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Passenger Acceptance of Alignments with Frequent Curves in Maglev or Other Very-High-Speed Ground Systems

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PREFACE

This report was prepared by the Operator Performance and Safety Analysis Division of the Office of Research and Analysis at the Volpe National Transportation Systems Center (VNTSC) for the Federal Railroad Administration (FRA). Its purpose is to help define guideway-alignment criteria for future high-speed ground systems from a passenger-comfort perspective.

The authors would like to thank all of the individuals who contributed to this study. Among these were John Harding, Chief Scientist of the Maglev Technology Development Staff in the FRA, and James Milner of Mitre Corp., who served as Technical Monitor for this project. At the Volpe Center, Robert Dorer, Chief of the High-Speed Ground Transportation Special Projects Office and Michael Coltman, Project Manager, supervised execution of the work.

Our major collaborators in this undertaking were staff members of Grumman Aerospace (now Northrop Grumman) in Bethpage, New York. Paul Shaw was Project Manager and Phil Danley was chiefly responsible for the development of the simulation software and computer-generated graphics. Dick Gran supervised the entire undertaking. Pilots Bill Patterson and Jim Dowd helped develop the experimental procedures and flew the pilot tests. John Eng, Dennis Brooks and Mike Yamond ran the simulator.

The New York State Energy Research and Development Authority provided some of the funding for the conversion of Grumman’s X-29 simulator to Maglev use and for a study of the effects of vibration on passenger comfort. Richard Drake, its Program Manager for Transportation led that effort. Berger, Lehman Associates, under contract to Will Ristau of the New York State Thruway Authority, developed the alignment, which was the basis for the flight paths used in the experiments described in this report. Donald Baker and the New York State Department of Transportation provided additional technical assistance in this effort.

United Beechcraft Inc. of Farmingdale, New York provided the 1900C aircraft and crew used in the final series of flights. Bill Dolan made the arrangements, Ray Marciano supervised the equipment installation and flew the check flight, while Wayne Demming and John Boruch, Jr. flew the nine experimental flights.

Carol Preusser and Bill Nissen of Preusser Research Group did their usual fine job of recruiting and managing subjects.

M. J. Griffin supplied expert advice and consultation on development of the ride-quality model, based upon his seminal work in the field.

Finally, we would like to thank our experimental subjects, whose responses form the basis of this entire report. We are especially grateful to those who experienced some symptoms of motion sickness, but stuck with the experiment to the end.

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EXECUTIVE SUMMARY

Proposed high-speed ground transportation systems, such as Maglev, may have motion characteristics affecting passenger comfort that set them apart from anything previously experienced. Operating at aircraft speeds along rights-of-way established for conventional ground vehicles, these systems may subject passengers to significantly larger vertical accelerations and roll rates than they have ever felt on existing common-carrier modes. If the design limits for guideway curvature are set too high in the interest of achieving the shortest travel times and/or maximum utilization of existing, short-radius right-of-way, substantial numbers of passengers may find the ride quality unacceptable because of excessive vertical acceleration and roll rates. In that case, speed would be reduced, resulting in moderately longer trip times. In areas where new right-of-way is unavailable, the question becomes how can a Maglev or other high-speed-system guideway be optimally fitted to it and what speeds should be used.

Previous research carried out by the Volpe National Transportation Systems Center for the National Maglev Initiative demonstrated that more than 95% of the public would accept isolated Maglev maneuvers involving bank angles up to 37 degrees and roll rates up to 7 degrees/sec. Since these limits were higher than those contemplated in most Maglev-system-design proposals, passenger acceptance did not appear to impose any significant constraints. However, further reflection on motion sickness as experienced in other modes suggests that the frequency of occurrence of motions, as well as their power spectra, are as important as their magnitude and that the view out the window may strongly influence the passenger's likelihood of becoming ill. Hence this study was undertaken to explore comfort and motion-sickness effects of Maglev travel in corridors characterized by frequent curves.

Four segments of the New York State Thruway, totaling 277 km (172 miles), were chosen as the hypothetical route for evaluating passenger acceptance for the following reasons:

- These segments are representative of a great deal of the hilly terrain found in the United States.

- Their length of 277 km (172 miles) is typical of the distance between several major city pairs which would be good candidates for Maglev service.

- The State of New York was willing to supply detailed maps containing the required data to construct the hypothetical route.

- The State of New York provided significant financial support to the construction of the simulator used for part of this study.

Route alignment data from the aerial photos and engineering drawings were coded and published by Berger, Lehman Associates. These were input to a set of computer models that generated files containing the exact bank angles at intervals of 0.1 second of a hypothetical Maglev following the Thruway. Alternative files were generated for various assumptions about maximum allowable bank angle, maximum allowable roll rate and the longitudinal acceleration and deceleration characteristics of the vehicle. These various sets of assumptions implied travel times over the 277-km (172-mile) route of 39 to 49 minutes. Bank angles as high as 40 degrees and roll rates as high as 12 degrees/sec were considered.

To facilitate both the experimental design process and subsequent data analysis, a procedure was developed for estimating the propensity of a given set of ride motions to induce motion sickness. This procedure is based upon the work of M. J. Griffin and British Standard 6841:1987 for ride quality. It generates a number called the Motion Sickness Dosage Value (MSDV), from which the proportion of passengers who will experience nausea can be estimated. The model predicts the incidence of kinetosis from the magnitude and duration of exposure to low-frequency (0.1 - 0.5 Hz) vertical accelerations. For the hypothetical route, 27 alternative sets of design limits for bank angle, roll rate and longitudinal acceleration and deceleration were initially considered, which had MSDV scores ranging from less than 2 to 13. British Standard 6841 provides an approximate method for convenient interpretation of these figures. In a "mixed population of unadapted male and female adults" BS 6841 gives the estimate:

$$\text{Percentage of persons who may vomit} = 1/3 * \text{MSDV}.$$

Also, the scores may be used for comparative purposes; motions leading to high MSDV scores may be expected to produce more motion sickness than motions leading to low scores.

The only means of simulating trips with realistic accelerations at reasonable cost is through the use of an airplane. In turning, aircraft naturally bank at just the right angle to eliminate lateral forces on the passenger, just as a Maglev would. Conventional ground vehicles would produce unpleasant and unrealistic lateral accelerations in rounding turns at high speeds, since they are restricted to low amounts of super-elevation and generally lack tilt-body suspensions. The principal disadvantage of using an airplane as a simulator is that it cannot provide a realistic out-the-window view a future Maglev passenger would see. Only a laboratory simulator can safely expose passengers to the visual effects of scenery rushing by at 400 kilometers per hour (about 250 miles per hour) at ground level. The laboratory simulator can also add realistic amounts of vibration.

To provide facilities for testing subjects in both the airliner and laboratory simulations, a contract was awarded to Grumman Aerospace Inc. (now Northrop Grumman Corp.). This contract supported the development of computer-generated-imagery of the New York State Thruway right-of-way, use of the simulator and staff for testing subjects and use of a 21-seat Gulfstream I and crew for flight experiments. Due to the merger with Northrop and the ensuing downsizing of the corporate fleet, a Beechcraft 1900C replaced this aircraft.

An experimental apparatus was constructed to facilitate flying an airliner through a series of several dozen roll maneuvers which would subject passengers to the same vertical accelerations and roll rates they would experience in a Maglev built to a given set of design standards. This apparatus was based upon two notebook computers linked to a roll-rate gyro and a three-axes accelerometer. It generated a cockpit display showing what the aircraft's bank angle was supposed to be at any given time, what its actual bank angle was, and the direction of the next maneuver. The pilot's job was simply to keep the two bars on the display parallel. The apparatus also recorded the outputs of the accelerometers and rate gyro at 0.1-second intervals, thus allowing MSDV and other measures of ride quality to be calculated.

After training the crew to fly the experimental procedures and securing use of restricted airspace, two preliminary tests were conducted using government and contractor personnel as subjects. These tests exposed subjects to two intervals of flying with relatively high bank angle limits, consistent with making the 277-km (172-mile) trip in about 38 minutes. More than half the subjects began feeling queasy at these higher limits. As a result, a decision was reached to restrict the exposure of subjects drawn from the general public to bank angles of less than 30 degrees and roll rates of less than 9 degrees/sec.

The final experimental design specified nine flights with 14 subjects each. Each flight simulated a 277-km trip made with one of the nine possible combinations of limits for bank angle and roll rate. The limits for bank angle were 14, 21 and 28 degrees while those for roll rate were 4, 6 and 8 degrees per second. Since the laboratory simulator seated only four subjects, two sessions were conducted with each combination of limits, allowing more than half of the persons who had flown to take the simulator trip as well. Subjects were required to rate ride comfort and their own tendency to motion sickness (both on seven-point scales) five times during both trips and to read magazine articles and answer questions about them.

Analysis of the data from the subject rating sheets and the instrumentation lead to the following conclusions:

1. Based on the results of this study there is no evidence that more than a small percentage of Maglev passengers would experience kinetosis on routes confined to the boundaries of existing highway rights-of-way. This study simulated a Maglev system traveling through representative portions of the proposed New York State route at average speeds that ranged from 320 to 400 kph (200 to 250 mph). While the vertical accelerations experienced by the subjects in the aircraft simulation were generally greater than those that would be experienced by Maglev passengers, only 2 of the 127 subjects vomited.

2. Within the bank-angle and roll-rate limits tested, the majority found the plane ride comfortable and felt no motion sickness. These limits were greater than those specified for the Maglev Systems Concepts Developers.

However, a significant minority, 23%, felt slightly queasy at some time during the flight, while 8% felt intermittently nauseous or worse during some portion of the flight and two subjects vomited. The reported differences between subjects in their perceptions of ride quality and propensity for motion sickness were greater than the physical differences in bank-angle and roll-rate limits for different flights. Ratings of ride comfort and motion sickness were not significantly correlated with bank-angle or roll-rate limits.

The percentages of passengers showing signs of motion sickness in the flight experiments are probably greater than the percentages who would do so aboard an actual Maglev, because the flights subjected them to somewhat larger doses of vertical acceleration than they would have received aboard a Maglev with the same nominal bank and roll limits. Furthermore, the limited views through the small airplane windows and/or anxiety about the flight may have contributed to the onset of nausea in some subjects. Hence the foregoing conclusions are conservative.

3. Cumulative dosage and duration of exposure showed significant correlation with motion-sickness ratings. The implication of this finding is that average values for bank angle and roll rate should be lower on longer routes than on short ones.

4. In the laboratory simulation, no subjects vomited and only one of 71 reported even intermittent nausea. Thus, the visual effects of scenery rushing by at 400 kph (250 mph) do not appear to present a problem when that view is limited to a side window, even as large as the 89 cm (35”) video monitors used in the experiment.

1. INTRODUCTION

1.1 Background and Objective

The development and evaluation of proposed Maglev transportation systems have been predicated upon the use of existing rights-of-way for some of the system route mileage. This constraint was expressed by Congress in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), which states:

> *It is the policy of the United States to establish in the shortest time practical a United States designed and constructed magnetic levitation transportation technology capable of operating along Federal-aid highway rights of way, as part of the national transportation system of the United States.*

The assumption of use of existing right-of-way is also a reflection of the fact that in the corridors between large cities, which are the primary candidates for Maglev routes, land values may be so high as to make it impractical to acquire large amounts of new right-of-way.

Because the existing rights-of-way were laid out for speeds below 160 kph (about 100 mph), the radii of curves and the lengths of spirals (segments of guideway where radii are changing from infinity to those of the curved segments) are sub-optimal for Maglevs or other very high-speed, fixed-guideway systems, operating at more than twice the maximum speed of existing ground systems. To negotiate curves at Maglev speeds, the vehicles must bank as aircraft do for reasons of both passenger comfort and to minimize lateral forces on the suspension and guideway structure. The centrifugal force developed in these curves and spirals will be resolved and experienced by passengers as positive vertical acceleration (g loading) just as in airplanes. For a curve of given radius, the faster the design speed for a Maglev guideway, the greater the bank angle must be and the greater the extra vertical g-force acting on the vehicle and passengers. For a spiral of given length, the greater the Maglev's speed, the greater the roll rate it will experience in traversing the spiral. Roll rate can be perceived as the rate of change in vertical acceleration. Since centrifugal force increases as the square of velocity, it becomes apparent that while it may be hardly noticed on the curves of Interstate Highways at normal passenger-car speeds, at 400 - 500 kph (250 - 300 mph) it can amount to several tenths of a g.

Recognition of these implications of guideway alignment leads to the following questions:

- What are the comfort limits for acceleration (lateral, vertical and longitudinal)?
- What are the comfort limits for roll rates and bank angles?

- What are the effects on comfort of sustained exposure to various accelerations and roll maneuvers (as opposed to situations in which such forces and maneuvers are encountered only in brief, isolated segments of a trip)?

- Does the visual environment that would be experienced by Maglev passengers introduce any additional concerns?

All of these questions are related to system design and economics in terms of right-of-way alignment constraints, forces acting on various components of the vehicles and guideways, average speeds attained, and a host of other issues.

Humans differ greatly in their perceptions of what constitutes a "comfortable" ride. Various aspects of ride quality, e.g., vertical acceleration and roll rates, seem to act synergistically in degrading perceived ride comfort. Existing tests and standards for ride quality were developed for other modes and translate poorly or not at all into a 500-kph-ground environment.

In attempting to answer these questions, the staffs of the National Maglev Initiative and the Volpe Center chose to begin with simplest ones:

- What are the tolerance limits of the public for individual, isolated maneuvers that generate positive or negative vertical acceleration alone?

- What are the tolerance limits for separated, coordinated turning maneuvers, that generate both positive vertical acceleration and a rolling sensation, in terms of maximum bank angle and maximum roll rate?

These questions were addressed in the Study to Establish Ride Comfort Criteria for High Speed Magnetically Levitated Transportation Systems (Ref. 1). That study concluded that fewer than 5% of the public would hesitate to ride on a system in which maximum bank angles were limited to 37 degrees and roll rates were limited to 7 degrees/sec. Since these values were higher than those specified in most of the concepts then being developed, it seemed that on the basis of the experiments described in the report, ride-quality considerations might not constrain system design significantly.

However, the fact that many people experience kinetosis (motion sickness) under a variety of conditions on vehicles which are not violating the aforementioned limits, suggests the necessity of looking beyond comfort ratings for isolated maneuvers. ("Isolated" means that maneuvers were separated in time by at least one minute, with an average period between moments of peak acceleration of nearly two minutes.)

Furthermore, as many have learned through personal experience in recent years, simulators and virtual-reality devices can produce symptoms of motion sickness in some individuals, even when there is little or no actual motion occurring. The authors of this report and staff from the National Maglev Initiative were provided with an opportunity to get a pilot's eye view of the world from an F-14 fixed-base simulator. At a simulated speed of 500 kph and an altitude of about 20 m while observing combat maneuvers, most of us began to feel a bit queasy in just a few minutes while viewing the giant, 180°-field-of-view screen. Although we found we could mitigate nausea by restricting our fields of view to small portions of the total projected image, we recognized the need to conduct tests to quantify the effects of cumulative exposure.

The literature (Ref. 2, 3, and 4) shows that the development of motion sickness depends not only on the magnitude of the accelerations experienced but also on their frequency characteristics and duration. Hence, for a given speed, it is the angle of tilt of the guideway (plus any additional tilt developed in the vehicle's suspension system) which determines the magnitude of the vertical acceleration. The length of the spiral determines the roll rate and hence the spectral distribution of the acceleration. Accelerations with periods in the range of 0.06 to 0.5 Hz are the primary contributors to motion sickness. Accelerations with shorter periods are sensed as vibration. They may be uncomfortable, but seldom induce motion sickness.

There are certain important insights to be gained from the literature that have served to guide the design of this study:

> 1. Motion sickness develops when there is some incongruity among sensory inputs from the visual, vestibular and kinesthetic systems. One may experience frequent accelerations and rolling movements of the head in many sports, for example, without any fear of sickness. Yet if a subject were sitting in a motion simulator and were exposed to the same accelerations, he might quickly become ill. Conversely, the phenomenon of "simulator sickness" has been widely reported (Ref. 5, pages 282-283). Subjects in simulators, who are feeling little or no actual motion, but are exposed to a visual field that suggests rapid movement, frequently develop one or more symptoms of motion sickness.
>
> 2. Controlling one's vehicle is a powerful preventative for motion sickness. Thus drivers virtually never become car sick, while passengers may. The best cure for seasickness is taking the helm. If an individual is not actively controlling a vehicle, looking out the window, especially at the horizon, helps ward off illness because it helps establish congruity between the various sensory inputs. Unfortunately, when passengers direct their visual focus toward reading, writing, operation of computers, etc., they effectively enhance whatever tendency they may have to motion sickness. Hence, common carriers catering to business travelers must provide smoother rides than user-operated modes.
>
> 3. Vertical motions with frequencies in the range from 0.06 Hz to 0.5 Hz are the primary ones of significance for motion sickness. More rapid motions (sensed as vibration) may cause discomfort and annoyance, but do not bring on nausea. Vertical accelerations induce more motion sickness than lateral or longitudinal accelerations of the same magnitude.

4. The longer passengers are exposed to motions with characteristics that induce motion sickness, the higher the proportion of them that will develop symptoms. For motions that might realistically be encountered in Maglev systems, symptoms could begin to develop in the most sensitive individuals in less than 15 minutes, while others would remain symptom-free for hours longer than the transit time for any foreseeable Maglev corridor. For a constant motion characteristic, the number of subjects experiencing vomiting is approximately proportional to the square root of the travel time up to about two hours.

1.2 Motion-Sickness-Dose Value

Motion-Sickness-Dose Value (MSDVz) refers to a methodology for quantifying the motion-sickness potential of a sequence of vertical accelerations. This internationally accepted measure is described in the new ISO 2631 (Annex C) on *Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration* (Ref. 6). The method involves computing a weighted root-mean-square (vertical) acceleration. The weighting is designed to attenuate accelerations that are not in the frequency range from 0.06 to 0.5 Hz. MSDVz was derived from British Standard 6841.

A body of literature exists supporting the use of MSDVz as a measure of motion-sickness potential -- relevant discussion can be found in *Handbook of Human Vibration* by M.J. Griffin (Ref. 5). Several studies have investigated MSDVz on ships. While motion sickness often occurs in planes, cars and other vehicles, the low-frequency vertical accelerations captured by MSDVz have been most common only in the marine environment. Thus the measure is of limited use in quantifying motion-sickness potential of aircraft and even less utility with respect to conventional ground vehicles. The causes of motion sickness are varied, and MSDVz is designed to assess a particular, known cause. In fact, ISO 2631 warns, “The methods ... should be primarily applicable to motion in ships and other sea vessels”.

Unlike traditional steel-wheel, steel-rail passenger systems that generate relatively low levels of vertical acceleration, modern high-speed, fixed-guideway systems could potentially produce substantial low-frequency vertical acceleration while traversing a sequence of curves. Through tilt technology, banked guideways or a combination thereof, the accelerations experienced by a passenger may be resolved through the vertical axis. A question of interest is whether the MSDVz, which takes as input data only the magnitude and duration of accelerations in the 0.06 - 0.5 Hz range, would be an appropriate tool for such a system.

The present study makes use of the MSDVz measurement technique in two ways. First, to aid in designing the study, MSDVz was estimated for each condition. Second, the MSDVz is used in data analysis: MSDVz was used as a predictor of the subjects’ ratings. Details of the calculation of the MSDVz, based on a measured sequence of accelerations and also based on a hypothetical route, are given in Appendix C.

It is important to realize that ISO 2631 provides no absolute guidance regarding the MSDVz measure, only relative guidance. Only with regards to the percentage of people who would vomit is there any absolute basis for evaluating the measure. The ISO reports that “...for a mixed population of unadapted male and female adults” the percentage of people “who may vomit” is 1/3 MSDVz. This prediction was investigated in the current study.

2. APPROACH

Because of the large number and complexity of the variables which influence the development of motion sickness, and because of the large differences among individuals in terms of susceptibility to that illness, an experimental design that attempted full-factorial treatment of variables would be impossibly expensive. Very early in course of this study, a decision was reached to test subject responses to sets of motions that resemble as closely as possible those of hypothetical Maglev vehicles operating over actual terrain. All tests would simulate passage through the same terrain, but the limits for maximum bank angle and roll rate would be varied. As higher limits for these variables are allowed, higher average speeds through turns are achieved. Thus, the results of the test could be expressed essentially as a tradeoff between travel time over an actual route and passenger comfort.

2.1 Modeling the Hypothetical Route

The ride-quality alignment model was developed to provide an aircraft pilot with a sequence of maneuvers that will simulate the vertical accelerations typical of a Maglev vehicle operating over a realistic guideway. In designing the model and selecting the route, the following criteria had to be met:

- a realistic Maglev guideway alignment of more than 100 miles (160 km) in length including detailed descriptions of guideway vertical and horizontal curvature at a scale of 1"=500’ or finer;

- including multiple terrain types;

- following an existing right-of-way and

- output from the model in a form which could be readily converted into a cockpit display.

The State of New York commissioned a study (Ref. 7) in which a Maglev guideway geometry was developed along four sections of the New York State Thruway and fit within the existing right of way. The four sections reported as appendices in the report are:

- The Thruway main line (I-87/90) (Appendix F begins between interchange #16 and #17 and ends between interchange #20 and #21) (Appendix G begins between interchange #30 and #31 and ends just beyond interchange #34A);

- I90 from Manchester to Rochester (Appendix H begins at about interchange #42 and ends at just before interchange #47) and

- The Berkshire Section (I-90) to the Massachusetts State Line (Appendix I begins at about interchange #B1 and ends just before interchange #B3).

These four sections represent multiple demographic, topographic and terrain types. The guideway geometry was available as engineering drawings (1"=500') and as data in the final report. However, neither the drawing nor the New York report specified individual spiral lengths or spiral start/end locations.

The Ride Quality Alignment Model reconstructed two dimensional spirals based on a combination of information supplied by the New York Thruway Authority, Berger Lehman Associates, the design drawing and the report. Output from the model could readily be translated to drive a cockpit display.

The Ride Quality Alignment Model has a coherent, fully extensible modular architecture. The six functional sections are: Alignment, Balance, Acceleration, Deceleration, Roll Rate, Bank Angle (as a function of arc length), and Travel Time (reparameterize in time) with smoothing. Modular subsections are arranged to automatically report constraint(s) which modify speed.

It was assumed that the study aircraft would fly at constant speed using smoothly transitioning maneuvers. No explicit vehicle characteristics (aerodynamic or propulsion technology) were considered. Acceleration and deceleration values were assumed equal. It was assumed that the radii of curvature reported in the New York study and input to the model described the radii at the apex of each curve. The four sections of guideway developed by the New York State Study were input as one continuous set.

The modeling approach was to first "build" the guideway and then "move" backward and forward over the entire track while computing the speed which satisfies physical laws and human-factors constraints. Backward and forward movement over the route ensures that interactions among sequences of curves will be fully modeled.

Locally, the program "looks ahead" to the next piece of track to ensure smooth speed transitions from one small piece of track to the next. The resulting speed profile was assumed smooth, and jerk was not explicitly modeled.

A speed profile for the entire route was computed separately for unconstrained or balanced lateral forces, for constrained lateral forces, for the induced vertical forces, and for longitudinal forces. As each force was computed, the value of speed that satisfies that constraint was compared to the previous lowest computed speed value at that point in space. If the new speed value was more constraining, i.e., lower, the speed was adjusted. The final speed profile satisfied all the considered constraints. Each time the speed profile was adjusted, the constraint that led to reduced speed was noted.

By taking advantage of symmetry, the Acceleration and Deceleration Modules and Reverse 1 and Reverse 2 Modules contained duplicate code. By choosing to implement code as a function of space rather than the traditional parameterization in time, the code was simplified. Outputs were the values of: speed at every point on the horizontal guideway as a function of space; speed at every point in time; and the most influential speed constraint at every point. After these values were calculated for the hypothetical Maglev trip profiles, they were used as inputs to a program which computed desired bank angles and roll rates for an aircraft flying at constant speed, which would subject passengers to the same amounts of vertical acceleration and roll at each moment of the trip.

The Appendices A, B and D contain a more detailed description of the model and a code listing.

2.2 Selection of Test Vehicles

The only available test vehicle that can come close to simulating the ride characteristics of a Maglev is an airplane flying through smooth air. As noted in the previous section, traversal of a curving right-of-way like the New York State Thruway at speeds of around 400 kph (250 mph) generates centrifugal forces ranging up to about 0.2 g. To avoid unpleasant lateral forces on passengers and excessive lateral loads on suspension, a Maglev can be designed so that it always banks at an angle which produces a coordinated turn, i.e., one in which the lateral force seems to disappear. Airplanes do this naturally; hence objects remain on tray tables, drinks do not spill, and passengers perceive no side forces as airliners bank and turn.

No practical ground-based simulator can reproduce the accelerations acting on passengers in a Maglev, because nearly all of them are positive. Thus a simulator would need to be miles high in order to generate an hour-long sequence of realistic, positive vertical accelerations. A wheeled vehicle following an appropriate, steeply banked course at the correct speed could generate the required vertical accelerations, but the guideway would be expensive to build and several versions would be required in order to test various speed profiles. Existing test tracks and racetracks would not produce the required pattern of g-forces, nor could a bus-like vehicle be driven fast enough to generate them.

The visual effects of seeing scenery at ground level rushing by at 500 kph were regarded as a potential problem of significant proportion for Maglev passengers. Since there was no feasible and safe method to test for visual effects at the same time subjects were experiencing realistic accelerations in an aircraft, a separate series of experiments in a ground-based simulator was devised. These would provide roll motions, visual effects and even simulated longitudinal accelerations based on the characteristics of the New York State Thruway route at various limits for roll rate and bank angle. Their prime objective was to determine whether the out-the-window view would induce kinetosis in any subjects.

2.3 The Flight Experiment

The principal disadvantages of the airplane as a Maglev simulator are:

- it can introduce unwanted motions (e.g., turbulence effects),
- it can not be safely flown at an altitude that produces a realistic out-the-window view,
- it is noisy,
- some persons find it inherently frightening,
- and, it cannot provide longitudinal acceleration or mid-frequency vibrations.

Flying only in calm air can minimize the first of these -- generally above 3657 meters (12,000 feet) when no storms are present. There is no practical solution to the second problem, other than a separate experiment (described below in Section 2. 4). Using a turbine-powered airliner, as opposed to smaller, piston-powered craft can mitigate the third.

Since a contract was being negotiated with Grumman Aerospace (later Northrop Grumman) for the use of its Maglev simulator and staff for the experiments described below, it was efficient to include rental of a Grumman corporate aircraft, a Gulfstream I 21-seat aircraft for the flight experiments. The contract was written for this aircraft and initial crew training flights and pilot tests were conducted with this plane.

After training one of Grumman's corporate air crews for about six hours (two hours in a simulator and four hours in flight), two preliminary test flights were conducted using employees of the U.S. Department of Transportation, the State of New York, other Federal agencies and contractors as subjects. These took place on March 11 and April 12, 1994.

These tests consisted of a series of ten-minute intervals in which bank-angle and roll-rate limits were raised to progressively higher values. By the intervals in which the limits reached 30^o and 12^o/sec, most of the subjects felt queasy or worse. There was general agreement in the debriefing sessions that members of the general public should not be subjected to rides as unpleasant as those the preliminary test subjects had experienced. The project team, based on these preliminary-test reactions selected lower limits, described below.

Due to Grumman's merger with Northrop and subsequent corporate restructuring in the summer of 1994, the Gulfstream I was sold. Grumman arranged to rent a Beechcraft 1900C, pictured in Figure 2-1, as a replacement. Figure 2-2 shows the interior of this aircraft. United Beechcraft, Inc. of Farmingdale, NY supplied the crews, who were trained in the course of two flights of about two-hour duration each in August 1994.

Figure 2-1. Exterior View of the Test Aircraft

Figure 2-2. Interior View of the Test Aircraft

2.4 The Simulator Experiment

Following the termination of the X-29 experimental fighter program, Grumman Aerospace was left with a multimillion dollar, full-motion-base simulator with elaborate computer-graphics capabilities. When Grumman became active in Maglev development work, this simulator was converted to study passenger reactions to various aspects of the ride quality of Maglev or other transport vehicles.

This simulator contains a passenger compartment about 3.66 meters (12 feet) in overall length, which resembles a portion of the first-class cabin of an airliner with four seats. Eighty-nine centimeter (35”) video monitors are fitted at both windows to present computer-generated views coordinated with the simulated movements of the module. Figure 2-3 shows an interior view of the module.

The seats and vestibule are enclosed with a hemispherical dome with a radius of about 3.05 meters (10 feet). The entire assembly is mounted on an array of hydraulic cylinders, as shown in Figure 2-4. These cylinders are powered by a set of hydraulic pumps through control valves operated by computers in an adjacent room.

The simulator experiments were driven with the same computer files of bank angle versus time data as were used in the aircraft experiment. However, since the simulator cannot produce sustained accelerations, the physical rolls were limited to about nine degrees in order to avoid subjecting the passengers to excessive lateral forces. Simulator motions mimicked the onset of a roll to higher angles and the out-the-window view in the monitors showed whatever angle of tilt was specified in the source file.

Because the creation of computer imagery is one of the significant cost elements in a simulation, only about 80 km (50 miles) of scenery were generated. These were repeated as necessary to provide a trip with a total length of 277 km (172 miles), just as the subjects experienced in the flight environment.

Figure 2-3. Interior View of the Northrop-Grumman Maglev Simulator

Figure 2-4. Exterior View of the Northrop-Grumman Maglev Simulator

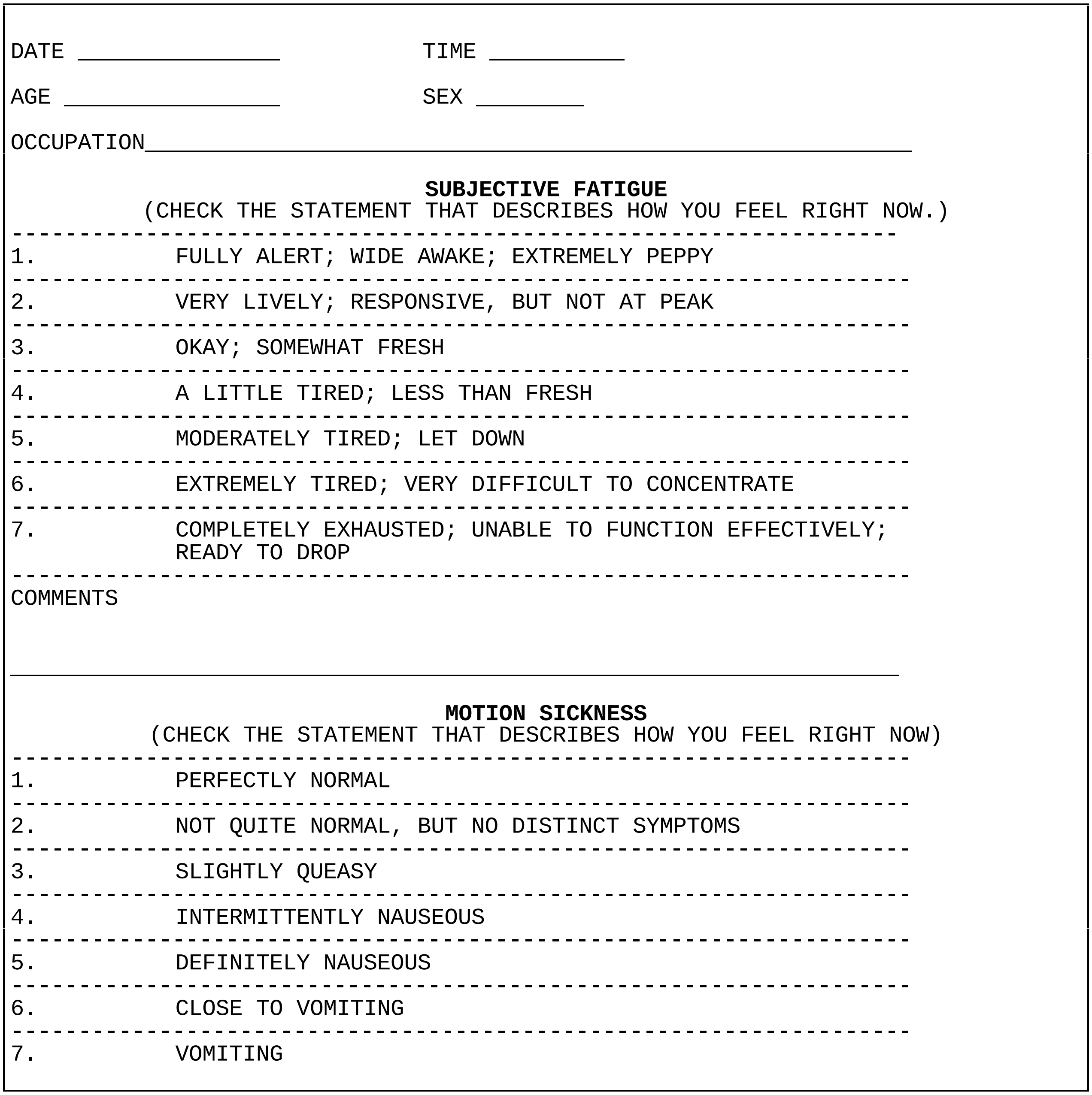
2.5 Subject Selection

Preusser Research Group, Inc. was retained to recruit, screen, and select at least 16 subjects for each of the nine test flights. Fourteen were intended to make each flight, while two extras were recruited to compensate for no-shows.

The subject pool was roughly balanced with respect to age (18 to 65 years) and sex, but excluded persons who have not made at least six round trips by air, including at least two in the past year. Persons with any medical condition that might lead to injury due to flying or g-loading (heart conditions, pregnancy, middle or inner-ear problems, etc.) were also excluded. Subjects selected were required to drive themselves to Republic Airport in Farmingdale on Long Island and were required to be somewhat flexible as to scheduling. Flights were subject to rescheduling for any of the following reasons: bad weather or rough air in the test zone; test area unavailable due to military use; aircraft in use for other business; or aircraft out of service for maintenance.

2.6 Experimental Procedure

In the lounges at the airport and at the simulator facility, contractor personnel briefed subjects and explained the way subjects were to evaluate each segment of the flight or simulator trip. Figures 2-5 and 2-6 show the first two pages of the rating booklet the subjects were given. The following pages were similar except that the subject description items were deleted. It was explained to subjects that they would be expected to complete one rating sheet at the beginning of the experimental portion of the trip and one additional sheet each time they were prompted to do so by the experimenter. There were five such prompts on each flight, so that the rating intervals ranged from about eight to almost ten minutes in length.



DATE ________________ TIME __________

AGE _________________ SEX ________

OCCUPATION____

SUBJECTIVE FATIGUE

(CHECK THE STATEMENT THAT DESCRIBES HOW YOU FEEL RIGHT NOW.)

1. FULLY ALERT; WIDE AWAKE; EXTREMELY PEPPY
2. VERY LIVELY; RESPONSIVE, BUT NOT AT PEAK
3. OKAY; SOMEWHAT FRESH
4. A LITTLE TIRED; LESS THAN FRESH
5. MODERATELY TIRED; LET DOWN
6. EXTREMELY TIRED; VERY DIFFICULT TO CONCENTRATE
7. COMPLETELY EXHAUSTED; UNABLE TO FUNCTION EFFECTIVELY; READY TO DROP

COMMENTS

____

MOTION SICKNESS

(CHECK THE STATEMENT THAT DESCRIBES HOW YOU FEEL RIGHT NOW)

1. PERFECTLY NORMAL
2. NOT QUITE NORMAL, BUT NO DISTINCT SYMPTOMS
3. SLIGHTLY QUEASY
4. INTERMITTENTLY NAUSEOUS
5. DEFINITELY NAUSEOUS
6. CLOSE TO VOMITING
7. VOMITING

Figure 2-5. First Page of Subject-Rating Booklet

INTERVAL #1

THE RIDE DURING THE PAST FIVE MINUTES WAS:

_____ VERY COMFORTABLE

_____ COMFORTABLE

_____ SOMEWHAT COMFORTABLE

_____ NEUTRAL

_____ SOMEWHAT UNCOMFORTABLE

_____ UNCOMFORTABLE

_____ VERY UNCOMFORTABLE

(PLEASE CHECK ONLY ONE ANSWER)

MOTION SICKNESS

(CHECK THE STATEMENT THAT DESCRIBES HOW YOU FEEL RIGHT NOW)

1. PERFECTLY NORMAL
2. NOT QUITE NORMAL, BUT NO DISTINCT SYMPTOMS
3. SLIGHTLY QUEASY
4. INTERMITTENTLY NAUSEOUS
5. DEFINITELY NAUSEOUS
6. CLOSE TO VOMITING
7. VOMITING

_______ Check here if you chose not to read because of queasiness.

What are a few of the names of the types of pianos mentioned in the article?

____

Figure 2-6. Example Page of Subject-Rating Booklet Completed at End of Each Interval

At the lounges, they were also presented with a assortment of magazine articles to read during the experimental portion of the flight. Each package contained five articles of a few pages each, one for each of the five intervals. Subjects were required to read and answer in writing one question about each of the articles they read. Subjects were free to choose from the following categories of articles: business, entertainment, fashion, home and family, science, sports, and miscellaneous.

Prior to leaving the lounges they were required to read and sign a consent form describing the experiment and its goals and risks. Copies of the forms are reproduced in Appendix F. Subjects were accompanied on each flight by two members of the research team and on each simulator trip by one Northrop Grumman staff member. Their schedule for one day was as follows:

DAILY SCHEDULE

09:15	8 morning simulator subjects arrive at security for check in.
09:30	Simulator subjects are escorted to simulator building.
	Morning flight subjects arrive at the boarding lounge for briefing and use of rest rooms.
09:40	First group of simulator subjects is briefed. Second group remains in conference room to read or watch video.
09:50	Subjects enter simulator.
09:55	Simulator run begins.
	Flight subjects board aircraft.
10:00	Aircraft departs gate.
10:05	Aircraft takeoff.
10:30	Aircraft reaches 4572 meters (15,000 feet) and is at least 16 km (10 miles) inside warning area 105. Experiment begins.
10:45	Second group of simulator subjects is briefed.
10:55	First simulator run ends. Subjects are escorted to conference room, debriefed and entertained with a video or reading materials.
11:00	Second group of subjects enters simulator.
11:05	Second simulator run begins.
11:10 to 11:30	Flight experiment ends.
11:40 to 12:00	Aircraft arrives at gate.

11:45 to 12:05	Second simulator run ends.
12:05	Box lunches are served to 8 subjects from morning simulator runs.
12:05	Flight subjects who are also simulator subjects are given maps and directions to Bethpage facilities and begin driving their cars. Other flight subjects are paid off and released.
112:30	Morning simulator subjects are escorted out through security and given maps and directions to airport.
12:35	Morning simulator subjects begin driving to Farmingdale.
	Afternoon simulator subjects arrive at security desk.
12:50	8 Afternoon simulator subjects are escorted to conference room and served box lunches.
13:05	Afternoon flight subjects arrive at boarding lounge for briefing and use of rest rooms.
13:20	Third group of simulator subjects is briefed.
	Fourth groups of simulator subjects remain in conference room to read or watch video.
13:25	Subjects enter simulator.
13:30	Simulator run begins.
	Flight subjects board aircraft.
13:35	Aircraft departs gate.
13:40	Aircraft takeoff.
14:05	Aircraft reaches 4572 meters (15,000 feet) and is at least 16 km (10 miles) inside warning area 105. Experiment begins.
14:15	Fourth group of simulator subjects is briefed.
14:10 to 14:30	Third simulator run ends. Subjects are escorted to conference room, debriefed, paid off and released.
14:35	Fourth group of simulator subjects enters simulator.
14:40	Fourth simulator run begins.
14:45 to 15:05	Flight experiment ends.
15:15 to 15:30	Aircraft arrives at gate. Subjects are debriefed, paid off and released.
15:20 to 15:40	Fourth simulator run ends. Subjects are debriefed, paid off and released.

From the time of takeoff, about 25 minutes were required to climb above 4572 meters (15,000 feet) and reach the test area. Each group of subjects then experienced a sequence of roll maneuvers with one of the nine possible combinations of limits on bank angle and roll rate shown in Table 2-1.

Table 2-1. Combinations of Limits on Bank Angles and Roll Rates

Max Roll Rate	Max Bank Angle		
	14^o	21^o	28^o
4^osec	x	x	x
6^osec	x	x	x
8^osec	x	x	x

For each combination of maximum bank angle and maximum roll rate, there is an implied average speed over the specified right-of-way. Speed is higher for the more severe combinations of bank and roll rate. Two-hundred seventy-seven km (172 miles) of the Thruway were simulated, implying trip times ranging from about 40 minutes for the higher limits to about 48 minutes for the most gentle ride.

Appendix E shows a plot of bank angle versus time for the worst-case trip, i.e., 28-degree bank-angle limit with an 8-degree/sec roll-rate limit. The units for the time axis are seconds; the total duration of the test sequence is 2354.4 seconds or 39.23 minutes.

The experimental portion of each flight was conducted in Warning Area 105, southeast of Long Island. Warning Areas are blocks of restricted airspace, which may not be entered without prior authorization from Air Traffic Control. They are normally used for training, military practice missions, and research. Only one aircraft is permitted to occupy a given block of airspace at a time, so that the pilot can devote his full attention to maneuvering without having to watch out for other aircraft.

Direction to the pilot in flying this series of rolls was provided by a computer-driven, simulated attitude display with one bar showing the desired bank angle at each instant and a second showing actual bank angle as measured by a gyro connected to the computer. The pilot's job was simply to keep the bars parallel. The display incorporates additional indicators regarding the desired bank angle 2 seconds and 10 seconds into the future.

The experimenter and flight crew were continuously monitored on radar by Calverton Tracker (Grumman's trackers who normally monitor test and training flights for fighter aircraft). Range and bearing information from Calverton VOR were relayed at frequent intervals to one member of the research team who plotted the aircraft's location on a chart. In order to keep the aircraft on a roughly circular course about 100 km (60 miles) in diameter and well within the boundaries of the warning area, the experimenter inverted the polarity of certain roll maneuvers. Figure 2-6 shows a portion of an aeronautical chart covering the area used for the test flights with the actual plotted positions for one of the flights.

It was agreed in advance that if any subjects reported or displayed symptoms of nausea, the flight would be terminated early. Only one subject did so, on flight #8, with bank angle limits of 28 degrees and roll limits of 8 degrees/sec. The pilot immediately began heading back to Republic Airport in a straight line, but after seven minutes of smooth flight, the subject asked that experimental maneuvers be resumed. The last interval of this flight was flown according to plan.

During flight #7 (28-degree bank-angle limits and 6-degree/sec roll-rate limits) a second subject vomited, as evidenced by the contents of an air-sickness bag found during cleanup after returning to Republic Airport. Since that subject never made any indication of illness during the experimental portion of the flight, it is presumed that this incident of emesis occurred just afterward.

At the end of each flight or simulator trip, the research team members collected the rating booklets, debriefed subjects, and recorded any pertinent comments regarding ride quality and comfort. Subjects were queried as to whether they felt dizzy, nauseous, or otherwise unable to drive home safely. Fortunately, the two who experienced vomiting had come with someone else who was not ill and was able to drive them home. Had any been incapacitated, arrangements had been made to transport them home safely by taxicab or other means.

All subjects were paid $50.00 at the conclusion of the flight. Extra subjects who are not used were also compensated and rescheduled for a later flight.

Half of the subjects were asked to take a one-hour trip in Grumman's Maglev Simulator located in Bethpage. Subjects who took this extra test were paid an additional $25.00 and given a box lunch between the morning and afternoon test sessions.

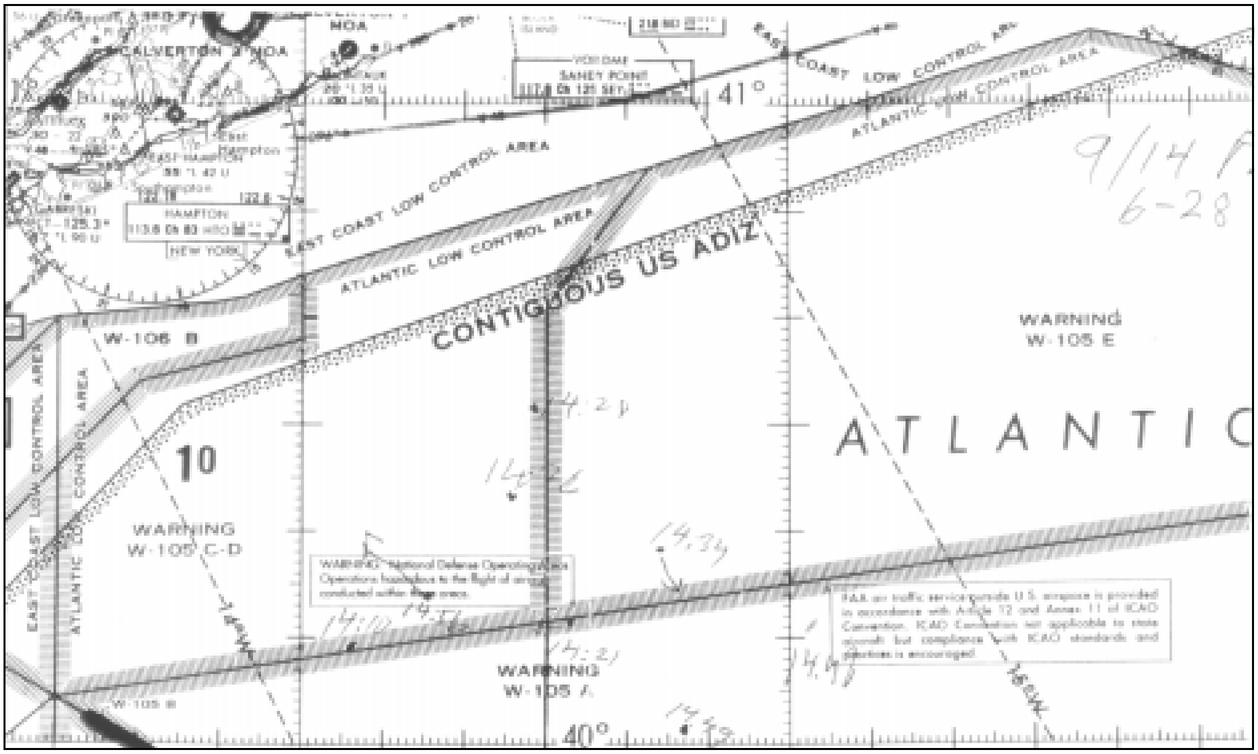


Figure 2-7. Partial Aeronautical Chart Showing the Warning Area Where Tests Were Conducted

2.7 Aircraft Instrumentation

The instrumentation package used for the flight experiments was required to perform three functions:

- Present to the pilot a display showing desired bank angle at each instant in time for a given set of limits.
- Provide feedback to the pilot as to how closely the aircraft's actual bank angle matched the desired bank angle.
- Record the roll rate, actual bank angles and accelerations in all three axes at intervals of 0.1 second.

To present the information on desired and actual bank angles, a small video display was mounted temporarily over the aircraft's normal attitude display. (Figure 2-8) This monitor was driven from a notebook computer running custom software through a converter that transformed the VGA output of the computer into an NTSC video signal for the monitor. The software contained a look-up table with the values for bank angle at 0.2-second intervals and routines to convert these numeric values into inclination angles for a red bar on the display. This computer was linked through its serial port to a second notebook that served as the data-acquisition computer. (Figure 2-9)

The second computer collected readings from three accelerometers and a roll-rate gyro at intervals of 0.1 second. These were installed in a small case located under one of the passenger seats in the aircraft. The accelerometers were contained in an Entran Devices Model EGCS3-A-2 three-axis unit (2 g full scale). The rate gyro was a solid-state device manufactured by Systron-Donner called the GyroChip, with a full-scale range of plus/minus 20 degrees/sec. The voltage outputs of these transducers were recorded through a Computer Boards Inc. PCM-DAS08 data-acquisition card using Laboratory Technologies' Labtech Notebook software. Bank angles were calculated within Notebook by integrating and smoothing the roll-rate data.

Bank-angle data were sent across the serial link along with a time stamp, allowing the first computer to update the pilot's display at intervals of 0.2 second. The software also provided two smaller indicators showing what the bank angle would be two seconds ahead of the current moment and the direction of the next maneuver.

Figure 2-8. Attitude Display Temporarily Installed in the Cockpit of the Beechcraft 1900C

Figure 2-9. Notebook Computers Used for Data Acquisition and Generation of the Cockpit Display

This instrumentation allowed pilots to fly a reasonable approximation of the desired sequence of maneuvers with only a couple of hours of practice. Figure 2-10 shows an example of the data acquisition screen displaying the correspondence between desired and actual bank angles. Desired bank angle (DBA) is shown in black, while actual bank angle (CBA) appears in gray. The deviations in the actual are primarily the results of slight turbulence and pilot actions in this example.

Figure 2-10. Example of the Correspondence between the Desired Bank Angles and the Actual Bank Angles during a Three-Minute Period

However the actual vertical acceleration dosage experienced by passengers on the plane trips was significantly greater than the theoretical dosage that should have been accumulated by a Maglev vehicle traversing a guideway built to the nominal limits. This extra vertical acceleration arose from several sources including:

- turbulence in the atmosphere
- altitude changes made in search of smoother air
- corrections of drift in the bank-angle measurement instrumentation (corrections required extra turns)
- extra turns required to keep the aircraft within the restricted airspace

- pilot error in following the displayed attitude indication.

The greatest excess of actual MSDV over desired MSDV occurred in flights 6 and 7, which were characterized by strong northwest winds in the test area and low temperatures. The latter required the use of windshield heaters, which effectively disabled the magnetic compass and eliminated direct feedback to the experimenter as to aircraft heading.

The peak roll rates were two to four degrees per second higher than intended on each flight. Hence the ratings developed here are conservative. An actual Maglev would not be subject to any of the aforementioned sources of vertical acceleration, and would generate substantially less vertical acceleration in the 0.06 to 0.5 Hz range than the plane flights did. Thus, the incidence of motion sickness observed (8% of the subjects reported "intermittently nauseous" or worse) probably exceeds that which would occur aboard an actual Maglev system built to the same nominal limits for bank angle and roll rate.

2.8 Simulator Instrumentation

Since the simulator could reproduce a specified series of movements precisely and consistently, there was no need to record accelerometer and rate gyro data in every trial. Rather, the simulator was programmed by the Northrop Grumman staff to one of the nine possible combinations of roll-rate and bank-angle limits for each trial using a data file of bank-angle values by time at 0.1-second intervals as supplied by the Volpe Center. These bank angles were reproduced exactly in the simulated out-the-window view, but the actual roll of the simulator capsule was limited to about one-third of the specified value in order not to generate unpleasant lateral accelerations.

Simulated trips of 80 km (50 miles) each were recorded on the same instrumentation as was used in the airplane for the following limits:

- 14-degree bank angle and 4-degree/sec roll rate
- 14-degree bank angle and 8-degree/sec roll rate
- 28-degree bank angle and 4-degree/sec roll rate
- 28-degree bank angle and 8-degree/sec roll rate.

Section 3-5 provides a graphic example of the motions generated for the fastest set of design limits.

3. ANALYSIS OF DATA

3.1 Description of Motion-Sickness-Dosage Value

A Maglev vehicle traveling at high speed and negotiating frequent curves requiring bank angles greater than 20 degrees has a potential for inducing motion sickness in some segment of the passenger population. If the route alignment and speed are known at all points on the route, then the complete set of passenger motions is readily available. For an assumed hypothetical route alignment, one can determine a minimum-time trajectory given limits on the speed, acceleration, deceleration, bank angle and roll rate. Such a trajectory was calculated for the New York State Thruway data as described in Section 2.1.

With regard to motion sickness, vertical accelerations at frequencies of 0.1 to 0.5 Hz are the predominant source of motion sickness, although other motions and visual stimuli can contribute. The known facts are well summarized in Ref. 5 and Ref. 8 and are reflected in ISO standard 2631 for ride quality measurements. Griffin and coworkers have unified much previous work. They have proposed a dosage measure for motion sickness that is the time integral of the square of the frequency-weighted vertical acceleration. This means that the vertical acceleration (as a time series) is to serve as input to a filter specified in British Standard 6841. (Ref. 8) The output is the frequency-weighted acceleration. It has frequencies appreciably outside the 0.06 to 0.5 Hz band significantly attenuated. The cumulative measure specified in the British Standard is referred to there as the Motion Sickness Dosage Value, which we refer to also as the MSDV. (See Appendix C, KINCALC.SAS for discussion of a method for calculating MSDV).

The dose measure was also used in selecting trajectories as scenarios for the experiment that were not so rigorous as to be likely to induce vomiting in many passengers, yet not so mild as to fail to induce any significant level of discomfort in any significant proportion of the persons evaluating the ride. The former limiting case could force flights to be cut short, while the latter would mean that no useful data were obtained.

There is a further potential use for a properly validated and calibrated MSDV. Just as optimum trajectories can be derived maximizing average speed with acceleration, bank angle and roll rate limited, we could add one more constraint: that total (cumulative) MSDV be limited to a certain value. Such analysis would provide the best analytic procedure for finding a velocity profile that allows maximum average speed while not inducing motion sickness in the passengers. Because we can in principle calculate the MSDV for every conceivable trajectory, it is possible to determine where to go fast and where to go slow in order to hold down the MSDV. The filter output itself indicates where the incremental dosage is high and these places are where speed should probably held down. Regardless of the computational procedure the goal is easily stated in principle:

> If one were to calculate the total MSDV for each trajectory satisfying the basic constraints (acceleration, bank angle, roll rate), which would have the highest average speed of all those that satisfy the motion sickness dosage limit constraint? With modern optimization

techniques, one need not examine even approximately all feasible trajectories and the calculational procedure will probably be easily within modest computing resources.

What does the dosage measure say about the proposed trajectories for the New York State Thruway route? Since vertical acceleration vs. time (ignoring grade changes) is available, one can calculate the cumulative Motion Sickness Dosage Index for each of the nine trajectories that have been developed. These nine cases represent all possible combinations of three levels each of bank angle and roll rate, and are as follows:

	Low	Medium	High
Bank Angle (deg.)	14	21	28
Roll Rate (deg./sec.)	4	6	8

The trajectories are constructed to maximize average speed over the whole route while holding acceleration/deceleration, bank angle, and roll rates to within the given limits. Each trajectory has (in general) a different overall average speed. In general the less restrictive the constraints the higher the average speed.

Some preliminary results concerning the nine test trajectories representing the New York State Thruway route can be given. Table 3-1 presents results on trajectories for all nine combinations of the conditions shown above. For each trajectory the values of the two conditions (independent variables) are given. Also, given are the outcomes variables: average speed (in kph and mph) and MSDV (cumulative over the whole route) calculated in two ways.

Table 3-1. Characteristics of the Nine Test Flights

Flight #	Roll Rate	Bank Angle	MSDVz Desired	MSDVz Actual	Average Speed		Transit Time
					(kph)	(mph)	(min.)
1	4	21	2.1	3.1	341	212	48.6
2	4	14	1.6	3.6	328	204	50.5
3	4	28	1.9	2.9	341	212	48.6
4	6	21	3.5	6.0	378	235	44.0
5	6	14	1.9	2.4	336	209	49.5
6	8	14	1.9	4.6	336	209	49.5
7	6	28	4.0	7.5	383	238	43.3
8	8	28	5.7	5.8	410	255	40.5
9	8	21	4.2	4.8	389	242	42.6

MSDVz and average speed were calculated for 27 different combinations of limits on roll rate, bank angle and longitudinal acceleration for the New York State route. Longitudinal accelerations were constrained to lie in the +/- 0.15g range (the normal acceleration limits of the proposed Maglev systems). These assumed longitudinal accelerations were used to modify the flight path so that the airplane subjects would experience the same levels of vertical acceleration as would passengers in a Maglev vehicle. (Commercial airliners can not generate substantial longitudinal accelerations except in takeoff or landing). Dosage vs. average speed is given in Figure 3-1. Note that MSDVz is determined largely but not solely by average speed.

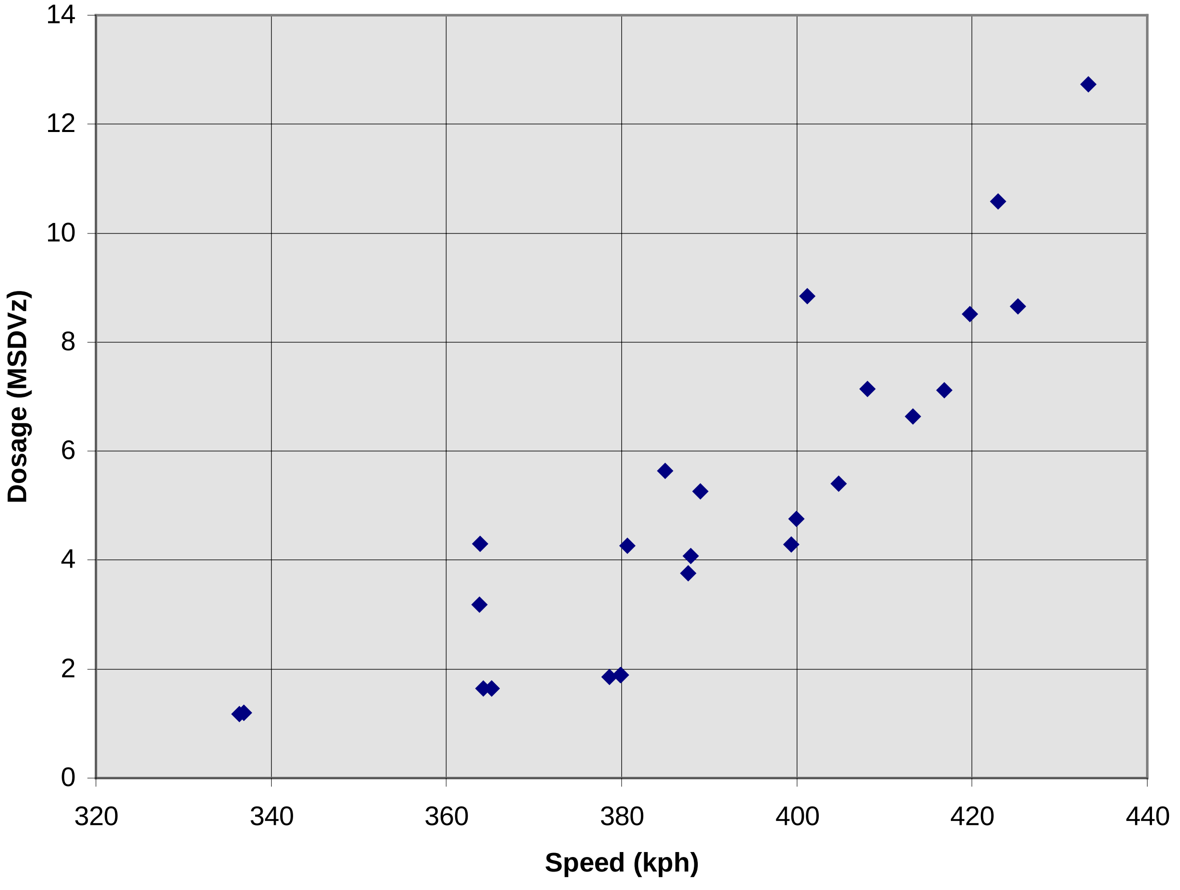


Figure 3-1. Motion-Sickness Dosage for 27 Hypothetical Combinations of Bank-Angle and Roll-Rate Limits for the New York State Thruway Route

3.2 Analysis of Flight Data

As noted in Table 3-1 above, all of the flights produced more vertical acceleration than would have been caused solely by following the hypothetical Maglev trajectory. The excess dosage ranged from about 2% on flight 8 to more than 100% on flights 2 and 6. These excess dosages were the result of a variety of problems discussed in Section 2.6. Thus all of the analyses and findings that follow are conservative, i.e. a real Maglev following the same trajectory should produce less passenger discomfort and motion-sickness.

On all but two of the flights, about four out of five passengers rated ride quality as "somewhat comfortable" or better in every interval. For the other two flights the proportion of such ratings fell to about two out of three. Figure 3-2 shows these data presented in terms of the percentage of subjects who reported a rating of "neutral" or worse in any interval of a specified flight.

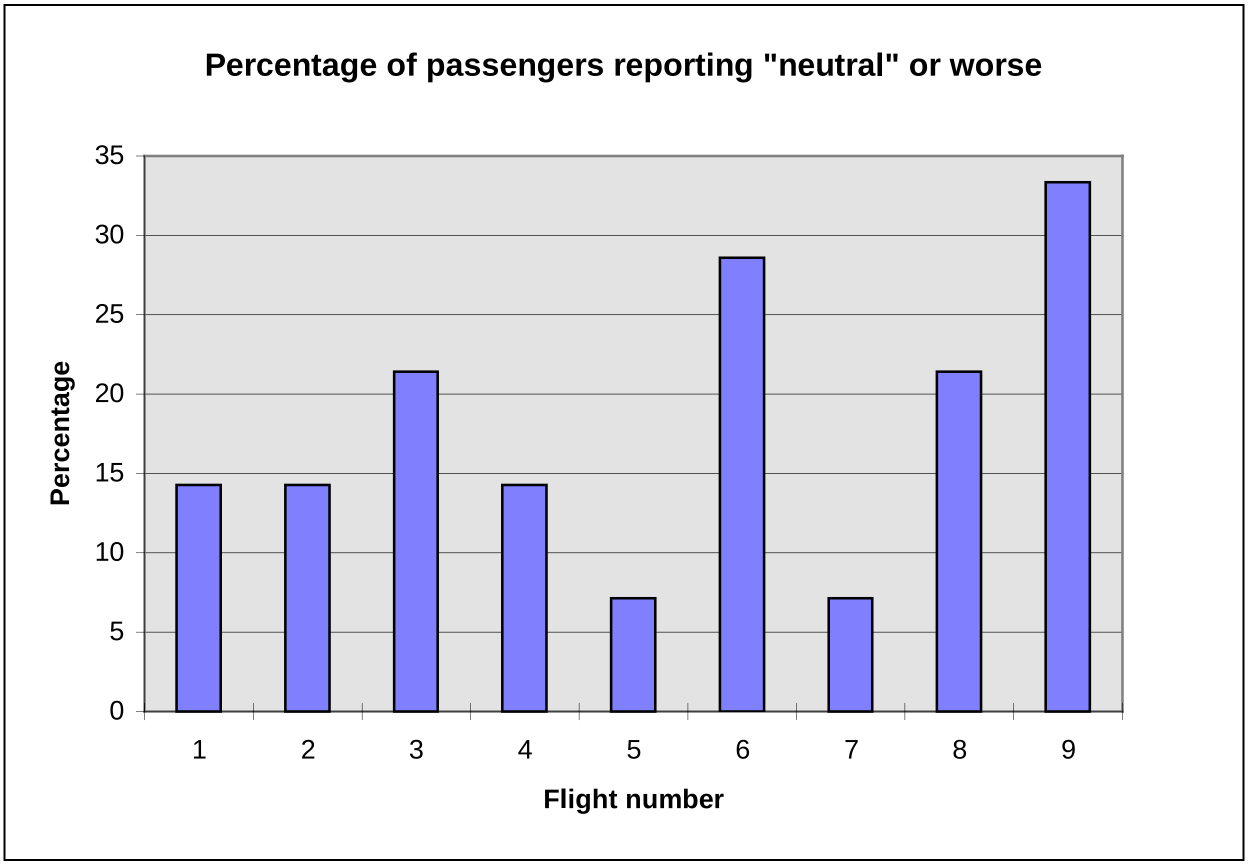


Figure 3-2. Passenger Ratings of Ride Comfort During the Flight Experiments as "Neutral" or Worse (4 or Greater on the 7-Point Scale)

By the more rigorous standard of "comfortable" or better, only about half the passengers on most flights were that well pleased. Note in Figure 3-3 that on flights 5 and 7, almost everyone felt comfortable. Flight 5 had the lowest actual MSDVz, but flight 7 had the highest. The authors can only conclude that differences between subjects as to how ride comfort is perceived overwhelmed the actual differences in ride motions.

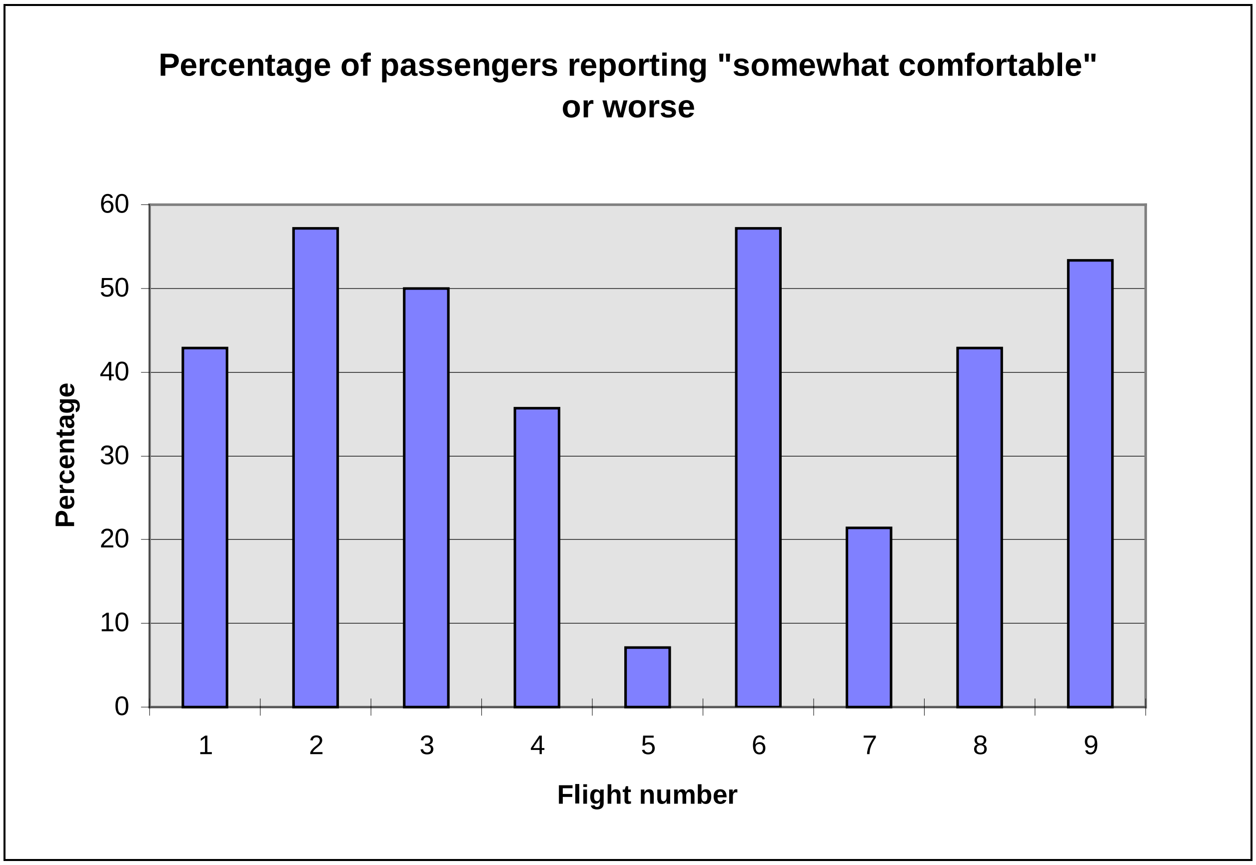


Figure 3-3. Passenger Ratings of Ride Comfort During the Flight Experiments as “Somewhat Comfortable” or Worse (3 or Greater on the 7-Point Scale)

Although only two subjects actually vomited, all of the flights induced some queasiness in two or more passengers as indicated in Figure 3-4.

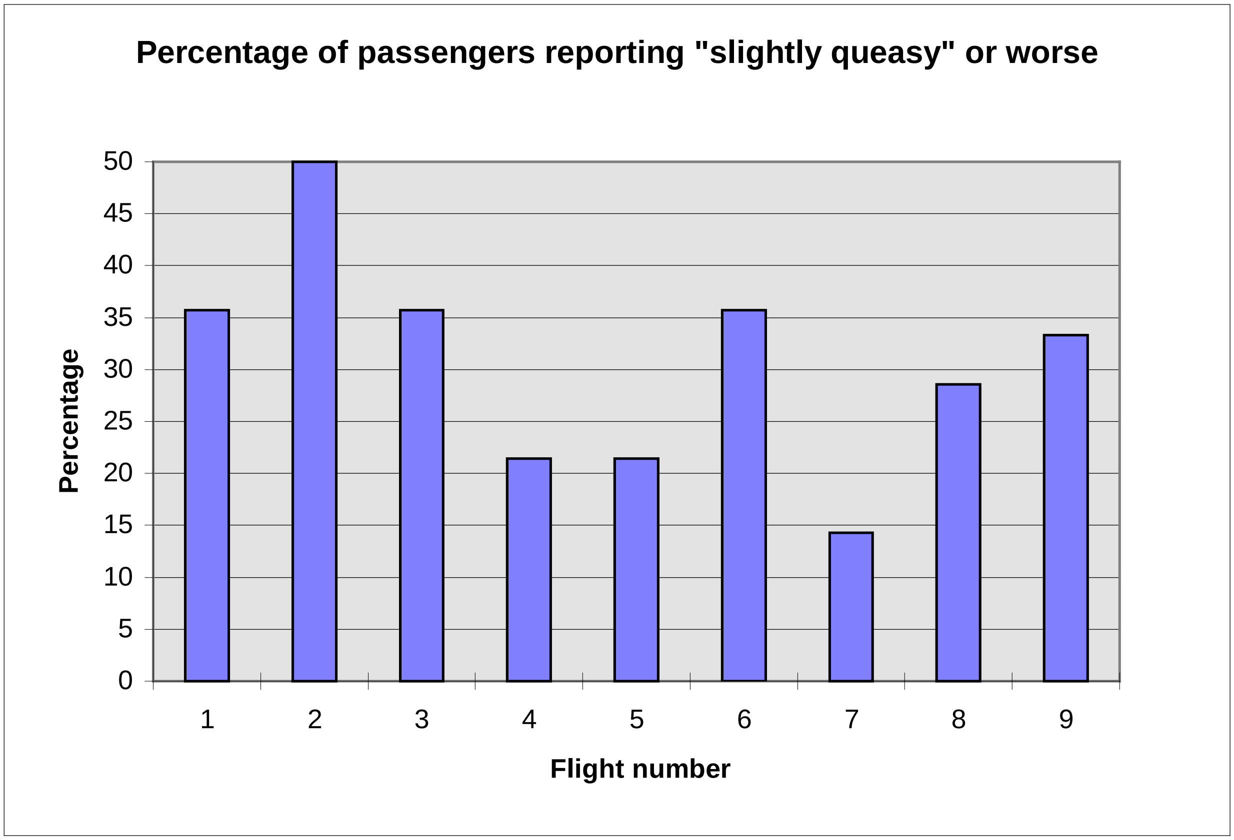


Figure 3-4. Percentage of Passengers Reporting “Slight Queasiness” or Worse (3 or Greater on the 7-Point Scale)

That such substantial percentages of the subjects should have felt queasy or worse is hardly surprising in view of the substantial dose of vertical acceleration they received. Figure 3-5 shows the roll rates and accelerations in all three axes for flight 8, which had nominal limits of 8-degrees/sec and 28-degrees maximum bank angle. Note period of about five minutes near end of flight in which traces are nearly flat and typical of normal airliner conditions. This occurred after a subject had vomited. After a few minutes, that subject requested that the experiment be resumed.

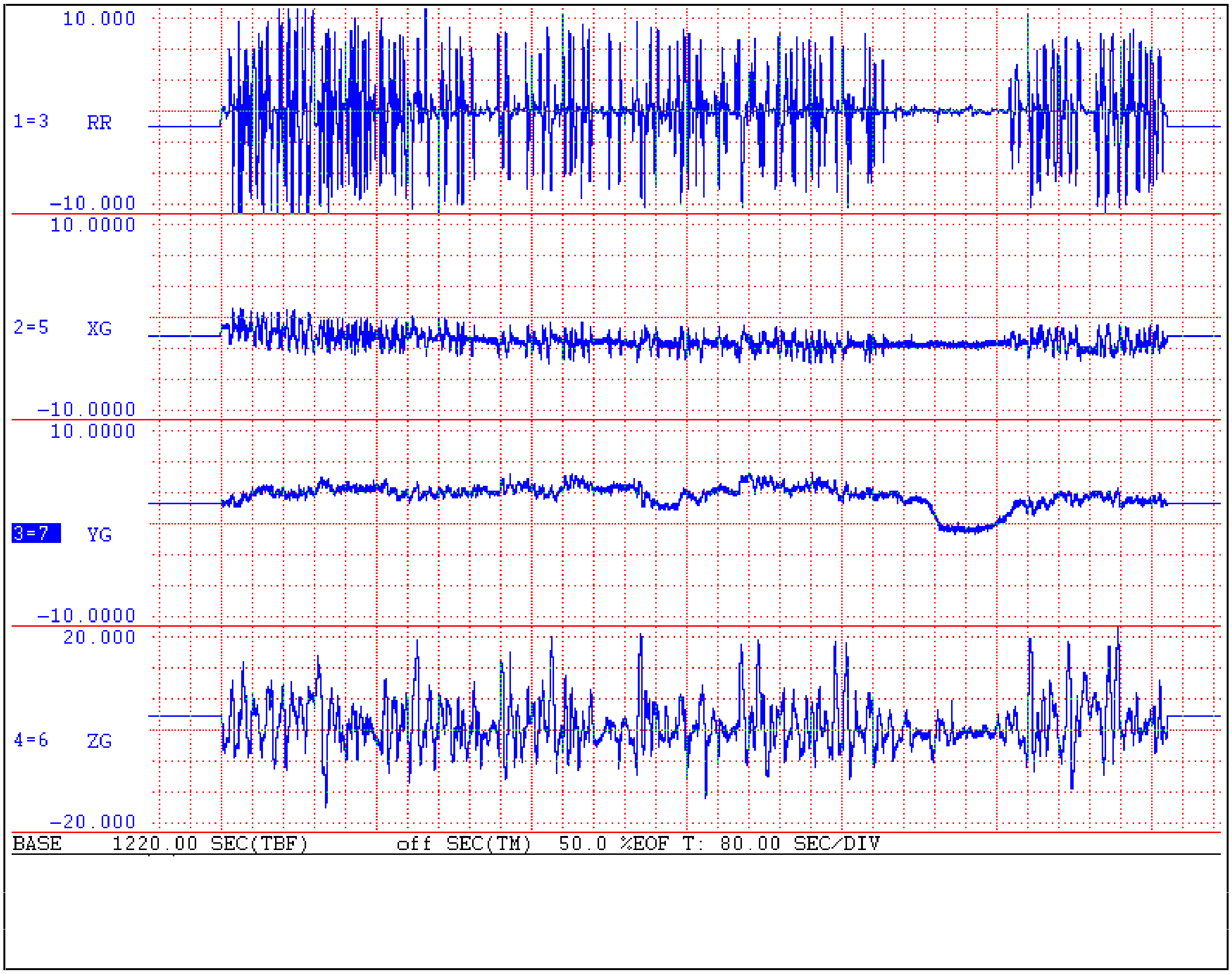


Figure 3-5. Roll Rates and Accelerations for Flight 8

The spectrum of the vertical acceleration record shown above is presented in Figure 3-6, which shows that most of the energy in the vertical movements is found below one Hz, with the peak at 0.0345 Hz. This implies that peak power is associated with roll maneuvers with periods of about 29 seconds.

Power spectra for the other flights are similar in shape with their peaks at nearly the same frequency. Peak amplitudes vary by several dB, depending on the severity of the ride.

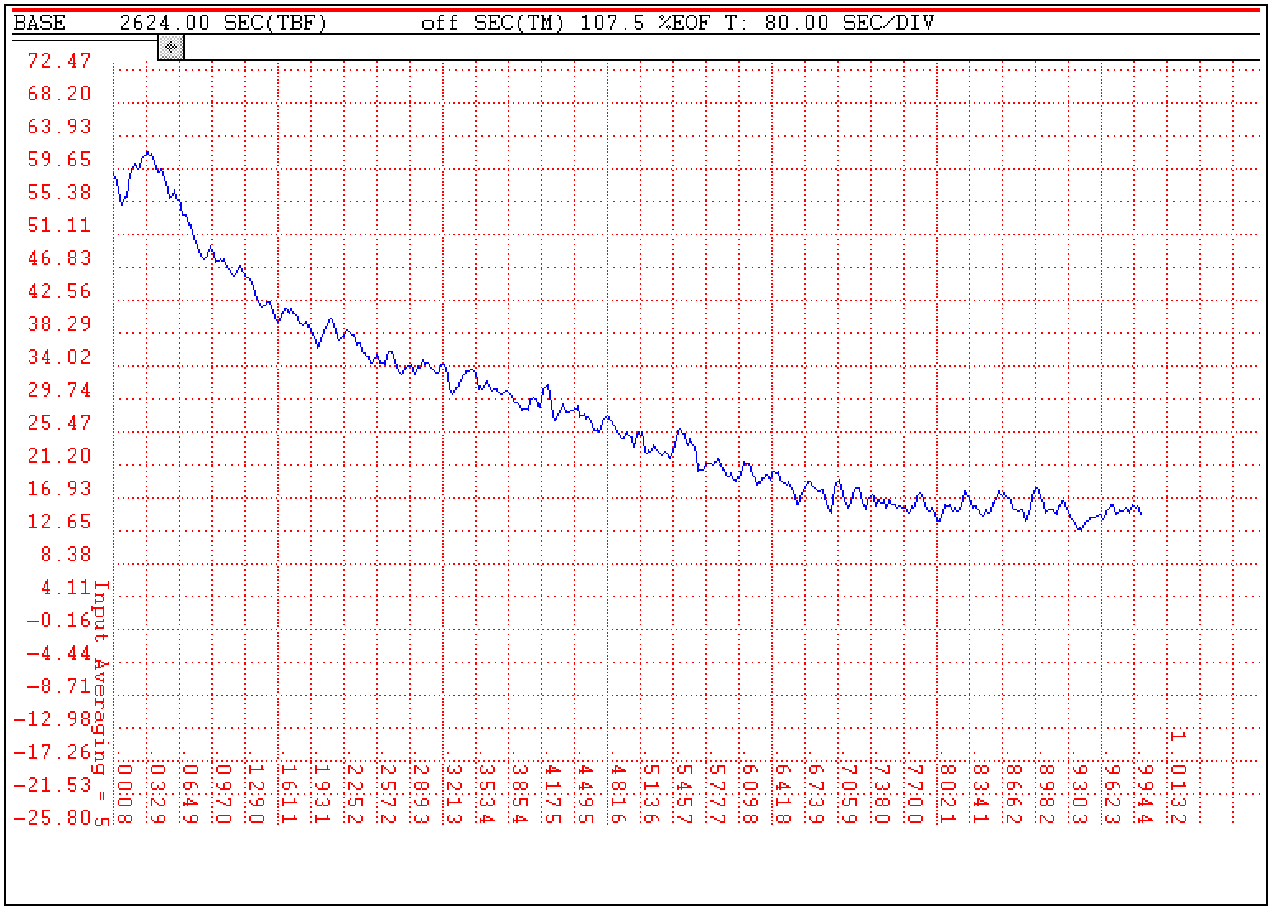
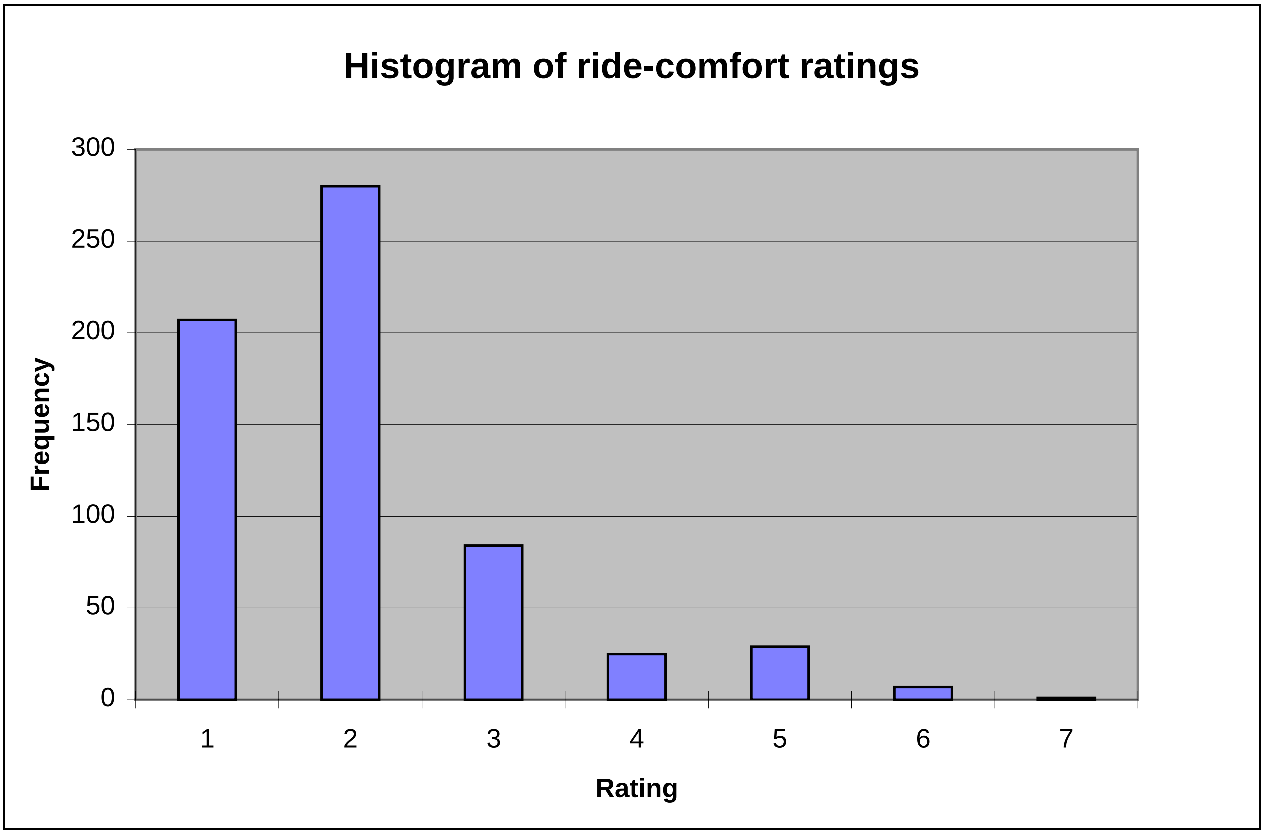


Figure 3-6. Spectrum of the Vertical Acceleration Record Shown in Figure 3-5
(Vertical scale in decibels, horizontal scale in hertz)

3.3 Discussion of Lack of Correlation Between MSDV and Subject Ratings

The two dependent variables of interest are the motion-sickness ratings (scale: 1 to 7) and ride-comfort ratings (scale: 1 to 7). There were 635 responses on each scale (9 flights times 14 subjects per flight times 5 ride intervals per flight equals 630, plus five more from an extra subject carried on flight 8). Figures 3-7 and 3-8 below show histograms of the motion-sickness and ride-comfort ratings, respectively. The figures show that the vast majority of subjects were comfortable and free of motion sickness. Uncomfortable ratings for ride quality were reported about twice as frequently as those for motion sickness.



(1=Very Comfortable, 7=Very Uncomfortable)

Figure 3-7. Passenger Ratings of Ride Comfort Summed across All Flights

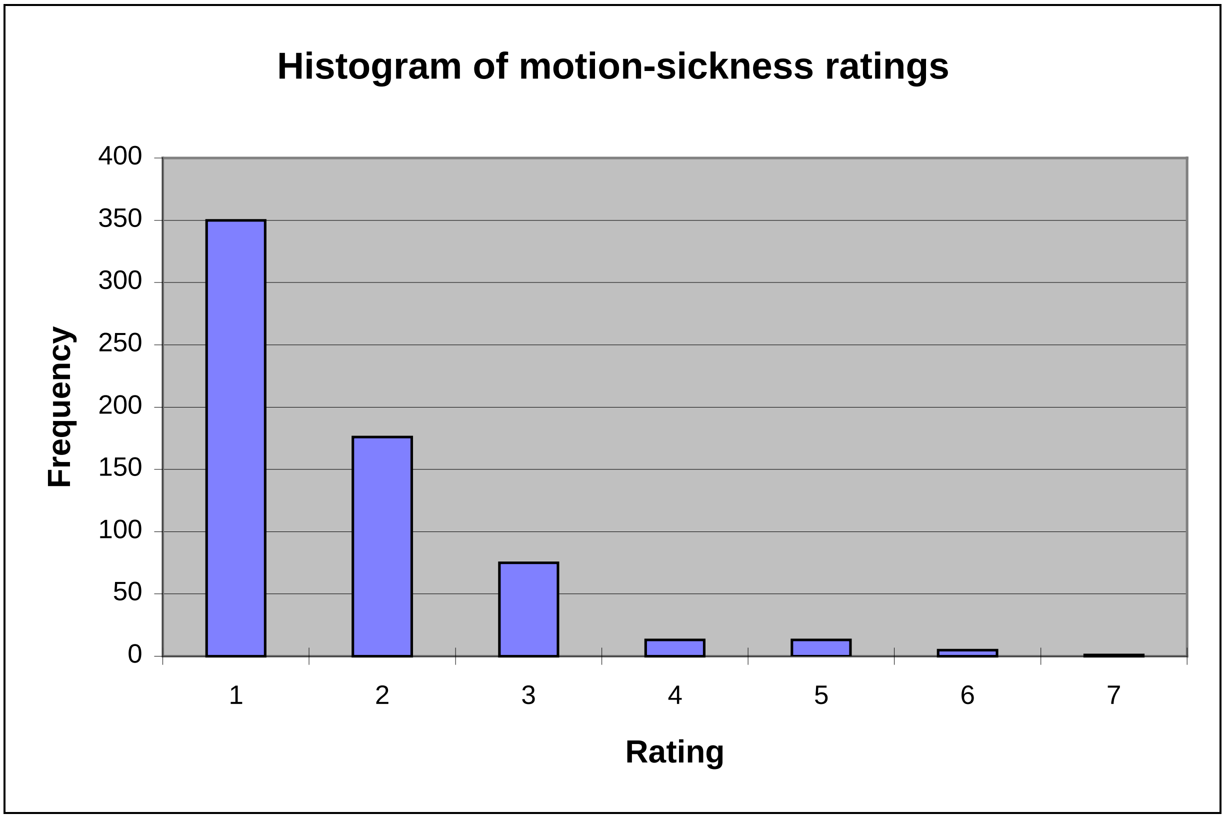


Figure 3-8. Passenger Ratings of Motion Sickness Summed across All Flights

Of primary concern is the extent to which the variance in the two dependent variables can be explained by variation in the ride parameters. There were three parameters that have been examined: Motion-sickness-dose value (MSDVz or Dose), mean square of roll rate (Roll), and mean-square vertical acceleration (MSYG). Dose is calculated as a frequency-weighted average of the vertical acceleration as measured by the accelerometers. Mean-square of roll rate involves averaging the squared roll-rate values measured by the rate gyro over the relevant time interval. Mean-square vertical acceleration, like the Dose value, is based on vertical accelerations measured by the accelerometer, but unlike the Dose value does not involve frequency weighting. Each of these measurements is taken in two forms: a "local" form and a "cumulative" form. In the local form, only the measurements from the relevant ride interval are included. The "cumulative" form includes all measurements from the start of interval 1 for the given flight.

Table 3-2 displays the results of fitting two linear models to the motion sickness data. The first model (Model 11) includes subject and cumulative dose as independent variables. The second includes the aforementioned plus the flight-interval variable. One interesting result is that the motion-sickness variable is a function of the flight interval; the sickness increases as the flight continues (note that the parameter estimate for interval is positive). This agrees with previous research that indicates that duration of exposure to nauseogenic motions elevates a person's motion-sickness levels. Thus, any regression with a cumulative-motion measure, such as cumulative dose, reveals a significant relation between the cumulative measure and the motion-sickness value, as evidenced in Model 11.

On the other hand, since such a relationship might be explained as an artifact of the "duration of exposure"/motion-sickness relation, it is important to consider the additional explanatory power of the proposed motion variable in a model that already includes interval. Only by demonstrating such an effect can we conclude that the motions measured by the motion variable are contributing to the elevated motion sickness scores. Examination of Model 12 in Table 3-2 shows that this effect was not significant**.** To further clarify this point, although in Model 11 the dose variable is significantly and positively related to motion sickness, the fact that this relationship does not hold up in Model 12 (where the flight interval variable is included) suggests that the dose variable is not important. Its significance in Model 11 is apparently due to its cumulative nature -- that is, it appears to serve as a proxy for the duration of exposure to the nauseogenic motions.

Table 3-2. Comparison of Two Linear Models Fitted to the Motion-Sickness Ratings

```
                                  Model 11
General Linear Models Procedure
Dependent Variable: MOT_SICK
                                   Sum of           Mean
Source                  DF        Squares         Square   F Value     Pr > F
Model                  127     531.950487       4.188587     18.72     0.0001
Error                  505     112.981582       0.223726
Corrected Total        632     644.932070
                  R-Square           C.V.       Root MSE        MOT_SICK Mean
                  0.824816       27.69722        0.47300              1.70774


Source                  DF    Type III SS    Mean-square   F Value     Pr > F
SUBJ                   126     529.887646       4.205458     18.80     0.0001
CUMDOSE                  1       7.368418       7.368418     32.94     0.0001


                                      T for H0:    Pr > |T|  Std Error of
Parameter                 Estimate   Parameter=0               Estimate

INTERCEPT              1.336374006 B        5.90     0.0001    0.22643242
CUMDOSE                0.121889564          5.74     0.0001    0.02123917
```

```
                                  Model 12
General Linear Models Procedure
Dependent Variable: MOT_SICK
                                   Sum of           Mean
Source                  DF        Squares         Square   F Value     Pr > F
Model                  128     533.549289       4.168354     18.86     0.0001
Error                  504     111.382781       0.220998
Corrected Total        632     644.932070
                  R-Square           C.V.       Root MSE        MOT_SICK Mean
                  0.827295       27.52782        0.47010              1.70774


Source                  DF    Type III SS    Mean-square   F Value     Pr > F
SUBJ                   126     524.554009       4.163127     18.84     0.0001
INTERV                   1       1.598802       1.598802      7.23     0.0074
CUMDOSE                  1       0.001014       0.001014      0.00     0.9460


                                      T for H0:    Pr > |T|  Std Error of
Parameter                 Estimate   Parameter=0               Estimate

INTERCEPT              1.554682580 B        6.50     0.0001    0.23923649
INTERV                 0.086166335          2.69     0.0074    0.03203569
CUMDOSE               -0.003465503         -0.07     0.9460    0.05116332
```

Another question involves the relationship of the flight-motion measures to the subjective measures on a flight-by-flight basis. Specifically, did those flights that experienced the greatest motions produce the greatest degree of motion sickness and discomfort? The answer to this question appears to be “No.” Table 3-3 shows the total of three motion variables (MSDVz, mean-square vertical accelerations, and mean-square roll rates) as well as four summary measures of the motion-sickness and comfort ratings (average of the average and average of the maximum motion-sickness and ride comfort). Table 3-4 is the correlation matrix of the seven variables presented in Table 3-3. Note that this analysis treats each flight as producing one observation; thus we have nine observations in the data set. This small number of observations, combined with the high degree of subject variability, may be partially responsible for the lack of a relationship between the motion variables and the response variables. It may also be due to the range of motions included in the study. Another surprising finding in the correlation matrix is the low correlation (r = .125) between the MSDVz and the mean-square vertical accelerations. The key difference between these two measures is that the MSDVz weights low frequencies (from 0.06 to 0.5 Hz) heavily and weights other frequencies zero, while the MS Accel does not use any frequency weighting.

Table 3-3. Dosages and Subject Responses for the Nine Flights

Flight	**Total MSDVz**	**MS Accel**	**MS Roll**	**AMMS**	**AMRC**	**AAMS**	**AARC**
1	3.1	39.3	5.0	1.9	2.4	1.5	1.8
2	3.6	22.9	4.3	2.6	2.7	2.0	2.3
3	2.9	24.0	4.4	2.0	2.8	1.7	2.2
4	6.0	22.0	11.1	2.0	2.5	1.5	2.1
5	2.4	9.5	5.1	1.6	1.9	1.3	1.5
6	4.6	11.2	5.5	2.6	3.2	2.2	2.5
7	7.5	28.0	10.5	1.6	2.1	1.4	1.7
8	5.8	23.4	11.3	2.1	2.7	1.7	2.0
9	4.8	16.1	9.5	2.3	3.1	2.1	2.6

Notes:

Total MSDVz - Cumulative motion-sickness dosage value
MS Accel - Cumulative (unweighted) vertical acceleration
MS Roll - Cumulative mean-square of roll rate
AMMS - Average (per flight) of the maximum (per person) motion-sickness rating
AMRC - Average (per flight) of the maximum (per person) ride-comfort rating
AAMS - Average (per flight) of the average (per person) motion-sickness rating
AARC - Average (per flight) of the average (per person) ride-comfort rating

Table 3-4. Correlation Matrix for Dosages and Subject Responses

	Total MSDVz	*MS Accel*	*MS Roll*	*AMMS*	*AMRC*	*AAMS*	*AARC*
Total MSDVz	1						
MS Accel	0.125	1					
MS Roll	0.866	0.051	1				
AMMS	-0.077	-0.266	-0.208	1			
AMRC	-0.013	-0.219	-0.052	0.872	1		
AAMS	0.000	-0.320	-0.139	0.959	0.933	1	
AARC	0.029	-0.258	-0.008	0.859	0.960	0.922	1

Figure 3-9 shows the mean motion-sickness rating for each interval on each flight (45 points). The lack of correlation with the cumulative dosage value is evident in the scatter.

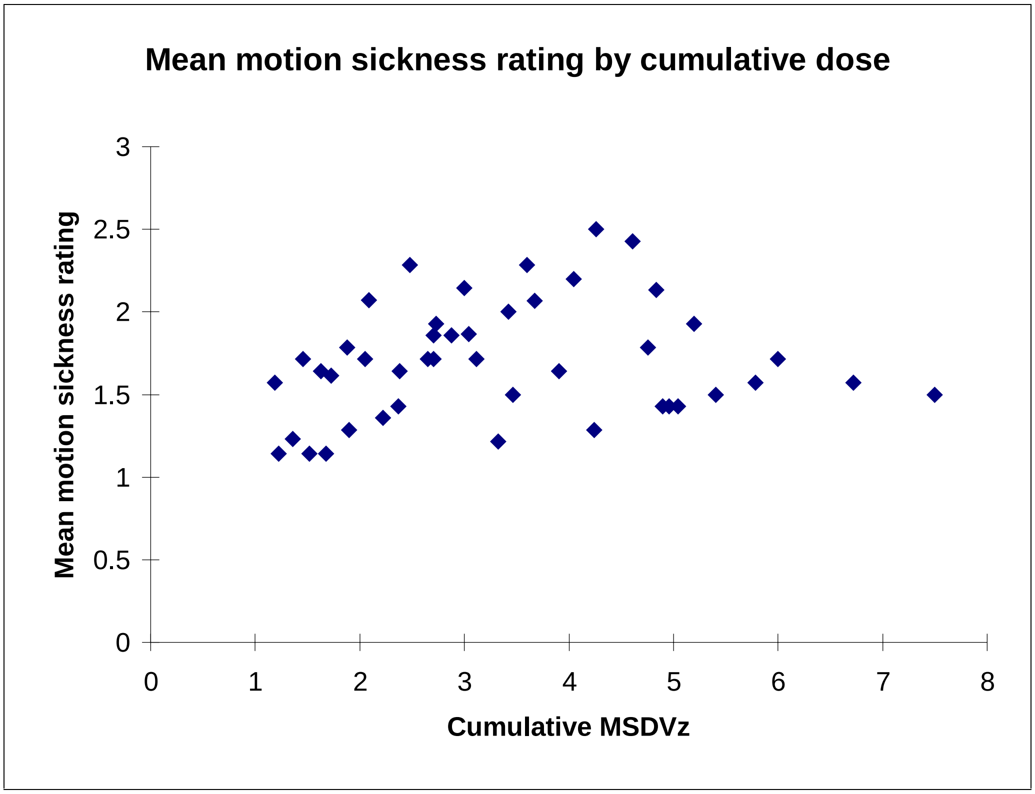


Figure 3-9. Motion-Sickness Ratings by Cumulative Dose

Figure 3-10 is a scatter plot of the 635 individual subject ratings. Since there were nine flights with five ratings each, there are only 45 discrete values that occur on the horizontal scale. Subjects were constrained to one of seven integer values for each response, so that most points on this scatter plot represent more than one subject response, i.e., there are many hidden points.

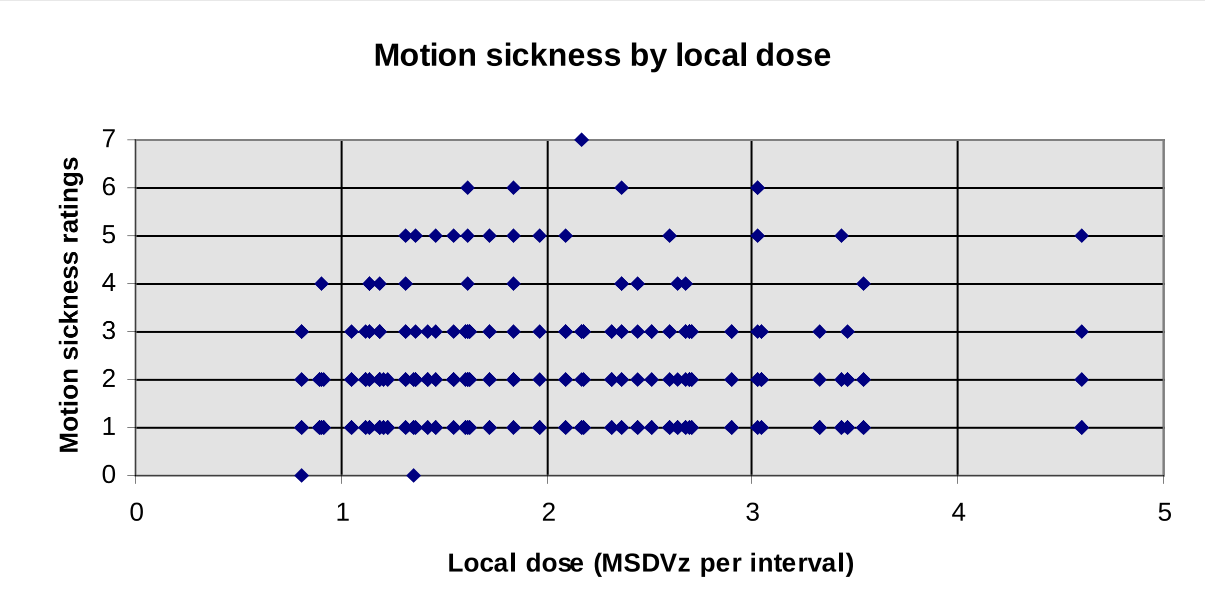


Figure 3-10. Scatter Plot of Motion-Sickness Ratings for Individual Intervals

3.4 Discussion of Correlation Between Duration and Subject Ratings

Subjects' motion-sickness ratings did show significant correlations with one independent variable -- duration (as represented by "interval" in their responses). As shown in Figure 3-11, there is a slight, but significant downtrend in the number of subjects reporting they feel "perfectly normal," offset by substantial increases in those feeling "slightly queasy" and smaller increases in those feeling worse.

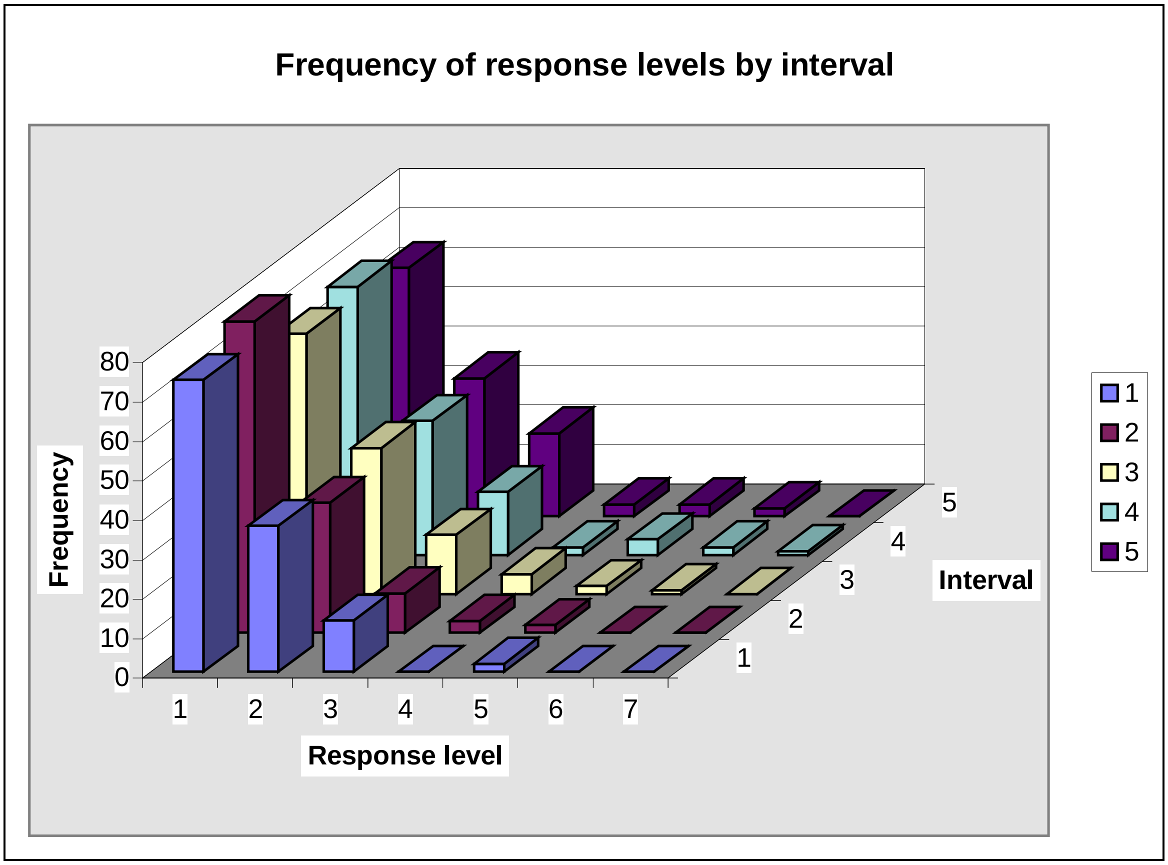


Figure 3-11. Motion-Sickness Ratings by Interval, Summed Across Flights

3.5 Comparison of Flights with Simulations

No one came close to vomiting in the simulator, while two subjects did so aboard the airplane. (The second instance of vomiting occurred just after the end of interval five and does not show up in the ratings data.) In fact, slightly more than half the subjects felt "perfectly normal" throughout the simulator trip, while only about 38% of the airplane subjects felt that well. Figure 3-12 shows this comparison.

However, subjects rated the ride comfort of the simulator as distinctly inferior to that of the airplane, as shown in Figure 3-13. Less than a quarter of the subjects on the simulator found every interval to be "comfortable" or "very comfortable," while about 60% of the subjects on the airplane so reported. Nearly 40% of the subjects rated at least one portion of the simulator trip as "somewhat uncomfortable" or worse, while only about 15% of them did so while riding on the airplane.

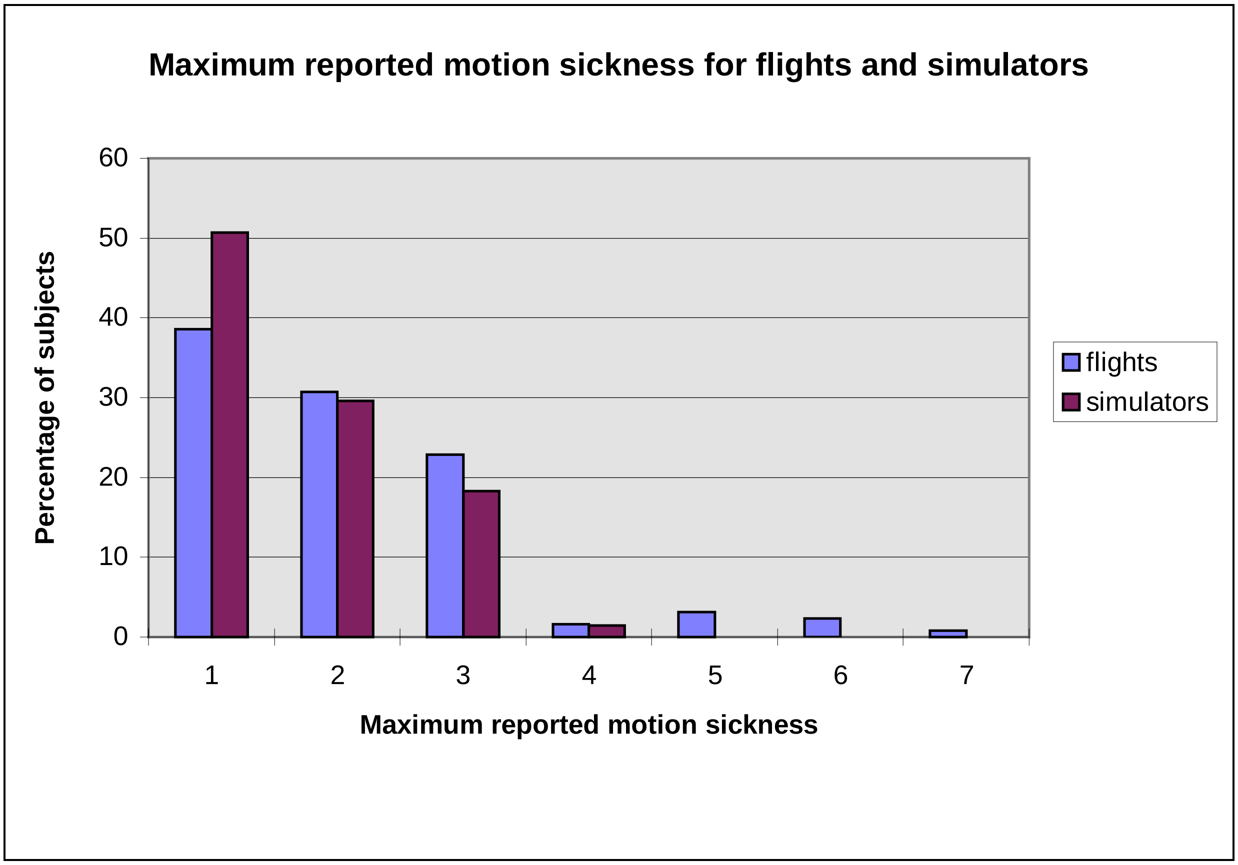


Figure 3-12. Comparison of Motion-Sickness Ratings between the Airplane and the Simulator

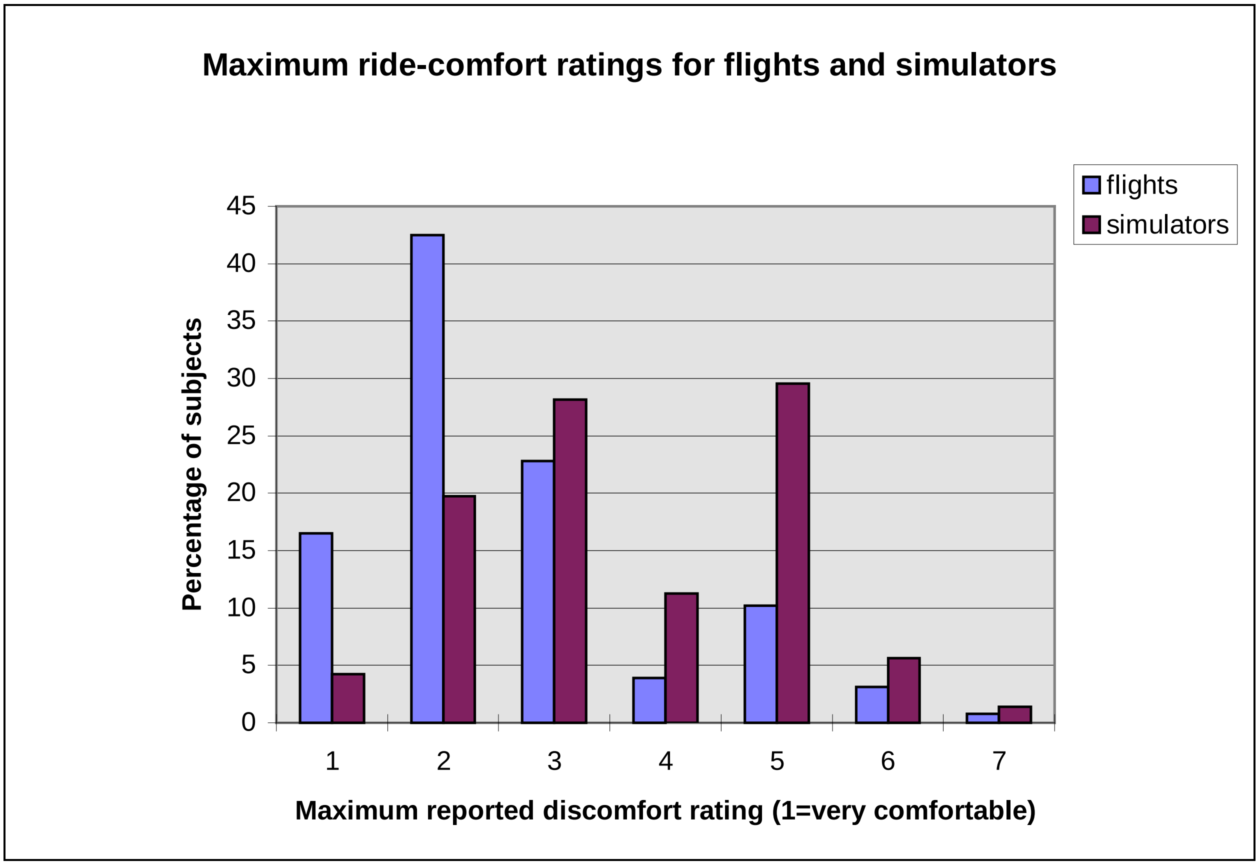
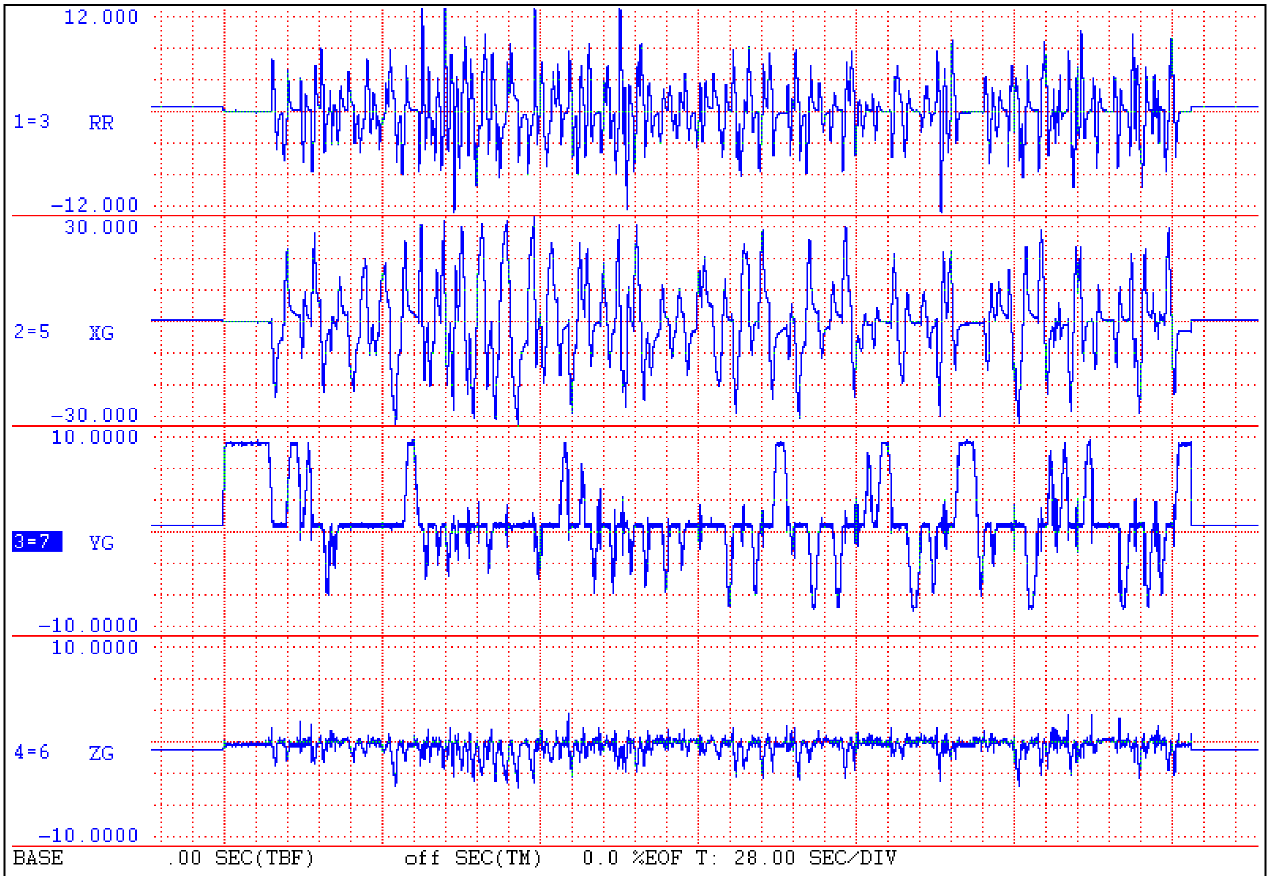


Figure 3-13. Comparison of Ride-Comfort Ratings for Flights vs. Simulator Trips

This disparity is most likely attributable to the annoying lateral forces experienced in the simulator, which are not present at all in flight, and not likely to occur in a Maglev or other high-speed-ground systems. Figure 3-14 shows a record of the roll rates and accelerations in all three axes experienced in the simulator during a 14-minute trip with simulated (i.e., visual) bank angles of 28 degrees and roll rates of up to 8 degrees/sec. Note that lateral acceleration (Xg) hit peak values of about 30 centi-g on several occasions.



Horizontal axis is time, 28 sec/division. Vertical scale is degrees/sec. for roll rate and centi-g for accelerations.

Figure 3-14. Roll Rates and Accelerations Experienced in the Simulator for the Worst Case

4. CONCLUSIONS

There were no significant statistical correlations between the subject ratings and the physical variables (vertical accelerations and roll rates) over the ranges tested. Nonetheless, several important conclusions can be drawn from this study:

1. On most flights, the actual vertical-acceleration dosage was significantly greater than the theoretical dosage that should have been accumulated by a Maglev traversing a guideway built to the nominal limits. This extra vertical acceleration arose from several sources including: turbulence in the atmosphere; altitude changes; corrections of drift in the bank-angle measurement instrumentation; extra turns required to keep the aircraft within the restricted air space; and pilot error in following the displayed attitude indication. The peak roll rates were two to four degrees per second higher than intended on each flight. Hence the ratings developed here are conservative. An actual Maglev would not be subject to any of these sources of vertical acceleration, and would generate less vertical acceleration in the 0.1 to 1 Hz range than the plane flight.

   The vast majority of subjects found the airplane simulation comfortable, even though in that simulation they experienced a motion environment considerably less comfortable than an actual Maglev or other high-speed ground system would produce. The average comfort rating for the plane trip ranged from 1.5 to 2.64 over the nine flights. These ratings were based on a seven-point scale where 1 is very comfortable, 2 is comfortable, 3 is somewhat comfortable, 4 is neutral, 5 is somewhat uncomfortable, 6 is uncomfortable and 7 is very uncomfortable. Eighty-two percent of the 127 subjects rated every interval as somewhat comfortable or better on the airplane.

   In the ground-based simulation, the average comfort rating varied from 1.68 to 4.57 over the 18 sessions, using the same rating scale described above. Fifty-two percent of the 71 subjects rated every interval as “somewhat comfortable” or better.

2. Motion sickness was not a problem for the majority of subjects. On the flights, 69% never felt even slight queasiness at any point, while 23% felt slight queasiness, but nothing worse. Eight percent (10 out of 127) felt “intermittently nauseous” or worse at least one time in flight. Two subjects vomited during the flights. The Griffin model had predicted that for 127 subjects exposed to the dosages given, 1.92 would vomit. This very close correspondence between the model and actual results may have been a coincidence, but suggests that the extension of this methodology to the evaluation of other modes may be useful.

   On the simulator, no one experienced definite nausea or vomiting and only one subject out of 71 reported intermittent nausea. Eighteen percent (13 subjects) reported slight queasiness, and more than 80% of the subjects were free of any symptoms of motion sickness. The relative lack of motion-sickness problems on the simulator was expected because it cannot produce sustained vertical accelerations, which are the major contributor to kinetosis.

3. Based on the results of this study there is no evidence that more than a small percentage of Maglev passengers would experience kinetosis on routes confined to the boundaries of existing highway rights-of-way. This study simulated a Maglev system traveling through representative portions of the proposed New York State route at average speeds that ranged from 320 to 400 kph (200 to 250 mph). While the vertical accelerations experienced by the subjects in the aircraft simulation were generally greater than those that would be experienced by Maglev passengers, only 2 of the 127 subjects vomited.

4. At the start of this study, higher limits for maximum bank angle and roll rate were contemplated, based on previous work with isolated maneuvers. However, because of concerns that motion sickness might be far more prevalent at these higher limits when the rolling maneuvers were separated by only a few seconds, two pilot tests were conducted using about 30 personnel associated with various Maglev research projects supported by the U. S. Department of Transportation. Based on the reactions of these subjects, ride quality ratings would have declined sharply, while the incidence of motion sickness would have increased sharply, had the subjects been exposed to roll-rate limits of 10 or 12 degrees/sec and bank angles as high as 40^o. More than half of the participants on the pilot tests reported queasiness or worse under these higher limits. These pilot-test ratings were the basis for the decision to limit the exposure of the public subjects to 8 degrees/sec in roll and 28 degrees in bank angle.

5. Among the independent variables in the experiments (maximum bank angles and roll rates, and duration of exposure), duration was the only significant predictor of the subjects' motion- sickness ratings. Flights were divided into five rating intervals, of eight to ten minutes each. Only two subjects felt “intermittent nausea” in the first interval, while nine subjects were “intermittently nauseous” or worse by the fourth interval. One subject vomited in the fourth interval and another just after the fifth. Had the experiments lasted longer, it is likely that some additional subjects would have reported motion-sickness symptoms.

6. The visual effects experienced in the ground-based simulator did not cause significant problems. Only one subject reported “intermittent nausea” in the simulator and none experienced any worse symptoms. Even though the windows were simulated with 35" video monitors, the proportion of the total visual field filled with moving images was sufficiently small to avoid creating problems for passengers. Since actual Maglev vehicles are likely to have smaller windows than the simulator, there is no reason to expect that significant numbers of future Maglev passengers will be adversely affected by seeing the scenery rushing past.

7. Because subject comfort and motion-sickness ratings were essentially randomly distributed across the nine flights, it must be concluded that for a small fraction of the population (the 8% who felt more than slightly queasy in the study), even a very modest

amount of rolling is uncomfortable. Such persons will likely avoid Maglev, except on routes that are relatively straight and flat. For the remainder of the population, bank angles at the high end of the tested range are acceptable, even when roll maneuvers are occurring every 15 or 20 seconds. However, it must be recognized that persons who are particularly prone to motion sickness probably did not volunteer to participate in this experiment. Thus the proportion of the general population who would not use Maglev on a route with numerous curves may be somewhat larger than 8%.

8. Both the airplane and simulator experiments contributed to our understanding of ride-quality and motion-sickness issues in high-speed ground systems. Other questions, such as limits on longitudinal acceleration, were not addressed in this study, but will require examination in simulator tests prior to actual system design.

APPENDIX A. COMBO.BAS: OVERVIEW AND EXPLANATION

Purpose

The purpose of this appendix is to provide an overview and explanation of the computer program COMBO.BAS. The discussion begins by explaining *what* the program does and how to use it and then explains *how* the program works by describing the program flow and the kinematic formulas it uses. The annotated code appears in Appendix B.

Overview

COMBO.BAS is a QUICKBASIC program which calculates a minimum time “speed profile” from a 2 dimensional “curvature trajectory” (a curve in the x-y plane). The term “curvature trajectory” refers to an idealized description of physical guideway/track geometry. “Speed profile” refers to a sequence of velocities and bank angles.

The objective of COMBO.BAS is to calculate the fastest speed profile possible given the input trajectory and maximum values for velocity, bank angle, roll rate, acceleration and deceleration. Furthermore, the velocities, bank angles and curvatures are “balanced” in that all accelerations are resolved along the vertical axis. Thus, a passenger traversing the route according to the resulting speed profile would experience no lateral accelerations. Implications are that lateral acceleration constraints are automatically satisfied, since lateral acceleration is everywhere zero. A further implication is that there is no lateral jerk, as lateral acceleration is constant; thus, lateral jerk limits are automatically satisfied. The final implication is that the speed is sometimes less than that which could have been allowed were balance not required.

Typically, one can expect travel time to decrease when the parameters (maximum velocity, bank angle, roll rate, acceleration, and deceleration) are increased. A valuable use of COMBO.BAS is to allow experimenting with these parameters to precisely determine their effect on travel time.

Description of Input

The program COMBO.BAS takes as input a geometric object - a curvature trajectory. COMBO.BAS does not in any way alter this input geometry. Based on this geometry, COMBO.BAS calculates velocities and bank angles for traveling through this sequence of curves. Thus, it is assumed that an alignment (but not a guideway with fixed bank angles) has already been determined.

For input purposes, the geometry (i.e. curvature trajectory) must be described by the radius of curvature (infinite for tangent sections) every delta s (100) feet[1]. To use COMBO.BAS the user must provide the data in this form. However, it is possible to take data of a different form and convert it to this radius/distance form. For example, for this study the geometric description provided by the State of New York (NYRDY.DAT) consisted of a sequence of curves of varying lengths, along with a prescription for spirals. Thus, it was necessary to transform these data into the “curvature trajectory form” described above. The program (ALIGN.BAS) discussed in Appendix D

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[1] The unit of distance (delta s) must be small enough that kinematic changes over each segment are negligible.

accomplished this conversion. The output of ALIGN.BAS, a file called RECONST.ROE, was input to COMBO.BAS.

Description of Output

The primary output of COMBO.BAS is a "speed profile," that is, a sequence of velocities and bank angles. The output sequence also contains the following information: segment number, distance along route, radius of curvature, cumulative travel time, roll rate, and a reasons code. The reasons code documents the last constraint which caused a change in velocity for each segment. The sequence is provided in a "constant distance" form (one record every delta-s feet) and in a "constant time" form (one record every delta-t seconds). These are saved in a ".ARC" file and a ".TIM" file, respectively. Both forms are useful; in particular, the ".TIM" file is used to estimate a motion-sickness dose value (as explained in Appendix C).

Introduction to Program Architecture

Given a flat planar alignment, i.e., a set of curves in the x-y plane, the primary focus of this effort is to determine a speed profile that traverses the curve in minimum time under constraints on:

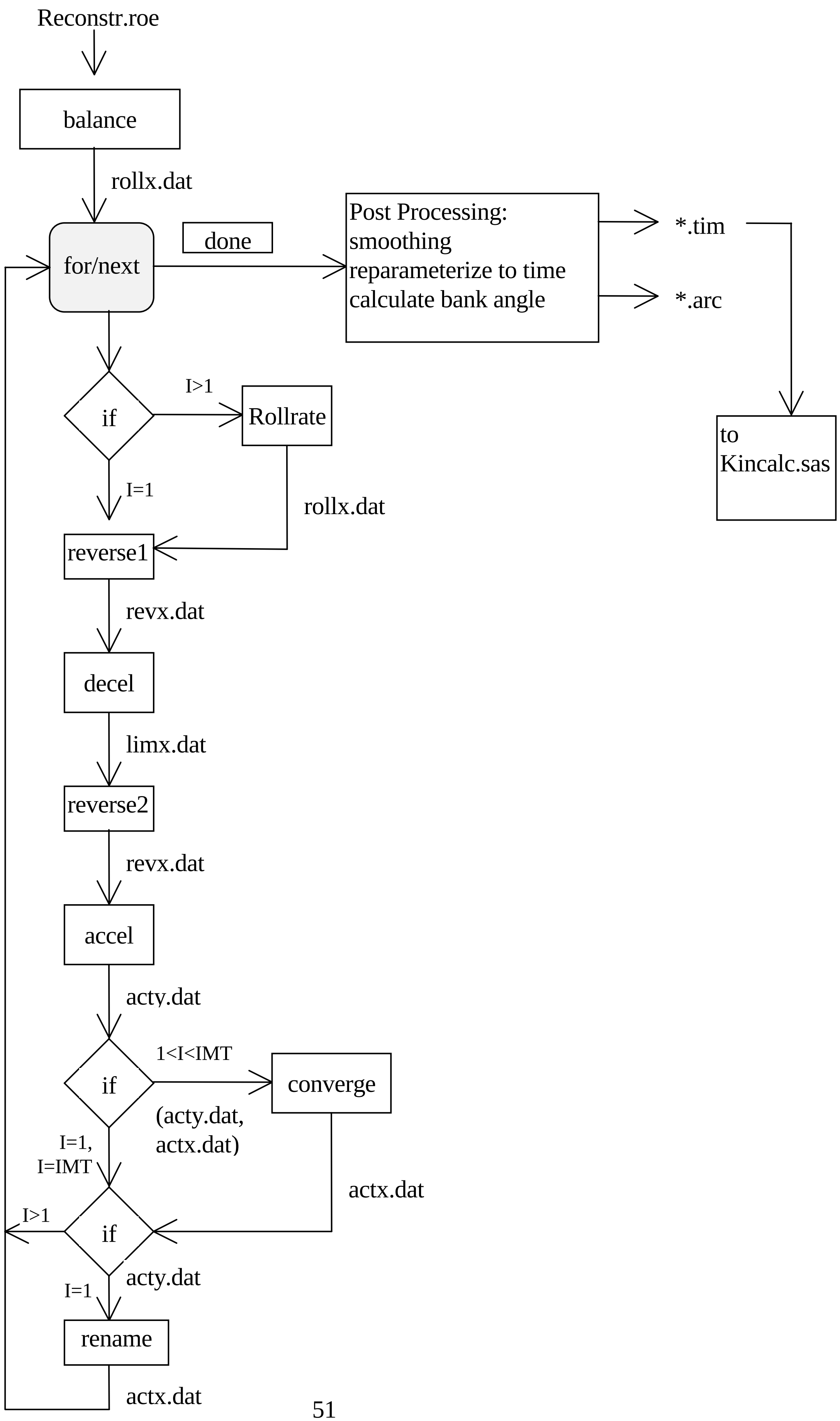
- speed
- bank angle
- acceleration
- deceleration
- roll rate

For the purpose of understanding the underlying program architecture it is helpful to distinguish between two types of constraints. *Immutable* constraints depend only on the point of computation along the curve whereas *dynamic* constraints require consideration of points before and after the computation point. Maximum allowable speed and maximum allowable bank angle are constraints that impose *immutable* restrictions. The speed must be kept below both the maximum speed and the speed implied by the local curvature and maximum bank angle. On the other hand, constraints such as acceleration, deceleration, and roll rate impose *relative* or *dynamic* limits, because as the vehicle moves from segment to segment the locally computed speed must accommodate speeds on segments that come before or after the computation point.

Recall that the input is a sequence of radii of curvature every 100 feet. From these radii, a sequence of *speed limits* is calculated based on balancing the accelerations and assuming the maximum bank angle (BANK). These *speed limits* are viewed as a sequence of posted speed restrictions every 100 feet. They are input to the primary loop as the initial values for the speed profile. The primary loop then determines whether any of the above five constraints is exceeded. Whenever an exceedance is obtained, the program reduces the vehicle speed. Also, whenever a current speed is found to be less than all applicable constraints, the program increases the speed. The process is repeated (iterated) several times, producing a final speed profile that minimizes transit time and adheres to the five constraints at all points.

Description of COMBO.BAS: Program Flow Control and Algorithms

COMBO.BAS consists of a main module and various sub-modules, as follows:


Reconstr.roe
balance
rollx.dat
for/next
done
Post Processing:
smoothing
reparameterize to time
calculate bank angle
*.tim
*.arc
to
Kincalc.sas
if
I>1
Rollrate
I=1
rollx.dat
reverse1
revx.dat
decel
limx.dat
reverse2
revx.dat
accel
acty.dat
if
1<I<IMT
converge
(acty.dat,
actx.dat)
I=1,
I=IMT
actx.dat
I>1
if
acty.dat
I=1
rename
actx.dat

Main Module

The main module takes inputs via a user interface for the limiting parameter values, file names, and several options. Next, the module performs set up operations (including declaring subroutines, setting flags for output options, and initializing variables). In addition, it provides tags that are used to record the speed limiting reasons at every point along the route. It then calls BALANCE, which calculates the *speed limits* (which serve as initial values for vehicle speed) and stores the result in ROLLX.DAT (a disk file). The bulk of the processing is done in a loop "FOR ITERATION=1 TO IMT." Upon completion of these iterations a solution is stored in ACTY.DAT. Then the main module calls several modules that perform three functions: reparameterize to time, calculate bank angle, and smooth the profile. The results are stored in the ". ARC" (one record every delta-s feet) and ".TIM" (one record every delta-t seconds) files.

Subroutine Balance

Balance calculates the "speed limits" based on the local curvature (input file RECONST.ROE) and the maximum bank angle (input parameter BANK). The formula used for this calculation is the balanced lateral equation:

$$\tan(\theta) = \frac{V^2}{gR}$$

This formula relates the radius of curvature (R), the velocity (V) and the bank angle (θ). It is used in other modules as well as in BALANCE; it is sometimes used to calculate a velocity (as in BALANCE where θ is taken to be the maximum allowable bank angle) and sometimes used to calculate a bank angle (for a given velocity).

In addition to calculating a speed based on the curvature and maximum bank angle, BALANCE checks that the speed implied by the balance equation does not exceed the user input maximum speed (LINESPEED) as may occur along straight segments or segments with a large radius of curvature (gentle curves). In such a case, the (immutable) "speed limit" computed by BALANCE is set equal to the LINESPEED. This process of checking speeds against the maximum is carried out by several of the modules. Thus there is no separate module for checking for speeds greater than LINESPEED.

Primary Loop

The minimization of transit time is accomplished by a *for/next* loop in the main module. This loop calls several modules which impose the restrictions on roll rate, acceleration, and deceleration (ROLLRATE, ACCEL, DECEL). The loop also calls modules which perform clerical functions (REVERSE1, REVERSE2 and RENAME) and one module which aids in convergence (CONVERGE). At the completion of each iteration, a new (updated) speed profile is output.

The steps in a typical iteration are as follows:

1. Determine the bank angles and roll rates based on current values for velocities. At each point along the curvature trajectory, limit velocity to meet the bank angle restriction or (if bank angle restriction does not apply) modify velocity (increase or decrease) to a value which makes roll rate closer to its given limit value.

2. Check for acceleration and deceleration limit violations. Where necessary, decrease the velocity to meet these restrictions.

3. Average the resulting speed profile with the speed profile obtained in the previous iteration. This is done to ensure convergence.

4. Return.

Subroutines ACCEL and DECEL

The purpose of the modules ACCEL and DECEL is to ensure that (longitudinal) acceleration and deceleration limits are obeyed. The code for subroutines ACCEL and DECEL is identical. ACCEL "looks behind" while going forward over the route from origin to destination. DECEL "looks behind" while going backward (which is effectively looking ahead) over the route from destination to origin. The reversal of time relationships (accomplished by modules REVERSE1 and REVERSE2) converts acceleration into deceleration and "look behind" into "look ahead." Combined, subroutines ACCEL and DECEL compute a speed profile that meets acceleration/deceleration limits at every point over the entire route.

The strategy that is used is "pedal-to-the-metal," whenever a change in speed is needed, the change is done using the maximum acceleration or the maximum deceleration. This method of "constant acceleration" is motivated by the goal of minimizing transit time. Simply put, there is never a reason for accelerating (or decelerating) at anything less than maximum value. Thus a well known formula from elementary kinematics is used: if a segment of length *s* is covered at constant acceleration *a* then:

$$V_2^2 - V_1^2 = 2as$$

where V_2 is the speed at the end and V_1 is the speed at the beginning of the segment.

The module ACCEL has the surprising property that with a single pass through the data the acceleration limit is obeyed along the entire route. This is accomplished by always making sure the output speed is no greater than that which can be reached from the output speed for the previous segment under maximum acceleration (using the above formula). Through this one-step-at-a-time process, a severe speed reduction at one point can be felt at a considerable distance "downstream." Of course, DECEL has the analogous property: a single pass through the data ensures that the deceleration limit is never exceeded.

If acceleration, deceleration, bank angle and maximum speed were the only restrictions to be placed on the speed profile a single pass through the data (a single iteration) would suffice. Using the speed limits determined by BALANCE, the program would need only reduce the speeds in the profile to the limits implied by ACCEL and DECEL. However, the roll-rate restriction complicates this matter. Consider the following example. Suppose a candidate speed profile exceeds the roll rate restriction at segment *i+1*. The bank angle from segment *i* to segment *i+2* changes too rapidly. The speed is reduced to accommodate the roll-rate restriction. As a result, the bank angle (implied by the new speeds and the balanced lateral condition) is also reduced from segment *i* to segment *i+2* (i.e., slower speeds through a fixed curve lead to gentler bank angles). This further reduces the roll rate at segment *i+1*. Also, this change affects roll rates at segments *i* and *i+2*. Thus, the consideration of roll-rate constraints necessitates the iterative procedure.

Subroutine ROLLRATE

The module ROLLRATE introduces the roll-rate restriction. It computes the rate of change of the bank angle and adjusts the velocity. By iteratively executing the roll-rate module the program arrives at a velocity profile which meets the roll-rate restriction. (Unlike the ACCEL/DECEL modules, the ROLLRATE module does not output a velocity profile that meets the relevant restriction in a single pass. It functions by replacing a velocity profile with one in which rolls are executed at rates that are closer to the limit value.)

The formula used by ROLLRATE for calculating the roll rate is based on the time derivative of bank angle:

$$\left|\frac{d\theta}{dt}\right| = \left|\frac{d\theta}{ds}\right|\left|\frac{ds}{dt}\right| \approx \left|\frac{\Delta\theta}{\Delta s}\right| V$$

where $\frac{\Delta\theta}{\Delta s}$ 1is the change in actual bank angle over a very short distance divided by that distance. If α is the maximum allowable roll rate, one could use

$$V = \frac{\alpha}{\Delta\theta / \Delta s}$$

to compute the velocity which meets the roll rate restriction. However, to avoid oscillation and ensure convergence, a geometric mean between the previous value (velocity from previous iteration) and the velocity implied by the above equation is calculated:

$$V = \left(\frac{\alpha}{\Delta\theta / \Delta s} V_{previous}\right)^{1/2}$$

The module ROLLRATE also checks to see that the bank-angle restriction is met using the balanced lateral equation.

Subroutine Converge

At the end of each iteration (except the first and last) the speed profile obtained is averaged with the speed profile obtained in the previous iteration. This step is included to aid convergence. Convergence was found to be sure and rapid on the data used.

Subroutines for Final Output

Having obtained the speed profile, the program performs three additional functions: calculate bank angle, reparameterize to time, and smoothing.

Subroutine ComputeConvergedBankAngle

The subroutine COMPUTECONVERGEDBANKANGLE computes bank angle as a function of arc length given the speed profile. The inputs are curvature, speed squared, cumulative distance segment number and speed limiting reasons tag. The bank angle is calculated using the balanced lateral equation. The outputs are speed (not squared), bank angle, curvature, cumulative distance, cumulative travel time, roll rate, segment number and speed-limiting-reason tag every 100 feet. The output file name is user specified with a standard file name extension of ". ARC."

Subroutine ReparameterizeToTime

Reparameterization is accomplished by REPARAMETERIZETOTIME, a module which outputs the velocity profile in equal time increments. The input file (*.ARC) contains speed, bank angle, curvature, cumulative distance, cumulative travel time, roll rate, segment number, and speed-limiting-reason tag every 100 feet. The module linearly interpolates each of these values to obtain a value every 0.1 seconds. Other methods of interpolation could be used. Output file name is user specified with standard file name extension ".TIM."

Subroutines ForwardSmooth, BackwardSmooth and Average

Exponential smoothing is performed in the forward direction (FORWARDSMOOTH) and in the backward direction (BACKWARDSMOOTH) and the results are averaged (AVERAGE). SMOOTHREVERSE1 and SMOOTHREVERSE2 are called to reverse the data order between forward smoothing and backward smoothing and after backward smoothing to restore the original order.

APPENDIX B. COMBO.BAS ANNOTATED CODE

Subroutine Balance Logic

The Balanced Speed Section uses the alignment data as input and a user-supplied parameter, the bank angle limit, to compute balanced velocity squared.

Input is a disk file (RECONST.ROE) containing curvature, cumulative distance and the segment number. Input parameters are bank angle limit and line speed limit.

Step 1) Bank angle limit is in degrees. It is converted to radians for computational uses.

Step 2) Balanced speed squared is computed using the maximum allowed bank angle and curvature for each segment piece.

Step 3) Computed speed squared is less than or equal to line speed limit squared.

Step 4) Outputs are the curvature, cumulative distance, balance speed squared, segment number and speed-limiting reasons tag for each standard unit distance (100 feet). Output file is ROLLX.DAT.

Program Logic: Deceleration

Step 1) Convert deceleration limit in g's to deceleration limit in feet/second^2.

Step 2) Check that prior tempVVS (speed squared from previous piece) is within line speed limit squared.

Step 3) Compute new temporary squared velocity using the constant deceleration formula:

VVS = prior tempVVS + 2*Deceleration*distance.

Step 4) Compare the input speed squared value for the current segment to the (incremented) speed squared value from the preceding segment and use the smaller value.

Step 5) If the speed was changed by the Deceleration Subroutine adjust the speed limiting reasons tag.

Step 6) Output the results of considering deceleration as a limiting factor for the present piece.

Program Logic: Acceleration

Step 1) Convert acceleration limit in g's to acceleration limit in feet/second^2.

Step 2) Check that prior tempVVS (speed squared from previous piece) is within line-speed-limit squared.

Step 3) Compute new temporary squared velocity using the constant acceleration formula:

VVS = prior tempVVS + 2*acceleration*distance.

Step 4) Compare the input-speed-squared value for the current segment to the incremented-speed squared-value for the preceding segment and use the smaller value.

Step 5) If the speed was changed by the Acceleration Subroutine adjust the speed limiting reasons tag.

Step 6) Output the results of considering acceleration as a limiting factor for the present piece.

Program Logic: Roll Rate

Step 1) Use the balanced lateral equation to compute the required bank angle based on the incoming-speed profile for three pieces, the present piece (#2) and it's predecessor (#1) and successor (#3).

Step 2) Compute the rate of change of the bank angle with respect to distance by taking the central difference, the difference between bank angle #3 less bank angle #1.

Step 3) Compute an upper limit for speed squared for the present piece (#2) using the lateral balance equation and the maximum allowed bank angle.

Step 4) Roll-rate-limited speed is computed as the rate of change of bank angle with respect to time (d theta/dt) divided by the rate of change of bank angle with respect to distance (d theta/dx)

roll-rate-limited speed = (d theta/dt) / (d theta/dx) = dx/dt

Step 5) If d theta/dx is not zero then compute the geometric mean of roll-rate-limited speed squared and previously-computed speed squared by taking the square root of (roll-rate-limited speed squared times input-speed squared).

Step 6) Compare the speed squared just computed to lateral-balance speed squared computed in step 3 and retain the smaller.

```
   '************* Beginning of Main Module (of COMBO.BAS) *********************
'The model is being developed as part of a Maglev Simulation Aircraft Flight
'Study.  The objective of the study is to assess passenger acceptance of
'ride quality typical of a Maglev vehicle operating over realistic routes.

'This is the main program. It is written in Quick Basic for a PC.
'The program architect is Dr. Peter. Mengert with support from
'Bob DiSario DTS-45 and Leonore Katz-Rhoads DTS-75.

TYPE PreARCdatatype
       sernum        AS SINGLE
       REVERSE       AS SINGLE
       SpeedSquared  AS SINGLE
       SegmentNumber AS SINGLE
       tagg          AS DOUBLE
END TYPE

' Declares for smoothing SUBROUTINE FILTER
TYPE filter
       TravelTime    AS SINGLE
       BankAngle     AS SINGLE
END TYPE
'TYPE FFilterType
'         TravelTime    AS SINGLE
'         Speed         AS SINGLE
'         BankAngle     AS SINGLE
'         Curvature     AS SINGLE
'         ArcLength     AS SINGLE
'         ROLLRATE      AS SINGLE
'         SegmentNumber AS SINGLE
'         PieceNumber   AS SINGLE
'         tagg          AS DOUBLE
'END TYPE


'tag tells where and when the program set speed values
'tag encodes 1) iteration: I, 2) module: M 3) parameter: PP
' in the form " IMPP.otherstuff"
' where letter "I" tags when a speed value changed
' the letter "M" tags where the speed value changed
' if M=1 then a speed value was set by ROLLRATE constraints
'         if the tag is negative, ROLLRATE increased speed
' if M=2 then a speed value was set by Deceleration
' if M=3 then a speed value was set by Acceleration
' PP is the parameter, roll rate in degrees/second
' or  accel or decel in %age of 1 G
' the .conv data comes from the Converge subroutine
' this subroutine combines two speed values.  Therefore tags are
' also combined using this method;
' the New tag has the value IMPP.OTHERSTUFF
' the Old tag has the value impp.otherstuff
' the combined tag: IMPP.imppOTHERSTUFF (otherstuff is ignored)
' Converge only combines if the new and old tag differ by 1.0e-8 or more
' if tags are not that different Converge just passes the new tag along

DECLARE SUB BALANCE (infile$, BANK, LineSpeed, tagg#)         '
DECLARE SUB ROLLRATE (MaxRollRate, BANK, LineSpeed, UpHandle, tagg#, LogFile$)
DECLARE SUB REVERSE1 ()                                      '
DECLARE SUB Deceleration (ACCEL, LineSpeed, tagg#, LogFile$)
DECLARE SUB REVERSE2 ()
DECLARE SUB Acceleration (decel, LineSpeed, tagg#, LogFile$)
DECLARE SUB Converge (LogFile$)
DECLARE SUB ComputeConvergedBankAngle (INDAT$, OUTDAT$, Style, LogFile$)
DECLARE SUB ReparameterizeToTime (INDAT$, OUTDAT$, LogFile$)
```

```
DECLARE SUB ForwardSmooth (A1, InputFile$)
DECLARE SUB SmoothReverse1 (InputFile$)
DECLARE SUB BackwardSmooth (A1)
DECLARE SUB SmoothReverse2 ()
DECLARE SUB Average (JKDAT$, LogFile$)
DECLARE SUB FullSmoothAverage (InputFile$, JKDAT$, LogFile$)

' The following SUBroutines are NOT called directly in the main program.
DECLARE SUB REVERSE (infile$, outfile$)
DECLARE SUB SmoothReverse (infile$, outfile$)

' AGAIN: is a label, it is the target of a GOTO at the end of the main program
'        the user is given the option of running another case (Do it again?)
AGAIN:
'
'USER INPUT SECTION PRINTS MESSAGES TO SCREEN AND ACCEPTS DATA
'Sign on banner - What are we?  what version?
banner$ = "COMBO Version 9 - 6/12/95 "
PRINT banner$

PRINT "DATA IN [BRACKET] IS DEFAULT VALUE"

PRINT "Enter name and path of input file [RECONST.ROE=DEFAULT]"
INPUT InputFileName$
infile$ = RTRIM$(InputFileName$)
InputFileName$ = LTRIM$(infile$)
IF InputFileName$ = " " OR InputFileName$ = "" THEN InputFileName$ =
"RECONST.ROE"

PRINT "INPUT ROLLRATE [8], BANK ANGLE [20], ACCEL [.04], DECEL, LINE SPEED
[440] "
INPUT MaxRollRate, BANK, ACCEL, decel, LineSpeed
IF MaxRollRate = 0 THEN MaxRollRate = 8
IF BANK = 0 THEN BANK = 20
IF ACCEL = 0 THEN ACCEL = .04
IF decel = 0 THEN decel = ACCEL
IF LineSpeed = 0 THEN LineSpeed = 439.6316667#
PRINT MaxRollRate; BANK; ACCEL; decel; LineSpeed

PRINT " "
PRINT "HOW MANY Iterations = [6]"
INPUT NumIter
IF NumIter = 0 THEN NumIter = 6

PRINT " "
PRINT "Do Converge on last iteration? [RETURN = NO] (1 = YES)"
INPUT DoLast

PRINT " "
PRINT "BEEP when done? [RETURN = NO] (1 = Yes)"
INPUT DoBeep

PRINT "REPARAMETERIZE IN TIME? [RETURN = YES] (-1 = NO) "
INPUT DoReparameterizeToTime

IF DoReparameterizeToTime <> -1 THEN
     PRINT " "
     PRINT "SMOOTH BANK ANGLE ? [RETURN = YES] (-1 = NO)"
     INPUT DoSmooth
     IF DoSmooth <> -1 THEN
        PRINT "Input averaging parameter  A1 [0.8] (0.0 TO 1.0)"
        INPUT A1
        IF A1 <= 0! THEN A1 = .8
        IF A1 >= 1! THEN A1 = .8
```

```
        PRINT "What kind of smoothing output file, basic (.SMO) or wide (.SMF)?
"
        PRINT "                                   [RETURN=.SMO] (1=.SMF)"
        INPUT DoSMF
        IF (DoSMF <> 1) THEN DoSMF = 0
     END IF
ELSE
    DoSmooth = -1
    DoSMF = 0
END IF

PRINT " "
PRINT "GIVE FILENAME FOR OUTPUT (Drive:Path\Filename [NO Extension])"
INPUT FILENAME$
outfile$ = RTRIM$(FILENAME$)
FILENAME$ = LTRIM$(outfile$)
IF FILENAME$ = " " OR FILENAME$ = "" THEN FILENAME$ = LTRIM$(STR$(MaxRollRate))
+ "_" + LTRIM$(STR$(BANK)) + "_" + LTRIM$(STR$(ACCEL * 100))

CLS
PRINT banner$
PRINT MaxRollRate; BANK; ACCEL; decel; LineSpeed
PRINT "OUTPUT to ", FILENAME$
PRINT " "

LogFile$ = FILENAME$ + ".LOG"
OPEN LogFile$ FOR OUTPUT AS 10
PRINT #10, banner$
PRINT #10, MaxRollRate; BANK; ACCEL; decel; LineSpeed
IF DoReparameterizeToTime <> -1 THEN
    PRINT #10, " REPARAMETERIZE AND OUTPUT  .TIM file."
    IF DoSmooth <> -1 THEN
      PRINT #10, "SMOOTHING PARAMETER = "; A1; " output to .SMO file."
    ELSE
      PRINT #10, " NOT SMOOTHING .TIM FILE THEN NO .SMO FILE "
      PRINT #10, " FILTER.EXE CAN CONVERT .TIM to .SMO LATER"
    END IF
ELSE
    PRINT #10, " Not REPARAMETERIZING THEN NO .TIM FILE CREATED"
    PRINT #10, " ALSO NO .SMO FILE CREATED "
    PRINT #10, " POST.EXE CAN CONVERT .ARC FILE TO A .TIM LATER"
    PRINT #10, " FILTER.EXE CAN CONVERT .TIM to .SMO LATER"
END IF
PRINT #10, "OUTPUTs to ", FILENAME$

UpHandle = 0
Style = 0
tagg# = 0
infile$ = InputFileName$
DS = 100                 ’Piece size 100’
LT = 1000                ’Maximum Spiral Length 1000’

’ a tag of 0001 means the velocity is set in the module BALANCE
tagg# = 1

PRINT " "
PRINT "Calling BALANCE - Using InputFileName$ to create initial velocity
profile"
CALL BALANCE(InputFileName$, BANK, LineSpeed, tagg#)

’Main convergence loop
IMT = NumIter
FOR IterationNumber = 1 TO IMT
    PRINT "  "
    PRINT banner$
```

```
    PRINT "pass number "; IterationNumber
    CLOSE
    OPEN LogFile$ FOR APPEND AS 10
    PRINT #10, " "
    PRINT #10, "pass number "; IterationNumber

    tagg# = IterationNumber * 1000

    IF IterationNumber > 1 THEN CALL ROLLRATE(MaxRollRate, BANK, LineSpeed,
UpHandle, tagg#, LogFile$)

    CALL REVERSE1
    CALL Deceleration(decel, LineSpeed, tagg#, LogFile$)
    CALL REVERSE2
    CALL Acceleration(ACCEL, LineSpeed, tagg#, LogFile$)

    IF (IterationNumber < IMT OR DoLast = 1) AND IterationNumber > 1 THEN
      CALL Converge(LogFile$)
    END IF

    IF IterationNumber = 1 THEN NAME "ACTY.DAT" AS "ACTX.DAT"
NEXT IterationNumber

' Remove Temporary Files, ComputeConvergedBankAngle uses ACTY.DAT for INPUT so
' we save it
KILL "LIMX.DAT"
KILL "ROLLX.DAT"
KILL "REVX.DAT"

' Generate final output files
INDAT$ = "ACTY.DAT"
OUTDAT$ = FILENAME$ + ".ARC"
'Use the computed speed profile to compute new theta = bank angle
CALL ComputeConvergedBankAngle(INDAT$, OUTDAT$, Style, LogFile$)

KILL "ACTX.DAT"
KILL "ACTY.DAT"
KILL "ACTZ.DAT"

INDAT$ = FILENAME$ + ".ARC"
OUTDAT$ = FILENAME$ + ".TIM"
IF DoReparameterizeToTime <> -1 THEN CALL ReparameterizeToTime(INDAT$, OUTDAT$,
LogFile$)

IF DoSmooth <> -1 THEN
    banner$ = "COMBO Version 9 Smoothing Filter - 6/12/95 "
    PRINT banner$

    InputFile$ = FILENAME$ + ".TIM"
    JKDAT$ = FILENAME$ + ".SMO"
    IF DoSMF = 1 THEN JKDAT$ = FILENAME$ + ".SMF"

     CLS
     PRINT banner$
     PRINT " "
     PRINT "INPUT FROM "; InputFile$
     PRINT "OUTPUT TO "; JKDAT$
     PRINT " "
     PRINT "SMOOTHING WITH A1 = "; A1
     OPEN LogFile$ FOR APPEND AS 10
     PRINT #10, " "
     PRINT #10, " "
     PRINT #10, banner$
     PRINT #10, " "
     PRINT #10, "INPUT FROM "; InputFile$
```

```
     PRINT #10, "OUTPUT TO "; JKDAT$
     PRINT #10, " "
     PRINT #10, "SMOOTHING WITH A1 = "; A1

     CALL ForwardSmooth(A1, InputFile$)
     CALL SmoothReverse1("ANGLE3.DAT")
     KILL "ANGLE3.DAT"
     CALL BackwardSmooth(A1)
     CALL SmoothReverse2
     IF (DoSMF <> 1) THEN
       CALL Average(JKDAT$, LogFile$)
     ELSE
       CALL FullSmoothAverage(InputFile$, JKDAT$, LogFile$)
     END IF

     CLOSE
     KILL "ANGLE1.DAT"
     KILL "ANGLE2.DAT"
     KILL "ANGLEREV.DAT"
     KILL "FLIPPED.DAT"

END IF

IF (DoBeep = 1) THEN BEEP

PRINT "Do another? (1=Yes, else=No)"
INPUT DoAnother
IF DoAnother = 1 THEN GOTO AGAIN

END

'********************* end of main module **************************


'******************** Acceleration subroutine ******************
SUB Acceleration (ACCEL, LineSpeed, tagg#, LogFile$)

PRINT "Entered Acceleration"
G = 32.2          ’GRAVITY
A = ACCEL * G    ’ACCELERATION AND DECELERATION        ‘Step 1
vsmax = LineSpeed * LineSpeed
um = vsmax

OPEN "REVX.DAT" FOR INPUT AS 1
OPEN "ACTY.DAT" FOR OUTPUT AS 2

tag# = INT(tagg#) + 300 + INT((ACCEL + .00001) * 100!)

NumPieces = 0
NumTouched = 0
DO WHILE NOT EOF(1)
    INPUT #1, RQ, DSCUM, VVS, SegmentNumber, tagold#
    NumPieces = NumPieces + 1
    IF um > vsmax THEN um = vsmax                      ‘Step 2
                                                       ‘Step 3
    um = um + 2 * A * 100'CONSTANT ACCELERATION AS A FUNCTION OF DS
                         'VELOCITY SQUARED = VVS initial + 2as
                         'Newtonian Mechanics  by  A.P. French
    IF VVS < um THEN                                   ‘Step 4
      um = VVS
      tagout# = tagold#
    ELSE
      tagout# = tag#                                   ‘Step 5
```

```
      NumTouched = NumTouched + 1
    END IF

    ug = um
    PRINT #2, RQ; DSCUM; ug; SegmentNumber; tagout#    ‘Step 6
LOOP
CLOSE

PRINT "Acceleration changed "; NumTouched; " of "; NumPieces

OPEN LogFile$ FOR APPEND AS 10
PRINT #10, "Acceleration changed "; NumTouched; " of "; NumPieces

END SUB

’************************** end of acceleration ***************************


’************************** average subroutine ***************************
SUB Average (JKDAT$, LogFile$)

PRINT "Entered Average"

OPEN "ANGLE1.DAT" FOR INPUT AS #1
OPEN "ANGLE2.DAT" FOR INPUT AS #2
OPEN JKDAT$ FOR OUTPUT AS #3

DO WHILE NOT EOF(1)
    INPUT #1, TIME, PRIOR
    INPUT #2, TIME, NEXT1
    BANKAVG = (PRIOR + NEXT1) / 2
    PRINT #3, TIME, BANKAVG
LOOP
CLOSE

OPEN LogFile$ FOR APPEND AS 10
PRINT #10, " "
PRINT #10, "Average: last line of "; JKDAT$
PRINT #10, TIME, BANKAVG
CLOSE

END SUB

’************************* end of average **************************


’************************* subroutine BackwardSmooth ***************
SUB BackwardSmooth (A1)

'Subroutine bankangle computes an exponential moving average
'values of the current and prior bankangle moving from
'the data stack front to back.

PRINT "Starting BackwardSmooth"

AA1 = A1
AA2 = 1 - A1

OPEN "FLIPPED.DAT" FOR INPUT AS #1
OPEN "ANGLEREV.DAT" FOR OUTPUT AS #2
```

```
INPUT #1, TIME1, FSTBANK
PRINT #2, TIME1, FSTBANK
RunningAverage = FSTBANK

DO WHILE NOT EOF(1)
    INPUT #1, TIME3, NXTBANK
    RunningAverage = AA1 * RunningAverage + AA2 * NXTBANK
    PRINT #2, TIME3, RunningAverage
LOOP
CLOSE

END SUB

’****************************** end of BackwardSmooth *****************


’******************************** subroutine Balance *******************
SUB BALANCE (infile$, BANK, LineSpeed, tagg#)
J = 0
G = 32.2
THETA = BANK * ATN(1) / 45                             ‘Step 1
VVS = 0
vsmax = LineSpeed * LineSpeed

tag# = tagg#
'TAG# = tagg# * bank

OPEN infile$ FOR INPUT AS 1
OPEN "ROLLX.DAT" FOR OUTPUT AS 2
DO WHILE NOT EOF(1)
    INPUT #1, CURVE, CUMFEET, SegmentNumber
    IF CURVE = 0 THEN
      VVS = 999999
    ELSE
      VVS = TAN(THETA) * G / ABS(CURVE)                ‘Step 2
    END IF
    IF VVS > vsmax THEN VVS = vsmax                    ‘Step 3
    PRINT #2, CURVE; CUMFEET; VVS; SegmentNumber; tag#‘Step 4
LOOP
CLOSE

END SUB

’***************************** end of balance **********************


’*************** subroutine ComputeConvergedBankAngle *************
SUB ComputeConvergedBankAngle (INDAT$, OUTDAT$, Style, LogFile$)

PRINT "Entered ComputeConvergedBankAngle, writing to   "; OUTDAT$
PRINT "              reading from "; INDAT$

OPEN INDAT$ FOR INPUT AS #1
OPEN OUTDAT$ FOR OUTPUT AS #2

G = 32.2
dt = .00001
CumulativeTravelTime = 0


'New Style - Starts with zero distance and zero bank angle, outputs first
```

```
’ segment
PriorCumulativeDistance = 0
PriorBankAngleDegrees = 0

DO WHILE NOT EOF(1)
    INPUT #1, Curvature, CumulativeDistance, VVS, SegmentNumber, tag#
    V = SQR(VVS)
    DD = CumulativeDistance - PriorCumulativeDistance
    dt = DD / V
    CumulativeTravelTime = CumulativeTravelTime + dt
    THETA = ATN(VVS * Curvature / G)
    BankAngleDegrees = THETA * 45 / ATN(1)
    IF BankAngleDegrees - PriorBankAngleDegrees = 0 THEN
      RollRateValue = 0
    ELSE
      RollRateValue = (BankAngleDegrees - PriorBankAngleDegrees) / dt
    END IF
    PRINT #2, V, BankAngleDegrees, Curvature, CumulativeDistance,
CumulativeTravelTime, RollRateValue, SegmentNumber, tag#
    PriorCumulativeDistance = CumulativeDistance
    PriorBankAngleDegrees = BankAngleDegrees
LOOP
CLOSE

OPEN LogFile$ FOR APPEND AS 10
PRINT #10, " "
PRINT #10, "ComputeConvergedBankAngle: last line of "; OUTDAT$
PRINT #10, "Speed", "Bank Angle", "Curvature", "Distance", "TravelTime",
"RollRate", " SegmentNumber", "ReasonCode"
PRINT #10, V, BankAngleDegrees, Curvature, CumulativeDistance,
CumulativeTravelTime, RollRateValue, SegmentNumber, tag#
CLOSE

END SUB

’************* end of ComputeConvergedBankAngle ****************


’**************** subroutine Converge ***************************
SUB Converge (LogFile$)
’This subroutine computes the average value
’of two velocity profiles

PRINT "Entered Converge"

OPEN "ACTX.DAT" FOR INPUT AS #1
OPEN "ACTY.DAT" FOR INPUT AS #2
OPEN "ACTZ.DAT" FOR OUTPUT AS #3

NumPieces = 0
NumTouched = 0
DO WHILE NOT EOF(1)
    INPUT #1, A, B, VVOLD, SegmentNumber, tagold#
    INPUT #2, A, B, VVNEW, SegmentNumber, tagnew#
    NumPieces = NumPieces + 1
    VVAVG = (VVOLD + VVNEW) / 2

’ tag encodes where the speed was set, if Converge is setting the speed it
’ encodes this by combining the tags from the two being averaged
’ the combination occurs only if the two tags differ substantially
’ in which case the main parts of the two tags are used combined into one
’ value
’ with the newer (i.e., later in the running) tag in the primary position
```

```
’
    IF (ABS(ABS(tagold#) - ABS(tagnew#)) < 1E-08) THEN
    ’if the tags are essentially identical, just pass tagnew# through
      tagout# = tagnew#
    ELSE
’ take the OLD tag’s main part (integer) and the NEW tag’s secondary
’ (fractional)
      tagout# = INT(ABS(tagold#)) + ABS(tagnew# - INT(tagnew#))
’ the tag we output is the main part of the new, with the above combo as
’ secondary
      tagout# = INT(ABS(tagnew#)) + (tagout# / 10000#)
      NumTouched = NumTouched + 1
    END IF

    PRINT #3, A; B; VVAVG; SegmentNumber; tagout#
LOOP
CLOSE

PRINT "Converge changed "; NumTouched; " of "; NumPieces

OPEN LogFile$ FOR APPEND AS 10
PRINT #10, "Converge changed "; NumTouched; " of "; NumPieces

OPEN "ACTZ.DAT" FOR INPUT AS #1
OPEN "ACTX.DAT" FOR OUTPUT AS #2

DO WHILE NOT EOF(1)
    INPUT #1, A, B, C, SegmentNumber, tagold#
    PRINT #2, A; B; C; SegmentNumber; tagold#
LOOP
CLOSE

END SUB

’******************* end of Converge *******************


’****************** subroutine Deceleration ***************
SUB Deceleration (decel, LineSpeed, tagg#, LogFile$)

PRINT "Entered Deceleration"

G = 32.2            ’GRAVITY
D = decel * G      ’ACCELERATION DECELERATION         ‘Step 1
vsmax = LineSpeed * LineSpeed
um = vsmax

tag# = INT(tagg#) + 200 + INT((decel + .00001) * 100!)

OPEN "REVX.DAT" FOR INPUT AS 1
OPEN "LIMX.DAT" FOR OUTPUT AS 2

NumPieces = 0
NumTouched = 0
DO WHILE NOT EOF(1)
    INPUT #1, RQ, DSCUM, VVS, SegmentNumber, tagold#
'CURVATURE,CUMULATIVE DISTANCE,VELOCITY SQUARED
    NumPieces = NumPieces + 1
    IF um > vsmax THEN um = vsmax                      ‘Step 2
    um = um + 2 * D * 100                              ‘Step 3

    IF VVS < um THEN                                   ‘Step 4
      um = VVS
```

```
      tagout# = tagold#                                ‘Step 5
    ELSE
      tagout# = tag#
      NumTouched = NumTouched + 1
    END IF

    ug = um
    PRINT #2, RQ; DSCUM; ug; SegmentNumber; tagout#   ‘Step 6
'CURVATURE,CUMULATIVE DISTANCE,VELOCITY SQUARED
LOOP
CLOSE

PRINT "Deceleration changed "; NumTouched; " of "; NumPieces

OPEN LogFile$ FOR APPEND AS 10
PRINT #10, "Deceleration changed "; NumTouched; " of "; NumPieces

END SUB
```

’****************** end of Deceleration *********************

POST PROCESSOR SUBS - Smoothing

’***************** subroutine ForwardSmooth ******************

```
SUB ForwardSmooth (A1, InputFile$)
'Subroutine bankangle computes the average value
'of the current and prior bankangle moving from
'the data stack front to back.

PRINT "Starting ForwardSmooth"

AA1 = A1
AA2 = 1 - A1

OPEN InputFile$ FOR INPUT AS #1
OPEN "ANGLE1.DAT" FOR OUTPUT AS #2
OPEN "ANGLE3.DAT" FOR OUTPUT AS #3

INPUT #1, TIME1, VINTP, FSTBANK, CINTP, SINTP, RINTP, SegmentNumber,
PieceNumber, tag#
PRINT #2, TIME1, FSTBANK
PRINT #3, TIME1, FSTBANK
RunningAverage = FSTBANK

DO WHILE NOT EOF(1)
    INPUT #1, TIME3, VINTP, NXTBANK, CINTP, SINTP, RINTP, SegmentNumber,
PieceNumber, tag#
    RunningAverage = AA1 * RunningAverage + AA2 * NXTBANK
    PRINT #2, TIME3, RunningAverage
    PRINT #3, TIME3, NXTBANK
LOOP
CLOSE
END SUB
```

’*************** end of ForwardSmooth ******************

’************** subroutine FullSmoothAverage ************

```
SUB FullSmoothAverage (InputFile$, JKDAT$, LogFile$)
```

```
PRINT "Entered FullSmoothAverage"

OPEN "ANGLE1.DAT" FOR INPUT AS #1
OPEN "ANGLE2.DAT" FOR INPUT AS #2
OPEN JKDAT$ FOR OUTPUT AS #3
OPEN InputFile$ FOR INPUT AS #4

DO WHILE NOT EOF(1)
    INPUT #4, TIME, VINTP, Ignore, CINTP, SINTP, RINTP, SegmentNumber,
PieceNumber, tag#
    INPUT #1, TIME, PRIOR
    INPUT #2, TIME, NEXT1
    BankAngleValue = (PRIOR + NEXT1) / 2
    PRINT #3, TIME, VINTP, BankAngleValue, CINTP, SINTP, RINTP, SegmentNumber,
PieceNumber, tag#
LOOP
CLOSE

OPEN LogFile$ FOR APPEND AS 10
PRINT #10, " "
PRINT #10, "FullSmoothAverage: last line of "; JKDAT$
PRINT #10, "TIME", "Speed", "BankAngle", "Curvature", "Distance", "RollRate",
"SegmentNumber", "PieceNumber", "ReasonsTag"
PRINT #10, TIME, VINTP, BankAngleValue, CINTP, SINTP, RINTP, SegmentNumber,
PieceNumber, tag#
CLOSE

END SUB
```

*’************** end of FullSmoothAverage *************

*’********** subroutine ReparameterizeToTime **********

```
SUB ReparameterizeToTime (INDAT$, OUTDAT$, LogFile$)
’input velocity, bank angle, curvature,
’input bank angle per constant units of distance
’output bank angle per constant units of time

PRINT "Entered ReparameterizeToTime, writing to   "; OUTDAT$
PRINT "              reading from "; INDAT$

OPEN INDAT$ FOR INPUT AS 1
OPEN OUTDAT$ FOR OUTPUT AS 2

DTR = .1    ’time units

V1 = 0
ANL = 0
CURV1 = 0
S1 = 0
TL = 0
RRL = 0
INPUT #1, V2, ANG, CURV2, S2, TF, RRF, SegmentNumber, tag#
TR = TL - DTR
PieceNumber = 1

DO WHILE ((NOT EOF(1)) OR (TR < TF))
    TR = TR + DTR
    IF (EOF(1) AND TR > TF) THEN TR = TF
    VINTP = (V2 * (TR - TL) + V1 * (TF - TR)) / (TF - TL)
    AINTP = (ANG * (TR - TL) + ANL * (TF - TR)) / (TF - TL)
    CINTP = (CURV2 * (TR - TL) + CURV1 * (TF - TR)) / (TF - TL)
```

```
    SINTP = (S2 * (TR - TL) + S1 * (TF - TR)) / (TF - TL)
    RINTP = (RRF * (TR - TL) + RRL * (TF - TR)) / (TF - TL)
    PRINT #2, TR, VINTP, AINTP, CINTP, SINTP, RINTP, SegmentNumber,
PieceNumber, tag#
LOP:
    IF ((TR >= TF) AND (NOT EOF(1))) THEN
      TL = TF
      ANL = ANG
      RRL = RRF
      V1 = V2
      CURV1 = CURV2
      S1 = S2
      INPUT #1, V2, ANG, CURV2, S2, TF, RRF, SegmentNumber, tag#
      PieceNumber = PieceNumber + 1
      IF TR >= TF THEN GOTO LOP
    END IF
LOOP
'PRINT #2, TF, V2, ANG, CURV2, S2, RRF, SegmentNumber, PieceNumber, tag#

CLOSE
OPEN LogFile$ FOR APPEND AS 10
PRINT #10, " "
PRINT #10, "ReparameterizeToTime: last lines of "; OUTDAT$
PRINT #10, "time", "Speed", "Bank Angle", "Curvature", "Distance", "Roll Rate",
"SegmentNumber", "PieceNumber", "ReasonsCode"
PRINT #10, TR, VINTP, AINTP, CINTP, SINTP, RINTP, SegmentNumber, PieceNumber,
tag#
PRINT #10, TF, V2, ANG, CURV2, S2, RRF, SegmentNumber, PieceNumber, tag#

CLOSE
END SUB
```

'******* end of ReparameterizeToTime **********

'*********** subroutine Reverse ****************

```
SUB REVERSE (infile$, outfile$)
DIM datum AS PreARCdatatype

PRINT "Entered REVERSE"

OPEN infile$ FOR INPUT AS #1
OPEN "rndax.tmp" FOR RANDOM AS #2 LEN = 24

N = 0
DO WHILE NOT EOF(1)
    N = N + 1
    INPUT #1, datum.sernum, datum.REVERSE, datum.SpeedSquared,
datum.SegmentNumber, datum.tagg#
    PUT #2, , datum
LOOP
CLOSE #1

OPEN outfile$ FOR OUTPUT AS #3
FOR J = N TO 1 STEP -1
    GET #2, J, datum
    PRINT #3, datum.sernum; datum.REVERSE; datum.SpeedSquared;
datum.SegmentNumber; datum.tagg#
NEXT J
CLOSE #3
CLOSE #2
KILL "rndax.tmp"
END SUB
```

```
’************** end of Reverse ****************

’************ subroutine Reverse1 *************
SUB REVERSE1
’reverse1 inverts the guideway in preparation
’for the next subroutine which will calculate
’speed limits due to braking
CALL REVERSE("ROLLX.DAT", "REVX.DAT")
END SUB

’************** end of Reverse1 ****************


’************** subroutine Reverse2 ************
SUB REVERSE2
CALL REVERSE("LIMX.DAT", "REVX.DAT")
END SUB

’************** end of Reverse2 ****************


’************* subroutine RollRate **************
SUB ROLLRATE (MaxRollRate, BANK, LineSpeed, UpHandle, tagg#, LogFile$)
’impose roll rate limits on velocity profile

PRINT "Entered ROLLRATE"

NumPieces = 0
NumDecreased = 0
NumIncreased = 0

G = 32.2                       ’gravity on feet per second squared
dThetaDT = MaxRollRate / 45 * ATN(1)  ’max roll rate in degrees per second
THETAMAX = BANK / 45 * ATN(1) ’bank angle in radians
TANMX = TAN(THETAMAX)          ’tangent of the bank angle
vsmax = LineSpeed * LineSpeed

roll = dThetaDT
tag# = INT(tagg#) + 100 + INT(MaxRollRate)
                         ’open temporary files
OPEN "ACTX.DAT" FOR INPUT AS 1
OPEN "ROLLX.DAT" FOR OUTPUT AS 2

                        ’read the first line of data curvature,
                        ’distance, estimated velocity squared
INPUT #1, RQFST, CUMFST, VVSFST, SegmentNumber, tagold#
NumPieces = NumPieces + 1
                       ’compute bank angle for the first 100 foot piece
THETAFST = ATN(VVSFST / G * ((RQFST) + 1E-08))         ‘Step 1
                       'temporary output file
PRINT #2, RQFST; CUMFST; VVSFST; SegmentNumber; tagold#

                      'read the second line of data
INPUT #1, RQCUR, DSCUR, VVSCUR, SegmentNumber, tagold#
NumPieces = NumPieces + 1
                    'compute bank angle for the current 100 foot piece
THETACUR = ATN(VVSCUR / G * ((RQCUR) + 1E-08))         ‘Step 1

'begin loop
```

```
DO WHILE NOT EOF(1)
    ’read the next line of data
    INPUT #1, RQNXT, DSNXT, VVSNXT, SegmentNumber, tagold#
    NumPieces = NumPieces + 1
    ’compute bank angle for the next 100 foot piece
    THETANXT = ATN(VVSNXT / G * ((RQNXT) + 1E-08))      ‘Step 1
    'compute d theta dx   CENTRAL DIFFERENCE
    dThetaDX = ABS((THETANXT - THETAFST) / 200)         ‘Step 2

    'compute current piece balanced (no lateral) speed at maximum bank
    VMCSCUR = TANMX * G / ABS(RQCUR + 1E-08)            ‘Step 3
    IF (VMSCUR > vsmax) THEN VMSCUR = vsmax

    vvsroll = VVSCUR  'IF dThetaDX=0   vvsRoll should have a reasonable value,
                  ' not just what's left from the prior iteration

    'test for potential ZERO DIVIDE, compute roll rate limited speed squared
    IF (dThetaDX <> 0) THEN vvsroll = ((dThetaDT / dThetaDX) ^ 2)  ‘Step 4
    IF (vvsroll > vsmax) THEN vvsroll = vsmax
    'if (vvsRoll > VMCSCUR) then vvsRoll = VMCSCUR

    'compute geometric mean of roll rate limited speed squared and input speed
    'squared
    vvstmp = SQR(vvsroll * VVSCUR)                      ‘Step 5
    IF vvsroll > VVSCUR THEN
       IF UpHandle > 0 THEN vvstmp = SQR(vvstmp * VVSCUR)
       IF UpHandle = -1 THEN vvstmp = VVSCUR
    END IF
    IF VMCSCUR < vvstmp THEN vvstmp = VMCSCUR           ‘Step 6

    IF ABS((VVSCUR - vvstmp) / (VVSCUR + vvstmp)) < .005 THEN
      tagout# = tag#
    ELSEIF VVSCUR < vvstmp THEN
      tagout# = -tag#
      NumIncreased = NumIncreased + 1
    ELSEIF VVSCUR > vvstmp THEN
      tagout# = tag#
      NumDecreased = NumDecreased + 1
    END IF

    PRINT #2, RQCUR; DSCUR; vvstmp; SegmentNumber; tagout#

    RQFST = RQCUR
    DSFST = DSCUR
    VVSFST = VVSCUR
    THETAFST = THETACUR
    RQCUR = RQNXT
    DSCUR = DSNXT
    VVSCUR = VVSNXT
    THETACUR = THETANXT
LOOP
'print to rollx.dat a temporary file
PRINT #2, RQCUR; DSCUR; VVSCUR; SegmentNumber; tagout#
CLOSE

OPEN LogFile$ FOR APPEND AS 10
PRINT #10, "RollRate increased "; NumIncreased; " of "; NumPieces
PRINT #10, "RollRate decreased "; NumDecreased; " of "; NumPieces

PRINT "RollRate increased "; NumIncreased; " of "; NumPieces
PRINT "RollRate decreased "; NumDecreased; " of "; NumPieces

END SUB
```

```
’************* end of RollRate **************


’********** subroutine SmoothReverse **********
SUB SmoothReverse (infile$, outfile$)
DIM datum AS filter

PRINT "Entered SmoothReverse"

OPEN infile$ FOR INPUT AS #1
OPEN "rndax.tmp" FOR RANDOM AS #2 LEN = 40

N = 0
DO WHILE NOT EOF(1)
    N = N + 1
    INPUT #1, datum.TravelTime, datum.BankAngle
    PUT #2, , datum
LOOP
CLOSE #1

OPEN outfile$ FOR OUTPUT AS #3
FOR J = N TO 1 STEP -1
    GET #2, J, datum
    PRINT #3, datum.TravelTime, datum.BankAngle

NEXT J

CLOSE #3
CLOSE #2
KILL "rndax.tmp"

END SUB

’********** end of SmoothReverse **********


’********** subroutine SmoothReverse1 **********
SUB SmoothReverse1 (InputFile$)
’SmoothReverse1 inverts the data in preparation
                    ’for the next subroutine which will calculate
                    ’an exponential moving average backwards

CALL SmoothReverse(InputFile$, "FLIPPED.DAT")

END SUB

’********** end of SmoothReverse1 **********


’********** subroutine SmoothReverse2 **********
SUB SmoothReverse2
’SmoothReverse2 inverts the data after
                    ’an exponential moving average backwards

CALL SmoothReverse("ANGLEREV.DAT", "ANGLE2.DAT")

END SUB

’********** end of SmoothReverse2 **********
```

APPENDIX C. KINCALC.SAS: BRIEF DESCRIPTION AND PROGRAM

KINCALC.SAS is a SAS program that calculates a motion- sickness dose value (MSDV) from a sequence of vertical accelerations. The resulting value may be used for comparing two proposed Maglev alignments. Also, the program could be used to locate segments of the trajectory that make large contributions to the MSDV.

The program KINCALC.SAS makes use of a SAS procedure, *Proc Spectra*, (part of the *ETS* module) to calculate the periodogram of the vertical accelerations. Other software packages are available for calculating a periodogram.

KINCALC.SAS applies the W_f filter for quantifying the motion sickness potential of an input sequence of vertical accelerations (see ISO 2631). This is done by applying a weight function to the periodogram of the vertical accelerations. The program could easily be modified to apply other weight functions such as are described in ISO 2631 (e.g. W_k) and could work with accelerations along axes other than the vertical axis.

The program, KINCALC.SAS, takes as input a file (ACCEL.DAT) which contains a sequence of longitudinal (xcg), lateral (ycg), and vertical (zcg) accelerations measured in hundredths of a g. The sampling rate is 10 measurements per second. The sampling rate should be at least twice as high as the highest frequency considered important. For the W_f weight function about 1 or 2 measurements per second is enough, but for other weight functions presented in ISO 2631 this would need to be much higher.

KINCALC.SAS was written to calculate the motion-sickness-dose value for the 9 flights of this study. For that application, the accelerations in the input file (ACCEL.DAT) were actually measured using accelerometers. To use KINCALC.SAS on the output of COMBO.BAS (the *.TIM file - see Appendices A and B), in addition to renaming the *.TIM file as ACCEL.DAT, an additional calculation is necessary. Note that the *.TIM file contains a sequence of bank angles instead of a sequence of vertical acceleration. By assuming all accelerations to be resolved through the vertical axis (with respect to the passenger) the acceleration (in g) experienced by a passenger traversing a curve must be calculated using the formula:

$$zg = \frac{1}{\cos(bank)} - 1 .$$

This calculation is presented in KINCALC.SAS in the second "data step" (commented out) which should be used place of the first data step. The replacement data step is shown below.

```
***********************************************;
* DATA STEP FOR COMBO.BAS OUTPUT FILE         *;
* use this data step instead of above if      *;
* accelerations need to be computed from bank *;
* angle                                       *;
* data tseries;
*   infile 'accel.dat';
*   INPUT bank;
*   zg=1/cos(bank*&PI/180)-1;
*   z=zg*9.8;           * Convert to m/s^2 *;
***********************************************;
```

Annotated Code: KINCALC.SAS

```
************************************************;
* KINCALC.SAS                                  *;
* Program to calculate motion sickness measure *;
* MSDVz                                        *;
*                                              *;
************************************************;
%LET SAMPRATE=10; * Adjust if other rate is used;
%LET PI=3.141592654;

data tseries;
  infile 'accel.dat';
  INPUT xcg ycg zcg;
  z=zcg/100*9.8;        * Convert to m/s^2 *;

***********************************************;
* DATA STEP FOR COMBO.BAS OUTPUT FILE         *;
* use this data step instead of above if      *;
* accelerations need to be computed from bank *;
* angle                                       *;
* data tseries;
*   infile 'accel.dat';
*   INPUT bank;
*   zg=1/cos(bank*&PI/180)-1;
*   z=zg*9.8;           * Convert to m/s^2 *;
***********************************************;

********************************************************
* Proc spectra converts the acceleration sequence into *
* the periodogram.  The output of this proc            *
* (contained in a data set "spec_out" is:              *
* freq - frequency in radians per unit time (tenths of *
* a second)                                            *
* p_01 - the value of the periodogram at the given     *
* frequency.                                           *
*******************************************************;

proc spectra data=tseries out=spec_out;
  var z;

*****************************************************
* squarit (square it) is a macro for obtaining the  *
* squared modulus of a quadratic in z=if where i is *
* the square root of -1 and f is an input frequency *
* in cps.                                           *
* the quadratic is g(z)=a z^2 + b z + c             *
*****************************************************;
%macro squarit;
f=2*&PI*fhz;ff=f*f;
g=a*a*ff*ff+(b*b-2*c*a)*ff+c*c;
```

```
%mend squarit;

*****************************************************
* The data step "filter" calculates the weighting   *
* function and the sum of the weighted periodogram  *
* The filter is specified by constants f1 -- f6 and *
* q4 -- q6                                          *
*****************************************************;

data filter;
  set spec_out;
  fhz=freq*&SAMPRATE/(2*&PI);
* The Wk filter and wf filter are presented ;
* The Wk filter is commented out ;
* the wk filter *;
*  retain f1 .4 f2 100 f3 12.5 f4 12.5 f5 2.37 f6 3.35
         q4 .63 q5 .91 q6 .91 sum01 0;
* the wf filter - based on ISO *;
   retain f1 .08 f2 .63 f3 999999999 f4 .25 f5 .0625
          f6 .1 q4 .86 q5 .80 q6 .80 sum01 0;
w1=2*&PI*f1;
w2=2*&PI*f2;
w3=2*&PI*f3;
w4=2*&PI*f4;
w5=2*&PI*f5;
w6=2*&PI*f6;

** first one calculates hk **;
** the high pass filter **;
  a=1; b=w1*sqrt(2); c=w1*w1;
  %squarit;
  d=g;
  a=1;b=0;c=0;
  %squarit;
  hk=g/d;

** second one calculates hl **;
** the low pass filter **;
  a=1; b=sqrt(2)*w2; c=w2**2;
  %squarit;
  d=g;
  a=0; b=0; c=w2**2;
  %squarit;
  hl=g/d;

** third one calculates ht **;
  a=w3; b=w3*w4/q4; c=w3*w4**2;
  %squarit;
  d=g;
  a=0; b=w4**2; c=w3*w4**2;
  %squarit;
  ht=g/d;

** fourth one calculates hz **;
  a=1;
  b=w6/q6;
  c=w6**2;
  %squarit;
  d=g;
  a=1;
  b=w5/q5;
  c=w5**2;
  %squarit;
  hz=g/d;
```

```
** now combine them **;
hu=sqrt(hk*hl*ht*hz);

** accumulate the sum of the weighted periodogram **;
sum01=sum01+hu*hu*p_01;


*********** end of data step "filter" **************;

** we want the final (maximal) value of sum01 *****;
proc means noprint;
 var sum01;
 output out=petesdat max=maxdose;


******************************************************
** The dose value is integral dt.                    *
** To multiply by dt we divide by the sampling rate. *
** Also, the theory predicts that the probability of *
**  vomitting is 1/3 of the dose                     *
******************************************************;

data fixit;
  set petesdat;
   dose=sqrt(maxdose/&SAMPRATE);
   pvomit=dose/3;

proc print data=fixit;
  var maxdose dose;
run;

**************** end of KINCALC.SAS ***************************;
```

APPENDIX D: ALIGNMENT.BAS AND NEW YORK STATE DATA

Program Logic

The purpose of the program ALIGNMENT.BAS is to transform engineering data describing a proposed Maglev alignment along sections of the New York State Thruway into the form required by the program COMBO.BAS. ALIGNMENT.BAS is a BASIC program that uses interpolation to reconstitute the New York State Thruway horizontal geometry with spirals. Spirals are computed subject to: maneuvering distance, target radius of curvature, and a spiral length limit of 1000 feet.[2] Spiral type could be anything; linear spirals are presently implemented. Where segment length is less than 2000 feet, target segment curvature will not achieved. Current implementation does not conserve change in heading. Conservation of change of heading can easily be implemented when appropriate.

Spirals are computed as linear rather than the sinusoidal shape used in the New York design because the aircraft pilot controls the specific rate of change of the bank angle for flying passengers and because linear spirals were considered appropriate to the ride quality mission.

Input is a batch file containing segment radius and length. Standard segment data units are feet for horizontal data. Output is to a disk file, RECONST.ROE, and has curvature and cumulative distance every 100 feet, and the segment number.

Specific Modeling Logic

The step numbers refer to the steps of logic and correspond to lines in the annotated code directly following this section.

Step 1) Compute curvature for each segment using the input radius. The resulting value is the given curvature somewhere within the segment.

Step 2) Use interpolation to compute a boundary curvature between each pair of adjacent segments.

Step 3) Divide each segment into very small pieces (100 feet each)

Step 4) Compute distance X from the segment boundary to the current piece being computed.

Step 5) Normalize distance XN between the current point and the point at which it could be at maximum curvature.

---

[2] Maximum spiral length is set to 1000 feet.

Step 6) Compute current point curvature using linear interpolation between beginning boundary curvature and the point at which it could be at maximum segment curvature, moving forward.

Step 7) Compute piece curvature using linear interpolation between end boundary curvature and to the segment curvature, moving backward.

NOTE: Since the initial boundary curvature and the final boundary curvature are not necessarily equal, the slopes and the lengths of the two spirals are independent of one another. Spiral shape is implemented as linear but can be altered, for example, to clothoid or sinusoid.

Step 8) If the sum of the spiral lengths is equal to total segment length, there is no constant curvature section. If the sum of the spiral lengths is less than total segment length, there is a constant curvature section.

Step 9) Output results are curvature every 100 feet and cumulative distance in feet.

'ALIGNMENT.BAS ANNOTATED CODE

```
'****************** Driver for Alignment Module ***********************
DECLARE SUB ALIGNMENT (infile$, DS, LT)

PRINT "DATA IN [BRACKET] IS DEFAULT VALUE"

PRINT "Enter name and path of input file [NYRDY.DAT=DEFAULT]"
INPUT InputFileName$
infile$ = RTRIM$(InputFileName$)
InputFileName$ = LTRIM$(infile$)
IF  InputFileName$  =  "  "  OR  InputFileName$  =  ""  THEN  InputFileName$  =
"NYRDY.DAT"
PRINT "Calling ALIGNMENT - Creating RECONST.ROE"
PRINT " Input from "; infile$
CALL ALIGNMENT(infile$, DS, LT)
'********************** End of Driver for Alignment Module ************

'********************** Beginning of Alignment Module *****************
"STEP #" refers back to the discussion in the previous modeling logic section.


SUB ALIGNMENT (infile$, DS, LT)
DIM Curvature(1000), FLAGG(1000), SEGLENGTH(1000)

DS = 100       'Piece size 100'
LT = 1000      'Maximum Spiral Length 1000'
NN = 0
RADFEET = 0    'radius in feet
SEGFEET = 0    'segment length in feet
CUMFEET = 0    'cumulative length over several segments

OPEN infile$ FOR INPUT AS 1    'input batch alignment data

J = 0
DO WHILE NOT EOF(1)
    INPUT #1, RADFEET, SEGFEET
    IF RADFEET = 0 OR SEGFEET = 0 THEN GOTO ENND
```

```
    J = J + 1

    IF (J > 1000) THEN
      PRINT "Over 1000 segments in input file"; infile$
      PRINT "Internal ARRAY size limit exceeded.  Do you want to "
      PRINT "    Continue using only first 1000 segments  OR "
      PRINT "    Abort processing "
      PRINT "    -1 = ABORT, anything else = Continue"
      INPUT AbortContinue
      IF AbortContinue = -1 THEN STOP
      GOTO ENND
    END IF

    IF RADFEET > 999000 OR RADFEET < -999000 THEN
      SEGCURV = 0
      FLAG = 1
    ELSE
      SEGCURV = 1! / RADFEET                         STEP #1
      FLAG = 0
    END IF

    Curvature(J) = SEGCURV
    FLAGG(J) = FLAG
    SEGLENGTH(J) = SEGFEET
ENND:
LOOP
CLOSE

'outer loop
OPEN "RECONST.ROE" FOR OUTPUT AS 2
N = J
FOR J = 1 TO N

  'NOTE LINEAR INTERPOLATION IS PRESENTLY USED - THUS LINEAR SPIRALS ARE
  'GENERATED
    'interpolate segment boundary curvature from prior & current curvature
    IF (J=1) THEN
      RRA = 0
    ELSE
      RRA = 0.5 * (Curvature(J - 1) + Curvature(J))    STEP #2 'BEHIND
IF FLAGG(J - 1) = 1 THEN RRA = 0
    END IF
    'interpolate segment boundary curvature from next & current curvature
    IF (J=N) THEN
      RRZ = 0
    ELSE
      RRZ = .5 * (Curvature(J + 1) + Curvature(J))     STEP #2 AHEAD
      IF FLAGG(J + 1) = 1 THEN RRZ = 0
    END IF

    'check for straight segment
    IF FLAGG(J) = 1 THEN RRA = 0: RRZ = 0
    'divide current segment into 100 foot pieces
    NN = INT(SEGLENGTH(J) / DS + 0.5)                STEP #3
    'readin the maximum curvature of the current segment
    RMC = Curvature(J)

    'begin JJ inner loop calculation for each piece in current segment
    FOR JJ = 1 TO NN
      ' working from the beginning of the segment forward
      X = JJ * DS                                    STEP #4 AHEAD
      XN = X / LT                                    STEP #5
  'NOTE LINEAR INTERPOLATION IS PRESENTLY USED - THUS LINEAR SPIRALS ARE
  'GENERATED
```

```
      ’interpolate  between  piece  beginning  boundary  curvature  and  maximum
curvature
      RX = RRA * (1 - XN) + RMC * XN             STEP #6

      ’working from the end of the segment backwards
      Y = SEGLENGTH(J) - X                             STEP #4 BEHIND
      YN = Y / LT                                      STEP #5
  ’NOTE LINEAR INTERPOLATION IS PRESENTLY USED - THUS LINEAR SPIRALS ARE
  ’GENERATED
      ’interpolate  between  piece  ending  boundary  curvature  and  maximum
curvature
      RY = RRZ * (1 - YN) + RMC * YN             STEP #6
      RQ = RMC
         IF  JJ <= 10  AND  JJ <= NN / 2  THEN RQ = RX
         IF JJ > NN / 2 AND JJ > NN - 10  THEN RQ = RY
       IF JJ <= ((LT + 1) / DS) AND JJ <= NN / 2 THEN RQ = RX
       IF JJ > NN / 2 AND JJ > NN - ((LT + 1) / DS) THEN RQ = RY

      ’ test for straight track and adjust curvature
      IF RMC = 0 THEN RQ = 0                           STEP #8
      CUMFEET = CUMFEET + 100
      PRINT #2, RQ, CUMFEET, J                   STEP #9
    NEXT JJ
NEXT J
CLOSE

END SUB
```

The New York State Data (NYRDY.DAT) follows: (column 1 is radius; column 2 is curve length) - read down, then across. Data is taken directly from Ref. 7.

radius	length	radius	length	radius	length	radius	length	radius	length	radius	length
999999	7250	19100	4510	999999	520	999999	8305	-30000	690	999999	1995
6800	4000	999999	1795	-13300	1870	-16000	2955	999999	9720	-10000	6420
999999	3780	-19100	50	999999	2955	999999	4140	30000	4110	-15000	6225
19800	1445	19100	3215	25000	2135	13300	2780	9000	3620	999999	3555
999999	2275	999999	1430	999999	3990	999999	1240	999999	800	80000	4625
-12000	4195	12000	4330	999999	620	14000	2480	-10000	4665	999999	925
999999	2010	999999	635	-15000	2605	999999	6640	-19100	4450	-2800	3120
32000	1015	-12000	4225	999999	790	-14000	2415	999999	1295	999999	630
999999	1395	12000	2605	15000	1420	999999	4760	11000	4860	3800	5120
-19100	4410	999999	2020	999999	6980	12000	2315	30000	3815	999999	2870
13300	3715	2800	2520	19100	1505	999999	3250	999999	1360	-3200	4590
-19100	2390	999999	455	999999	2325	30000	685	-19100	4600	999999	600
999999	830	-10000	2160	-19100	1305	999999	8940	999999	8705	2800	3545
28000	2975	999999	1675	999999	1160	90000	1245	-20000	4355	999999	620
-13300	3400	-4200	3375	-15000	5075	999999	6140	20000	2545	2800	3525
6000	3635	999999	3980	999999	2160	-20000	1510	999999	645	999999	610
999999	5010	20000	1220	10000	4625	999999	9595	-20000	5060	-5500	2890
-10000	1845	999999	1230	999999	330	-19100	2285	999999	4850	999999	640
999999	1720	6000	4140	-19100	2315	999999	12550	13300	2485	12000	1030
19100	3220	999999	2825	999999	3330	999999	735	999999	855		
999999	1420	13300	4055	-8000	2100	30000	800	-19100	3195		
-8000	1890	999999	2120	999999	725	999999	3985	999999	7065		
999999	1570	-4000	2985	8400	3895	11000	5280	19100	3815		
8000	1495	999999	855	999999	3485	999999	2795	999999	2895		
999999	1250	20000	1705	-4200	4485	-11000	5760	19100	3340		
-10000	2890	999999	1580	999999	5475	80000	3855	999999	2670		
999999	1015	20000	1450	9000	4235	999999	490	19100	5805		
10000	2880	999999	3980	999999	8895	-9000	3155	-19100	6180		
999999	225	-13300	2710	-19100	4905	999999	2595	999999	6785		
-11000	2715	20000	2470	999999	2625	-30000	640	-15000	6675		
999999	1505	999999	3770	-13300	5615	999999	7630	999999	5850		
6000	3135	-19100	2515	999999	6380	100000	7625	15000	6365		
-6000	3735	999999	1720	-19100	2340	999999	1935	999999	18185		
5500	5585	4400	1795	999999	2585	20000	4185	-19100	5155		
-10000	2325	999999	940	13300	3035	999999	585	19100	3445		
999999	1605	-7000	2115	999999	7200	-10000	2735	999999	2475		
13300	2615	999999	9020	-6000	2630	999999	305	-30000	855		
-13300	3600	20000	2305	999999	23925	25000	1855	999999	8450		
999999	2650	999999	1355	15000	4950	999999	600	19000	3700		
11000	4015	-25000	4700	999999	2220	-25000	1550	999999	1940		
999999	1715	-1330	1055	-7000	3930	999999	7015	-19000	13320		
-19200	2425	999999	270	999999	15050	-25000	1390	19000	3325		
999999	3255	7000	3315	14000	3035	999999	3825	9000	10385		
-20000	3260	999999	3810	999999	3850	20000	4630	999999	760		
999999	1810	-6000	2635	50000	2605	999999	12320	-3800	4015		
-8000	2305	999999	1655	999999	5305	30000	550	999999	670		
999999	600	20000	640	-7000	2885	999999	3310	5500	5445		
13300	1560	999999	680	999999	3510	-20000	4540	999999	1920		
999999	1480	-20000	825	9000	2935	999999	1295	-5000	3150		
-7500	3245	999999	2160	18000	745	30000	700	999999	530		
999999	1730	9000	2710	8000	2905	999999	1960	3600	3800		

APPENDIX E: PLOTS OF BANK ANGLE AND ROLL RATE VS. TIME FOR THE WORST CASE (28 DEGREES AND 8 DEGREES/SEC)

Figure E-1. Plots of Bank Angle and Roll Rate for the Beginning Third of the Worst-Case Flight

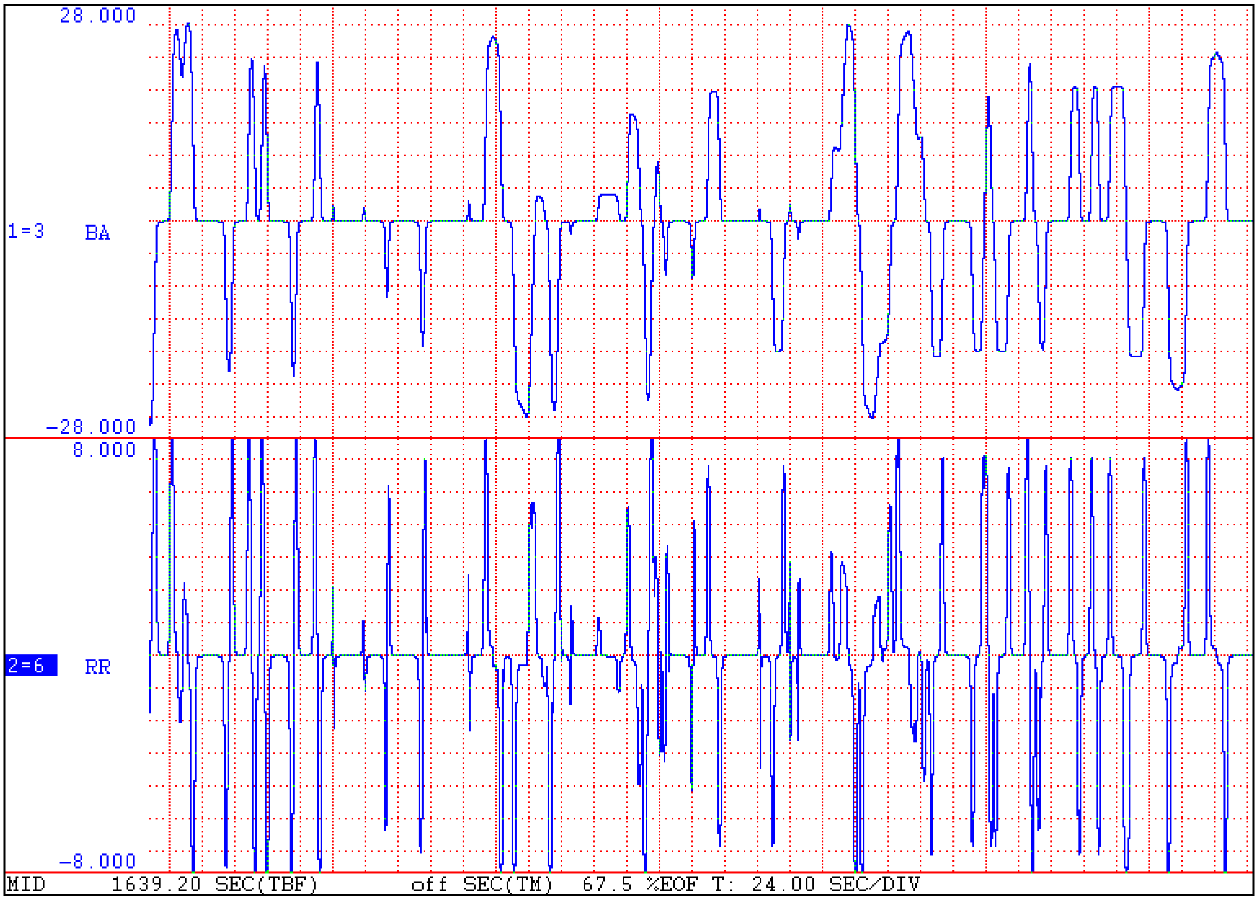


Figure E-2. Plots of Bank Angle and Roll Rate for the Middle Third of the Worst-Case Flight

Figure E-3. Plots of Bank Angle and Roll Rate for the Last Third of the Worst-Case Flight

APPENDIX F. SUBJECT CONSENT FORM

SUBJECT CONSENT FORM
MAGLEV RIDE-QUALITY STUDY

I, ________________________________, consent to be a subject in the research project described below.

1. The purpose of this experiment is to help set the design standards for the speed of future high-speed ground transportation systems. Congress has proposed that 300 MPH, magnetically levitated (Maglev) systems be demonstrated in this country and that they use existing rights-of-way as much as possible. Since the Maglev vehicles would operate at speeds much higher than conventional trains, their passengers would experience much higher levels of acceleration (also known as g-forces) both vertically and longitudinally, as well as much higher roll rates.

   In setting the standards for future systems, it is very important to know what levels of g-forces and roll rates are acceptable to most people. If the allowable levels are set too high in the design standards, many people may refuse to use the system because of the discomfort they experience; if they are set too low, the system will be more expensive to build and/or will operate at a lower average speed. The goal of this experiment is to determine the point at which passengers would just begin to experience motion sickness.

2. I have been selected to participate in this study as a representative member of the traveling public, who has made at least six round trips by air, of which at least two occurred in the past year.

3. I understand that in the experimental session I will be flown in a 20-passenger twin turboprop aircraft for about two hours total, of which 45 minutes to one hour will consist of roll maneuvers simulating a Maglev train following the portions of the right of way of the New York State Thruway. These roll maneuvers may involve bank angles as high as 28 degrees, which are slightly higher than the maximum bank angles ordinarily used by commercial airliners (25 degrees). The vertical maneuvers may produce accelerations of as much as 0.2 g greater than normal. (For comparison, accelerations experienced in typical elevators are about .15 g.) Maneuvers may occur as frequently as four or five per minute. I understand that the risk of injury involved in this experiment is similar to that of flying in a commercial airliner.

4. I understand that in filling out my rating booklet, I will disclose my age, sex and occupation along with my ratings for ride comfort and whether I am experiencing any degree of motion sickness. My name will not be recorded in the subject booklet or in any other experimental records, except this consent form and the receipt for the fee. I understand that all reasonable efforts will be made to keep my identity confidential.

5. I understand that I may contact the following individual with any questions I may have about this study or my participation in it as a research subject:

   John K. Pollard, Project Manager
   U. S. Dept. of Transportation, DTS-45
   55 Broadway
   Cambridge, MA 02142
   (617) 494-2449

6. I understand that in the unlikely event of a physical injury, emergency care will be provided.

7. I understand that certain medical conditions, such as, pregnancy, retinal detachment, back injuries, heart ailments, unusual tendency to motion sickness etc., may be aggravated by greater than normal g-forces. To the best of my knowledge, I do not have any medical or psychological condition that would interfere with my ability to complete my participation in a safe and satisfactory manner. I agree to answer questions regarding my medical condition to insure that no such problems exist.

7. I understand that I may experience some queasiness or the beginnings of nausea in this experiment. I understand that I am free to withdraw from the experiment if I so chose. I understand that the experimental portion of the flight will be terminated if any passenger becomes nauseous.

8. I understand that the flight session will require about two hours of my time and that I will receive compensation of $50.00. I understand that if I also take the one-hour simulator ride, I will be paid an additional $25.00.

I have read and understand the various aspects of my participation in this study, all my questions have been answered and I voluntarily agree to participate.

Name: ______________________________
(Subject, Please print)

Signature: _________________________

Date: ______________________________

APPENDIX G. REFERENCES

1. Sussman, E.D., Pollard, J.K., Mengert, P., DiSario, R. (1994). *Study to Establish Ride-Comfort Criteria for High-Speed Magnetically Levitated Transportation Systems*. U.S. Dept. of Transportation, Federal Railroad Administration, Washington, D.C. DOT/FRA/NMI-94/1.

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6. International Organization for Standardization, (1994). *Mechanical Vibration And Shock - Evaluation of Human Exposure to Whole-Body Vibration - Part 1*. Draft International Standard, ISO/DIS 2631-1.

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