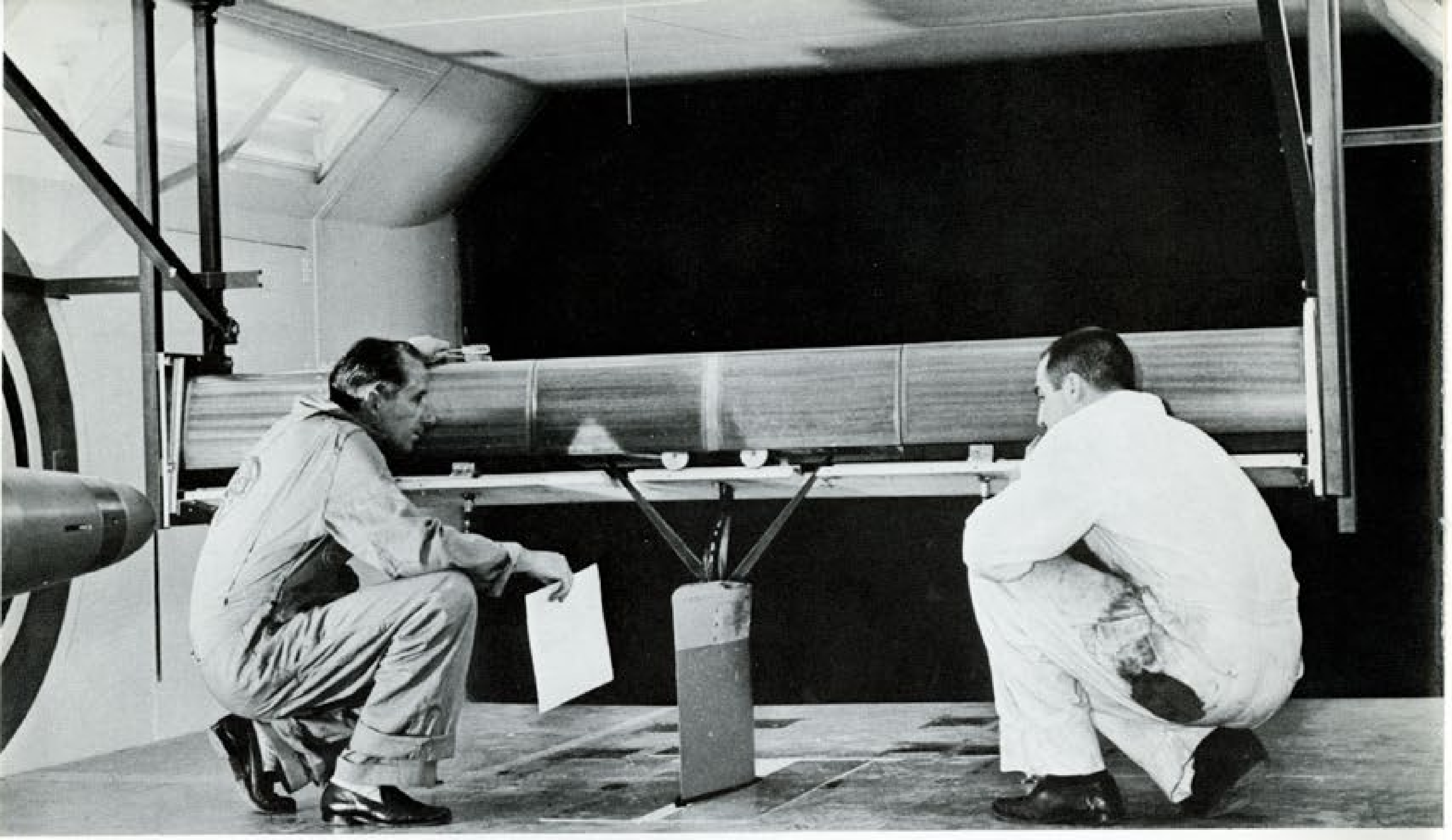
ASSURING THE STABILITY OF THE BARTD LIGHTWEIGHT RAPID TRANSIT VEHICLE

SUBMITTED TO THE SAN FRANCISCO BAY AREA RAPID TRANSIT DISTRICT
BY PARSONS BRINCKERHOFF-TUDOR-BECHTEL
April 1964



Scale model of proposed vehicle in wind tunnel.

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April 17, 1964

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Gentlemen:

The decision to use lightweight, high-speed transit vehicles on the San Francisco Bay Area Rapid Transit District System has required a complete examination of their lateral stability, particularly under high winds. We have explored this problem thoroughly.

It is now conclusive that the lateral stability of lightweight vehicles in the 800-pounds-per-linear-foot class can be assured through designs incorporating a 5'-6" gauge track. This is the most effective and most economical design measure by which the desired stability can be obtained.

We must point out that the findings of this investigation are based on circumstances unique to the BARTD System.

This report describes the lateral stability investigation, research procedures employed, findings and recommendations.

Very truly yours

W.A. Bugge
Project Director

I. INTRODUCTION

Plans for the San Francisco Bay Area Rapid Transit System are based upon a fleet of trains operating at very high speeds and at close intervals, particularly during the commuter rush hours. To meet these requirements, designers have proposed individually powered cars capable of reaching a top speed of 80 miles per hour and of averaging 45 to 50 miles per hour throughout the system, including station stops.

Such performance will require that BARTD trains be able to accelerate and decelerate rapidly between stations.

Here, the matter of vehicle weight comes to the front as a major design consideration. The lighter the vehicle, the easier it will be to move it from a standstill to a high speed and to decelerate it smoothly. These tasks will require less power, a lighter propulsion unit, and a smaller, quieter braking system.

A lightweight train will be far more economical to operate. It is estimated that 75% of the power requirement of this system will be directly proportional to the weight of the train.

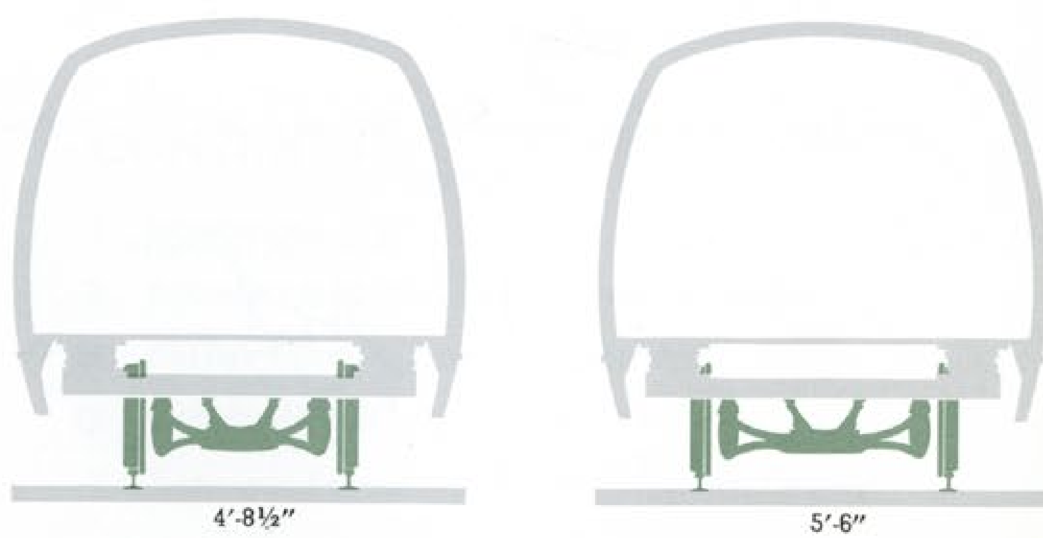
Consequently, development of a lightweight rapid transit vehicle has been a major objective for the BARTD system. This goal is close to realization. It now appears probable that cars for the system will weigh no more than 800 pounds per linear foot.

Although there are transit cars in this weight range, no other rapid transit system in the world operates cars of such light weight at the high speeds required here and under the environmental conditions of the Bay Area. Thus, BARTD system designers face some completely new design considerations.

One of these is that of vehicle stability, stability ordinarily being a linear function of weight. How will lightweight vehicles behave at the high speeds envisioned on the system, at grade or on aerial structures 30 feet or more above grade, and in areas where they will be directly exposed to high winds?

Answers to such questions have now been established through intensive research.

The purpose of this report is to review the factors associated with lightweight vehicle stability and to recommend the most logical measure for assuring stability in BARTD system trains.



Comparison of vehicle and track designed to 5'-6" gauge with the standard 4'-8½". This major design feature would solve the problem of lateral stability in the kind of lightweight vehicles proposed for the BARTD System.

II. SUMMARY OF FINDINGS AND RECOMMENDATIONS

As previously noted, the BARTD System will utilize lightweight cars operating at higher average speeds than any other transit system in the world. Furthermore, it is possible that these vehicles will be subjected occasionally, on 31 miles of aerial structures and 24 miles of at-grade construction, to high winds.

This combination of conditions made it necessary to initiate a comprehensive review of the lateral stability problem and to undertake intensive research into methods of assuring safe operation of such trains.

After exploration of various alternatives, it has become apparent that a track gauge significantly wider than the standard 4'-8½" offers the most practical possibility of obtaining the desired lateral stability.

The consulting engineers accordingly subjected wider gauge designs to mathematical analysis, and Stanford Research Institute was retained to check and refine these calculations, to perform extensive wind tunnel tests, and to incorporate the results of those tests in the stability calculations.

The effects of a variety of factors on the stability of a lightweight car were investigated. These included the dimensions, shape and weight of the proposed vehicle, the velocity of winds in the Bay Area, the passenger load distribution in the car, the anticipated operating speed of the trains, track gauge, the effects of trackside parapets, ribbed roof surfaces, aerial structures and sloped embankments.

Mathematical formulae were developed to determine the reliability of vehicle-track systems constructed to a range of gauges under various combinations of adverse conditions. Two of the extreme hypothetical situations developed could be expressed in the following questions:

1. How stable will be an empty lightweight train stopped on a superelevated curve, with a high wind blowing from outside the curve?

2. How stable will be a moving train on curved track, with unbalanced superelevation, subjected at the same instant to track irregularities and high wind from inside the curve?

In the first instance, a situation was assumed in which the vehicle had come to a stop on a superelevated curve and was leaning to one side. It was assumed that a high crosswind was pushing the car even farther off balance. An empty vehicle was selected in this case since it is less stable than a vehicle with a uniformly distributed passenger load.

The second instance assumed an empty vehicle moving at a high speed around a curve, subjected to a high crosswind, and experiencing all of the overturning influences of an irregular track. Thus, the vehicle was assumed unbalanced by centrifugal forces, by a high cross wind, and by track imperfections.

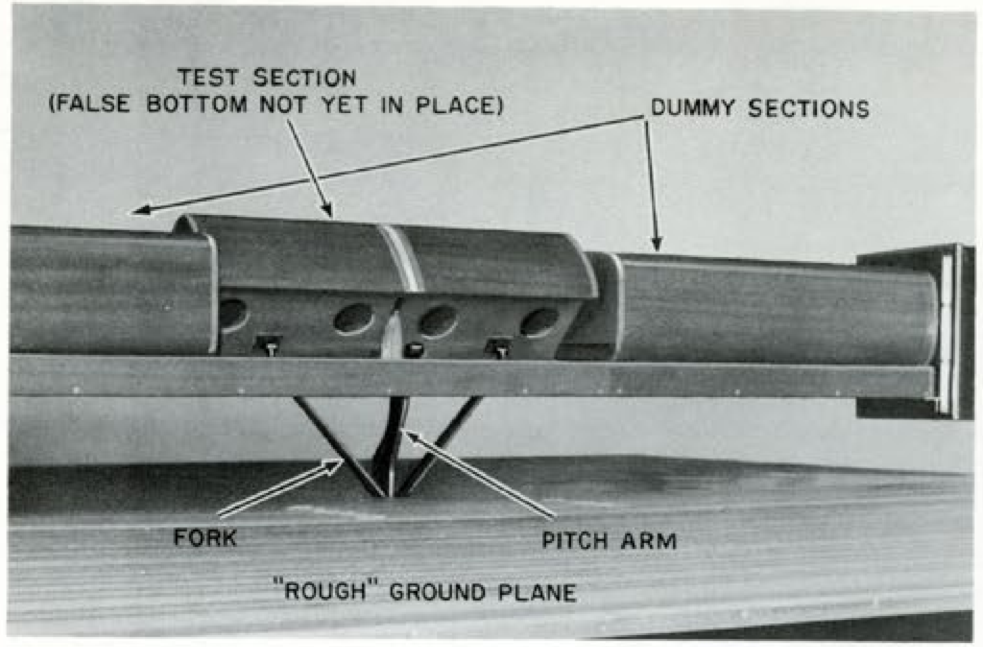
The analysis indicates that under both such conditions a vehicle-track system designed to a 5'-6" gauge would provide the necessary degree of stability. A gauge of less than 5'-6" would not provide an adequate margin of stability, and although a wider gauge would obviously provide greater stability the advantage would be offset by additional costs and other practical considerations.

As a result of these investigations, it is recommended that the BARTD System vehicle and track system be designed to a gauge of 5'-6". Findings clearly indicate that this approach would assure the lateral stability and safety of the desired lightweight vehicle more effectively and economically than any other design approach.

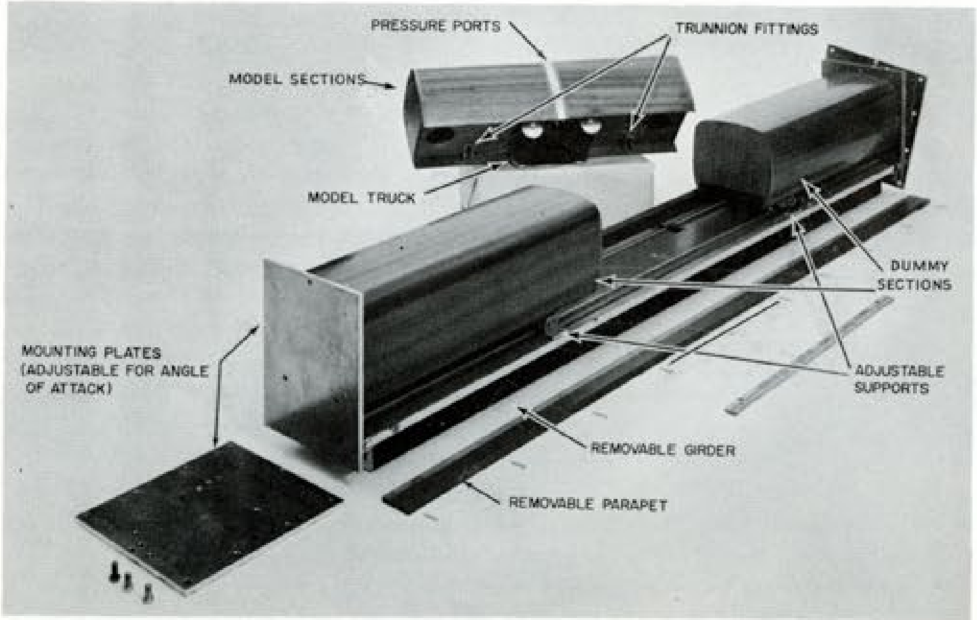
The solution of the stability problem in this way would make possible the operating economies inherent in a lightweight rapid transit system. Cost estimates show that savings would far surpass the additional cost of constructing wide gauge track.

It is probable, also, that a wide gauge installation will yield an increase in riding comfort. The side-to-side rolling characteristic exhibited by vehicles on standard gauge would be reduced on a 5'-6" track.

In short, it can be safely anticipated that the major consideration of stability, as well as lower operating costs and greater riding comfort, will result from the design of a lightweight vehicle for the wider gauge track.



Test section in wind tunnel, showing "dummy" sections on each side to simulate its position in a rapid transit train.



Model section used in wind tunnel tests, showing pressure ports at which wind pressures were measured, removable parapet, and other mechanisms.

SUMMARY OF "MARGIN OF STABILITY" FINDINGS

"Margin of stability" as used in this report is technically defined as the ratio of the net righting moment (righting minus overturning moments) to the righting moment of the car.

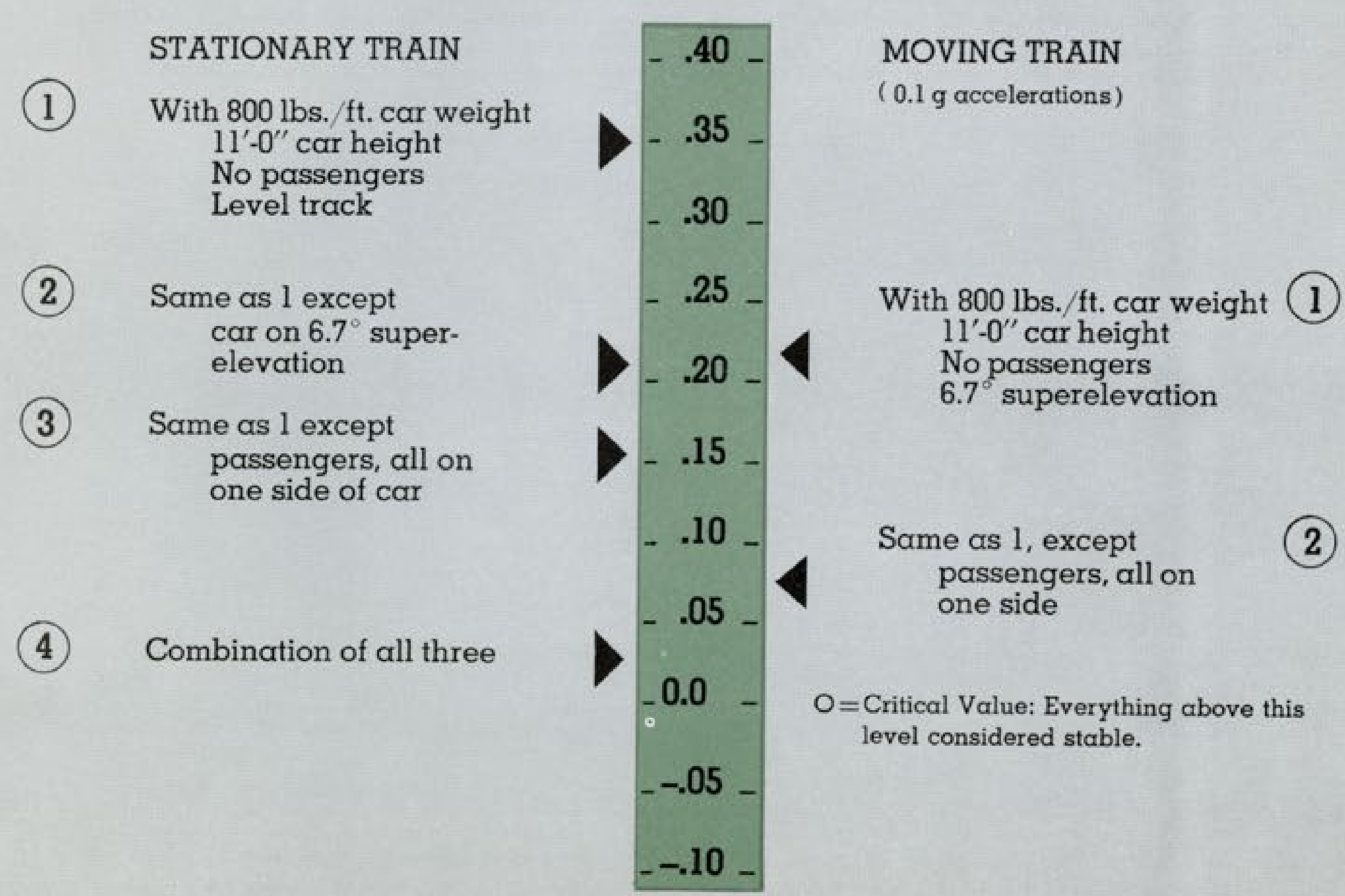
The value of "0" in the graphs represents the level *below which* a vehicle theoretically would overturn and *above which* it would not overturn. Any value above "0" indicates a stable condition.

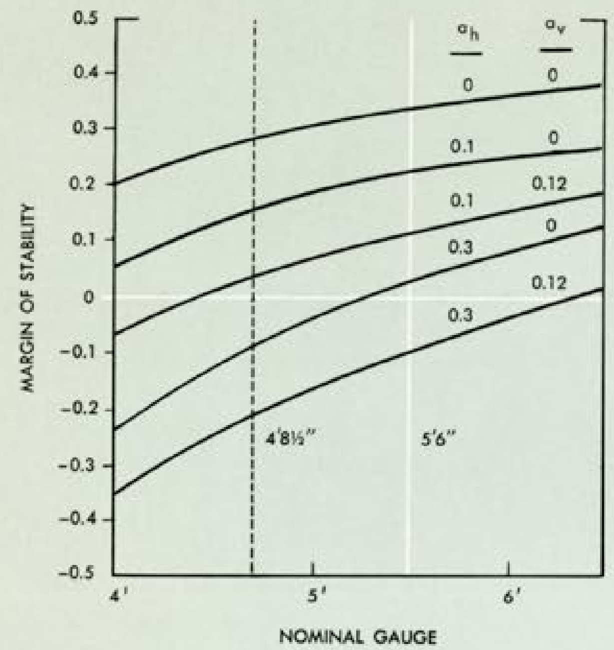
It is highly improbable that the several conditions incorporated in the hypothetical situations below would occur at once. The analysis indicated, however, that even under these various combinations of adverse conditions, the lightweight vehicle on 5'-6" track would not overturn.

Six examples are plotted below:

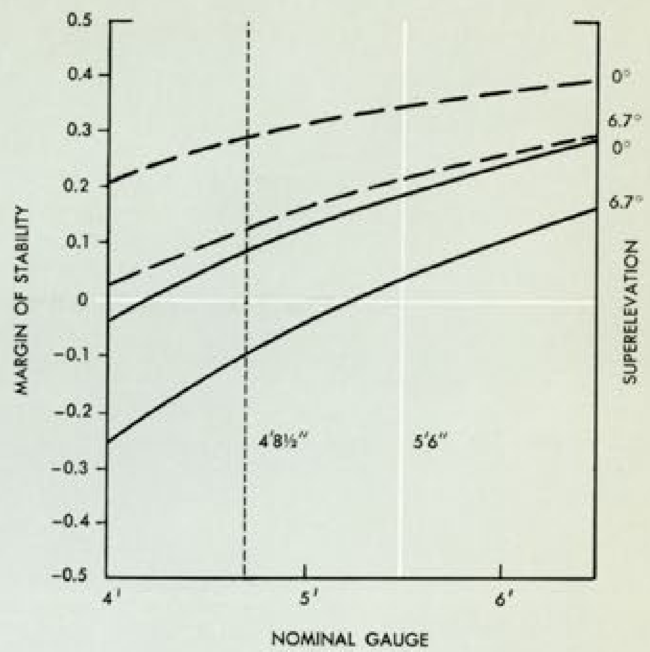
Margins of Stability

For Vehicle on 5'-6" Track under Various Adverse Conditions (85 mph crosswind assumed)

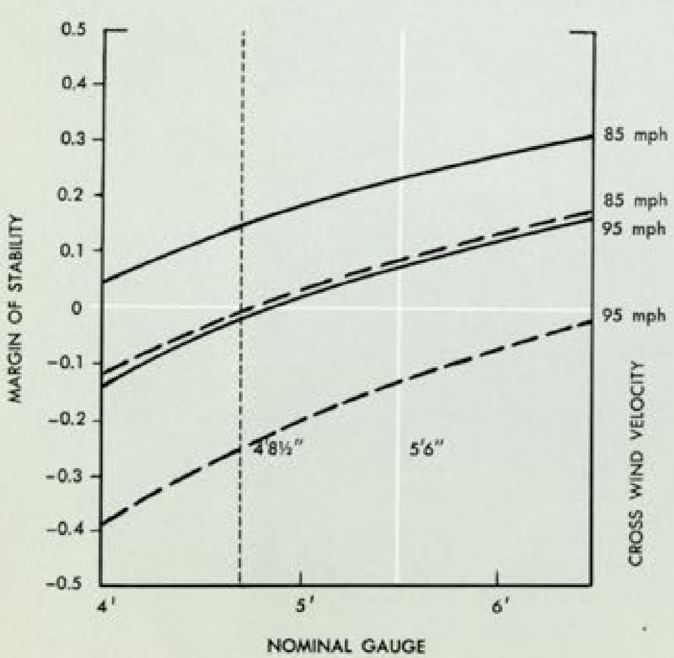




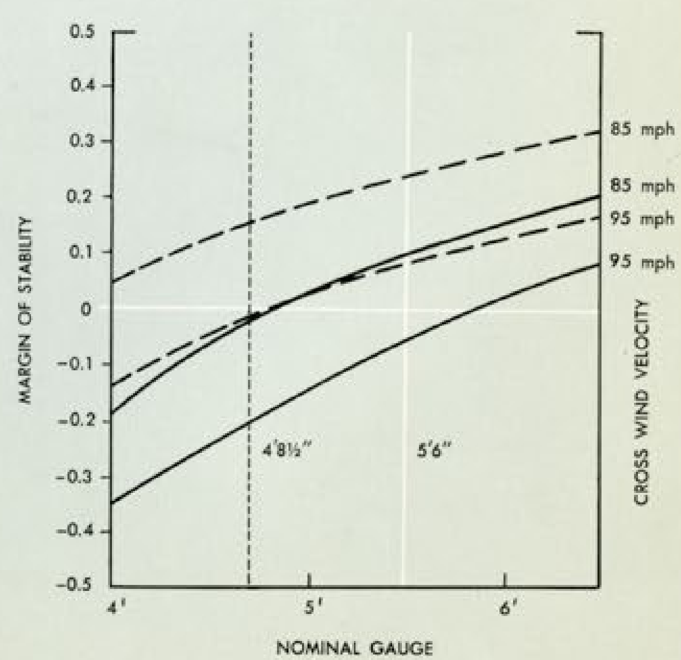
Effect of various combinations of accelerations experienced on curves and irregular track. Assuming car weight of 800 lbs./ft., height of 11'-0", 85 mph. wind and no passengers. a_h = horizontal accelerations and a_v = vertical accelerations.



Effect of 6.7° superelevation and eccentric loading of passengers on stationary car. Assuming car weight of 800 lbs./ft., car height of 11'-0", and 85 mph. crosswind.
——— Passengers ------ No Passengers



Effect of car weight. Assuming 11'-0" car height, horizontal acceleration of 0.1 g, and no passengers.
——— 800 lbs./ft. ------- 650 lbs./ft.



Effect of passengers eccentrically loaded on moving car. Assuming car weight of 800 lbs./ft., car height of 11'-0", and horizontal acceleration of 0.1 g.
——— Passengers ------ No Passengers

V. ECONOMIC BENEFITS AND INCREASED RIDING COMFORT

The successful adoption of lightweight vehicles through use of a wider gauge track would produce substantial cost savings and a more comfortable ride for passengers.

It is impossible at this time to determine these savings closely because many design elements have not been finalized. However, it has been estimated that they would more than offset the additional cost of installing a wide gauge system.

In brief, the following conclusions have evolved from an investigation of comparative costs:

1. The adoption of 5'-6" gauge would entail little, if any, additional cost in vehicle development, production, financing, or maintenance.

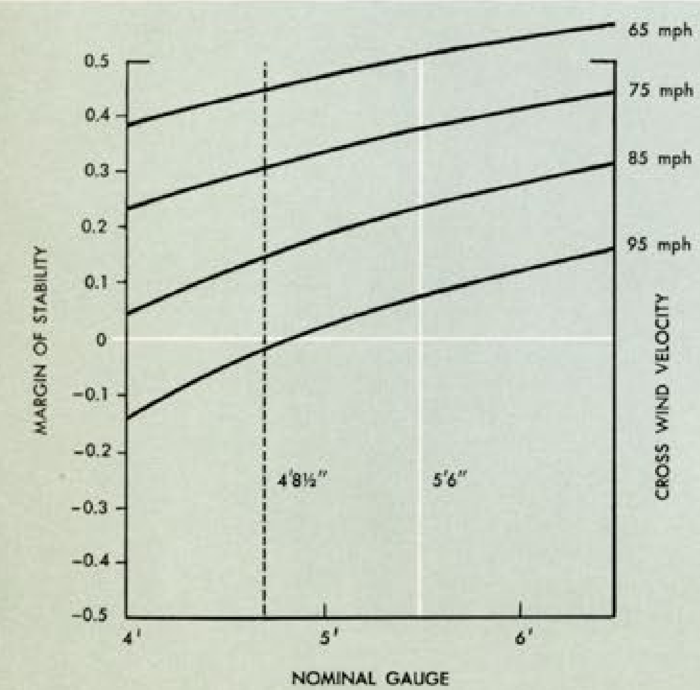
2. The additional cost of constructing at-grade, aerial and subway structures, turnouts and turnback track for wide gauge would be approximately $2 million over that of 4'-8½" gauge.

3. For any margin of stability judged to be appropriate, a train using 5'-6" gauge track could weigh approximately 100 pounds per linear foot less than one on 4'-8½" gauge track. Based upon a power cost of 10¢ per pound per year, the capitalized value of the savings would be approximately $4 million.

4. The net saving from a 5'-6" track gauge would, therefore, amount to approximately $2 million.

It is generally anticipated that adoption of a wider gauge design would lead to some improvement in riding comfort.

As a car passes over an irregularity in one rail, an angular rotation or acceleration is transferred to the car body, producing a distinctly uncomfortable type of movement. This acceleration is reduced as the rails are moved farther apart. Therefore, for the same amount of vertical sag of one rail in respect to the other, the resulting movements would be about 20% less for 5'-6" gauge than for standard gauge.



Effect of crosswinds of high velocities. Assuming car weight of 800 lbs./ft., car height of 11'-0", horizontal acceleration of 0.1 g, and no passengers.

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