為 80mm、120mm 及 160mm 皆有許多特殊的情況，也如同以上的討論一般，沒有產生渦流。這是我們百思不解之處，也是我們想要進一步仔細實驗的主題。

5. 流速的測定：

（1） 以上討論中一些問題的原因探討，我們相信是可以從水槽中的流速「場」的測定，而知道其大致的模樣。

（2） 由於本次實驗壓力感測器與訊號放大器的問題無法解決，所以這部份沒有結果。若有機會，本組擬利用更精密的感測器及訊號放大器，對這一部份的實驗，再做一次測量，希望能得到更充足的資料來分析。

6. 水流的補充：

（1） 由於水流的補充，無法做到完全的靜止，而造成整個水槽有一個方向的水流「場」。

（2） 對這一部份，我們希望改進之處有：

a. 將方形水槽改為圓形

b. 增大水槽的面積

c. 注水區由單邊，增為四周皆均勻注水

八、結論：

1. 從一個孔洞的渦流形成，到兩個孔洞所形成的渦流。其增加的變因與形成的複雜程度，遠遠超過我們當初的想像。從討論中，我們發現了許多有趣的問題，例如某些情況下，渦流不會出現；而另某些情況下，卻能出現雙渦流。這些問題的答案，需要更仔細的分析，即更細微的孔距及孔徑變化。
2. 某些情況下，渦流不會出現。讓我們想到，當單孔渦流出現後，另一個渦流的加入若能夠使渦流消失的話，這或許是消弭颶風(颱風)的一個途徑。
3. 我們討論中的一個重要的因子就是水流「場」。整個實驗中，因為水的補充使得有水流「場」的產生，也可能是影響渦流產生的因素。正如同大氣中的「氣壓場」對颱風的影響，不可忽視。

九、參考書目：

1、褚德三主編，高中物質科學物理篇（下，第 2 版，龍騰文化事業公司編印，2002 年 1 月。
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十、附錄：實驗記錄

1. 預備實驗： 氣壓校正曲線

表 1-1：壓力感測器兩端的電壓記錄(一)

空氣體積 (ml)	空氣壓力 (mmHg)	氣壓變化 (mmHg)	電壓 (V)	電壓變化 (V)
50.0	758.51	0.00	-0.391	0.000
45.0	842.79	84.28	-0.264	0.127
40.0	948.14	189.63	-0.110	0.281
35.0	1083.59	325.08	0.084	0.475
30.0	1264.18	505.67	0.352	0.743
25.0	1517.02	758.51	0.682	1.073
20.0	1896.28	1137.77	1.162	1.553

表 1-2：壓力感測器兩端的電壓記錄(二)

空氣體積 (ml)	空氣壓力 (mmHg)	氣壓變化 (mmHg)	電壓 (V)	電壓變化 (V)
50.0	758.51	0.00	-0.394	0.000
45.0	842.79	84.28	-0.285	0.109
40.0	948.14	189.63	-0.120	0.274
35.0	1083.59	325.08	0.066	0.460
30.0	1264.18	505.67	0.295	0.689
25.0	1517.02	758.51	0.647	1.041
20.0	1896.28	1137.77	1.146	1.540

2. 探討兩孔洞孔徑大小與雙孔渦流間之關係

表 2-1 孔距為 40mm 時不同孔徑的渦流內外直徑

外直徑 / 內直徑		P_1孔徑大小(mm)				
		10	15	20	25	30
P_2 孔徑大小 (mm)	10	9.32 / 6.54	12.98 / 9.85	18.65 / 12.84	*	*
	15	–	16.78 / 13.56	29.28 / 15.71	*	*
	20	–	–	14.54 / 8.64	29.58 / 18.75	30.03 / 21.01
	25	–	–	–	18.09 / 12.53	*
	30	–	–	–	–	26.66 / 19.47

表 2-2 孔距為 80mm 時不同孔徑的渦流的內外直徑

外直徑 / 內直徑		P_1孔徑大小(mm)				
		10	15	20	25	30
P_2 孔徑大小 (mm)	10	*	13.64 / 10.65	20.84 / 14.54	13.29 / 7.84	34.62 / 22.31
	15	–	17.52 / 14.13	27.14 / 15.01	22.98 / 15.97	35.53 / 27.23
	20	–	–	15.91 / 11.36	35.91 / 24.54	*
	25	–	–	–	22.54 / 15.12	42.73 / 30.91
	30	–	–	–	–	–

表 2-3 孔距為 120mm 時不同孔徑的渦流的內外直徑

外直徑 / 內直徑		P_1孔徑大小(mm)				
		10	15	20	25	30
P_2 孔徑大小 (mm)	10	12.13 / 8.63	16.32 / 12.66	22.48 / 17.41	14.79 / 9.86	20.36 / 10.38
	15	–	20.31 / 17.65	18.57 / 12.87	*	*
	20	–	–	10.91 / 6.81	40.34 / 31.03	45.83 / 35.42
	25	–	–	–	26.66 / 17.48	22.52 / 11.51
	30	–	–	–	–	30.13 / 19.01

表 2-4 孔距為 160mm 時不同孔徑的渦流的內外直徑

外直徑 / 內直徑		P_1孔徑大小(mm)				
		10	15	20	25	30
P_2 孔徑大小 (mm)	10	13.26 / 9.31	14.92 / 11.13	20.35 / 15.16	17.98 / 10.73	15.27 / 9.38
	15	–	19.23 / 16.75	30.11 / 18.53	18.88 / 11.72	20.63 / 12.58
	20	–	–	16.11 / 11.66	50.41 / 36.02	*
	25	–	–	–	17.41 / 12.96	20.02 / 10.71
	30	–	–	–	–	24.52 / 15.01

表 2-5 孔距為 200mm 時不同孔徑的渦流的內外直徑

外直徑 / 內直徑		P_1孔徑大小(mm)				
		10	15	20	25	30
P_2 孔徑大小 (mm)	10	15.97 / 11.87	14.88 / 12.28	22.21 / 15.65	15.28 / 8.67	18.76 / 10.82
	15	–	18.64 / 15.87	26.67 / 14.44	16.28 / 13.14	27.85 / 20.86
	20	–	–	11.88 / 5.13	32.08 / 22.08	37.73 / 2.736
	25	–	–	–	21.13 / 16.03	18.18 / 10.03
	30	–	–	–	–	20.01 / 13.85

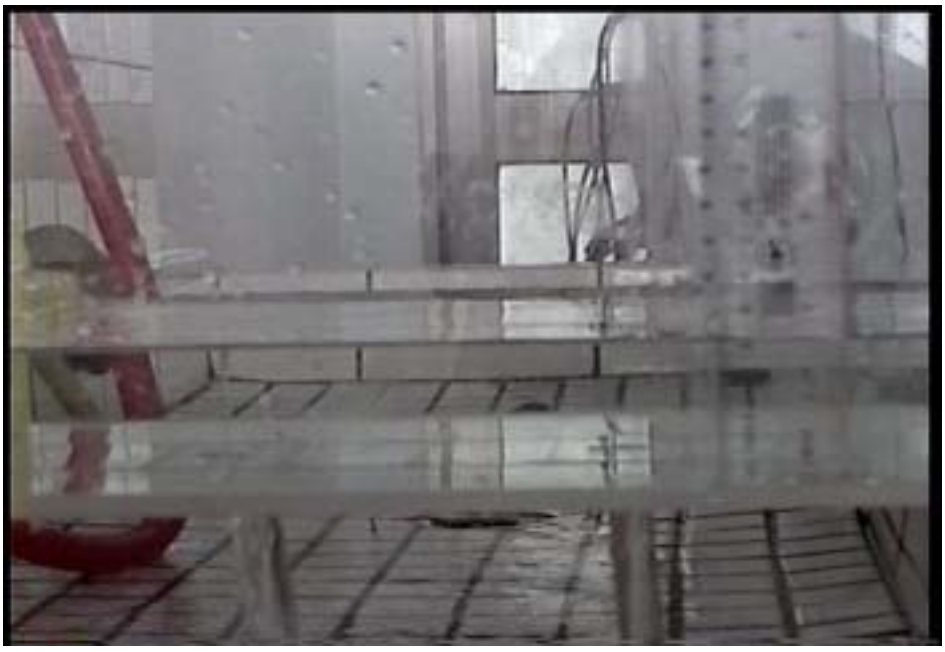
表 3　兩孔徑在各孔徑時，在不同孔距的內外直徑

外直徑 / 內直徑			孔距(mm)					
			40	80	120	160	200	
P_1、P_2兩孔徑大小(mm)	P_1	30	26.66 / 19.47	*	30.13 / 19.01	24.52 / 15.01	20.01 / 13.85	圖 1
	P_2	30	*	*	*	*	*	
	P_1	30	*	42.73 / 30.91	22.52 / 11.51	20.02 / 10.71	18.18 / 10.03	圖 2
	P_2	25	*	*	*	*	*	
	P_1	30	30.03 / 21.01	*	45.83 / 35.42	*	37.73 / 27.36	圖 3
	P_2	20	*	*	*	*	*	
	P_1	30	*	35.53 / 27.23	*	20.63 / 12.58	27.85 / 20.86	圖 4
	P_2	15	*	*	*	*	*	
	P_1	30	*	34.62 / 22.31	20.36 / 10.38	15.27 / 9.38	18.76 / 10.82	圖 5
	P_2	10	*	*	*	*	*	
	P_1	25	18.09 / 12.53	22.54 / 15.12	26.66 / 17.48	17.41 / 12.96	21.33 / 16.03	圖 6
	P_2	25	*	*	*	*	*	
	P_1	25	29.58 / 18.75	35.91 / 24.54	40.34 / 31.03	50.41 / 36.02	32.08 / 22.08	圖 7
	P_2	20	*	*	*	*	*	
	P_1	25	*	22.98 / 15.97	*	18.88 / 11.72	16.28 / 13.14	圖 8
	P_2	15	*	*	6.15 / 4.32	7.22 / 3.88	*	
	P_1	25	*	13.29 / 7.84	14.79 / 9.86	17.98 / 10.73	15.28 / 8.67	圖 9
	P_2	10	*	*	*	*	*	
	P_1	20	14.54 / 8.64	15.91 / 11.36	10.91 / 6.81	16.11 / 11.66	11.88 /5.13	圖 10
	P_2	20	*	*	*	*	*	
	P_1	20	29.28 / 15.71	27.14 / 15.01	18.57 / 12.87	30.11 / 18.53	26.67 / 14.44	圖 11
	P_2	15	*	*	*	*	*	
	P_1	20	18.65 / 12.84	20.84 / 14.54	22.54 / 17.41	20.35 / 15.16	22.21 / 15.65	圖 12
	P_2	10	*	*	*	*	*	
	P_1	15	16.78 / 13.56	17.52 / 14.13	20.31 / 17.65	19.23 / 16.75	18.65 / 15.87	圖 13
	P_2	15	*	*	*	*	*	
	P_1	15	12.98 / 9.52	13.64 / 10.65	16.32 / 12.66	14.92 / 11.13	14.88 / 12.28	圖 14
	P_2	10	*	*	*	*	*	
	P_1	10	9.32 / 6.54	*	12.13 / 8.63	13.26 / 9.31	15.97 / 11.87	圖 15
	P_2	10	*	*	*	*	*	

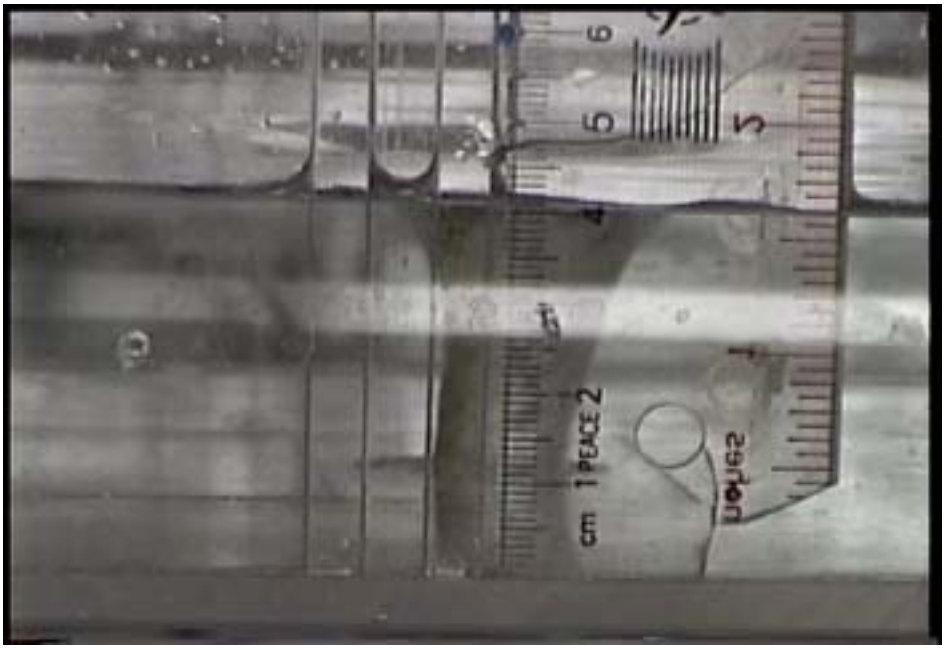
十一、附圖



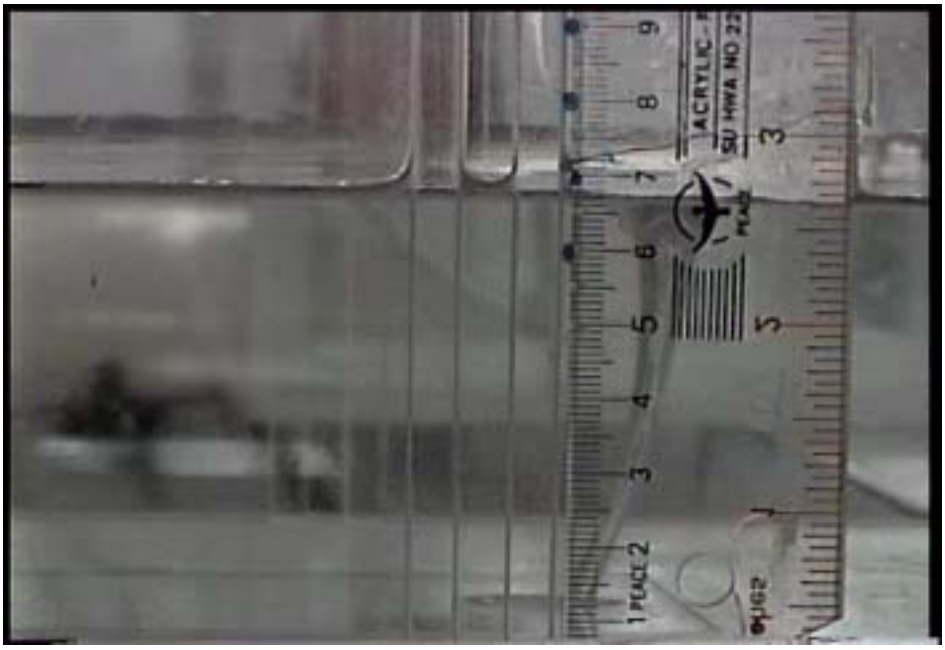
於 a=45mm b=15mm c=25mm d=160mm 時所得影像



於 a=42mm b=15mm c=25mm d=120mm 時所得影像



於 a=41mm b=20mm c=25mm d=120mm 時所得影像



於 a=67mm b=25mm c=25mm d=160mm 時所得影像

Table of Content

Introduction....2
Theory....3
Materials & Methods....4
Results....6
Discussion....11
Conclusions....14
Application....15
Attachment....16
Acknowledgements....20
References....21

Introduction

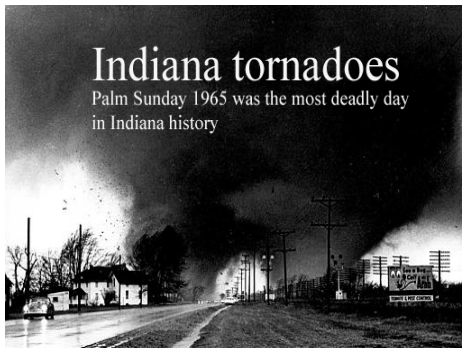


Fig.1. These twin tornadoes in northern Indiana were part of the twister outbreak on Palm Sunday, April 11, 1965. (AP Photo)

Vortices exist in a large variety of natural phenomena, with diameters ranging from a few centimeters (e.g., bathtub vortices) to several hundred meters (e.g., tornadoes). Especially, tornadoes are destructive, rather unpredictable, and yet very intriguing as a natural event. A single twister may possess enormous power to cause devastating property damages, human injuries and even deaths. Scientists thus have made a great deal of observations of tornadoes, and are working very hard toward constructing reliable forecasting and warning systems. In particular, it has been observed that two tornadoes that are close enough to each other usually interact vigorously, but the exact interaction mechanism still is not fully understood.

Of course, to understand such mechanism, one need not produce full-scale tornadoes. Instead, in this study we produce twin vortexes by draining a water tank through two apertures located on the bottom of the tank, thereby simulating the dynamics of two interacting tornadoes through well-controlled experiments. More specifically, we have looked into the movement and swirling trends of the twin vortices thus produced by varying the diameters the two apertures and the distance between them.

Theory

Suppose that fluid viscosity is negligible; then the Bernoulli equation

$$P_1 + \frac{1}{2}\rho v_1^{\,2} + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^{\,2} + \rho g h_2$$

relates the atmospheric pressures $P_{1,2}$, velocities of fluid particles $v_{1,2}$, vertical coordinates $z_{1,2}$, and density of fluid ρ between any two points in the fluid. In particular, for two points on the free surface, P_1=P_2, so that

$$\frac{1}{2}\rho v_1^{\,2} + \rho g h_1 = \frac{1}{2}\rho v_2^{\,2} + \rho g h_2$$

Our observations indicate that $|v_\theta| >> |v_r|, |v_z|$, and hence $v \approx v_\theta$. Note also that $h \to H$ and $v_\theta \to 0$, as $r \to \infty$. Hence the Bernoulli equation reduces to

$$\rho g H = \frac{1}{2}\rho v_2^{\,2} + \rho g h_2 \text{ ---(1)}$$

For invisid fluids, the angular momentum of fluid particles can be considered to be conserved, so that the "circulation"

$$\Gamma = 2\pi r v_\theta = const \text{ ---(2)}$$

Combining then (1) and (2), we obtain an expression for the free surface shape:

$$h = H - \frac{\Gamma^2}{8\pi^2 r^2 g}.$$

Note that the circulation Γ is a measure of the vortex strength; and it is clear from the above expression that the surface shape of a vortex is determined by its strength.

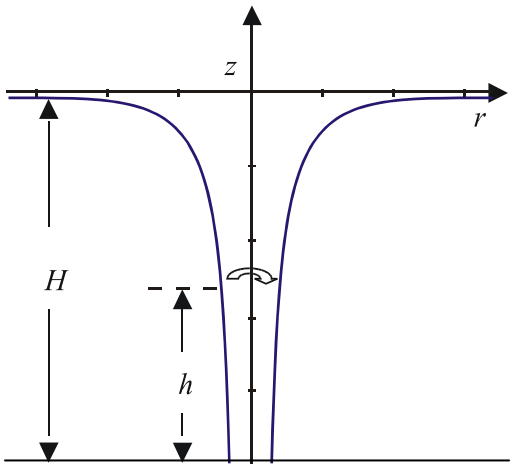


Fig.2. The structure of the vortex.

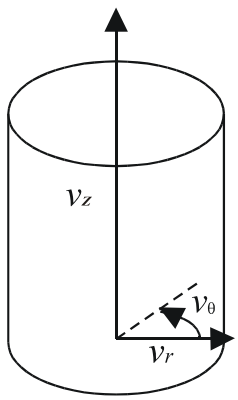


Fig.3. The directions of Velocity components.

Materials & Methods

A water tank was made of transparent acrylic as shown in Fig. 4. The bottom of the tank was divided into six replaceable parts so that the diameters of the two apertures and the distance between them could be adjusted at will. The water inlet was located on the left, with a piece of sponge set beneath the inlet to minimize flow disturbances to some extent, and the flow rate was adjusted to match the drain rate so that the water level remained constant at the desired level throughout the experiments.

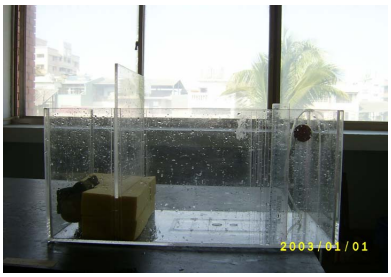




Fig.4. The observation water tank.

1. Inquiry into the effect of the distance between the two apertures:
   (1) Locating two apertures on the bottom of the water tank; initially the distance between the two apertures was set at 40 mm.
   (2) Starting water supply, fixing the water depth in the tank at 50 mm.
   (3) With the 50 mm water depth fixed, starting digital camera recording. The recording was then imported into a personal computer and still photos of vortexes were selected for further analysis.
   (4) Calculating the outer and inner diameters of the vortices by using the reference scales.
   (5) Increasing the distance between the two apertures from 40 mm to 200 mm, with an increment of 20 mm; then repeating steps (2) to (4) described above.
   (6) Analyzing the data thus collected and presenting the results graphically.

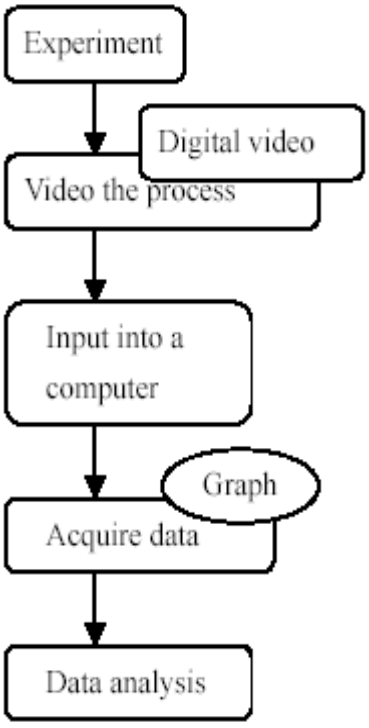


Fig.5 Experimental procedures

2. Inquiry into the effect of the diameters of the two apertures:
   We varied the diameters of the two apertures according to the 15

combinations shown in Table 1 below. For each of the 15 combinations, collecting and analyzing data by following steps (1) to (6) described above.

Table 1. Diameter combinations of the two apertures (mm)

	A	B	C	D	E
1	(30, 30)				
2	(30, 25)	(25, 25)			
3	(30, 20)	(25, 20)	(20, 20)		
4	(30, 15)	(25, 15)	(20, 15)	(15, 15)	
5	(30, 10)	(25, 10)	(20, 10)	(15, 10)	(10, 10)

3. Measurement of the vortex strength (i.e., the circulation Γ):

Measurement A:

(1) Setting A1 diameter at 25 mm and A2 diameter at 30 mm.

(2) Repeating steps (1) to (3) in 1 above. (However, in this set of experiments, the digital camera was set right above the water tank.)

(3) Calculating r and *v* of the vortices by using the reference scales.

(4) Changing the A2 aperture diameter from 30 mm to 25 mm, 20 mm, 15 mm, 10 mm successively; then repeating steps (1) to (3) described above for each setting.

Measurement B:

(1) Setting A1 and A2 diameters both at 25 mm.

(2) Increasing the distance between the two apertures from 40 mm to 120 mm, with an increment of 20 mm; then repeating steps (2) to (3) in 3-A described above.

(3) Analyzing the data thus collected and presenting the results graphically.

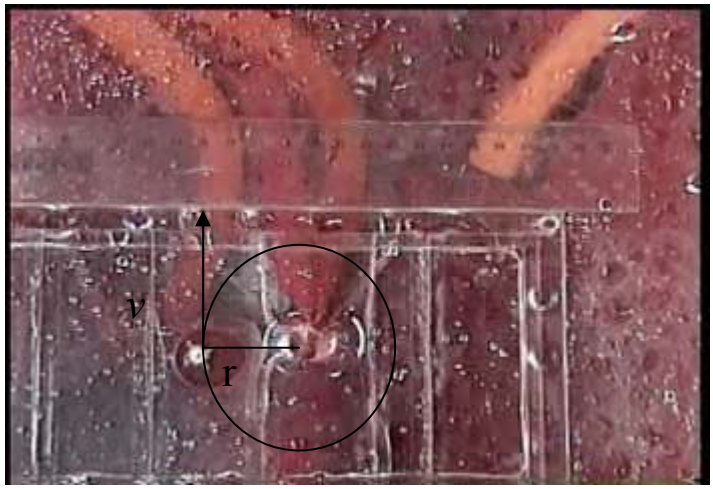


Fig.6. The measurements of *r* and *v*.

Results

1. Aperture Separation
   (1) Only one vortex was formed above A1 when the two apertures were very close.
   (2) The outer diameter of the vortex above A1 decreased but then increased again when we gradually increased the aperture separation.
   (3) Two vortices appeared only when the aperture separation was in some intermediate range.
   (4) When a second vortex appeared, the outer diameter of the first decreased. As the aperture separation increased, the outer diameter of the A1 vortex increased and the outer diameter of the A2 vortex decreased, indicating an interaction between them.
   (5) When the aperture separation was increased by too much, the outer diameter of the vortex also decreased (Fig. 7).
2. Aperture Sizes
   (1) With the diameter of A2 aperture fixed, when the diameter of A1 became smaller, the outer diameter of the vortex decreased accordingly.
   (2) When the diameter of A1 aperture fell below a certain size, a vortex over A2 formed at the expense of the vortex above A1 (Fig. 8).
3. Appearances of Twin Vortices
   For certain size and separation combinations, twin vortices formed (Table 2).
4. Vortex Strength
   (1) Vortex strength was correlated with the outer diameter of the vortex (Fig. 10 and Fig. 11).
   (2) Our data suggested that the outer diameters could be viewed as a measure of the vortex strength.

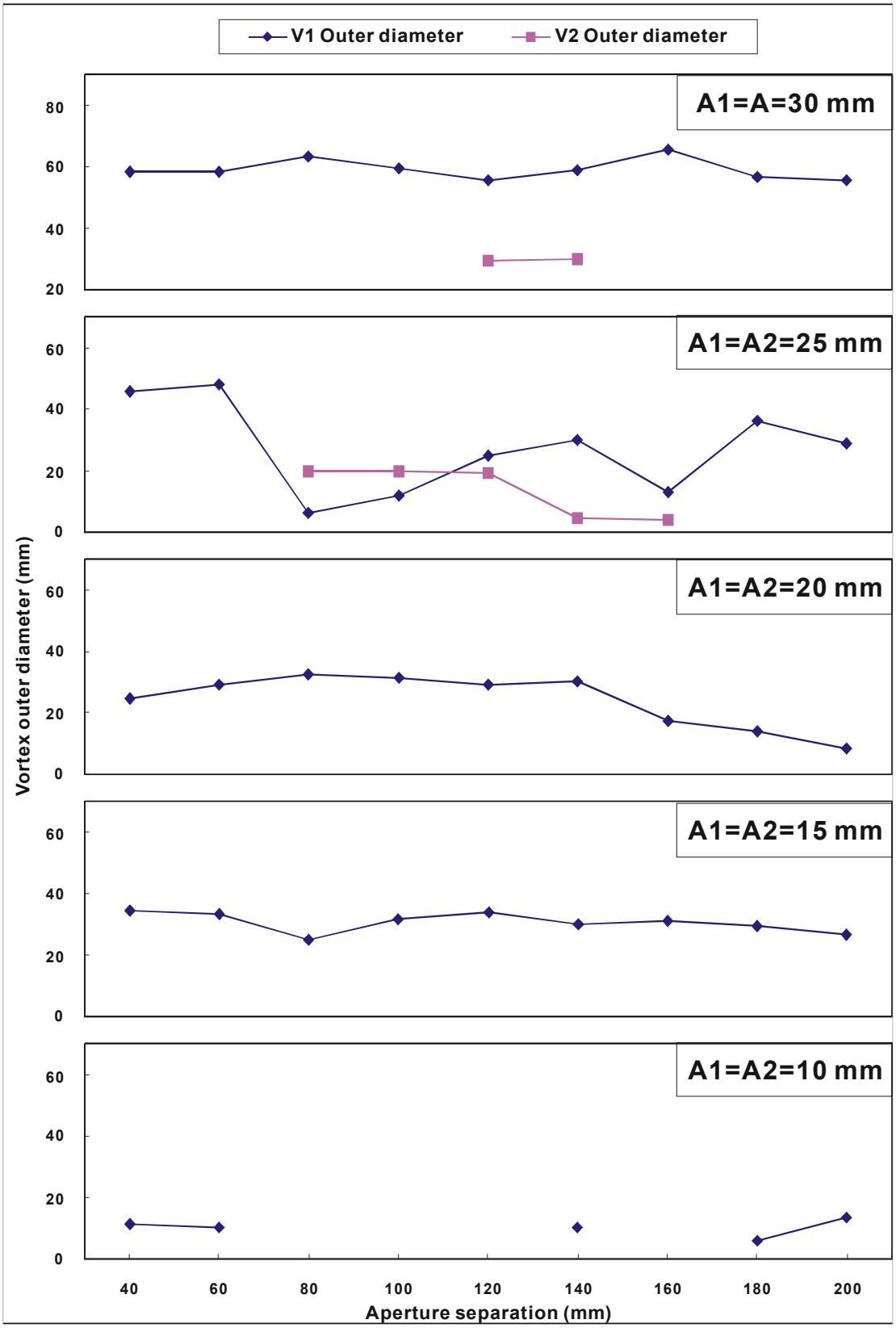


Fig.7. Variation of outer diameters with A1=A2 at different distances. The errors are estimated to be 1.1%.

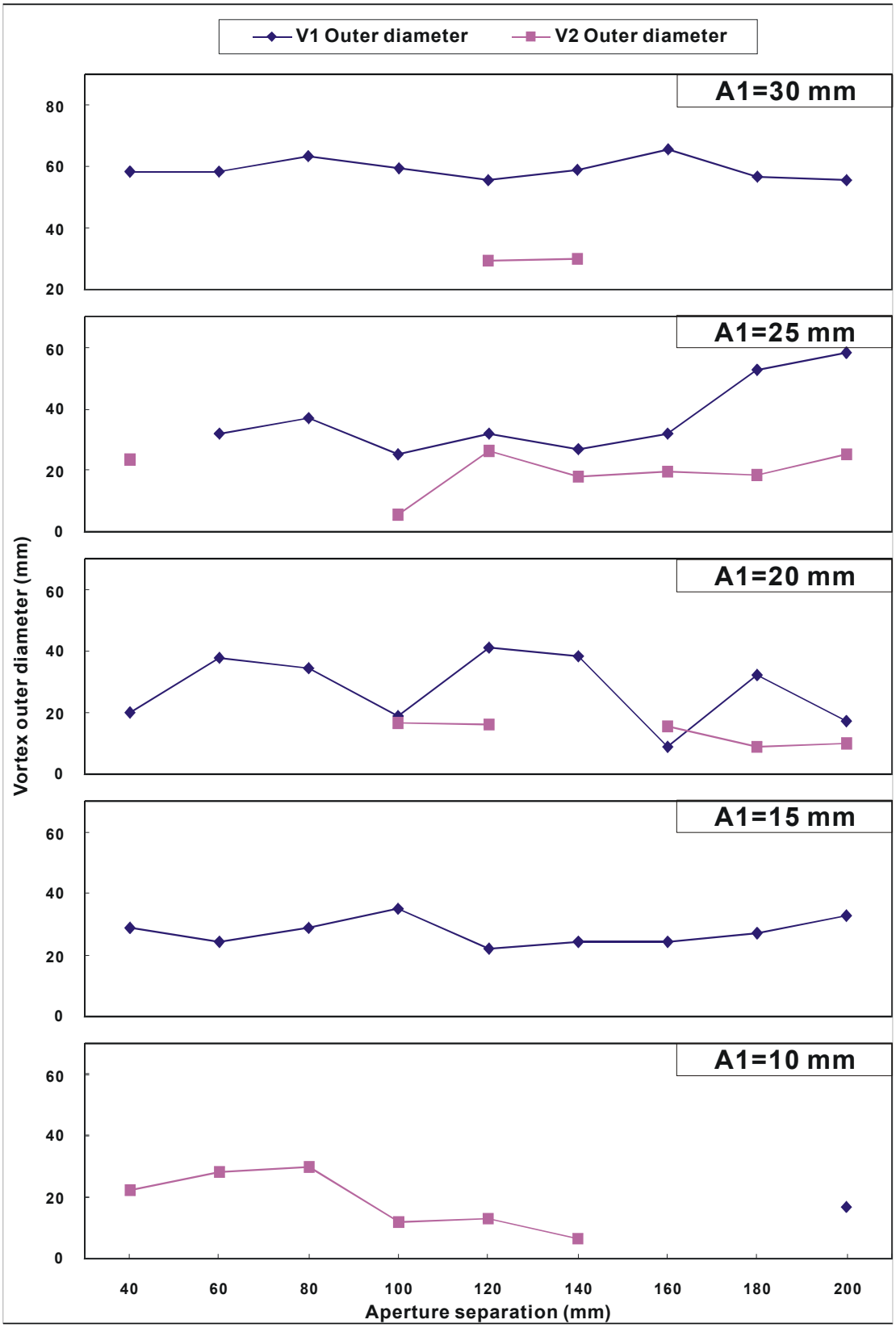


Fig.8. Variation of outer diameters with A1=30 mm. The errors are estimated to be 1.1%.

Table 2. Whether twin vortices appear or not at different ratios of A1 to A2.

Ratio of A1 to A2 (A1/A2)	Aperture separation (mm)								
	40	60	80	100	120	140	160	180	200
1.00 (30/30)	○	○	○	○	◎	◎	○	○	○
1.00 (25/25)	○	○	◎	◎	◎	◎	◎	○	○
1.00 (20/20)	○	○	○	○	○	○	○	○	○
1.00 (15/15)	○	○	○	○	○	○	○	○	○
1.00 (10/10)	○	○	X	X	X	○	X	○	○
0.83 (25/30)	○	○	○	◎	◎	◎	◎	◎	◎
0.80 (20/25)	○	○	○	○	○	◎	◎	◎	◎
0.75 (15/20)	○	○	○	○	○	○	○	○	○
0.67 (20/30)	○	○	○	◎	◎	○	◎	◎	◎
0.67 (10/15)	X	X	○	○	○	○	X	○	X
0.60 (15/25)	○	○	○	○	◎	◎	X	X	◎
0.50 (15/30)	○	○	○	○	○	○	○	○	○
0.50 (10/20)	○	○	○	○	X	○	○	○	○
0.40 (10/25)	○	○	○	○	○	○	○	○	○
0.33 (10/30)	○	○	○	○	○	○	X	X	○

◎ twin vortices ○ one vortex X no vortex

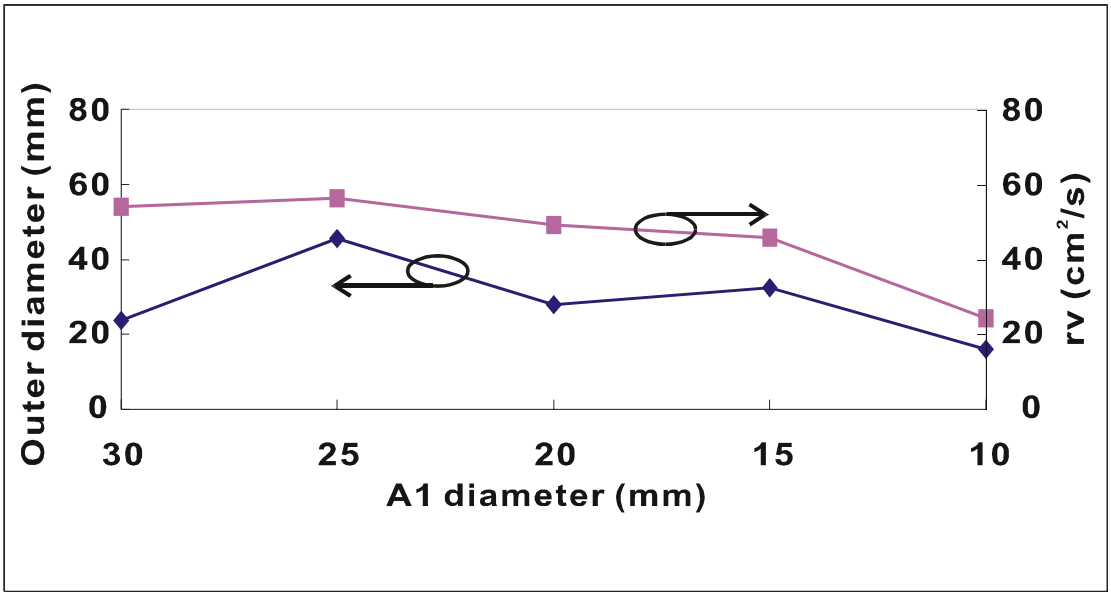


Fig.10. Variation of Γ/2π with A2=25 mm. The estimated errors of rv= 0.7% outer diameter:=1.1%.

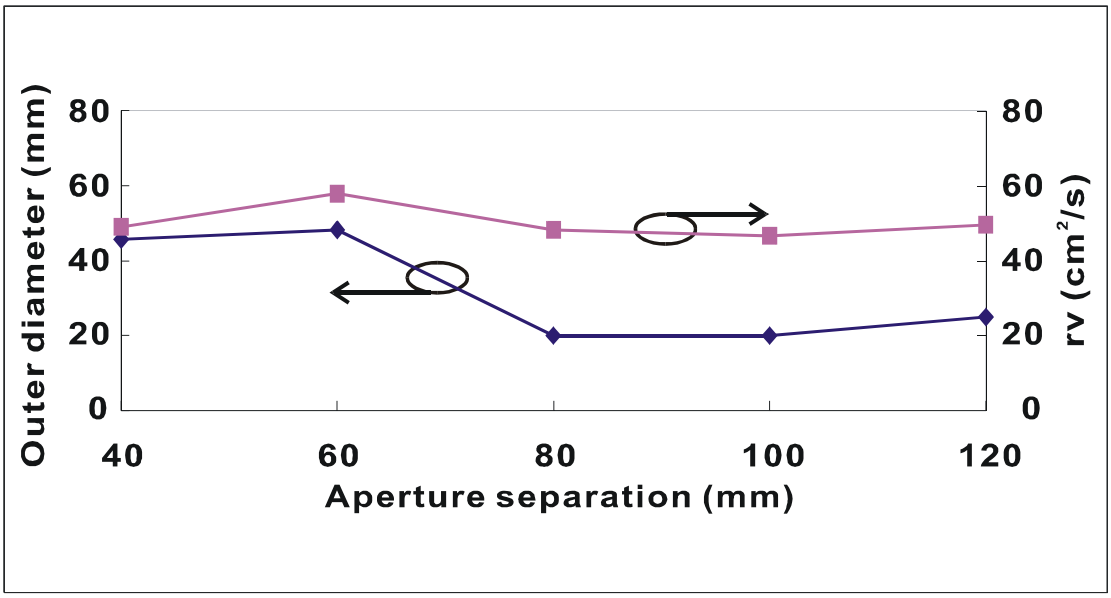


Fig.11. Variation of Γ/2π with the distance between apertures for A1=A2=25 mm. The estimated errors of rv= 0.7% outer diameter= 1.1%.

Discussion

1. Influence of Water Current on Observations
   (1) *The current from the water inlet to the draining apertures clearly affected the vortices.* Despite that a piece of sponge was set beneath the water inlet to minimize flow disturbances, the current velocity could not be reduced due to mass conservation. So, in the observations, the flow of water from the inlet to the draining aperture could not be avoided. In particular, it was observed that the current made the vortex a little lopsided.
   (2) *The current had a stronger effect on A2, which is closer to the water inlet.* According to the apparatus design, as the distance between the two apertures became longer, aperture A2 also became closer to the water inlet, and hence was affected by the water current to a greater extent. Experimental data showed that when the distance between the two apertures was increased above 160mm, no vortex was generated by aperture A2.

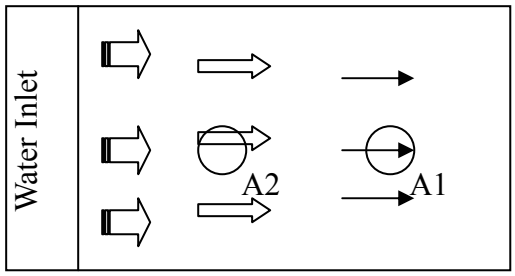


Fig.12. The influence of water

2. Vortex
   (1) The invisid-flow theory related the vortex profile to its strength (circulation Γ; see Fig. 2). To verify the validity of the theory, we measured the vortex surface height h and local swirling velocity v as functions of local radius r.
   (2) In most of the experiments, because of the influence of the water current, vortex did not appear above the aperture A2. Even when it did appear over there, when the diameters of the two apertures were close, the outer diameter of the vortex above A2 (referred to as A2 vortex below for simplicity) was smaller than that above A1 (referred to as A1 vortex below).
   (3) Only A2 vortex but not A1 vortex was observed when A2 (=30mm) was much larger than A1 (=10mm). We speculated that this was because the disparity between the diameters of A1 and A2 produced a stronger draining force for A2, to overcome the influence of the imposed water current discussed above.
3. Distance between the Two Apertures
   (1) As discussed in 1-(1) above, due to the influence of the water current, the A1 vortex appeared to be a little lopsided, because it seemed to be pushed when the distance between the two apertures became longer. Nevertheless, the

water current was not affected on the whole, and the water fell into A1 aperture naturally, and generating a vortex, too.

(2) In general, when a second vortex appeared, the diameter of the first decreased. Also, as the distance between the two apertures increased, the diameter of the first vortex (even when there was only one) decreased slightly. We believed that this decrease resulted from the influence of the tank walls.

(3) The study of single vortices indicated that single vortices did not appear unless the water level stayed at a certain depth or below. We also found that, for a vortex to emerge, there was a relationship between the diameter of the aperture and the water depth in the tank. The smaller the diameter of the aperture was, the lower the water depth was required for vortices to appear. This phenomenon could be explained by the smaller centripetal force (provided by the pressure variation in the fluid) associated with a smaller swirling vortex.

(4) The water pressure around the aperture decreased as the water flowed into the aperture. More water followed, and this water current considerably enlarged the pressure variation (or "pressure gradient") around the aperture. The closer the water was to the aperture, the greater the pressure gradient was, the smaller the radius of the cross section of the vortex would be, resulting in greater fluid velocity and centripetal force. Therefore, at a certain water level, the pressure gradient would become too small to provide the centripetal force required to maintain the structure of a swirling vortex.

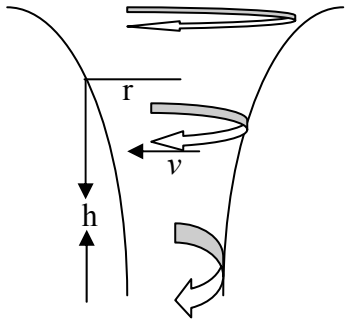


Fig.13. The structure of the swirling vortex.

(5) When the diameters of the two apertures were the same (see Fig.7), vortices generally did not appear over A2 aperture. The reason goes like this. There was a tendency for A2 vortices to form in the beginning because of water pressure decreases (see discussion above). But as the velocity of the water current from the water inlet grew greater than that around aperture A2, so was the water pressure near the water surface decreased accordingly. The decreases of water pressure around aperture A2 and near the water surface reduced the pressure gradient to maintain a swirling vortex; as a result, the vortex was not formed.

(6) When the distance between the two apertures was set at 40mm, it is observed that sometimes only one vortex was formed and that the water velocity was

pretty high (A1 outer diameters were large). It was presumed that the high water velocity occurred because the water that should have formed two vortices reinforced the water current. In this case, the pressure gradient got greater and the strength of the vortex got greater, too. In other cases when only one vortex was formed and the outer diameters were observed to be very small at the distance of 40mm, it was assumed that the range of reinforcement was below 40 mm.

(7) As the distance between the two apertures was increased, the velocity of the water current in between the vortices was decreased due to cancellation. As a result, the outer diameters observed were comparatively small.

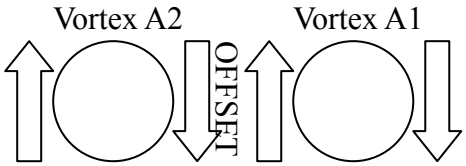


Fig.14. The effect of offset.

4. Diameters of the Two Apertures

When the distance between A1 and A2 became shorter, the imposed water current didn't just exert a push on the water, it was also pulled by apertures A1 and A2. The pull from A2 would become stronger as the margin between diameters of A1 and A2 apertures grew, because the pressure gradient was decreased. This then had the effect of cutting down the velocity of the current and made the outer diameter of A1 decrease.

5. Measurement of the Strength of the Vortex

From our experiment (see Fig.10 and Fig.11), we found that there was a relationship between the Outer vortex diameter and the circulation Γ. The greater the outer diameter was, the stronger the vortex was. So our data of outer diameters could be viewed as a measure of the vortex strength.

6. Water Supply

(1) Because of the supply of water, it was basically impossible to achieve a state of completely steady current. The water supply also created a directional flow which affected all the water in the tank.

(2) For this, three modifications were recommended to minimize the influence of the water current:

a. Change the rectangular tank to a round one.
b. Enlarge the water tank.
c. Supply water from all sides instead of simply from one side.

Conclusions

(1) The formation and interaction of the vortices were clearly observed.
(2) Two vortices merged together and became stronger when they were very close.
(3) The vortices size was not a monotonic function of the aperture separation.
(4) The difference of the aperture sizes significantly affected the vortex properties.
(5) The outer diameter was an indicator of the vortex strength.

Application

1. Our results were related to the prediction of the influence of current (wind) on the movement of twin vortices (tornadoes).
2. Under some circumstances in the study, one instead of two vortices appeared. This suggested that if we could use one vortex as an offsetting force to make another vortex disappear, we probably could create a device to produce a vortex to make a typhoon or a tornado diminish or even disappear. In addition, many transportation vehicles (e.g., automobiles, airplanes) in motion produced some vortices around them because of air movements, which then created a dragging force. Generally, the solution was to make the design more streamlined. The same idea seemed very likely to be applicable, too.
3. It was also found, accidentally, that the act of filling water into the tank itself created a current of great influence. The greater the water supply was, the stronger the influence would be. When it got strong enough, it would further cause the vortex closer to the water inlet to diminish or even disappear, regardless of the diameter of the vortex. It did just what the air supply did to a typhoon or a tornado. That is to say, it is possible to create an artificial vortex to fuel the influence of the airflow and destroy the structure of a typhoon or a tornado.

Attachment

1.The pictures of the vortices



A1=30 mm A2=30 mm Aperture separation=80 mm



A1=30 mm A2=30 mm Aperture separation=140 mm



A1=10 mm A2=30 mm Aperture separation=80 mm

2. The outer and inner diameters of different vortices

Outer / Inner Diameter (mm)			Aperture separation (mm)				
			40	60	80	100	120
Aperture diameters of A1 and A2 (mm)	A_1	30	5.813/1.188	5.846/1.231	6.313/1.625	5.938//1.375	5.529/1.118
	A_2	30					2.941/0.294
	A_1	25		3.187/0.312	3.687/0.750	2.533/0.800	3.214/0.928
	A_2	30	2.375/0.375			0.533/0.133	2.642/0.571
	A_1	20	2.000/0.400	3.800/0.800	3.466/0.666	1.866/0.600	4.133/0.933
	A_2	30				1.666/0.400	1.600/0.333
	A_1	15	2.857/0.428	2.428/0.285	2.882/0.470	3.500/0.562	2.187/0.312
	A_2	30					
	A_1	10					
	A_2	30	2.235/0.471	2.813/0.563	3.000/0.688	1.188/0.250	1.313/0.250
	A_1	25	4.563/0.875	4.813/1.188	0.625/0.125	1.188/0.250	2.500/0.625
	A_2	25			2.000/0.375	2.000/0.313	1.938/0.375
	A_1	20	2.800/0.600	2.357/0.571	2.214/0.571	2.071/0.786	2.067/0.467
	A_2	25					
	A_1	15					1.143/0.214
	A_2	25	3.231/0.615	2.615/0.538	1.929/0.357	1.857/0.214	1.357/0.357
	A_1	10			2.400/0.400	2.200/0.333	1.867/0.333
	A_2	25	1.600/0.200	1.438/0.188			
	A_1	20	2.467/0.400	2.938/0.625	3.250/0.813	3.125/0.625	2.933/0.600
	A_2	20					
	A_1	15	3.143/0.643	2.667/0.533	2.533/0.533	3.200/0.667	3.000/0.600
	A_2	20					
	A_1	10				1.625/0.313	
	A_2	20	1.467/0.267	1.867/0.333	1.267/0.200		
	A_1	15	3.465/0.712	3.313/0.688	2.500/0.438	3.176/0.588	3.412/0.647
	A_2	15					
	A_1	10			1.857/0.357		1.143/0.214
	A_2	15				1.929/0.357	
	A_1	10	1.143/0.214	1.000/0.143			
	A_2	10					

Outer / Inner Diameter (mm)			Aperture separation (mm)				
			140	160	180	200	
Aperture diameters of A1 and A2 (mm)	A_1	30	5.867/1.133	6.583/1.583	5.643/1.417	5.571/1.571	
	A_2	30	3.000/0.400				
	A_1	25	2.666/0.600	3.200/0.600	5.266/1.200	5.800/1.000	
	A_2	30	1.800/0.533	1.933/0.533	1.866/0.333	2.533/0.333	
	A_1	20	3.857/1.500	0.866/0.266	3.200/0.866	1.733/0.333	
	A_2	30		1.533/0.200	2.133/0.200	1.000/0.200	
	A_1	15	2.437/0.375	2.437/0.375	2.714/0.357	3.266/0.666	
	A_2	30					
	A_1	10				1.667/0.400	
	A_2	30	0.625/0.125				
	A_1	25	3.000/0.688	1.313/0.313	3.600/0.933	2.857/0.929	
	A_2	25	1.813/0.438	1.250/0.375			
	A_1	20	3.000/0.933	3.200/1.067	2.571/0.786	2.333/0.600	
	A_2	25	1.133/0.333	1.267/0.400	1.000/0.357	1.333/0.333	
	A_1	15	2.333/0.667			2.333/0.783	
	A_2	25	1.467/0.357			0.733/0.200	
	A_1	10	2.400/0.400	2.800/0.600	2.533/0.533	2.267/0.467	
	A_2	25					
	A_1	20	3.000/0.643	1.733/0.333	1.400/0.333	0.867/0.267	
	A_2	20					
	A_1	15	2.600/0.533	3.125/0.688	3.313/0.750	3.200/0.733	
	A_2	20					
	A_1	10	1.933/0.333		1.067/0.267		
	A_2	20		1.000/0.200		1.214/0.286	
	A_1	15	3.000/0.625	3.125/0.625	2.938/0.563	2.688/0.438	
	A_2	15					
	A_1	10	1.867/0.400		1.533/0.333		
	A_2	15					
	A_1	10	1.000/0.071		0.571/0.071	1.357/0.286	
	A_2	10					

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評語及建議事項

產生雙漩渦之雙孔距離及孔徑大小會影響窩流的強弱及動態行爲，題目看似單純，卻有意想不到的結果，值得探討了解，故題目本身具創新性。

實驗測量雖精確度不足，但可初步彰顯主要性質。對現象的解釋稍嫌籠統，但符合高中生之程度，且大致合理。