Tests of "Zephyr" Model in the Wind Tunnel at the Massachusetts Institute of Technology

The "Zephyr" is a three car articulated motor-train unit, built by the Edward G. Budd Manufacturing Company for the Chicago, Burlington and Quincy Railroad. The general characteristics have been quite widely published;[1][2] therefore only a brief description will be given.

The Zephyr accommodates seventy-two passengers, can carry twenty-five tons of baggage, express and mail. It is 197 ft. long, of light weight construction with a gross weight of 120 tons. The principal structural material is stainless steel. The maximum speed is somewhat above 100 miles per hour. The power plant consists of one 660 B.P.H. Winton Diesel engine driving an electric generator. The two propulsive motors are located in the front truck.

The external form of the Zephyr is maintained as smooth as practical to minimise air resistance. The front is rounded, the rear slightly tapered, all structural members and apparatus below the cars are enclosed in a rounded bottom. Within the limits imposed by utility it is "streamlined". The effect in combination with the highly polished stainless steel side covering is to make a strikingly handsome train.

During the development of the design, the Edward G. Budd Manufacturing Company needed to know the air resistance for

(1) Railway Age, April 14, 1934.

(2) A.S.M.E. Transactions, September, 1934.

ground

estimating performance. A model of the Zephyr and a model of a corresponding conventional three-car gas-train (included for comparison) were therefore made and tested in the wind tunnel at the Massachusetts Institute of Technology.

The tunnel used for these tests is a large Venturi like tube, 5 feet in diameter at the throat where the model is mounted for test. Through this tube air is drawn by a four-bladed propeller type fan, driven by 75 H.P. electric motor. The speed of the air is varied by controlling the revolutions per minute of the motor by the Ward-Leonard system. The return flow of the air to the mouth of the tunnel is through the open room.

For these tests the model was held by wires close to a smooth fiber board. Figure I. The purpose of this board is to represent the ground. This it does but somewhat approximately, as the board and train model are fixed, with the air flowing by them, while the ground and air should be fixed with the train moving by. The relative velocity of train and air is correct, but not that of wind and ground. If the ground were not present the flow lines of the air below the model would not be like those between train and ground. It was not thought necessary to represent the track. The presence of the board reduced the measured resistance of the "Zephyr" model 10%.

The models were tested parallel to the airstream corresponding to travelling through still air, and also at an angle to the airstream as if travelling through a wind blowing across the track. For the first tests, the models were held by wires; for the second series, they were mounted on a rod supported by the regular air-

foil testing wire balances. The model of the "Zephyr" was $\frac{1}{40}$ scale, about 60 inches long. All tests were made at a wind speed of 60 miles per hour. It must be remembered that this is the relative wind speed -- for the real train the combination of the speed along the rails and the wind which may be blowing, not the speed along the track except when there is no wind. These forces were determined; the resistance meaning the force along the rails, the cross rail force, the lift.

It is convenient to express the resistance force on the "Zephyr" model parallel to the wind as a coefficient:

$$D = \text{Resistance} = D_c \, A \, V^2$$

A is the cross sectional area in square feet.

V is the relative wind in miles per hour.

D is the resistance in pounds when the air density is .00238 slugs per cubic foot.

This coefficient may be used in estimating full scale resistance closely, as, though there were of necessity minor parts omitted from the model, the surface frictional resistance coefficient would be less full scale. All other forces will be given as ratios of that basic force.

D_c is .00100

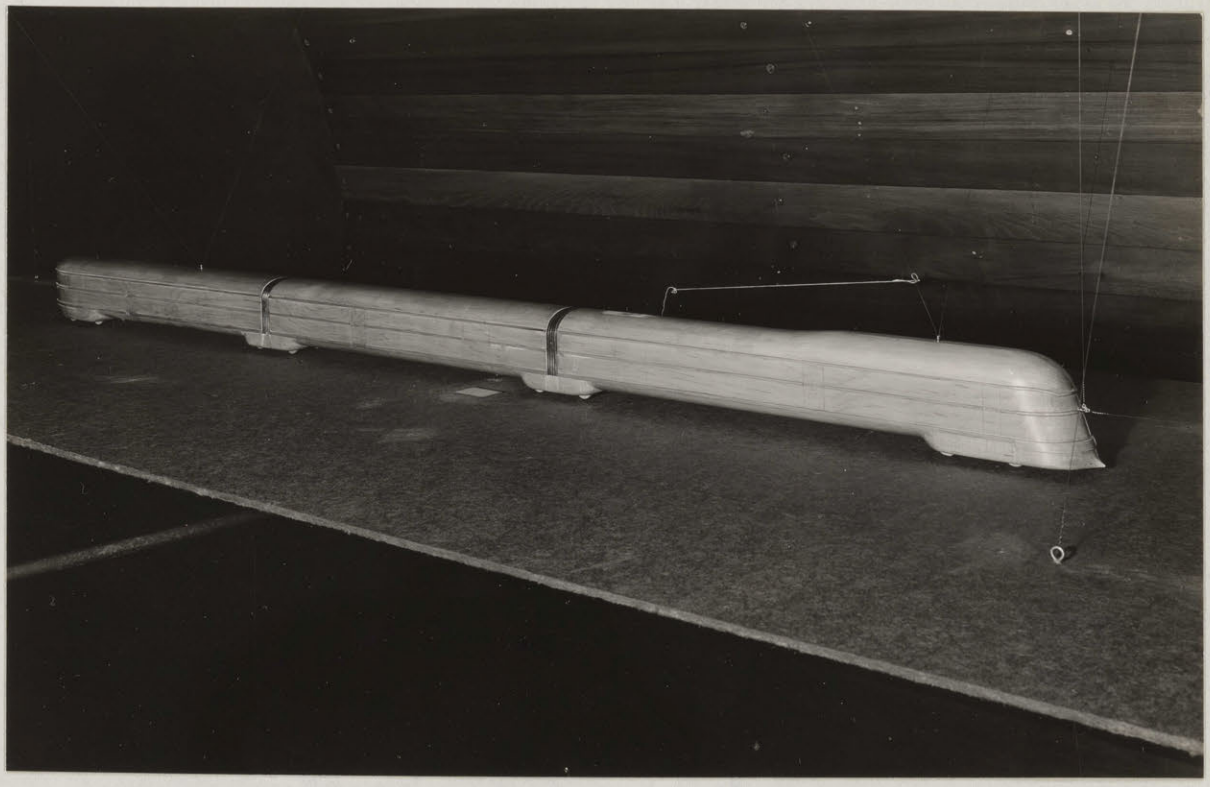
The force ratios are given on Figure 2.

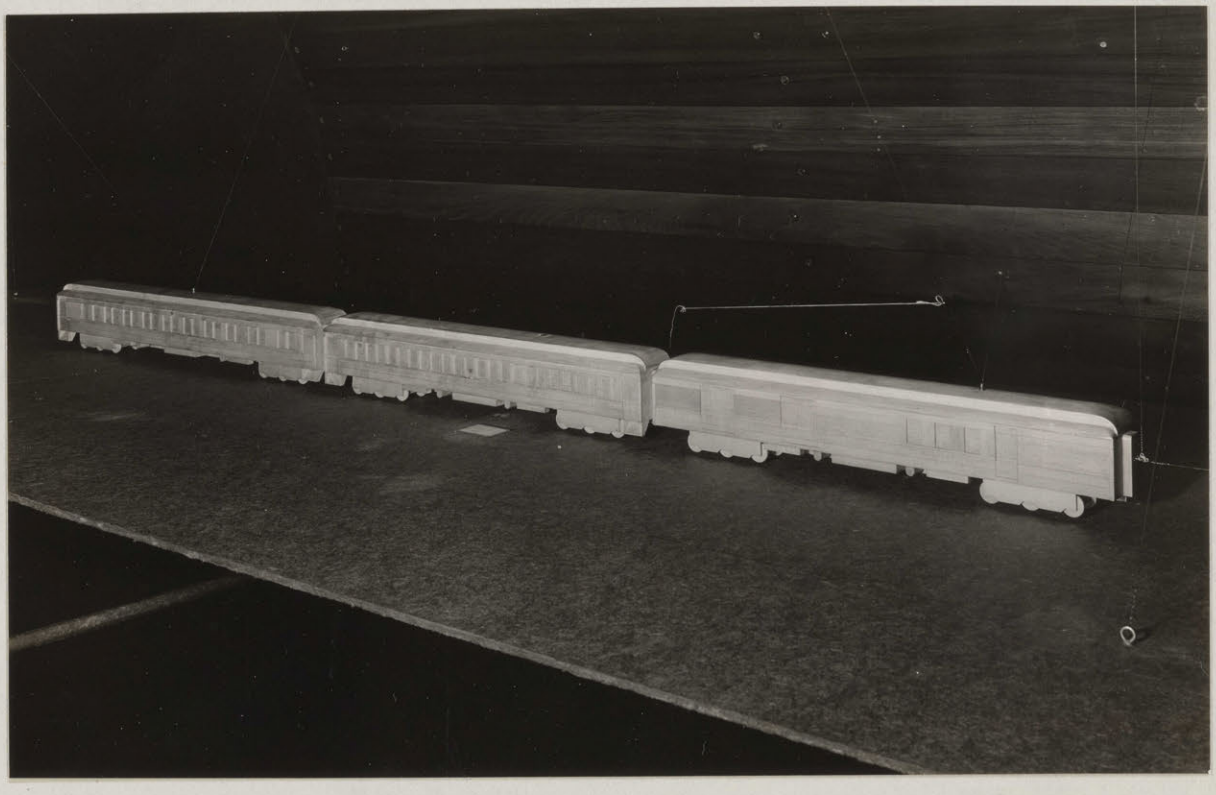
Translated, the air resistance force of the "Zephyr" requires 290 H.P. on the rail at 100 M.P.H., while the regular train would require over 900. The rolling resistance at that speed requires about 230 H.P.

It will be noticed that both the side force, which leads to an overturning moment, and the lift force are larger on the conventional model than on the streamlined model. At 80 M.P.H. an angle of 15° means 21½ M.P.H. across track wind, and the side force would be 3200 pounds, the lift 1300 pounds. The air resistance first increases with side angle then drops off (the side force acting like a sail on a yacht.) The side force will cause an increase in rolling resistance.

Test results on the "Zephyr" indicate that the air resistance coefficient found by these tests gives very closely the correct full scale resistance. The presentation of this description of the wind tunnel tests is made possible by the courtesy of the Edward G. Budd Manufacturing Company.

November 19, 1934 Shatswell Ober.





EDWARD G. BUDD MANUFACTURING CO.

MAKERS OF THE ALL-STEEL AUTOMOBILE BODY
AND
STAINLESS STEEL RAILWAY CARS AND EQUIPMENT

PHILADELPHIA, U. S. A.

November 30, 1934

Prof. Shatswell Ober
Massachusetts Inst. of Technology
Cambridge, Mass.

Dear Sir:

I am not sure that you have received the summaries of our performance calculations of the Burlington ZEPHYR, so I am inclosing curves of this work.

I believe you understand that we consider it advisable to add 20% to the results from the wind tunnel to correct for scale affect. This was a thoroughly arbitrary figure based on what we believe the drag coefficient of the standard car to be.

It is of considerable interest to notice that the actual performance is within the limits of this 20% range. Our actual top speed at the engine power for which the performance was calculated was between 95 and 97 miles per hour. With a bit of a down grade and certain adjustments to the engine governor, a very accurately timed actual speed for the train was 112-1/2. The detailed data for this run is entirely lacking.

I have for sometime been interested in the possibility of streamlining the head end of a train by the use of some type of ring cowling. It has been my belief that a very inexpensive relatively square end could be built with this cowling surrounding it and still have a fairly good drag coefficient. Unfortunately, I can get no appropriation for investigating this. I wonder if some of the fellows in the rather desperate search for thesis subjects might not be interested in tackling this problem.

I would be glad to communicate with anyone who might be or better yet, would be glad to talk to him in the case he might be in the vicinity of Philadelphia during the Christmas vacation.

Yours very truly,

EDWARD G. BUDD MANUFACTURING COMPANY

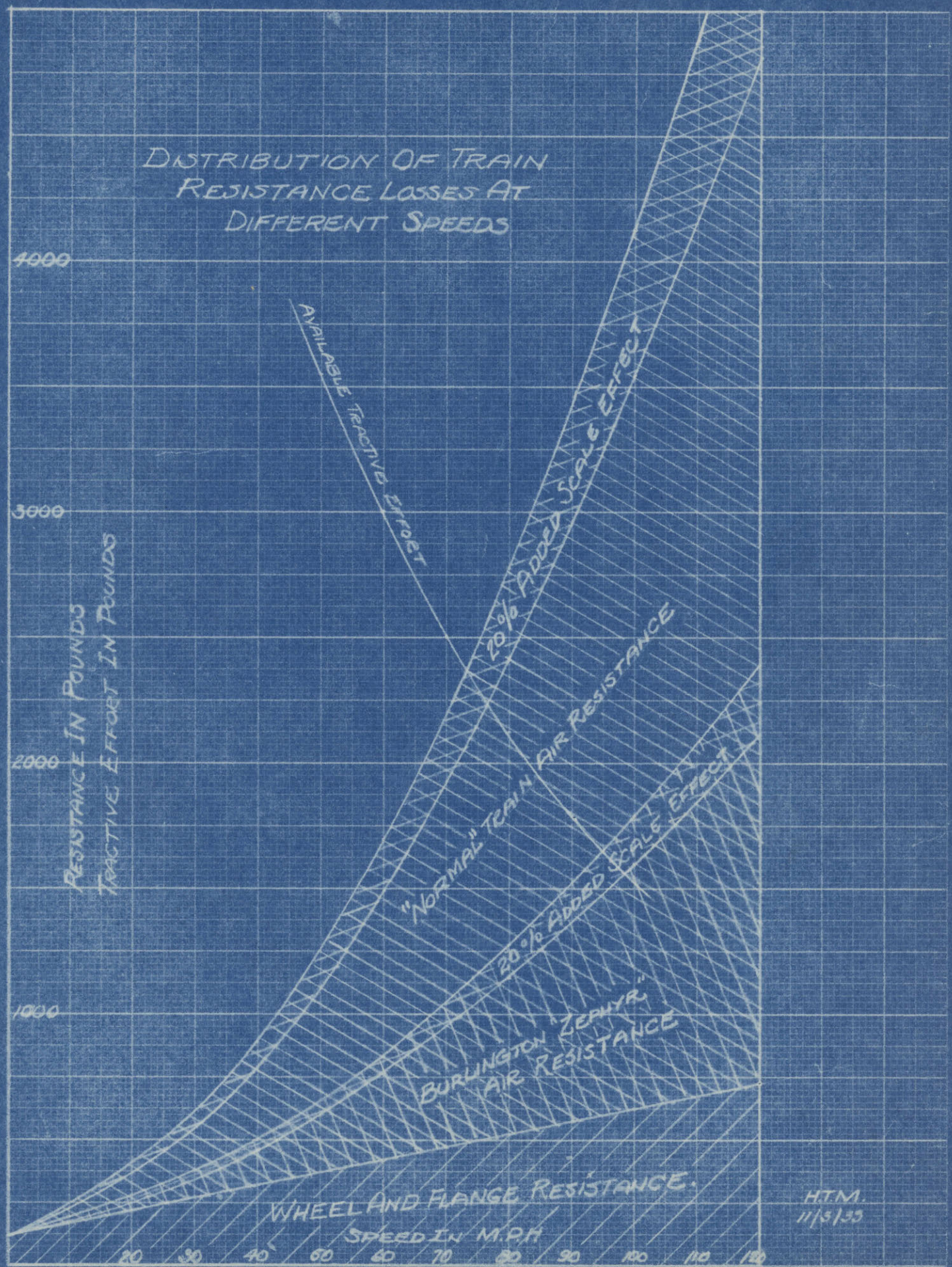
A. G. Dean

ON. Albert G. Dean

EDWARD G. BUDD MANUFACTURING CO.

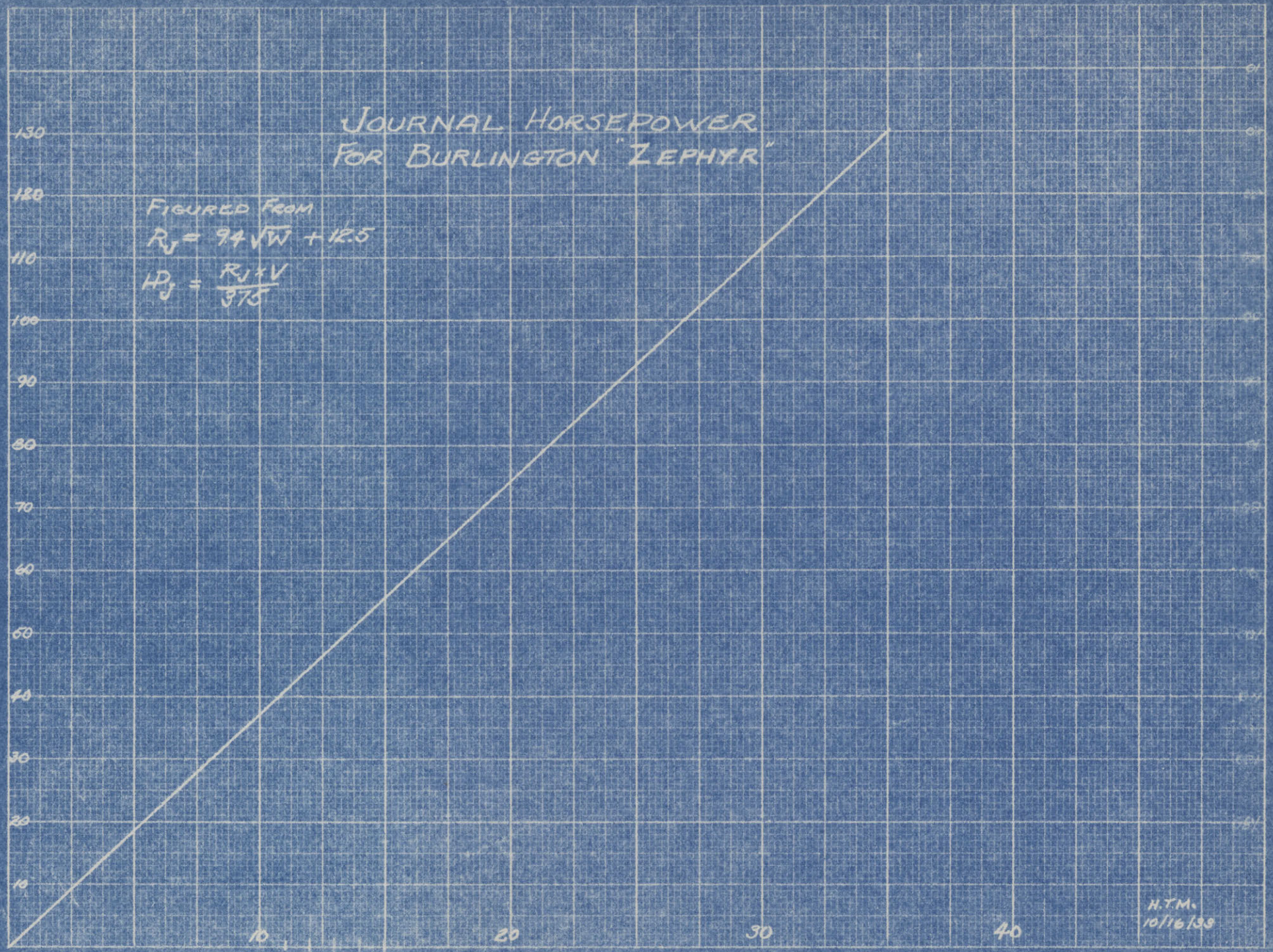
HIGH TENSILE DIVISION LABORATORY

EUGENE DIETZGEN CO., CHICAGO-NEW YORK NO. 346 B



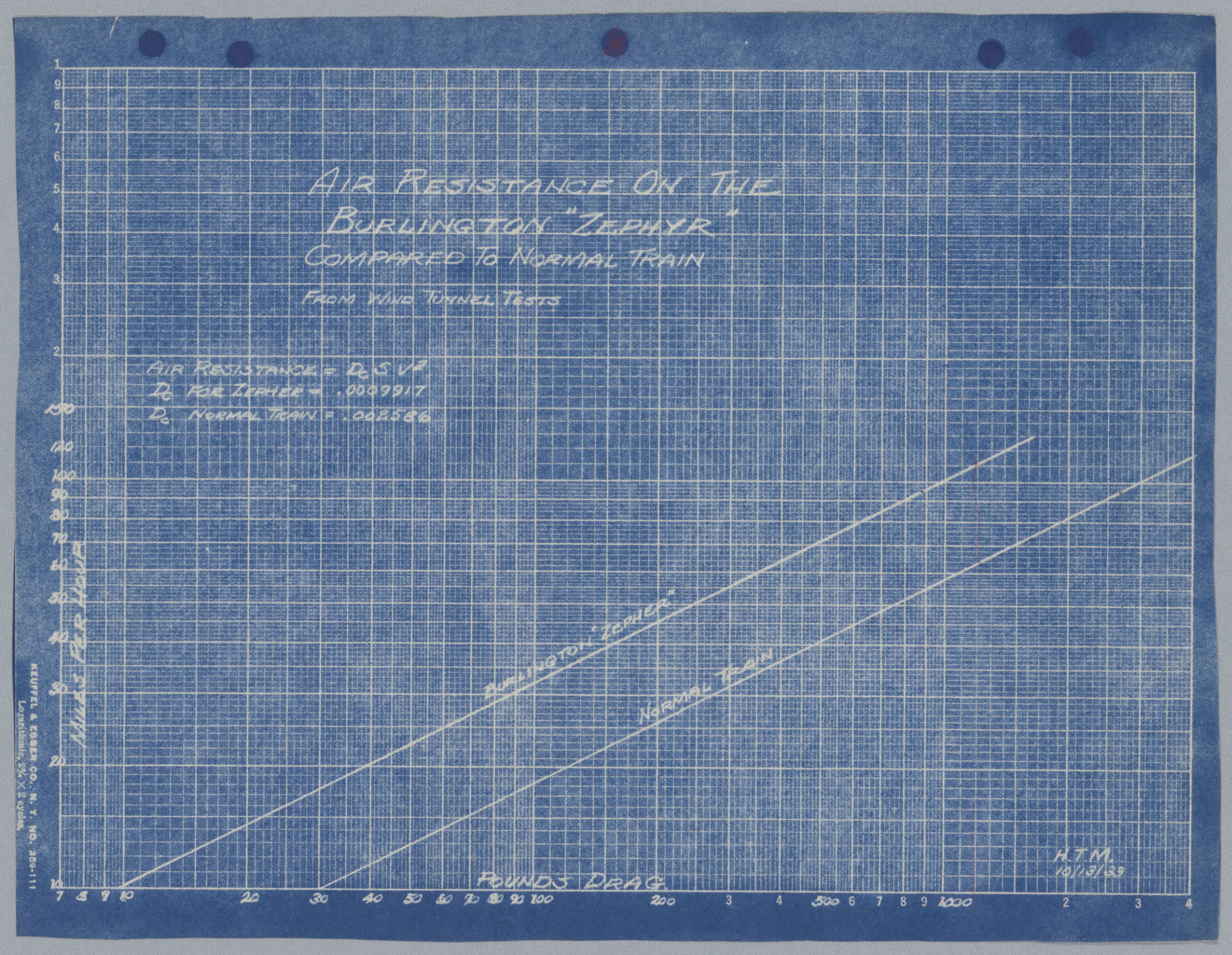
EDWARD G. BUDD MANUFACTURING CO.

HIGH TENSILE DIVISION LABORATORY



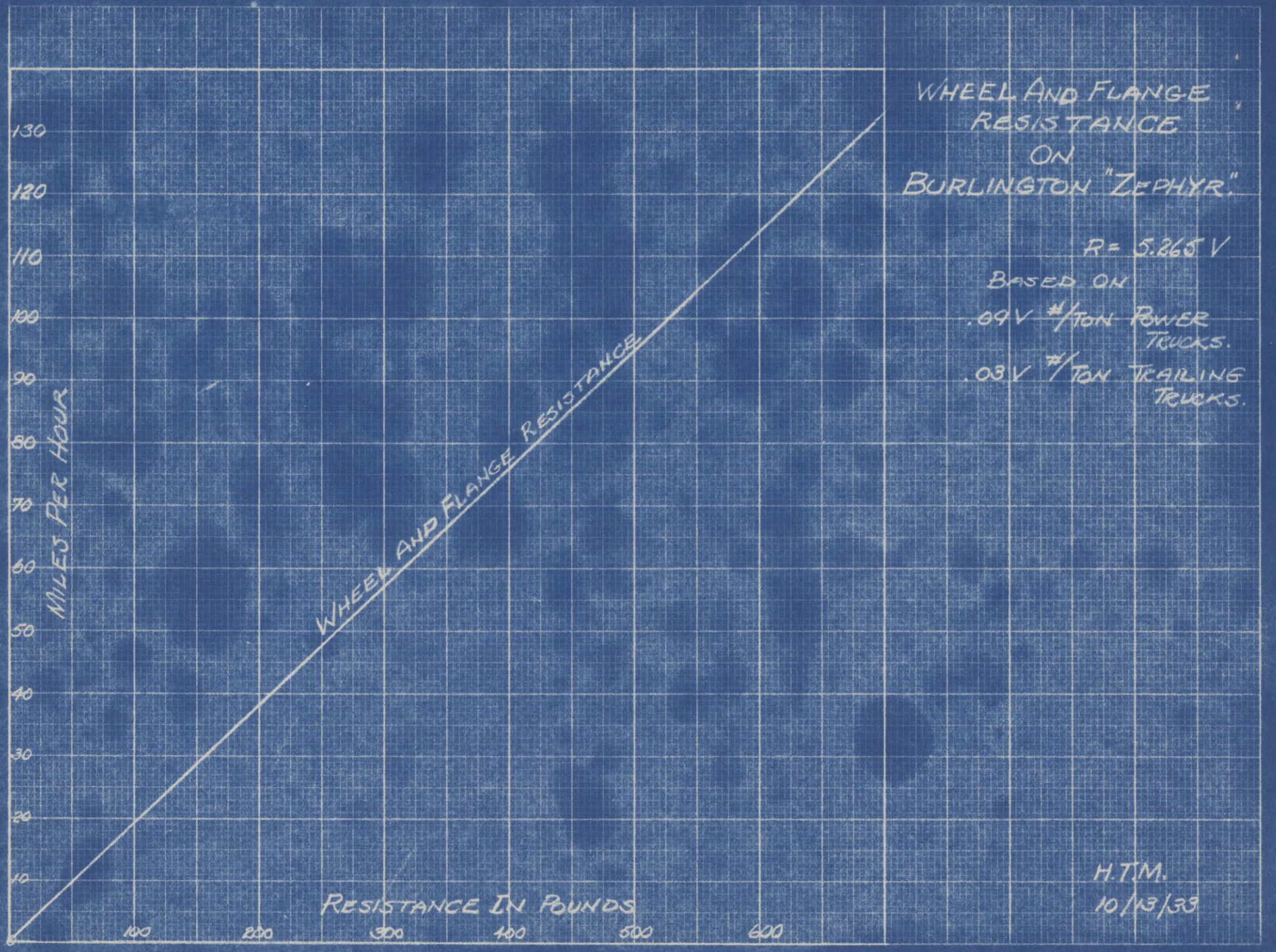
EUGENE DIETZGEN CO., CHICAGO-NEW YORK NO. 346 B

GERMANY


AIR RESISTANCE ON THE
BURLINGTON "ZEPHYR"
COMPARED TO NORMAL TRAIN
FROM WIND TUNNEL TESTS
AIR RESISTANCE = $D_c S V^2$
D_c FOR ZEPHER = .0009917
D_c NORMAL TRAIN = .002586
MILES PER HOUR
BURLINGTON "ZEPHER"
NORMAL TRAIN
POUNDS DRAG
H.T.M.
10/13/29
KEUFFEL & ESSER CO. N. Y. NO. 359-111
Logarithmic, 2¾ X 2 cycles

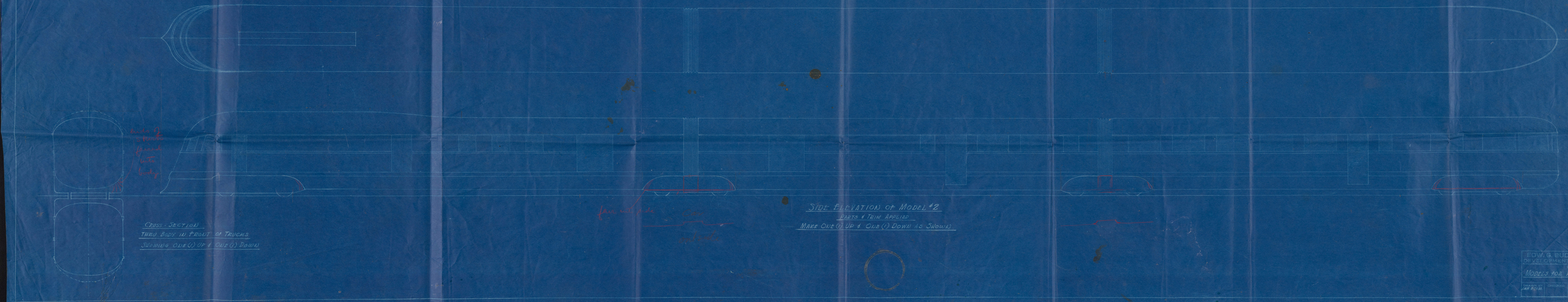
EDWARD G. BUDD MANUFACTURING CO.

HIGH TENSILE DIVISION LABORATORY

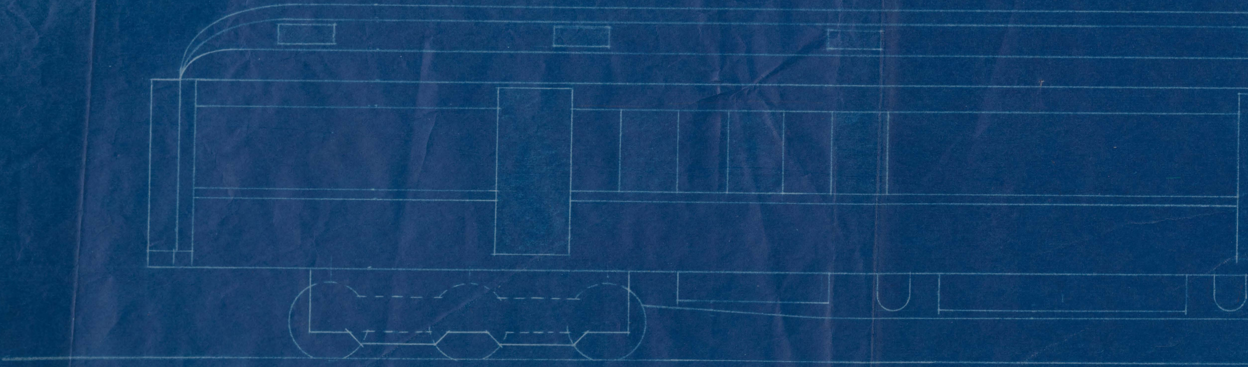


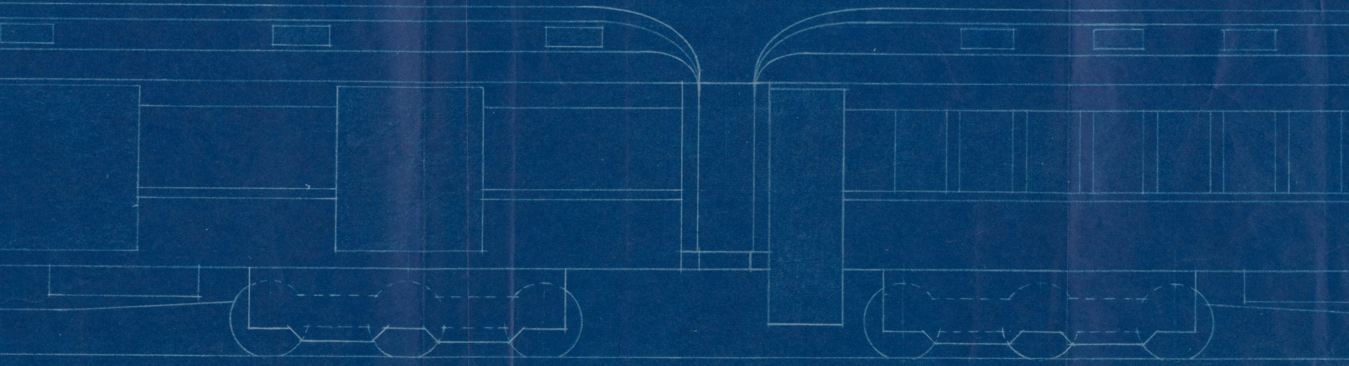
EUGENE DIETZGEN CO., CHICAGO-NEW YORK NO. 346 B

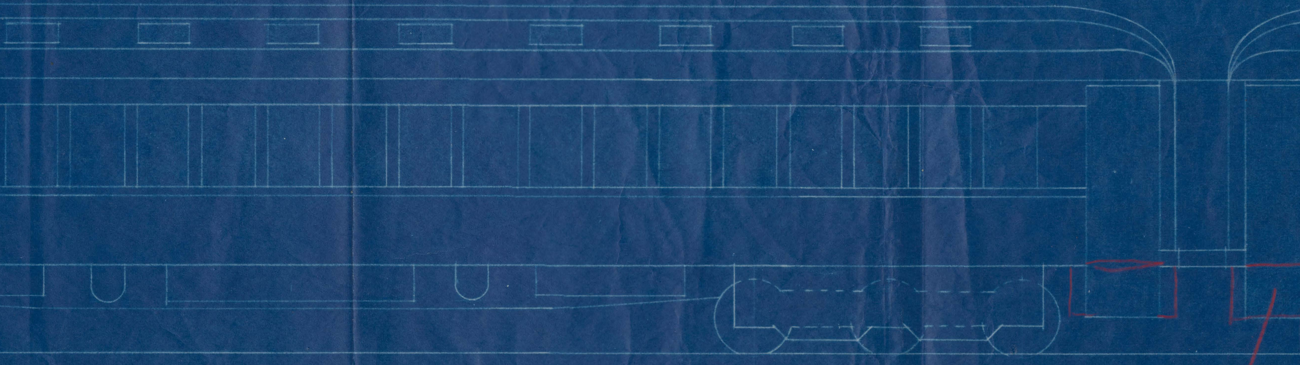
GERMANY



EDW. G. BUDD MFG. CO., PHILA., PA.
DEVELOPMENT DEPARTMENT
DESIGNATION
Models for Wind Tunnel Tests
SK-3927



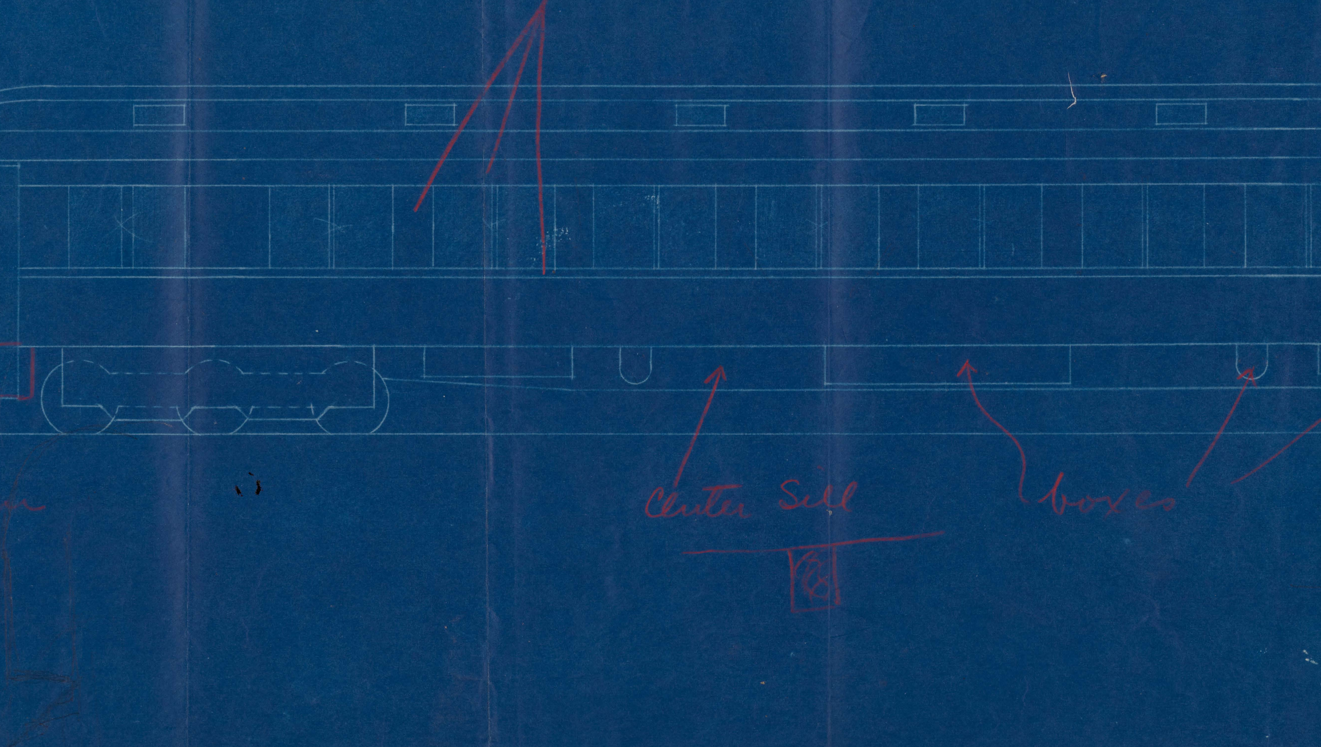


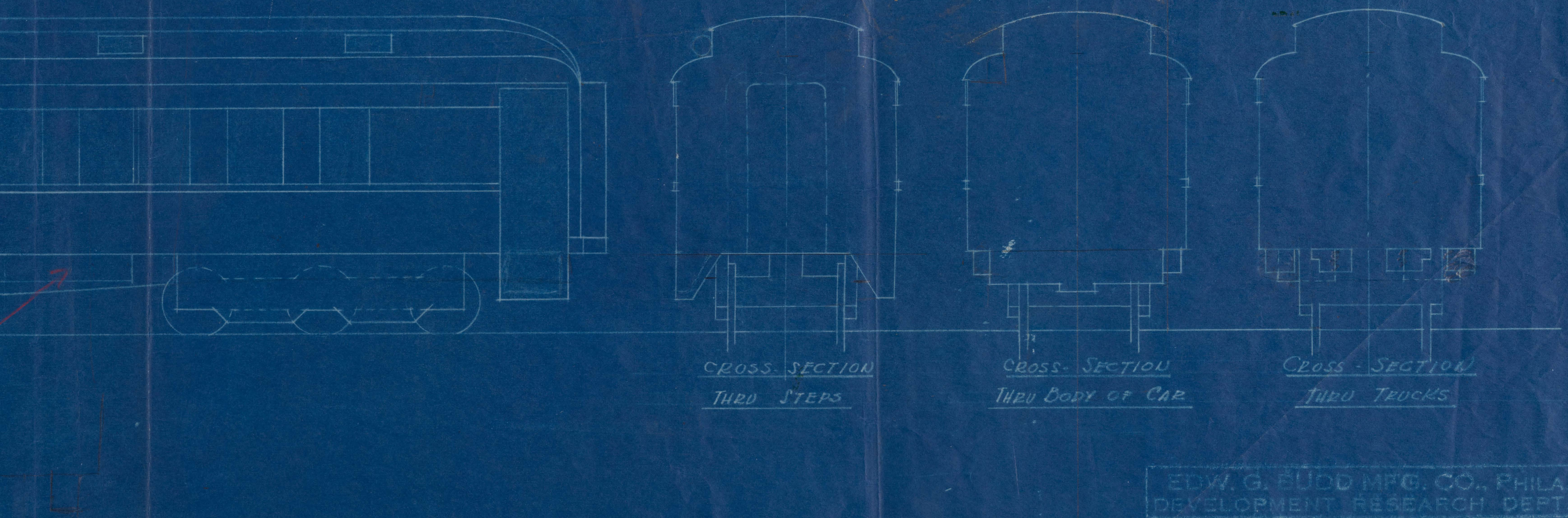


SIDE ELEVATION OF MODEL

MAKE ONE (1) UP & ONE (1) DOWN

All trim 1/16" card board pasted on


Center Sill
boxes


CROSS-SECTION
THRU STEPS
CROSS-SECTION
THRU BODY OF CAR
CROSS-SECTION
THRU TRUCKS

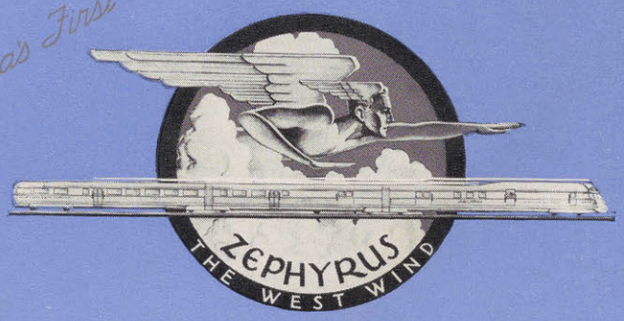
EDW. G. BUDD MFG. CO., PHILA. PA.
DEVELOPMENT RESEARCH DEPT. 477

DESCRIPTION
MODELS FOR WIND TUNNEL TESTS

DRAWN BY	CHECKED	APPROVED	DRWG. NO.
J.W.P. 8-22-33.			SK-5928.

The BURLINGTON Zephyr

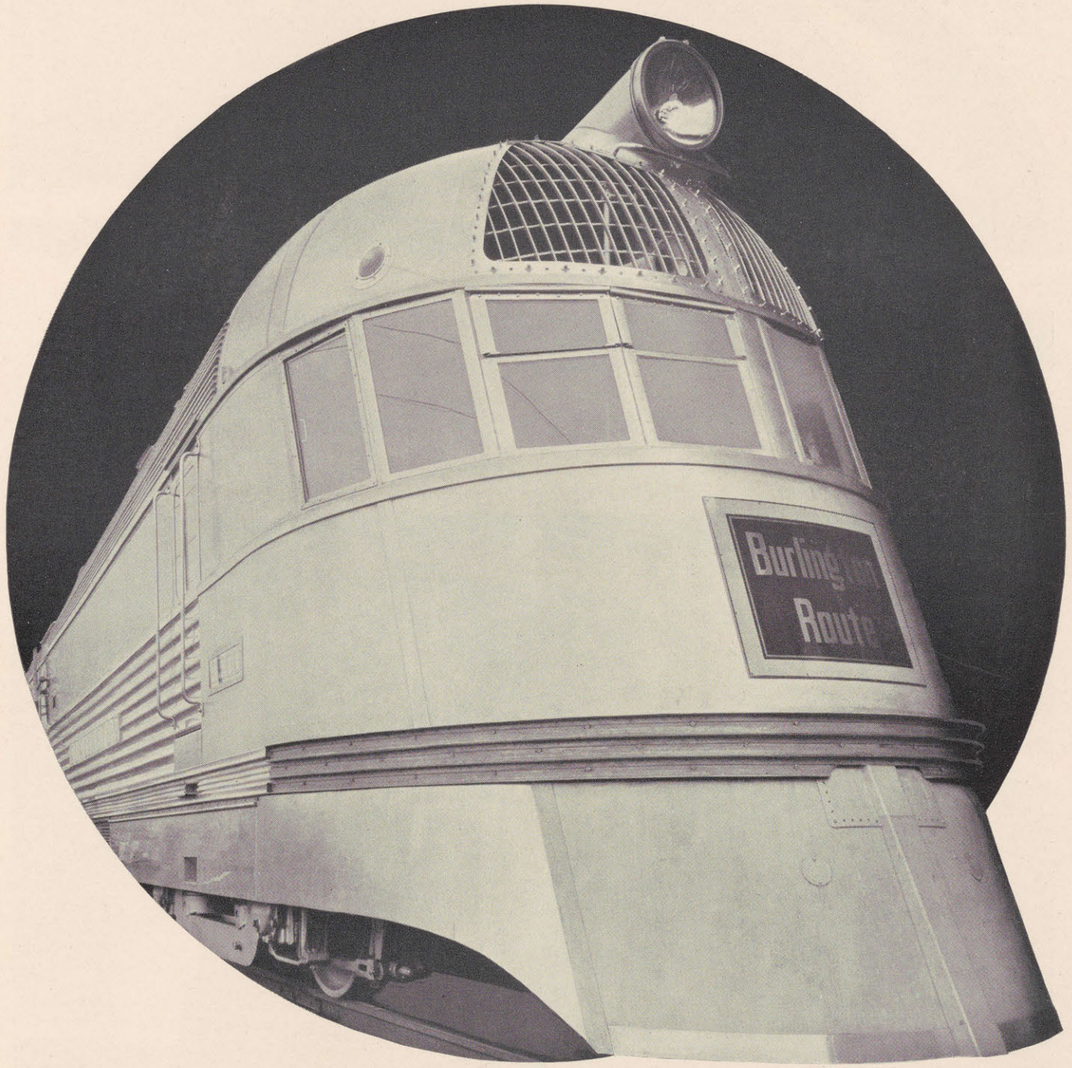
America's First Diesel All-Steel Streamlined Train



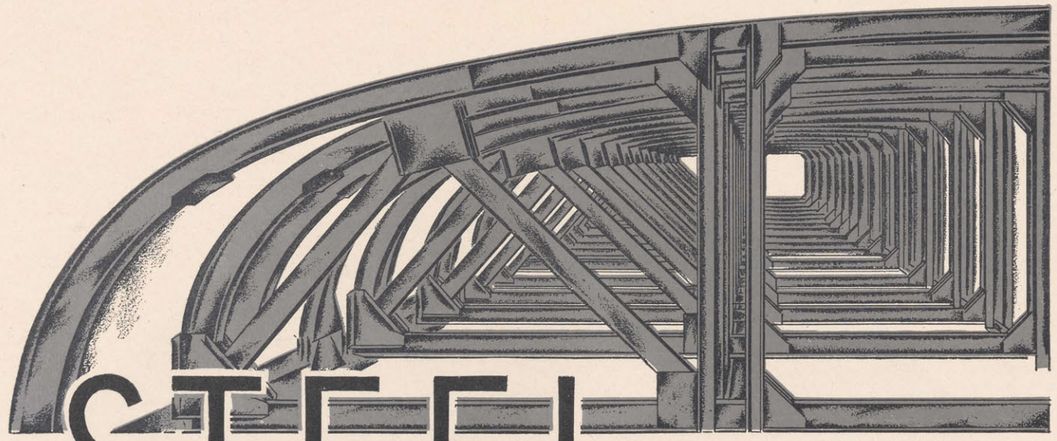
THE OUTSTANDING ACHIEVEMENT IN SAFE, LIGHT, RAILWAY TRANSPORTATION

by the

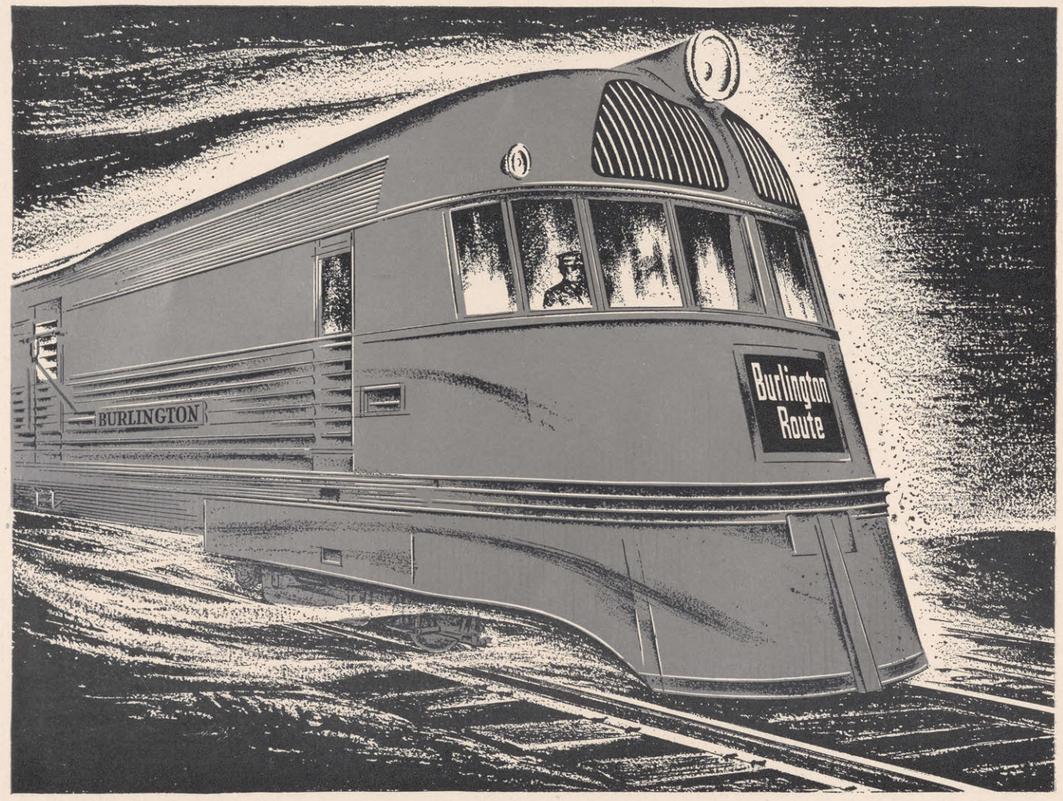
EDWARD G. BUDD MANUFACTURING COMPANY
PHILADELPHIA, PA.

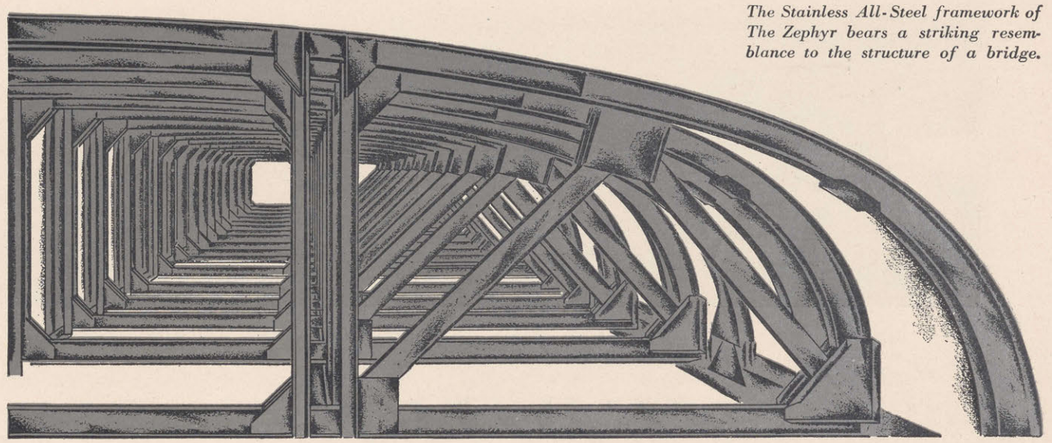


Reprinted from
Railway Age
April 14, 1934



STEEL..WRITES RAILWAY HISTORY AGAIN.....IN THE "ZEPHYR"





The Stainless All-Steel framework of The Zephyr bears a striking resemblance to the structure of a bridge.

Ours is an industrial civilization — an age of *Steel.* The nation's transportation system can mark its genuine development from the time when steel became readily available. Great bridges would still be dreams of the future except for steel. Railway trains, ocean liners, automobiles, airplanes — none of these could exist as we know them today, without the strength and safety of Steel. More than any other metal, Steel is the fabric of the modern world.

Naturally, there have been refinements in steel—stronger, tougher, harder, more uncomprising materials have been developed, each of which has spread a new vista of accomplishment before the eyes of the nation's key industries—of which this Corporation has been a leader.

There could be no better example than that of USS Stainless Steel. In this new metal, the Chicago, Burlington and Quincy Railroad and the Edw. G. Budd Manufacturing Company alike saw the long awaited material for building the railway trains of the future. By its use, weight could be reduced two-thirds, without the slightest sacrifice of safety.

So this light-weight, high-speed, streamlined train—The Zephyr—is of Stainless All-Steel construction—many important parts being fabricated from USS Stainless. Steel, that has made American Railway transportation the safest and most dependable in the world. Steel, in which the American public, passengers and shippers alike, have long placed implicit faith. *Steel, the symbol of safety!*

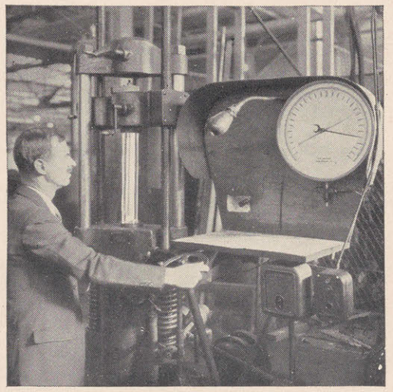
For literature and full information on USS Stainless Steel, write any of the subsidiary manufacturing companies of United States Steel Corporation listed below.

AMERICAN SHEET and TIN PLATE COMPANY, Pittsburgh
Steel Sheets and Light Plates
AMERICAN STEEL & WIRE COMPANY, Chicago
Cold Rolled Strip Steel, Wire and Wire Products
ILLINOIS STEEL COMPANY, Chicago and CARNEGIE STEEL COMPANY, Pittsburgh
Bars, Plates, Special and Semi-Finished Products
NATIONAL TUBE COMPANY, Pittsburgh
Pipe and Tubular Products

Pacific Coast Distributors:
COLUMBIA STEEL COMPANY, San Francisco
Export Distributors:
U. S. STEEL PRODUCTS COMPANY, New York City

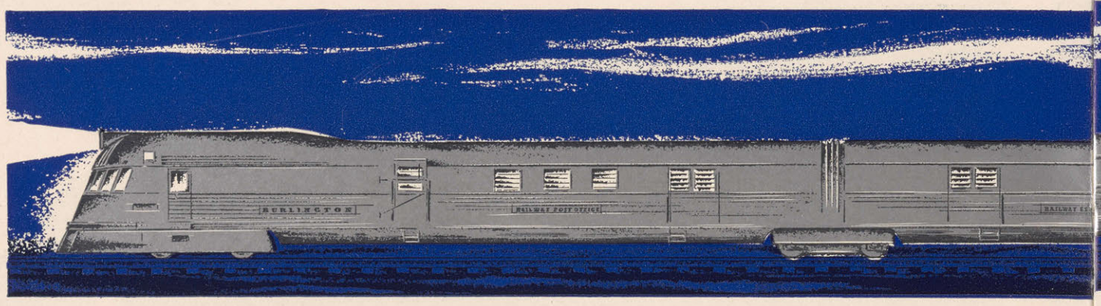
USS Chromium-Nickel Alloy Steels are produced under licenses of the Chemical Foundation, Inc., New York; and Fried. Krupp, A. G. of Germany.

An 18-inch, 36-ounce length of frame section being literally "squashed" under test—but it takes hydraulic pressure of more than 52,000 pounds to do it. Uniformity is so great that strength has proved predictable to within less than 3%.



USS

STAINLESS and Heat Resisting ALLOY STEELS

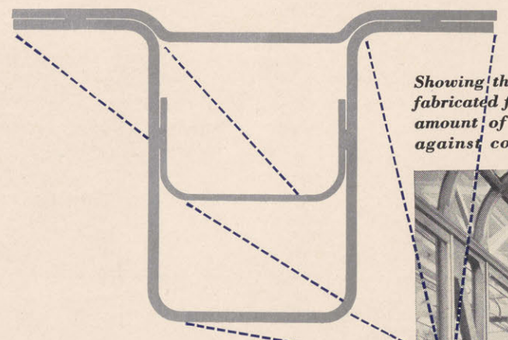


The ZEPHYR... MADE POSSIBLE BY THE BUDD SHOTWELD SYSTEM OF STAINLESS ALL-STEEL CONSTRUCTION

Speed — blurring speed — flashing "pick-up," with "braking power" to match — new beauty, new comfort — rock-bottom operating economy — the performance of an airplane with the safety of a train — could this dream of the future be made to come true today? If so, how could the desired weight-strength ratio be obtained?

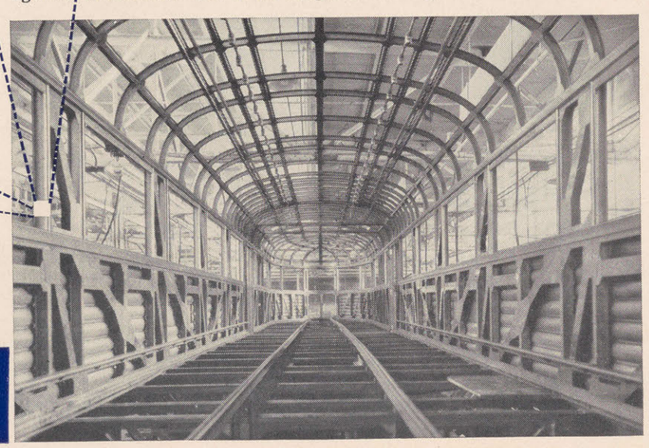
Asked of the Edw. G. Budd Manufacturing Company, these questions were answered with the Budd System of Stainless Steel Construction by *SHOTWELD.* An entire train of Stainless Steel! The material that everybody had been wanting to use! Fabricated by a new and vastly improved scientific process that makes a precision operation out of welding — adding unparalleled strength to welded joints of high tensile Stainless Steel. A train without a single rivet to mar the surface of its streamlined contours!

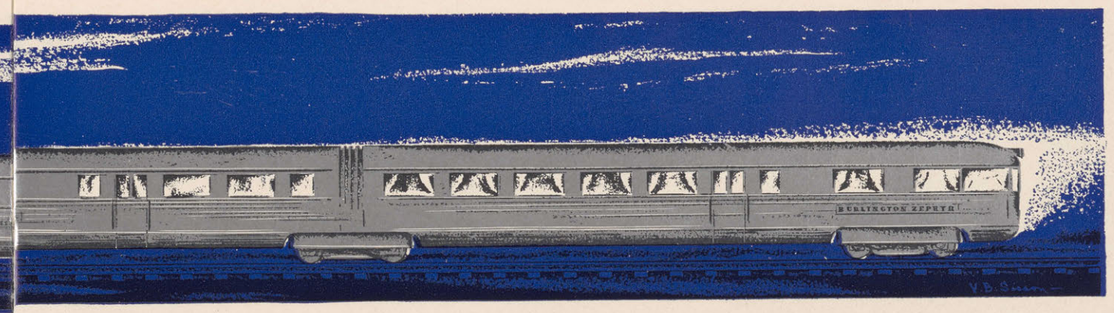
SHOTWELD



Showing cross-section in actual size of one of the side-posts. There are 46 such side-posts in the frame of The Zephyr, weighing but 24 ounces per linear foot. Weight of complete train is 85 tons, as against 300 tons for such units of conventional type.

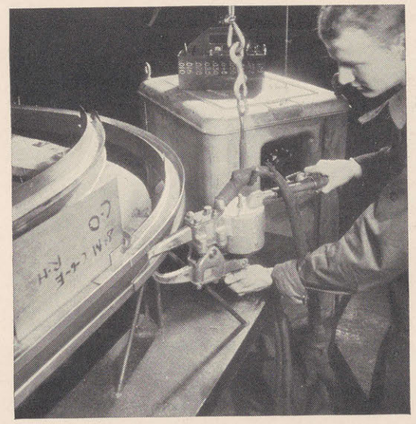
Showing the high tensile Stainless All-Steel framework. Frame sections are fabricated from sheet stock by the SHOTWELD process. In the past, a large amount of excess metal — and weight — have been needed for protection against corrosion. This is no longer necessary, with Stainless Steel.



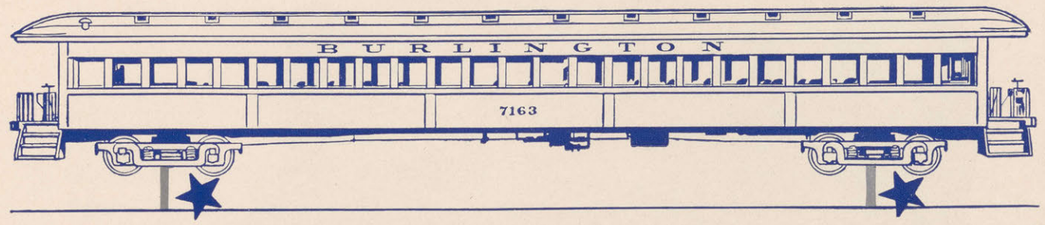


THE ZEPHYR... HIGH-SPEED, LIGHT-WEIGHT, STREAMLINED TRAIN WHICH HAS BEEN PLACED IN OPERATION BY THE BURLINGTON RAILROAD. BUILT BY EDW. G. BUDD MANUFACTURING COMPANY, PHILADELPHIA, WITH DIESEL ELECTRIC DRIVE

The Budd SHOTWELD System has made such a train possible at last, by permitting the use of thin-section steel. Made possible for the first time a high-speed, light-weight, streamlined train of Stainless All-Steel Construction. The Zephyr — meeting the public demand for *speed, with the utmost safety.* This all-steel train of the Burlington Railroad is charting the course for the railway development of the future!



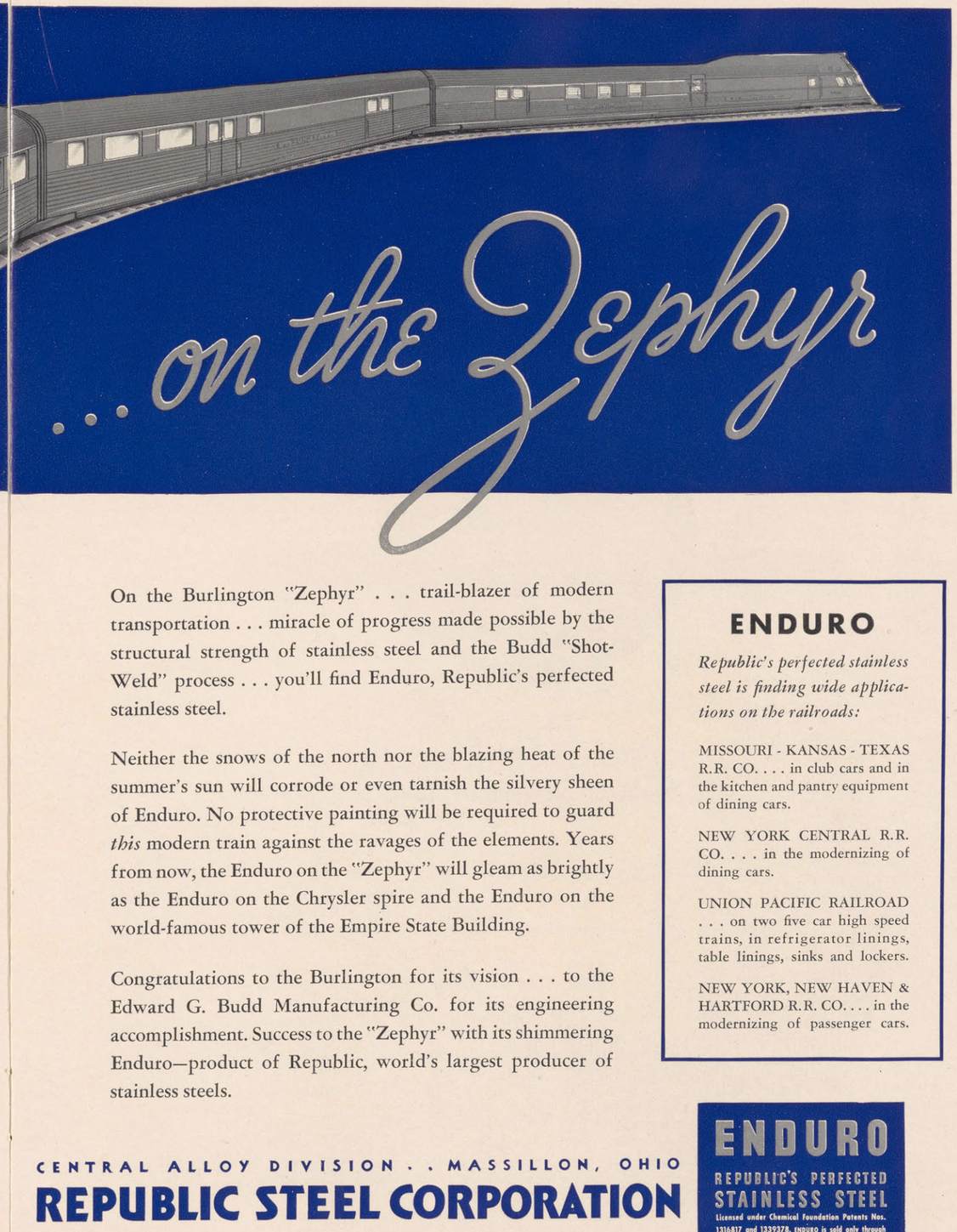
Showing the Budd SHOTWELD Process which for the first time permits fabrication with thin-section, high tensile Stainless Steel.



EDW. G. Budd...
MANUFACTURING COMPANY
PHILADELPHIA

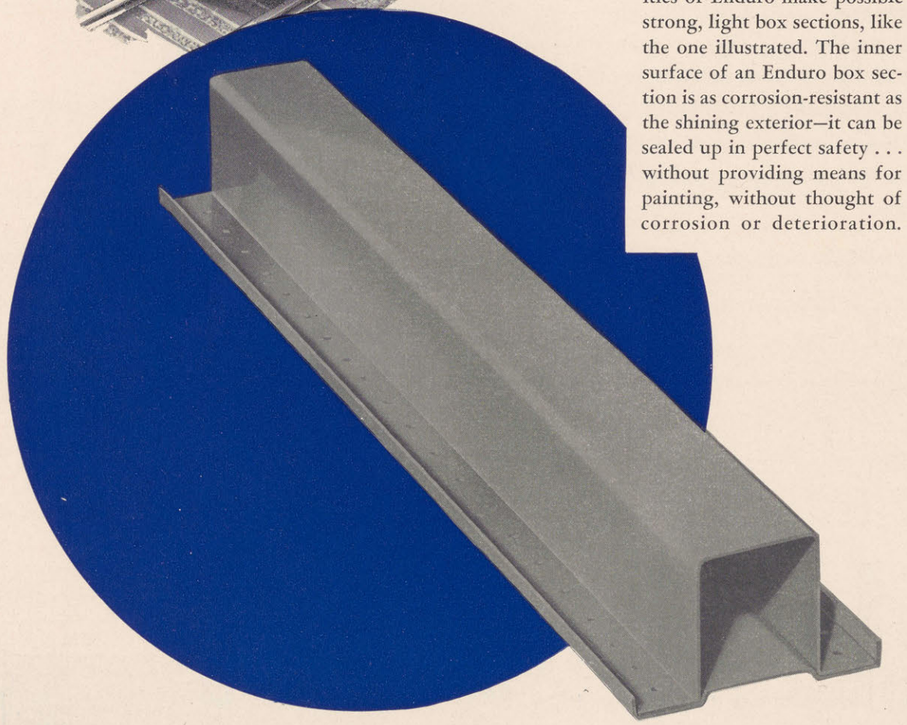
Two 18-inch lengths of frame section weighing only 36 ounces apiece can support a 100,000 pound car with ease. Here is strength that spells SAFETY.

ENDURO



. . . on the Zephyr

The corrosion-resisting qualities of Enduro make possible strong, light box sections, like the one illustrated. The inner surface of an Enduro box section is as corrosion-resistant as the shining exterior—it can be sealed up in perfect safety . . . without providing means for painting, without thought of corrosion or deterioration.



On the Burlington "Zephyr" . . . trail-blazer of modern transportation . . . miracle of progress made possible by the structural strength of stainless steel and the Budd "Shot-Weld" process . . . you'll find Enduro, Republic's perfected stainless steel.

Neither the snows of the north nor the blazing heat of the summer's sun will corrode or even tarnish the silvery sheen of Enduro. No protective painting will be required to guard *this* modern train against the ravages of the elements. Years from now, the Enduro on the "Zephyr" will gleam as brightly as the Enduro on the Chrysler spire and the Enduro on the world-famous tower of the Empire State Building.

Congratulations to the Burlington for its vision . . . to the Edward G. Budd Manufacturing Co. for its engineering accomplishment. Success to the "Zephyr" with its shimmering Enduro—product of Republic, world's largest producer of stainless steels.

ENDURO

Republic's perfected stainless steel is finding wide applications on the railroads:

MISSOURI - KANSAS - TEXAS R.R. CO. . . . in club cars and in the kitchen and pantry equipment of dining cars.

NEW YORK CENTRAL R.R. CO. . . . in the modernizing of dining cars.

UNION PACIFIC RAILROAD . . . on two five car high speed trains, in refrigerator linings, table linings, sinks and lockers.

NEW YORK, NEW HAVEN & HARTFORD R.R. CO. . . . in the modernizing of passenger cars.

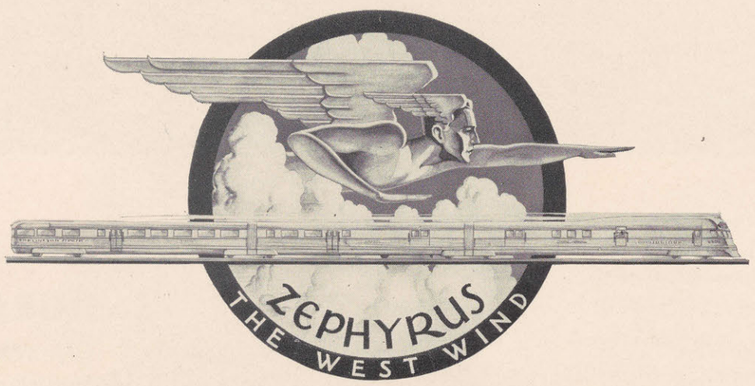
CENTRAL ALLOY DIVISION . . MASSILLON, OHIO

REPUBLIC STEEL CORPORATION

GENERAL OFFICES YOUNGSTOWN, OHIO

Reg. U. S. Pat. Off.

ENDURO
REPUBLIC'S PERFECTED
STAINLESS STEEL
Licensed under Chemical Foundation Patents Nos. 1316817 and 1339378. ENDURO is sold only through Republic Sales Offices and Authorized Distributors



America's First Diesel
All-Steel Streamlined Train

Burlington "Zephyr" Completed at Budd Plant

The first Diesel-propelled articulated train of stainless-steel construction for high-speed service will be introduced to the public next week

A SELF-PROPELLED, three-car, articulated high-speed train of light-weight stainless steel construction has been completed for the Chicago, Burlington & Quincy by the Edward G. Budd Manufacturing Company, Philadelphia, Pa. This train, which is known as the "Zephyr," will receive its first introduction to the public at the Broad Street Station of the Pennsylvania Railroad in that city next week. It will then embark upon a two months' exhibition tour, taking in the principal cities across the continent, and will thereafter spend the summer on exhibition at A Century of Progress Exposition, Chicago. On its return to the home rails it will be placed in service between Kansas City, Mo., Omaha, Nebr., and Lincoln, replacing existing steam service with much faster schedules and, it is anticipated, with a considerable reduction in operating cost.

The train is driven by a Winton 600-hp. Diesel-electric power plant and is designed for speeds of approximately 110 m.p.h. This involved considerations of aerodynamics in shaping the train to reduce the air resistance, both head-end and frictional. Wind-tunnel tests of scale models at the Massachusetts Institute of Technology indicate that at an operating speed of 95 m.p.h. the total resistance to motion will have been reduced to about 47 per cent of that of a train of three coaches of conventional shape, weight being equal.

But in the development of the train attention was not confined to advanced engineering features. The architectural firms of Paul Cret, of Philadelphia, Pa., and Holabird & Root, of Chicago, collaborated in working out the arrangement, ornamentation and decoration of the passenger accommodations and in the design of the furnishings in order that the train may provide the utmost in comfort and attractiveness to the traveler.

The train consists of three car bodies carried on four trucks. It is 196 ft. in length and it is estimated to weigh 195,000 lb. There are seats for 72 passengers in the second and third cars and space is provided in the first and second cars for 50,000 lb. of baggage and express. The first car also contains a 30-ft. mail compartment. The passenger accommodations are divided among three compartments. At the rear end of the second car is a 16-ft. smoking compartment with seats for 20 persons. At the front of the third car is a 31-ft. compartment with seats for 40 persons, and at the rear of this car is a solarium-lounge with chairs for 12. Side doors and steps are provided for passengers in the two rear cars. In the second car the entrance is between the smoking compartment and the buffet adjoining the baggage compartment. In the rear car the entrance is at the rear of the main passenger compartment.

The Car Body Structure

In its structure this train is a complete departure from conventional design. To a very large extent the entire body structure from floor to roof performs load-carrying functions. The characteristic truss form of construction adapted by the Budd company for the utilization of built-up sections of thin-gage Shotweld stainless steel is used. The main members of the car bodies are the Pratt truss side frames which have, in effect, been carried up to the roof by the use of diagonals in wide

Foreword

THE loss of railway passenger traffic during the last decade has been caused by a shifting of travel from the railways to the highway and not from a decline in total travel. In fact, the total passenger one-mile units of travel have greatly increased, but the percentage of the total which has been handled by the railways has been greatly diminished and only twenty per cent as much local traffic by rail was performed in 1933 as in 1920.

Conventional lines have been followed in the design of passenger equipment for a great many years. In departing from convention and undertaking to make improvements that would result in lower train operating costs with added travel comfort, our idea has been to call upon the industry which has taken from us much of our traffic, namely, the automobile industry.

We have accordingly collaborated with the Edward G. Budd Manufacturing Company, the General Motors Corporation and the Massachusetts Institute of Technology, and with two architectural firms, Paul Cret and Holabird & Root. These concerns were given carte blanche in designing and decorating the Zephyr without any restrictions except those which are inherent to railway equipment, namely, the gage of the track and the clearances within which the outside dimensions must be kept.

The railways are very jealous of their record of safety, and stress was laid in our instructions that no compromise be made with safety but that insofar as possible the safety factors must be increased.

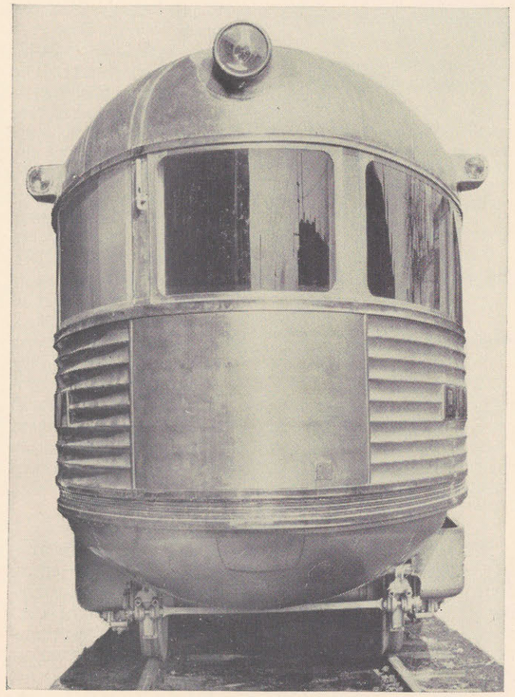
In the consideration of material, the character of which must provide the greatest strength with a minimum of weight, it was of paramount importance that we select a material not only uniform in structure, but one entirely non-corrosive to the end that the section which we rely upon and design for may be permanent during the entire service life of the train.

Ralph Budd

The Burlington "Zephyr" Is Built of Stainless Steel and Driven by a 600-Hp., Two-Cycle Diesel Engine

deadlights between the windows and of which the roof forms the top chord. The truss members are generally of flanged box sections formed of deep flanged channels and cover plates joined by Shotwelds. The steel of which these sections are formed has a minimum tensile strength of 150,000 lb. per sq. in. and an elastic limit of 120,000 lb. per sq. in., with satisfactory ductility.

One of the illustrations shows a specimen of a section originally 14 in. in length tested to destruction in compression and reduced to a length of 6¾ in. without a break in the material. This member, of material 0.050 in. thick, has a sectional area of 0.51 sq. in. and weighs 1.77 lb. per lineal foot. Its moment of inertia is 0.35 in.^{4} about either axis, and its radius of gyration is 0.8 in. It withstood under compression 36,000 lb., or over 70,000 lb. per sq. in. After failure had started the load required to continue the destruction varied up to a maximum of 28,000 lb. As an indication of the weight efficiency, a structural-steel T-section, with the same moment of inertia about its most effective axis, weighs 3.56 lb. per foot, and to secure the same moment of inertia about the least effective axis would require a section weighing 6.4 lb. per foot. A T-section with a least radius of gyration of approximately 0.8 in. weighs 10.5 lb. per foot. The section illustrated, owing to the varying nature of the imposed loads, has the least efficiency of any of those used in the structure. Others carry not less than 100,000 lb. per sq. in. under similar tests.



A Solarium-Lounge Is at the Rear End of the Train

The tenacity of the welds is also clearly indicated in the illustration of the failed specimen. The Shotweld process, developed and patented by the Edward G. Budd Manufacturing Company, effects a specific regulation of the pressure, the electric current value and the duration of its flow, thus maintaining unimpaired the strength and corrosion-resisting properties of the material. The welds develop a shearing strength of 75,000 lb. per sq. in. and will withstand torsion up to 90 deg. before rupture. All welding in the structure of the Burlington train was done by this process.

The floor structure is made up of a corrugated sheet of stainless steel, the bottoms of the rectangular corrugations of which are welded to a flat sheet and both in turn welded to the longitudinal stringers, of which there are eleven across the car. These, in turn, are secured to transverse supports built into the car frame. The floor thus forms a stiff horizontal girder through which end loads are distributed to the side girders. In the baggage compartments it is designed for a loading of 600 lb. per lineal foot.

The roof constitutes a primary structural member assuming the entire compression load. It is built-up of longitudinal corrugated sheets welded to roof carlines and is locally reinforced at points of maximum stress. The roof-sheet corrugations are 7/16 in. deep, with a pitch of 1½ in.

In cross-section the car assumes something of tubular form. The enclosure below the floor, however, is of only incidental value as a part of the load-carrying structure and the trussed center sills are designed primarily to serve as means of attachment for apparatus, to stabilize the floor beams and to serve as local reinforcement.

Among the special features in the structure which are of particular interest are the engine bed and the method of tying the articulation castings into the framing of the coach bodies. The engine bed, fabricated by Lukenweld, Inc., is a rigid arc-welded structure of steel plate, annealed after completion of the welding. It forms a combination bumper, engine bed and bolster and is 25 ft. 3½ in. long, by 8 ft. 8 in. wide. The material is Lukens Steel Company Cromansil, an alloy of chromium, manganese and silica, with a tensile strength of 90,000 lb. and an elastic limit of 70,000 lb., possessing a high resistance to fatigue and shock. The completed structure weighs 6,070 lb. It is built into the lower chord member of the side trusses and forms the foundation for the nose structure of the car.

The nose construction consists of a deep, stiff member which extends diagonally outward and downward on the longitudinal center plane of the car from the roof to the bumper portion of the engine bed. This is reinforced with a stiff horizontal arch at the belt rail and with a diaphragm which forms the bottom of the engine-cooling air-intake chamber above the cab windows. The diaphragm is composed of two 0.109-in. stainless-steel sheets welded together and reinforced with stiffeners.

Each articulation casting is tied into the frame structure at the end of the car by riveting to the center sills, to the end posts and to the lower chords and vertical members of the stainless-steel end trusses. No rivets other than these are used in the structure. The transverse horizontal arms of the castings extend out only far enough to carry the side bearings, and the load is carried to the side frames through the end truss structure with a considerable saving in weight. Through the stiff end structure the reaction from the weight on the truck center plate is carried to the main side frames. The greater part of the bending moment due to the eccentric loading at the center pin is resisted by compression loading in the roof and the remainder by a bending stress in the center sills. The end posts are built-up of ⅛-in. stainless-steel plates and are 12 in. deep.

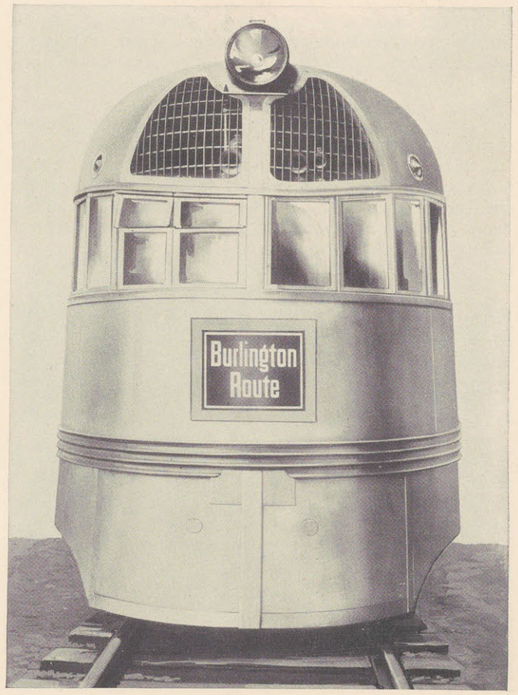
Unlike the stainless-steel cars previously built by the Budd company, the sheathing on the Burlington train is not all of the fluted type adopted to prevent the formation of shear lines and other weaves which would develop in the 0.020-in. sheets. Uncorrugated sheets of stainless steel are used around the curved surfaces at the front and rear ends of the train, on the curved roof at the rear end, and on the roof over the engine room. Except on the front end, where plates are ⅛ in. thick, the material is 0.030 in. in thickness.

The deadlight panels are also finished with smooth surfaces. These panels are of Plymetl, in which the outside surface of the plywood is covered with stainless steel and the inside with copper to prevent warping. These panels, some of which are of unusual length, are flexibly mounted in channels at the top and bottom, in which they are sealed with a plastic calking material. Below the window rail are mounted the customary fluted side sheets.

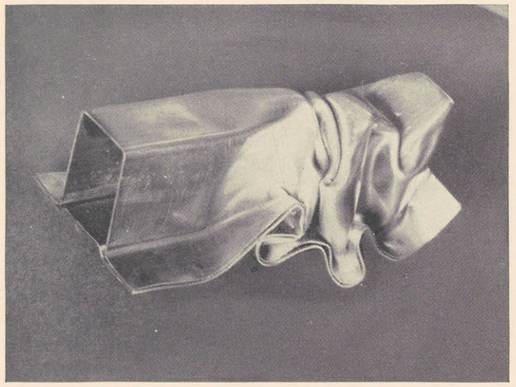
The space below the floor level is enclosed with light corrugated sheathing similar to the roofing. To prevent resonance from air-borne noises and direct concussions this sheathing is insulated with hair felt placed between two layers of 80-lb. Craft paper, the outer of which is cemented to the sheathing.

The walls and roofs of the cars are insulated throughout with Alfol. This material, which is made up of several sheets of crinkled aluminum foil, weighs about ¼ oz. per ft., board measure. It combines low conductivity with low convection air spaces and high reflectivity.

In the passenger compartments the side walls are fin-



Front End of the "Zephyr"



A 14-In. Section of a Structural Member Tested to Destruction Under Compression—It Withstood Over 70,000 Lb. Per Sq. In.

ished with Masonite panels. The headlining is of Agasote. The walls of the baggage rooms are finished with galvanized sheets. The floors are laid with $\frac{5}{16}$-in. cork tiling cemented over the corrugated steel and cork filler in the recesses of the corrugations. In the mail compartment 1-in. maple flooring is laid over the cork. In the baggage compartment a layer of roofing paper is placed between the cork and the maple flooring.

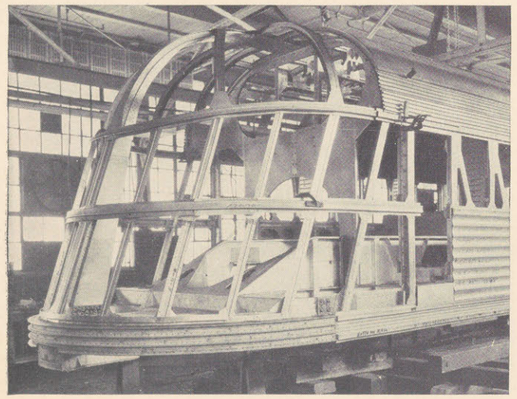
All doors, when closed, form unbroken surfaces with the outside sheathing of the car. The doors serving the passenger compartments are of the swinging type and give access to step-wells in the floor which are closed by trap doors. The bottom step folds up when the door is closed and, together, they form an unbroken surface with the undersheathing adjoining the step wells. The side doors in the two baggage compartments and in the railway postoffice are of the sliding type. They are guided in top and bottom tracks so shaped as to move the door outwards into its flush position in the door opening when it is closed.

Vestibule passages between the car bodies are enclosed by diaphragms bolted to the ends of the cars. The foot plate is formed by an approximately semi-circular plate, its straight edge secured to the end of one car and the circular edge enclosed in a horizontal recess in the end of the opposite car within which it is free to slide when the cars pass over curved track. To provide continuity of the outer surfaces accordian type diaphragms are attached between the ends of adjoining cars.

The safety window glass supplied by the Pittsburgh Plate Glass Company differs from that ordinarily used. The proposed high speeds of the train and the large area of glass called for increased strength over what would be required in automobile use, but this strength had to be obtained, if possible, without any additional weight. The glass which was finally approved was 15 per cent lighter than the standard safety plate glass and much stronger.

Generally speaking, the weight of safety glass is in the glass and the strength is in the plastic sheeting. Therefore, the thickness of the plate glass for this special laminated product was reduced from $\frac{7}{64}$ in. to 0.09 in., and the thickness of the plastic was raised from 0.025 in. to 0.050 in. for the safety glass to be used in the rear and side windows and to 0.075 in. for the safety glass in the front windows. In order to overcome the problem of severe weathering a special plastic sheeting was used which is highly resistant to the ultra-violet sun rays and the glass is developed to almost entirely filter out these rays. With this double protection it is expected that the glass will outlive the train.

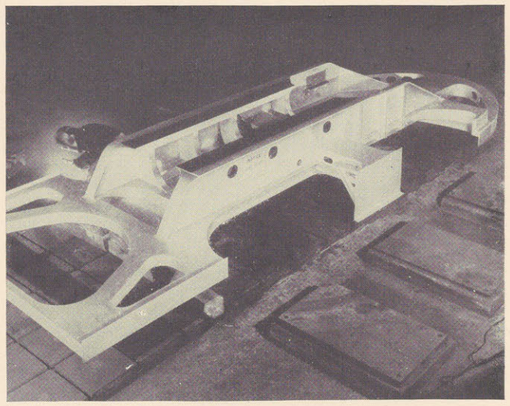
Because of the type of construction it was calculated that there would be a certain amount of weaving of the coach bodies which would crack the glass under usual glazing methods. A system was developed of setting it in dum-dum putty, a non-hardening material, which allows play but still hermetically seals the windows to



Front-End Frame Structure Showing the Welded Engine Bed

Partial List of Equipment and Specialties on the Burlington "Zephyr"

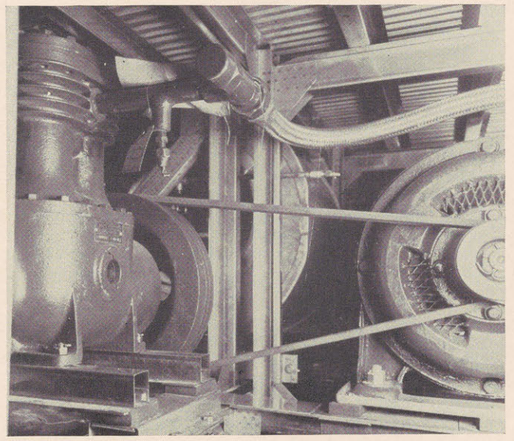
Builder	Edward G. Budd Mfg. Co., Philadelphia, Pa.
Stainless Steel	Allegheny Steel Co., Brackenridge, Pa. American Sheet & Tin Plate Co., Pittsburgh, Pa. American Steel & Wire Co., Chicago. Republic Steel Corp, Youngstown, Ohio Superior Steel Co., Pittsburgh, Pa.
Helical volute springs	Cyrus J. Holland, Chicago



The Welded Engine Bed

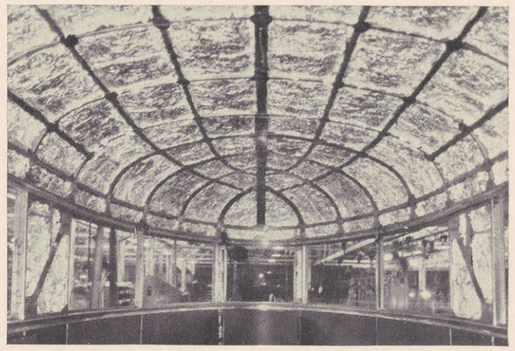
Elliptic springs	Mather Spring Co., Toledo, Ohio
Coil springs	American Steel Foundries, Chicago
Brake rigging	
Brake shoes	American Brake Shoe & Foundry Co., New York
Engine bed	Lukenweld, Inc., Coatesville, Pa.
Truck and body-articulation castings	General Steel Castings Corp., Eddystone, Pa.
Wheels and axles	Bethlehem Steel Co., Bethlehem, Pa.
Railway postoffice	
Side bearings	A. Stucki Co., Pittsburgh, Pa.
Axle bearings	Timken Roller Bearing Co., Canton, Ohio
Rubber insulation	U. S. Rubber Co., New York
Rubber bumpers	Quaker City Rubber Co., Philadelphia, Pa.
Rubber	Continental Rubber Co., Erie, Pa. Dryden Rubber Co., Chicago Goodrich Rubber Co., Akron, Ohio
Air brakes	Westinghouse Air Brake Co., Wilmerding, Pa
Hand brake	National Brake Co., Buffalo, N. Y.
Flexible metal hose	American Flexible Metallic Tubing Co., Philadelphia, Pa.
Flexible metal hose	Pennsylvania Flexible Metallic Tubing Co., Philadelphia, Pa.
Couplers	McConway & Torley Corp., Pittsburgh, Pa.
Equalizer	Camden Forge Co., Camden, N. J.
Power plant, complete	Winton Engine Co., Cleveland, Ohio
Oil pump	Viking Pump Co, Cedar Falls, Iowa
Oil radiators	Young Radiator Co., Racine, Wis.
Ventilating fans	B. F. Sturtevant Co., Boston, Mass.
V-belts	Dayton Rubber Co., Dayton, Ohio
Sidelining	Masonite Corp., Chicago
Headlining	Agasote Milboard Co., Trenton, N. J.
Weatherstripping	Midgley & Borrowdale, Chicago
Insulation	Alfol Insulation Co., New York
Felt	Fidelity Felt Co., Philadelphia, Pa.
Diaphragms between cars	Morton Mfg. Co., Chicago

Lounge chairs and tables	S. Karpen Bros., Chicago, furnished by Mandel Bros., Chicago
Seats and partitions	Hale & Kilburn, Philadelphia, Pa.
Seat covering and carpets	L. C. Chase Co., New York, furnished by Mandel Bros., Chicago
Copper screen	Newark Wire Cloth Co., Newark, N. J.
Rubber weatherstrip	Manhattan Rubber Co., Passaic, N. J.
Sash	O. M. Edwards Co., Syracuse, N. Y.
Window glass	Pittsburgh Plate Glass Co., Pittsburgh, Pa.
Door locks	Russell Erwin Co., New Britain, Conn.
Door tracks and hangers	Richards-Wilcox Co., Aurora, Ill.
Hinges	Homer D. Bronson, Beacon Falls, Conn. Soss Mfg. Co., Roselle, N. J. Stanley Works, New Britain, Conn.
Castings (assist door handles)	American Chain Co., Bridgeport, Conn.
Plymetl dead light panels	U. S. Plywood Co., New York
Insulation and fibrous adhesive	Johns-Manville Co., New York
Lumber	Sykes Lumber Co., Philadelphia, Pa.
Molding	Herron-Zimmer Molding Co., Detroit, Mich. Martin Parry Co., York, Pa.
Cork floor	Armstrong Cork and Insulation Co., Lancaster, Pa.
Stainless steel engine-cooling grille	Tuttle & Baily, New Britain, Conn.
Buffet	Angelo Colonna, Philadelphia, Pa.
Table tops	Formica Insulation Co., Cincinnati, Ohio.
Air-conditioning and cooling	York Ice Machinery Corp., York, Pa.
All pipe insulation	Keasbey & Mattison Co., Ambler, Pa.
Air duct insulation	Celotex Co., Chicago, Ill.
Air filter	Brillo Mfg. Co., Philadelphia, Pa.
Freon refrigerant	Kinetic Chemicals Co., Wilmington, Del.
Exhaust fans	Robbins & Meyers Co., Springfield, Ohio
Air-conditioning grilles	Uni-Flo Grille Corp., Detroit, Mich.
Heating and cooling controls	Pennsylvania Electric Switch Co., Des Moines, Iowa
Heating plant and thermo-static controls	Vapor Car Heating Co., Chicago
Radiation	J. A. Nesbitt, Inc., Philadelphia, Pa.



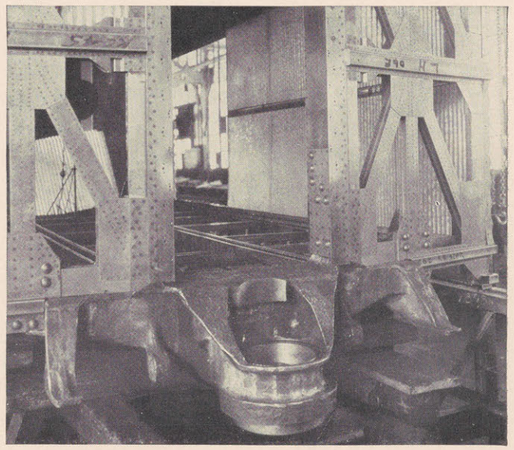
One of the York Refrigerant Compressors in Place in the Underbody

Conduit fittings	Crouse-Hinds Co., Syracuse, N. Y.
Storage batteries	Electric Storage Battery Co, Philadelphia, Pa.
Electrical fittings	Arrow, Hart & Hegeman Co., Hartford, Conn.
Electric power equipment	General Electric Co., Schenectady, N. Y.
Air compressors	
Auxiliary battery charging generator	
Electric grills and urns	
Bearings on main driving motors, ventilating equipment and air-brake equipment	S K F Industries, Inc., Philadelphia, Pa.
Lamp bulbs	National Lamp Co., Cleveland, Ohio
Lamp regulator and fixtures	Safety Car Heating & Lighting Co., New York
Fans in railway post office	
Conduit and light fittings	Taplet Mfg. Co., Philadelphia, Pa.
Fuse blocks	Trumbull Electric Co., Plainville, Conn.
Nofuze load centers	Westinghouse Elec. & Mfg Co., East Pittsburgh, Pa.
Wire	Gilby Wire Co., Newark, N. J. Okonite Co., New York
Drape curtain rods	Kirsch Co., Sturgis, Mich.
Curtain material (drapes)	Bassett McNabe Co., Philadelphia, Pa.
Rolled curtains	Adams & Westlake Co., Chicago
Curtains	Pantasote Co., New York
Waterproof carpet runner	John Wanamaker, Philadelphia, Pa.
Lamps and smoking stand	Gaumer Biddle, Philadelphia, Pa.
Radio	Stromberg-Carlson Tele. Mfg. Co., Rochester, N. Y.
Converter for radio	Electric Specialty Co., Stamford, Conn.
Special fittings	Crane Co., Chicago
Piping and fittings	Chase Brass & Copper Co., Waterbury, Conn.
Lavatory equipment	Dayton Mfg. Co., Dayton, Ohio

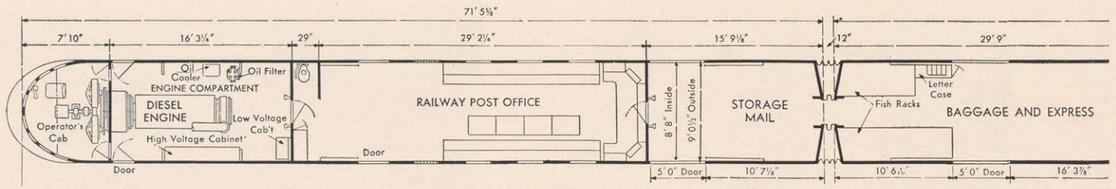


The Insulation in Place Ready for the Application of the Interior Finish

Paper cups and dispensers	Logan Drinking Cup Company, Worcester, Mass., Division of United States Envelope Company
Paper towels and cabinets	Northern Paper Mills, Green Bay, Wis.
Water coolers	Henry Giessel Co., Chicago
Enamel, baggage room, post office, engine room	Larkin Co., Inc., Buffalo, N. Y.
Speedometer	Weston Electrical Instrument Co., Newark, N. J.
Sanders	Graham-White Sander Co., Roanoke, Va.
Signal valve	National Pneumatic Co., New York
Whistle valves	Lunkenheimer Co., Cincinnati, Ohio
Tyfon horns	Leslie Mfg. Co., Lyndhurst, N. J.
Monel screws and nuts	International Nickel Co., New York
Fibre nuts	Elastic Stop Nut Corp., Elizabeth, N. J.
Head and back-up lights	Electric Service Supplies, Philadelphia, Pa.
Marker and classification lights, conduits and light fittings	Pyle-National Co., Chicago
Oilite center bearing plates	Amplex Mfg. Co., Detroit, Mich.
Clear vision mechanism	Motor Products Corp., Detroit, Mich.



The End Frame and Articulation Casting



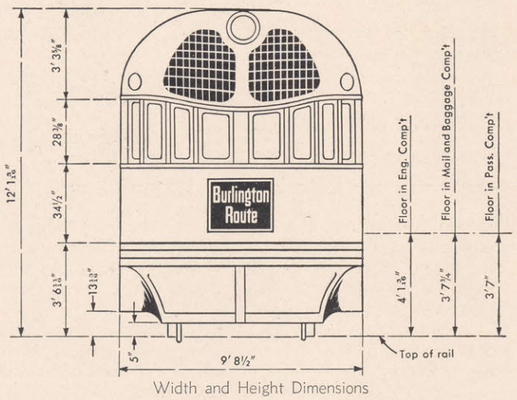
Floor Plan of the Burlington Zephyr

permit the air-conditioning system to operate efficiently. The window sash, furnished by the O. M. Edwards Company, are set flush with the outside surfaces of the train.

The Power Plant

The power plant for driving the train, including power auxiliaries, was designed by the Winton Engine Corporation, a subsidiary of the General Motors Corporation. The main generator, exciter, auxiliary generator and traction motors were built by the General Electric Company.

Power for propulsion of the train originates in a Winton 600-hp. high-compression, two-cycle, 8-in. by 10-in. eight-in-line Diesel engine. Power for all auxiliaries, whether driven directly or indirectly, is taken from the engine in excess of its rated output of 600 hp. at 750 r.p.m.



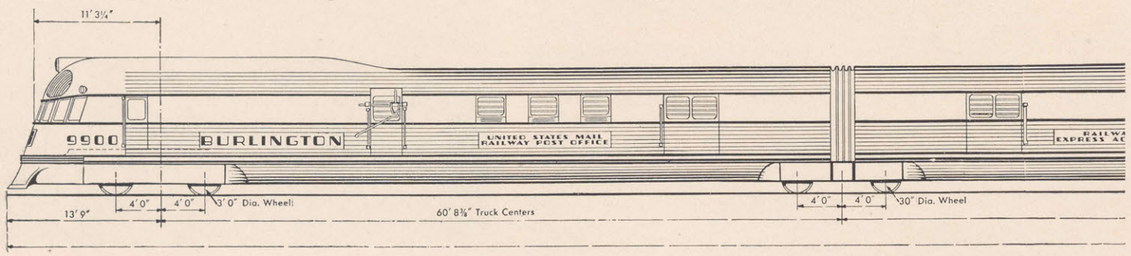
Width and Height Dimensions

Incorporated in this engine are several novel features of construction and design. For example, engine weight has been reduced to about 22 lb. per hp. by the Lukenweld process for welding steel plate to form a single-piece engine block, comprising the crankcase and cylinder block, to which a light oil pan is attached. A nine-bearing crankshaft is carried on main bearing seats fastened to the end of individual cross members cut to form frames for the fabricated engine block. In this manner combustion stresses are transmitted directly to the bearing seats, through the solid frames held rigid by the various patterns of welded plate, which incidentally form the air-intake passages, top and bottom of the cylinder block, webbing, etc. Steel-backed, lead-bronze-faced main bearing liners, 6½ in. in diameter, are clamped by shimless bearing caps held in place with jack screws acting against the frame arch below the cylinder block.

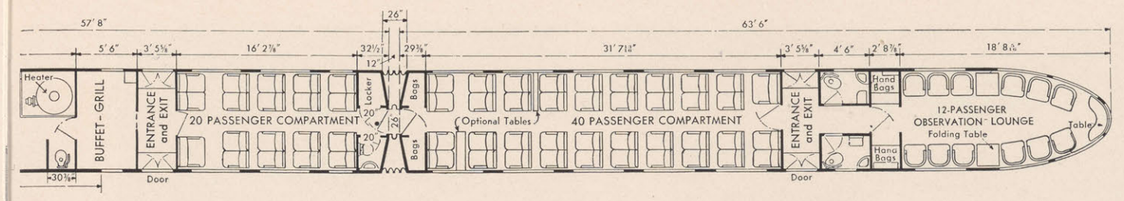
Water jacketed cylinder liners of heat-treated cast iron are bolted to the cylinder heads, which in turn are fastened in the usual manner to the cylinder block. About mid-length are cast twenty-four oblique air-intake ports circling each cylinder liner. Thus, the cylinder block forms an air-intake manifold in which pressure is maintained by a three-lobed twin-rotor scavenging blower or compressor, mounted on the front end of the engine block. This arrangement of air intake and the use of four exhaust valves per cylinder insures scavenging of the cylinder at a minimum blower pressure. The heads of the aluminum alloy pistons are cooled by a stream of oil emitted from the top of special I-section connecting rods fitted with bearing liners having a 6-in. bore.

The possibilities in power economy, afforded by streamlining railroad equipment, required the remodeling of the conventional engine-cooling and exhaust systems to provide a smooth roof line. To accomplish this the exhaust manifold was lowered into a drop section in the car roof and the customary roof radiators regrouped to form two long sections suspended from the roof inside the engine room. Heretofore, with the roof-type radiators air circulation through the radiators was furnished by the motion of the train, while with the new system of inside mounting an artificial breeze was needed for cooling purposes. Two large engine-driven fans are mounted above the partition separating the engine room from the control cab. A grilled opening in the front of the train admits air to the fans via a duct formed by the cab ceiling and the car roof. The large volume of air brought into the engine room passes through the cooling radiators and thence outside through a central longitudinal slot in the roof. This assures a minimum disturbance of the air stream at the headend of the train and insures a thoroughly ventilated engine room.

The main generator is a single-bearing, differentially wound machine placed forward of the engine and directly connected through a flexible steel-disc coupling. A direct-connected exciter is used for generator excitation purposes to give inherently the generator characteristic which permits full engine utilization over a wide range of train speed. A shaft extension is provided at the exciter end of the main generator to drive through V-belts a 25-kw. auxiliary generator mounted above the main generator. The opposite end of the auxiliary generator shaft is also extended for V-belt connections to the two fans which draw air into the engine room.



Longitudinal Dimensions



Burlington Zephyr

The two traction motors are mounted on the front truck of the leading car. They are series-wound motors of General Electric manufacture, having axle-bearing linings suitable for a 7½-in. axle and a double nose for spring support on the truck bolster. The gearing is single reduction with a 25-tooth pinion and a 52-tooth gear. The armatures have SKF roller bearings and the axle bearings are of the sleeve type.

The traction motors are self-ventilated by multiple fans mounted at the pinion ends of the armatures. Ventilating air is taken from the engine room through canvas ducts, and motor ventilation is aided by the slight positive air pressure—about 1 in. of water—in the engine room.

Motor control consists essentially of one master controller, electro-pneumatically operated motor contactors, and reversor, together with the necessary auxiliary magnetic contactors, switches, relays, etc. The control provides for operation from the front of the train only and for starting and stopping the engine, regulating headlights, cab lights, etc. The traction motors are progressively connected in series, parallel and parallel-shunted-field combinations with transfer from one connection to the next higher effected manually.

The 25-kw. two-bearing 76-volt auxiliary generator is of the four-pole direct-current commutating-pole type. The output of the generator is furnished to the air compressors, the air-conditioning equipment, motor for train heating boiler, battery charging, lights, control, buffet utensils, etc., at a constant voltage regardless of load, over a range of engine speed from idling to full speed, including engine regulation. This has been made possible by the combined effect of inherent regulation and the use of a new dynamic relay.

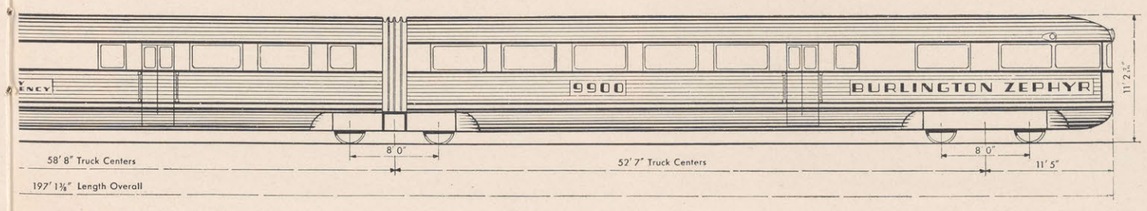
The storage battery is an Exide Ironclad 32-cell, 64-volt battery rated at 450 amp. hr. at the 10-hr. discharge rate, which is placed in a stainless-steel battery pit in the engine room. The weight of the battery is 3,260 lb. Ventilating scoops are used to increase air circulation in the battery box. The battery is used for engine cranking in addition to supplying power to the auxiliary circuits.

Two General Electric 25-cu. ft. air compressors, driven by 76-volt motors, furnish the necessary air for the train. These compressors are of standard design, but with aluminum frame parts to obtain a light-weight equipment.

Interior of the Baggage Car Framing Showing Local Reinforcing of the Roof

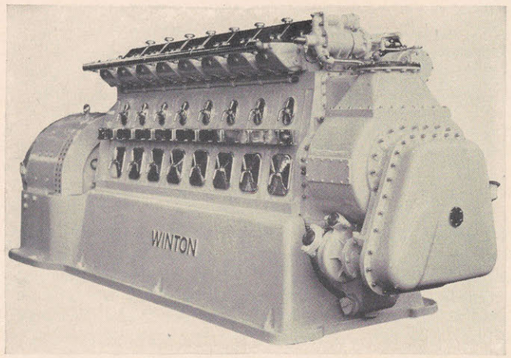
The Trucks

The four trucks are all of conventional outside bearing type of construction. All have cast-steel frames and bolsters, furnished by the General Steel Castings Corporation. Their combined weight is 55,000 lb. without the motors and gears in the power truck. The power



of the Burlington Zephyr

model 61.1 scale 61.1 / 197.1 × 12 = 1 / 39.7

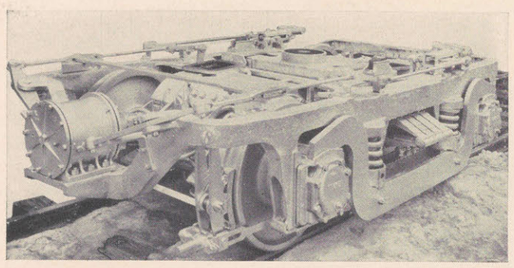


The Winton Eight-Cylinder, 600-Hp., Two-Cycle Diesel Engine

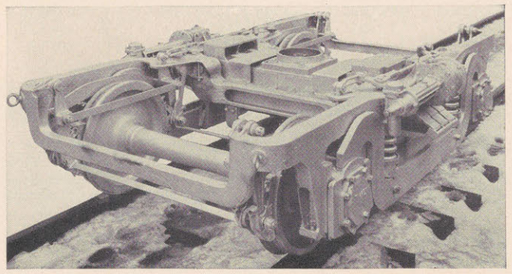
truck, in which are mounted the two traction motors, has 36-in. wheels. This is the front truck and carries the weight of the power plant. The trailer trucks, although of the same general type, are considerably lighter in construction and run on 30-in. wheels. All journals are fitted with Timken roller bearings. The axles are hollow-bored to reduce weight.

Of particular interest in the construction of the trucks is the extensive use of rubber insulation to prevent the transmission of sound and other high-frequency vibrations to the car bodies. There are inserts under the center plate, in both top and bottom equalizer spring seats and between the ends of the equalizers and journal boxes. Rubber liners in the pedestals are faced with Oilite metal plates, vulcanized on, which serve as bearing surfaces for the faces and flanges of the boxes. The bolster pads, which insulate the bolster from the truck frame, are also faced with Oilite metal. In addition to the pad under the center plate, rubber thimbles are provided around the king pin and the center-plate bolts, the latter also including washers. A further precaution against unnecessary noise is the provision of automotive brake lining wherever the members of the truck brake rigging are likely to rub. To dampen vibrations of lower frequency Holland helical-volute springs are used on the equalizers of all four trucks. These springs consist of the conventional helical outer coil with an inner volute spring in place of the inner helical coil. The center plate bearing, the bearing between the articulation castings and side bearings are all faced with Oilite.

No two of the trucks carry the same load. With the train normally loaded the power truck is estimated to carry a weight at the rails of 98,000 lb.; the first trailer truck, between the first and second car bodies, 67,000 lb.; the second trailer truck, between the second and third car bodies, 45,000 lb., and the third trailer truck, at the rear end of the train, 30,000 lb. The nominal journal sizes are, respectively: Power truck, 6 in. by 11 in.; first trailer, 5½ in. by 10 in.; second trailer, 5 in. by 9 in.; third trailer, 4¼ in. by 8 in.



The Power Truck



One of the Trailer Trucks

Brakes

The train is fitted with Westinghouse SME-3 brake equipment, which has been modified specifically for high-speed articulated train units. This is a straight-air system with emergency feature and also has a brake pipe which permits standard automatic operation of the brakes in case it should be necessary or desirable to move this train in connection with steam-train equipment. There are three air lines on the train: (1) The emergency pipe through which the supply reservoirs for each vehicle are charged at all times under normal operation and the loss of pressure from which causes the control valves to effect an emergency application of the brakes; (2) the straight-air pipe, pressure variations in which cause the control valves to effect graduated service application and release, and (3) the brake pipe by means of which automatic operation of the brakes can be effected when the articulated train is moving in connection with steam-train equipment or when backing up and on which the conductor's valve in the rear car is placed.

The brake valve operates the brakes by controlling the pressure in the straight-air pipe. It is self-lapping, the degree of service application varying with the position of the handle, a feature by which great sensitivity is attained. The dead-man control is operated either pneumatically by a foot pedal or electro-pneumatically by a push-button on the brake-valve handle. The release of both of these automatically cuts off the power and causes an emergency application of the brakes. The brake valve also provides, electro-pneumatically, for an emergency application of the brakes should a failure of pressure in the straight-air pipe prevent a response to a movement of the brake valve to service application position within a predetermined time interval.

In order to effect the high rates of retardation required to keep stopping distances from speeds of 100 or more miles per hour within present limits, the brake system is designed for a 200-per cent braking ratio at 100 lb. cylinder pressure. Because of the increasing coefficient of brake-shoe friction as the speed is reduced, the brake-cylinder pressure is controlled automatically as the train slows down by a retardation controller, a pendulum inertia device by which brake-cylinder pressure is reduced at a rate sufficient to maintain a constant predetermined retardation rate. The retardation controller is wired in the battery circuit to solenoids on the control valves and through these the control of brake-cylinder pressure is effected.

Aluminum has been used extensively in the air-brake equipment in the interest of weight reduction. This includes the control-valves and brake cylinders, etc. The supply reservoirs are of stainless steel.

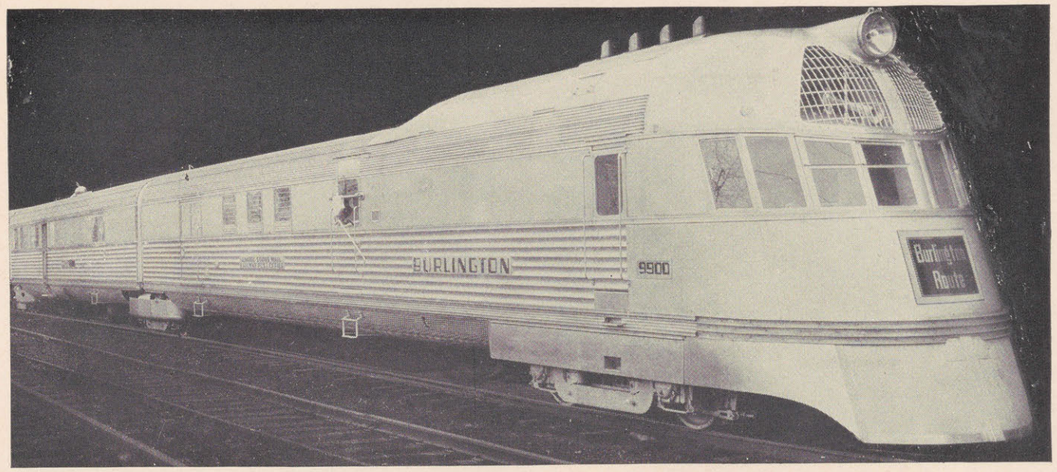


Photo by Wendell MacRae, New York

The Operator's Cab Has Clear Vision Through 180 Deg.—Cooling Air for the Engine Enters Through the Grilles Over the Cab Ceiling

The Heating System

The train is equipped with steam heat throughout. Each passenger compartment also has its own mechanical air-conditioning system. These are interlocked with the heating system so that the force-ventilation feature of the air-conditioning equipment is available both winter and summer.

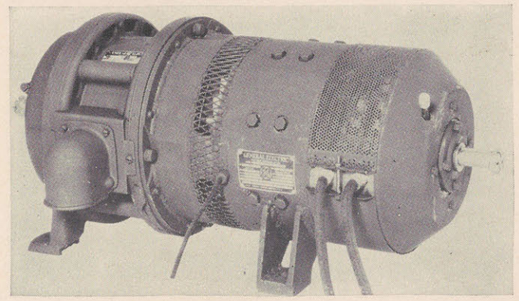
Steam for heating is provided by an oil-fired Peter Smith boiler with an evaporative capacity of 500 lb. per hour at a pressure of 85 lb., furnished by the Vapor Car Heating Company. This boiler is located at the rear end of the baggage room in the second car. Its operation is completely automatic and, in order to reduce weight, the condensate from the radiators is returned to the 50-gal. feedwater storage tank. Storage is provided for 75 gal. of fuel oil.

The operation of the boiler is subject to three controls: (1) A water-level control; (2) a low-water control, and (3) a burner load control. The water-level and low-water controls are of the electrode, commonly called spark-plug, type. The electrodes are inserted in a container or bottle which is connected to the boiler in the same manner as a water column. They are of three lengths. The lower end of the longest one corresponds to low-water level and the vertical distance between the other two marks the variation in water level within which the feed pump is controlled. Current at 110 volts, furnished by a small motor-generator set, passes from the electrodes to their grounded metal container through the water. If the water drops below the end of the longest electrode, the failure of the current acts to close the oil-supply valve and stop the burner motor. A variation of the water between the ends of the intermediate and short electrodes serves to cut the feed pump in or out.

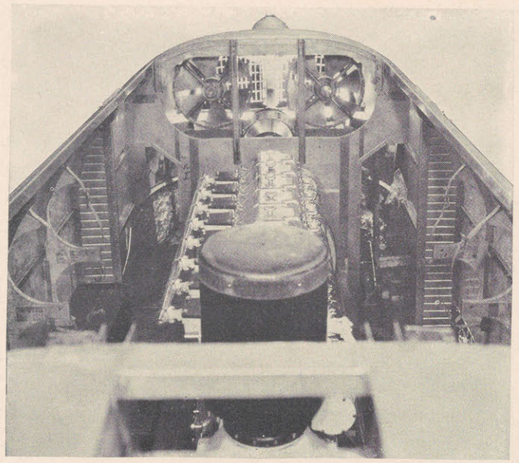
If pressure in the boiler builds up beyond a predetermined point owing to a load insufficient to utilize all of the steam being produced, a pressure switch operates automatically to reduce the flow of oil to the burner and the speed of the burner motor, thus maintaining a flame which is little more than a pilot light until such time as the reduction in pressure restores the flow of oil and the speed of the motor fan to their full load amount.

Heat is supplied to the passenger compartments from two sources. A fin-tube coil in the evaporator unit of the air-conditioning system in each compartment supplies heat to the fresh and recirculated air passing through the units to the compartments. Steam is also supplied to a copper fin-pipe along the truss plank near the floor on each side of the compartment. The admission of steam to both radiators is controlled by motorized valves which are actuated by independent thermostats. A thermostat for the control of the air-conditioner radiators is located on a deadlight panel near the center of each compartment about 5 ft. above the floor. The thermostat for the side-wall radiators is placed near the floor and serves to bring these radiators into action automatically when the heat distribution from the air-conditioning unit is not sufficient to maintain a predetermined temperature at the floor.

A unique scheme has been developed for returning condensate from the radiators of the front and rear cars to the feedwater storage tank on the second car. Water from the radiator traps drains into small sumps, one on each of the two cars. As the water level rises in the sump, a float causes a relay to open a solenoid valve in the brake pipe, admitting air to the sump under regulated pressure and forcing the condensate through a separate return line to the storage tank. During layover periods the entire train can be heated by steam from the terminal supply. The heating and thermostatic controls



The General-Electric A.C.-D.C. Motor Set which Drives the Two Air-Conditioning Compressors and Condenser Fans Under the Rear Car



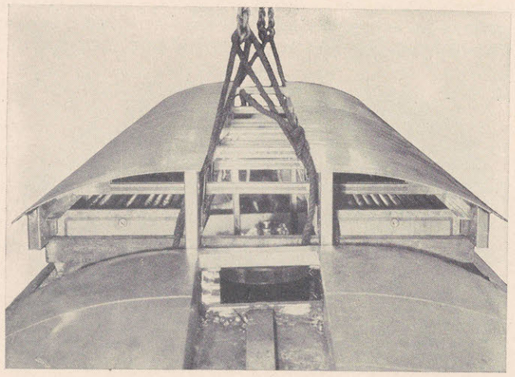
Looking Into the Engine Room with the Hatch and Radiators Removed

are the product of the Vapor Car Heating Company.

Air Conditioning

Each of the three passenger compartments is served by a complete York mechanical air-conditioning unit of 1½ tons nominal capacity. The compressors as well as the condenser and evaporator units are all located within the underbody below the floors of the coaches. The evaporators deliver air through the grilles in the bulkheads over the center doors into the compartments. Recirculated air leaves the compartments through filter-protected openings in the floor over the evaporator units.

The motors for operating the compressors and the evaporator unit fans were manufactured by the General Electric Company. A 7½-hp. a.c.-d.c. motor operates the two compressors and the condenser fans on the third car and a 3-hp. d.c. motor drives the compressor unit and the condenser fan on the second car. For standby service when the main power plant is not in operation a tap from a 220-volt, 60-cycle terminal supply can be plugged in to operate the a.c. motor on the rear coach. This drives the two units on this coach and the d.c. motor becomes a generator which supplies current for reduced-capacity operation of the unit on the second car. The d.c. motors operate on 76-volt current from the head-end supply.

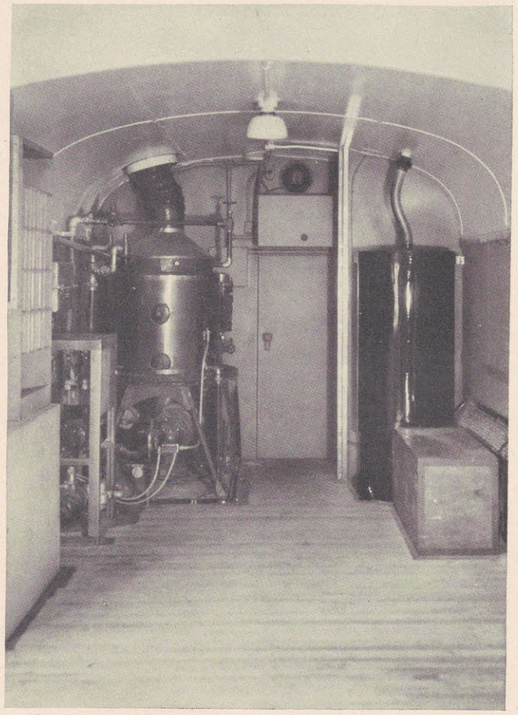


Lowering the Engine-Room Hatch Into Position—Engine Cooling Radiators Are Directly Attached to It

Two ¼-hp. and one ⅓-hp. motors drive the evaporator fans.

The entire air-conditioning equipment has been designed with the requirement for light weight as a major objective. The evaporator units, including both steam and refrigerating fin coils, are aluminum. The compressor motors operate at 1,750 r.p.m. The complete equipment, including the motors and controls, has a total weight of about 2,400 lb., and with refrigeration lines, water lines, electric cables, etc., included, does not exceed 3,000 lb.

Copper pipe with sweated fittings has been used throughout the train for water, steam and air. Its use has effected a piping weight reduction estimated at 60 per cent. It is scale-proof and once installed possesses



The Peter Smith Automatic Oil-Fired Heating Boiler

a high degree of permanence. Because of the difficulty of access for replacement of some of the piping on the Burlington train, this factor was of considerable importance. Except for a few special fittings, no iron or steel pipe has been used.

Interior Decorations

The interiors of the passenger compartments in the Zephyr are all finished in pastel shades effectively used on the smooth wall surfaces without striping. The only ornamentation consists of the polished stainless-steel bands above the windows and along the ceiling at the open side of each lighting duct, and the stainless steel window sills. Each compartment has a distinctive color harmony to which wall colors, window drapes, upholstery and floor covering all contribute. In the smoking compartment the walls are finished in a pastel rose with golden rose window drapes. The seats are upholstered

in leather medium brown in color. The floor is covered with Linotile with a dark mottled surface neutral in tone. The lavatory and buffet floors are covered with linoleum to harmonize with the Linotile.

The walls of the main passenger compartment are finished in a warm gray with a hint of green. The seats in this compartment are upholstered with Chase Velmo low-pile mohair. The color is gray-green with a gold background, the pile woven to form a striped pattern. The silk window drapes in this compartment match the green of the upholstery. The floor is covered with a plain taupe Chase Seamloc carpet. In the lounge the walls are finished in gray, in this case with a suggestion of purple-blue. The furnishings consist of comfortable lounge chairs and tables. The frames of the chairs are of scratch-brushed aluminum and the upholstery is of a purple-blue with gold background. The material and the pattern are similar to that of the seat coverings in the pas-

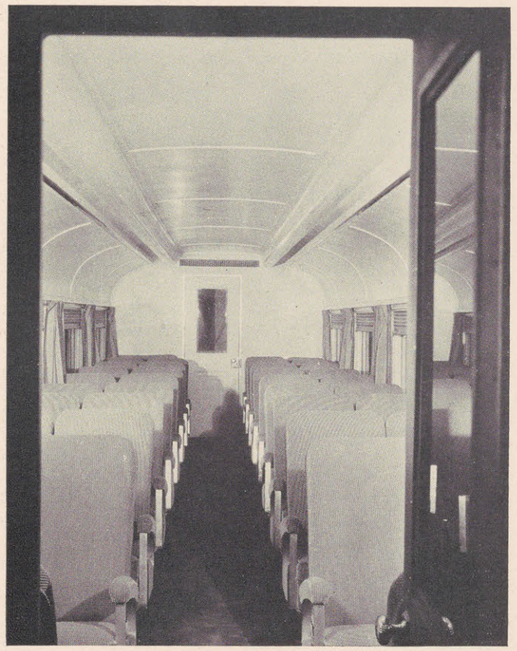


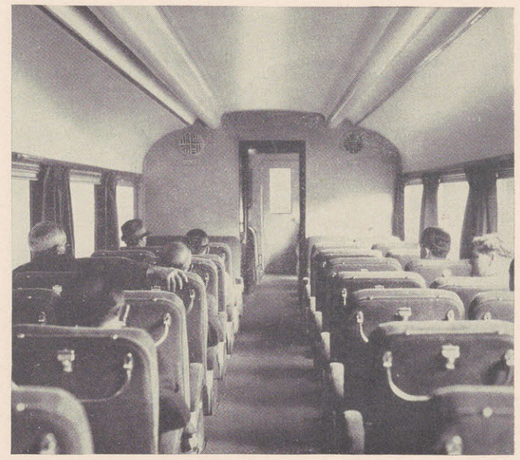
Photo by Wendell MacRae, New York
Looking Toward the Rear of the Main Passenger Compartment From the Smoking Room—The Air-Conditioner Grille Is Over the Door in the Bulkhead

senger compartment. The window drapes are of gold and the carpet is plain platinum-gray Chase Seamloc. The ceilings in all three compartments are finished in a light cream.

Furnishings

The tables in the lounge are finished in non-blistering Formica of the same shade of blue as the upholstery. The side tables have drop leaves and are edged with filigree stripes of aluminum.

The window shades are of Pantasote with an inside fabric facing of a neutral two-tone pattern which harmonizes with the color schemes in all three compartments. The windows in the lounge are not shaded, except with the heavy silk drapes. The outside surfaces of the window shades have an aluminum finish, which closely

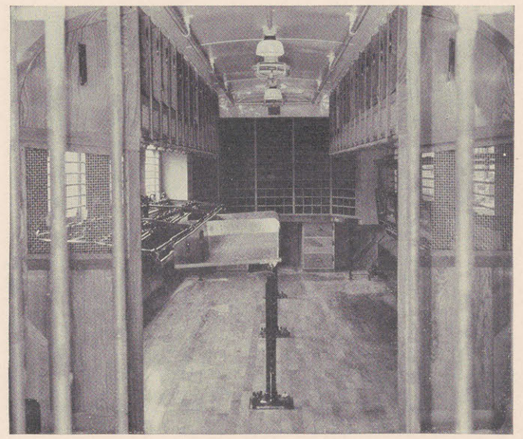


Looking Toward the Front End of the Main Passenger Compartment—The Radio Loud Speaker Is Behind the Grille in the Bulkhead at the Right

matches the unpainted stainless-steel exterior of the train.

In the smoking and passenger compartments the lighting is indirect, the lights being concealed within longitudinal ducts below the ceiling along each side of the car. The sides of these ducts toward the sides of the car are open and the light reflected from the curved inner surfaces of each duct and against the curve of the ceiling and the side of the car is diffused in a wide angle which reaches completely across the car at the reading height. The illumination on each side of the car is thus received from the lights in both conduits. The exterior of the conduit is blended into the surface of the ceiling by smooth flowing curves. The lighting is designed to produce an intensity of eight foot-candles at reading height. The lounge is lighted directly through diffusing glass which covers the underside of long ducts placed along the walls just above the windows.

The seats in the smoking and passenger compartments are built on light-weight aluminum frames. The height of the seat and the angle of the seat and back have been carefully chosen for travel comfort. The backs are ad-



Interior of the Railway Postoffice

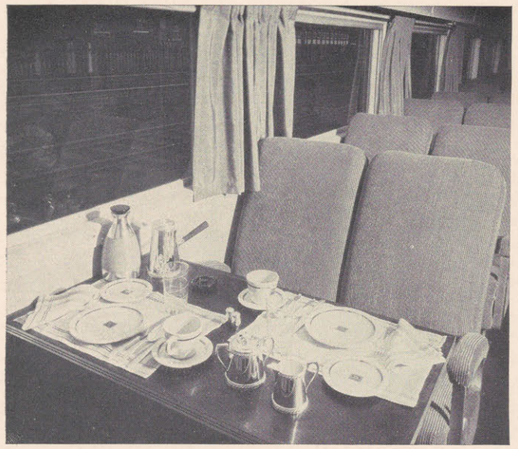


Photo by Wendell MacRae, New York
Meals Are Served to the Passengers at Their Seats

justable from the normal upright to a semi-reclining position. They are built with a clear space 18 in. high underneath for the stowing of hand baggage. Facilities for holding overcoats and hats are provided by a metal rod and a spring clip fastened to the back of each of the paired chairs in the passenger and smoking compartments. Further storage space for luggage has been provided in racks on either side of the short passage at the front end of the rear car and also at the front end of the lounge. It has thus been possible to eliminate the conventional overhead racks for luggage and apparel and to preserve the motif of unbroken surfaces in the passenger compartments.

The train has a buffet which is equipped to supply grill service and to serve ice cream and both hot and cold drinks. It occupies a compartment 5 ft. 6 in. long across the center car. In the design of its equipment great ingenuity has been used to provide all of the necessary facilities, including ample refrigerator space, electric grills, urns for hot water and coffee, storage for dishes, cupboards for storage of foods, utensils, etc. Service may be provided either at the counter or at the seats in the passenger compartments. Removable trays, which can be bracketed between the seats, serve as dining tables. These trays are finished in black nonblistering Formica with aluminum filigree stripes on the edges. The dishes, which have been especially made for the train, are a deep cream color, each decorated with a single band of gold and with the Burlington emblem in colors. The plates have a ½-in. rim instead of the conventional 2-in. bevel to conserve storage space and to fit the service trays without crowding. Communication with the buffet from each seat is made possible by an annunciator. All passenger compartments of the train have radio reception from a Stromberg-Carlson 11-tube radio receiver.

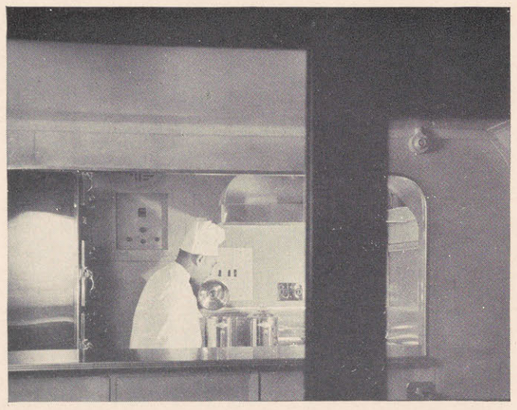


Photo by Wendell MacRae, New York
The Grill As Seen from the Front End of the Smoking Compartment

Lights

The front headlight is a 14-in., 250-watt, Golden Glow unit made by the Electric Service Supplies Company. The back-up light is a 9-in., 40-watt unit made by the same manufacturer. The marker and classification lights are Pyle-National airplane-wing lights in housings made by the Budd company. These lights are all built into the body of the train.

All lights inside the car and also all auxiliary apparatus are controlled through Westinghouse Nofuze load centers. Arrow, Hart & Hegeman heater switches provide for connecting inside lights all in multiple, for using only alternate lights and for dimming the lights by connecting the two groups in series.

Zephyr's Place in Burlington Passenger Operations

After a three weeks' tour of eastern cities, and a six weeks' tour of western cities, the Zephyr will be placed on exhibition at A Century of Progress in Chicago. At the close of the Fair it will be assigned to turn-around service between Kansas City, Mo., St. Joseph, Omaha, Nebr., and Lincoln, on a four-hour schedule for the 251 miles.

The main idea back of the Zephyr is an effort to reduce the cost of passenger train operation, particularly that of the two- to five-car trains that are now handling head end and passenger business with little or no profit, and which produce 25 per cent of the passenger train mileage of the Burlington. At the same time, it is hoped that the train will have a sufficient appeal to the public to attract more business. With these objectives in mind, the Zephyr was designed especially to meet the conditions prevailing between Kansas City and Lincoln rather than as a train that can be used in any territory.

The distance from Kansas City to Lincoln is short enough so that an appreciable stepping up of train speeds will permit of a schedule that will give the passengers considerable time during business hours either before the beginning of the trip or after its termination. Because the bulk of the traffic of present trains is toward Kansas City in the morning, the Zephyr will leave Lincoln at about 8 a.m. and will arrive in Kansas City at noon. It will return during the afternoon of the same day. The schedule adopted will make it possible to eliminate two locomotives and six passenger train cars which equipment has a total weight equal to eight times that of the Zephyr.

The physical conditions of the route are such as to require only moderate expenditures to place the track in condition for high speed movements. The curvature and gradients are moderate; only nine per cent of the curves are in excess of one degree and only one per cent are in excess of three degrees. Wye or loop tracks are available at both Kansas City and Lincoln on which the train may be turned around. High speeds between Kansas City and Omaha are favored, also, by the fact that there are only six highway grade crossings in that distance.

M. I. T. Wind Tunnel
Report 355.

Report on Tests of Rail Train Models.

In order to obtain comparative data on the wind resistance of a streamlined three-car rail train and a similar train of three conventional cars, two models have been submitted by the Edward G. Budd Manufacturing Co. for test. The tests were made in the five-foot throat wind tunnel at Massachusetts Institute of Technology.

The streamlined train has flush window and doors with a nicely rounded front end, a back tapered in plan slightly (doubtless as much as utility allows), and all structure and appliances housed in a false bottom. The other tested for comparison only had indented window, much exposed gear underneath, partial openings between cars, etc. The models were made about five feet long, this dimension limiting the size. The maximum cross section of the streamlined cars was 9.61 □" and of the regular cars 7.27, □" the track gauge was approximately 1.46" for the streamlined train and 1.14 for the regular. The models are then different scale. For details, see Budd SK5927 and 5928 or photographs in this report. The models were single, not mirror, and so were tested with a board close below the wheels to simulate the ground. Suspended by two V's of fine wire the models were tested in line with the airstream (corresponding to movement through calm air). The effect of a side wind was found by yawing the models, in these tests the model was held on its side by a rod through from top

to bottom of the train. This rod was then mounted on the wire balance used for airfoil tests. The airspeed in all tests was 60 miles per hour.

Results are plotted and tabulated. All forces are expressed as pounds on the model at 60 miles per hour. Three forces are given: the drag defined for these tests as the force along the track, cross rail force defined as the force normal to the track, (always away from the wind) and the lift, the force tending to raise the train off the track. In the side wind tests the airspeed must be understood to be the resultant vector combination of the train velocity and wind velocity. It is difficult to estimate the probable accuracy of the results. The experimental error is small, perhaps 1 or 2% but how closely the full scale values would correspond is questionable because of effect of change in scale and model detail and because the representation of the ground by the board is not exactly correct. The full scale forces may be approximated by multiplying the model force by the square of the scale factor and the square of the ratio of the airspeed to 60 miles per hour.

The wind resistance of the streamline train was naturally much lower. If allowance is made for the difference in scale of models it is only 1/3 that of the other train. This reduction is a saving of perhaps 120 draw-bar horsepower full scale at 60 m.p.h., 300 at 80 m.p.h. The cross rail force and lift are also less on the streamline train model. The drag of the streamline train is about 1/3 that of a disc of the same cross section, that of the regular train .8 the disc drag. A rough check gives a friction drag for the streamline model of .16 lbs. about 2/3 of the total, for that model. It would

be difficult to lower the resistance materially with a body so long in proportion to its cross section, giving due consideration to the limitations of shape variation imposed by the wheels and interior arrangements.

Shatswell Ober.

October 7, 1933. Shatswell Ober.

Edward G. Budd Manufacturing Company

Rail Train Model Tests

Tested M. I. T. Five Foot Tunnel

Wind Speed 60 M.P.H.

Date - - Oct. 1933.

Streamlined Model

ψ	Drag	C.R.F.	Lift
0	.24	0	-.03
5	.27	.19	.02
10	.29	.59	.24
15	.28	1.18	.43

Regular Train Model

ψ	Drag	C.R.F.	Lift
0	.47	0	0
5	.53	.38	.21
10	.63	.97	.60
15	.67	1.86	.97

Drag is the force along the track in pounds.

C.R.F. is the force normal to track in pounds.

Wire Drag = .160 at 60 MPH

20 ft. of .0160 wire

$$.16 = D_C \quad \frac{20 \times .016}{12} \times 3600$$

$$D_C = \frac{.16 \times 12}{20 \times 3600 \times .016} = \frac{1}{600} = .00166$$

.0015 at 40

$$15 \text{ ft} + \frac{24 + 25 + 9 + 15\frac{1}{2}}{12} \text{ of } .016 \text{ wire}$$

$$15 + \frac{73.5}{12} = 15 + 6.125 = 21.125 \text{ ft of } .016 \text{ wire}$$

---

5 ft of .020 wire ✓

Thus wire drag both models =

$$\frac{21.125 \times .016}{12} \times .00166 \times 3600 = .169$$

$$\frac{5 \times .020}{12} \times .00166 \times 3600 = .050$$

---

wire drag = .219

4

Stream lined Model - (drag of cross rod)

$$\frac{12.31}{.50}$$
$$11.81''$$

$$\frac{11.81}{12} \times \frac{5}{16 \times 12} \times .0037 \times 3600 = .295 \text{ lbs}$$

Regular Iron Model -

drag of cross rod = $.295 \times \frac{11.97}{11.81} = .298$ lbs

$$\frac{12.47}{.50}$$
$$11.97$$

Consequently Stream lined Model Wire Drag = .219 + .295 = .514 lbs at 60 MPH

Regular Model Wire Drag = .219 + .298 = .517 lbs.

Wire on Reg Train Model Drag Test

front V $33 + 23\frac{1}{2}$
back V $32\frac{1}{2} + 23\frac{1}{2}$ } = 112.5" of .016

+ 3 x $2\frac{1}{2}$ = $7\frac{1}{2}$ ft of .016

+ $2\frac{1}{2}$ ft — of .020 wire

= 7.5
9.375 } = 16.875 ft of .016

2.5 ft of .020

16.875 (x) $\frac{.008}{.016}$ (x) ~~3600~~ (x) $\frac{1}{600}$ = .135 lb

2.5 x $\frac{.01}{.020}$ (x) ~~3600~~ 6 x $\frac{1}{600}$ = .025 lb

.160 lb

Streamlined wire = 32.25 24
32.25 $23\frac{1}{2}$ } = 112"

wire drag = .160 lb.

Stream lined Model – (yaw test)

0° yaw drag (gross) = .67.90

0° (drag test) = .216

.4630

Therefore. wire & spindle drag should be .463 lbs.
by direct calculation .514

Regular Model.

0° yaw drag (gross) = .9235

0° (drag test) = .4583

.4652

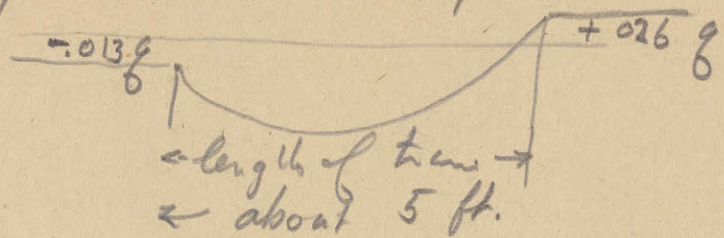
Therefore wire & spindle drag should be

.4652 lbs — or 10% wing drag
by direct calc 517 probably due shielding of rod.

Now (?) in regard to suction

correction.

Pressure gradient not uniform



∴ cannot use standard Vol x $\frac{dp}{dx}$ method.

but so near to ‖ body can use Area x ($P_{nose} - P_{tail}$)

drop $\Delta p = P_{nose} - P_{tail} = q(-.013 - .026) = -.039\,q$

∴ increase, or forward force, on drag should be greater than measured.

$.039 \times \underset{q \text{ at } 60}{9.23} = .36$ #/sq-foot. (in free flight)

Area streamlined (effective) $2.90 \times 3.33 = 9.65$

Force $9.65 \times \frac{.36}{144} = +.0241$ streamline

Vol $9.65 \times 57\frac{1}{8} = 552$ cu in or .319 cu ft.

Area ordinary model:

$2\frac{5}{8} \times 2\frac{1}{2} = 6.56$

$6.56 \times \frac{.36}{144} = +.0164$ plain.

Vol. $6.56 \times \underset{\text{sum of cans}}{57\frac{1}{8}} = 374$ or .217 cu ft

---

Preliminary data without board. (streamline)

	1	2
Drag Readings	198	171
	40	56
	158	115
	163	118
	118	
	281	
	.703	
	679	
	24	

tenths

drag.. gross

gross with board

forces on regular x 1.64 to give them on size corresponding to Zephyr.

Yaw	Zephyr D.	Ratios to (D at 0) CRF	L.
0	1.00	0	—
~~5~~	1.13	.79	—
10	1.21	2.5	1.0
15	1.17	4.4	1.8
	Regular		
0	3.2	0	—
5	3.6	2.6	1.4
10	4.3	6.6	4.6
15	4.6	12.7	6.6

$.240^{\#} \times \frac{1600}{3600} \quad 10000 = 1070 \times \frac{100}{375}$

450
280
740

77

88

100 (286)
95 245 x 1.20 294
Total 520
Residual at 95 226

Streamlined Car - peripheral length

$= 10\frac{5}{8}$" model length 60"

$= \left(\frac{637.50}{144}\right)$ sq ft

$D_f = D_{cf}\ S\ V^2$ $\left(D_{cf} = .0000102\right)$

$= .0000102 \times \frac{637.5}{144} \times \frac{25}{3600}$

$= .163$ lbs

Reg train —

7.27 sq in

$D_{Tag} = .474$ lbs

at 60 MPH

$D = D_c S V^2$

$.474 = D_c \times \frac{7.27}{194} \times \frac{25}{3600}$

$D_c = \frac{.474}{7.27 \times 25} = .0026$

$\frac{.0026}{.0032} = .81$

.75
.24
.50# saved on modest say $\frac{1}{40}$

1600
800# at 60

$\frac{800 \times 60}{375} =$

Streamlined train

9.61 sq in

Drag = .240 lb

at 60 M.P.H

$D = D_c S V^2$

$.240 = D_c \frac{9.61}{144} \times \frac{3600}{25}$

$D_c = \frac{.240}{9.61 \times 25} = .0010$

$\frac{.0010}{.0037} = .31$

FIG. 2.

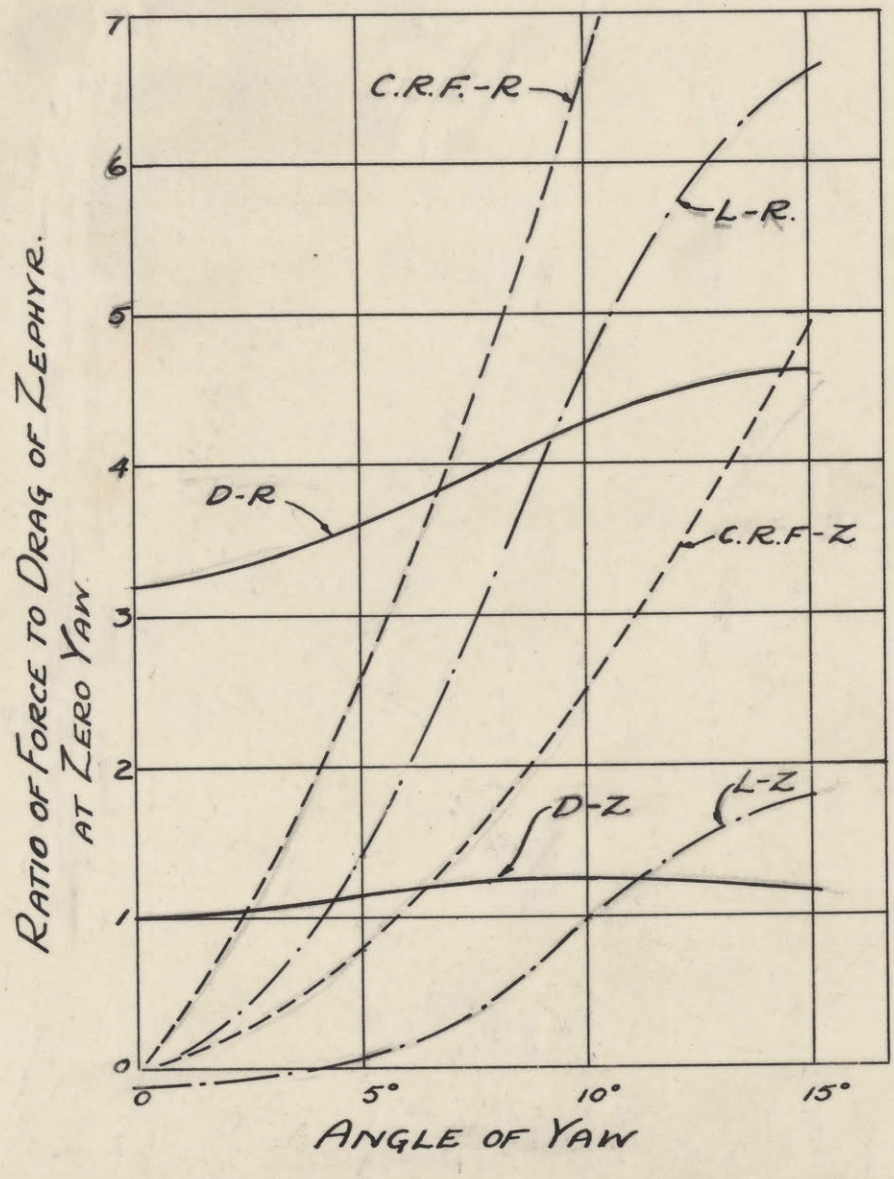
Z = ZEPHYR MODEL

R = CONVENTIONAL MODEL

C.R.F. = CROSS RAIL FORCE RATIO ----

D = RESISTANCE RATIO ——

L = LIFT RATIO —·—



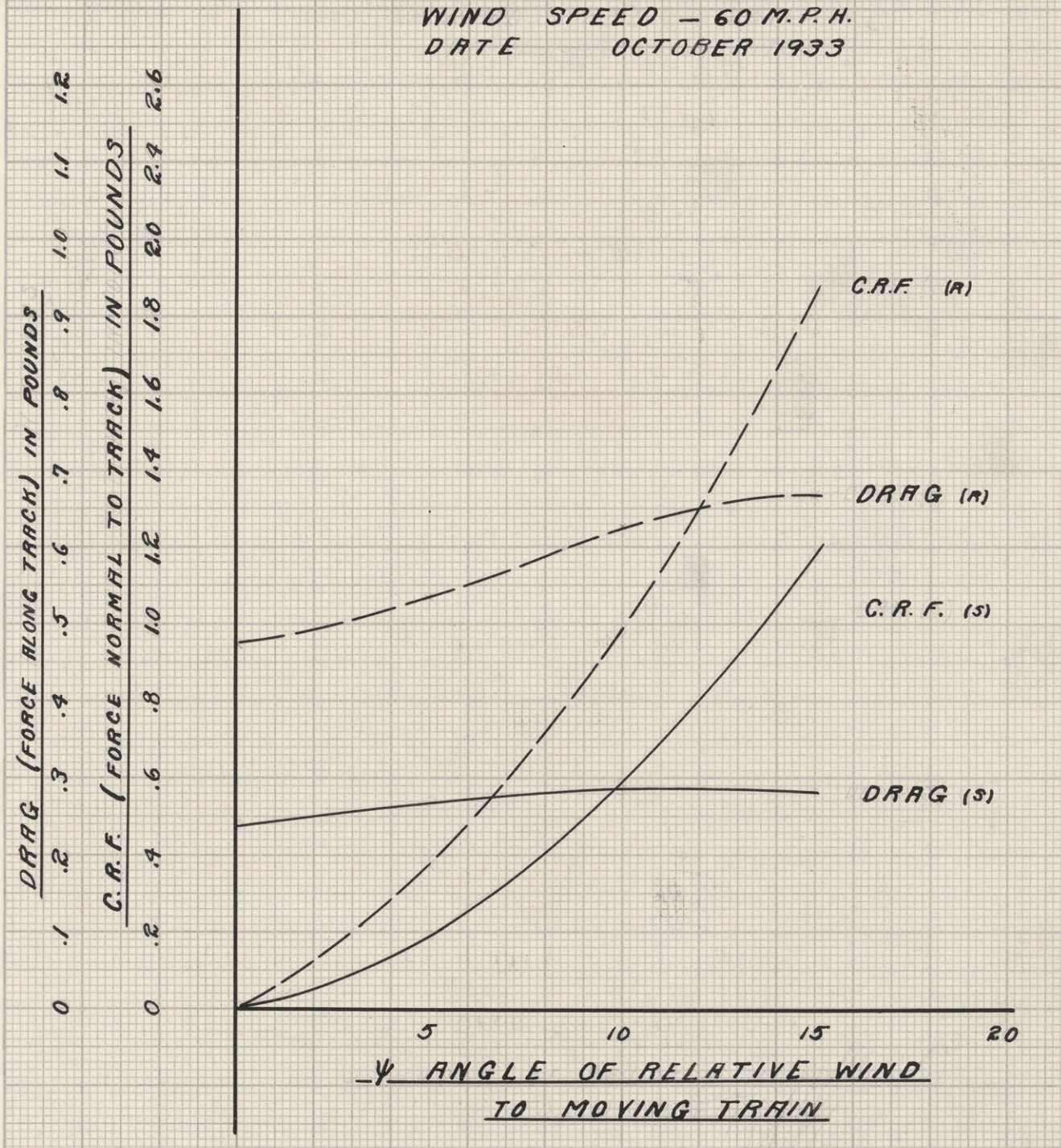
AERODYNAMIC FORCES ON TRAIN MODELS
(MODELS CORRECTED TO SAME SCALE.)

EDWARD G. BUDD MANUFACTURING CO.

RAIL TRAIN MODEL TESTS

TESTED M.I.T. 5FT. TUNNEL

WIND SPEED — 60 M.P.H.
DATE OCTOBER 1933



(S) — STREAMLINED MODEL
(R) — REGULAR TRAIN MODEL