A METHODOLOGY FOR LONG-RANGE PREDICTION OF AIR TRANSPORTATION*

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ABSTRACT

The purpose of a research study reported in this paper was to provide a framework and methodology for long term projection of demand for aviation fuels. It required a close examination of some of the fundamental problems of predicting long run futures. The approach taken includes two basic components. The first was a new technique for establishing the socio-economic environment within which the future aviation industry is embedded. The concept utilized was a definition of an overall societal objective for the very long run future. Within a framework so defined, a set of scenarios by which the future will unfold are then written. These scenarios provide the determinants of the air transport industry operations and accordingly provide an assessment of future fuel requirements.

The second part was the modeling of the industry in terms of an abstracted set of variables to represent the overall industry performance on a macro scale. The model was validated by testing the desired output variables from the model with histroical data over the past decades.

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THE PURPOSE OF THIS PAPER is to report the results of a NASA sponsored research program for development of a methodology for projecting the long term requirements for future aviation fuels.

An integrated study of future aviation fuels requires consideration of a number of related areas. (See Fig. 1) The kind of fuel and the magnitude of future demand depends on the engine and airframe performance characteristics of future aircraft, the characteristics of the air transport system and the availability of future aviation fuels. As depicted in Figure I, the aircraft may be considered as a component of a larger system--air transportation--which in turn is a subset of the transportation system. Similarly, availability, price, and technical characteristics of aviation fuel fit into the overall energy picture of the future. Finally a future transportation demand and energy requirements interact with and are impacted by many socio-economic variables.

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1. THE PROBLEM OF LONG RANGE PREDICTION

The long lead times needed to develop and produce new engines and new aircraft types require some means for predicting very long term futures. Decisions which are made now must be based on future prospects of successful outcomes However, we cannot know the future and out extrapolation of past trends as a means of forecasting the future inevitability will result in wide divergencies between predicted results and what really will come to be. Witness, for example, previous projections by well recognized authorities of airline transportation (Fig. 2). The extrapolations shown all reflect an exponentially increasing variance associated with futurity. It is indicative of the difficulty of the problems, that eight different projections made by the FAA, CAB, several airlines and several aircraft manufacturers all fell within the dashed lines of Fig. 2. Actual growth of air transport for that same short period of ten years, 1962 to 1976, fell outside the range of all of them. The question then is how can a methodology be developed for providing a view of the future needed for decision-making in the present in the face of an almost completely unknowable future.

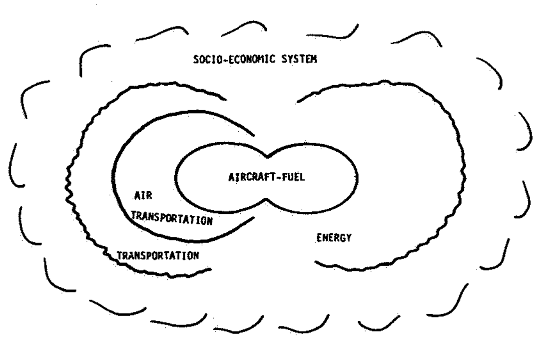

Fig. 1 Aviation Fuel and Its Related Areas

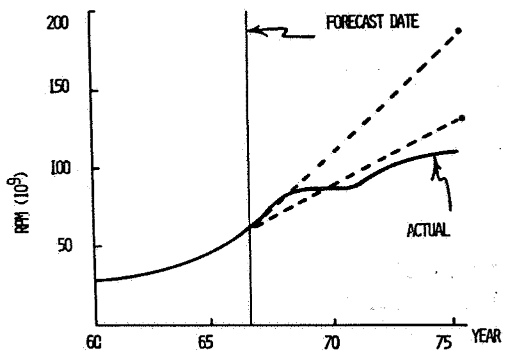

Fig. 2 Air Traffic Forecasts

The solution to this problem must be found by taking a new perspective of prediction from that of conventional forecasting. Our approach is to limit forecasts to those variables for which a very long experience and reasonably reliable record of success already exists, specifically, population and gross national product (GNP). Even for these major economic variables, an assumption must be made that there will not be some kind of major human catastrophe. One aspect of long range general economic projections that should be recognized is the difference between the variance of time and variance of result. It can reasonably be asserted that a certain economic future will come to be. However, the variance in the time such an occurence is finally achieved can be quite sizeable. Furthermore, the distribution about the expected time certainly will not be linear in time. Probably log time will be a more meaningful measure. (1)*

It might be further noted that in keeping with time perception on a log scale, the actual time frame may not be important. If a given aspiration is achieved at all whether it takes 30 years or 50 years, may not be significant in making a present decision to launch and R&D program for a new engine.

The aspiration approach can be illustrated by reference to (Fig. 3). The horizon for forecasting the air transportation system is necessarily short because the divergence quickly exceeds useful decision making bounds. However, the aspiration bounds determined by a forecast of a much longer term horizon of the general economic environment are quite narrow. Thus as the future unfolds within the forecast time frame, special efforts will always become evident for redirecting action towards the long run aspiration. These action boundaries will tend to converge in contrast from the divergent forecast boundaries.

Given an economic environment that falls within reasonable bounds over the very long range, such as for example, fifty years, it becomes possible to describe the kind of future for which there would be generally accepted economic aspirations. The decisions and actions required to achieve such aspirations then become definable. These aspirations must be defined broadly in consonance with a value system which generally and presently is considered to be representative of human welfare. Furthermore, the constraints on such aspirations can readily be determined by consideration of the physical limits on resources needed to satisfy the economic conditions which were forecast.

Of course it is readily recognized that the detailed characteristics of this long term future economy can vary widely. Also the way in which component systems such as the airline transportation system will be inter-related with the economy may evolve in any number of ways. Thus, writing scenarios also is a useful forecasting tool.

What will result is a somewhat fuzzy picture of the state of the particular system of interest in some long run future along with a precise measure of what that system is today. The aspiration of a desirable future, coupled with the scenario, together would provide a set of exogenous variables which are inputs as well as constraints on the actual system of concern, i.e. the transportation system.

We may describe the air transport future in terms of the set of endogenous variables which have been modeled to demonstrate the actual operation. By this procedure a reasonable prediction of the future air transportation system operation may be made.

It will be recognized and perhaps should be emphasized that there is a self fulfilling aspect of such a prediction. Nevertheless, in the face of an unknowable future the only reasonable starting point properly should be a broad statement of presently perceived long run future desires in order to identify the actions needed now to take a first step in the direction needed to reach the aspiration.

2. THE ASPIRATION FRAMEWORK

In a preliminary study (English, et al 1977),(2), a long term prediction of the air transport industry was based on 5 scenarios describing future developments of the U.S. economy. These five scenarios were essentially abstracted from four scenarios of the future depicted by the Hudson Institute plus one which we added. The Hudson Institute scenarios

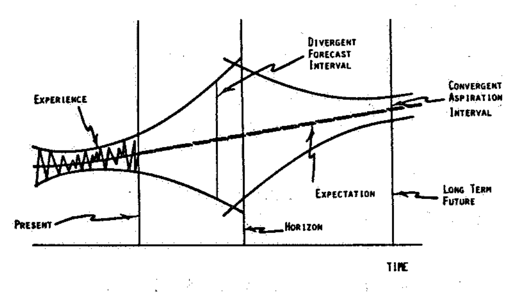

Fig. 3 Problem of Prediction

*Numbers in parentheses designate References at end of paper.

ranged from a very pessimistic future, (3), based on "A Limit to Growth," viewpoint, extension of the past U.S. experience at about the same rate of 3.4% as has been in existence, to a very optimistic growth rate. The intermediate Hudson Institute scenarios were essentially projections of GNP growth at different growth rates. In contrast, with the usual scenarios of some given steady growth, our fifth sceanrio was introduced in an attempt to consider effects of a serious dislocation of historical steady economic growth patterns. Such disruption was assumed to be due to a shortfall of energy supplies between now and 2000. However, in this sceanrio it was assumed that economic growth would be resumed following development of alternative energy supplies. This was termed the "Interrupted Growth Scenario." Such an interruption was also an implicit conclusion of the WAES, (4), an MIT study published independently and coincidently with our report. However, an important difference between WAES study and our interrupted growth scenario is that it shows a gap between supply and demand. The study group acknowledged that such a gap could never occur. Either added supplies would have to develop from somewhere or demand, with attendant economic contraction, would decline. A big unknown which remained unresolved, was the degree to which GNP and energy may be coupled. A Harvard study by Stabaugh and Yurgin, (5), "Energy Future," 1979 contends that such a linkage is weak and that energy consumption without an attendant reduction in GNP. Nevertheless, this is moot and the interrupted growth scenario was considered when written in 1976, to be at least as likely as a moderate growth scenario.*

The introduction of the aspiration approach made it reasonable to encompass the future economic environment within the three scenarios of slow growth, interrupted growth and moderate growth. The extreme conditions of even more rapid growth as a most optimistic case and the "Limits to Growth," case as the most pessimistic case were not considered worth exploring in greater depth. Neither of these cases could result in important changes in NASA R&D policy. There would be no problem for the first extreme, and disaster in the second.

*Over three years has elapsed since the writing of the interrupted growth scenarios and in many ways the economy is showing signs of following that scenario. Current projections of various econometric models are indicating a recession in 1980 from which, while expecting recovery in 1981, the economy is not expected soon to exhibit any vigorous resurgence. Air transportation may have received a separate specific impulse as a result of deregulation in 1978. As a result the incipient decline in that industry may have been masked until now.

The essence of the median scenarios are summarized as follows:

I. SOCIALLY CONSTRAINED GROWTH-2%
- Decoupling of Energy/GNP Linkage
- Conservation Option Emphasized
- Major Changes in Life Styles
- Economic Growth Below Historical Norms
- Significant Change in Transportation Modes

II. - UNINTERRUPTED GROWTH-3.4%
- Historical Growth Pattern Continues in Future
- No Major Changes in Economic Structure
- Energy/GNP Ratio Declines Slowly
- Air Transportation Continues to Grow Faster than GNP
- Business as Ususal

III.- INTERRUPTED GROWTH
- Major Restructuring of Energy Supply Systems
- Energy Shortage with Strong GNP/Energy Dependence Drives Economy to Depression
- Recovery in 10 to 15 Years will Require Major Supply Side Investments
- Investments Require Higher Energy/GNP Ratios which can't be Realized
- RESULT: Lower Living Standards.
- Resumed Growth with Quite Different Component Growth Pattern

The UCLA work is continuing in order to refine a reasonable aspiration within these various economic futures, fifty years hence.

3. THE FUTURE AIR TRANSPORTATION TECHNCLOGY

Because the prime objective of the study is to assess the level of total fuel demand, any improvements in overall fuel consumption will depend on possibility of improvement in operating efficiency. In turn, because of a changing mix of cost factors of airline operations, both travel demand and fuel demand will be affected by efficiency. Therefore, in order to establish aviation technology as an exogenous variable for the air transportation model, to be discussed in section 4,...,it was necessary to project possible technical changes in new aircraft and engines.

Improvements which may be expected to reduce fuel requirements per seat mile of capacity may be of two types:

a) Basic technological improvements
b) Operational induced design changes

The first of these will be due to such things as increased engine performance due to higher operating temperatures, improved airplane performance due to availability of better materials, structural concepts, active controls, boundary layer control and the like. In many cases the feasibility of design improvements are not dependent on break-throughs in new technology. The design principles may have been established long ago, but the economic justification for introducing them now derives from the changing ratio of fuel cost to other operating costs.

The second category will evolve from the response of operators to such things as the changing value systems of the traveling public. The trade-off between fare and such amenities as seat density, airplane size, speed and so forth, will lead to evolutionary changes in aircraft design.

Both of these kinds of changes take considerable time to effect changes in the charactersitics of total fleet operations. Nevertheless, they must all be part of any prediction model for the long term air transport future.

4. THE AIR TRANSPORTATION MODEL

A model is an abstraction of reality. A fundamental difficulty in devising any model is to strike a proper balance between representing the system in too great detail on the one hand and oversimplifying on the other. The degree of complexity should be no greater than that needed to afford the desired precision of prediction of various measures of performance under given hypothesized inputs.

In the case of the long run future for air transport, in general, the significant inputs derive from the socio-economic environment. As pointed out above the relative description of the environment is obtained from a postulation of a long run socio-economic aspiration which is recognized as realizable. Given such an environment described in the broadest sense, the specific inputs into air transportation may then be determined by means of scenarios.

Thus, as depicted in Fig. 2 one can work from this somewhat cloudy picture of the environment to a more detailed depiction of the desired system--air transportation.

The justification for this indirect modeling must be that it affords an ability to forecast as well as a greater credibility of the forecast, as compared with a direct extrapolation of future air transportation from historical data . An important further justification is that the use of the model under a wide variety of changes in input variables, as well as of model parameters, will provide better insights into the underlying processes governing air transportation demand and hence of fuel requirements.

It should be noted that such a approach to modeling starts from a quite different perspective than that of an individual airline company. The airline company perspective necessarily is oriented towards a much shorter range viewpoint. It must be much more specific and detailed because company objectives are directed to the decision process of buying a particular aircraft type today.

In keeping with the overall industry view and the aspiration-scenario concept, a model was designed for predicting air transportation. The essence of the model and its relation with the environment is shown in Fig.4. . . However, it is detailed for computerized application in Fig. 5. . .

The complete model includes submodels or input models which for the present are incomplete. Those shown in rectangular boxes in Fig. 5, are:

I. U.S. ENERGY MODEL to project supply, demand and price of the major energy types. A large energy model originally developed at Dartmouth College and known as Coal 2 was investigated and has promise for a direct coupling (6).

II. AVIATION FUEL MODEL to project aviation fuel specification, availability, andprice of future aviation fuel. A representative refinery model, developed by Gordian Associates, was originally thought might be used. However, it requires some modification to be utilized.

II TECHNOLOGICAL ADVANCEMENT IN NEW AIRCRAFT to project changes in engine and air frame developments. This is being investigated but probably will not be computerized. Direct assessments of technological changes may best be left as exogenous imputs.

IV. LOAD FACTOR AND UTILIZATION to provide an integral component of the air transportation model. Work is presently proceeding on this and should provide refinements for the operation of the model. Presently the load factor and utilization variables remain exogenous inputs specified in the scenarios.

The Model Core (7) what remains - depicted by the bubbles in Fig. 5,...-- constitutes the computerized model core. A basic premise was profit maximization--i.e. the differences between revenue and cost. Revenues depend on the variables of fare and demand. Costs are categorized as direct cost, indirect cost, and investment.

The air transport industry represented by the mutual interaction of the operators and the public response to the inputs from socio-economic environment. The major difference between this model and others used widely by the industry is its macro nature. Other models generally represent only segments of the industry for example, cargo, passengers, trunk lines, or local service lines. In such models demand for the particular sector is the only endogenous variable. Such variables as fare and investment are treated exogenously. Finally, the air transport system is treated dynamically with feedbacks within itself, as well as with the socio-economic environment.

The Digraph Approach a projective model is essentially an explicit expression of 'cause' and 'effect' relationship among a set

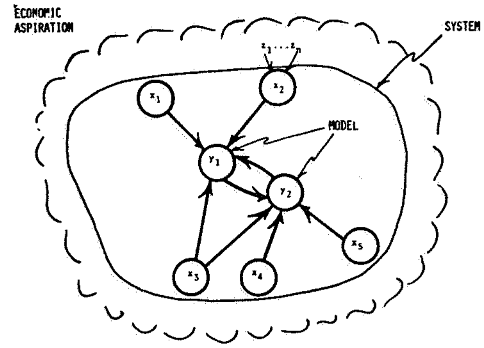

Fig. 4 System in Its Dynamic Environment

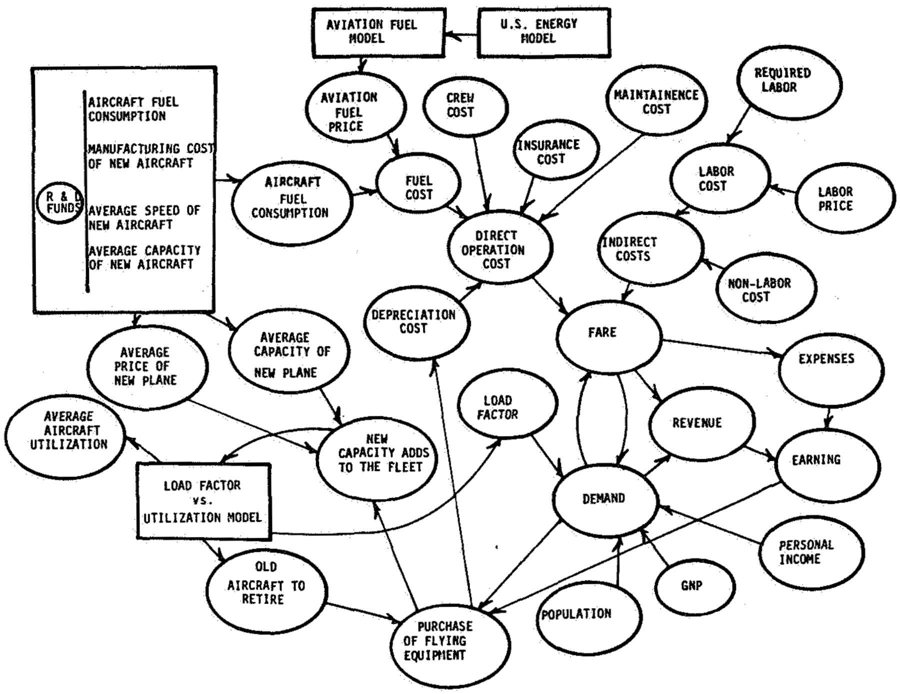

Fig. 5 A Conceptual Model of Aviation Industry

of variables. By knowing these cause/effect relationship and by assuming the future course in the change of causes, one can make projections of the system response. In constructing such a model, graph theory and in particular, digraph theory--the theory of directed graphs--have a natural appeal.

A digraph is a collection of nodes and arrows symbolize the relationship between variables. Construction of digraph models require identification of variables and determination of relationships among variables. The established relationships, then are represented by a cross-impact matrix. This is the essential element of a pulse process by which future values for endogenous variables of the system are projected (7,8). The choice of major variables of the air transportation system is based primarily on judgement aided by statistical analysis.

As an illustration and with reference to Figure 6,...each variable, may be a constant, a time variable, or a linear or non-linear function of one or more variables of the system. If it can be demonstrated that certain w's are constants then they may be determined from reliable historical data. The structure of the model and the relationships between variables was found by examining a large number of hypotheses. These included appropriate time lag nodes.

Figures 7 and 8 show the results of the simulation. The values of endogenous variables of the system, demand, fare and investment are predicted. Each predicted point utilized the predicted value of that variable one period ago and not the historical data.

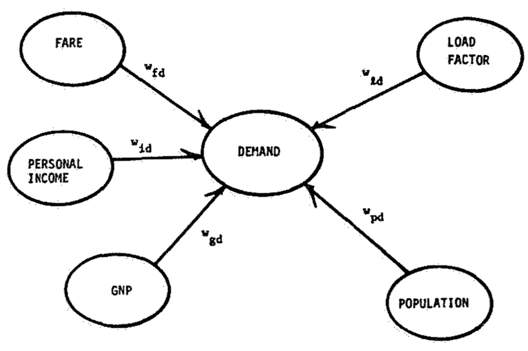

Fig. 6 Demand and Its Determinants

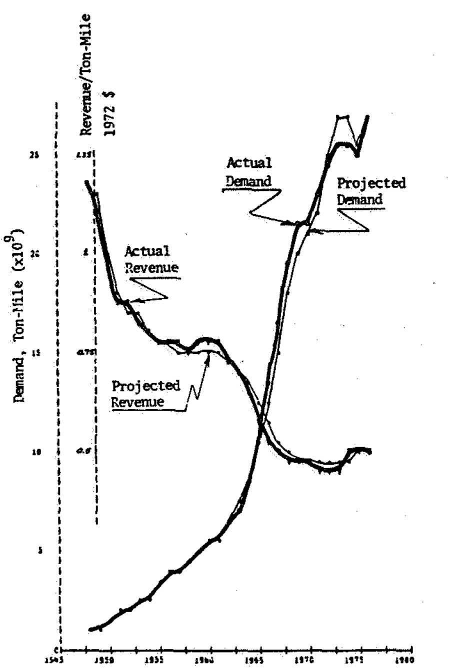

Fig. 7 Validation Test: Fare and Demand for Air Transportation

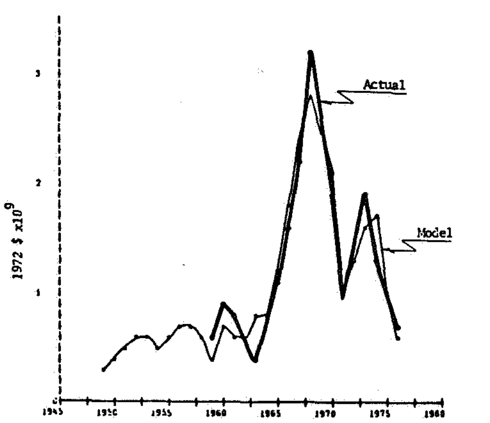

Fig. 8 Validation Test: Annual Purchase of Flying Equipment

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