

THE INTEGRATED MANUAL AND AUTOMATIC CONTROL OF COMPLEX FLIGHT SYSTEMS

Final Technical Report

For

NASA Grant NAG 4 - 1

NASA Grant To The

Purdue Research Foundation
West Lafayette, IN

Project Period

January 1, 1980

to

April 30, 1989

Research Performed For The

NASA Ames Research Center
Dryden Flight Research Facility

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Technical Monitor

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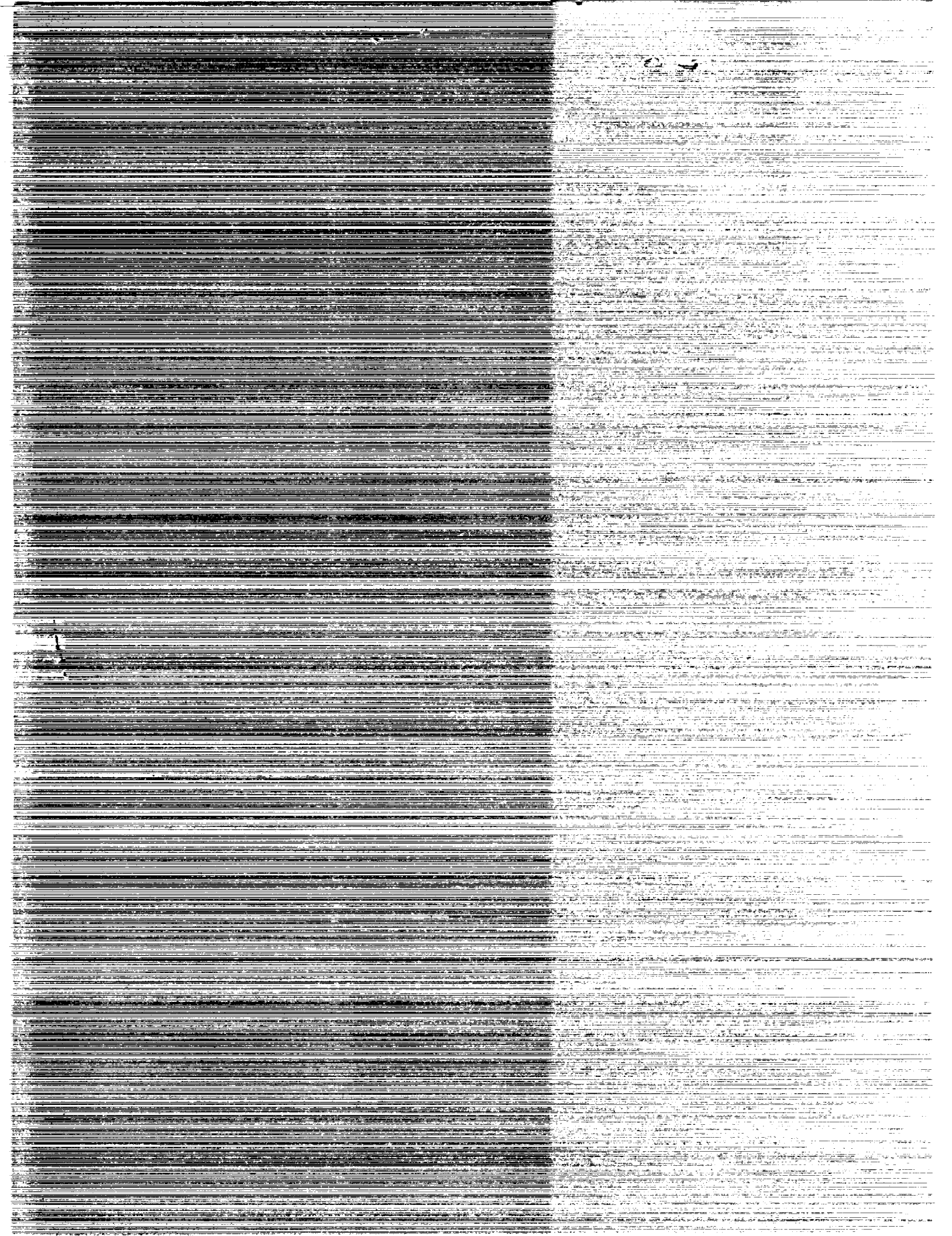


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1. Introduction

This constitutes the final technical report for a grant from the NASA Ames Research Center to the Purdue Research Foundation and Purdue University (NAG 4-1). The grant technical monitor was Mr. Donald Berry, of the NASA Ames/Dryden Flight Research Facility. The grant was administered through Purdue University, and the technical activities were performed while the principal investigator, Dr. David K. Schmidt, was affiliated with that institution. The project was performed during the period from January 1, 1980 to April 30, 1989. The title of the project was "The Integrated Manual and Automatic Control of Complex Flight Systems."

2. Summary

Research performed under this grant dealt with the general area of optimal flight control synthesis for manned flight vehicles. The work was generic, no specific vehicle was the focus of study. However, the class of vehicles generally considered were those for which high authority, multivariable control systems might be considered, for the purpose of stabilization and the achievement of optimal handling characteristics.

Within this scope, the topics of study included several optimal control synthesis techniques, control-theoretic modeling of the human operator in flight-control tasks, and the development of possible handling qualities metrics and/or measures of merit. Basic contributions were made in all these topics, including human operator (pilot) models for multi-loop tasks; optimal output feedback flight control synthesis techniques; experimental validations of the methods developed; and fundamental modeling studies of the air-to-air tracking and flared landing tasks.

The technical results were reported widely throughout the technical community. In particular, eight journal publications and 20 conference proceedings papers were published on grant research results. Four NASA technical reports were also published as well. Additionally, seven formal oral presentations and seminars were given throughout the U.S. as well as in the Netherlands, in which research from this grant was presented. It is noteworthy, furthermore, that the presentation in the Netherlands was a result of an invitation from the Dutch, made through AGARD, for the principle investigator to visit and participate in a technical interchange of results in the subject area of this grant.

Finally, this grant has had a most positive effect on graduate engineering education in this country. In total, 13 aerospace engineering graduate students received support from the grant, thus allowing them to complete their graduate studies. Nine of the 13 are native U.S. citizens, while four were foreign nationals (one of these has since become a U.S. citizen). Five of these 13 students completed their doctoral studies under this grant, while two more will soon complete their doctoral degrees. These two students, plus six others completed their MS degrees supported at least in part by this grant. Three of the 13 students are on the faculties of aerospace engineering departments at three U.S. universities, three are employed at NASA, one is a U.S. naval officer, one is with a U.S. Navy research laboratory, and three are aerospace engineers in the U.S. aerospace industry. The two remaining students are employed outside the U. S. One is with a national aerospace laboratory in Taiwan, and one is with a Canadian aerospace firm.

3. Documentation of Research Results

3.1 List of Journal Publications on Grant Results

1. Bacon, B.J., and Schmidt, D.K., "A Modern Control Approach to Pilot/Vehicle Analysis and the Neal-Smith Criteria," *Journal of Guidance, Control and Dynamics*, Vol. 6, pp. 339-347, Sept.-Oct., 1983.
2. Innocenti, M. and Schmidt, D.K., "Quadratic Optimal Cooperative Control Synthesis with Flight Control Application," *Journal of Guidance, Control, and Dynamics*, Vol. 7, No. 2, March-April, 1984.
3. Biezad, D.J. and Schmidt, D.K., "Normalized Predictive Deconvolution: A Time Series Algorithm for Modeling Human Operator Dynamics," *Journal of Guidance, Control, and Dynamics*, Vol. 8, No. 6, Nov.-Dec., 1985.
4. Anderson, M.R. and Schmidt, D.K., "Closed-Loop, Pilot/Vehicle Analysis of the Approach and Landing Task," *Journal of Guidance, Control, and Dynamics*, Vol. 10, No. 2, March-April, 1987.
5. Garg, S. and Schmidt, D.K., "Cooperative Synthesis of Control and Display Augmentation," *Journal of Guidance, Control, and Dynamics*, Vol. 12, No. 1, 1989.
6. Garg, S. and Schmidt, D.K., "Model-Based Analysis of Control/Display Interaction in the Hover Task," *Journal of Guidance, Control, and Dynamics*, Vol. 12, No. 3, 1989.
7. Garg, S. and Schmidt, D.K., "Cooperative Synthesis of Control and Display Augmentation in Approach and Landing," *Journal of Guidance, Control, and Dynamics*, Vol. 13, No. 3, 1990.
8. Garg, S. and Schmidt, D.K., "Experimental Investigation of Control/Display Augmentation Effects in a Compensatory Tracking Task," *Journal of Guidance, Control, and Dynamics*, to appear, 1991.

3.2 List of Conference Proceedings Papers on Grant Results

1. Schmidt, D.K., "On the Use of the OCM's Objective Function as a Pilot Rating Metric," *Proceedings*, 17th Annual Conference on Manual Control, UCLA, Los Angeles, California, pp. 305-313, June 16-18, 1981.
2. Schmidt, D.K., "Multivariable Closed-Loop Control Analysis and Synthesis for Complex Flight Systems," *Proceedings of the AGARD Flight Mechanics Symposium on Combat Aircraft Maneuverability*, AGARD CP 319, Florence, Italy, Oct. 5-8, 1981.
3. Schmidt, D.K., "Time Domain Identification of an Optimal Control Pilot Model with Emphasis on the Objective Function," *Proceedings*, USAF/NASA/AIAA Conference on Flight Testing to Identify Pilot Workload and Pilot Dynamics, Edwards AFB, California, Jan. 19-21, 1982.
4. Schmidt, "Time Domain Identification of Pilot Dynamics and Control Strategy," *Proceedings*, 18th Annual Conference on Manual Control, Dayton, Ohio, June 8-10, 1982.

5. Bacon, B.J. and Schmidt, D.K., "A Modern Control Approach to Pilot/Vehicle Analysis and the Neal-Smith Criteria," *Proceedings*, of the AIAA Atmospheric Flight Mechanics Conference, San Diego, California, August 9-11, 1982.
6. Schmidt, D.K., "Modern Approaches to Handling Qualities Research," *Proceedings*, USAF Flying Qualities Symposium, (AFWAL-TR-82-3064), Flight Mechanics Lab., Wright-Patterson AFB, Ohio, March 2-5, 1982.
7. Innocenti, M. and Schmidt, D.K., "Integrated Pilot-Optimal Augmentation Synthesis for Complex Flight Vehicles: Experimental Validation," *Proceedings*, IEEE National Aerospace and Electronics Conference, Dayton, OH May, 1983.
8. Schmidt, D.K., "Integrated Task-Tailored Control Augmentation Synthesis," *Proceedings*, AIAA Guidance and Control Conference, Gatlinburg, TN, August, 1983.
9. Schmidt, D.K. and Yuan, P.J., "Model Estimation and Identification of Manual Controller Objectives in Complex Tracking Tasks," *Proceedings*, 20th Annual Conference on Manual Control, NASA Ames Research Center, Moffett Field, CA, June, 1984.
10. Biezad, D.J. and Schmidt, D.K., "Time Series Modeling of Human Operator Dynamics in Manual Control Tasks," *Proceedings*, 20th Annual Conference on Manual Control, NASA Ames Research Center, Moffett Field, CA, June, 1984. Also in *Proceedings*, AIAA Guidance and Control Conference, Seattle, WA, August, 1984.
11. Anderson, M.R. and Schmidt, D.K., "Pilot/Vehicle Analysis of the Flared Landing Task," *Proceedings*, 21st Annual Conference on Manual Control, Dayton, Ohio, June, 1985.
12. Garg, S. and Schmidt, D.K., "Optimal Cooperative Control Synthesis of Active Displays," *Proceedings*, 21st Annual Conference on Manual Control, Dayton, Ohio, June, 1985.
13. Biezad, D.J., Schmidt, D.K., Leban, F., and Mashiko, S., "Modified Superposition: A Simple Time Series Approach to Closed-Loop Manual Controller Identification," *Proceedings*, 21st Annual Conference on Manual Control, Dayton, Ohio, June 1985.
14. Anderson, M.R. and Schmidt, D.K., "Closed-Loop/Vehicle Analysis of the Approach and Landing Task," *Proceedings*, AIAA Guidance and Control Conference, Snowmass, CO, August, 1985.
15. Garg, S. and Schmidt, D.K., "Model-Based Evaluation of Display Dynamic Effects In Pursuit Tracking," *Proceedings*, 22nd Annual Conference on Manual Control, Dayton, Ohio, July, 1986.
16. Garg, S. and Schmidt, D.K., "Cooperative Synthesis of Control and Display Augmentation," *Proceedings*, AIAA Guidance and Control Conference, Williamsburg, VA, August, 1986.
17. Garg, S. and Schmidt, D.K., "Model-Based Analysis of Control/Display Interaction in the Hover Task," *Proceedings*, AIAA Atmospheric Flight Mechanics Conference, Monterey, California, August, 1987.
18. Garg, S. and Schmidt, D.K., "Experimental Investigation of Control/Display Augmentation Effects in a Compensatory Tracking Task," AIAA Paper No. 88-4325, Atmospheric Flight Mechanics Conference, Minneapolis, August, 1988.

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19. Schmidt, D.K. and Silk, A., "Modeling Human Perception and Estimation of Kinematic Responses," AIAA paper 88-4186, Guidance, Navigation, and Control Conference, Minneapolis, August, 1988.
20. Garg S. and Schmidt, D.K., "Cooperative Synthesis of Control and Display Augmentation for a STOL Aircraft in the Approach and Landing Task," AIAA Paper No. 4187, Guidance, Navigation, and Control Conference, Minneapolis, August, 1988.

3.3 List of Technical Reports on Grant Results

1. Schmidt, D.K. and Innocenti, M., "Pilot Optimal Multi-variable Control Synthesis by Output Feedback," NASA Contractor Report 163112, School of Aeronautics and Astronautics, Purdue University, West Lafayette, Indiana, July, 1981.
2. Schmidt, D.K. and Innocenti, M., "Optimal Cooperative Control Synthesis Applied to a Control-Configured Aircraft," NASA Contractor Report 170411, School of Aeronautics and Astronautics, Purdue University, West Lafayette, Indiana, January, 1984.
3. Bacon, B.J. and Schmidt, D.K., "Modern Control Approaches to Pilot Vehicle Analysis," NASA CR 170416, School of Aeronautics and Astronautics, Purdue University, West Lafayette, Indiana, April, 1984.
4. Garg, S. and Schmidt, D.K., "Optimal Cooperative Control Synthesis of Active Displays," NASA CR-4058, Prepared for NASA Ames by the School of Aeronautics and Astronautics, Purdue University, West Lafayette, Indiana, June, 1987.

3.4 Presentations and Seminars on Grant Results

1. Schmidt, D.K., "Modern Approaches to Handling Qualities Research," USAF Flying Qualities Symposium, Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, March 2-5, 1982.
2. Bacon, B.J. and Schmidt, D.K., "A Modern Control Approach to Pilot/Vehicle Analysis," 18th Annual Conference on Manual Control, Dayton, Ohio, June 8-10, 1982.
3. Innocenti, M. and Schmidt, D.K., "Application of an Optimal Cooperative Control Technique for Augmentation Synthesis for a Control Configured Aircraft," AIAA Guidance and Control Conference, San Diego, CA, August 9-11, 1982.
4. "Pilot Modeling, Modal Analysis, and Control of Flexible Aircraft," Dept. of Mechanical Engineering, University of California at Santa Barbara, February, 1984.
5. "Pilot Vehicle Analysis of Multi-Loop Control Tasks," National Aerospace Laboratory (NLR), Amsterdam, The Netherlands, September, 1985.
6. "Control Theoretic Approaches to Man-Machine Systems Analysis," School of Mechanical Engineering, Purdue University, West Lafayette, Indiana, March, 1987.
7. Schmidt, D.K. and Davidson, J.B., "An Extended Optimal-Control Model for Manual Control," IEEE Systems, Man, and Cybernetics Conference, Los Angeles, CA, November, 1990.

4. Graduate Students Supported by the Grant

Dr. Mario Innocenti, PhD Purdue Univ.
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NASA Lewis Research Center

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