出國報告（出國類別：科學技術--國外研究、考察及國際會議）

2015 年新加坡國立大學之淡馬錫研究中心
合作計畫成果報告暨工作會議
出國報告書

服務機關：國立暨南國際大學

姓名職稱：林繼耀副教授

派赴國家：新加坡

出國期日：104 年 5 月 1 日至 5 月 5 日

報告日期：104 年 7 月 10 日

摘要

暨南大學電機系 2012 年與新加坡國立大學之淡馬錫研究中心簽署合作計畫合約，合作內容是機翼伺服气动弹性的建模與控制問題。此合作計畫為由新加坡國防部資助、淡馬錫研究中心執行的一項整合型計畫中的子計畫，出差人員林繼耀副教授為此子計畫主持人，研究工作結合了暨大林副教授在非線性系統辨識與控制設計方面的專長，以及淡馬錫研究中心計算流體力學及流體實驗方面的專長及設備。此計畫執行至 2014 年 12 月截止，至今已研發出系統建模與控制設計的方法，此次出國是為計畫成果做成果報告，同時商討接續的實驗工作事項。

目次

一、出差事由

此行程主要任務如下：

(一) 為執行中合作計畫作期末報告。

(二) 策劃接下來的工作細節。

二、出差人員

林繼耀副教授【學術研究領域：飛控與導航技術、流動感應技術、非線性動態控制、錯誤檢測、系統辨識。】

三、背景

(一) 暨南大學電學機系於 2012 年與新加坡國立大學之淡馬錫研究中心 (Temasek Laboratories at the National University of Singapore) 建立研究計畫合約，出差人員林繼耀副教授為此計畫主持人。

(二) 暨南大學電學機系於 2014 年與新加坡國立大學之淡馬錫研究中心為促進雙方研究與合作交流簽署合作備忘錄。

(三) 淡馬錫研究中心網址: http://www.temasek-labs.nus.edu.sg/

四、目的

(一) 暨南大學電學機系與新加坡國立大學之淡馬錫研究中心 2012 年所建立的研究合作計畫題名為 Nonlinear Reduced-Order Modeling and Adaptive Control Design for Aeroservo-Elastic Systems，內容是機翼伺服气动弹性的建模與顫振控制問題。研究工作結合了暨大林副教授在非線性系統辨識與控制設計方面的專長，以及淡馬錫研究中心計算流體力學及流體實驗方面的專長及設備。

(二) 此合作計畫為由淡馬錫研究中心執行的一項整合型計畫中的子計畫，主計劃經費來自新加坡國防部。計畫執行至 2014 年 12 月截止，此次出國為作成果報告，同時商討接續的工作事項。

(三) 此計畫的研究工作結合了暨大林繼耀副教授在非線性系統辨識與控制設計的專長，以及淡馬錫研究中心計算流體力學(CFD)及流體實驗方面的專長及設備，目

的是設計一部能即時消除機翼顫振 (wing flutter) 的飛行控制系統。計畫執行至今 2.5 年，經過合作雙方的密切溝通、資料分享、林副教授幾次赴新加坡與合作伙伴會面商討，進行得相當順利，至今已研發出系統建模與控制設計的方法，下一步將是關鍵，須將此作法應用在淡馬錫設計的實驗機翼上，並作風洞測試。為此，此次成果報告也同時商討實驗工作的細節。

五、過程

日期	地點/行程	工作記要
5/1	埔里→新加坡	啟程
5/2	新加坡	個人行程(星期六)
5/3		個人行程(星期日)
5/4	新加坡，淡馬錫研究中心	出差事由
5/5	新加坡→埔里	回程

(一) 成果報告稱為計畫的 D4 Review (第四期報告) ，會議由對方計畫主持人 Dr. Kwok Leung Lai (黎博士) 主持，報告人員包括林副教授、黎博士及和淡馬錫中心的 Dr. Zhenbo Lu (盧博士)，出席人員包括淡馬錫中心主任 Prof. Khoo Boo Cheong (邱教授)、副主任 Mr. J. Ting，以及數位淡馬錫中心的研究員及新加坡國防部特派人員。

(二) 黎博士彙報了 CFD 的結果，包括最新的實驗機翼的流場域與力矩模型與計算結果。

(三) 林副教授彙報了此研究在 wing flutter 建模的基本方法及其原理，以及利用淡馬錫中心的 CFD 數據所建立的動態模型、其驗證方法，和基於此模型而設計的 flutter 控制。

(四) 盧博士彙報了實體機翼的基本設計、風洞測試結果、和控制系統架構。

(五) 會議深入討論數據模型的精準度及控制法則的可行性，並為將要做的實驗制定了目標及準備工作項。

(六) 會議擬定於 2015 年 8 月中旬進行風洞實驗以驗證此計畫所研發的技術，到時林副教授也會赴新加坡參與。

(七) 會議紀錄如附件一。

六、心得與建議

(一) 此合作的基礎不僅建立於雙方的專長領域，更重要的是雙方多年來的個人關係與友誼。(林副教授曾擔任淡馬錫中心研究員兼副主任，至 2011 年止。) 此次出國有助於計畫的圓滿完成，並有利於接下來的合作關係。

(二) 跨國合作需要的不只是學術專長和經費，更需要有效的溝通，而英語為各國科技合作的共同語言，英語能力不僅在技術交流上是唯一管道，在行政上也是必備。此計畫學生參與部分極少，主要原因是學士和碩士生在技術基礎上與計畫所需不配對，而原本招收博士生的規劃並不順利。

(三) 要促進暨大科院各系與外國大學的合作務必使科院課程更國際化、單一領域應當更深入，如國外常見的主修制度 (major) 和專業學程 (specialization track)，以之取代個別課程選修，而且培養一個全英授課和研究的環境、加強行政人員的英語能力。

七、會議留照

左至右: Dr. M. Debiasi, Dr. Z. Lu, Dr. K.L. Lai, A/Prof. K.-Y. Lum, Dr. Y. T. Jiang, Mr. M. Yeo, Mr. J. Tang, Mr. J. Ting.

附件一

Meeting minutes of Modeling and Control of Aeroelastic/Aeroservoelastic Systems via Nonlinear Reduced-Order Modeling

Minutes of Meeting
D4 Review

4th May, 2015

附件一

Meeting minutes of Modeling and Control of Aeroelastic/Aeroservoelastic Systems via Nonlinear Reduced-Order Modeling D4 Review

Date: 4 May 2014
Time: 9:30 AM – 12:00 PM,
Venue: Seminar room, Level 8, Temasek Laboratories
Attendees:
FSTD: Johnson Tang
DSO: Jiang Yi-Tsann, Yeo Wei Kiong Matthew
TL: Khoo Boo Cheong, Ting Sing Kwong Joseph, Lai Kwok Leung, Lu Zhenbo, Debiasi Marco, Cui Yongdong
NCNU[1]: Lum Kai Yew

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1. Opening Remark

   Meeting called to order at 9:30 am by Dr Lai Kwok Leung. Dr Lai introduced the purpose of the meeting as a fulfillment of the D4 deliverables of the aero-servo-elasticity (ASE) research program. The program's objective is to develop methodologies for aeroservoelastic analysis and design, and to apply the developed methods in the design of control law for flutter suppression. The research entails both numerical investigations and experimental studies. The former involve computation and modeling of unsteady aerodynamics, structural dynamics analysis of aeroelastic wing, reduced-order modelling, and control law design; while the latter involve the design, fabrication, and wind-tunnel testing of a flexible aeroelastic wing. Research developments reported in the meeting includes computational aeroservoelastic modeling of flexible wings, nonlinear reduced-order modeling and identification, and active control design for flutter suppression for aeroservoelastic systems.

2. Presentation of Technical Report

   Dr Lai presented the research developments for computational aeroservoelastic (CASE) modeling and simulations. He reviewed the CASE techniques developed in the program and their uses in deriving a flutter suppression control design, together with results of benckmark studies includng the BACT wing, transonic flutter of AGARD wing, F-5 aircraft, F-16 model, and flutter boundaries of a wing-flap model.

   Dr Lai presented the structure model of the prototype wing and its results of structural dynamic analysis by using Abaqus finite element analysis and its CAE results calculated for system identification. Regarding the FEA calculated structure dynamic properties of the prototype wing, Mr. Tang enquired if verification studies performed to validate the accuracy of FEA calculation. Dr. Lai responded that the FEA results were compared with experimental results of the shaker test and the wind-induced vibration test based on the physcial wing model; results shown that the natural frequencies predicted by FEA were in accord with the experimental results. Due to lack of equipments, the natrural vibration mode shapes were not measured in experiments and thus comparison of mode shapes with FEA were not done. Dr. Lai also cautioned that the structural design of the prototype wing with many interfacial contacts would inevitably introduce nonlinear structural dynamics which was not addressed in the FEA model. Mr. Tang inquired if modelling accuracy be improved by adopting a simpler structural design. Dr. Lai responded that the prototype wing was designed to be flutter at the TL's wind tunnel testing condition; among the different designs, including solid wings, the current design was found suitable for the proposed flutter test.

   Regarding the CASE techniques, Mr Yeo enquired if aerodynamic model such as panel method can be used instead of the current model based on the Euler and Navier-Stokes equations. Dr. Lai responded that the choice of aerodynamic model in CASE calulations was bsaed on the prominent flow characteristics, Euler equations and Navier-Stokes were used to enhance modeling fidelity, while panel model based on potential flow theories was generally used for low-fidelity calculations.

   Prof Lum presented the progress of research developments in reduced-order modelling (ROM) and identification, and flutter suppression control design. He reviewed the timeline of development of ROM techniques in the program, and the various techniques explored. These techniques included the

[1]Research Collaboration Project No. 101A053 between TL@NUS and National Chi Nan University (NCNU)

附件一

ARMA model, $\mu-$Markov structure, Hammerstein correlation techniques in block model structure, Hammerstein-Wiener with $\mu-$Markov structure in non-block model structure. He presented the ROM-predicted flutter boundaries to demonstrate the accuracy and viability of different ROM techniques developed. Regarding the flutter prediction results, Mr. Yeo inquired which were the flutter modes according to ROM prediction. Prof Lum responded that the flutter boundaries were calculated by using stability analysis in which the speed index was increased from zero until it reached a value where a eigen-pair crossed the imaginary axis. This value was considered as the flutter speed index, and the eigen frequency as the flutter frequency. In this approach the flutter modes were not tracked.

For the different ROM techniques, Dr Jiang raised the question of how would one determine the accuracy of the computed ROM. Prof Lum responded that the ROM was calculated by system identificiation techniques based on a given set of input-output data that the resulting ROM would of course match with this data; the ROM should be tested with another set of data if made available. Moreover, Prof Lum pointed out that other parameters such the order of ROM, the value of transfer delay had to be determined properly in order to arrive at an accurate ROM, and to avoid problems such as numerical noises.

Prof Lum reported the research in robust control design for flutter suppression. He presented the control architecture for flutter suppression, the linear FSI system, modeling of speed index uncertainty, and low-order controller design. Prof Lum presented the preliminary results of flutter suppression using the developed control design which shown about 10% improvement of flutter boundaries. He highlighted that the present prototype wing model exhibited significant nonlinearity, of the second mode in partiular, the ROM techniques were revised in order to better represent the dynamics of the physical system.

For the current flutter suppresion control, Mr Yeo inquired if the method of gain scheduling could be implemented to enlarge the coverage of flight conditions of the controller. Prof. Lum replied that the current control design was based on ROM technique and the fact that different flight conditions would call for different ROMs, which would lead to a complex system and thus not a practical way to enhance controller robustness. On a related note, Mr Yeo suggested that, in order to test the controller's robustness, flutter suppression tests would be performed for different prototype wings.

Mr Tang enquired the details of the experimental tests to be conducted to demonstrate the developed control design for flutter suppression. Prof Lum responded that the experimental tests would be conducted with the prototype wing and control inputs would be the kinematic information such as displacements and velocities picked up by accelerometers, and control outputs would be trailing-edge flap deflections. He further pointed out that the methodology developed based on the numerical model was using modal values as inputs; since the measured values by accelerometers would be in physical units, a conversion matrix would be required to transform values from modal to physical values as inputs to the controller.

3. Other Business

   There being no other business.

   Meeting adjourned at 12:00 PM.

Minutes taken by Lu Zhenbo

Vetted by Lai Kwok Leung