

STUDIES OF HUMAN DYNAMIC SPACE
ORIENTATION USING TECHNIQUES OF CONTROL THEORY

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I. INTRODUCTION

Research activity in the Man-Vehicle Control Laboratory centers upon the application of the techniques of control theory to analytical and experimental investigations of situations requiring a human operator to maintain himself or a vehicle in a desired orientation in space. The research may be divided into three areas; engineering descriptions of the basic biological subsystems, development of general models for the human operator as an element in the control system of multiple-loop, time-varying vehicle orientation systems, and finally application of these models to selected vehicle control problems. The investigations supported by the subject grant emphasize the dynamic orientation aspects of manual control and in particular the effects of vehicle motion as sensed by the vestibular system.

II. BASIC BIOLOGICAL SUBSYSTEMS

Physiological subsystems investigated this year touched briefly on extension of our earlier work on visual tracking, but concentrated on understanding the operation of the human vestibular system. A lengthy series of experiments on patients with various degrees of inner ear disease was undertaken by the Laboratory in conjunction with Dr. Ashton Graybiel, Director of Research at the U.S. Naval Aerospace Medical Institute. These experiments allow us to relate quantitatively the nonvisual sensation of motion and the ability to use the vestibular and tactile methods in active vehicle orientation.

The control models for the vestibular system which had previously been developed elsewhere for the semi-circular canals and in this laboratory for the otoliths, were based on output measurements (subjective sensation or objective recording such as eye movement). In order to ascertain that these transfer functions indeed did apply to the vestibular system, as opposed to tactile or visual inputs, one could either eliminate the other sources of input wholly or partially, or take the alternate approach of using subjects with known

defects or complete absence of a functioning vestibular system. The latter approach was used in our experiments with the Navy, in which eleven carefully tested subjects with well-known defects of the gravity receptors or semicircular canals participated in a week's testing. The experiments paralleled earlier tests done in creating the model for normals; and included eye movement measurements and threshold determination for linear and angular accelerations, subjective perception of phase for linear oscillations, and the ability to control a simulated unstable vehicle with and without motion cues. Preliminary analysis of the data shows the clear function of the otolith in nonambiguous detection of low level accelerations, but also indicates the very great extent to which nonvestibular cues can be used to detect tilt and acceleration.

A summary of this aspect of the research was presented to the National Academy of Sciences Workshop on Orientation in the Exploration of Space, Ames Research Center, January 1966, in a paper entitled: "Control Engineering Approaches to the Human Dynamic Space Orientation," by L.R. Young, J.L. Meiry, and Y.T. Li. Portions of the introduction appear below:

Introduction

This paper reviews briefly some of the research that has been under way at M.I.T. in the last few years, at the Man-Vehicle Control Laboratory, in the Aeronautics and Astronautics Department. It covers work on mathematical descriptions of the input-output relations characterizing the vestibular mechanism and some work on eye stabilization, including the influence of vestibular inputs, neck proprioceptive inputs and fixed head visual tracking. Finally, results are presented relating the vestibular research to description of man as a member of a closed loop control system controlling the orientation and position of a vehicle. We have concentrated on visual input, tactile inputs, and vestibular inputs, when these are either in agreement or conflict.

At the output end, we consider not only the usual joystick hand control, but also postural control as a possible output mechanism. Another study deals with the adaptive mechanism for manual control. Naturally, the purpose of this type of study is to achieve a sufficient mathematical description of the human as an input-output device or set of devices, including all the nonlinearities and the statistical nature of the random components, to permit the control systems engineer to make rational quantitative estimates about what the reactions of a man will be in a piloting-type task.

Additional work has begun on the biophysics of the vestibular mechanism, including physical analysis of the thermodynamics involved in the caloric response of the semicircular canals, the fluid dynamics of the canals when subjected to rotation, the interaction of linear and angular motions on the semicircular canals, and the mechanics of simultaneous rotation about two axes as sensed by the vestibular system. One of the difficulties in performing such analyses is the lack of data on certain physical parameters associated with the

vestibular system, consequently instrumentation has been developed for measurement of the viscosity of small samples of endolymph at various temperatures. Samples of cat and human endolymph are being obtained through the cooperation of the Massachusetts Eye and Ear Infirmary.

Two scientific papers were written by Prof. J.L. Meiry, based on the research presented in his Sc.D. thesis (MVCL Report T-65-1, June 1965). Abstracts of these papers are as follows:

"A Mathematical Model for the Neck
Receptors - Ocular Reflex"

Presented at

Engineering in Medicine and Biology

18th Annual Conference, Philadelphia, 1965

Lateral eye movements are controlled by a multi-input servo control system with inputs fed to it by the vestibular system and the neck receptors, by the eye itself and by the voluntary tracking intentions of humans. This control system rotates the eye in order to maintain the image of an object of fixation upon the retina. A displacement of this image is caused by the motion of the visual target and by rotations of the head on the body. The eye movement control system responds to these disturbing motions with two different modes of eye movements: tracking and compensatory movements. Tracking eye movements follow the moving target in the visual field. Compensatory eye movements rotate the eye in a direction opposite to the rotation of the human body. Although the role of neck receptors as a source of compensatory eye movements has been suggested by physiologists, their participation in the control system has not been assessed previously. In the

experimental series reported here, these eye movements are shown to obey a simple lag-lead model.

"A Model for Otolith and Its Implication
on Human Spatial Orientation"

Presented at

International Astronautical Federation

Athens, Greece, September 1965

Abstract

The dynamic characteristics of the otoliths are investigated by measurements of human subjective perception of motion. A series of psychophysical experiments relates the human's sensation of motion to the imposed motion pattern. Since a pure linear motion simulator was used throughout the reported experiments, the otoliths are presumably the only part of the vestibular system which is stimulated, and the measured response is free of sensors' interaction effects.

Dynamically the otoliths are linear velocity meters for motions with frequencies within the range 0.016 cps to 0.25 cps. The threshold of perception of linear accelerations is about 0.005 g in the plane of the otoliths. A mathematical model for the otoliths represents the dynamics of the sensors to consist of a linear second order portion followed by a non-linearity corresponding to the threshold of perception.

Finally, Professor Young organized and chaired a panel entitled: "What Control Gives and Takes from Biology," at the IEEE International Convention, New York, March 1966. Professor Young's introduction to that discussion is given below:

Introduction

Many of the intuitive bases for automatic control stem from attempts to imitate the manner in which human beings use feedback and programmed control in accomplishing difficult tasks. Certainly, some efforts in artificial intelligence, pattern recognition, and adaptive control are attempts to emulate control characteristics long recognized in humans. There has been a concurrent trend in the reverse direction, namely, the application of control theory to biological systems. A variety of complex biological control or regulatory systems have proved amenable to quantitative analysis. Some of the implications of this bidirectional flow of knowledge will be discussed.

III. HUMAN OPERATOR MODELS

In the development of models of the human operator for use in system design, our work concentrated on descriptions of the human as an adaptive controller and the effects of vehicle motions on the ability of pilots to retain control for a wide variety of vehicle dynamics. Our general notions of the adaptive functions of man stress his ability to exhibit rapid adaptation based on the use of limited information to form a partially defined performance index for the closed-loop system. These ideas are summarized in a paper entitled: "Adaptive Functions of Man-Vehicle Control," by Y.T. Li, L.R. Young and J.L. Meiry, presented at the International Federation of Automatic Control (Teddington) Symposium, September 1965. The abstract is given below:

Abstract

Inability of human pilots to introduce adequate adaptation of their control provided much of the motivation for the development of automatic adaptive control systems. The rapid change in vehicle system characteristics in high performance aircraft, which may climb from sea level to extreme high altitudes in minutes, required automatic adaptive control to relieve the burden on the operator.

This paper examines the principles and compositions of existing automatic adaptive control systems and on these bases the human adaptive as well as primary control functions are analyzed.

In general, the human outshines the automatic system with his huge capacity of open loop or programmed control; but he lacks the capacity and speed for making on line computation which is needed in the operation of an active continuous adaptive system. Humans can also perform some passive type or very simple active type adaptation, but would require the assistance of a computer to perform complicated active adaptation.

This limitation is responsible for the domination of mechanized systems for adaptive control. There are advantages attributable to a computer assisted human adaptive control system considering the huge capacity of his open loop adaptation. Visual or some other form of multi-input display becomes a necessary medium when computer-man coupling is to be made effectively. Considering man's remarkable ability of pattern recognition this task may be in many cases easier than the coupling of a computer with an automatic actuator when a complicated function is to be recognized and manipulated.

Further consideration of the adaptive control problem was expressed by Professor Li in his paper entitled: "Man in an Adaptive and Multi-Loop Control System," presented at the MIT-NASA Working Conference on Manual Control, February 1966. The conclusion of that paper appears below:

Conclusion

In consideration of the difficulties involved in the control of a multi-loop system such as that of providing effective visual contact displays, the complications involved in providing other forms of displays, all the computation needed to decouple the intercoupled input-output relationships of a multi-loop system, the compensation of the higher order dynamics, and the computation of the performance index for the adaptive control loop, it would appear that humans have very little place in the control of this type of system. Indeed one primary advantage of the human is his visual perception

of natural surroundings. But the other equally important aspect of the human operator is his ability to make impromptu adaptive control under situations which were unexpected by the systems designer or too complicated to be included in the system design. The importance of the human operator is illustrated by the numerous accident aversions handled by experienced pilots or drivers. In such a situation he is powerless unless he has the primary control. For this reason manual operation should be employed in a primary control loop of the dominating vehicle output for the critical phase of operation. Automatic devices may be used to bypass the pilot for load relieving purposes. By this reasoning, in a multi-loop vehicle control system, man should be burdened only with those functions for which his attention is needed, under adverse operating conditions. For this purpose, both the system design and operator training should put emphasis on the effectiveness of the operator's function of facing all unforeseeable emergencies in the control loop. This type of impromptu adaptation with the handling of the primary control loop should therefore play a much more important role than the operator's possible function in the on-line fast adaptation of the handling quality of the primary control loops.

Considerable effort has been devoted this year in developing a learning model to describe the states of control laws a human operator passes through in learning a single relatively simple control task. A Markov model describing states of knowledge of the system is being constructed, with the learning model being described by Markov transition probabilities.

The ability to predict the effects of motion on pilot performance would greatly enhance our confidence in system design using pilot models and enable us to extrapolate the results of fixed-base simulations.

Some of the background for this problem was presented in a paper by Professor Young, entitled: "Some Effects of Motion Cues on Manual Tracking," at the MIT-NASA Working Conference on Manual Control. The summary appears below.

Summary

It has been adequately demonstrated that sustained high acceleration or vibration can have a deleterious effect on tracking ability. This paper, however, considers some situations in which the motion cues, as felt in flight or moving base simulation, yield a significant improvement in pilot performance.

The first of these situations is in a control task requiring more lead compensation than is easily developed from visual displays. The vestibular and tactile sensations contribute velocity and acceleration information which is used in stabilization. Experiments on control of inverted pendulums and VTOL's, with and without motion cues, demonstrate the extent to which this lead is used in certain tasks. Tests of labyrinthine defective patients on similar tasks demonstrated the critical importance of vestibular inputs.

The importance of motion cues in rapid adaptation to controlled element failures was investigated in a simulated blind landing experiment. Motion effects were found to be important in a class of flexible booster control experiments. These results were combined with many comparisons of fixed base-moving base-flight experiments in the literature to arrive at some general conclusions regarding the effects of motion cues on tracking.

A major effort is now being devoted to generating the data base for extension of the theory of the effect of motion cues in vehicle control. A large range of simulated vehicle dynamics, covering first, second, and

third order systems typical of the plant dynamics for vehicle control, are to be simulated in both fixed-base and moving-base tests, using our Ames Research Center NE2 simulator. Fixed base vs. moving base performance will be compared, for example, at various points on the static stability vs. time constant map, to determine those areas in which motion cues are helpful or harmful. Pilot describing functions as well as error scores are to be derived, in anticipation of developing a theory which will enable us to modify quantitative pilot models in order to include the effects of vehicle motion. Only compensatory single axis tracking will be studied in this phase of the program, with input spectrum and amplitude of the motion expected to be important parameters.

Another area of human operator modeling which has continued to occupy us is the characterization of nonlinearities in the human's control law. The near-optimum nonlinear behavior of a human operator in some well-learned tracking tasks has led to a study of display for optimal control, to be described under the section on applications. An interesting phenomenon of human operator nonlinearity is the bang-bang behavior exhibited by an operator facing a control task near the limits

of his control. A paper entitled: "Bang-Bang Aspects of Manual Control in High Order Systems," by L.R. Young and J.L. Meiry, was published in the IEEE Transactions on Automatic Control, Vol. 18-10, July 3, 1965. The abstract appears below.

Abstract

The tendency of many human operators to respond in a bang-bang fashion when controlling some high-order systems is investigated. A three-mode switch is compared with a linear control stick and shown to permit better manual control of some systems with more lag than double integration. In experiments requiring stabilization of a moving base flight simulator programmed as an unstable system (undamped inverted pendulum), operators use the linear control stick in a bang-bang fashion. In place of quasi-linear models for these situations, a simple on-off model for the human is suggested, and the switching lines and error trajectories in the phase plane are presented. The ability to control an unstable system with visual and motion cues is compared.

IV. VEHICLE APPLICATIONS

A number of vehicle control applications problems are studied in the Laboratory, all of which bring out some particularly interesting aspect of the operator's control, and are intended to tie in with the more basic research performed on the biological subsystems and human operator models. A significant effort this past year has been devoted to the manual control problems associated with VTOL hovering, manual control of an elastic booster, ability to recover from disturbances in aircraft blind landings, requirements for a narrow vehicle for high traffic permeability, human and automatic bicycle stabilization, and phase plane displays incorporating optimal switching lines for higher than second order systems. In addition, the problems of combined audio-visual display, three-dimensional display linked to head movement, "anti-vertigo" peripheral displays, and vehicle control through the postural balancing mechanism have been considered briefly. Results of the first three investigations were recorded in Master's theses, the abstracts of which are given below.

"Bending Mode Acceleration Influence
on Pilot Control of Flexible
Booster Dynamics"

Philip S. Kilpatrick

S.M. thesis, M.I.T.

September 1965 (MVCL T-65-2)

Abstract

This investigation is concerned with the general problem of man's ability to directly control a large flexible launch vehicle. Specifically, the effect of a flexible body mode on pilot control of simulated single axis Saturn V rigid body dynamics is studied. First bending mode amplitude and natural frequency, and the type of simulation, fixed or moving base, are the variables considered most intensively. Brief studies of variations in the RMS level of the disturbance signal and comparisons of two proposed control stick filters and vehicle augmentation schemes are included.

The effects of the flexible mode on the pilot and his closed loop performance are analyzed by ratios of attitude error to disturbance signal and control stick output to attitude error, and by computed pilot transfer functions.

Results show that pilot's ability to generate lead compensation and to control the attitude error decreased as the bending mode amplitude increased. Significant deterioration occurred at the lowest bending mode amplitude, $1/3$ the value at the proposed location of the Saturn V attitude gyro, under study. The pilot's gain and ability to control the attitude error decreased during the moving base experiments. This result is attributed to dynamics and nonlinearities associated with the simulator, a less sensitive moving base display, and possibly vestibular uncertainty and insensitivity concerning small deflections from the vertical. With increasing bending mode amplitude, pilot performance deteriorates at approximately the same rate for both $\omega_{nbd} = 5$ and 7 rad/sec. However, for a given amplitude, the 5 rad/sec bending mode generates only one-half the acceleration of the 7 rad/sec bending mode.

"Visual and Motion Cues in Helicopter Flight"

Peter Benjamin

S.M. thesis, M.I.T.

January 1966 (MVCL T-66-1)

Abstract

This paper investigates the relative importance of motion and visual cues on the ability of experienced pilots and non-flying subjects to control a hovering helicopter. It examines the interaction of these different forms of input information and the methods by which they are utilized by these two classes of subjects. The method by which control of such a high-order system as a helicopter is effected is discussed and a theory on this is advanced. A simple visual display system which provides a unique description of position and attitude with respect to a defined axis system and utilizes relatively inexpensive and available analog equipment is presented.

"Human Role in the Control-Loop
of the Automatic Landing Aircraft"

Veikko Olavi Vuorikari

S.M. thesis, M.I.T.

September 1965

Abstract

The object of this thesis is to study what kind of information the pilot can obtain from three different kinds of windshield displays during automatic approaches and landings, and if he is able to detect the possible malfunctions in the automatic system from his display. In the study, an airplane landing was simulated by using analog computer and two degree of freedom moving-base simulator. The picture of the runway projected to the pilot was his only visual information source in the cockpit.

The tests were performed by feeding step and ramp disturbances into roll rate or pitch rate integrators in the analog computer, and the roll, yaw and pitch response times were calculated from the recordings.

It can be seen that for roll control only the most simple picture of the runway, two lines representing the runway boundary lines, are enough in most cases, but the yaw control lacks accuracy and damping in this case. Adding the horizon to this picture improves a little yaw control by allowing the pilot to add yaw rate feedback to his control.

The pilot was not able to obtain enough information from these two simplified pictures of the runway to control the longitudinal axis and several crash landings were recorded during this part of testing.

The flight path marker provided enough information to the pilot for controlling also the longitudinal axis, and the response time to moderate pitch rate disturbances was less than half of the response time without the flight path marker. No crashes were recorded when the flight path marker was used.

In the tests, both moving-base and fixed-base simulation were made, and it was found that the fixed-base lateral response times were about twice as long as the respective moving-base values.

The problem of manual control of a motor bike, motorcycle or narrow passenger vehicle, as proposed by Professor Li, is of unusual interest for at least two reasons. First, the multi-loop control required of the human is brought out quite clearly, and his ability to use motion cues to stabilize the inner loop may be investigated. Secondly, aside from his steering commands, the human is closely coupled to the vehicle control by means of his weight shift and the resulting structural resonance

as the mass of his body shifts with respect to the vehicle frame. Many of these problems are covered in the paper entitled: "Stability and Controllability of Vehicles for High Speed and High Traffic Permeability," presented by Professor Li at the International Federation for Automatic Control (Tokyo) Symposium, August 1965, and the Society of Automotive Engineers Congress, Detroit, Michigan, January 1966, published as SAE paper 660024. The abstract appears below.

Abstract

A general study of the basic requirements of vehicles for individual and public transportation systems leads to the belief that the incorporation of an active suspension system into the vehicle would constitute a major step forward. Various aspects of an active suspension system were scrutinized. Favorable results from an experimental test vehicle confirmed that belief. By incorporating the principle of an active suspension system, a narrow vehicle was proposed for commuter traffic; a utility vehicle for agriculture and military application; and a monorail vehicle for public transportation as well as for super high-speed intercity transportation.

In continuing investigation of phase plane displays, we have demonstrated that the human operator's control of a force limited second order system can very quickly approach optimal control when an optimal switching line is shown on the display, and that once having learned the optimal controlling technique, the switching line may no longer be necessary. This method has been extended

to higher order systems by displaying in the phase plane an "instantaneous switching line" represented by the intersection of the optimum switching plane in state space with the plane containing the first two state variables. This switching line consequently moves as a function of the higher state variables, but by reversing control whenever the phase trajectory crosses the moving switching line, the human operator is still able to maintain close to optimal control. Full exploration of this technique had been curtailed by lack of adequate hybrid computer facilities, which are now available with the installation of the Laboratory's PDP8-GPS290T hybrid computer. This hybrid computer facility, designed to Professor Meiry's specifications, is expected to be a very versatile tool for vehicle simulation, biological control systems simulation, on-line data analysis for human operator experiments, and off-line data processing of some of the more extensive experimental results.

IV. MIT-NASA SYMPOSIUM

In an attempt to bring together the engineering psychology specialists who have been developing more advanced models of the pilot in a control loop, and some of the engineers concerned with application of such models to advanced vehicle systems, a three-day specialists' conference was organized by Professor Young and Mr. Roger Winblade of NASA Headquarters. Approximately 100 people attended the MIT-NASA Working Conference on Manual Control in Cambridge, Massachusetts, February 2 - March 2, 1966. The conference consisted of formal research papers for which prepared discussants were solicited and informal presentations on a variety of aspects of manual control. The extensive participation by a large number of investigators and the continuing lively discussion attest to the current high level of interest and activity in manual control. The conference proceedings are being published as a NASA Special Publication. The program of the Conference follows below.

Session I. Discrete and Continuous Models

"Sine Wave Tracking Revisited"
R.W. Pew, J.C. Duffenback, L.K. Fensch
University of Michigan

"Asynchronous Finite State Models of Manual Control Systems"

G. Bekey, E. Angel
Univ. of Southern California

"An Adaptive Asynchronous Sampled Data Model of the Human Operator Design for Digital Simulation Studies"*

A.S. Jackson
Control Technology Inc., Long Beach, California

"Neuromuscular Subsystem Dynamics"*

D.T. McRuer
Systems Technology Inc., Hawthorne, California

Session II. Adaption Control

"On the Process of Adaptation by the Human Controller"

J.I. Elkind, D. Miller
Bolt Beranek and Newman, Cambridge, Massachusetts

"Model of Human Operator Response to Step Transitions in Controlled Element Dynamics"

D.H. Weir, A.V. Phatak
Systems Technology Inc., Hawthorne, California

"An Adaptive Model of the Human Operator in a Time-Varying Control Task"

K.S. Fu, E.E. Gould
Purdue University

"Man in an Adaptive and Multi-Loop Control System"

Y.T. Li
M.I.T.

"Time Varying and Nonlinear Models of Human Operator Dynamics"*

W. Wierwille, G. Gagne
Cornell Aero Laboratory, Buffalo, New York

Session III. Information Theory

"An Information-Processing Analysis of Automobile Driving"

J.W. Senders
Bolt Beranek and Newman, Cambridge, Massachusetts

* Denotes informal presentation.

"The Usefulness of Transinformation as a Measure of Human Tracking Performance"
 D. Baty, T. Wempe
 NASA Ames Research Center, Moffett Field, California

"Measured Information Capacity as a Performance Index in Manual Tracking"
 P. Gainer
 NASA Langley Research Center, Hampton, Virginia

Session IV. Multivariable Control

"Human Performance in Single and Two-Axis Tracking Systems"
 E.P. Todosiev, R.E. Rose, L.G. Summers
 TRW Systems, Redondo Beach, California

"Two-Dimensional Manual Control Systems"
 W. Levison
 Bolt Beranek and Newman, Cambridge, Massachusetts

"Pilot Describing Function Measurements in a Multiloop Task"
 R.L. Stapleford, D.T. McRuer, R. Magdeleno
 Systems Technology, Inc., Hawthorne, California

"Pilot Response in Multi-loop Tracking Tasks in Combination with Side Tasks"
 J.J. Adams
 NASA Langley Research Center, Hampton, Virginia

Session V. Display

"Symbolic and Pictorial Displays for Submarine Control"
 R.C. McLane, J.D. Wolf
 Honeywell, Inc. (340), St. Paul, Minnesota

"Prediction Display"
 R. Bernotat, H. Widlok
 Technical University of Berlin

"Tracking Experiments with Tactile Displays"*
 J.C. Bliss
 Stanford Research Institute, Menlo Park, California

"Delayed Force Feedback in Manipulation"*
 W.R. Ferrell
 M.I.T.

Session VI. Motion and Stress

"Some Effects of Motion Cues on Manual Tracking"

L.R. Young

M.I.T.

"Acceleration Stress Effects on Pilot Performance and Dynamic Response"

M. Sadoff, C. Dolkas

NASA Ames Research Center, Moffett Field, California

"The Effect of Minor Alcohol Stress on Tracking Skill"

C.B. Gibbs

Defense Research Labs, Toronto, Ontario, Canada

"An Evaluation of Three Types of Hand Controllers Under Random Vertical Vibration"

A.Z. Weisz, R.W. Allen, C.J. Goddard

Hughes Aircraft Company, Culver City, California

"Human Describing Functions Measured in Flight and on Simulators"

H.J. Smith

NASA Flight Research Center, Edwards, California

Session VII. Applications

"Present and Future Applications of Pilot Dynamics Data in Flight Control System Design and Development"*

C.B. Westbrook

Wright-Patterson AFB, Ohio

"Application of Sampled Data Human Operator Models to Booster Flight Control System Design"*

R.O. Hookway

Martin Company, Baltimore, Maryland

"Manual Control in Advanced Space Vehicles"*

J.F. Pavlick, G.D. Ritter

NASA Marshall Space Flight Center, Huntsville, Alabama

"Effect of Variations in the Simulated Turbulence Model on VTOL Handling Qualities in Hovering and Low-Speed Flight"*

D.P. Miller

United Aircraft Research Laboratories, East Hartford, Conn.

Session VIII. Optimal Control

"Preview Control Behavior and Optimal Control Norms"
T.B. Sheridan, B.F. Fabis, R.D. Roland
M.I.T.

"Studies in Optimal Behavior in Manual Control Systems:
The Effect of Four Performance Criteria in Compensatory
Rate-Control Tracking"
R.N. Obermayer, R.A. Webster, F.A. Muckler
Bunker-Ramo Corporation, Canoga Park, California

"Human Decision-Making in Manual Control Systems"
R.E. Thomas, J.T. Tou
Battelle Memorial Institute, Columbus, Ohio

"Differential Games and Manual Control"
S. Baron
NASA-ERC, Cambridge, Massachusetts

Session IX. Analysis and Design Methods

"Dynamical System Modeling of Human Operators"
P.L. Falb, G. Kovatch
NASA-ERC, Cambridge, Massachusetts

"A 'Critical' Tracking Task for Man-Machine Research
Related to the Operator's Effective Delay Time"
H.R. Jex, J.D. McDonnell, A.V. Phatak
Systems Technology, Inc., Hawthorne, California

"Design Applications of Self-Adjusting Vehicle Simulators"
C.R. Kelley
Dunlap and Associates, Santa Monica, California

"Discussion of Spectral Human Response Analysis"
L.W. Taylor, Jr.
NASA Flight Research Center, Edwards, California

"Analysis and Prediction of Performance of a Digital
Computer Facility for Flight Simulation Studies"
M.C. Grignetti, J.I. Elkind
Bolt Beranek and Newman, Cambridge, Massachusetts

Publications by Staff of
Man-Vehicle Control Laboratory
July 1965 - June 1966

Theses:

Kilpatrick, P.S., "Bending Mode Acceleration Influence on Pilot Control of Flexible Booster Dynamics," S.M. thesis, M.I.T., September 1965 (MVCL T-65-2).

Benjamin, P., "Visual and Motion Cues in Helicopter Flight," S.M. thesis, M.I.T., January 1966 (MVCL T-66-1).

Vuorikari, V.O., "Human Role in the Control-Loop of the Automatic Landing Aircraft," S.M. thesis, M.I.T., September 1965.

Other:

Young, L.R. and Meiry, J.L., "Bang-Bang Aspects of Manual Control in High Order Systems," IEEE Trans. on Automatic Control, Vol. AC-10, No. 3, July 1965, pp. 336-341 (Presented at 1965 JACC, Troy, New York).

Li, Y.T., Young, L.R., and Meiry, J.L., "Adaptive Functions of Man in Vehicle Control," Intl. Fed. Automatic Control (Teddington) Symposium, September 1965.

Young, L.R. and Kupfer, C., "A Systems Analysis View of Intraocular Pressure Regulation," 6th Intl. Conf. on Med. Electronics and Biol. Engrg., Tokyo, August 1965.

Young, L.R., Meiry, J.L., and Li, Y.T., "Control Engineering Approaches to Human Dynamic Space Orientation," Natl. Academy of Sciences Workshop-Orientation in the Exploration of Space, NASA Ames Res. Ctr., January 1966, NASA SP.

Young, L.R. and Winblade, R., "Manual Control -- Summary of the MIT-NASA Conference," IEEE Spectrum (in preparation).

Young, L.R., "The Dead Zone to Saccadic Eye Movements," Symposium on Biomedical Engineering, Marquette Univ., June 1966 (in preparation).

Meiry, J.L., "A Mathematical Model for the Neck Receptors - Ocular Reflex," presented at Engineering in Medicine and Biology, 18th Annual Conference, Philadelphia, 1965.

Meiry, J.L., "A Model for Otolith and Its Implication on Human Spatial Orientation," presented at International Astronautical Federation, Athens, Greece, September 1965.

Li, Y.T., "Man in an Adaptive and Multi-Loop Control System," presented at the MIT-NASA Working Conference on Manual Control, Cambridge, Mass., February 1966.

Li, Y.T., "Stability and Controllability of Vehicles for High Speed and High Traffic Permeability," presented at Intl. Fed. for Automatic Control (Tokyo) Symposium, August 1965, and the Society of Automotive Engineers Congress, Detroit Michigan, January 1966, SAE paper 660024.