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SAFETY AND CRASHWORTHINESS OF DUAL MODE VEHICLES

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16. Abstract

Particular features of Dual Mode System (DMS) safety are reviewed together with the degree of safety that is expected of such systems. Some of the inherent advantages and disadvantages of DMSs in this regard, are also outlined. Possible categories of vehicle safety are defined to aid in developing measures of collision survivability in terms of human tolerance.

The available analytical tools for crashworthiness prediction are discussed, and the type of parameter studies that can be performed with computer programs of simplified simulation models are suggested. The importance of energy absorption devices and impact energy management concepts is emphasized so that optimum design conditions can be attained. Finally, a review is made of some biomechanics dynamic models useful for the assessment of injury potential.

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Crashworthiness, Safety, Collision Simulation, Energy Management, Mathematical Model, Computer Program, Structual Dynamics, Biomechanics

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PREFACE

As part of the effort under UM408, the Transportation Systems Center, in support to the Urban Mass Transportation Administration's dual mode program, is developing analytical techniques for evaluating safety designs and structural crashworthiness of dual mode vehicles. By use of appropriate analytic models and associated computer programs, various factors which influence safety and vehicle damage can be explored and critical design parameters identified. The experience of recent crashworthiness programs sponsored by NHTSA and UMTA in the areas of automobiles and urban rail vehicles can be utilized in formulating analytic models and conducting parametric investigations of dual mode vehicle safety and crashworthiness.

During the summer of 1973, Dr. J.N. Rossettos, Associate Professor of Mechanical Engineering at Northeastern University, held a temporary appointment with the Mechanical Engineering Division of the Transportation Systems Center. While at TSC, he was instrumental in the development and implementation of a three-dimensional frame analysis computer program for prediction of vehicle crashworthiness.

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1. INTRODUCTION

The increase in automobile population and automobile use during the past decade combined with a corresponding decline in the use of public transportation has resulted in a severe strain on the road and highway systems in urban areas. The resulting traffic congestion has produced increased air pollution, increased travel times, and increased fuel consumption. The reduction in public transportation services in urban areas has resulted in a decreased mobility for the young, elderly, poor and handicapped who are incapable of driving or are unable to purchase an automobile. The conventional solution to traffic congestion is the construction of more and better highways and increasing the number of lanes of existing highways. This approach has not proven to be successful in urban areas and has frequently resulted in an increase in urban traffic congestion. Construction of new highways or widening of existing highways is extremely expensive in terms of construction costs, land acquisition costs and social and economic disruptions in urban communities.

The Dual Mode and Personal Rapid Transit System concepts offer a new technology option for increasing the flow of people and goods while providing the safety and convenience of the automobile without requiring the use of excessive amounts of land and extensive new road construction. It is believed that the use of automatic control of vehicles could result in a sevenfold increase in the capacity of a lane of traffic as discussed below. In other terms, two lanes of dual mode operation would provide the equivalent service of a fourteen-lane highway.

Highway capacity is currently limited by the driver's perception of his ability to detect an emergency condition and take appropriate corrective action. Figure 1 shows the relationship between vehicle speed and vehicle density for a simplified model of driver behaviour. This model assumes that the vehicle acceleration is a function of the difference between the maximum speed a driver would travel on a given road and the distance and closing

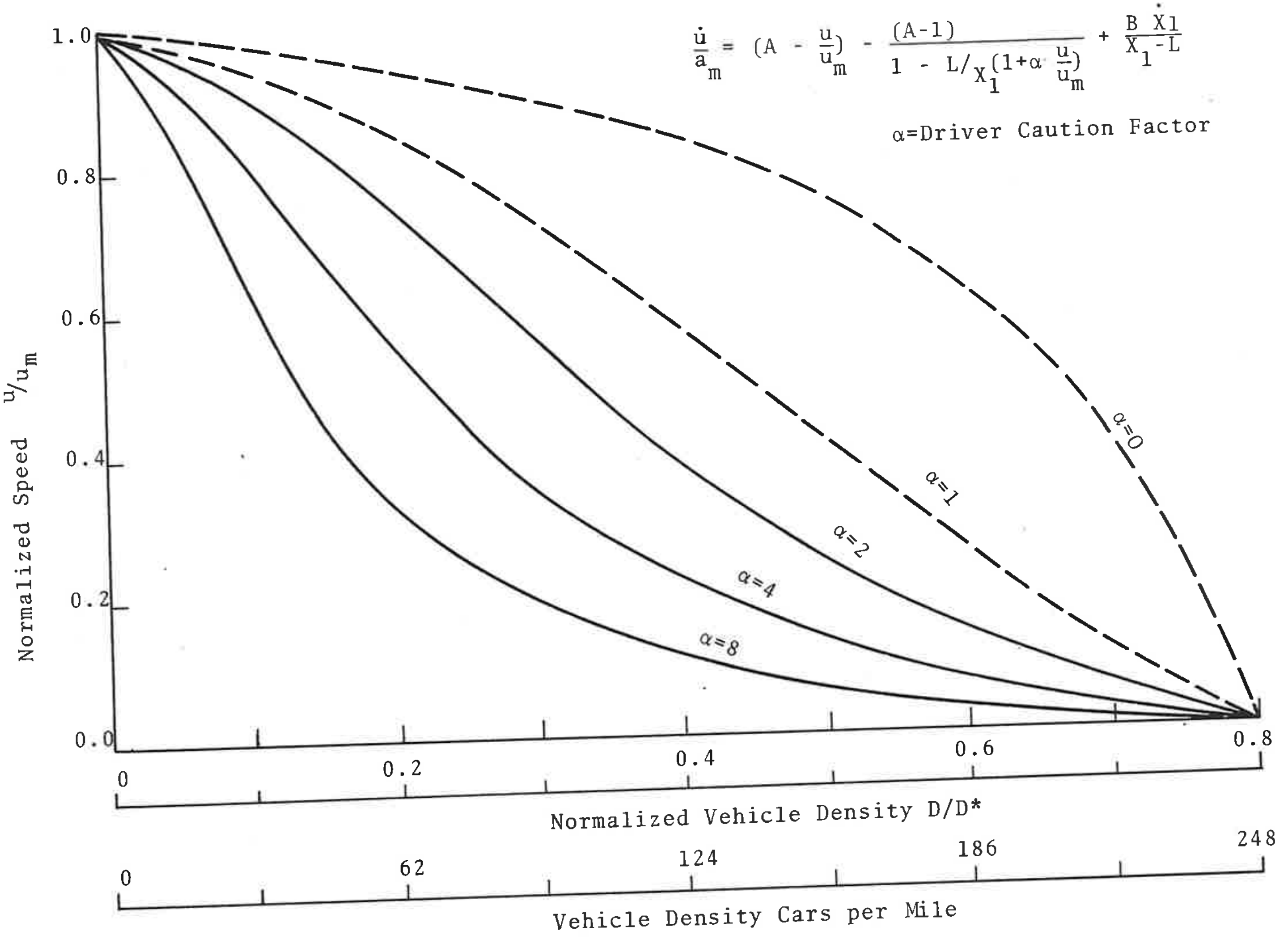


Figure 1. Speed of Single Lane of Traffic vs. Vehicle Density

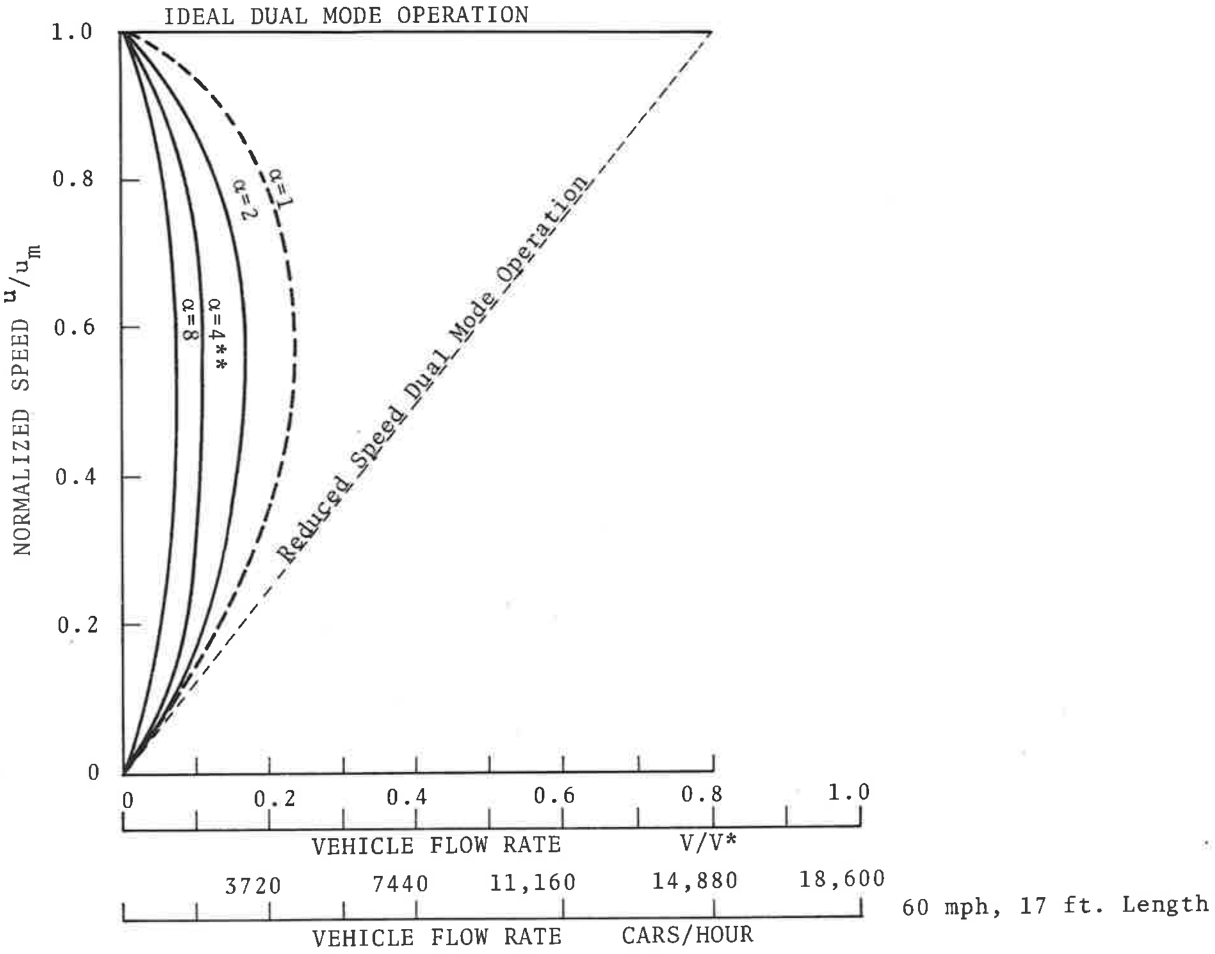
velocity between the vehicle and the one in front of it. The parameter α is a driver caution factor which could depend on road conditions, weather conditions or world tensions. Experimental data indicates that the curve for $\alpha = 4$ is a good approximation for freeway driving. The California Highway Rule recommends a separation of one car length per 10 mph speed increment.

As shown in Figure 2, this decrease in speed as a function of traffic density results in a maximum throughput of the highway lane. For $\alpha = 4$, the maximum capacity is about 2,000 cars per hour, with an average speed of 30 mph. An attempt to increase the number of cars on the road will result in a further decrease in speed and a decrease in the net flow of traffic. Above this critical density the traffic flow becomes unstable with stop-and-go driving conditions, resulting in further decreases in throughput and increased likelihood of low-speed accidents due to traffic congestion. Current efforts towards metering of freeway traffic by control of on-ramps and in some cases traffic control signals interrupting traffic flow are directed towards keeping lane densities below this critical value.

In Dual Mode operation the computer which controls the vehicle would have sufficient knowledge of the current and planned changes in the trajectories of the vehicles in front of the vehicle one is occupying to permit closer headways than a human operator. The close control of speed would permit headways approaching zero without risk of collision. The Dual Mode system could therefore have potentially the speed throughput relation shown in Figure 2, making travel speed independent of density.

The Dual Mode Vehicle operating on its own guideway provides some very strong potentials for improved highway safety. Some of these are listed below:

1. Head-on collisions are impossible.
2. Human error (or operating under the influence of drugs or alcohol) is eliminated.



**α=4 corresponds approximately to combined data obtained from various studies by Bureau of Public Roads, Highway Capacity Manual, 1965

Figure 2. Traffic Speed as a Function of Traffic Flow Rate

3. The computer can anticipate events which are miles ahead of the vehicle and take corrective action in a controlled programmable fashion, eliminating surprises and near misses.
4. Vehicles are inspected regularly and maintenance is under central control.

The engineers concerned with the safety of such a system must however ask the question of what happens if something goes wrong. If there is a failure of a component in the control system, what is the liklihood of a collision? If the collision can occur what injury will it produce?

The permissible headways and component reliabilities are directly related to the crashworthiness of the vehicle.

Accordingly, Transportation Systems Center is conducting for the Urban Mass Transportation Administration design trade-off studies to evaluate the significant parameters affecting vehicle crahsworthiness. The basic requirements for vehicle crashworthiness are:

1. The vehicle shall be able to sustain low speed impacts (under 10 mph) with no occupant injury or functional damage.
2. The vehicle shall provide the occupant with injury protection at least equivalent to the automobile.
3. Overall system safety shall be at least equivalent to transit system standards and experience.

While operating off the guideway the vehicle must also conform to highway safety standards.

This paper reviews some of the parameters relevant to this study and the status of the analytic tools to be applied in predicting Dual Mode crashworthiness.

2. INFLUENCE OF HEADWAY ON VEHICLE IMPACT VELOCITIES

If an obstacle were to be introduced on the guideway and the maximum deceleration under emergency conditions was 0.34g (11 ft/sec^2), the minimum warning that a Dual Mode vehicle travelling at 60 mph would require to permit stopping with no impact velocity is:

$$h = \frac{V^2}{2(11)} = \frac{88^2}{22} = 352 \text{ ft.}$$

If there were a delay in detecting the obstacle and activating the vehicle emergency-braking system, the impact velocity would be given by:

$$V_I^2 = (88)^2 - 22h$$

so that if the emergency-braking system was activated at a distance of 176 feet from the obstable, the impact velocity would be 62.2 ft/sec or 42.4 mph. If the braking system was activated at 350 feet, the impact velocity would be 6.6 ft/sec or 4.5 mph.

For a twenty-foot car length, a requirement that the headway be greater than this emergency stopping distance (i.e. 352 ft) would result in a requirement of 18 car-lengths between vehicles compared to the six car-lengths proposed by the California Highway Rule. Human drivers can operate at closer headways than the emergency stopping distance, because the cars in front of them require a finite period of time to effect a velocity change. If the braking characteristics of the vehicles are identical, the minimum headway required to produce a zero-impact velocity is the distance required for a driver to perceive that the car in front is decelerating and to brake his vehicle. If this reaction time is .75 seconds, the minimum headway would be 66 feet to avoid collision, which would be about 4-1/3 car lengths.

Equations for determining the impact velocity, V_I, as a function of headway D_O, involved in the collision of the rear of one vehicle and the front of another vehicle with initial velocities of V_{O1} and V_{O2} (at t_O, time of brake initiation of the leading

vehicle), respectively, constant deceleration rates of a_1 and a_2, respectively, and a driver reaction time t_R, in the following vehicle (as illustrated in Figure 3) are as follows:

$$V_I = V_{I2} - V_{I1} \tag{1}$$

$$V_{I1} = V_{01} - a_1 t_I \qquad V_{I1} = 0 \text{ for } t_I \geq \frac{V_{01}}{a_1}$$

$$a_1 = 0$$

$$V_{I2} = V_{02} - a_2\,(t_I - t_R) \qquad t_R < t_I$$

$$V_{I2} = V_{02} \qquad t_I \leq t_R$$

$$D_0 + D = V_{02} t_I - \frac{1}{2}\, a_2 (t_I - t_R)^2$$

$$D = V_{01} t_I - \frac{1}{2}\, a_1 (t_1)^2$$

$$D_0 = (V_{02} - V_{01}) t_I + \frac{1}{2}\left[a_1 t_I^2 - a_2 (t_I - t_R)^2\right] \tag{2}$$

Variations of impact velocity with headway distance are shown in Figure 4 for three situations. In each situation both vehicles are assumed to have the same initial velocity. Initial velocities are 60 mph (88 ft/sec), 30 mph (44 ft/sec) and 10 mph (14.7 ft/sec). In the situations depicted both vehicles decelerate at 11 ft/sec and driver reaction time is .75 seconds. For comparison variations of impact velocity with headway distance for no deceleration (braking failure) of the following vehicle are shown in Figure 5. As might be expected from Figure 3, maximum impact velocity is the same for the three situations depicted on Figure 4 with the extent of headway distance resulting in maximum impact velocity decreasing with decreasing initial velocity. As also might be expected from Figure 3, the initial and final portions of the plot on Figure 4 are symmetrical. It is interesting to note that "tailgating" reduces impact velocity rapidly with decreasing headway below 3 feet. The distance involved, however, would seem very impractical for the human vehicle operator, whereas if Dual mode instrumentation and computer automation could be designed to detect particular closing

speeds and distances and give relevant decisions, close headways are feasible. However, in the event of a major system malfunction, such as braking failure, relatively large impact velocities could occur as indicated on Figure 5.

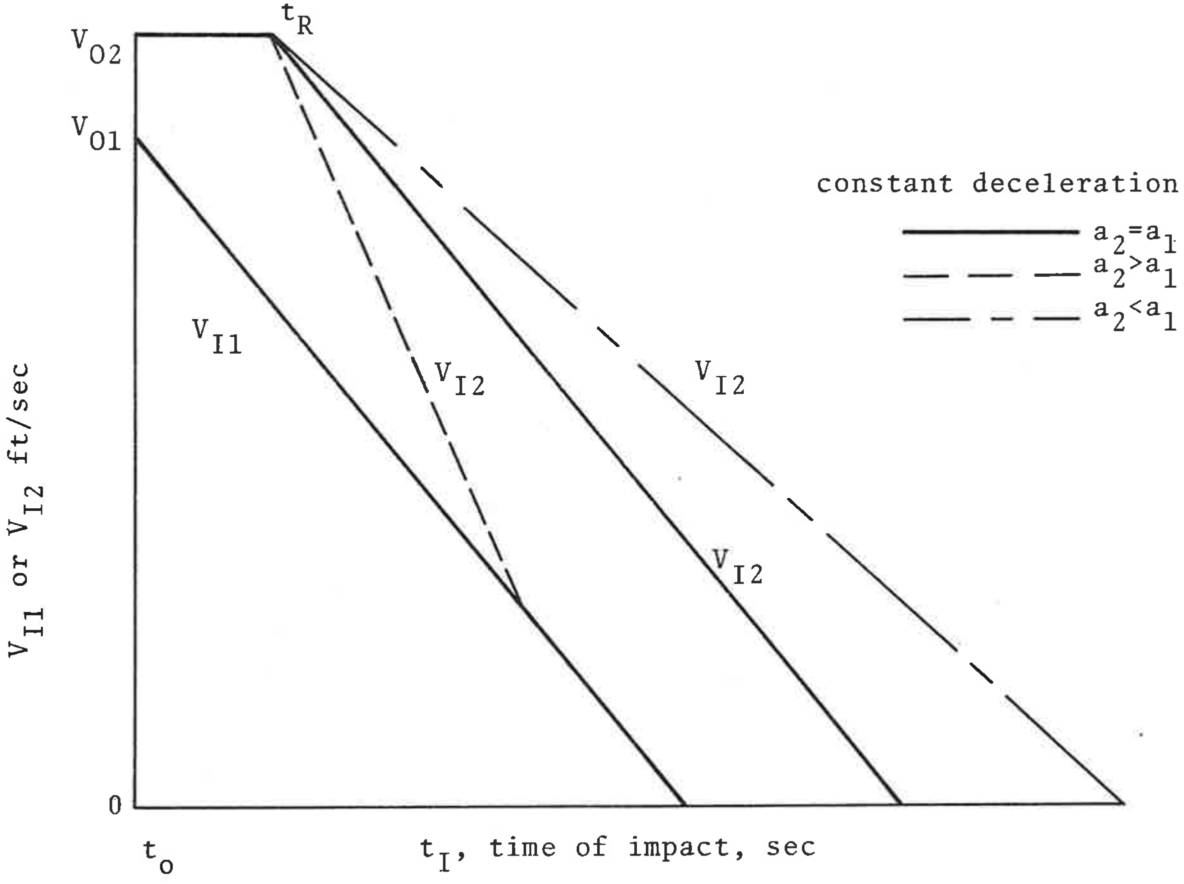


Figure 3. Impact Velocity, V_{I2}-V_{I1}, Front-end to Rear-end Collision

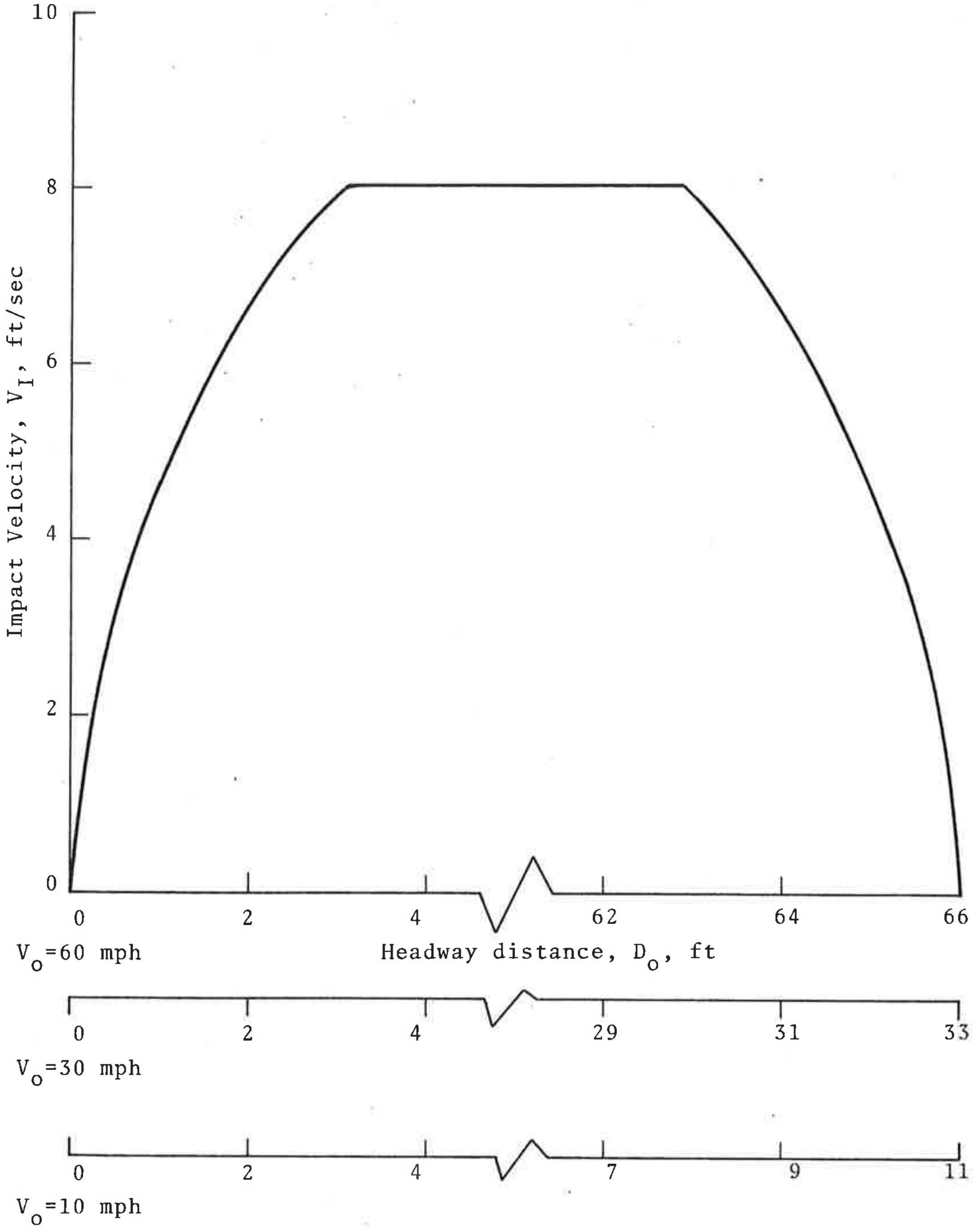


Figure 4. Variations of Impact Velocity with Headway Distance for Two Vehicles Traveling at the Same Initial Velocity with Both Vehicles Braking with the Same Deceleration, 11 ft/sec^2, and Driver Reaction Time .75 sec.

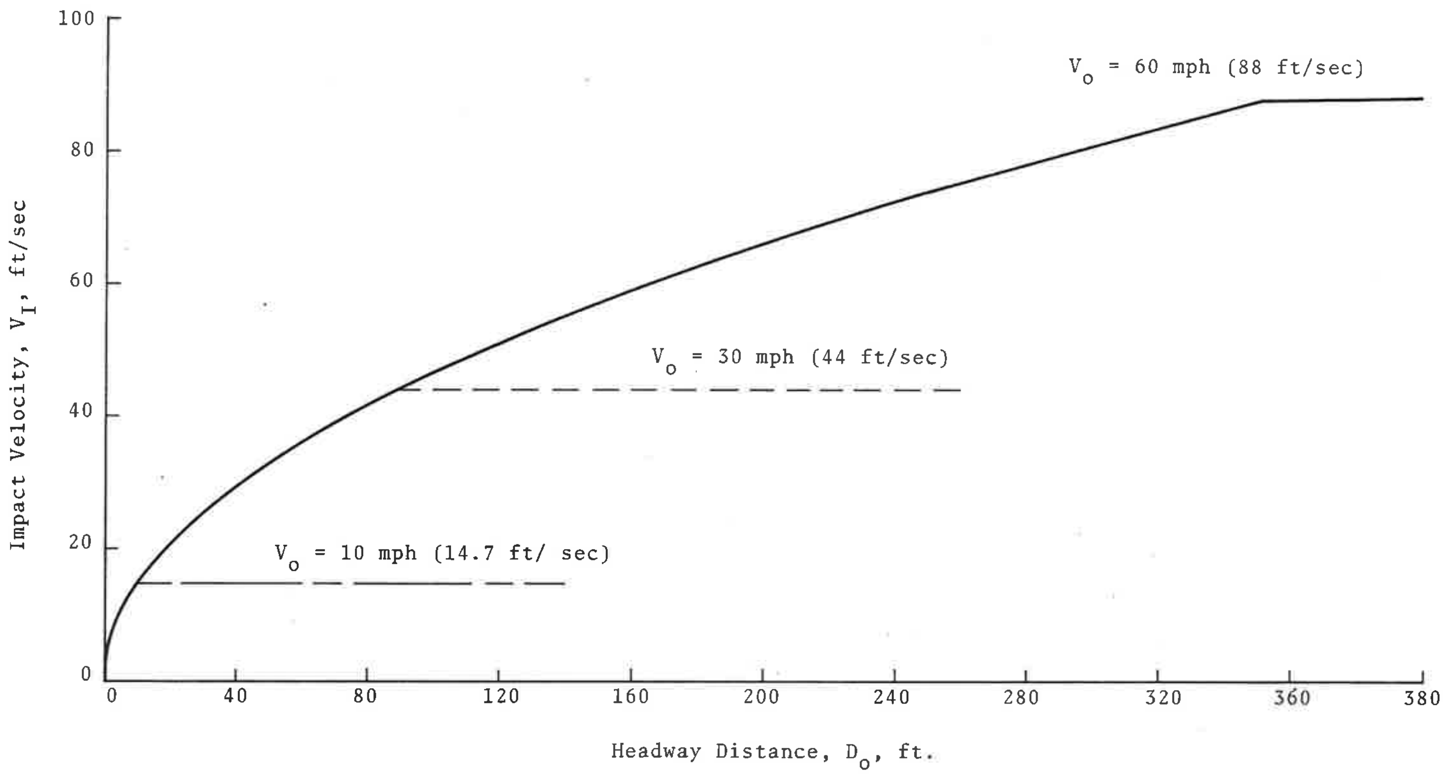


Figure 5. Variations of Impact Velocity with Headway Distance for Two Vehicles Traveling at the Same Initial Velocity V_O with Lead Vehicle Braking only at Deceleration of 11 ft/sec^2

3. CRASHWORTHINESS AND CATEGORIES OF VEHICLE SAFETY

Since Dual Mode System (DMS) development, even with shorter headway, must reproduce or improve on the degree of safety that is expected for the automobile, the definitions of safety in terms of past research for automotive vehicles must, at the least, be adopted in DMS crashworthiness studies. The vast amount of work that has already been carried out in the auto and rail vehicle areas[1-4] has given rise to analytical simulation models which have proven to be important aids in the prediction of vehicle crashworthiness. The availability of such tools can also be useful for DMS studies. The more recent possibility of using scale-model crash testing should also form an important adjunct to such studies.[5]

The crashworthiness of Dual Mode vehicles must be designed so that it may accept controlled collision possibilities, so that it would be useful to delineate possible categories of vehicle safety which can be used in conjunction with various design and automatic control strategies. For convenience, the following qualitative categories, numbered 0, 1 and 2 can be defined:

0 - operational (no injury or damage)

1 - operational (no injury; minor damage)

2 - safe (no fatalities; minor injury; non-operational damage)

Tradeoff studies, using computer simulation models, can allow a more quantitative separation of these levels. Collisions at different speed ranges will be associated with the above categories, which may or may not include passenger restraint devices. Now, research and tests by human volunteers[6] indicate that deceleration levels up to 35 g's can be tolerated by humans under proper restraints and no impacts from sharp edges or packages. Auto tests of adequately restrained bodies indicate tolerable acceleration levels in frontal collisions with fixed objects up to 35 mph; for side collisions with a tree or utility pole, up to 10 mph; and

side collisions with similar size vehicles, up to 25 mph.

This discussion indicates the particular importance of energy absorption devices for optimum energy management to allow reduction of peak g levels. For instance, by increasing the impact deflection via appropirate crush devices, peak g levels can be decreased, and together with selective use of several levels of energy absorption in the vehicle design, a nearly constant acceleration could very well be attained. The various safety levels alluded to must necessarily be derived by properly correlating injury criteria with the vehicle structural response, which can be calculated by using appropriate analytic tools to perform parameter studies.

In conducting design tradeoff studies, some of the parameters being considered by Transportation Systems Center are:

1) bumper and energy absorber deformation characteristics (i.e. in terms of force levels and stroke lengths),
2) relative locations of absorbers and large masses,
3) restraint systems and biomechanics parameters (i.e. peak g levels tolerable), and
4) overall allowable vehicle crush distances.

These studies are conducted using available analytical tools to be described in the next section.

4. ANALYTICAL TOOLS FOR CRASHWORTHINESS PREDICTION

In recent years various simulation programs have been developed to model the dynamic structural response under vehicle impact conditions. The models vary from the very simple which can give only average features of the overall response, to the rather complex, where greater detail in the response can be provided. It is noteworthy to mention that limited success has been achieved by utilizing simplified spring-mass configurations with nonlinear resistances modelled by means of individual or group-component testing or other available information.[7-11] Good overall agreement with vehicle-impact tests has shown that such simple models can be used successfully for specific configurations in conjunction with engineering judgement. In many cases they will be sufficient where "ball park"-type prediction will serve to clarify the alternatives in any decisions involving designs and standards. As will be discussed later, any dynamic response and/or crashworthiness analysis will serve to yield information helpful toward: the identification of significant parameters which would allow extrapolation of available crash test data, and the judicious planning of future tests; correlation with injury criteria in the development of safety limits and design standards; proper design for energy absorption to optimize energy management during impact.

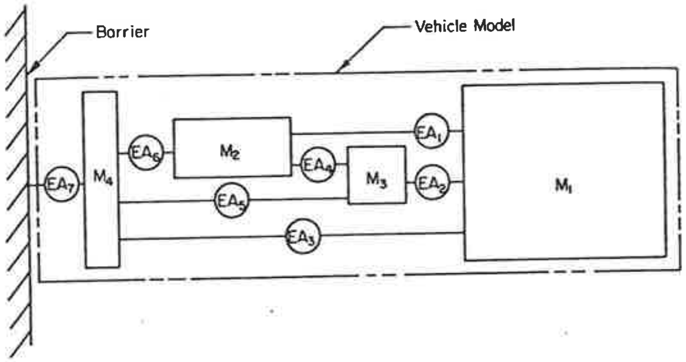
Of the simplififed spring-mass models, representatives are the Tani-Emori,[7] and the Kamal[8] models. In the Tani-Emori barrier impact model, there are two masses and four nonlinear resistive elements which represent gross structural properties. The model is capable of establishing general trends, and good correlation with test results of peak-body deceleration has been shown to be within 10 percent. In the Kamal Model, there are three masses and eight nonlinear resistive elements. Masses represent the passenger compartment, engine transmission unit, and engine cross member. The resistances are determined experimentally by crushing gross vehicle components quasi-statically. In addition, an empirical strain rate correction factor is used in the program.

The model can be used to perform parameter studies for existing designs and in the prediction of general vehicle behavior (average values of acceleration are predicted). Good correlation with test results has been shown for body displacement and velocity.

A larger spring-mass model which can handle a greater number of parameters is embodied in the Battelle FMCCM computer simulation program[9,10] (see Figure 6, which has been taken from reference 10.) This model handles collinear vehicle-to-vehicle as well as vehicle-to-barrier impact conditions. It can include four masses and up to 35 nonlinear resistances in the form of elastoplastic springs, hydraulic energy absorber elements, and viscous dampers. The load deformation characteristics are obtained from theoretical and/or experimental data. An empirical strain rate correction factor is also included in the program. Rebound characteristics are programmed into the model for the purpose of handling impact between different size vehicles in aggressiveness studies. This aspect of the program has yet to be checked out. The model has shown good simulation ability, and in its present form is a useful tool for predicting general and specific behavior; for preliminary evaluations and comparisons of vehicle energy absorption devices; for aiding in the planning and evaluating crash tests.

With regard to the FMCCM model simulation ability, predicted values of peak vehicle crush using FMCCM runs fall very close to a median line (road research laboratory data curve) for a large variety of current production cars (Figure 7). Also, very good correlation is indicated for predicted engine deceleration/time response for an FMCCM run and an experimental result obtained by Emori and Tani.

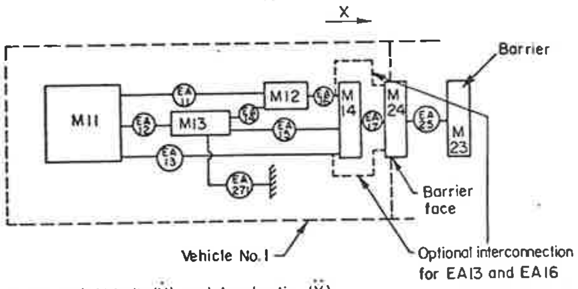
The next step in complexity for analytical simulation models involves the frame models.[12-16] The Calspan model,[12] which represents the earliest development in this regard, is applicable to 2-dimensional frame structures. It is essentially a finite element model with straight-beam elements, lumped masses at nodes, and localized plastic hinges at pre-selected nodes. The program is operational, and at present, can be useful for simple front frame and bumper configurations (Figure 8).



M1 - Body/Chassis Mass
M2 - Engine/Transmission Mass
M3 - Front Crossmember/Front Suspension Mass
M4 - Bumper Mass
EA1* - e. g., Driveline, Transmission Mount, Engine/Firewall Interface, etc.
EA2* - e. g., Torque Box
EA3* - e. g., Front End Sheet Metal (Hood, Fenders, etc.)
EA4* - e. g., Engine Mounts
EA5* - e. g, Front Frame
EA6* - e. g., Engine/Radiator Interface
EA7* - e. g., Bumper and/or Barrier Face Characteristics

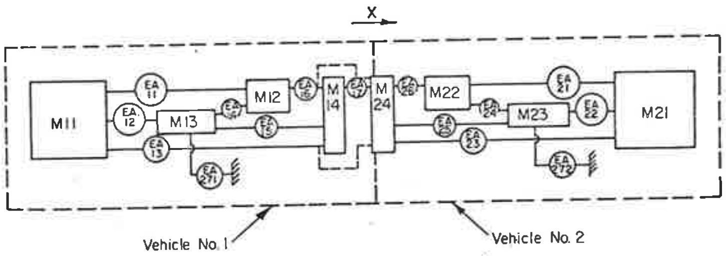
*Any combination of up to five linear or nonlinear energy absorbers.

BARRIER IMPACT MODEL (FRONTAL COLLISION VERSION)



Position (X), Velocity ($\dot{X}$), and Acceleration ($\ddot{X}$) are positive to the right (⟶).

a. Car/Barrier Crash Simulation Model.



Position (X), Velocity ($\dot{X}$), and Acceleration ($\ddot{X}$) are positive to the right (⟶).

b. Car/Car Crash Simulation Model.

FINAL MODEL CONFIGURATIONS SELECTED FOR THE BASIC CAR/BARRIER AND CAR/CAR COLLISION VERSIONS OF THE FMCCM PROGRAM

Figure 6. Battelle Collision Models

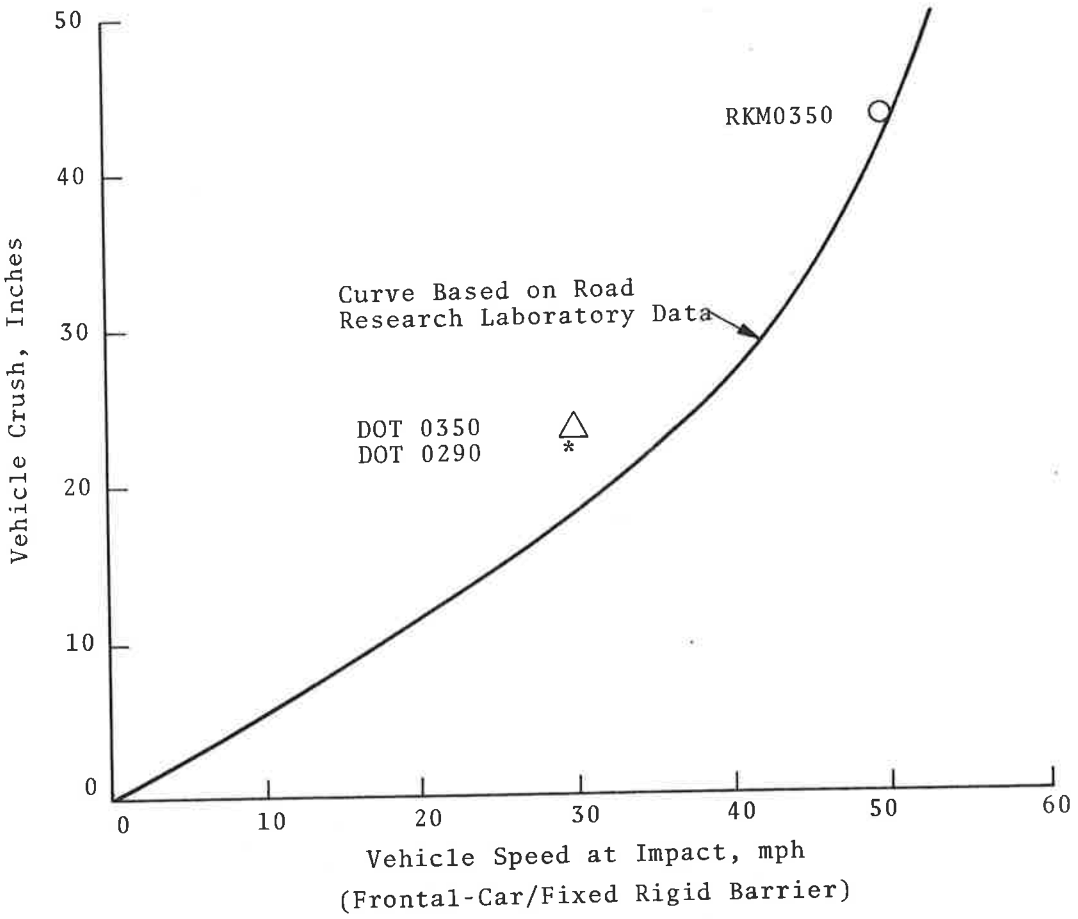


Figure 7. Vehicle Crush as a Function of Impact Speed

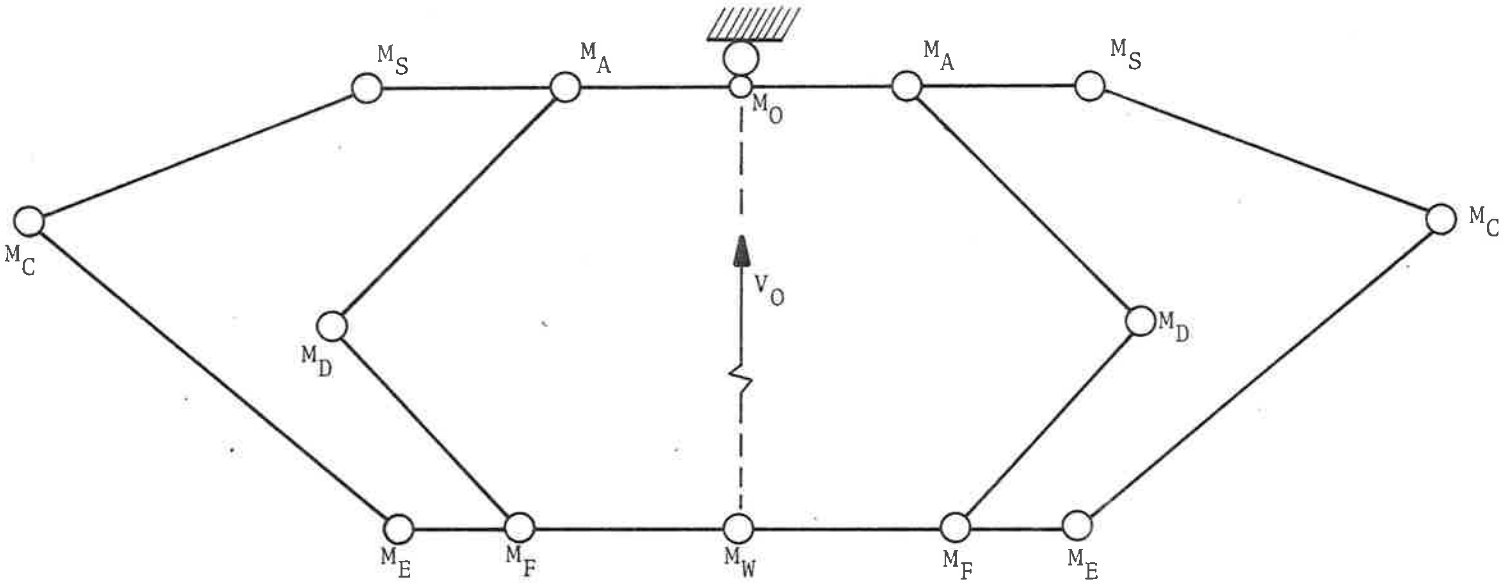


Figure 8. Modified Automotive Front Frame and Bumper

The 3-D TSC Model[13] presently being developed at the Transportation Systems Center can be regarded as a three-dimensional extension of the Calspan model, in the sense that the assumptions on ideal plastic hinges and lumped masses at nodes are the same as in reference 12. The analysis and computer implementation of the TSC model is more heavily based on finite element techniques,[17-22] which are being utilized at present to also include lumped parameter elements in the program, by means of substructuring concepts.[23,24] Another three-dimensional frame mode, developed by Lockheed and referred to as KRASH,[14] has been installed and running on TSC equipment. It is, however, operational only for specific aircraft applications at the present time. Much more work is needed for these and other more complex models,[15,16] to make them truly operational. By and large they are still in the so-called prototype stage with a limited number of check cases to their credit. It appears then, that for the present, the simplified mass-spring models, tailored specifically for Dual Mode configurations will form the initial analytical tools.

In summary, the simplified lumped parameter models are to be regarded as especially useful in making design tradeoff studies, where many parameters are involved and larger models would be expensive. On the other hand, the large finite element models are more suitable when a proposed design is studied, for which parameter values are relatively fixed.

5. PARAMETER STUDIES AND ENERGY MANAGEMENT

By using analytical tools oriented specifically toward DMS configurations, parameter studies can be performed to yield useful data, especially during the feasibility stage of new ideas. Such studies will aid in identifying the important parameters characteristic of Dual Mode vehicles, useful in future crash testing, formulating standards, and in structural design and optimum energy management concepts. The several design parameters will be defined, among other things, with respect to: a) bumper configurations, b) energy absorbers and their relative locations, c) shape and orientation of structural members (ie. frames, compartment, engine or motor mounts), d) overall and individual mass c.g. locations (ie. engine or motor, passenger compartment, etc), e) weight of payload relative to structural weight, and f) guideway elasticity.

In order to contribute data for purposes of defining useful measure of safety and collision survivability, other impact parameters will consider: a) permissible overall crush distances, and stroke lengths of absorbers, b) maximum acceleration levels at selected points, c) parameters that can be used in conjunction with injury criteria related to critical body regions (i.e. head, chest, pelvis and femurs), and d) restraint-system characteristics.

The model studies can be made to simulate various types of collisions, which can be classified according to the following impact arrangements: a) impact into a rigid pole or line barrier, b) impact into a flexible pole or line barrier, and c) impact of two simulated vehicles which are the same size or of different sizes, in bumper-to-bumper and head-on collisions. The spring-mass models can be used in parameter studies where stroke lengths and absorber activation forces will be design variables, and the effects of different absorber characteristics and their location on peak acceleration can be evaluated.

The results of the various studies of simplified impacts between vehicles of different sizes can help design for least damaging

aggressivity. For instance, a particular alternative might be to favor small vehicles and use different absorber force levels in each vehicle weight class. Studies can also be made to differentiate between high and low speed impacts. For instance, in a defined "low" speed collision, the absorber will not be activated and the bumper with an auxiliary "oleo strut" device might be sufficient. It will also be possible to study the concept wherein activation of "multi-stage" absorbers can be defined to occur at certain established impact speed levels.

Proper energy management (i.e. optimum location of absorbers in the vehicle, force-deformation characteristics, proper use of restraint systems) can be instrumental in achieving safety at high-speed levels. In regard to energy absorption devices, a general classification would include: a) innovative bumpers, b) collapsible frames and structures and c) passenger-restraint systems. For high-speed collisions, devices in the second category play an important role and are discussed at length in references 4 and 25-29. The parameters that define different absorbers are: a) maximum energy absorbed in a given stroke (determines the speed of impact that can be decelerated), b) peak force in a given stroke (leads to peak deceleration to be experienced by occupants), and c) stroke length. The favored device attains least peak force for a given absorption energy and stroke. A typical Force-Stroke curve is shown in Figure 9. The linear portion of the curve is desirable in that the jerk rate is limited. Another desirable feature is to have a substantial flat portion. Since the area under the curve equals the kinetic energy that can be absorbed, the flat part of the curve implies uniform force levels during absorption. Selection of an appropriate device would depend on the application. For instance, a variable force device could provide lower stroking forces for low-speed impacts while avoiding the extremely long strokes necessary for high-speed impacts. A low initial force followed by a higher force (at longer strokes) could be achieved with a velocity-sensitive device, but it could also be achieved with multiple-stage, constant-force devices.[4] As detailed in references 14 and 25, selection can be made from extrusion devices, material deformation devices, and friction devices. In any case,

some devices can yield shorter stroke lengths for a given amount of energy, while others are more easily adapted for re-usability. Both will influence DMS design. From the point of view of weight and cost, it appears that crushable honeycomb is the simplest, lightest and least expensive system which can provide a constant deceleration.[4]

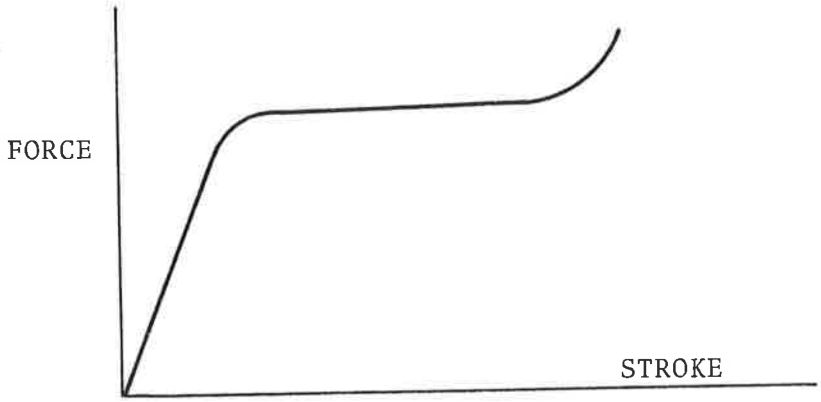


Figure 9. Energy Absorber Characteristics

6. BIOMECHANICS DYNAMIC MODELS AND ASSESSMENT OF INJURY POTENTIAL

There is a need to develop well-defined ranges for certain parameters which will allow quantitative evaluation of passenger safety. In this regard biomechanics dynamic models are essential so that the structural dynamic response can be related to injury criteria. As such mathematical models of different aspects of the acceleration response of the human body have been developed. Some results to date have yielded the acceleration waveform for the passenger compartment most beneficial to the occupant, as shown in Figure 10. Simple studies of an articulated model of the occupant bear this out.[30,31,32] In a frontal impact, for a fully lap and shoulder belted occupant, these studies show that an early high deceleration pulse, followed by a lower sustained deceleration level (Figure 10) is least damaging to passenger. Experimental investigations have substantiated these studies.[33] Excellent reviews on various models are given in references 34 and 35. For instance, the mathematical model of the head and neck, that is described in reference 36 (see Figure 11), can be viewed as a development aimed ultimately at direct injury prediction, in the sense that it simulates the body mechanism (i.e. the head-neck action) associated with the specific injury of interest, "whiplash." As more definitive injury criteria are developed for this type of injury, the analytically predicted actions can be compared with injury thresholds. The model in reference 36 is limited to planar motions in rear collisions and to linear system characteristics. Another highly simplified situation considers point-mass models which have been used in references 37 and 38 in fundamental studies of the behavior of a restrained occupant in a frontal autombile collision (Figure 12). The evaluation of injury potential[38] were based entirely on consideration of the occupant (ie. point mass) deceleration. In reference 37, evaluations of relative injury hazards were based on predictions of the velocity with which the simulated occupant would strike the vehicle interior, with consideration also given to the level of occupant deceleration produced by the restraints. These models, although simplified, can be used with analytical computer simulation of vehicle structural dynamic response to obtain useful indexes of injury.

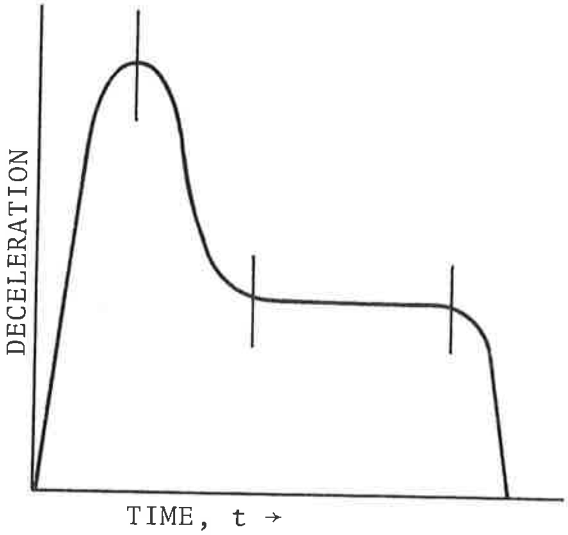


Figure 10. Passenger Compartment Waveform most Beneficial to Occupant

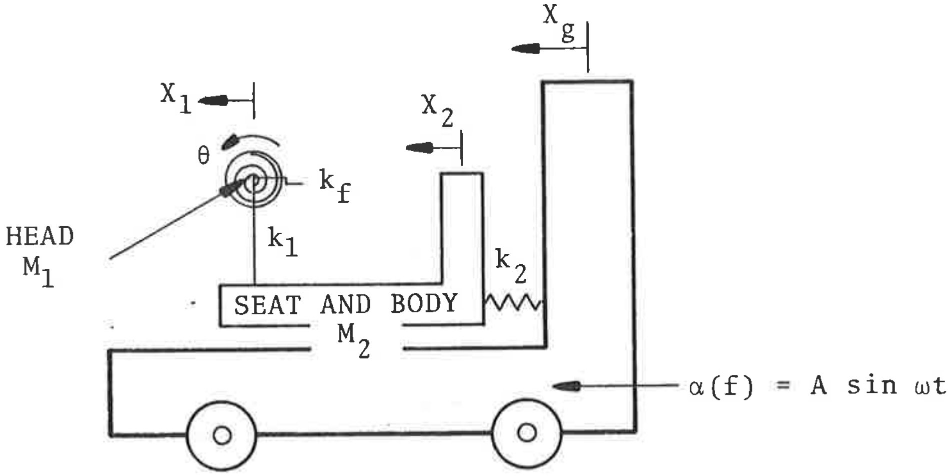


Figure 11. Head-Neck Model

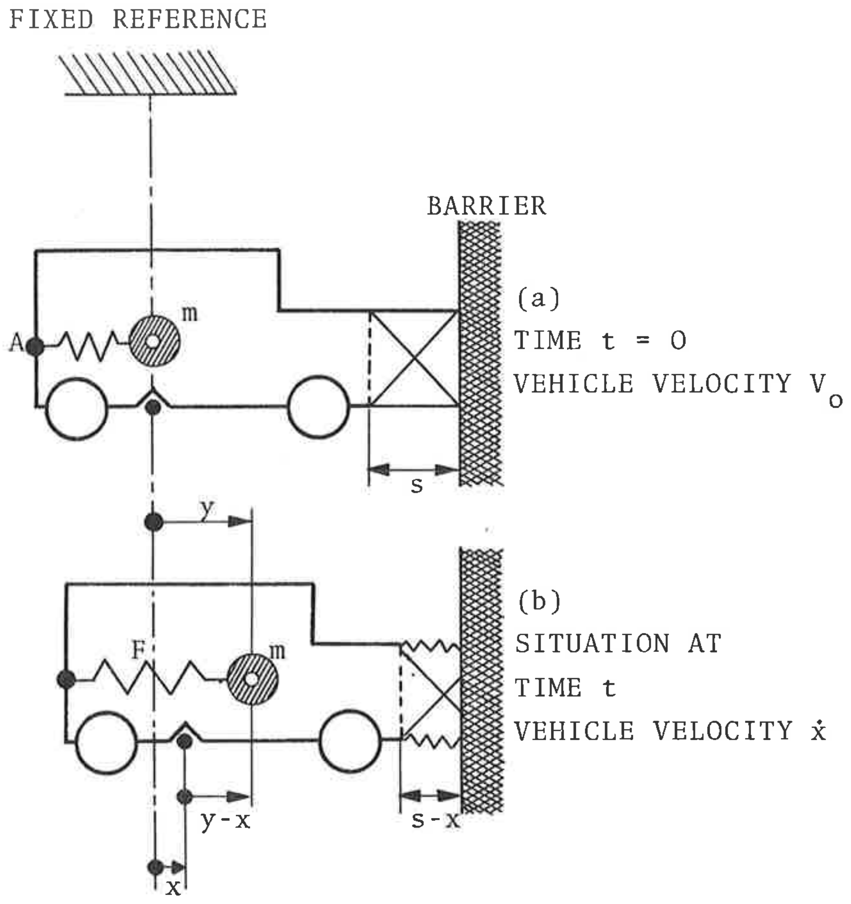


Figure 12. The Crash System

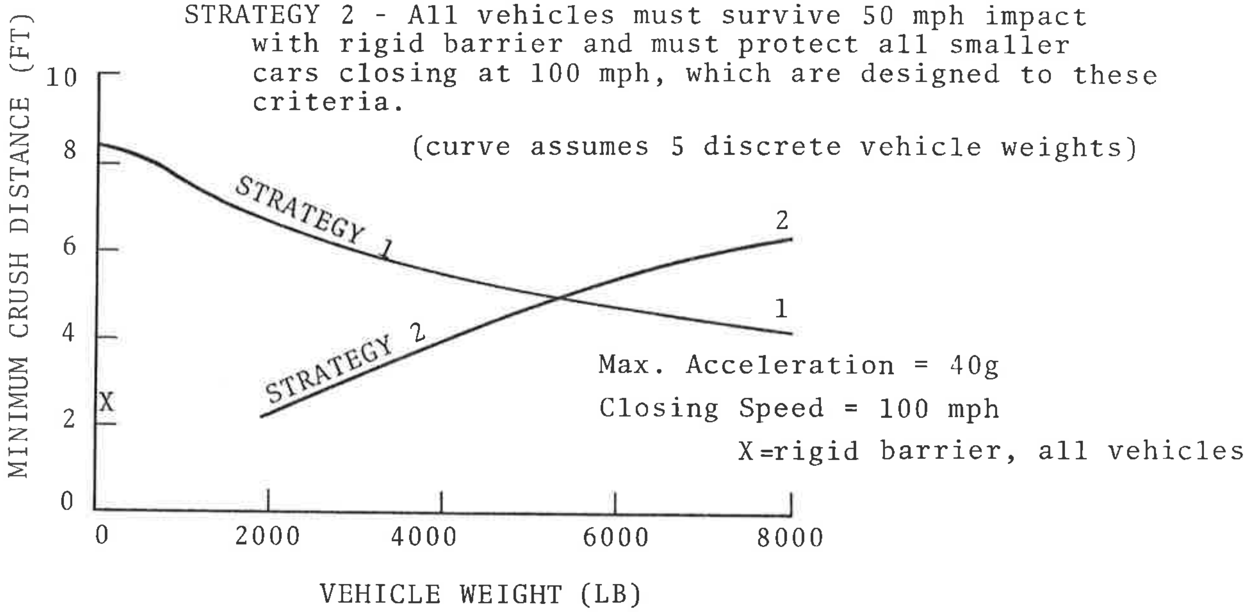
7. RECENT STUDIES IN PREDICTING OPTIMUM CRUSH CHARACTERISTICS OF VEHICLES

An important area, presently being studied at the Transportation Systems Center, involves the ability to design for optimum crush characteristics of various size vehicles. It is related to energy management concepts and the proper use of energy absorption devices. For instance, depending on the strategy, lighter vehicles may require absorbers which must deform with larger crush distances than those in heavier vehicles in a collision. Two possible strategies are indicated in Figure 13. In strategy 1, all new vehicles should be capable of collision with a rigid 8,000 pound vehicle closing at 100 mph and collision at 50 mph with a rigid barrier. In strategy 2, all vehicles shall be capable of collision with rigid barrier at 50 mph, and must protect all smaller cars closing at 100 mph which are designed to this criteria. Other tradeoffs are currently under study at the Transportation Systems Center.

STRATEGY 1 - All vehicles must survive collision with rigid 8,000 lb vehicle closing at 100 mph, and 50 mph impact with rigid barrier.

STRATEGY 2 - All vehicles must survive 50 mph impact with rigid barrier and must protect all smaller cars closing at 100 mph, which are designed to these criteria.

(curve assumes 5 discrete vehicle weights)



Max. Acceleration = 40g

Closing Speed = 100 mph

X=rigid barrier, all vehicles

Figure 13. Minimum Crush Distance vs. Vehicle Weight

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