# Secondary Users of Aerospace Biomedical Technology

T. D. Browne
*Denver Research Center*

# AN OPTIMAL CONTROL ALGORITHM FOR RAMP METERING OF URBAN FREEWAYS

Li Shin Yuan and John B. Kreer
Michigan State University
East Lansing, Michigan

## Abstract

An urban freeway is treated as a dynamic process. A state model for the freeway is obtained with sectional traffic densities as states and entrance flow rates as controls. A linear programming problem is solved to obtain the optimal freeway densities and entrance flow rates under steady-state conditions, and a state regulator is used to minimize the deviations in traffic densities from these optimal steady-state values.

## Introduction

It is well established by theoretical and experimental work that a plot of the steady-state flow rate, y, (in vehicles per hour) as a function of the traffic density, x, (in vehicles per mile) for a long uniform section of freeway or street with no exit or input points is of the general form shown in Figure 1.[1] It follows that the density on any freeway will eventually exceed the point of maximum flow rate if access is uncontrolled under heavy demand. Consequently, maximum effective use of any freeway facility, or surface street network, whether of good or bad design and construction, can be realized only by controlling its loading. With the high cost of construction of urban freeways, even a modest increase in the efficiency of their operation will result in a considerable economic gain.

A method called ramp metering[2,3] is being used in some cities to keep the freeway density below the critical value by controlling entrance ramp flow rates. However, existing ramp metering systems base their control action only on conditions in the immediate vicinity of the individual entrance ramps. For an alternative this paper describes a freeway control algorithm which coordinates the entrance ramp flow rates used by the individual controllers to:

(1) maximize the number of vehicles served under conditions of over-demand.
(2) balance the lengths of the ramp queues created by access control of the freeway.
(3) suppress the effects of random disturbances in the traffic flow.

Such a system would be implemented by placing vehicle presence detectors at appropriately selected locations along the freeway to sense vehicle density. This information would be transmitted to a digital processor which would set the ramp metering rates according to the algorithm to be described.

## Development of a State Model of a Freeway

The dynamic behavior of a freeway as required for on-line control is dominated by two mechanisms: (i) conservation of vehicles, and (ii) drivers in the traffic stream reacting to increasing density by reducing their speed. Mechanism (i) can be expressed mathematically by

$$\frac{\partial x}{\partial t} + \frac{\partial y}{\partial z} = 0 \qquad (1)$$

where z is the position coordinate along the freeway. Equation (1) can be interpreted as saying that for a short section of freeway the rate of change of flow with respect to position along the freeway, $\partial y/\partial z$, is proportional to the difference between the flows into and out of the section. If this difference is nonzero, a change in density in the section as a function of time will be observed.

At any given point the flow and density are related by

$$y = vx \qquad (2)$$

where v is the speed of the vehicles. A number of relationships have been proposed for quantitatively describing (ii). Based on the data taken from the Lodge Freeway[1] the linear model of Greenshields appears to be the most realistic for these purposes. Thus the speed will be given by

$$v = v_f\left(1 - \frac{x}{x_j}\right) \qquad (3)$$

where $v_f$ is the free speed, the limiting value of speed as density approaches zero. The jam density, at which all vehicles will come to a halt, is denoted by $x_j$. Typically $x_j$ is approximately 40% of the bumper to bumper density.

Equation (2) is a per lane relationship. If at same z the lane densities are assumed to be uniform, (2) combined with (3) can be modified so that

$$y = \ell(z)\, v_f\left(1 - \frac{x}{x_j}\right)x, \text{ for } x \leq x_j \qquad (4)$$

where y and $\ell(z)$ are the total flow rate and the number of lanes in each direction at z.

Entrance and exit ramps are assumed to cause a discontinuity in the freeway stream flow by the amount of the ramp flow. The effects of the ramps will enter the model by the presence in $\partial y/\partial z$ of terms of the form

$$-\sum_j y_i^j \delta(z^j) + \sum_k y_o^k \delta(z^k)$$

where $\delta(z^j)$ is the Dirac impulse function, $z^j$ is the location of the jth entrance ramp, and $y_i^j$ and $y_o^k$ are the flows of input ramp j and output ramp k respectively.

## Discretization of the Freeway Model

As indicated by (1) and (4) a freeway is a nonlinear, distributed parameter system. The analysis which follows will employ spatial discretization of (1). Instead of discretizing into sections of uniform length, the boundaries between sections of the freeway are assumed to be chosen so that all exit ramps, entrance ramps, and changes in number of lanes occur at the boundaries of sections. Additional section boundaries may be added at points of pronounced change in geometric features of the freeway which could be expected to affect the flow of traffic. With these assumptions as to the location of the section boundaries, for each section (1) can be approximated by

$$\frac{dx^k}{dt} = \frac{1}{d^k}[y^{k-1} - \delta_o^{k-1} y_o^{k-1} - y^k + \delta_i^k y_i^k \quad (5)$$

where

$y^k$ = the flow rate at the downstream boundary of section k

$x^k$ = the density in section k corresponding to $y^k$

$y_i^k$ = the input rate of the entrance ramp of section k

$y_o^k$ = the flow rate of the output ramp of section k

$\delta_i^k$ = 1 if an entrance ramp is located in section k, 0 if no entrance ramp is located in section k

$\delta_o^k$ = 1 if an exit ramp is located in section k, 0 if no exit ramp is located in section k

$d^k$ = the physical length of section k

$y^o$ = flow rate from uncontrolled section of the freeway into section 1

k = 1, 2, ... n

Since the entrance and exit ramps always occur at a section boundary, the convention has been adopted to assign them to sections such that an entrance (exit) ramp always is at the upstream (downstream) end of the section. $y^n$ is the outflow at the end of the freeway onto the city street system or outbound into the intercity portion of the freeway network. Assuming that, at any exit ramp, a known fraction $f^k(t)$, of the total flow will leave the freeway, the exit flow at ramp k is

$$y_o^k = f^k y^k \quad (6)$$

Using (4) and (6) in (5), it becomes

$$\frac{dx^1}{dt} = \frac{1}{d^1}[y^o - \ell^1 v_f^1 (x^1 - \frac{[x^1]^2}{x_j^1}) + \delta_i^1 y_i^1] \quad (7a)$$

$$\frac{dx^k}{dt} = \frac{1}{d^k}[\ell^{k-1} v_f^{k-1} (x^{k-1} - \frac{[x^{k-1}]^2}{x_j^{k-1}})$$

$$(1 - \delta_o^{k-1} f^{k-1}) - \ell^k v_f^k (x^k - \frac{[x^k]^2}{x_j^k}) +$$

$$\delta_i^k y_i^k] \quad (7b)$$

k = 2, 3, ... n

where $y^o$ is the inflow from the uncontrolled portion of the freeway at the upstream end. In compact form:

$$\frac{dx}{dt} = F(x) + B y_i \quad (8)$$

where

F(x) is a vector whose components are the terms on the right hand side of (7) involving $x^k$

$$B = \text{diag}\,[\frac{\delta_i^1}{d^1}, \frac{\delta_i^2}{d^2}, \ldots \frac{\delta_i^n}{d^n}].$$

In (8) the symbol $\delta_i^1 y_i^1$ is understood to include the contribution of both $y^o$ and $\delta_i^1 y_i^1$ in (7a).

Optimal Control of the Freeway

It is reasonable to assume that after the freeway is under control, the entrance flow rates as well as the traffic densities along the freeway will finally approach some steady state values. Therefore, the control vector $y_i(t)$ is divided into a steady state component, called a reference component, which is constant during each control interval and a time varying component. The reference component is selected on the basis of maximizing the total number of vehicles served and also balancing the entrance queues using a steady state model of the system which considers the nonlinearities.

For this reference value of control vector there will be a corresponding steady state density in each section of the freeway. A local linearization of the freeway model is performed about this reference value of density. The varying component of the control vector is determined using standard linear regulator techniques based on the linearized model and a quadratic performance functional of deviations from reference density and reference ramp flow rates.

The philosophy used here is first to find an optimal steady state density vector and then regulate the entrance ramp rates to keep the state of the system near this vector.

The steady state model can be derived by setting $dx^k/dt$ to zero in (5), eliminating $\delta_o^k y_o^k$ using (6), and setting $y_i^k = y_{ir}^k$. The result is

$$y_r^1 = \delta_i^1 y_{ir}^1 \quad (9a)$$

$$y_r^k = (1 - \delta_o^{k-1} f^{k-1}) y_r^{k-1} + \delta_i^k y_{ir}^k \quad (9b)$$

The dependent variables which are subject to control are $y_r^k$ for k = 1, 2, ... n. By recursive substitution, explicit expressions for $y_r^k$ are obtained as:

$$y_r^k = (1 - \delta_o^{k-1} f^{k-1})(1 - \delta_o^{k-2} f^{k-2})$$

$$\ldots (1 - \delta_o^1 f^1)\, \delta_i^1 y_{ir}^1 + (1 - \delta_o^{k-1} f^{k-1})$$

$$(1 - \delta_o^{k-2} f^{k-2}) \ldots (1 - \delta_o^2 f^2)\, \delta_i^2 y_{ir}^2$$

$$+ \ldots + \delta_i^k y_{ir}^k, \quad (10)$$

k = 2, 3, ..., n

The optimal values for $y_{ir}$ are obtained by solving the following linear programming problem:

Maximize $\sum_{k=1}^{n} (c_q^k q_i^k + c_d^k d_i^k) y_{ir}^k$ subject

to the constraints

$$y_r^k \le y_m^k, \; k = 1, 2, \ldots n. \quad (11)$$

$0 \le y_{ir}^k \le y_{im}^k$, for all k such that

$$q_i^k > 0. \quad (12)$$

$$0 \le y_{ir}^k \le \min (y_{im}^k, d_i^k) \text{ for all k such}$$

$$\text{that } q_i^k = 0. \qquad (13)$$

where $q_i^k$ and $d_i^k$ are the queue length and demand rate respectively at entrance ramp k, $c_q$ and $c_d$ are two constant weighting vectors, $y_m$ and $y_{im}$ are the maximum allowable flow rate and entrance flow rate respectively and $y_r^k$ are expressed in terms of $y_{ir}$ by (9a) and (10).

Note that the object function of the linear programming problem always gives higher priorities to entrance ramps with longer queues and higher demands, so it is designed to balance the queues at the entrance ramps while maximizing the freeway service.

Once $y_{ir}$ has been determined by linear programming, the corresponding value for $x_r$ can be found by using (9a) and (10) to find $y_r$. The reference density for each section can be calculated from the flow-density characteristic, using the lower of the two densities which is possible for the $y_r^k$, i. e.

$$x_r^k = \frac{1}{2} [ x_j^k - \sqrt{(x_j^k)^2 - \frac{4x_j^k y_r^k}{\ell^k v_f^k}} ] \qquad (14)$$

In the absence of any random disturbances in the traffic flow on the freeway maintaining the ramp metering rates at $y_{ir}$ should keep the density at $x_r$. Since random accelerations and decelerations of vehicles in the traffic stream are certain to occur, it is necessary to superimpose a variable component on the ramp metering rates to regulate the densities to $x_r$. For this purpose let

$$x(t) = x_r + e(t) \qquad (15)$$

and

$$y_i(t) = y_{ir} + w(t) \qquad (16)$$

where e(t) and w(t) are perturbation vectors. Substituting (15) and (16) into (8), expanding $F(x_r + e)$ around $x_r$ by Taylor series expansion, and neglecting the second order terms in e (F is quadratic in x so that the partial derivatives of F with respect to x of order higher than two are zero), one has:

$$\begin{aligned} \dot{e}(t) &= A\, e(t) + B\, w(t) \\ e(0) &= x(0) - x_r \end{aligned} \qquad (17)$$

where

$$A = \begin{bmatrix} \frac{\partial F^1}{\partial x^1} & \frac{\partial F^1}{\partial x^2} & \frac{\partial F^1}{\partial x^n} \\ \frac{\partial F^n}{\partial x^1} & \frac{\partial F^n}{\partial x^2} & \frac{\partial F^n}{\partial x^n} \end{bmatrix}_{x=x_r} = [a^{ij}] \qquad (18)$$

with

$$a^{kk} = \frac{-\ell^k v_f^k}{d^k} [ 1 - \frac{2x_r^k}{x_j^k} ] \qquad (19a)$$

$$a^{k,k-1} = \frac{\ell^{k-1} v_f^k}{d^k} [ 1 - \delta_o^{k-1} f^{k-1} ] [ 1 - \frac{2x_r^{k-1}}{x_j^{k-1}} ] \qquad (19b)$$

$$a^{k\ell} = 0, \text{ for } \ell \ne k, k-1 \qquad (19c)$$

Fortunately, system (17) is completely controllable.[4] Due to this complete controllability it is well known that an optimal control which minimizes the performance functional

$$J(w) = \frac{1}{2} \int_0^\infty [< e(t), Qe(t)> + <w(t), Rw(t)> ] \, dt \qquad (20)$$

(Q is a positive semidefinite and R is a positive definite matrix) exists, is unique, and is given by the equation:

$$w^*(t) = - R^{-1} B^T \hat{K} e^*(t) \qquad (21)$$

where $\hat{K}$ is the constant n x n positive definite matrix which is the solution of the algebraic Riccati equation:

$$-\hat{K}A - A^T \hat{K} + \hat{K} BR^{-1} B^T \hat{K} - Q = 0 \qquad (22)$$

the * denotes the optimality and T means transpose. The optimal entrance flow rate $y_i^*$ is obtained by:

$$y_i^*(t) = y_{ir} + w^*(t) = y_{ir} - R^{-1} B^T \hat{K} e^*(t) \qquad (23)$$

The vector $e^*(t)$ is obtained by:

$$e^*(t) = x(t) - x_r \qquad (24)$$

where the vector x(t) is measured by the density detectors along the freeway.

## Implementation of the Control Algorithm

The data which the central controller must have in order to compute the optimal entrance ramp rates determined by this algorithm are x, $d_i$, $q_i$, $x_j$, $v_f$ and f. These quantities can all be measured using suitably placed vehicle presence detectors. Densities are determined by accumulating the fraction of time a vehicle is indicated as present by the detector and multiplying this by the density of average length vehicles which would exist at bumper to bumper density. Demand is measured by counting vehicles passing a detector at a point far enough upstream on the entrance ramp that the queue will not reach it. The queues are measured from the difference between the counts of the demand measuring detectors and the counts of detectors placed at the downstream ends of the ramps. The fraction of the traffic stream leaving at each exit ramp $f^k$ is measured by suitably placed detectors. Speeds are measured by dividing the time a vehicle presence is detected by average vehicle length. By curve fitting to a number of pairs of density and average vehicle speed measurements it is possible to determine values of $x_j$ and $v_f$. These latter quantities change slowly so that the fact that it takes longer to arrive at an individual measurement of them is not serious.

The flow chart for the computer program which would implement the control algorithm is shown in Figure 2. The vectors x, $x_j$, $v_f$, $d_i$, f and $q_i$ are monitored continuously. Whenever a density above a level judged to be critical is detected in any section of the freeway, the optimal ramp rates are computed and ramp metering is activated. New values of x, $d_i$, and $q_i$ can be obtained approximately once per minute from the vehicle detectors. The ramp metering is continued until all queues are reduced to zero. New values of $x_r$ and $\hat{K}$ are computed and used by the controller any time the measurements indicate a significant change in $x_j$ or $v_f$ and when a significant change in the relative demands or queue lengths occurs. The latter is considered to have occurred whenever the inequality

$$\left| \frac{c_q^k q_i^k(m+1) + c_d^k d_i^k(m+1)}{\sum_k [c_q^k q_i^k(m+1) + c_d^k d_i^k(m+1)]} - \frac{c_q^k(m) \; q_i^k(m) + c_d^k d_i^k(m)}{\sum_k [c_q^k q_i^k(m) + c_d^k d_i^k(m)]} \right| > \epsilon_3$$

m = index of the $q_i$ and $d_i$ measurements

$\epsilon_3$ = suitably chosen threshold value

is satisfied for some value of k.

## Conclusion

It has been demonstrated that well established techniques of optimal control can be applied to the optimization of ramp metering of urban freeways.

## Acknowledgment

The research described in this paper was partially supported by the Crouse-Hinds Company under contract with Michigan State University.

## References

1. Kreer, J. B. and Goodnuff, J. L., "On the Automatic Control of Freeway Density," IEEE Automotive Conference, Detroit, Michigan, September 1967.

2. May, A. D., "Improving Network Operations with Freeway Ramp Control," 43rd Annual Meeting of the Highway Research Board, Washington, D.C., January 13-17, 1964.

3. McCasland, W. R., Drew, D. R., and Wattleworth, J. A., "Houston Freeway Surveillance and Control Project: 1966 Progress Report." Program Review Meeting, Research and Development of Traffic Systems, Gaithersburg, Md., December 6-8, 1966.

4. Kalman, R. E., "Contributions to the Theory of Optimal Control," Bol. Soc. Mat. Mex., vol. 5, pp. 102-199, 1960.

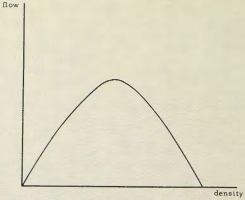


Figure 1. Steady State Flow Density Plot.

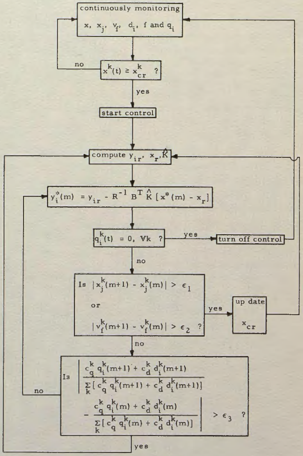


Figure 2. Flow Chart of Optimal Control Algorithm.

# SURVEY DATA COLLECTION FOR URBAN SYSTEMS ANALYSIS

Alex N. Sommers
Vitro Laboratories, Silver Spring, Maryland

## Summary

A major obstacle faced by an aerospace organization attempting to analyze a specific urban problem is the scarcity of reliable, valid data on the urban environment. While comprehensive demographic data can be obtained from censuses and origin-destination studies, little data is available on the needs and attitudes of commuters, minority groups, handicapped workers, intercity travelers, and other urban residents. The analyst must generally collect his own data for incorporation into simulation models and optimization processes. The results of such models and processes are only as good as the data fed into them.

A questionnaire survey is described which generates reliable and valid data on the determinants of intercity traveler mode choice. Using seven-point semantic differential questions, rank ordering scales, and open-ended discussion questions, the survey quantifies the roles of such factors as convenience, comfort, time, and safety in the transportation decisions of short haul business travelers. Survey data indicates that citizen needs and attitudes can be quantified through the use of a voluntary questionnaire, with return rates of around 90 percent. This data is readily incorporated into impact, transportation, or other urban models. Survey results are given for a sample of businessmen in a short haul market composed of three major midwestern cities. Respondent attitudes and need fulfillments with respect to safety, time, and cost are discussed in detail as three of the major determinants of short haul mode choice. Mode choice hypotheses are presented and supported. The survey method appears applicable to many other urban data collection problems including intracity transit, urban renewal, and airport location.

## Introduction

For a number of years citizens throughout the United States and in many other countries have become increasingly aware of problems peculiar to the modern industrial state and its urban society. It is perhaps monotonous to list them all, but serious problems do exist in housing, transportation, pollution, and public services; problems exacerbated rather than alleviated by rising levels of affluence and sophistication. Efforts are being made to solve these problems, often through the use of novel, subtile techniques created for other applications but judged valid for use in the urban environment. Great expectations are held for the use of systems engineering, a technique developed by aerospace companies. Operations research methods emerging from universities and consulting firms are viewed as panaceas by city managers beset by crippling transportation bottlenecks and pungent garbage strikes. Yet many system studies have been made, mathematical models built, simulations performed, and reports published without any great impact on the problems they were supposed to help solve.[1] Paper analyses and solutions abound, but the problems remain. A gap appears between systems analysis and harsh reality. What are the reasons for this gap, and what bridges are available?

An obvious reason why so many urban problems remain unalleviated is that funds cannot be found to implement suggested solutions. This implies, of course, that the problems are not sufficiently severe to result in the all-out mobilization of resources and increases in taxes necessary to affect solutions. Traffic congestion may be bad, and a constant topic of conversation, but yet drivers may still be reluctant to switch to mass transit or pay the bills for new, advanced transit facilities. Consequently any practical analysis of such a congestion problem must consider these driver attitudes when formulating final proposals. The analysis should present the problem in its true perspective and make recommendations which will be acceptable to the populace, and hence implemented. Radical redesigns, while beautiful from a theoretical viewpoint, will most likely never be implemented in the designer's lifetime. One can therefore argue that, if sponsored by tax dollars, such designs are a waste of public funds. The challenge to modern systems analysis and operations research in the public domain is therefore to fully understand the social environments in which urban problems exist before creating and evaluating solutions. Since this is an extremely difficult task it is not hard to understand why it is done so seldom. A procedure for accomplishing it is the topic of this paper.

## Citizen Input to Systems Analysis

Consider an organization faced with the task of applying systems analysis to an urban problem such as mass transit or urban renewal. The organization must first collect data and facts relevant to the problem. What physical facts exist to define the problem and its environment? What are the size of the resident population, the traversing traffic volumes, the birth and accident rates? This information is not difficult to find. Countless censuses, origin-destination studies, and inventory counts are readily available.[2,3] Economic data is also not difficult to obtain.

What is difficult to obtain, however, is data on the needs, preferences, and attitudes of citizens connected to the problem. Any urban system is a man-machine system. The machine segment is quantitative, and amenable to mathematical analysis. The other section, the most important, is not definable in purely mathematical terms. What is the behavior of commuters, minority groups, intercity travelers, and housewives? What behavioral changes do they desire, and what would they tolerate? This information the systems analyst must generally procure himself, and he must do so if he is to meet the true needs of the affected society and produce solutions both "optimal" and acceptable to that society.

It is necessary for the systems analyst to communicate with those citizens involved in the urban problem he is trying to solve. A tested technique is the questionnaire survey administered by mail or interview. Mail surveys are inexpensive, and response rates of 80 percent are common.[4] Interview surveys can be more intensive and comprehensive, but are quite costly. A mailed questionnaire survey, therefore, offers a quick and effective means of communicating with a large number of citizens whose attitudes, preferences, and behavior are crucial elements of any urban system and problems thereof.[5]

## An Example: Intercity Business Travel

Increasingly severe congestion above and in urban airports has stimulated efforts to procure aircraft capable of vertical and short field takeoff and landing. Such V/STOL aircraft have yet to leave their drawing boards, but feasibility studies and demonstrations are being performed as initial steps toward eventual implementation.[6,7] If V/STOL aircraft are developed, will they be successful in short haul markets? Will they attract passengers away from competing modes in sufficient volumes to be economically feasible? These questions must be answered now. If answers are negative, then capital investment will not be forthcoming, and V/STOL's will never leave the ground in commercial service. If highly affirmative, then V/STOL's will probably emerge as an effective, new mode of short haul travel.

To determine civil V/STOL feasibility it is necessary to understand contemporary short haul (under 400 miles) intercity mode choice. What determines such mode choice today, and how will V/STOL's, or any other innovation, fit into future mode choice behavior? Why does a traveler choose one mode over another? These are not easy questions to answer. No data bank exists. It is therefore necessary to go to individual travelers to determine their actual short haul mode choice behavior and the determinants thereof.

To create initial data on short haul mode choice behavior, a questionnaire survey of 373 businessmen was performed in 1967-68 to study business travel mode choice between three major midwestern manufacturing cities. The hub city in which the businessmen have their homes, City A, is about 274 miles from City B and 112 miles from City C, thereby constituting a typical short haul market. Businessmen were analyzed because they are expected to be the major customers of V/STOL systems offering reduced travel times at cost premiums: time is money in the business community. The questionnaires were distributed by interoffice mail, not by the post office; and 327 were returned, giving a return rate of 87.6 percent with but one follow-up letter. Of those returned, 27 were part of a pilot study, leaving 300 as a final sample size for mode choice analysis. The questionnaire investigated the roles of comfort, convenience, time, cost, weather reliability, noise, and safety in mode choice for the three-city market, but also sought to obtain any other factors or determinants relevant to a respondent. Multiple-choice, semantic differential, and open-ended questions were employed.[8] Most respondents answered all questions, but seemed disinclined to verbalize their thoughts on open-ended or essay questions, a common finding.[9] Sample questions and results will be discussed below as components of a technique used successfully to obtain attitudinal and behavioral data. Discussion of applications to V/STOL is better left to other references.[10,11]

## Safety, Time, and Cost

On an average basis the mode choice survey indicates that total door-to-door travel time is most important when selecting a mode of travel for a business trip to either City B or City C, followed by convenience, safety, weather reliability, comfort, cost, and noise, in that order. This ranking is logical. Nonproductive travel time is costly to a company, more costly than the price of a ticket. The purpose of a business trip is usually of such importance that speed is of the essence, coupled, of course, to convenience, which tends to expedite a trip and minimize delay. Comfort, cost, and noise trail the list; accomplishing the mission overcomes discomfort, the minor cost of fares, and disadvantages such as cabin noise and vibration. Relative rankings of these factors appear in Table 1. The values attached to each factor may be interpreted as utilities,[12] and represent the relative importance of that factor in a mode choice decision for a business trip to either City B or City C. While the rankings are perhaps intuitive, the utilities are quantities which could not be estimated with accuracy. The survey therefore generated actual numerical data immediately useful in quantitative analysis; data unobtainable from other sources.[2,3]

Considering the survey as a technique for gathering attitudinal and behavioral data, it is interesting to look at businessmen responses to

Table 1. RELATIVE FACTOR RANKINGS

| Destination: City B | | Destination: City C | |
|---|---|---|---|
| Factors | Relative Rank | Factors | Relative Rank |
| 1. Time | 2.1162 | 1. Time | 2.2926 |
| 2. Convenience | 2.9461 | 2. Convenience | 2.8465 |
| 3. Safety | 3.5228 | 3. Safety | 3.5560 |
| 4. Weather Reliability | 4.1286 | 4. Weather Reliability | 4.1079 |
| 5. Comfort | 4.7137 | 5. Comfort | 4.7199 |
| 6. Cost | 4.9336 | 6. Cost | 4.8796 |
| 7. Noise | 6.6390 | 7. Noise | 6.6390 |

Note: These values were generated by questions of the following form. "Imagine that you must travel to City B on a company business trip. You will travel alone, and can choose your form of transportation. Rank the following factors in order of their importance to you when selecting your form of travel. Place a (1) next to the most important factor, a (2) next to the second most important, etc. Place any other factors you consider important on the bottom of the list, and include them in the ranking."

questions on safety, time, and cost in more detail. These three factors span the range of factor importance for the City A study. The factor of safety is the most qualitative of the three. Attitudes toward safety are the result of psychological factors unique to each individual, unlike the definable although stochastic factors of time and cost. Travel times and costs are usually available to a traveler before he makes a trip. The likelihood of an accident is not available, however; and must remain a subjective variable that the traveler must analyze himself.

Semantic differential questions were presented to each respondent in the context of hypothetical business trips from City A to Cities B and C. These questions covered only the two modes feasible for contemporary business travel: namely, automobile and airline. A sample question follows below.

"Suppose you must make a business trip from City A to City B. There is good weather, and you will travel alone. How would you rate airline travel for this trip on the basis of overall safety, and safety alone? Check one box below."

Very unsafe, unacceptable (_) (_) (_) (_) (_) (_) (_) Very safe, acceptable

Similar questions covered all factors of interest, and were scored or coded by assigning seven points to the right-most box, one point to the left-most box, and so forth in between. Responses are thereby quantified, and mean responses and deviations from the mean can be computed for each mode on the basis of each factor. Respondent attitudes are measured in terms of seven-point scales. Mean responses can therefore be considered "acceptance indices" or acceptability ratings for a particular destination-mode-factor combination.

Table 2 gives the responses for the preceding semantic differential question classified with respect to respondent age and standardized to obtain equivalent sample sizes (N = 300) in each age group. While some distortion inevitably results from such standardization, the classification does show some interesting relationships. First, all age groups rated airline travel to City B as predominantly safe, i.e., on the right-hand portion of the differential scale. Ignoring the few respondents in the extreme age categories it is also evident that the safety ratings appear to be independent of age. The percentages in each right-hand column are quite similar, suggesting that a much larger sample size would result in the same column percentage for each age group with only small random sampling variations.

Compare Table 2 with Table 3, an equivalent safety versus age listing for airline/automobile business travel to City B. It is immediately obvious that car travel is viewed as more hazardous than airline travel for this trip. Many respondents, from nearly half the age categories, rated car travel as very unsafe. None gave airlines this rating. The largest percentages in Table 3 appear in the column right of center, indicating an opinion of "slightly" or "somewhat" safe travel by automobile. Nevertheless, about 10 percent rate car travel as very safe. This suggests that even for an automobile business trip of around 274 miles, requiring a travel time of roughly 5 hours on a busy intercity route, safety is not of concern to about 10 percent of the businessman population, regardless of age.

Table 2. AIRLINE CITY A TO CITY B SAFETY RATINGS VS. RESPONDENT AGE

| Respondent Age | Standardized Percent of Samples Choosing Differential Scale | | | | | | |
|---|---|---|---|---|---|---|---|
| | Very Unsafe 1 | 2 | 3 | 4 | 5 | 6 | 7 Very Safe |
| 21-25 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 50.00 | 50.00 |
| 26-30 | 0 | 0.00 | 0.00 | 0.00 | 2.94 | 52.96 | 44.10 |
| 31-35 | 0 | 0.00 | 0.00 | 4.78 | 16.66 | 35.70 | 42.86 |
| 36-40 | 0 | 0.00 | 0.00 | 3.72 | 9.25 | 42.59 | 44.44 |
| 41-45 | 0 | 0.00 | 0.00 | 0.00 | 4.11 | 36.99 | 58.90 |
| 46-50 | 0 | 1.89 | 1.89 | 1.89 | 13.21 | 47.16 | 33.96 |
| 51-55 | 0 | 0.00 | 0.00 | 0.00 | 9.52 | 42.86 | 47.62 |
| 56-60 | 0 | 0.00 | 0.00 | 0.00 | 10.00 | 60.00 | 30.00 |
| 61-65 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0.00 |

Table 3. AUTOMOBILE CITY A TO CITY B SAFETY RATINGS VS. RESPONDENT AGE

| Respondent Age | Standardized Percent of Samples Choosing Differential Scale | | | | | | |
|---|---|---|---|---|---|---|---|
| | Very Unsafe 1 | 2 | 3 | 4 | 5 | 6 | 7 Very Safe |
| 21-25 | 0.00 | 0.00 | 20.00 | 10.00 | 40.00 | 20.00 | 10.00 |
| 26-30 | 2.94 | 5.88 | 8.82 | 26.47 | 20.59 | 26.47 | 8.83 |
| 31-35 | 0.00 | 2.38 | 11.90 | 11.90 | 42.86 | 21.43 | 9.53 |
| 36-40 | 1.85 | 5.56 | 9.26 | 22.22 | 33.33 | 18.52 | 9.26 |
| 41-45 | 2.75 | 6.85 | 17.81 | 20.55 | 32.88 | 12.32 | 6.85 |
| 46-50 | 0.00 | 7.55 | 9.43 | 15.09 | 37.74 | 18.87 | 11.32 |
| 51-55 | 0.00 | 19.05 | 9.52 | 23.81 | 23.81 | 23.81 | 0.00 |
| 56-60 | 10.00 | 10.00 | 30.00 | 30.00 | 10.00 | 0.00 | 10.00 |
| 61-65 | 0.00 | 0.00 | 33.33 | 0.00 | 33.33 | 33.34 | 0.00 |

It is now interesting to compare safety ratings versus travel experience for a trip to City B. Respondents were asked how many business trips they make in a normal year to all destinations. This was used as a measure of travel experience to test the hypothesis that experienced travelers are less concerned with mode safety than are inexperienced travelers. Tables 4 and 5 give the results for airlines and cars. The hypothesis is not easily supported. With respect to airline travel (Table 4) respondents with over 10 trips per year seem to rate airline safety higher than infrequent travelers. On Table 5 they appear to rate car safety lower than infrequent travelers. This implies that frequent or experienced business travelers prefer airline travel more than infrequent travelers on a safety criterion. If anything these experienced travelers may be more safety conscious than infrequent travelers, and thus are inclined to use air travel, generally considered to be less prone to accident than automobiles.

Some comments on cost and time are now in order for the businessman sample. Generally the respondents indicated that the direct out-of-pocket costs of both car and airline travel are completely acceptable to their companies.[10] Their opinions hold that a company expects to pay fares and mileage when it requires that a business trip be made. Consequently such costs are acceptable as a matter of course. This assumes, naturally, that the traveler uses conventional modes of travel, and does not incur excessive charges. Travel time, however, is very important to the sample, and is viewed as a real although indirect cost to a company. Travel time is minimized in order to accomplish the mission

Table 4. AIRLINE CITY A TO CITY B SAFETY RATINGS VS. TRAVEL EXPERIENCE

| Travel Frequency (Trips/Yr.) | Standardized Percent of Samples Choosing Differential Scale | | | | | | |
|---|---|---|---|---|---|---|---|
| | Very Unsafe 1 | 2 | 3 | 4 | 5 | 6 | 7 Very Safe |
| 0 | 0 | 0.00 | 0.00 | 2.50 | 17.50 | 45.00 | 35.00 |
| 1-5 | 0 | 0.00 | 0.00 | 0.75 | 6.72 | 44.03 | 48.50 |
| 6-10 | 0 | 0.00 | 1.85 | 0.00 | 11.11 | 44.44 | 42.60 |
| 11-15 | 0 | 0.00 | 0.00 | 3.23 | 9.68 | 32.26 | 54.83 |
| >15 | 0 | 2.44 | 0.00 | 4.88 | 2.44 | 48.78 | 41.46 |

Table 5. AUTOMOBILE CITY A TO CITY B SAFETY RATINGS VS. TRAVEL EXPERIENCE

| Travel Frequency (Trips/Yr.) | Standardized Percent of Samples Choosing Differential Scale | | | | | | |
|---|---|---|---|---|---|---|---|
| | Very Unsafe 1 | 2 | 3 | 4 | 5 | 6 | 7 Very Safe |
| 0 | 0.00 | 10.00 | 7.50 | 30.00 | 27.50 | 12.50 | 12.50 |
| 1-5 | 0.75 | 4.48 | 12.68 | 18.66 | 35.82 | 18.66 | 8.95 |
| 6-10 | 3.70 | 3.70 | 12.96 | 20.37 | 29.63 | 20.38 | 9.26 |
| 11-15 | 6.44 | 9.68 | 22.58 | 3.23 | 32.26 | 22.58 | 3.23 |
| >15 | 0.00 | 12.20 | 12.20 | 21.95 | 31.70 | 17.07 | 4.88 |

quickly and minimize the cost of unproductive man-hours. This is implied by Table 6, a listing of semantic differential cost acceptance ratings for an automobile trip to City C classified by time acceptance ratings for the same trip. An automobile is preferred for this trip since travel by airline incurs ground connection delays which often make air travel slower than car travel on a door-to-door basis. The bottom row, right-hand column entry in Table 6 is the largest percentage in the table. This implies that car travel for this trip is completely acceptable to most respondents on both a travel time and a travel cost criterion. Airline travel is also completely acceptable on a cost basis, but less acceptable than a car on a time criterion. For a trip to City B, both modes are acceptable with respect to direct cost, but car travel is unacceptable on a time criterion unless the businessman uses much of his own personal time driving during the trip.[10] Tables showing these differences are not included since Table 6 serves as an example of the cross-classification technique. As a final validating note, the conclusions were supported by a final question in the survey which determined that 96.6 percent of the respondents would fly to City B, and 47.3 percent would fly to City C, for an average business trip in good weather. The rest would drive an automobile.

## Survey Results and Conclusions

The businessman questionnaire survey generated a great quantity of data on mode choice behavior, only a small portion of which is detailed in the preceding section. Conclusions derived from this data are as follows.

1. Short haul intercity business travelers in a Midwestern market segment emphasize total door-to-door travel time as the major criterion in mode choice under normal weather conditions. Consequently, any innovative mode of transportation which offers definite time savings will possess an edge over competitors and capture significant market shares.[6, 7, 11] If V/STOL airline service, for example, can give downtown-to-downtown service with considerable time savings over car and conventional airliner travel, then it is likely that such service would quickly attract the bulk of business travelers in that short haul market.

2. Airline travel is perceived as being safer than automobile travel by experienced or frequent businessman travelers. Infrequent travelers view the automobile more favorably. Both groups, however, consider a long car trip hazardous. They prefer air over auto travel for long trips, but are indifferent for short trips of around 112 miles.

Table 6. AUTOMOBILE CITY A TO CITY C COST RATINGS VS. TIME RATINGS

| Time Differential | Standardized Percent of Samples Choosing Cost Differential Scale | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Completely Unacceptable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Completely Acceptable |
| 1 | | 0.00 | 20.00 | 0.00 | 40.00 | 0.00 | 0.00 | 40.00 | |
| 2 | | 10.00 | 0.00 | 10.00 | 30.00 | 0.00 | 10.00 | 40.00 | |
| 3 | | 0.00 | 2.44 | 12.20 | 17.10 | 9.73 | 17.05 | 41.48 | |
| 4 | | 2.16 | 2.16 | 13.11 | 34.77 | 8.68 | 15.19 | 23.93 | |
| 5 | | 0.00 | 3.39 | 8.49 | 16.93 | 10.85 | 20.34 | 40.00 | |
| 6 | | 0.00 | 3.45 | 1.14 | 8.04 | 5.73 | 19.56 | 62.08 | |
| 7 | | 1.89 | 0.00 | 1.89 | 9.68 | 1.89 | 15.41 | 69.24 | |
| Completely Acceptable | | | | | | | | | |

3. Age has no apparent influence on the safety considerations of businessman travelers. Attitudes and preferences with respect to mode safety appear to be unique to an individual, probably determined by complex personality and experience factors, but they do affect mode choices. Safety is ranked third behind time and convenience as a mode choice determinant. (It is surmized that safety is more dominant in personal and pleasure travel, particularly when a family travels as a unit.)

4. Travel direct cost comprised of fares, rental fees, and mileage is of little importance in making business travel mode choice decisions. Such costs are small when compared to the cost of nonproductive man-hours spent in travel or to the potential profit or business which requires the trip or mission. Cost is rated sixth of the seven factors, followed only by travel noise which appears to be ignored by traveling businessmen. (Again, cost is probably far more important to the family traveling for pleasure or personal reasons, and the noise of transportation systems is a hot political issue among subdivisions bordering airports and freeways.)

It is evident that the survey provides data not to be found in census reports. Measurements of attitude, opinion, and behavior can only be made by communicating directly with citizens through some medium and with an accurate measuring instrument. The described businessman survey employed a printed and pre-tested questionnaire, distributed through various company interoffice mail systems, with a high degree of success. One can speculate that given today's anonymity of the individual, any sophisticated and meaningful campaign to elicit an individual's opinions and evaluations will be about 90 percent effective. This should be most encouraging to the systems analyst faced with the collection of attitudinal-behavioral data for inclusion in man-machine systems design and simulation. Perhaps more importantly, the availability of such data increases the validity of systems evaluation procedures and maximizes the likelihood that selected systems will meet with the citizen acceptance and funding necessary for their implementation. This latter objective remains a vital part of the challenge to a systems analyst dealing with an urban or social problem. It is one thing to design a good systems solution; it is a much better thing to design such a solution and see it put into practice. Whether the solution works, of course, is decided by the technical competence, genius, or luck of the analyst.

## References


1. Hoos, Ida R., "A Critique on the Application of Systems Analysis to Social Problems," Working Paper No. 61, Space Sciences Laboratory, University of California, Berkeley; May, 1967.

2. Bureau of the Census; Publications, Methodological Reports, and Data Files, U.S. Department of Commerce, Washington, D.C.

3. Highway Research Board; Record, Highway Research Abstracts, and Program Reports, National Research Council, Washington, D.C.

4. Bass, F. M., et al, "Market Segmentation: Group versus Individual Behavior," Journal of Marketing Research, Volume 5, No. 3, August, 1968.

5. Scott, Christopher, "Research on Mail Surveys," Journal of the Royal Statistical Society, Series A, 124, Part 2, 1961.

6. Boeing Company, "Study of Aircraft in Short Haul Transportation Systems," Renton, Washington; August, 1967.

7. McDonnell-Douglas, Incorporated, "Technical and Economic Evaluation of Aircraft for Intercity Short Haul Transportation," St. Louis, Missouri; April, 1966.

8. Osgood, C. E., et al, "The Measurement of Meaning," University of Illinois Press, Urbana, Illinois; 1957.

9. Cronbach, Lee J., "Essentials of Psychological Testing," Second Edition, Harper and Row, Incorporated, New York, New York; 1960.

10. Sommers, A.N., "Nondemographic Factors in V/STOL Business Travel Markets," Ph.D. Thesis, Purdue University, Lafayette, Indiana; 1968.

11. Sommers, A.N., and Leimkuhler, F.F., "A Nondemographic Factor V/STOL Prediction Model," paper presented at ORSA National Meeting, Philadelphia, Pennsylvania; 8 November 1968.

12. Fishburn, Peter C., "Utility Theory," Management Science: Theory, Volume 14, No. 5, January, 1968.

SESSION CHAIRMAN

RICHARD L. LESHER

ASSISTANT ADMINISTRATOR

OFFICE OF TECHNOLOGY UTILIZATION

NASA, WASHINGTON, D.C.

# SECONDARY USES OF AEROSPACE BIOMEDICAL TECHNOLOGY

Theodore D. Browne
Denver Research Institute
University of Denver
Denver, Colorado

The purpose of this paper is to present and discuss certain research findings developed by the Denver Research Institute (DRI) in its Project for the Analysis of Technology Transfer (PATT). The project sponsor has been the National Aeronautics and Space Administration (NASA). Although this research has encompassed information usage by businesses, government, and academic institutions, the focus of this presentation is the biomedical field.

The first section will concern what "spin-off" is and why the public expects secondary benefits from aerospace expenditures. Second, a review of why aerospace technology might contribute to the medical field is covered. Third, the manner in which aerospace technology has been transferred from the originator to secondary uses is discussed and resulting applications identified. Barriers to transferring aerospace technology to other uses are briefly discussed. Finally, ways to promote improved transfer in the biomedical area are recommended.

## Background

A large mass of scientific and technological information is being generated in Federal Government-sponsored research and development (R & D) programs. The majority of it comes from mission-oriented R & D in the fields of national defense, space, and atomic energy. It is applicable primarily to these specialized missions.

The public has been encouraged to think of both technology and science as being widely useful. This is particularly true of government-sponsored R & D, and broad usefulness has been a traditional justification for such sponsorship. It is understandable that the public is conditioned to expect visible benefits from the $16 billion spent annually on tax-supported R & D. This expectation has been reinforced by occasional justification of the spending by assurances of "fallout," "spin-off," and other terms indicating secondary application, in addition to those related to the primary missions. This belief is further supported by the evident effects of new technology on American life.

The public interest in R & D has been translated into specialized concerns. Government policy and decisionmakers and scholars show increasing interest in R & D administration in general. A few in each category have become interested in optimizing secondary applications of R & D—in improving technology transfer. As a NASA research project reported:

> The logic behind efforts to accelerate such technological transfer is straightforward: Increased application of technology in the commercial sector of the U. S. economy is generally accepted as a desirable economic objective. Well over half of the nation's research and development resources are being devoted to military and space programs; much new technology is being generated by these efforts. Some should have commercial application and, for the economy to receive optimum benefit of this technology, it should be applied in both the government and commercial sectors.[1]

Several government agencies historically have taken direct action to enhance technology transfer. The Departments of Interior, Agriculture, and Commerce have long histories of making their research results available. The Atomic Energy Commission has developed a progressive program. The major new problems of technology transfer relate to secondary use—the enhancement of non-defense and non-space use of R & D defense, space, and atomic energy programs.

The most comprehensive program for technology transfer is that of the National Aeronautics and Space Administration. According to former NASA Administrator, James E. Webb:

> . . . A clear directive from Congress and the President sets NASA the objective of extracting knowledge from its scientific and technological program and making this knowledge available to the maximum extent for the nation's industrial development.[2]

The Technology Utilization Division (TUD) is the NASA organization responsible for this function. However, technology transfer is also encouraged by NASA activities other than the TUD program. These include a variety of conferences sponsored by NASA field facilities, papers and publications by NASA staff, press releases, and other activities.

As part of its responsibility, TUD has sponsored research on the technology transfer process. The Project for the Analysis of Technology Transfer (PATT) at the University of Denver's Research Institute is one mechanism for the effective and continuing study of this process. It was established in November 1967.

The primary purpose of PATT is to perform research on the technology transfer process in such a manner as to enhance the effectiveness of NASA's technology transfer program. Specifically, the objectives of PATT for the first year were:

1. To document actual and potential cases of information use and transfer of space-related technology and secondary uses that

result from NASA's Tech Brief program and, where possible, to evaluate these cases.

2. To establish and maintain a Transfer Data Bank.

3. To initiate the development of criteria for selecting space-related technology most appropriate for dissemination to selected classes of potential secondary uses.

4. To suggest for NASA's consideration programs on mechanisms to improve the effectiveness and to reduce the cost of NASA's technology transfer program.

5. To maintain awareness of past and on-going research contributions to the understanding of the technology transfer process.

6. To maintain contact with sources of technology, with channels of technological communication, and with users of technology.

The balance of this paper reports on one of several functional areas analyzed in the research project. This is the biomedical field.

## Applicable Technology

In addition to specific Tech Briefs, Contractor Reports, and professional journal articles, two specific NASA publications have catalogued technology which might be applicable to biomedical uses. The first was published in July 1965, titled Medical and Biological Applications of Space Telemetry,[3] and demonstrated that telemetry was one of the areas in which NASA had achieved major technological advances. The report discussed specific areas of space biomedical applications which might have applicability in secondary uses. The second and most recent document, NASA Contributions to Bioinstrumentation Systems,[4] prepared at Spacelabs, Inc., again catalogued the various developments for primary application, although it identified only limited secondary usage. Therefore, a long list of potential technology for secondary application has been identified and documented.

Based upon the above-mentioned documents and other publications, it is apparent that a considerable reservoir of technology with potential application in the biomedical area has been developed. Perhaps, more relevant technology has been developed than can be applied by present non-aerospace medical practitioners and researchers.

In order to have a meaningful use of space-development technology, there should be not only significant technology, but there also must be a technology recipient who has the capacity for understanding and application. In the case of non-aerospace biomedical use of advanced state-of-the-art knowledge in the biomedical area, it appears that aerospace has generated more advances than can be effectively applied in secondary uses. Nevertheless, the applications which have been made, or might be made in the near future, are noteworthy.

## Secondary Applications

Exciting and novel applications of space-related technology have been reported in Congressional hearings, professional papers, press releases, and by other mechanisms. Examples which have been mentioned often include a technique for measuring how to measure the heart beat of a chick embryo,[5] and the use of a wheelless wheelchair for crippled children based upon a lunar gravity simulator.[6] The Food and Drug Administration has applied this device in studies on the effect of drugs on developing avian embryos.

The lunar walker was originally designed by Space General Corporation for an unmanned moon landing. The vehicle was designed to carry instruments across difficult terrain of the lunar surface. It has been adapted as a means for conveying handicapped children over areas inaccessible in an ordinary wheelchair. Nevertheless, there are other less dramatic examples which also illustrate the benefits which have been derived from research in the space program.

Significant examples of secondary usage include the following:

- One area of application to clinical medicine has been the development of biomedical instrumentation capabilities that allow accurate measurement of man in various conditions. These conditions have been related to exercise. This expertise has been applied by Dr. Cooper, School of Aviation Medicine, in the investigation of the effect of exercise on arterial-sclerotic heart disease. Dr. Cooper's work, supported by the School of Aviation Medicine, has yielded one of the major pillars for the advocates of jogging as a preventive measure for heart attacks.[7]

- Conductron Corporation (a subsidiary of McDonnel Douglas), utilizing as a base the devices developed for the Mercury and Gemini programs, is manufacturing a line of physiological monitoring devices. Conductron has developed and made commercially available these devices for use in hospitals in the medical research field.

  In a personal interview with Dr. Herbert Zimmerman, a cardiologist with Jewish Hospital in St. Louis, he illustrated that the units were capable of measuring ECG, respiration rate, temperature, indirect blood pressure, internal blood pressure by means of a catheter strain gage, and many other physiological parameters. The modular units were installed and in operation in the intensive care area of this hospital.

The testing and modification program for these units involved a cooperative effort between Conductron and Jewish Hospital. The initial development period required approximately two years of research and experimentation utilizing the services of two engineers, two technicians, and the part-time services of two physicians.

° The Instrument Systems Division of Whittaker Corporation manufactures and markets several models of implantable and external biomedical transmitters. As a result of breadboarding and packaging of several biomedical circuits under Ames Research Center support, followed by independent work on biomedical circuitry and packaging, the manufacturer produced commercial devices.

Based upon a September 1968 standard price list, implantable pressure transducers range in price from $395 to $600 each in limited quantities. Demodulators for temperature, biopotential, and pressure subcarriers have a price range from $335 to $425. Robert H. Russell, Manager, Biomedical Instrumentation, reported that the principal customers for the Whittaker devices have been NASA research centers, other governmental biomedical research centers, universities, hospitals, and the National Institutes of Health.

° An Ames-developed tiny biomedical amplifier which combines high performance with low power drain is currently being used in the operating room of the Memorial Hospital for Cancer and Allied Diseases in New York City. The use of this device has been restricted to anesthesiologists for operating room use. The amplifier is applied as a new monitoring technique for electrocardiogram and electronyogram readings.

The application costs included $50 for components, three man-hours reviewing the information, and 16 hours in fabrication.

° Dr. L. Sherman Watson, Senior Research Physiologist, Research Laboratories of Merck, Sharp & Dohme, West Point, Pennsylvania, plans to make use of the spray-on electrodes developed at Flight Research Center. These electrodes, reported in Tech Brief 66-10649, are to be used in the cardiovascular testing of unanesthetized animals injected with newly developed drugs.

Medical Electronic News was Dr. Watson's initial source of awareness about this innovation. (This publication has been an effective communication channel in many biomedical situations.)

° An associate in Pharmacology of the College of Physicians and Surgeons, Columbia University, has constructed a prototype miniature electrometer preamplifier. It costs between $50 and $75 in comparison to commercially available units costing $500 to $600. The preamplifier is currently being used in obtaining biomedical micro-electrode readings.

The application was based upon an Ames Research Center Tech Brief titled "Miniature Electrometer Preamplifier Effectively Compensates for Impact Capacitance."

There are other examples which could be cited demonstrating the application of aerospace inventions not only in industry, but by government and academic users. Although these examples might not have the universal appeal of the lunar gravity simulator, they represent "spin-off" from the primary mission of our space program. Knowledge of these inventions has been disseminated not only through aggressive publication of them by NASA, but also through personal contact, professional journal publications, the business press, and other varied communication channels.

## Barriers to Transfer

There are a limited number of professionals who can utilize the biomedical advances made by government-sponsored research. For example, many practicing physicians and medical researchers have been acquainted with traditional devices during their education and practicing experiences. New items incorporating an advanced technology often are difficult for them to understand. Further, physicians require extensive orientation with new techniques and equipment before widespread application might be made. Therefore, a large portion of the market for ideas and advances of a sophisticated and technical nature in the biomedical field do not meet a receptive market.

For many established medical practitioners, it is easier, and far more comfortable, to rely upon a traditional stethoscope for listening to heart sounds rather than reading output on an oscilloscope. It is doubtful if this will change in the near future, although certain newer generation medical school graduates will at least have been acquainted with basic electronics as applied to biomedical situations. Therefore, time and patience are required in order to incorporate the vast amount of technology which has been developed in a relatively brief period of time by aerospace researchers.

While time passes, more and more technology is developed which might have biomedical applications. Therefore, the supply of technology is probably well in excess over the present and future demand in the biomedical field. Of course, not all aerospace technology is applicable or suitable for secondary use.

For many, the cost, in time or dollars, of learning about these new inventions and the seemingly complex technology associated with them does not equate with the potential benefits to be derived. Therefore, the new ideas are not even considered. Yet, to others, these inventions represent a way to improve practice of medicine, to perform more significant research, and advance the medical profession. In order to meet a receptive audience, aerospace ideas must compete with many other concepts and pressures in the biomedical marketplace.

## Promoting the Value of Secondary Applications

If we accept that there is value in applying aerospace biomedical technology to secondary uses, the question then becomes, what approaches should be utilized to capitalize upon this resource? Based upon the evidence that has been collected thus far, it is apparent that advances in biomedical technology are of value to humanity and their widespread application should be encouraged. Several possibilities to enhance technology transfer in this area include:

1. Incorporating aerospace biomedical advances in certain portions of medical school curriculums. This approach will enable the new generation of physicians and medical researchers to appreciate and understand the potential of applying aerospace-generated advances to future problems.

   It might be possible for experienced aerospace researchers to serve, on a limited basis, on medical school faculties. Potential accreditation barriers should be recognized in this approach.

2. Encouraging more intra-Federal Government exchange of technical information. For example, constructive liaison between NASA and the National Institutes of Health should be fostered. It might be possible to incorporate in medical research contracts that an information search be made of aerospace information banks in order to identify technology which might be applicable to the research problem under consideration.

3. Rewarding aerospace researchers who report their research findings and applications in various media. For instance, a professional publication in a respected journal, as well as participation in symposia, should be a factor in promotional considerations, as well as annual salary reviews. The use of such traditional communication channels, rather than reliance upon specialized techniques, might stimulate increased usage of aerospace technology in secondary biomedical applications.

4. Continuing the concept of selective problem-solving approaches demonstrated by the Biomedical Application Teams. These organizations, based at Midwest Research Institute, Southwest Research Institute, and Research Triangle Institute, have been focusing on problems being attacked by medical researchers. They attempt to identify relevant aerospace technology as an aid in the solution of specific problems. This innovative technique has considerable promise.

5. Identifying and aggressively promoting, on a selective basis, those inventions which have the greatest potential for extensive, practical application in the biomedical area. Widespread dissemination of every idea developed in aerospace research might be an approach which lowers receptivity and produces undesirable results with limited applications.

In our opinion, technology transfer of aerospace research results and applications to secondary uses is a worthwhile investment. Often, it is difficult and frustrating. However, it is logical to encourage an extra dividend from mission-oriented expenditures, even though the expenditures can best be justified on the merits of the primary mission. The biomedical field holds exceptional promise, based upon evidence already collected, as a high and effective user of aerospace technology both today and in the future.

## References


1. John G. Welles, et al., The Commercial Applications of Missile/Space Technology (Denver, Colorado: University of Denver Research Institute, 1963), p. v.

2. James E. Webb, "Commercial Use of Space Research and Technology," Astronautics and Aeronautics, June 1964, p. 74.

3. Hamilton Standard Division, United Aircraft Corporation, Medical and Biological Applications of Space Telemetry, NASA, SP-5023, 1965.

4. Gershon Weltman, et al., NASA Contributions to Bioinstrumentation Systems, NASA, SP-5054, 1968.

5. National Aeronautics and Space Administration, Medical Benefits from Space Research, (Washington, D. C.: U. S. Government Printing Office, 1967).

6. Hartwig, Quentin L., "Contributions of Space Technology to Solutions of Medical Problems," paper delivered at the U. N. Conference on the Peaceful Uses of Outer Space, Vienna, Austria, August 22, 1968.

7. Personal communication from Dr. M. K. Baird, Medical Department, Grumman Aircraft Engineering Corporation, October 14, 1968.