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DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH

PROFILES IN SCIENCE

Dr. Robert D. Myers

Dr. Robert D. Myers, who is Professor of Psychological and Biological Sciences and Director of the Psychobiology Program at Purdue, has been an ONR contractor for many years.

Among his research contributions are: (1) discovery of the site of action of bacteria in the brain that induces fever; (2) formulation of the amine theory of thermoregulation; (3) reversal of alcohol drinking by drugs that affect brain amine metabolism; (4) development of a new theory on the central mechanism which establishes changes that occur in the brain of a feeding animal; (5) discovery of chemical agents and methods which induce addiction to alcohol.

He has reported his research results in nearly 200 scientific papers and has authored a definitive monograph in his field, the *Handbook of Drug and Chemical Stimulation of the Brain.* In addition he is the editor and participating author in the widely recognized series of volumes on *Methods in Psychobiology*. His contributions based largely on research supported by the Office of Naval Research have made him a widely recognized scientist in the field of psychobiology.

System Identification — An Overview†

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Systems Control, Inc.

Introduction

System identification, the technology of modeling vehicles from their dynamic response, has emerged from its theoretical foundation to a practical Naval development, test, and evaluation test. This article reviews the status of this technology and its present and potential impact on the fleet. The Office of Naval Research has supported through the years much of the research which has made system identification the useful tool it is today.

The vehicle (e.g. ship, submarine, aircraft) results from an extensive design process which is initiated by engineering knowledge of how basic physical laws can be controlled to perform a desired function. The more complex the machine, the more the engineer relies on mathematical models, from simple formulae to large systems of equations, to represent these laws and guide the design decisions throughout the design phase. This model also is used to develop quantitative specifications for evaluating performance of the vehicle and guide design modifications.

During the 1960's, there emerged another requirement on the accuracy of system models. These models were also used for the development of multivariable digital control and state estimation algorithms which were becoming an integral part of vehicle avionic systems. These new concepts, particularly that of state estimation (viz. Kalman filtering) for navigation systems, have played an increasingly important role in improving operational capabilities of Navy ships and aircraft. As these concepts were implemented, however, it became clear that accuracy of the design models was becoming a fundamental limitation to the potential improvements which could be practically realized.

The need for better models could be partially met with physical analysis and scale model tests. However, the uncertainties involved in these approaches precludes sufficiently accurate models for many of the advanced vehicles of the 1970's and beyond. Examples are the

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†This article is based on a presentation made by the author at the ONR Symposium, "Naval Applications of Estimation, Identification, and Control," July 1975.

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difficulties in theoretically predicting flows in extreme aerodynamic or hydrodynamic regimes or in extrapolating from scale model results to full scale, because of nonsimilitude of viscous effects.

What was needed was a comprehensive technology for improving models based on tests of the actual system. Such a technology is that of system identification. This technology of system identification embodies more than estimation of model coefficients from data, but also the specification of tests by which that data is obtained. To explore this multi-faceted aspect of system identification, the following definition is discussed.

System Identification—A Definition

System identification is a highly mathematical technology and may be rigorously defined in statistical terminology. For application as an engineering technology, however, the following definition has been found useful [1]:

> System identification determines, from a given input/output data record of vehicle test response, an estimate of the physical model which relates the observed data.

This definition implies that system identification involves the following:

(1) *A mathematical model:* Though the governing equations for many vehicles are known, it is frequently found that other equations (e.g. effects) are present, and the data must be analyzed to isolate what the actual model is.

(2) *Parameters of the model:* This is parameter identification, where the coefficients of the model are quantified from the data.

(3) *Random errors:* Random errors in data arise from model errors, instrumentation or external forces such as from gusts. These errors must be identified and removed from the model effects.

Figure 1 shows an example of how the system identification procedure is used with submarine input and output data, corrupted by random seaway and instrument distrubances, to produce estimates of linear and nonlinear hydrodynamic coefficients.

It is significant that aircraft, missiles, aircraft engines, ship propulsion, magnetic anomaly detectors, and inertial navigation units could just as well benefit from this identification process. Any physical system whose test input and output can be measured, can be analyzed to validate or improve the system model accuracy. In addition, instrumentation errors and the effects of external forces can also be calibrated. The potential of this technology therefore promises important improvements in the vehicle development process. To realize such a potential, however, it is necessary to understand that system identification technology

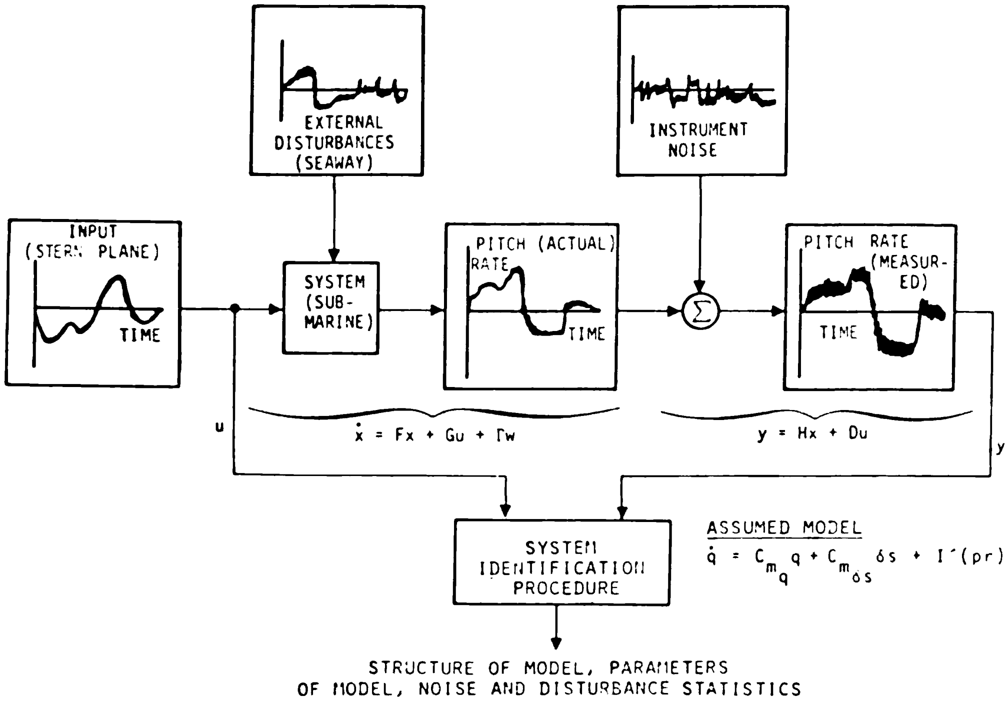


Figure 1 — System Identification Methods used with Submarine input and output data

requires more than an algorithm to estimate model parameters from data. Figure 2 summarizes the requirements which do exist and which must be integrated into a methodology for practical engineering results.

It is known that *input design* for flight test, *instrumentation specification,* and *the algorithm* are highly dependent on each other to produce model parameters as well as a characterization of the errors due to modeling or identification procedure errors. Because of the dependence of each of these elements on each other, a systematic approach is necessary for satisfying the needs of specific application. Figure 3 is such an approach and has proven successful in application to Navy vehicles. This approach successively treats each subproblem associated with identification model structure, parameter estimates of the model, and accuracy of the model, and then iterates on the input and instrumentation until convergence to an acceptable model is achieved. Each subproblem has specific requirements for data from analysis, scale model tests, or previous tests.

To implement the approach, a number of algorithms, software, and hardware considerations must be evoked. The status of these various considerations is now discussed.

System Identification—State-of-the-Art

The basic theoretical foundations of present applications of system identification were stated by Gauss, Fisher, Weiner, Komogorov, and

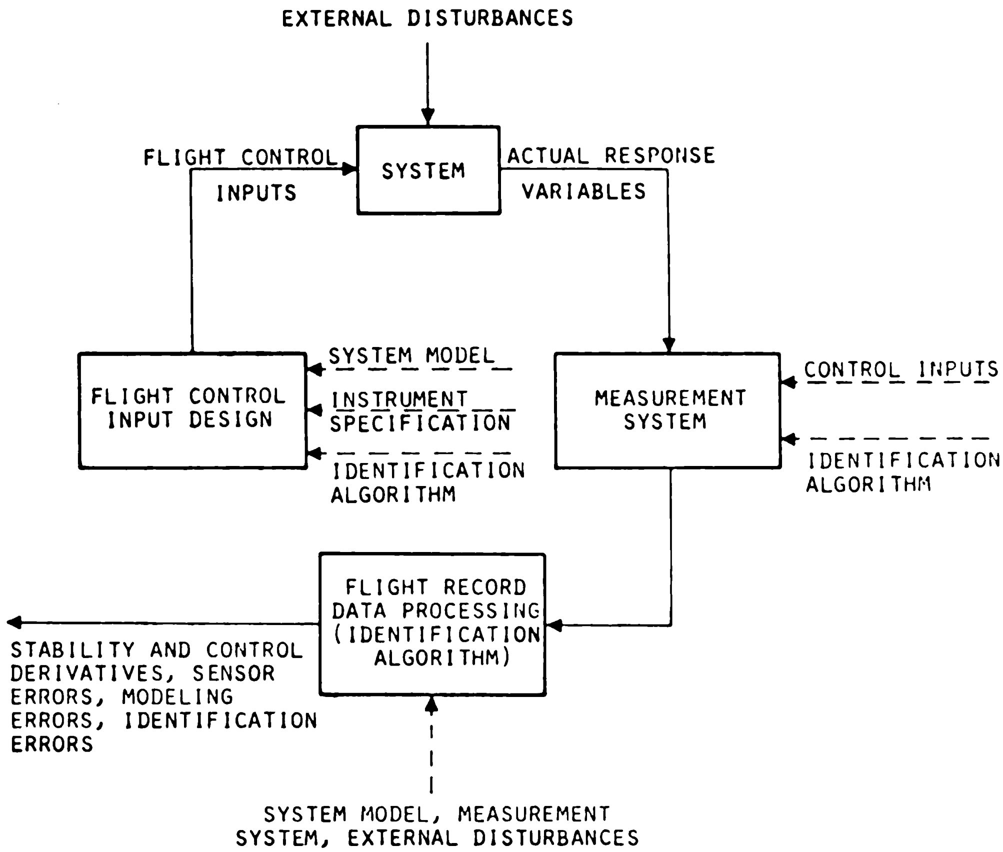


Figure 2 — The Integrated System Identification Process

Kalman. During the 1960's, system identification applications to Navy-type vehicles (notably aircraft) were limited to simple mathematical models from which basic stability and control parameters could be determined. More complete models were difficult to identify because of the effects of measurement noise, gust effects, lack of systematic input design capability, and the limited capability of computers to handle large-scale problems. A more subtle limitation to progressing the state-of-the-art was the lack of a clear requirement for better models *after* the vehicle had been built and flown.

What, then, has changed? Over the past six years, definite requirements for better vehicle models have emerged and significant improvements in system identification capability have been achieved. Specific requirements include:

(1) Higher performance attainment for Navy vehicles and subsystems is dependent on better models upon which design decisions can be formulated, and estimation and control algorithms can be developed. System identification is needed to obtain stability and control parameters of basic system, nonlinear regime model structure, understanding of subsystem interaction, extrapolations of physical (scale) model estimates,

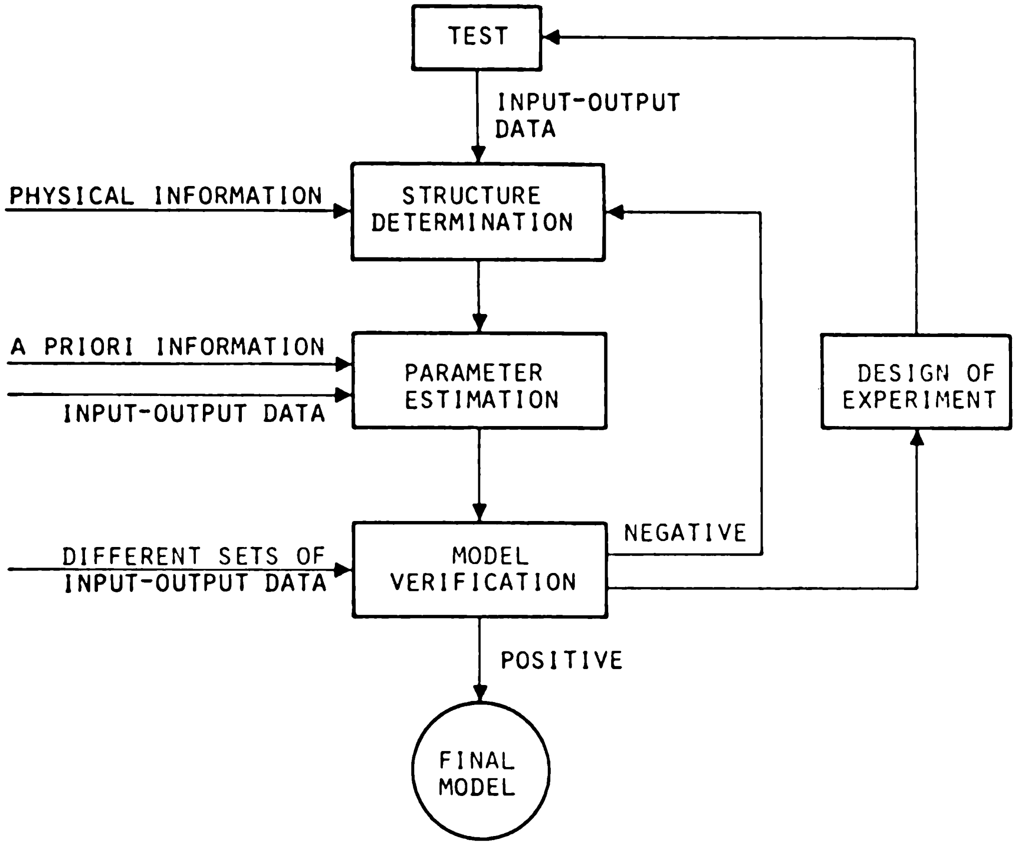


Figure 3 — Subproblems of Parameter Identification

statistics of disturbances, simulator validation, cause of failures, and calibration of instruments.

(2) Changes in design methods arising from higher performance requirements and cost considerations have placed more reliance on simulations and "fly-before-buy" specifications.

(3) Changes in other technologies, such as lightweight composite materials and computer miniaturization, have lead to innovative concepts which place even more emphasis on integrating such advances with the effects on basic vehicle response characteristics.

To meet such requirements, the technology of system identification has undergone two important changes. First, the understanding of the theory and techniques for implementing the methods has improved. Secondly, the applications of the technology have become more widespread and some significant successes have been achieved (e.g. reduction of flight test time, upgrading of simulators).

For the purpose of this overview, the basic elements of system identification — algorithms for parameter and model structure identification, input design, and instrumentation — are now reviewed with respect to the state-of-the-art.

System Identification Algorithms

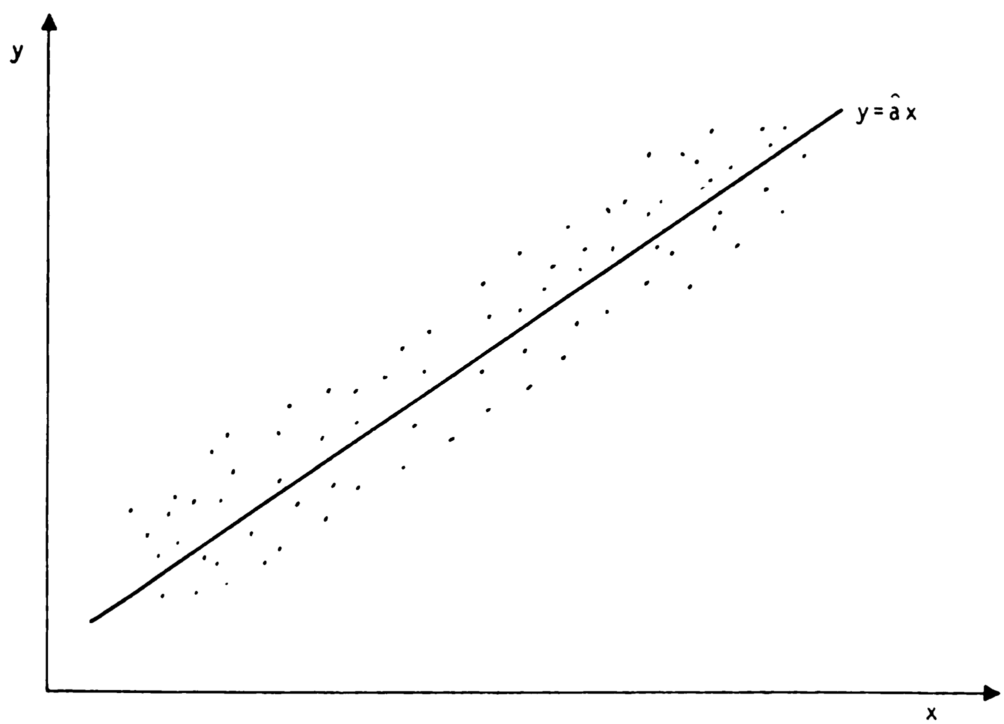
Even a cursory review of the literature reveals a confusing number of various identification algorithms. Some of the most frequently encountered are: least squares/equation error/regression methods; correlation methods, instrumental variable method, output error methods, input error methods, generalized error method, maximum likelihood estimation, kalman filter smoothing, stochastic identification. Closer examination of those various methods, both from a theoretical and practical point of view, however, allows categorization into three principal methods which characterize modern system identification. These are [2,3]:

(1) Equation error methods (also known as least squares or regression)

(2) Output error methods

(3) Advanced methods

Equation error methods are the modern equivalent to Gauss' original least squares procedures which are used to model observations of planetary motion. Figure 4 summarizes this least squares principle.



y = ax + NOISE

FIND a = â SUCH THAT

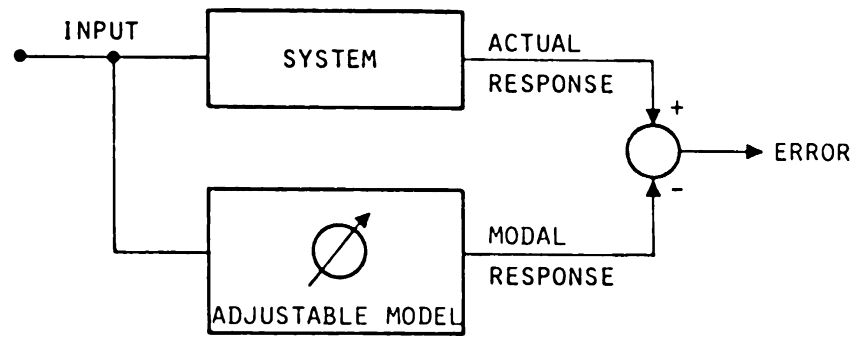
$(y - \hat{a}x)^2$

IS "SMALL".

Figure 4 — Least Squares

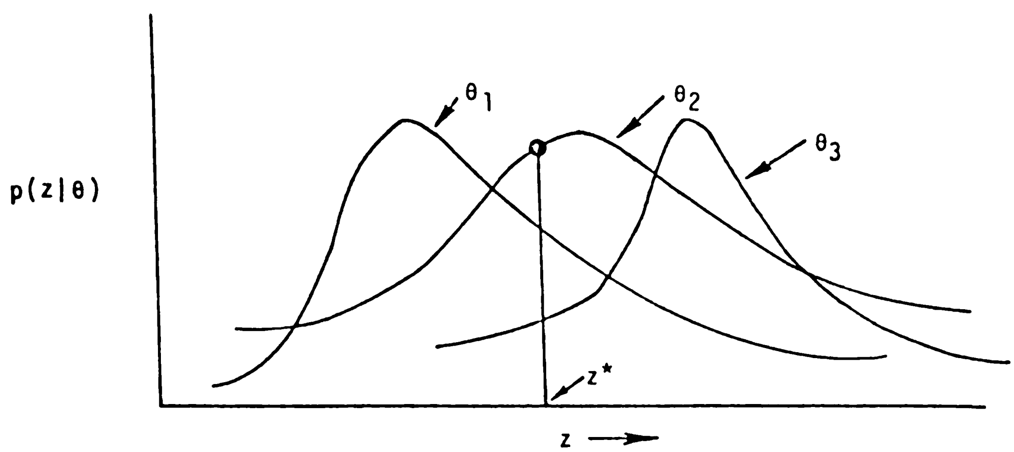
Output Error methods (Figure 5) are derived, in principle, from analog computer matching techniques of identification. Because of higher flexibility and accuracy, both of these basic methods are being replaced by *advanced methods* — extended Kalman filter and maximum likelihood being the most widespread. The maximum likelihood method, in particular (Figure 6), is rapidly achieving widespread use. This is based on two factors. *First*, both equation error and output error methods can be shown to be special cases of the maximum likelihood method. *Secondly*, the maximum likelihood method has undergone extensive development under ONR research and is now being adopted by NASA, Air Force, and Army agencies. A flowchart of one implementation of the maximum likelihood method is shown in Figure 7. Table I lists some of the various computational techniques associated with each of these basic methods.

o BASED ON ANALOG MATCHING, ALSO CALLED MODEL REFERENCE



o ADJUST PARAMETERS TO MINIMIZE ERROR
(NOTE: PARAMETERS IN ERROR IF HAVE PROCESS NOISE)

Figure 5 — Output Error



SUPPOSE θ CAN TAKE ONE OF THREE VALUES: θ_1, θ_2 AND θ_3. IF z* IS THE OBSERVED VALUE OF z, THEN θ_2 IS THE MAXIMUM LIKELIHOOD ESTIMATE OF θ.

Figure 6 — Maximum Likelihood

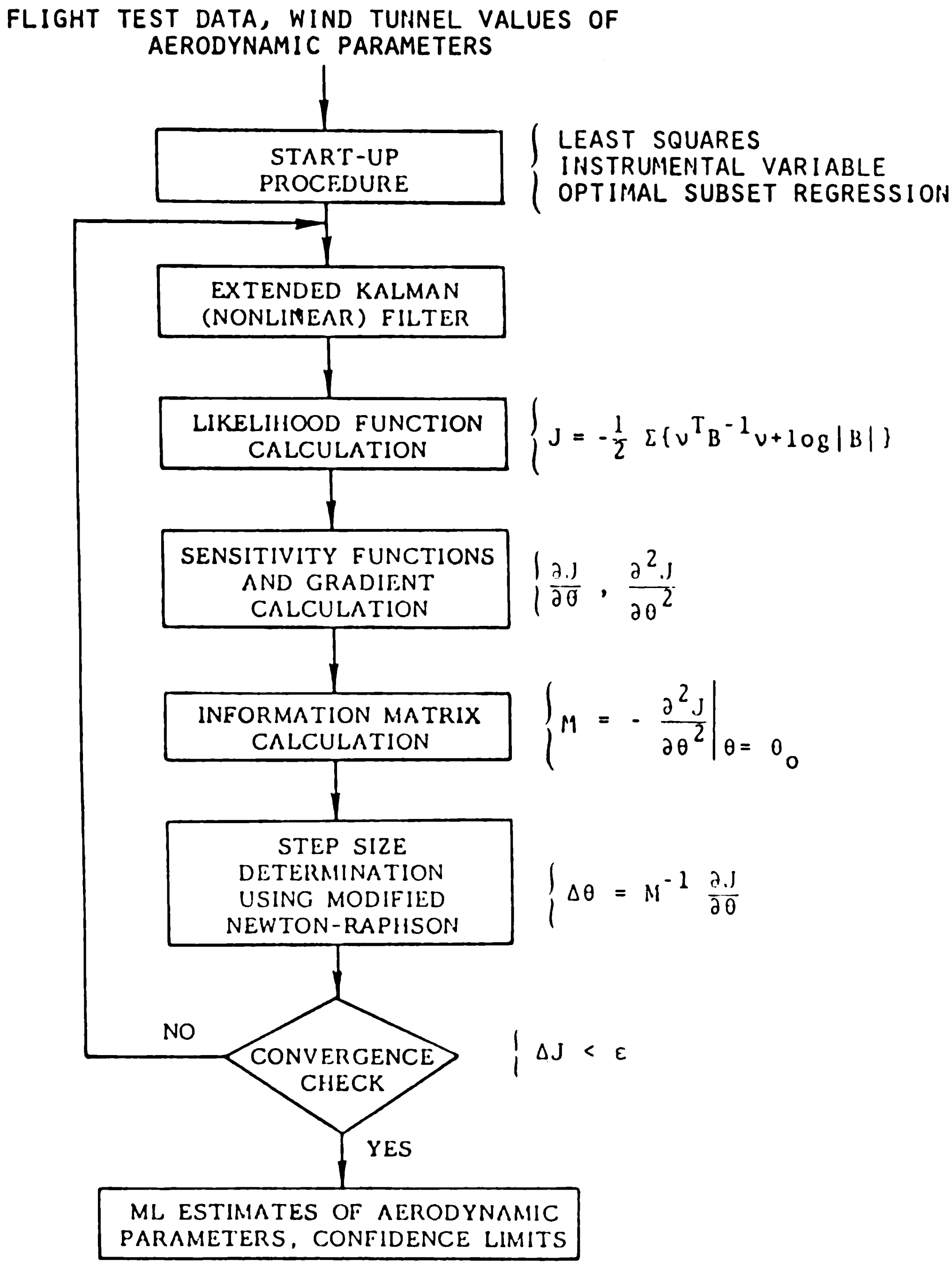


Figure 7 — Flow Chart of Maximum Likelihood Identification Program

TABLE I Categories of Parameter Identification and Computation Methods
I. Equation Error Method • Least Squares • Weighted Least Squares • Method Functions • Transform Methods • Spline Functions
II. Output Error Method • Newton-Raphson • Modified Newton-Raphson • Quasi Linearization • Kalman Filter • Gradient Techniques • Conjugate Gradient • Steepest Descent
III. Advanced Methods (Those that Account for both Measurement and Process Noise) • Maximum Likelihood • Kalman Filter/Smoothing

All three of these basic techniques can be used both for estimating *model structure* from input/output data or for *parameter estimation* for a specified model. Practical system identification requires both model and parameter estimation.

Model Structure Determination [1,4]

Model structure determination procedures consist of testing input/output data successively against several assumed identification models and testing for "goodness of fit" in some sense. Equation error identification methods are frequently used for such structure estimation because they do not generally require start-up values of model parameters and thus provide estimates of both model and parameters. These parameter estimates are usually biased, however, because of the sensitivity of the equation error techniques to uncertainties on the state of the system. Maximum likelihood methods may also be used successively but there may be a significant penalty in computation time and possibility of divergence because of required start-up estimates in many implementations. Regardless of the particular algorithm, however,

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the ultimate success of a model structure procedure depends on the "goodness-of-fit" test. This is because of the so-called *identifiability problem* which arises because the basic algorithm cannot, on the basis of the data provided, distinguish between parameters or alternative model structures.

One approach which has been found useful for determining the model structure which relates input and output data is to plot some "goodness-of-fit" parameters as a function of the number of parameters in a model. Figure 8 shows such a plot with two such goodness-of-fit parameters — the multiple correlation coefficient, R^2, and the model F-ratio. Details of these quantities may be found in any good statistics book. For our purposes, the R^2 parameter measures the decrease in fit error as parameters are added, while the F-ratio takes into account the fact that some additional parameters explain the data better than other parameters. The R^2, therefore, increases with the number of parameters, while the F-ratio reaches a maximum when the "best" parameters are reached and indicates no further parameters should then be added.

Use of such methods to estimate model structure is an effective way to avoid divergence and incorrect results in subsequent parameter identification.

Parameter Identification [1]

Parameter identification for a given model historically has been the focus of system identification. It has only been recently recognized

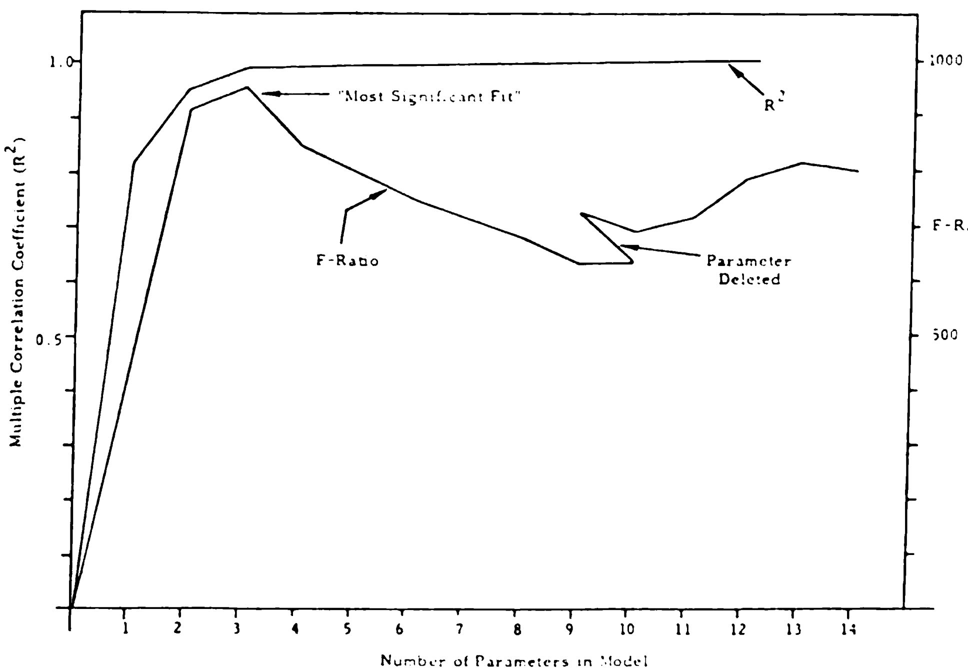

Figure 8 — Multiple Correlation Coefficient (R^2) and F-Ratio Variation as Parameters are added to Model (Lateral Case)

that parameter identification is a *subproblem* of system identification, since results depend so heavily on the validity of the model for which the parameters are identified.

One particular application of parameter identification where extensive effort has been made is the determination of aircraft stability and control derivatives. For this application, at least for most handling-quality evaluation objectives, the linear aircraft model is reasonably well represented by well known sets of developed linear longitudinal and lateral differential equations of motion.

Figures 9 and 10 summarize one example of an extensive flight test program in aircraft derivative estimation performed by the Naval Air Development Center [5]. (Applications at the Naval Air Test Center are reported in Ref. 6.)

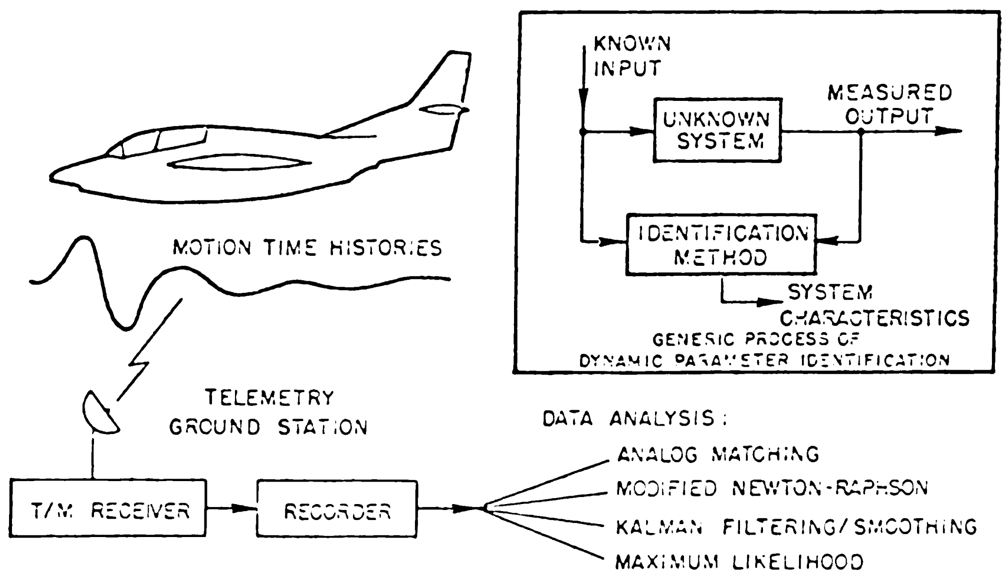

Figure 9 — Airframe Dynamics Identification

Figure 10 is a summary of results from maximum likelihood methods applied to flight data from a NADC T-2B aircraft. These outputs consist of a set of parameter values (the circles) and an estimated 20 confidence bounds of these estimates (brackets). These estimated confidence bounds are an important aspect of evaluating the reliability of the parameter estimates. In general, the wider the brackets, the less confidence one should assign to the estimate.

When low confidence of parameter estimates results from processing of data, there are several alternatives for improving that confidence. If the confidence has been degraded because of noise, a maximum likelihood algorithm can be used to extract more reliable estimates

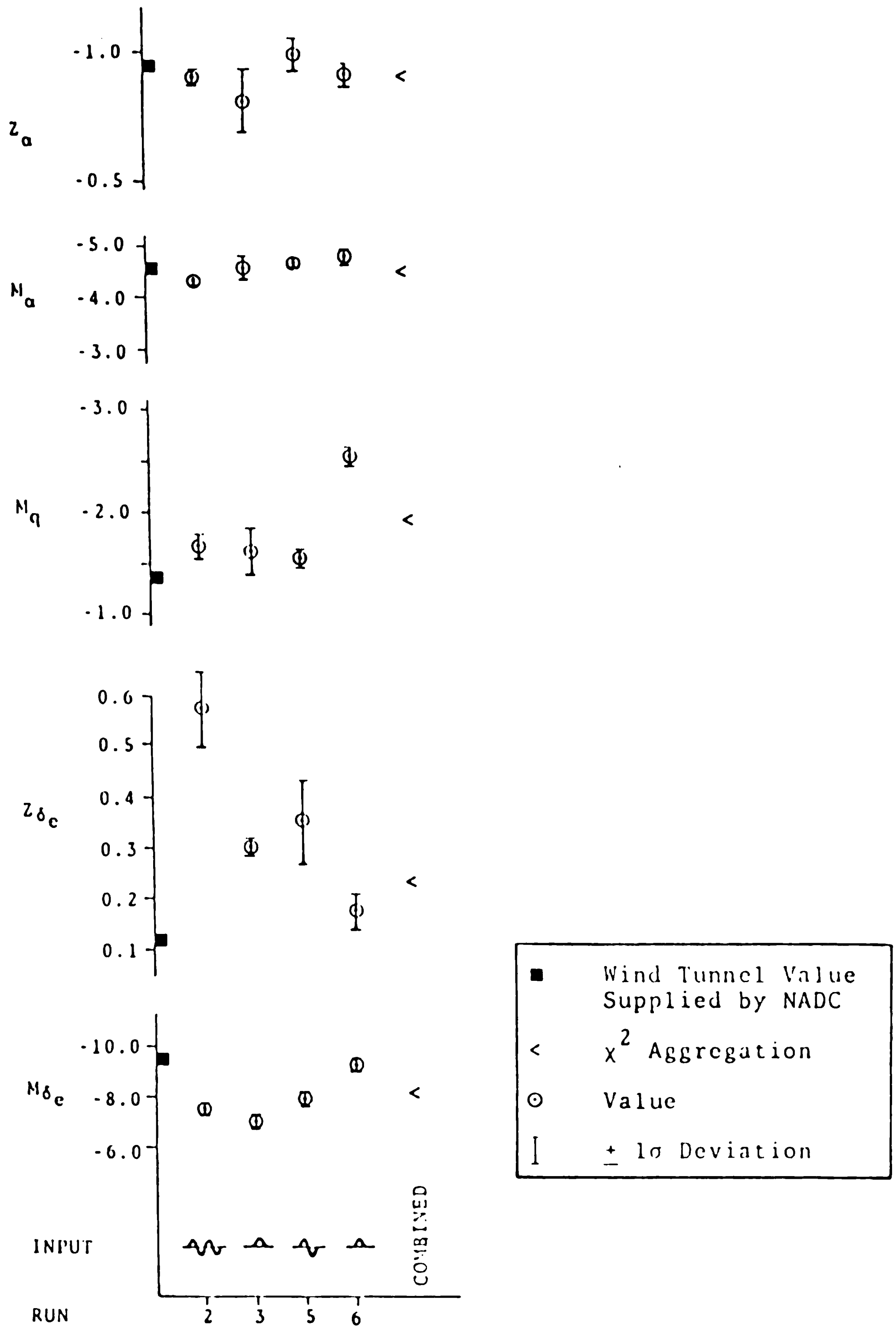

Figure 10 — Comparison of Stability and Control Derivatives at Low Speed Approach Configuration (236 ft/sec)

by using various computational options. If, however, the responses which are most affected by the desired parameters are not sufficiently excited by the system inputs, it is necessary to redesign these inputs for a subsequent test. Such input designs are optimized for improving parameter estimate confidences, and are hence denoted as optimal inputs.

Optimal Inputs

The input design process is shown in Figure 11 [7]. It is seen that the process requires some a priori knowledge of the aircraft characteristics and data collection parameters. In addition, it is necessary to specify the objectives of the identification procedure (e.g. what model response parameters are to be identified).

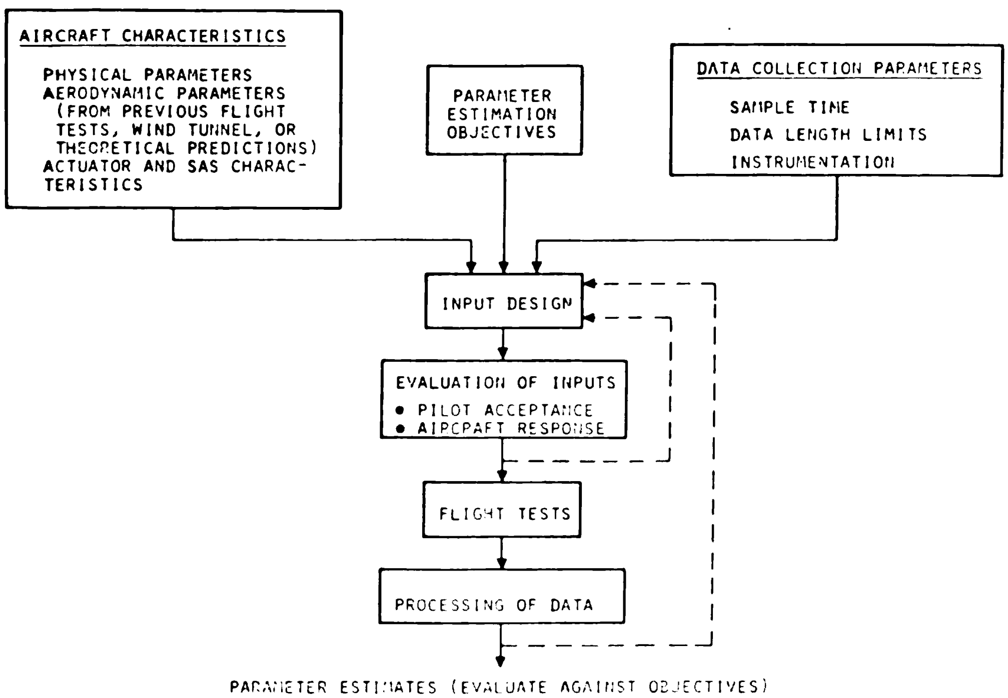

Figure 11 — Use of Optimal inputs for Flight Test Design

An optimal input for a C-8 aircraft is shown in Figure 12 (simulated data). Also shown is a stepwise approximation to that input. It has been verified that the approximated input produces very accurate results relative to the true optimal input. Such stepwise inputs are, in some cases, easier to implement.

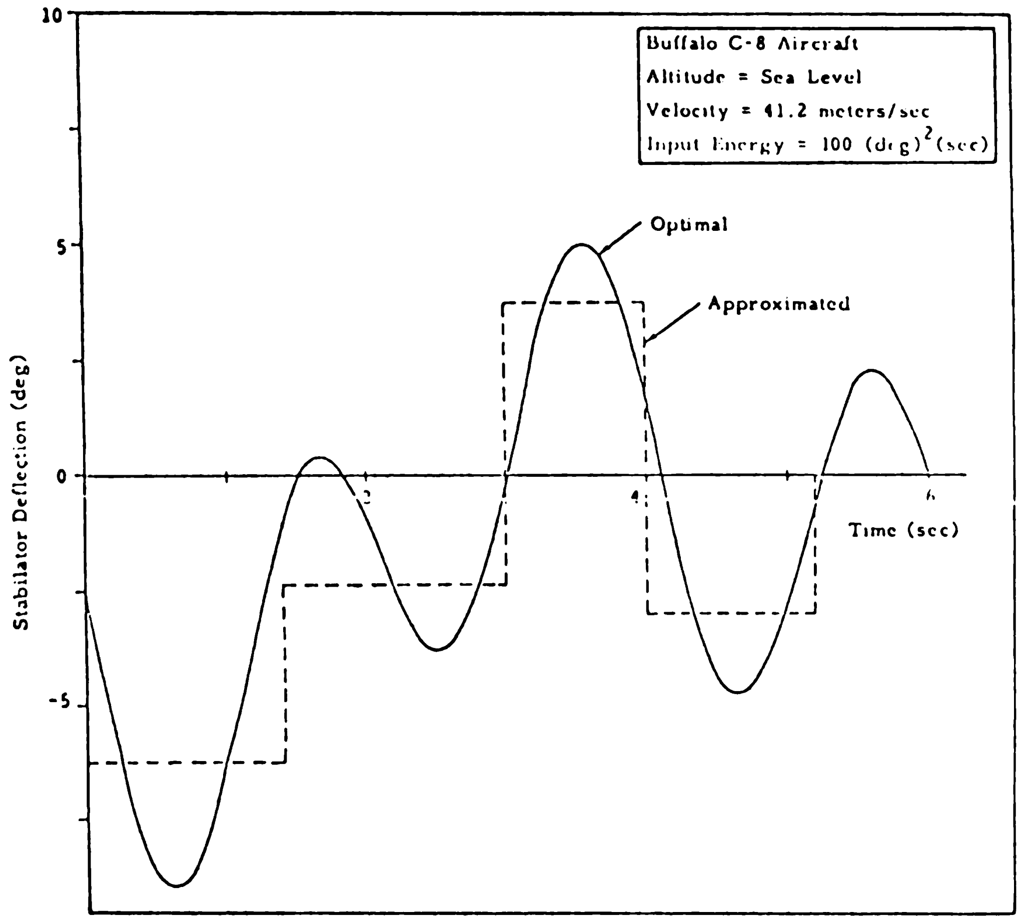

Figure 12 — Optimal and Approximated Elevator Inputs

Figure 13 shows the improvement in estimated standard deviations of parameter estimates for the input of Figure 16 versus a conventional stabilator doublet input. It is seen that all derivative estimates are improved in accuracy by the optimal input. Improvements are also obtained when the optimal inputs are used with actual flight data, as has been demonstrated for a T-2B Navy trainer aircraft.

Instrumentation

Another important aspect for improving the accuracy of parameter estimates is by using a specially selected set of aircraft motion sensors.

Instrumentation is generally not installed for parameter identification objectives, although the utility of having an adequate measurement system for such purposes is now being recognized. The basic factor which confuses the specification of instrumentation is that there is a trade-off between sophisticated and accurate instrumentation and hardware versus comprehensive software which upgrades data quality by various filtering

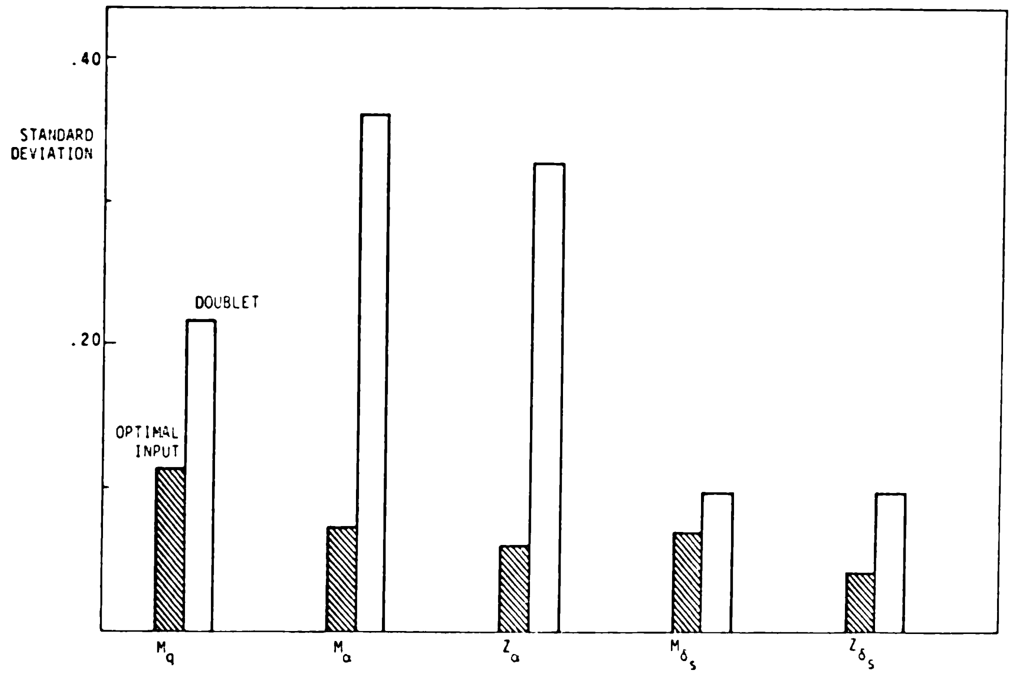

Figure 13 – Comparison of Standard Deviation in Parameter Estimates for Optimal input and Doublet (Same input Energy)

and smoothing techniques. There is therefore a need to utilize techniques which specify what type and accuracy of instrumentation is required for a specific identification task.

Some work has, in fact, been developed for such an objective. Based on manufacturer's specification, typical parameters which characterize a particular sensor may be determined, as shown in Table II [8]. The next step is to use efficient software which determines the effect of these instrument performance parameters on the accuracy of particular coefficients. An example of such calculations is shown in Figure 14a and b. From such plots, the necessary accuracy of particular instruments is established to achieve some identification accuracy goal.

Computation Time

A recurring issue in state-of-the-art identification practice is computation time of estimates for a given length of data. It is now clear that, for any given algorithm, computation time may be reduced by decreasing the number of parameters to be identified, decreasing the length of maneuvers, or reduce the accuracy required for the parameters. These alternatives are usually available as options in a generalized flexible computer program.

Dramatic reductions in computation time may be achieved by reducing the flexibility of the software, such as "hardwiring" parts of the code into machine language. This approach has the disadvantage of restricting program usage to a particular machine.

Table II
Accuracy Characteristics of Typical Commercial Rate Gyros
(Values Given are Manufacturers' ± Quotes Unless Noted)

Type	Range	Bias	Noise	Nonlinearity or Scale Factor	Resolution	Mass Unbalance	Comment
	deg/sec	deg/sec	deg/sec	% Full Scale	deg/sec	deg/sec g	
Timex SD-060	60	± .03-.12	± .18	± 2	± .01	± .05	a.
Sperry DG 312		.0011-.036		.04-.23			Numbers are 1σ (Sperry DG 312 through Kearfott T2010)
Northrup GI-G6		.015-.094		.07-.32			
Kearfott Alpha 2		.001-.003		.02-.09			
Kearfott T2010	40			± .5-1	± .04	± .01	
Systron Donner 8160	40	± .4		± 1.0	$\pm .4 \times 10^{-3}$		b.
Lear Siegler	80	± .03	± .1				
Sperry	40	± .1	± .04	± 2.5-5	± .04	± .05	

a. Scale factor proportional to voltage and power supply frequency
b. Scale factor and bias vary with temperature

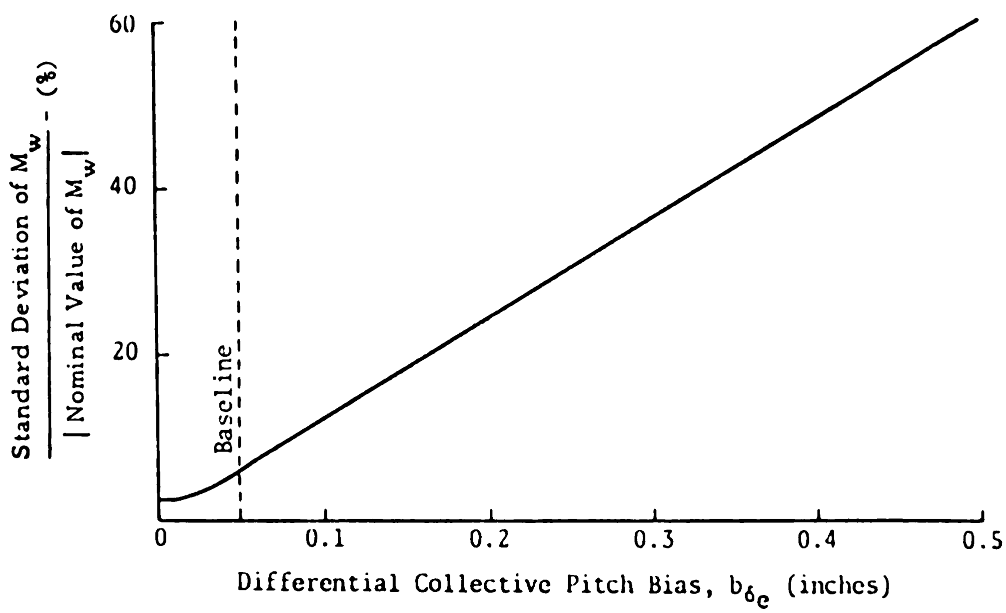

Figure 14a — Variation of M_w Error with Bias b_{δ_c}

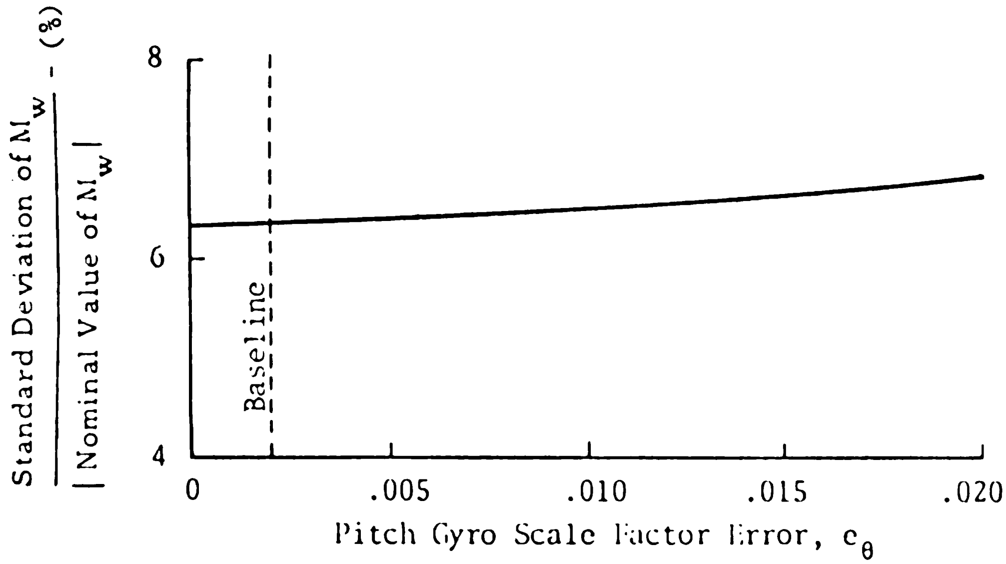

Figure 14b — Variation of M_w Error with Scale Factor Error e_θ

If a priori values of parameters are available (e.g. wind tunnel values) the program can be constrained to estimate parameters to within certain tolerances of the given values. Such an approach reduces the number of iterations required for identification convergence, but may place more confidence in a priori values than is justified.

Alternately, the identification theory may take advantage of certain system properties, such as linearity, to achieve a significant reduction in computation time. Figure 15 shows an example of such a reduction for a maximum likelihood algorithm which is now being applied to Navy aircraft by NATC [9]. Three bands are shown. The left-hand band is the basic solution time dependence. The next band (clockwise) and the shaded band show the effect of various theoretical reformulations on this solution time. It is significant that the shaded band represents solution time which is theoretically exact (e.g. no approximations) and machine independent.

Summary

Only a broad brush treatment of the rich and exciting technology of system identification has been possible in this article. It is concluded that system identification is rapidly having an impact on many Navy programs. As shown in Figure 16, this input can be integrated systematically into both research and development programs. Specific examples where this integration has taken, or is taking place, are shown in Table III. The following conclusions are presented:

- System identification has now emerged from an extensive basic research program to a state-of-the-art tool for improving understanding of vehicle characteristics.

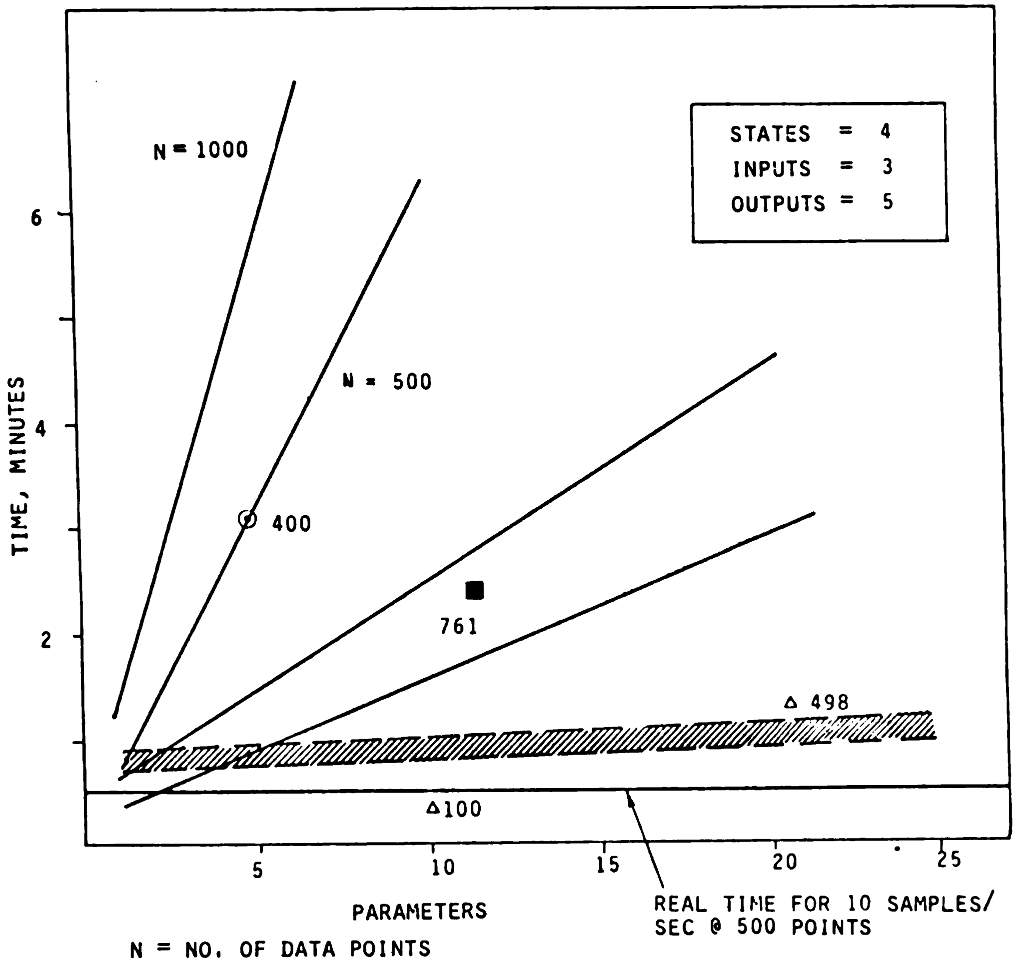

Figure 15 — Reduction for maximum likelihood algorithm

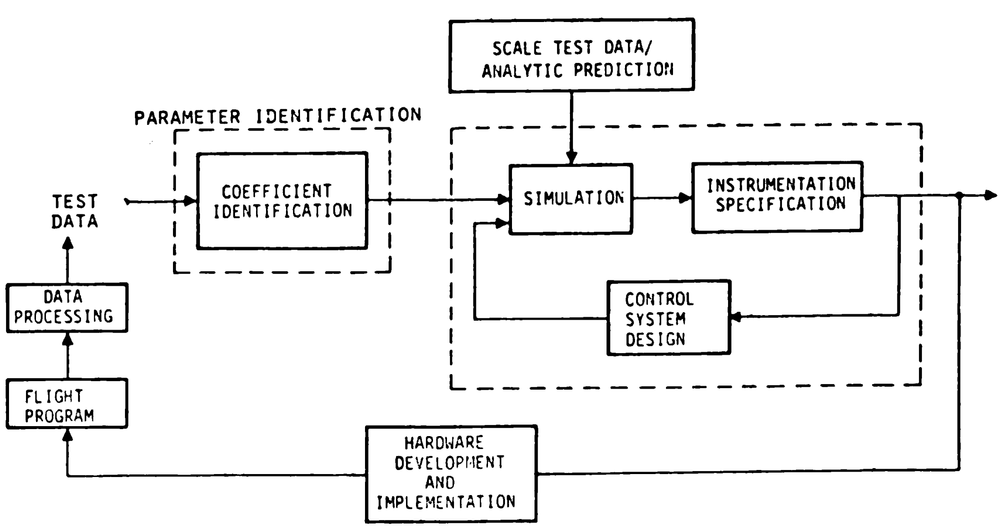

Figure 16 — Parameter Identification can play an Integral part in Navy System Technology and Design

TABLE III
Applications to Navy Systems

- Parameter Identification
  - Hydrodynamic Coefficients (for Submarines, Ses, Swath)
  - Navigation System Components (Platform Misalignment, Gyro Bias)
  - Ballistic and Reentry Vehicle Aerodynamic Coefficients (Ablation Disturbances, High Mach Transition)
  - Definition of Gust field around a Carrier
  - Definition of Random Seaway forces and moments
  - Structural Stiffness and Damping Coefficients
  - Precision Tracking and Pointing System Coefficients
  - Nuclear Reactor Propulsion Systems

- Input Design
  - Tow Tank Test Planning
  - Full Scale Ship Testing
  - Aircraft Maneuver Design

- Instrumentation Analysis
  - Tradeoff of Instruments for Desired Accuracy
  - Instrument Calibration
  - Post-Test Data Processing

- Successful application demands integration of test planning, instrumentation, and post-test data processing.
- Past and on-going Navy and other applications of system identification have isolated most basic problems. The basic technology appears to be ready for application to a wide range of Navy systems/vehicles, if carefully applied.
- Future advances for this technology will come from the problems encountered in applications.

Acknowledgment

The author wishes to acknowledge the contributions made by personnel at SCI and various technical personnel at Navy locations. Specifically, discussions with J. S. Tyler, N. K. Gupta and R. L. Mohr of SCI clarified many of the approaches necessary to concisely discuss the broad aspects of system identification. Without the support of A. Piranian of the Naval Air Development Center, R. Burton of the Naval Air Test Center, and R. A'Harrah of Naval Air Systems Command, many of the results published here would not have been possible.

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Advanced Elasticity Theory Solves Outstanding Problem in Fracture Mechanics

In many engineering problems such as the propagation of waves of short wave length due to an impact and the determination of the stress concentration at a crack tip, classical continuum mechanics fails to give realistic results. Because the effect of the internal structure of the material is ignored, one obtains the unacceptable conclusion from continuum theory that an infinite stress arises at a sharp crack tip. A so called non local continuum theory developed by Dr. Eringen, Princeton University under ONR contract includes material micro-structure and interatomic interactions. The theory was successfully applied to the study of wave propagation and the crack problem and yielded a finite stress at the crack tip. As a result it was concluded that a fracture criterion based on a maximum stress hypothesis was correct. Cohesive stresses necessary to break the atomic bond were calculated and found to be in excellent agreement with atomic theory. It appears that the outstanding problem of infinite stress at a sharp crack tip has been resolved.

New Approaches in Naval Safety Research

Ronald L. Huston*
University of Cincinnati

While crew safety has long been a concern of the armed services, it has recently been receiving attention and study with unprecedented sophistication. Particular attention is being given to aircraft-occupant safety with an emphasis on head-neck dynamics during crashes and periods of high acceleration. The interest in head-neck dynamics stems from the fact that 60-80% of crash fatalities can be traced to injuries to the head-neck system.

Early and ongoing research in aircraft-occupant safety used dummies and cadavers to model the human body. The preference for dummies and cadavers over live volunteers or animals is due to the obvious dangers of using volunteers and due to the expense and range of applicability with animals. One notable exception to this is the work of Dr. Channing Ewing and his associates at the Naval Aerospace Medical Research Laboratory in New Orleans with live volunteers using elaborate testing equipment. However, the use of dummies and cadavers is not free from disadvantages. It is expensive and there is the nagging question of reliability and accuracy of the modelling. These factors and others have stimulated researchers to look for new approaches to crash-victim simulation and modelling. Specifically, with the advent and development of the high-speed digital computer and with corresponding advances in mathematical-biodynamic modelling, it was invisioned that simulation of crash-victim dynamics could be accomplished on a computer.

These visions have recently been realized with the development of several, user-oriented, crash-victim computer simulation codes. Of these codes, two currently stand out as being the most comprehensive and broadly applicable: CALSPAN developed at the Calspan Corp. and UCIN developed at the University of Cincinnati. CALSPAN was developed with the support of the Department of Transportation and the code was originally designed to study crash-victim dynamics associated with automobile and pedestrian accidents. UCIN was developed with the support of the Office of Naval Research with the objective of studying crash-victim dynamics associated with aircraft accidents, pilot ejection, and parachute shock injuries. A comparison of the CALSPAN and UCIN codes and experimental verification

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can be found in References (1-4). A brief summary of other simulation codes can also be found in References (1-3). However, the discussion in the balance of this article is concentrated primarily on the UCIN code since its objective is application with naval vehicles.

Actually, there are three distinct UCIN codes: (1) the original and the most widely used is UCIN-CRASH which is designed to study whole-body, gross-motion, crash-victim dynamics; (2) the most specialized is UCIN–NECK which is designed to study the dynamics of the head-neck system in detail; and (3) the most general is UCIN-SUPER which is designed to study the dynamics of general configurations of linked rigid bodies.

In UCIN-CRASH, the human body is modelled as a system of linked rigid bodies representing the various limbs and the torso of the human body. This system is then placed in a vehicle frame cockpit. Figure 1 provides a schematic representation of the vehicle-model

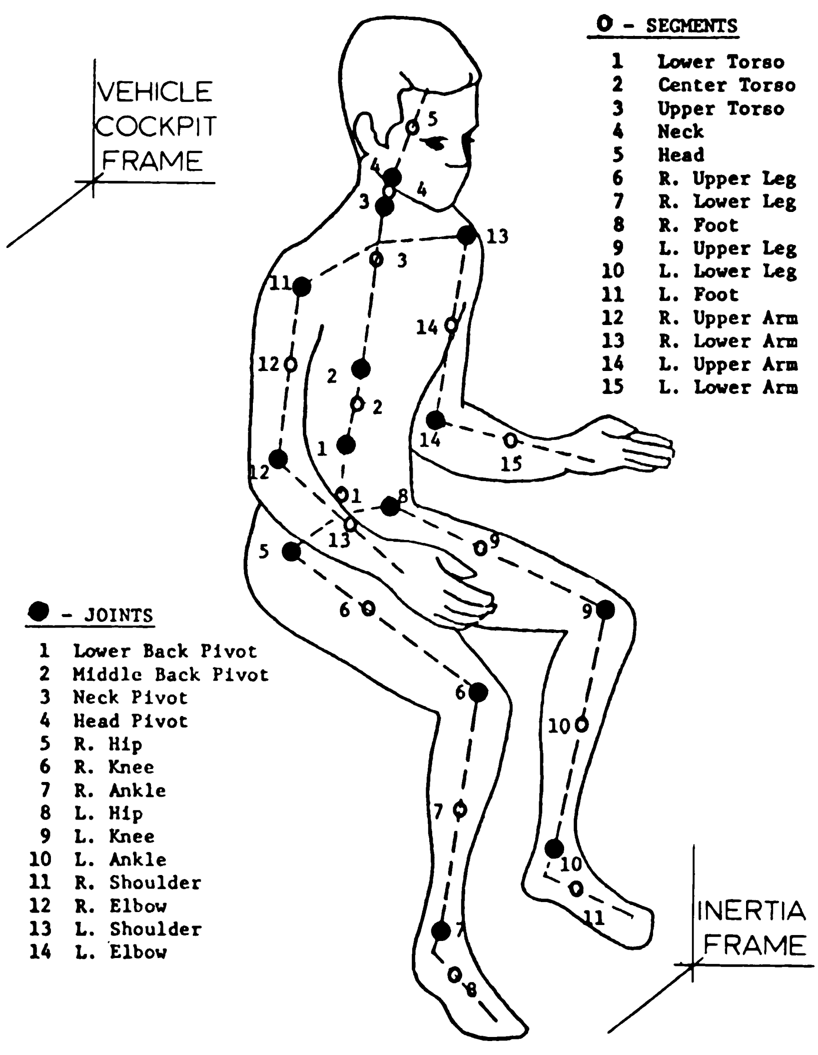

Figure 1 — UCIN Vehicle-Model System

system. The soft tissue at the joints (muscles, discs, and ligaments) are modelled by nonlinear dampers. The model is anchored to the vehicle or cockpit by a seat and by seat, shoulder and other restraining belts modelled as linear one-way, springs. The physical dimensions of the bodies of the model, the spring and damping coefficients, and the number and position of the attach points of the restraining belts are arbitrarily specified input data. External forces and moments may also be applied to the bodies of the model. In a typical run the acceleration or deceleration profile of the vehicle or cockpit is specified. The computer then predicts the subsequent position, velocity, and acceleration of the various bodies and points of the model. It also predicts seat belt forces and restraining forces between the bodies of the model.

The UCIN-NECK model is shown schematically in Figure 2a and 2b. It consists of rigid bodies and nonlinear springs and dampers representing the bones, discs, ligaments, and muscles of the head-neck

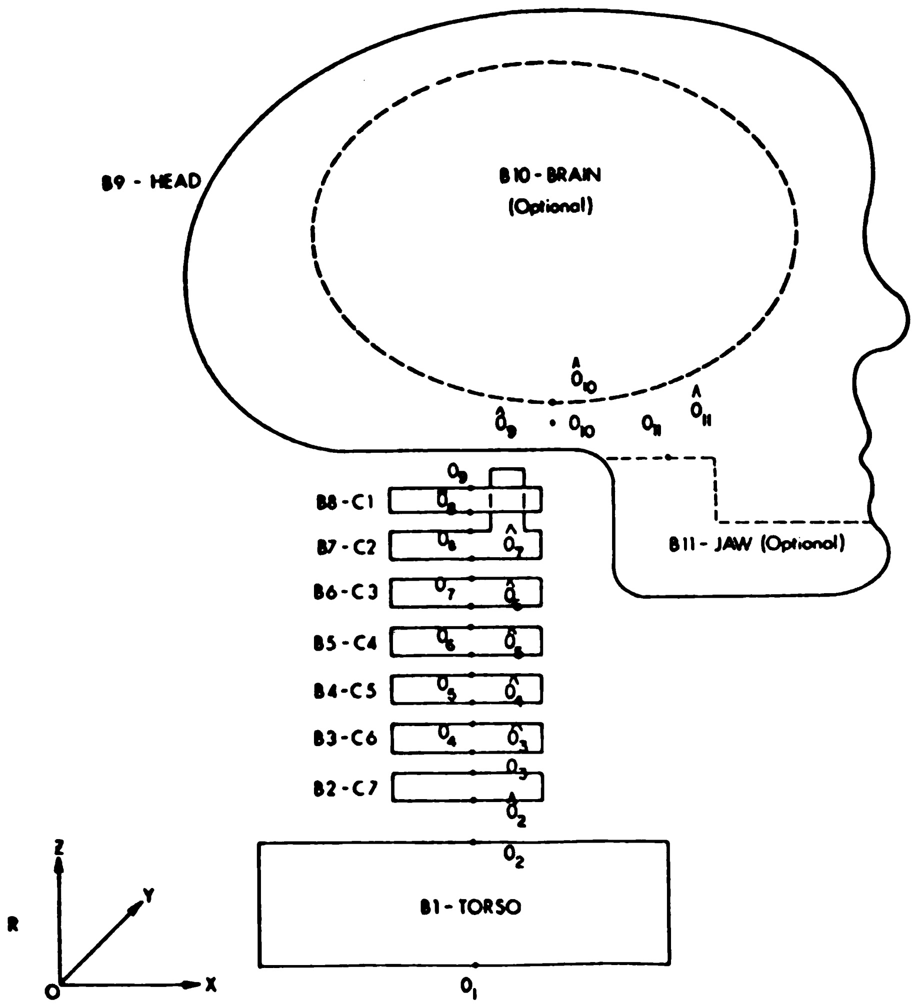

Figure 2a — Three-dimensional head-neck response model with coordinate axes

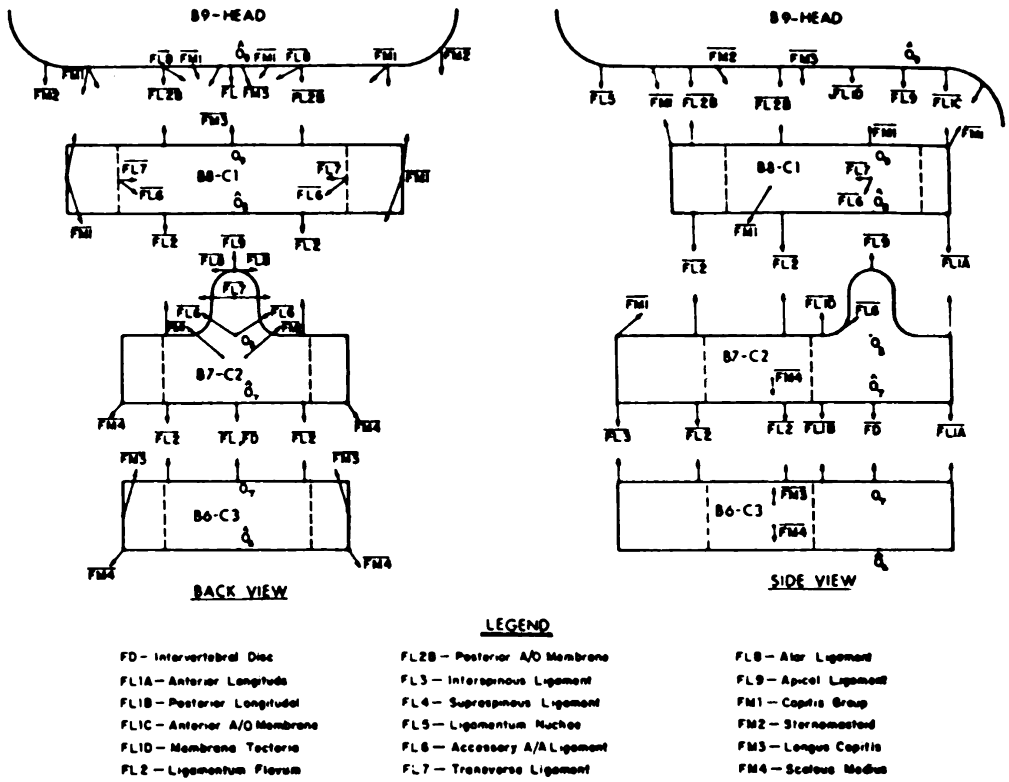

Figure 2b – Connective tissue and joint details for head, C-1, C-2, and C-3

system. Unlike UCIN-CRASH there is provision in UCIN-NECK for translation (in addition to rotation) between the bodies of the model. In a typical run the acceleration or deceleration profile of the torso T1 is specified and the computer then predicts the subsequent position, velocity, and acceleration of the various bodies and points of the model. Muscle and ligament forces may also be determined. Figure 3 illustrates the comparison of a computer generated UCIN-NECK model versus a live volunteer during an increment of time in a sudden deceleration. Figures 4 and 5 illustrate respectively a comparison of the computer generated output from the UCIN-NECK model versus the human volunteer experimental results of Ewing (25) for head angular acceleration and head angular velocity obtained from sudden deceleration. The excellent comparisons between the computer prediction and the human volunteer experimental tests demonstrate the validity of using the UCIN computer models. In addition to being at least an order of magnitude cheaper than experimental tests, the computer models also provide highly efficient means for designing and assessing safety devices such as energy absorbing pilot ejection seats, pilot restraint systems, and helmets.

The UCIN-SUPER model consists simply of a series of rigid bodies arbitrarily assembled such that no closed loops are formed (sometimes

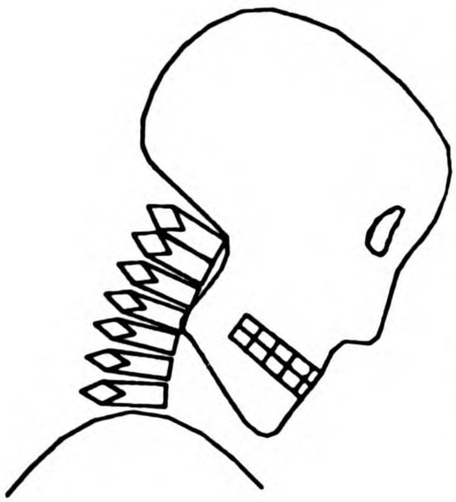

Figure 3 – Computer display of UCIN-Neck and human volunteer in test condition

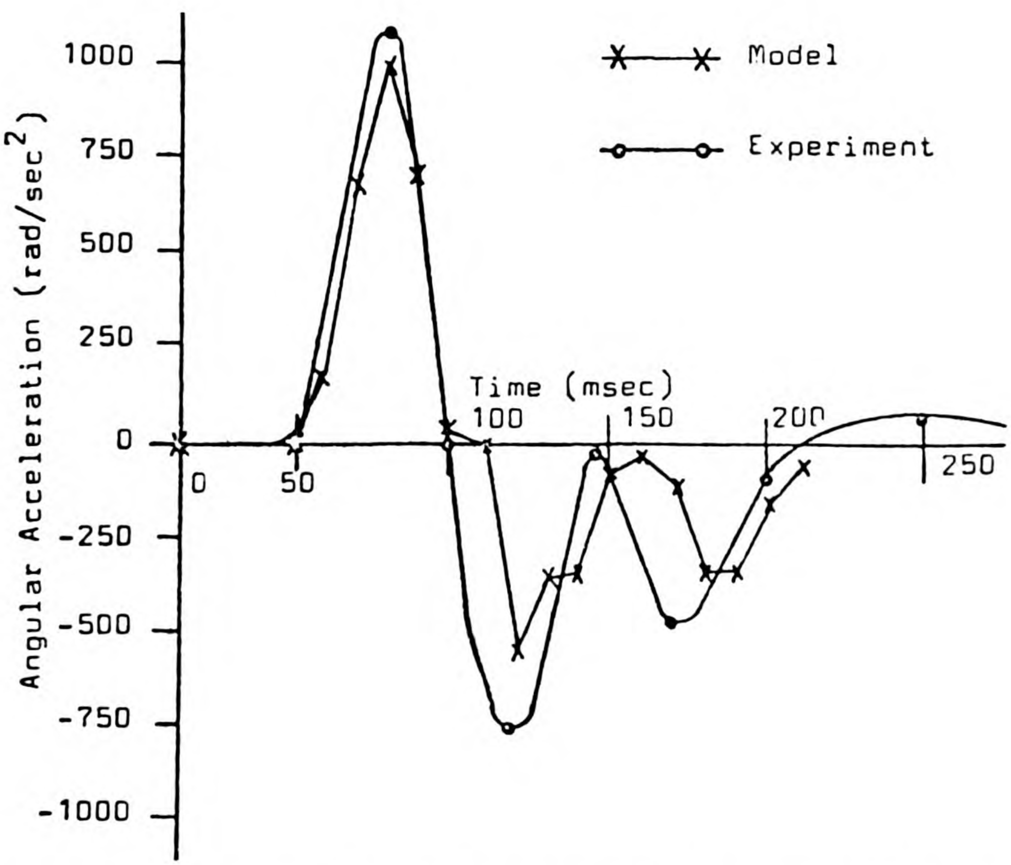

Figure 4 – Comparison of model and Ewing experiment for head angular acceleration

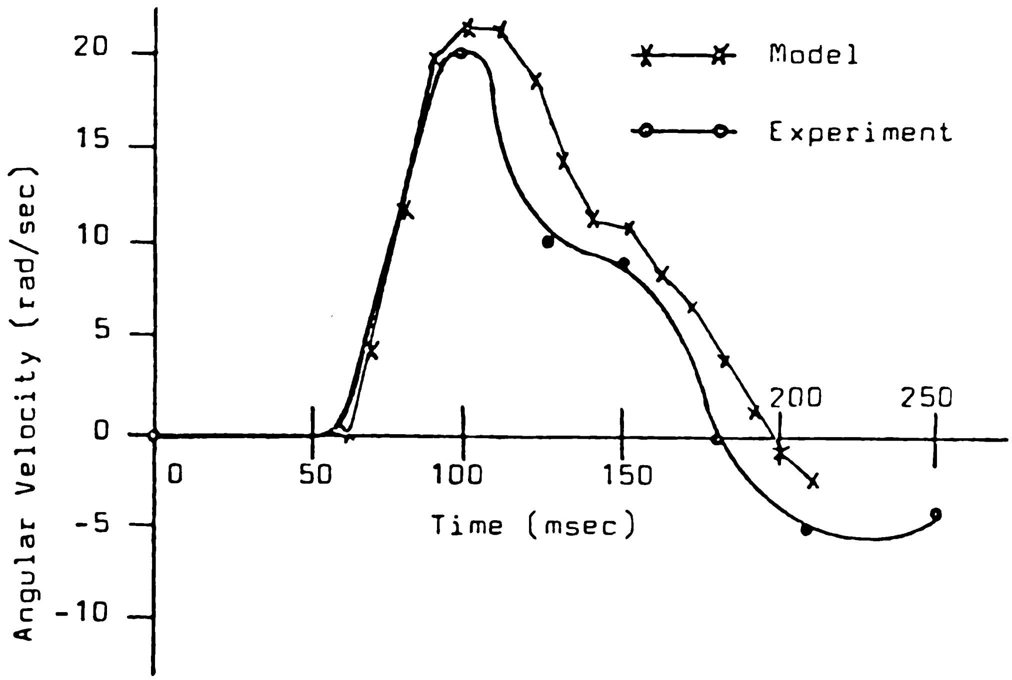

Figure 5 — Comparison of model and Ewing experiment for head angular velocity

called a "general-chain", "open-chain", or "open-tree" system). For this model, forces, moments, and prescribed motion are arbitrarily specified for the bodies of the system and the computer then predicts the subsequent unknown position, velocity, and acceleration of the various bodies of the system together with the restraining forces and moments between the bodies. UCIN-CRASH is, in a sense, a specialized version of UCIN-SUPER.

These UCIN codes are being used to study crash—victim dynamics in a variety of situations. (See References (5-12).) They have also been used to study swimming, walking, and cable dynamics. Current research involves studies with parachutist dynamics and vehicle passenger (e.g. ship passenger) dynamics. Additional information may be obtained in References (13-24) or from the author.

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Demulsifying Bilge, Fuel Tank and Oily Waste

Dr. Ralph C. Little and Robert L. Patterson at the Naval Research Laboratory have developed a pair of chemical agents for use in demulsifying oily waste found in ship's bilges, fuel tanks, storage tanks and oil spills.

The demulsifiers, will enable the Navy and maritime industries to break up waste emulsions and remove water from oil or oil from water, whichever the case may be, economically and effectively.

The scientists say they have laboratory-tested the two chemical systems — each tailored to a specific emulsion type — and found them to be much more effective and economical to use than demulsifying agents commercially available today.

The scientists believe if the Navy accepts their systems, it will save a good deal of money and time, and will help diminish pollution by providing for the recycling of the components of oily sludge.

The researchers say that for water-in-oil emulsions, a two part chemical system comprising an effective wetting agent (sodium dioctyl sulfosuccinate) and a high molecular weight polymer (polyethylene oxide) have been shown to be very effective.

And for the inverse types of emulsion (oil-in-water, as an example) selected quaternary (having four organic radicals) ammonium chlorides - as exemplified by dicocodimethyl ammonium chloride - have been shown in laboratory tests to be extremely effective.

As in the latter case, these positively charged agents reduce emulsion stability by neutralizing the negative charge on the oil droplets of oil-in-water emulsions.

In addition, both demulsifier systems function at temperatures as low as 50° (F) (compared to 100° (F) operating temperatures required for presently available commercial agents), even in the presence of dirt, rust and other particulate matter which can often make significant contributions to emulsion stability.

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A simple field test will determine which emulsion is present. Once this is done the emulsified waste problem is reduced to the selection of the proper demulsifier agent.

The system could be used in the event of oil spills to effecitvely remove the water from the oil while it is being pumped into barges during cleanups. Thus, fewer oil transport barges would be required.

The Environmental Protection Agency does not allow oil sludge to be pumped overboard from ships, even in a highly diluted state. However, these systems would, in many cases, clean the separated water to the point where it would be acceptable under EPA standards for return to environmental waters. In more difficult cases, a final "polishing" step involving a mechanical separation or charcoal adsorbent might be required to remove the last traces of dispersed oil.

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Cover Caption

Film strip of live volunteer subjected to high deceleration loads in the horizontal direction. Courtesy of Dr. Chan Ewing, Naval Aeromedical Research Facility.

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