

14:14:20

OCA PAD INITIATION - PROJECT HEADER INFORMATION

04/19/90

Active

Project #: E-16-682                      Cost share #: E-16-315                      Rev #: 0  
Center # : 10/24-6-R6930-OA0          Center shr #: 10/22-1-F6930-OA0          OCA file #:  
Contract#: SCEE-NSWC/90-B093                      Mod #:  
Prime # : N60921-87-D-A315-B093                      Document : DO  
Contract entity: GTRC

Subprojects ? : N  
Main project #:

Project unit:                      AE                      Unit code: 02.010.110  
Project director(s):  
STALFORD H L                      AE                      (404)894-3003

Sponsor/division names: SE CNTR FOR ELEC ENGR EDUC /  
Sponsor/division codes: 500 / 004

Award period: 900206 to 900930 (performance) 900930 (reports)

Sponsor amount	New this change	Total to date
Contract value	30,500.00	30,500.00
Funded	30,500.00	30,500.00
Cost sharing amount		1,525.00

Does subcontracting plan apply ? : N

Title: MISSILE AUTOPILOT DESIGN USING MU-SYNTHESIS

PROJECT ADMINISTRATION DATA

OCA contact: Kathleen R. Ehlinger 894-4820

Sponsor technical contact

JOHN BIBEL  
(703)892-6146

Sponsor issuing office

*[Handwritten signature: JANETTE FOSTER]*  
**JANETTE FOSTER**  
**SCEE**  
(407)892-6146  
11TH & MASSACHUSETTS AVENUE  
ST. CLOUD, FL. 34769

Security class (U,C,S,TS) : U                      ONR resident rep. is ACO (Y/N): N  
Defense priority rating : N/A                      N/A supplemental sheet  
Equipment title vests with: Sponsor X                      GIT

NONE PROPOSED.

Administrative comments -  
INITIATION OF PROJECT.



SR601-2  
GEORGIA INSTITUTE OF TECHNOLOGY  
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 03/25/91

Project No. E-16-682 \_\_\_\_\_ Center No. 10/24-6-R6930-0A0\_  
Project Director STALFORD H L \_\_\_\_\_ School/Lab AERO ENGR \_\_\_\_\_  
Sponsor SE CNTR FOR ELEC ENGR EDUC/ \_\_\_\_\_  
Contract/Grant No. SCEE-NSWC/90-B093 \_\_\_\_\_ Contract Entity GTRC  
Prime Contract No. N60921-87-D-A315-B093 \_\_\_\_\_  
Title MISSILE AUTOPILOT DESIGN USING MU-SYNTHESIS \_\_\_\_\_  
Effective Completion Date 900930 (Performance) 900930 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	910318
Final Report of Inventions and/or Subcontracts	Y	_____
Government Property Inventory & Related Certificate	Y	_____
Classified Material Certificate	N	_____
Release and Assignment	Y	910318
Other _____	N	_____

Comments \_\_\_\_\_

Subproject Under Main Project No. \_\_\_\_\_

Continues Project No. \_\_\_\_\_

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Management	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other _____	N
_____	N

NOTE: Final Patent Questionnaire sent to PDPI.

M. Wolfe  
E-16-682

# Georgia Tech

## School of Aerospace Engineering

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Georgia Institute of Technology  
Atlanta, GA 30332-0150  
(404) 894-2770 or 894-3000

MEMORANDUM

June 14, 1990

TO: Kathleen R. Ehlinger, OCA/PAD

FROM: Harold Stalford *HS*

SUBJECT: Reports for Project No. E-16-682

Pleased find enclosed the reports:

Interim Report April 1990

Progress Report April 1990

Progress Report July 1990

RECEIVED

JUN 15 1990  
ADMINISTRATIVE  
OFFICE OF CONTRACTS

OCA/PAD

JUN 14 1990  
RECEIVED

**Interim Report  
April 1990**

**MISSILE AUTOPILOT DESIGN USING MU-SYNTHESIS**

**CONTRACT NUMBER:**

**N60921-87-D-A315, Task B093  
SCEEE/NSWC-88/B093  
Project Number: E-16-682**

**CONTRACT AMOUNT:**

**\$30,500.00**

**AWARD:**

**Noncompetitive**

**SPONSOR:**

**John E. Bibel  
(703) 663-7481  
Aeromechanics Branch  
Naval Surface Warfare Center  
Dahlgren, VA 22448-5000**

**H. L. Stalford, Project Director**

**SCHOOL OF AEROSPACE ENGINEERING  
GEORGIA INSTITUTE OF TECHNOLOGY  
ATLANTA, GEORGIA 30332**

**Interim Report  
April 1990**

## **MISSILE AUTOPILOT DESIGN USING MU-SYNTHESIS<sup>1</sup>**

**H. L. Stalford, Project Director**

**School of Aerospace Engineering  
Georgia Institute of Technology  
Atlanta, Georgia 30332**

The meeting during 11-16 March 1990 between Dr. Stalford and John Bibel was used to conduct a preliminary H-Infinity/Mu-Synthesis design of a missile autopilot. The meeting was held at the School of Aerospace Engineering of the Georgia Institute of Technology, Atlanta, Georgia. Our overall objective was (1) to formulate a preliminary missile autopilot problem into the standard block diagram of the structured singular value, (2) to code the resulting block diagram into Mu-synthesis software and (3) to generate a robust controller using the software. First we walked through the three step approach using a test example. Then we set up our particular problem of interest, ran it through the software and generated a very nice controller after several iterations.

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<sup>1</sup> Sponsored by The Naval Surface Weapons Center, Dahlgren, VA under contract number N60921-87-D-A315, Task B093 of SCEEE/NSWC-88/B093, Georgia Tech project number E-16-682. Technical Monitor John Bibel, Aeromechanics Branch, NavSWC.

**Progress Report  
April 1990**

**MISSILE AUTOPILOT DESIGN USING MU-SYNTHESIS**

**CONTRACT NUMBER:  
N60921-87-D-A315, Task B093  
SCEEE/NSWC-88/B093  
Project Number: E-16-682**

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**AWARD:  
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**SPONSOR:  
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**SCHOOL OF AEROSPACE ENGINEERING  
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ATLANTA, GEORGIA 30332**

**Progress Report**  
**April 1990**

## **MISSILE AUTOPILOT DESIGN USING MU-SYNTHESIS<sup>1</sup>**

**H. L. Stalford, Project Director**  
**School of Aerospace Engineering**  
**Georgia Institute of Technology**  
**Atlanta, Georgia 30332**

This initial progress report covers the period from 6 February 1990 to 6 April 1990. During this period a plan for accomplishing the contract objectives was developed and agreed upon by the sponsor. The plan is (1) to conduct a Mu-synthesis design using a test example, (2) to perform a Mu-synthesis design on a preliminary autopilot in which some parameteric uncertainties and some flexible mode uncertainties are ignored, (3) to increase the complexity and number of the uncertainties in the Mu-synthesis design process and (4) to perform a trade-off between robust performance and robust stability by pushing the bandwidth to its limit, while holding the stability specifications fixed.

Both synthesis designs of (1) and (2) have been accomplished. The procedure for incorporating flexible mode uncertainties into the design process has been established. An ad hoc procedure has been identified for setting the performance bandwidth a priori in the closed loop Mu-synthesis design.

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<sup>1</sup> Sponsored by The Naval Surface Weapons Center, Dahlgren, VA under contract number N60921-87-D-A315, Task B093 of SCEEE/NSWC-88/B093, Georgia Tech project number E-16-682. Technical Monitor John Bibel, Aeromechanics Branch, NavSWC.

**Progress Report  
July 1990**

**MISSILE AUTOPILOT DESIGN USING MU-SYNTHESIS**

**CONTRACT NUMBER:  
N60921-87-D-A315, Task B093  
SCEEE/NSWC-88/B093  
Project Number: E-16-682**

**CONTRACT AMOUNT:  
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**Progress Report  
July 1990**

## **MISSILE AUTOPILOT DESIGN USING MU-SYNTHESIS<sup>1</sup>**

**H. L. Stalford, Project Director  
School of Aerospace Engineering  
Georgia Institute of Technology  
Atlanta, Georgia 30332**

This progress report covers the period from 6 April 1990 to 6 July 1990. During this period Mu-synthesis design has been conducted on model with increasing complexity and number of uncertainties. Bending modes have been incorporated into the normal acceleration and angular acceleration channels together with several parametric uncertainties in the dynamics. A trade-off between robust performance and robust stability has been performed by pushing the bandwidth to its limit, while holding the stability specifications fixed. The work is documented as a paper ( authored by the sponsor Mr. John Bibel and the project director H. L. Stalford ) in the proceedings of a conference held in June.

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<sup>1</sup> Sponsored by The Naval Surface Weapons Center, Dahlgren, VA under contract number N60921-87-D-A315, Task B093 of SCEE/NSWC-88/B093, Georgia Tech project number E-16-682. Technical Monitor John Bibel, Aeromechanics Branch, NavSWC.

**Final Report  
September 1990**

## **MISSILE AUTOPILOT DESIGN USING MU-SYNTHESIS<sup>1</sup>**

**H. L. Stalford, Project Director  
School of Aerospace Engineering  
Georgia Institute of Technology  
Atlanta, Georgia 30332**

Methods were developed for designing  $H_\infty/\mu$  robust controller for flexible missiles. The first method was based on covering the flexible modes with an unmodeled dynamics weight. That method is presented in the paper: Bibel, John and H. Stalford, " $\mu$ -Synthesis Autopilot Design for a Flexible Missile", 29th Aerospace Sciences Meeting, January 7-10, 1991, Reno, Nevada, AIAA 91-0586. A second method was developed in which the first two mode dynamics are included in the nominal plant description and in which the higher modes are covered by an unmodeled dynamics weight. This second method was partially developed during a one week meeting held during the fall of 1990 between Dr. Stalford and John Bibel. The method consists of inserting appropriate S and T weights at each of the plant outputs to govern the following: (1) maximize the bandwidth of the closed-loop system while attaining a 20 db rolloff of the loop-transmission function at the lowest flexible mode frequency, (2) obtaining specified gain and phase margins at input and output locations and (3) small overshoot of closed-loop system time response to step input. The method was used to derive a robust controller for the autopilot of a flexible missile.

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<sup>1</sup> Sponsored by The Naval Surface Weapons Center, Dahlgren, VA under contract number N60921-87-D-A315, Task B093 of SCEE/NSWC-88/B093, Georgia Tech project number E-16-682. Technical Monitor John Bibel, Aeromechanics Branch, NSWC.

**Final Report  
September 1990**

**MISSILE AUTOPILOT DESIGN USING MU-SYNTHESIS**

**CONTRACT NUMBER:**

**N60921-87-D-A315, Task B093  
SCEEE/NSWC-88/B093  
Project Number: E-16-682**

**CONTRACT AMOUNT:**

**\$30,500.00**

**AWARD:**

**Noncompetitive**

**SPONSOR:**

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