

出國報告（出國類別：國際會議）

參加美國航空太空協會
「2018 科學技術論壇與展覽」

服務機關：國防大學理工學院機械及航太工程學系

姓名職稱：尤懷德 助理教授

派赴國家：美國

出國期間：自民國 107 年 1 月 6 日至民國 107 年 1 月 15 日

報告日期：民國 107 年 2 月 9 日

摘要

中華民國 107 年 1 月 6 日至 1 月 15 日期間，吾人至美國佛羅里達(Florida, USA) 參加美國航空太空協會(AIAA)舉辦之「2018 科學技術論壇與展覽(2018 SciTech)」 並發表著作「平板掠翼暫態流在定加速度振幅下之暫態作用力演化(Transient Force Evolution of Swept Flat-Plate Wings Pitching at a Constant Acceleration Amplitude)」。依「行政院及所屬各機關出國報告綜合處理要點」規範，提報參加研討會議經驗與所見所聞，除便利公眾共享外，更可提供日後國內各機關、機構及公營事業之研發人員及大專院校教職人員參考運用。

目次

壹、	前言	1
貳、	會議目的	1
參、	會議過程	1
肆、	與會心得及建議	7
伍、	致謝	8
陸、	參考資料	8

壹、 前言

本報告係依據「行政院及所屬各機關出國報告綜合處理要點」相關規定撰擬，旨在提報個人開會經驗與所見所聞，並提供日後國內大專院校相關教職人員或研發人員參考運用。

貳、 會議目的

美國航空太空協會多年前開始整合研討會，以五大論壇進行產官學界間交流，包含科技論壇及展覽(Science and Technology Forum and Exposition, 簡稱 SciTech Forum)、防禦與安全(Defense and Security Forum, 簡稱 DEFENSE Forum)、航空與航空學論壇及展覽(Aviation and Aeronautics Forum and Exposition, 簡稱 AVIATION Forum)、推進與能源論壇(Propulsion and Energy Forum)、太空與航太學論壇及展覽(Space and Astronautics Forum and Exposition, 簡稱 AIAA SPACE Forum)，分別於每年元月、五月、六月、七月及九月舉行。

本次參加科技論壇及展覽，論壇地點為美國佛羅里達州(Florida)基西米市(Kissimmee)的蓋洛德棕櫚飯店(Gaylord Palms Resort)，活動時間自 2018 年 1 月 8 日至 1 月 12 日止，為期 5 日。活動內容包含技術會議(Technical conference)、論壇(Forum)及展覽(Exhibition)等 3 部分。其中參加技術會議者必須於前年 6 月前提交初稿文章，主辦單位於 8 月中旬通知是否文章接受發表。收到接受信函後，通聯作者必須於 12 月初將完稿文章上傳投稿系統 ScholarOne。未於期限內上傳完稿文章者，文章會被撤銷，不能於會議中發表。投稿者必須參加會議並口頭報告文章內容，所發表文章才能被收錄於研討會論文集(Conference Proceedings)。未依議程完成口頭報告之文章會從論文中撤銷。所有與會人員登錄該協會 ARC(Aerospace Research Center)資料庫後，可以閱讀並下載該年度研討會論文集任何一篇收錄的文章。

本次參加會議主要目的是發表著作，著作英文名稱為「Transient Force Evolution of Swept Flat-Plate Wings Pitching at a Constant Acceleration Amplitude [2]」，中文譯為「平板掠翼暫態流在定加速度振幅下之暫態作用力演化」。文中主要以實驗方式探討等加速度對俯仰平板掠翼在自由流場中之作用力演化過程，為延續去年發表文章[3]之研究，是去年度(105 年度)科技部專題研究計畫「俯仰機翼非環流效應探討」延伸研究議題之一，配合今年度(106 年度)科技部專題研究計畫「非侵入式流體動力測定演算法開發」建立研發探討工具，可幫助相關研發人員或學者們瞭解高攻角高升力之空氣動力學及載具高敏捷性能。

參、 會議過程

基西米市(Kissimmee)靠近美國重要民用機場樞軸的奧蘭多國際機場(MCO)。經查詢我國中華航空所提供自桃園國際機場(TPE)至奧蘭多國際機場之來回航線，最低票價新台幣 6 萬 6,767 元，長榮航空所提供之來回航線票價最低為新台幣 6

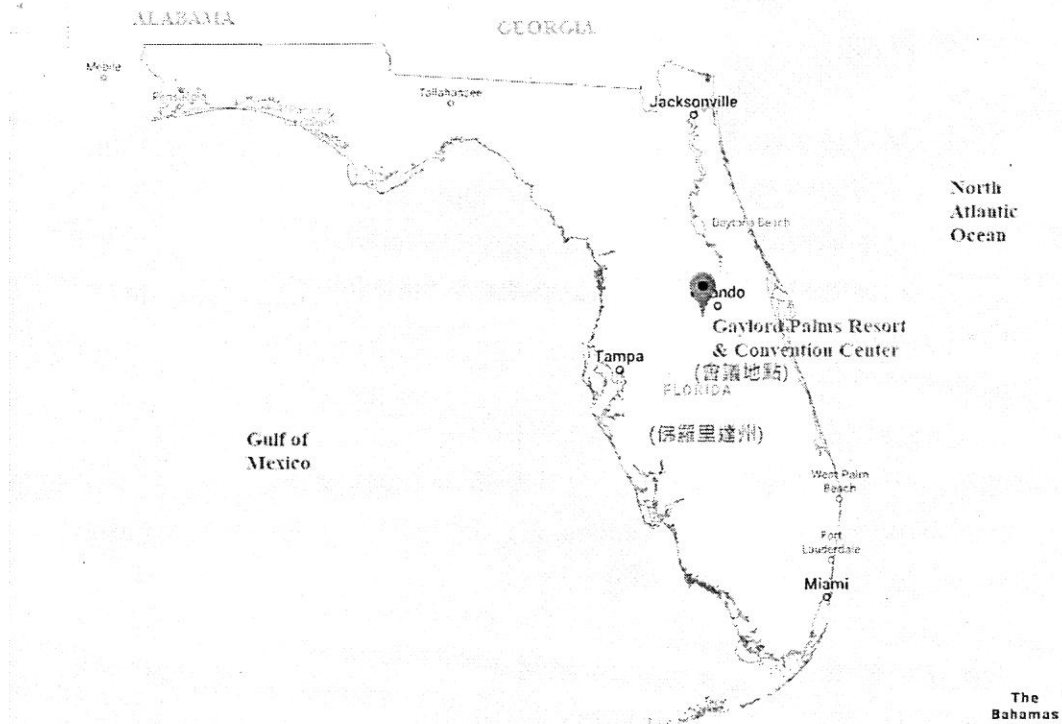


圖 1 美國航空太空協會「2018 科學與技術論壇與展覽」地點。

萬 3,817 元，國內旅行社代辦最低來回票價為美國航空(American airlines)新台幣 3 萬 7,646 元。為擲節研究經費，本次行程選擇花費較便宜之美國航空，但去程必須於日本東京成田機場(NRT)及美國洛杉磯國際機場(LAX)轉機，回程必須於美國達拉斯／沃斯堡國際機場(DFW)及日本東京成田機場(NRT)轉機。吾人民國 107 年 1 月 6 日由桃園國際機場搭機依原規劃行程搭機飛往奧蘭多國際機場。然而，日本東京成田機場起飛之航班 AA0170，因該班機波音 777 維修與保養之故取消，吾人在日本空服人員協助下，重新安排航班，入境日本並夜宿過境旅館 (Hotel Nikko Narita)。隔日 1 月 7 日(日本東京時間)改搭乘美國航空航班 AA176 前往美國達拉斯／沃斯堡國際機場，然後轉機前往目的地-奧蘭多國際機場。回程仍依原規劃行程，沒有因為班機維修或天氣因素取消或延誤，1 月 14 日(美國奧蘭多國際機場時間)搭乘航班 AA1289 啟程返國。其餘研討會行程與工作內容摘要如表 1。

一、技術會議(Technical Conference)

今年美國航空太空協會「科學與技術論壇與展覽」之技術會議計整合 11 場會議。

1. 自應適結構會議(Adaptive Structures Conference)。
2. 航空科學會議(Aerospace Science Meeting)。
3. 大氣飛行力學會議(Atmospheric Flight Mechanics Conference)。

4. 導航、尋航及控制會議(Guidance, Navigation, and Control Conference)。
5. 航空資訊技術會議 (Information Systems - Infotech @ Aerospace Conference)。
6. 模式與模擬技術會議(Modeling and Simulation Technologies Conference)。
7. 非決定性方法會議(Non-Deterministic Approaches Conference)。
8. 太空載具結構會議(Spacecraft Structures Conference)。
9. 結構與結構動力學及材料會議(Structures, Structural Dynamics, and Materials Conference)。
10. 風能座談(Wind Energy Symposium)。
11. 太空飛行力學會議(Space Flight Mechanics Meeting)。

今年技術會議增加「太空飛行力學會議」，但是沒有將「太空資源運用座談(Symposium on Space Resource Utilization)」納入議程，所以今年技術會議數與去年相同。各領域文章數量統計如表 2。

今年技術會議發表文章共有 45 項領域，納入議程部分文章共計 2,296 篇，比去年增加 165 篇。表 2 所顯示粗體字體加底線部分為今年增加的場次，計有通訊系統(CMS, Communication System)、進氣道、噴嘴與推進系統整合(INPSI, Inlets, Nozzles and Propulsion System Integration)、社會與航太技術(SAT, Society and Aerospace Technology)、太空飛行力學(SFM, Space Flight Mechanics)、獨特與變形飛行(UTF, Unique and Transformational Flight)等五場。表 2 欄位顯示斜刪除線部分代表未納入今年議程之場次，計有數位航空電子設備(DA, Digital Avionics)、壓力增益燃燒(PGC, Pressure Gain Combustion)、太空資源運用(SRE, Space Resources Utilization)等三場次。各欄位括弧中之正、負號分別表示今年各場次文章較去年增、減情形。議程中僅口頭報告(即無文獻可查)之場次沒有彙整列入表 2。

本次投稿文章屬航空科學會議(Aerospace Science Meeting)，文章歸屬「應用空氣動力學(Applied Aerodynamics，縮寫 APA)」領域項下之「高攻角與高升力空氣動力學(High Angle of Attack and High Lift Aerodynamics)」。「應用空氣動力學」領域接受 253 篇文章發表，占所有文章數量的百分之 11.00，該領域文章數量僅次於「流體動力學」(所有文章數量的百分之 11.83)，略高於「導航、尋航及控制」(所有文章數量的百分之 10.32)。文章數量成長較去年增加之前三個領域依序為「獨特與變形飛行」、「結構」及「導航、尋航及控制」。

表 1 行程摘要(美國時間)

日期	2018/1/8	2018/1/9	2018/1/10	2018/1/11	2018/1/12
起訖地點	美國佛羅里達	美國佛羅里達	美國佛羅里達	美國佛羅里達	美國佛羅里達
工作紀要	報到與會	練習簡報	練習簡報	修改文章	口頭簡報

(一) 文章發表

技術會議議事安排與往年大致相同，每日口頭發表計有上午與下午場次，各場次最多安排 7 場口頭報告，每場口頭報告時間 30 分鐘，含問答時間 5-10 分鐘。上午與下午場次分別於 09:30 時與 14:00 時開始。依大會議程規劃，發表人得於當日早上 07:30 至 08:00 時至發表地點向主持人報到，發表人可利用該段時間將簡報檔案複製於大會所提供之筆記型電腦，並測試簡報檔案，或測試自己的簡報筆記型電腦與大會投影機連結狀況。該場次簡報結束後，主持人會將大會筆記型電腦中發表人所儲存簡報檔案刪除。

表 2 美國航空太空協會「2018 科學技術論壇與展覽」之技術會議各領域文章發表數量。

AA	ABPSI	ACD	AFM	AMT	APA	ASC	<u>CMS</u>	CPS	DA
45(-3)	0(-12)	56(+3)	61(-2)	41(-27)	253(+32)	23(-9)	<u>4(+4)</u>	1(-2)	0(-3)
DE	EDU	FD	GEPC	GNC	GT	GTE	HIS	HSABP	ICC
14(-2)	8(-3)	272(-14)	0(-12)	237(+55)	23(-20)	41(+2)	1(-3)	53(+13)	4(-1)
<u>INPSI</u>	IS	ISC	MAT	MDO	MST	MVC	NDA	OPS	PGC
<u>23(+23)</u>	52(+25)	18(-1)	63(+29)	71(+16)	77(-1)	33(+13)	55(-7)	5(-1)	0(-30)
PC	PDL	SATS	<u>SAT</u>	SCS	SD	SE	SEN	<u>SFM</u>	SOF
95(-39)	58(0)	15(-9)	<u>2(+2)</u>	40(+13)	97(-38)	10(+1)	19(+7)	<u>109(+109)</u>	7(-1)
SRE	STR	SUR	TES	<u>UTF</u>	TP	UAS	WE	N/A	N/A
0(-12)	124(+68)	6(-3)	15(-4)	<u>11(+11)</u>	56(-2)	45(+1)	53(-1)		

符號說明：AA (Aeroacoustics), ABPSI (Air Breathing Propulsion Systems Integration), ACD (Aircraft Design), AFM (Atmospheric Flight Mechanics), AMT (Aerodynamic Measurement Technology), APA (Applied Aerodynamics), ASC (Adaptive Structures), CMS (Communication Systems), CPS (Computer Systems), ~~DA (Digital Avionics)~~, DE (Design Engineering), EDU (Education), FD (Fluid Dynamics), GEPC (Green Engineering), GNC (Guidance, Navigation, and Control), GT (Ground Testing), GTE (Gas Turbine Engines), HIS (History), HSABP (High Speed Air Breathing Propulsion), ICC (Information and Command & Control Systems), INPSI (Inlets, Nozzles and Propulsion System Integration), IS (Intelligent Systems), ISC (International Student Conference), MAT (Materials), MDO (Multidisciplinary Design Optimization), MST (Modeling and Simulation Technologies), MVC (Meshing, Visualization, and Computational Environments), DA (Non-Deterministic Approaches), OPS (Space Operation and Support), ~~PGC (Pressure Gain Combustion)~~, PC (Propellants and Combustion), PDL (Plasmadynamics and Lasers), SATS (Small Satellites), SAT(Society and Aerospace Technology), SCS (Spacecraft Structures), SD (Structural Dynamics), SE (Systems Engineering), SEN (Sensor Systems), SFM (Space Flight Mechanics), SOF (Software Systems), ~~SRE (Space Resources Utilization)~~, STR (Structures), SUR (Survivability), UTF (Unique and Transformational Flight), TES (Terrestrial Energy), TP (Thermophysics), UAS (Unmanned Systems) 、 WE (Wind Energy)。



圖 2 議事手冊與識別證。

去年發表者得於會議結束後得將文章修改並更新檔案。今年文章口頭發表後，修改或更新後之文章必須於會議結束後 12 日以前，上傳至投稿系統 ScholarOne，修改部分會經由 Crossmark 系統追蹤，讓讀者了解會議前後，該文章內容修改狀況，這追蹤功能是今年大會新增的服務。另外，本次研討會所收納的文章不再以第幾屆研討會註記，取而代之的是西元年份 2018。

依大會議程安排，吾人口頭發表時間為美國當地時間 2018 年 1 月 12 日 10:00 時，文章譯名為「平板掠翼暫態流在定加速度振幅下之暫態作用力演化 (Transient Force Evolution of Swept Flat-Plate Wings Pitching at a Constant Acceleration Amplitude)」[2]。中、英文摘要如下，簡報內容如附錄。

(二) 中文摘要

本文以實驗方法探討掠翼在平均弦雷諾數為 8900 之自由流場中，俯仰等加速度/等減速度運動下，流體動力瞬態的演化過程。所考量之機翼平面形狀包括正梯形和直角三角形，這兩種機翼皆是平板，幾何展弦比皆為四，俯仰方式皆是從零度攻角至數個最大攻角。前掠翼組態(Swept-Forward Wing Configuration)是將俯仰樞軸與同軸線的機翼直邊置放於上游處。當這俯仰樞軸置於下游時就形成後掠翼組態(Swept-Back Wing Configuration)。實驗數據顯示，不論哪種掠翼組態，法向作用力(Normal Force)影響都大於軸向作用力(Axial Force)。在俯仰加速階段，前掠翼比後掠翼承受較多的作用力。在鬆弛期間(Relaxation Period)，瞬態現象(Transient Phenomena)取決於機翼平面形狀，而不是翼形掠角。當最大攻角低於 18 度時，三角形翼容易受到典型振盪流場影響。然而，在最大攻角高於 21 度時，梯形翼較容易受到激烈瞬態作用力(Transitory Force)影響。

(三) 英文摘要

This paper presents the experimental evolution of transient hydrodynamic forces

acting on swept wings undergoing a constant pitching acceleration/deceleration. The pitching maneuver concerns a wing from a zero-incidence angle to several maximum angles of attack in a free stream with a mean-chord-based Reynolds number of 8900. Two planform shapes include a right trapezoid and a right triangle. Both wings are flat plates with a geometric aspect ratio of four. A swept-forward configuration adapts the axis of pitching pivot about a wing straight-edge upstream; however, a downstream-pivot-axis configuration yields the swept-back wing. The experimental force data disclose the domination of the normal force over the axial force on the pitching wings in the transient flow. During the phase of pitching acceleration, the swept-forward wings experience much more hydrodynamic forces than swept-back wings. During the period of relaxation, the transient phenomena are dependent on the planform shape, not the swept angle. As the maximum angle of attack lower than 18 degrees, the triangle wing is susceptible to the typical oscillating flow. However, the trapezoid wing confronts more severe transitory force generation as the maximum angle of attack higher than 21 degrees.

二、論壇

表 3 為本次大會演講與論壇主題，活動時段與技術會議衝突，與會人員無法參加所有活動，必須選擇性參加。所幸大會將本項活動全程錄影且現場直播，提供與會人員於會議後可點選觀賞，亦提供當日無法與會人士瞭解大會安排之演講或論壇內容，論壇網址為 <http://livestream.com/AIAAvideo/scitech2018>。

表 3 美國航空太空協會「2018 科學技術論壇與展覽」論壇議題。

日期	1/8	1/9	1/10	1/11	1/12
主題 演講 (Plenary Section)	0800 - 0900 Digital Enterprise Business Models and their Impact on the Aerospace Industry	Data, Everywhere... the Power & Potential	DataDude, Where's My Flying Car?	Welcome to the Holodeck	Serving our Robot Overlords
論壇 (Forum 360)	0930 - 1130 The Dawn of Digital Engineering	Data, Everywhere... the Devil in the Details	On-Demand Mobility Enabling Technologies and Capabilities	Digital Natives - Leading the Digital Transformation in Design and Knowledge Environments	
	1400 - 1600 Digital Transformations Disrupting Aerospace Business Models	Prizes & Challenges: How Crowdsourcing Can Help Solve Technology Gaps	On-Demand Mobility Regulatory and Operational Challenges	Human-Machine - Teaming	

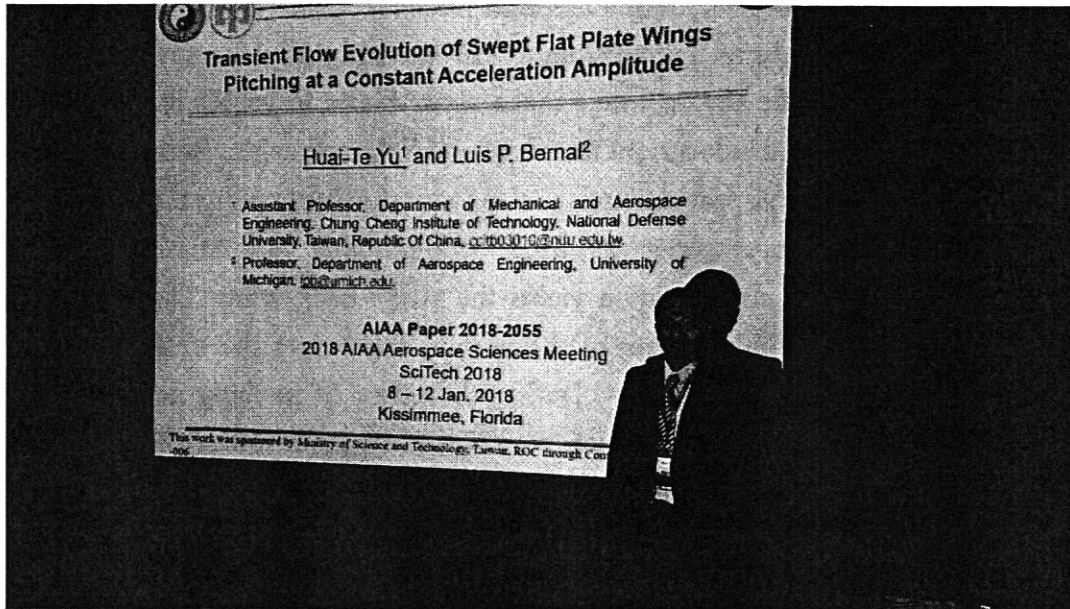


圖 3 口頭報告照片。

三、展覽

今年度參加展覽攤位計有 55 家，除加拿大國家研究委員會(National Research Council of Canada)外，都是美國本土的廠商、書商及政府研發機構(包含 Arnold Engineering Development Complex, Digital Thread and Digital Twin Revealed, National Reconnaissance Office, Office of Naval Research, NASA)。下一屆會議舉辦地之加州聖地牙哥市旅遊管理局(San Diego Tourism Authority)也加入展覽攤位行列。

肆、與會心得及建議

一、有效推動資源整合

美國航空太空協會(AIAA)在財務緊縮的情況下，多年前開始以五大論壇將過去每年舉辦之數十個研討會逐漸整合，按文章領域安排場次，因研究議題相似，有助於學者們討論所遇到的難題。另外，科技會議文章於會議前就已經公開，提供已註冊人士下載閱讀。也就是說，在會議之前，與會人士可以知道報告內容，並在會議中提出疑問。而發表人員於會議後的指定時期內，可以小幅修改文章，或將研討會文章投稿該協會所發行情刊。

由於與會人士來自世界各國，報到時間可能會因班機或天氣等種種因素影響，在不同時間點報到，該協會於會場架設多台電腦資訊系統與印表機，與會人員可以自行輸入姓名，現場列印識別證件，然後至鄰近攤位領取議程手冊、識別證(套)及配件，這樣做法可以減少現場工作人員與工作量及相關人事成本。這套自行報到系統自前年起就已經開始運作，過去曾因連線問題，電腦發生當機或印表機無法印製等狀況，導致大排長龍等待報到的人潮現象，今年該自行報到系統已逐漸

穩定成熟，等待人潮相對減少許多。

二、善用數位工具，提前公開研討會資訊

美國航空太空協會自去年(西元 2017 年)起開始推動論壇錄影與直播，今年(西元 2018 年)增加 Crossmark 系統追蹤文章內容變動服務，各研討會的屆別也開始使用西元年取代註記。配合轉型工作，該協會提前公開活動時間與地點，並將資訊提前公佈於該協會網站，明年及後年的科技論壇及展覽舉辦時間與地點分別將於加州聖地牙哥市(2019/01/07-01/11)及佛羅里達州奧蘭多市(2020/01/6-01/10)舉行，這些資訊都已經可以從該協會網站查知，讓有意願與會人士有足夠時間準備投稿文件。該協會網頁顯示，本次科技論壇及展覽吸引多達 43 國學者投稿參與。

三、結合科技發展趨勢，推動產官學合作

本次科學技術論壇的主題為「掌握住下一波的數位轉型(SEIZING THE NEXT DIGITAL TRANSFORMATION)」。隨著突破性創新(Disruptive Innovation)、物聯網(Internet of Things)、數位工程(Digital Engineering)、機械學習(Machine Learning)等領域逐漸引起產業界熱切關注，也激發多重學科整合問題等待解決。IBM 全球大學計畫副總裁 Naguib Attia 認為區塊鏈(Blockchain)的使用可為航太與國防帶來更安全資訊協定，而量子電腦(Quantum Computer)的發展將大幅提升運算能力，處理未來龐大數據資料庫。喬治亞理工學院 Dimitri Mavris 認為數位化線程(Digital Thread)可將產品生命週期(Product life-Cycle)以數位方式連結，減少物流成本。空軍研究實驗室 Pamela Kobryn 展示數位化模擬(Digital TWIN)將運用現在知識，模擬未來系統性能。這一系列的發展將逐步重新雕塑我們的未來生活，因為這數位化發展牽涉層面廣，需要各界共同合作，尋求或思索合適的解決方案或訂定新規範。

伍、 致謝

感謝科技部支持本研究與贊助參加研討會所需經費，研究計畫編號：MOST 106-2221-E-606-006。感謝主持人 Brian McGrath(任職於 Johns Hopkins University Applied Physics Laboratory)協助拍照。

陸、 參考資料

- [1] Home: The American Institute of Aeronautics and Astronautics, <http://www.aiaa-scitech.org/>
- [2] Yu, H.-T. and Bernal, L.P., "Transient Force Evolution of Swept Flat-Plate Wings Pitching at a Constant Acceleration Amplitude," 2018 AIAA Aerospace Sciences Meeting, AIAA Paper 2018-2055, Jan. 2018. <http://dx.doi.org/10.2514/6.2018-2055>

- [3] Yu, H.-T. and Bernal, L.P., "Direct Force Measurements during Transient Flow about Pitching Flat Plates," 55th AIAA Aerospace Sciences Meeting, AIAA Paper 2017-0995, Jan. 2017.
[http://dx.doi.org/doi: 10.2514/6.2017-0995](http://dx.doi.org/doi:10.2514/6.2017-0995)



Transient Flow Evolution of Swept Flat Plate Wings Pitching at a Constant Acceleration Amplitude

Huai-Te Yu¹ and Luis P. Bernal²

¹ Assistant Professor, Department of Mechanical and Aerospace Engineering, Chung Cheng Institute of Technology, National Defense University, Taiwan, Republic Of China, ccitb03010@ndu.edu.tw.

² Professor, Department of Aerospace Engineering, University of Michigan, lpb@umich.edu.

AIAA Paper 2018-2055
2018 AIAA Aerospace Sciences Meeting
SciTech 2018
8 – 12 Jan. 2018
Kissimmee, Florida

This work was sponsored by Ministry of Science and Technology, Taiwan, ROC through Contract MOST 106-2221-E-606-006.



Outline

- Introduction
- Experimental Setup
- Results and Discussion
 - C_N and C_A evolution course
 - Comparisons of C_N and C_A at t_p and $30 t_c$
 - Transitory force maxima and minima analysis
- Conclusions

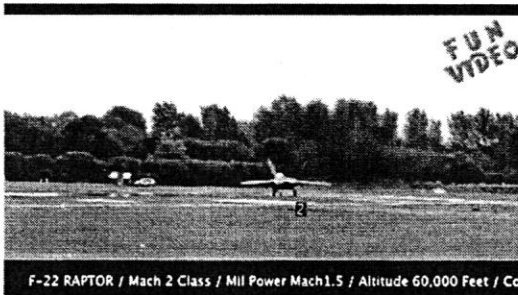


Introduction

Applications



Pitching maneuver



F-22 RAPTOR / Mach 2 Class / Mil Power Mach 1.5 / Altitude 60,000 Feet / Co

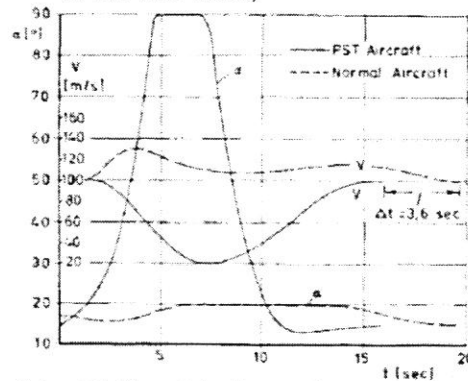
F-22 in serve in Dec. 2005 (from wiki)

Perching maneuver!



Cory, R., and Tedrake, R., "Experiments in Fixed-Wing UAV Perching," AIAA 2008-7256.

For manned vehicle, post-stall maneuver, supermaneuverability in the late 1980,



Herbst, W.B., "Future Fighter Technologies", Journal of Aircraft, Vol. 17, No. 8, 1980, pp. 561-566.
Herbst, W.B., "Dynamics of Air combat", Journal of Aircraft, Vol. 20, No. 7, 1983, pp. 594-598.

3/20



Introduction

- North Atlantic Treaty Organization (NATO) Science and Technology Office (STO) AVT 202 panel for Fundamental Flow Physics to Practical MAV Aerodynamics,
- Eldredge, J. D., Wang, C., and Ol, M. V., "A Computational Study of a Canonical Pitch-up, Pitch-down Wing Maneuver," AIAA Paper 2009-3687, June 2009.
- Yu, H.T. and Bernal, L.P., "Effect of Pivot Point on Aerodynamic Force and Vortical Structure of Pitching Flat Plate Wings," AIAA Paper 2013-0792, Jan. 2013.

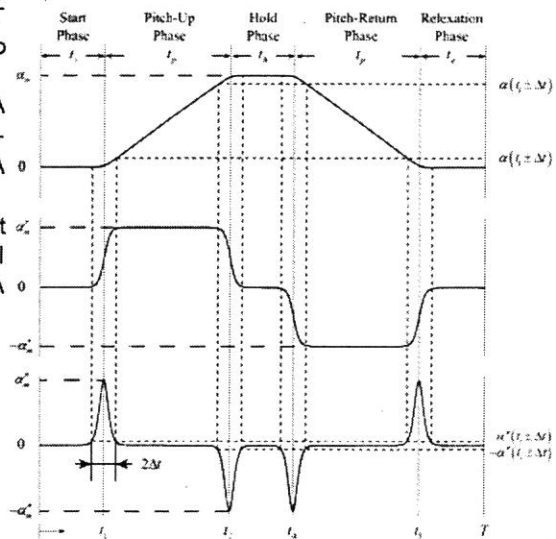
Constant Rate of Change of Pitch Angle

$$\alpha(t) = \frac{\alpha_m}{2B} \sum_{i=1}^i (-1)^{i+1} \ln \left\{ \cosh \left[B\beta(t-t_i) / \Delta t \right] \right\}$$

$$\gamma = |\alpha''(t, \pm \Delta t) / \alpha_m''| \quad \beta = \Delta \alpha / \alpha_m$$

$$B = \cosh^{-1}(\sqrt{1/\gamma}) / \beta \quad B = 2t_p / t_a$$

$$\Delta t = \beta t_p \quad t_e = et_c \quad t_h = ht_c \quad t_s = st_c \quad t_p = \alpha_m / \alpha_m' \quad t_a = \alpha_m' / \alpha_m''$$



4/20



Introduction

- Using the kinematics of constant pitch rate,
 - The existence of transitory force generation in the relaxation phase of a wing at a high angle of attack is evidenced by NATO STO AVT 202 (2016) in joined effort.
 - Ol and Babinsky (2016), and Yu and Bernal (2017) reported the dependence of transitory force generation on reduced pitch rate and pivot axis location.
 - Son *et al.* (2016) reported the dependence of transitory force generation on aspect ratio.
 - Yu and Bernal (2017) reported **the occurrence** of transitory force on pivot axis location would be the same for the same reduced pitch rate case as the time scale is compensated by the convective time traveling from leading edge to pivot axis.
- Yu and Bernal (2017) utilized symmetrical flat plate wings at mid chord pivot undergoing a constant pitch acceleration and reported the dependence of transitory force generation on wing planforms. The effect of reduced pitch rate was suppressed.

5/20



Objectives

- Using a right trapezoid and a right triangle flat plate wings to capture dynamic flow at constant pitch acceleration from zero-incidence to several maximum angles of attack using direct force measurement technology.
- To determine the transitory force generation of unsteady flow as functions of angle of attack, planform shape, and swept angle.

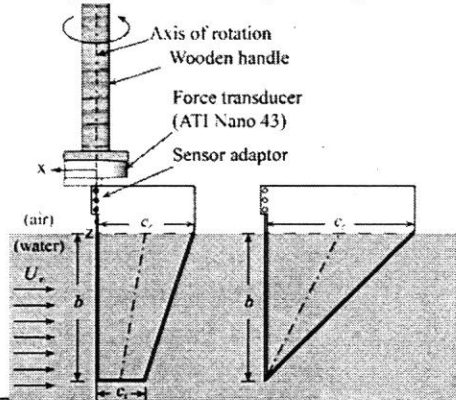
6/20



Experimental Setup

Swept-forward wing configuration

- Low-turbulence water channel at University of Michigan (61cm wide and 57 cm height). $U_\infty = 17.5$ cm/s ($Re = 8,900$).
- All wings are made of Plexiglass and rounded edges.
- All wings have 2" mean chord and 4" wetted span with thickness to mean chord ratio of 6.25%.
- All wings were pitched at a straight edge.
- Force sensor is Nano 43 by ATI.



Wing	Mass (g)	Leading-edge sweep angle (deg)	Trailing-edge sweep angle (deg)	Half chord line Sweep angle (deg)	Half span (in)	Wetted area (in ²)	Root chord (in)	Tip chord (in)	Taper ratio, c_t/c_r	GMC (in)	MAC (in)
Trapezoid	24.2	0	18.43	9.46	4	8	2.67	1.33	0.5	2	2.074
Triangle	27.9	0	45	26.56	4	8	4	0	0	2	2.667

Note: GMC = Geometric Mean Chord; MAC = Mean Aerodynamic Chord

7/20



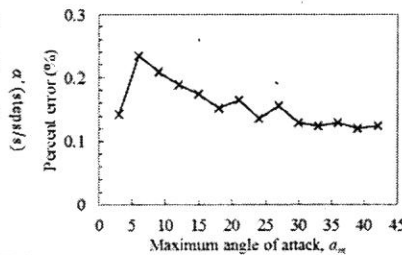
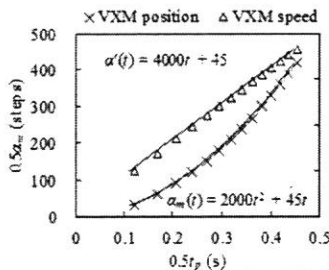
Wing kinematics of a Constant-Acceleration

- The kinematics is a quadratic time variation function by

$$\alpha'(t) = \alpha'_0 t + 0.5\alpha''_m t^2$$

where α'_0 is $2.25^\circ/s$ and α''_m is a value of $200^\circ/s^2$ ($\alpha''_m t_c^2 = 0.2942$).

- Wing kinematics was carried out by Velmex Rotary Table B4818TS.



Reduced pitch rate

$$K = 0.5c \alpha'_m / U_\infty = 0.5\alpha_m (t_c / t_p)$$

$$t_c = c / U_\infty (= 0.2903 \text{ s})$$

α_m	3°	6°	9°	12°	15°	18°	21°	24°	27°	30°	33°	36°	39°	42°
t_{p_theo}	0.223	0.325	0.402	0.468	0.526	0.578	0.626	0.671	0.713	0.752	0.790	0.826	0.861	0.894
t_{p_exp}	0.224	0.325	0.403	0.469	0.527	0.579	0.627	0.672	0.714	0.753	0.791	0.827	0.862	0.895
t_p/t_c	0.770	1.118	1.386	1.612	1.811	1.991	2.156	2.310	2.455	2.592	2.722	2.847	2.966	3.081
K	0.034	0.047	0.057	0.065	0.072	0.079	0.085	0.091	0.096	0.101	0.106	0.110	0.115	0.119

8/20



Direct Force Data Processing

• **Tare procedure:** to remove inertia and weight contributions due to the wing position and acceleration.

➤ **Static tare:** the measurements in air and still water at fixed angle from 0° to a maximum angle of attack.

✦ It is negligible because of the very small mass of the wing and mounting hardware, i.e. $< 46.2g$

➤ **Dynamic tare:** the measurements in air with the same kinematics as in the flow experiments.

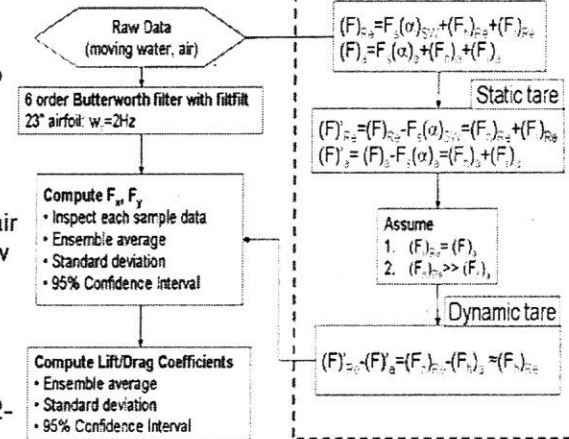
✦ The same filter and cutoff frequency as in the flow experiments was used.

• A low-pass, zero-phase, first order, 2-path Butterworth filter was used.

• The cutoff frequency is 8.76 Hz.

• 60 samples were averaged.

Data Processing

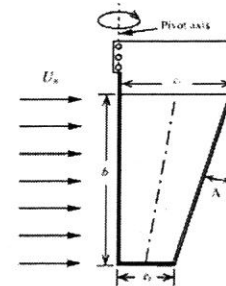
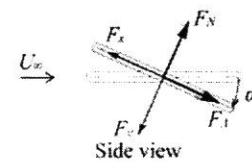
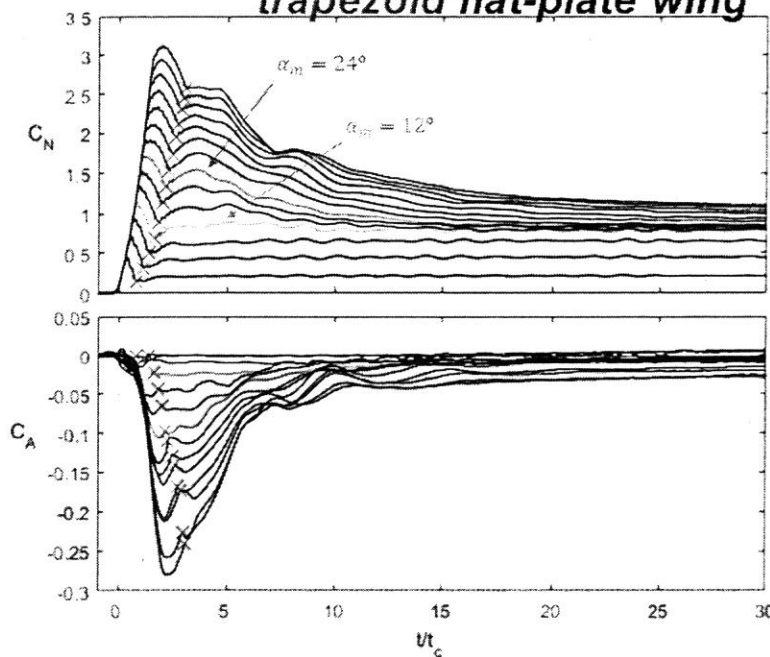


Yu, H.-T., and Bernal, L.P., "Effects of Pivot Location and Reduced Pitch Rate on Pitching Rectangular Flat Plates." AIAA Journal. Vol. 55, No. 3, 2017, pp. 702-718.

9/20



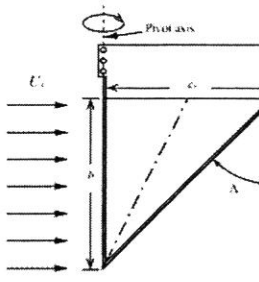
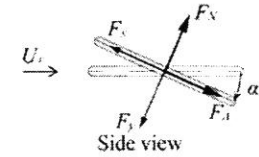
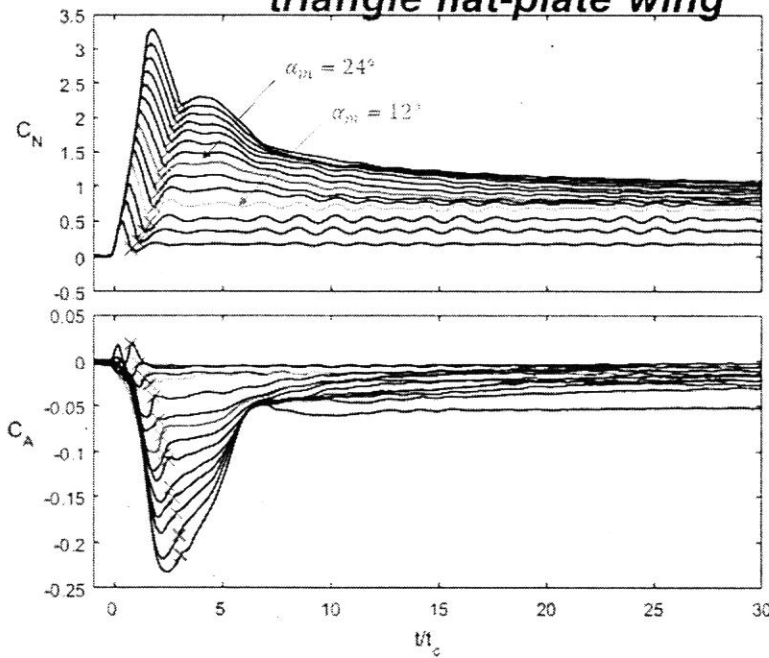
Transient forces for a swept-forward trapezoid flat-plate wing



10/20



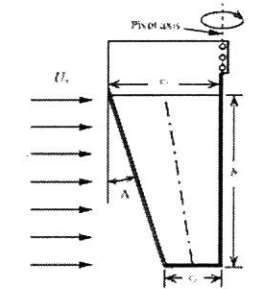
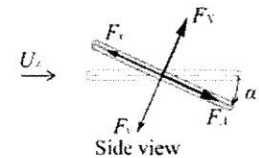
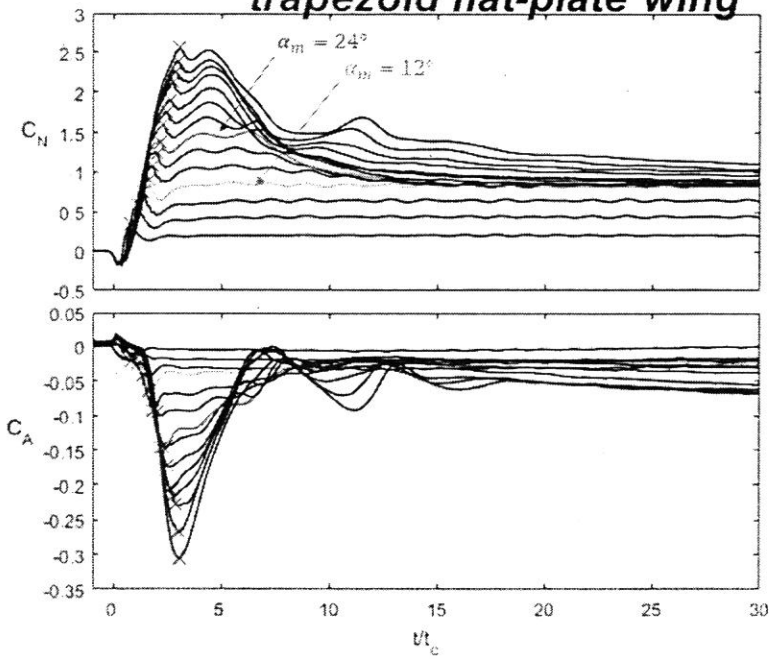
Transient forces for a swept-forward triangle flat-plate wing



11/20



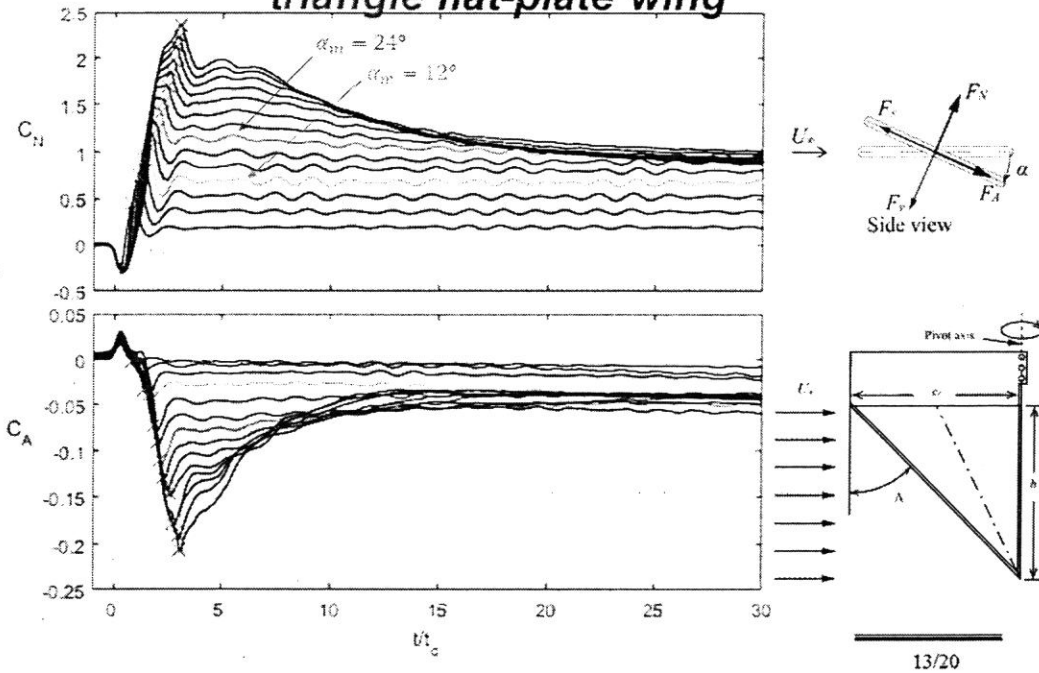
Transient forces for a swept-back trapezoid flat-plate wing



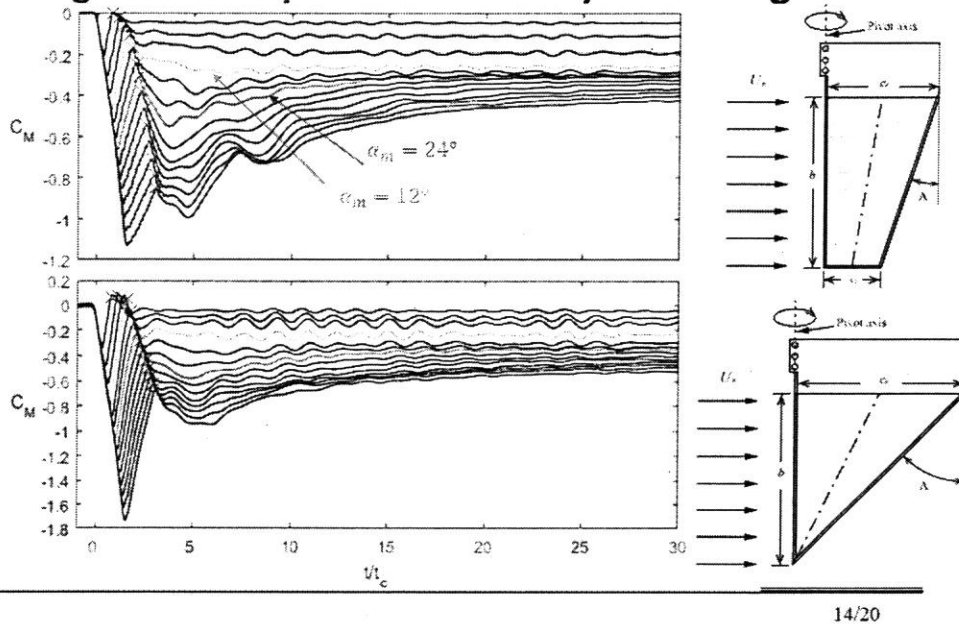
12/20



Transient forces for a swept-back triangle flat-plate wing

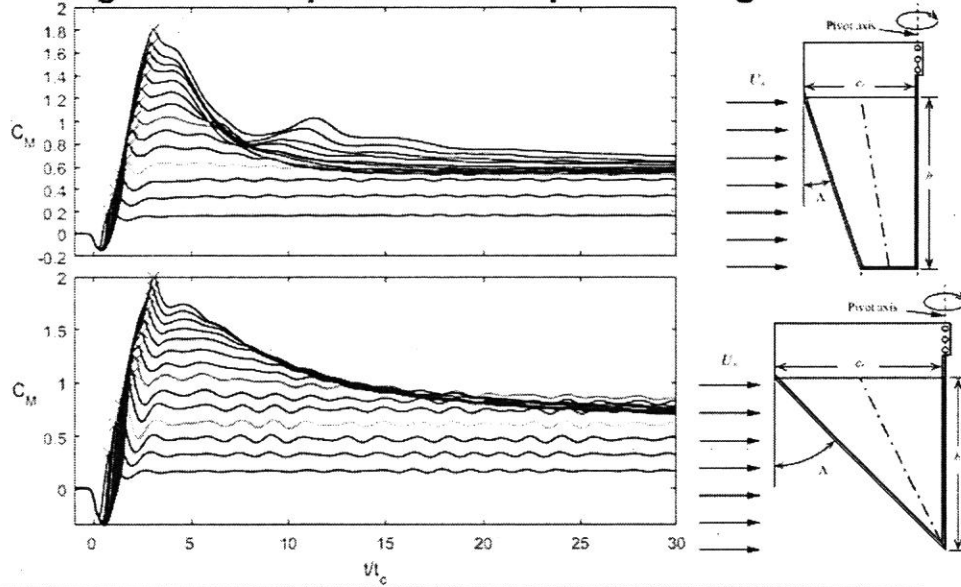


Pitching moment coefficient about leading-edge for swept-forward flat-plate wings





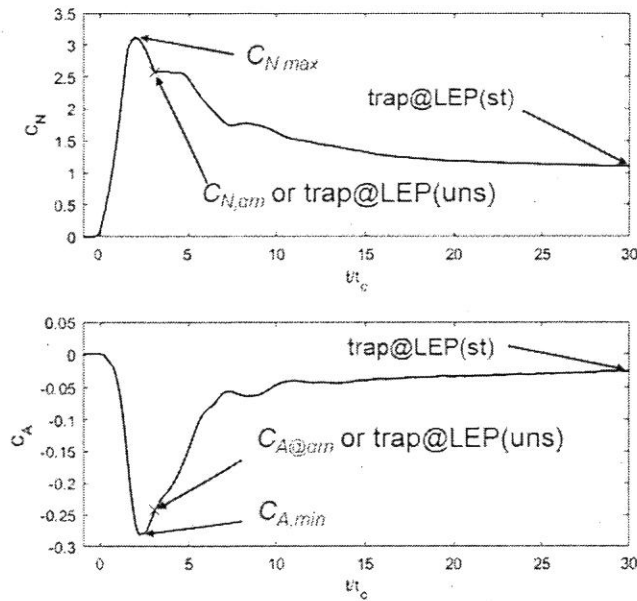
Pitching moment coefficient about trailing edge for swept-back flat-plate wings



15/20



Notation for Instantaneous Force Analysis

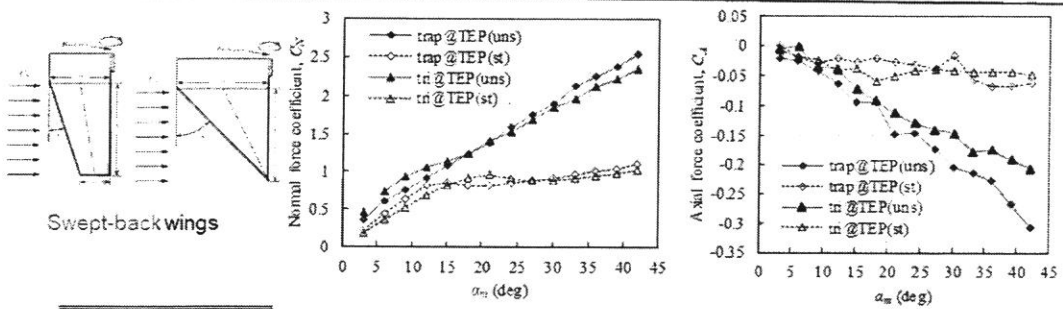
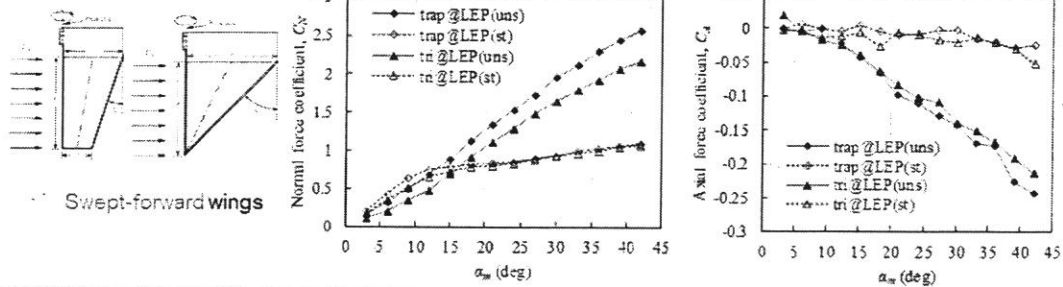


16/20



Comparisons of C_N and C_A at t_p and $30 t_c$

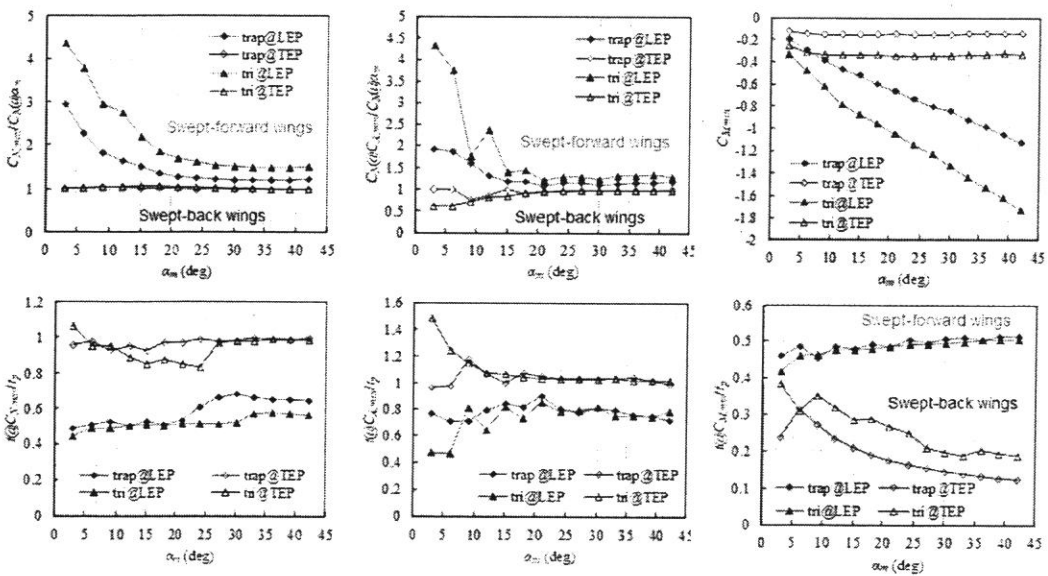
"uns" represents a wing at $t = t_p$; "st" represents a wing at $t = 30 t_c$.



17/20



Transitory Force Maxima and Minima Analysis



18/20



Conclusions

- During the pitching acceleration,
 - for the swept-forward configuration, the normal force coefficient on the triangle wing is higher than that on the trapezoid wing.
 - for the swept-back wing configuration, the triangle shape encourages more the normal force generation than the trapezoid shape as the maximum angle of attack lower than 18 degrees. As the maximum angle of attack increases, the normal force on the wing planform has opposite effects.
- During the relaxation phase,
 - for all flat-plate wings considered, the maximum angle of attack of 12 degrees is the benchmark for the transitory force generation.
 - As the maximum angle of attack increases, a transitory force develops at around 5 tc. Lately, another transitory force is generated more significantly on the trapezoid shape than the triangle one, dependent on the maximum angle of attack.

19/20



Conclusions

- The first peak of the normal force occurs within the pitching maneuver of swept-forward wings; whereas the swept-back wings have the first normal-force peak close to the end of the pitching maneuver. The nadir of the axial force lags behind the first normal force peak in general.
- The pitching moment coefficient C_M about a pivot axis has characteristics similar to the normal force coefficient C_N . The values of C_M on the triangle shape is higher than the trapezoid shape for the similar swept-angle. A configuration of leading edge pivot stimulates a negative C_M development; a trailing-edge-pivot configuration encourages a positive C_M course.

20/20