This thesis is submitted in canicy for a B.Des in industrial Design at the National College of Art and Design,

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Dublin 8.

Now You're Sucking Diesel

-A Design History of the American Diesel Locomotive

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SYNOPSIS

In America, the Steam Locomotive evolved to a general type that became known as The American Standard. This type, with is four coupled driving wheels and four undriven pilot wheels, cow-catcher, broad chimney, bell and cab for the crew, is one of the earliest pieces of distinctive American Engineering Design. Since then, American Locomotive design has always been distinctive and the diesel form which has evolved over 40 years, 1930 to 1970, is one of the strongest statements of functionalism and brutalism in non-military design this Century. The aim of this thesis is to investigate the American diesel locomotive from three particular angles; history, design, and related imagery.

The history of the diesel locomotive is broken into three eras:

(i) Streamlined articulated unit trains (1934 - 1938), which draw their imagery primarily from the aircraft of the day (esp. Zeppelins).

(ii) Streamline locomotives (1937-1963), which have strong links with the automotive form.

(iii) Road switchers (1945 to present day), which draw on brutal machine imagery and are functional in the extreme.

Applied colour is discussed as a barometer of the changing public perception of locomotives and to illustrate the publicly perceived gulf between the roles of passenger and freight locomotives.

1. PETROL RAILCARS

By the end of the 19th Century American Railroad Companies were beginning to realise the limitations of the Steam Engine. Although the technology was simple, the size of the facilities and the size of the workforce necessary to build a full size steam locomotive were enormous. In 1901, eight companies joined to form Alco, the American Locomotive Company. By 1918, there were only three companies large enough to deal with mainline steam locomotive building: Alco, Baldwin and Lima.[1]

It was on the branch-lines that the death of steam started. In 1890, a railcar powered by an 18 h.p. gasoline engine via a 12 kilowatt generator and battery was demonstrated.[2] The idea was taken up by the Union Pacific Railroad in 1905 for branchline and suburban services.[3] These vehicles were essentially railway cars with a gasoline engine mounted on one of the bogies. They operated individually, or sometimes pulling a baggage car or another passenger car. Their great advantage lay in their simplicity and the simplicity of the facilities needed to build them. They did not need enormous cast steel underframes nor five foot diameter forged wheels. They were built by General Electric and by Union Pacific in

1 Gordon, *Trains*, P.49

2 Bush, *Streamline Decade*, P.57

3 Tufnell, *Railway Locomotives*, P.32

their own workshops from mostly stock material.[4] In operation they showed more of the advantages that would come with bogie. For Union Pacific the most important of these was complete independence from water supplies. This meant that ageing water towers on remote branch-lines could be done away with. By 1913, Union Pacific had 138 of these machines in operation.[5]

4 Tufnell, *Railway Locomotives*, P.32

5 Bush, *Streamline Decade*, P.57

2. STREAMLINERS

During the 1930's the world, especially America, was preoccupied with streamlining. It was the great white hope of the decade, what would wipe away the Depression. Aerodynamics was a new science in 1930 and was far from fully understood. From this mathematically complex black art was derived the common man's cureall - streamlining. Streamlining, for the most part was a non-science based on simple empirical ideas that reflected the hi-tech shapes of the day.

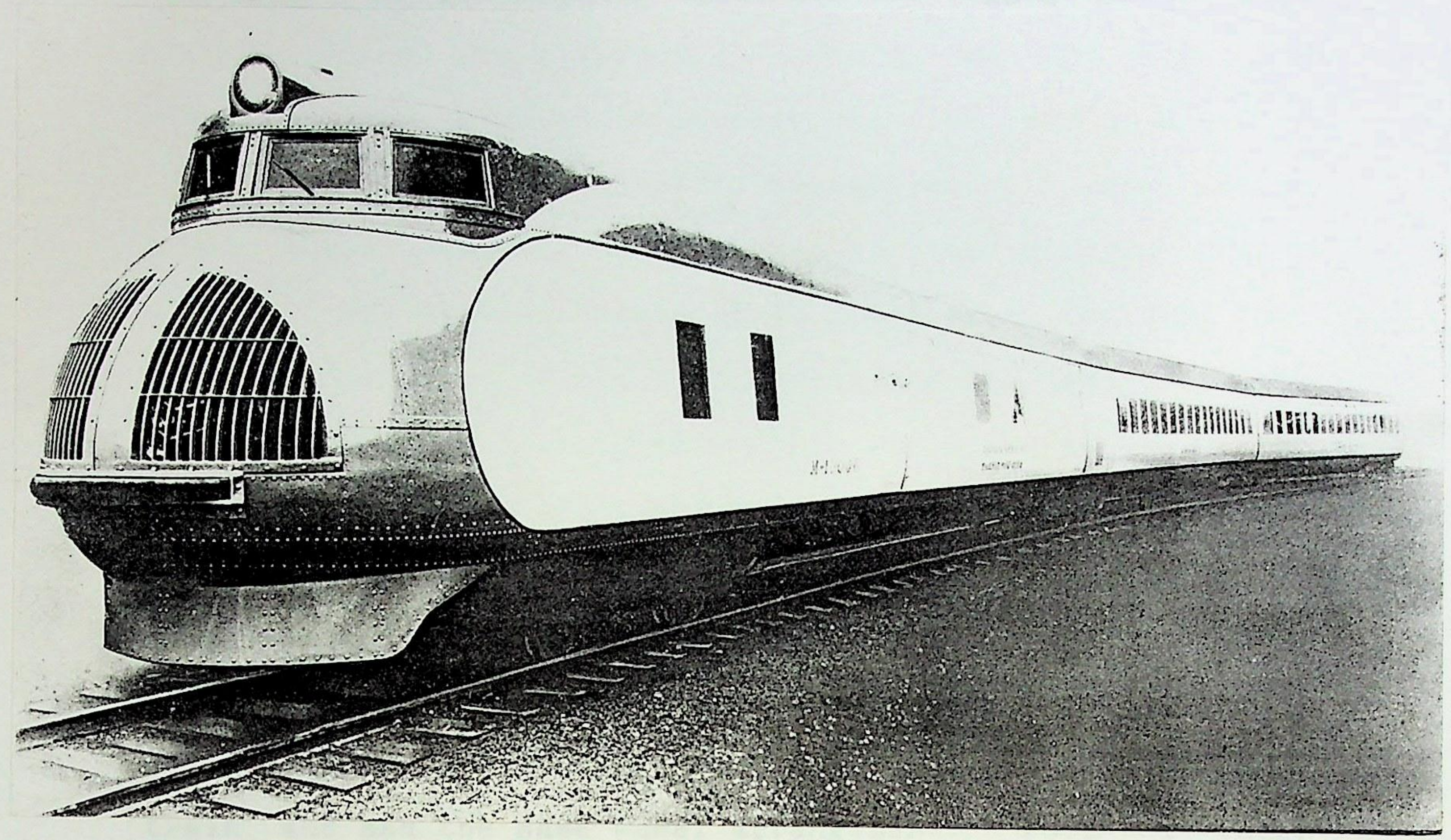
By 1933, the American Railway Association had bitten the 'streamline bait'. This was probably in response to the threat posed by the 1929 *Ford Trimotor* Airliner (this was a threat that would eventually come to life and destroy the passenger train in North America).[6]

Again, it was Union Pacific who set the pace. The *City of Salina* was delivered to them by Pullman in February 1934.[7] This vehicle was a unit train, i.e., its elements were inseparable from one another. It consisted of three cars, a combined power/baggage car and two passenger cars. Each car shared a set of wheels with its neighbour and the gaps between them were closed by rubber sheeting.[8] Each passenger

6 The first Trans-Continental passenger air-service was initiated during 1929, using a Ford Trimotor.

7 Bush, *Streamline Decade*, P.62

8 Lowey, *Locomotive*, P. 104



City of Salina,1934(streamline decade) car had accomodation for 72 in all forwards facing seating.[9] The power car provided accomodation for baggage and a post office. Power was provided by a Winton 201 600 h.p. V12 diesel engine, mounted integrally with the leading bogie.[10] This drove through an electric transmission.[11] The entire power bogie assembly was supplied by the Electro Motive Division of General Motors.[12] The Engineer (driver) sat above and forward of the power bogie and had an excellent view over the radiator intake. This was followed two months later by the Chicago, Burlington and Quincy railroads *Pioneer Zephyr.*[13] *Pioneer Zephyr* was an essentially similar unit train to the *City of Salina* created by the E.G. Budd Manufacturing Corporation.[14] It was driven by the same Electro Motive Division power bogie as the Union Pacific train and had the same wheel arrangement.[15] Four of these trains were eventually built, the final one, the *Mark Twain Zephyr* consisted of five cars with accomodation for 368 (compared with 144 on the *Pioneer*) propelled by an 800 h.p.

9 Allen, *Modern Railways the World Over*, P.27

10 Allen, *Modern Railways the World Over*, P. 28

11 Tufnell, *Railway Locomotives*, P. 238

12 Hollingsworth, *Modern Trains*, P.20

13 Allen, *Modern Railways the World Over*, P.27

14 Bush, *Streamline Decade*, P.64

15 Allen, *Modern Railways the World Over*, P.27

engine.[16]

These trains were quick. Union Pacific claimed a top speed of 110 m.p.h. and a cruising speed of 90 m.p.h.[17] On the 18 April 1934 *Pioneer Zephyr* covered 1,015 miles from Denver to Chicago in 13 hours 4 minutes - an average speed of 77.6 m.p.h.[18]

The American public was craving for speed and many railroads rushed trains of the *Zephyr* and *City of Salina* pattern into service. But, while the public were now happy, the railroads could see the lightweight *Zephyr's* limitations. Prime among these was that it was an indivisable, articulated unit. Since each coach shared a bogie with its neighbour, if the power plant was defective or there was any problem with any one part of the train, the whole train was out of action. The coaches could not be separated and attached to another locomotive.

16 Whitehouse, *Great Trains of the World*, P.27

17 Bush, *Streamline Decade*, P. 63

18 Allen, *Modern Railways the World Over*, P.27

3. SUPER CHIEF

The Atchison, Topeka and Santa Fe Railroad's finest passenger train, the *Super Chief*, ran between Chicago and Los Angeles. This train took over from the steam powered *Chief* early in 1936 and was intended to compete in performance and appearance with the new generation of streamliners.[19] The Santa Fe had good reason to adopt diesel power for this new service. It shares with the Chicago, Milwaukee, St. Paul and Pacific ('Milwaukee') Railroad, the distinction of owing its own tracks the entire way from Chicago to Los Angeles.[20] The route goes South from Chicago through Kansas City, Albuquerque, across Arizona and the Mohave Desert and into Los Angeles.[21] Water is in short supply along almost half of the 2,227 miles.[22] This had two effects. Firstly, the Santa Fe were unable to run any of their really fast or powerful steam locomotives - their water consumption would have been enormous (the New York Central's *20th Century Limited* used about 45,000 gallons on its 950 mile run from New York to Chicago[23]). This would have hit the Santa Fe pretty badly, since there were four passes of over 7,000 ft. on their

19 Bush, *The Streamline Decade*, P.81 - 83

20 Whitehouse, *Great Trains*, P.129

21 Taylor, *A Railway Atlas of America*, P. 31

22 Whitehouse, *Great Trains*, P. 129

23 Hollingsworth, *Modern Trains*, P. 17

route through the Rockies.[24] Secondly, in the early 30's, the Santa Fe had to haul and store millions of gallons of water at a cost of 40 cents per 1,000 gallons. Often locally available water was unusable because it caused corrosion or excessive lime-scaling in the boiler tubes.[25]

The Santa Fe tackled diesel power in a different way to the Burlington or Union Pacific. With the benefit of hindsight, they saw the problems of the unit train. Also, the Santa Fe, being a bit late off the mark, found it difficult to get either Budd or Pullman to take their order.[26] Furthermore, they had plenty of perfectly adequate stock which had been pulled by their steam locomotives.

In early 1935, an order was placed with EMD (The Company that had built the power bogies for the unit trains) for two mainline diesel locomotive sets.[27] The resulting locomotives were the Mammy and Daddy of all modern diesel electric locomotives.

24 Whitehouse, *Great Trains*, P. 129

25 Bush, *Streamline Decade*, P. 81 - 83
Allen, *Modern Railways the World Over*, P. 14

26 Allen, *Modern Railways the World Over*, P. 28

27 Tufnell, *Railway Locomotives*, P. 241

4. DIESEL

The compression-ignition engine has taken its name from Rudolph Diesel (1858 - 1913). It uses a heavy oil which, for many years, was one of the cheapest products of petroleum distillation (the grade of diesel oil large engines ran on in 1930 cost one farthing a gallon, i.e., about one cent[28]). It gives far more torque in the low speed range than a gasoline or kerosene engine. Instead of a mixture of vaporized liquid and air, the cylinder is charged with clean air. No spark is needed, as the fuel, which has to be injected into the cylinder at extremely high pressure, is ignited by the heat of the air as it is compressed by the piston. Because no fuel is mixed with the air before compression, the diesel engine is particularly suited to two-stroke operation. This allows twice as much power to be produced, compared with the same size four-stroke engine. In addition, these engines can do away with a lot of valves, camshafts and other wearing parts. A diesel engine, like all internal combustion engines uses inertia to sustain its operation. It must, therefore, be able to turn over free of any connection to the locomotive's road wheels while it is stationary. A connection, however, is needed to transmit the effort from the engine smoothly to the wheels when the locomotive is required to move. EMD chose an electric transmission to do this job. Their locomotives and power

28 O'Neill, H., Conversation, March 1990

bogies used the diesel engine to drive a large generator (later versions used an alternator for greater reliability and efficiency). This produced direct current at about 600 volts (this is a standard for railways; the London Underground and several other electric railways use this voltage), which was used to drive electric motors geared directly to the driven axles.[29]

This system has several advantages over its competitors (hydraulic and mechanical transmissions were popular in Europe; hydraulic was expensive, compact and efficient; mechanical, popular in Britain, was hugely expensive, unreliable, heavy and hard on rails). Among these advantages are simplicity and cost effectiveness. Disadvantages were weight and size.

[29] Hollingsworth, *Modern Trains*, P. 85

5. EMD

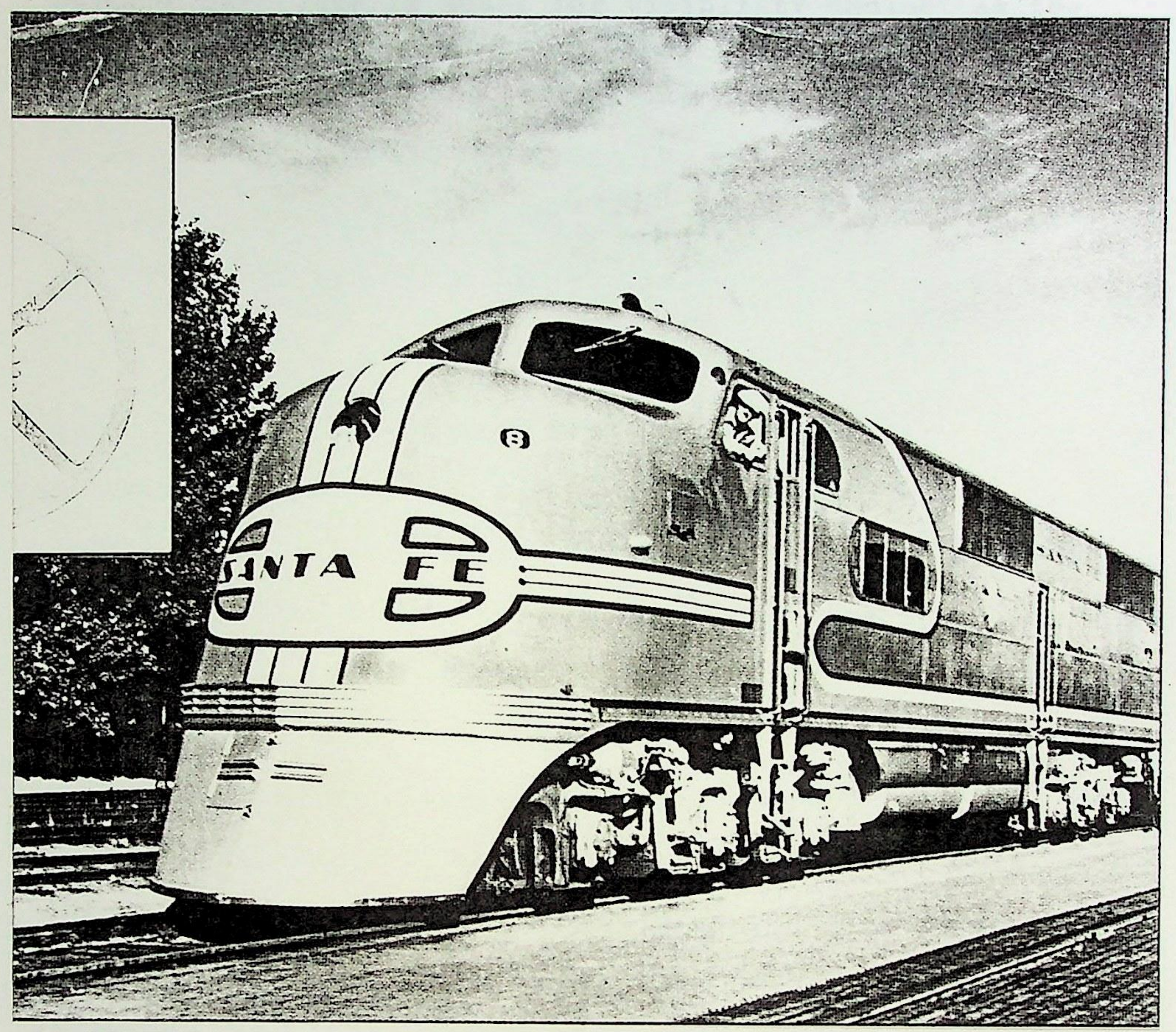
In 1930 the General Motors Corporation made two purchases which were to have dramatic effects on the American Locomotive scent; the first of these was the Winton Engine Company, a builder specialising in lightweight diesel engines. The second was Winton's chief customer, The Electro Motive Corporation, established in 1922 to design and market petrol-electric and diesel-electric rail cars, of which it sold 500 units in ten years.[30]

With the engine-building facilities and the expertise acquired in these purchases, G.M's new Electro Motive Divison (EMD) was a major partner in the streamlined trains of 1934. The following year they produced four mainline diesel locomotives for Santa Fe. These *D1A* locomotives were powered by two Winton 201E 900 h.p. engines and were of Bo-Bo configuration[31] (see Appendix A for a full explanation of wheel arrangement notation). They operated in two lots of two locomotive 'sets', each set producing 3,600 h.p. Like the stock of the *Super Chief* they hauled, they were only an interim solution. They were erected by the Baldwin Locomotive Works and consisted of two enormous chasis rails, on to which was built a rectangular boxcar shaped body.[32] Raymond Lowey described them thus:

30 Hollingsworth, *Modern Trains*, P, 20

31 Allen, *Modern Railways the World Over*, P. 28

32 Foxx, C.J. Telephone conversation, March 1990



General Motors, *E1A*, 1936 (Modern Railways)

America's most powerful diesel electric engine, greatly handicapped by a rather dreadful design treatment. The baroque camoflage is meant for visibility and act as the 'coup de grace' to a design already painful.[33]

In an attempt to give the vehicles some sort of character, a grotesque fairing was fitted over the engineer's position. This probably made them the worst looking railway engineer's of all time.

In 1936, EMD moved into its own purpose-built works at LaGrange, Illinois, and work commenced on the next locomotives. These were the first of the *E* series, also known as the Streamline Series. Like the four earlier locomotives, they had two 900 h.p. Winton engines, but the chassis and body were completely new.[34] The body had its main load-bearing strength in two bridge type girders, which formed the sides. To this, the skin of the vehicle was rigidly attached, contributing to the overall strength and rigidity of the machine. For major servicing, the engines could be extracted after removing a series of panels in the roof after removing the 300 odd screws which were used to retain the panels in place - they also were part of the

33 Lowey, *Locomotive*, P. 119

34 Hollingsworth, *Modern Trains*, P. 21

Roof panel of Metrovic locomotive showing screw holes (Author) structure.[35]

The bogies had three axles to give greater stability at high speeds and to spread loads on rails, but as four motors were needed, the centre axle of each bogie was an idler, giving a wheel arrangement of A1A-A1A. They weighed around 140 tons.[36]

The locomotives were produced in two versions, *A* units with a driver's cab and *B* units without. The Santa Fe was the launch customer, buying eight *E1A's* and three *E1B's*. They were used in pairs, one *A* and one *B*, to haul the all new streamlined *Super Chief* of 1936. This train was designed by architect, Paul Cret, and was built by E.G. Budd. Cret had previously designed the Burlington *Zephyr* train sets, also built by Budd.[37]

Other purchasers of these early EMD's were:

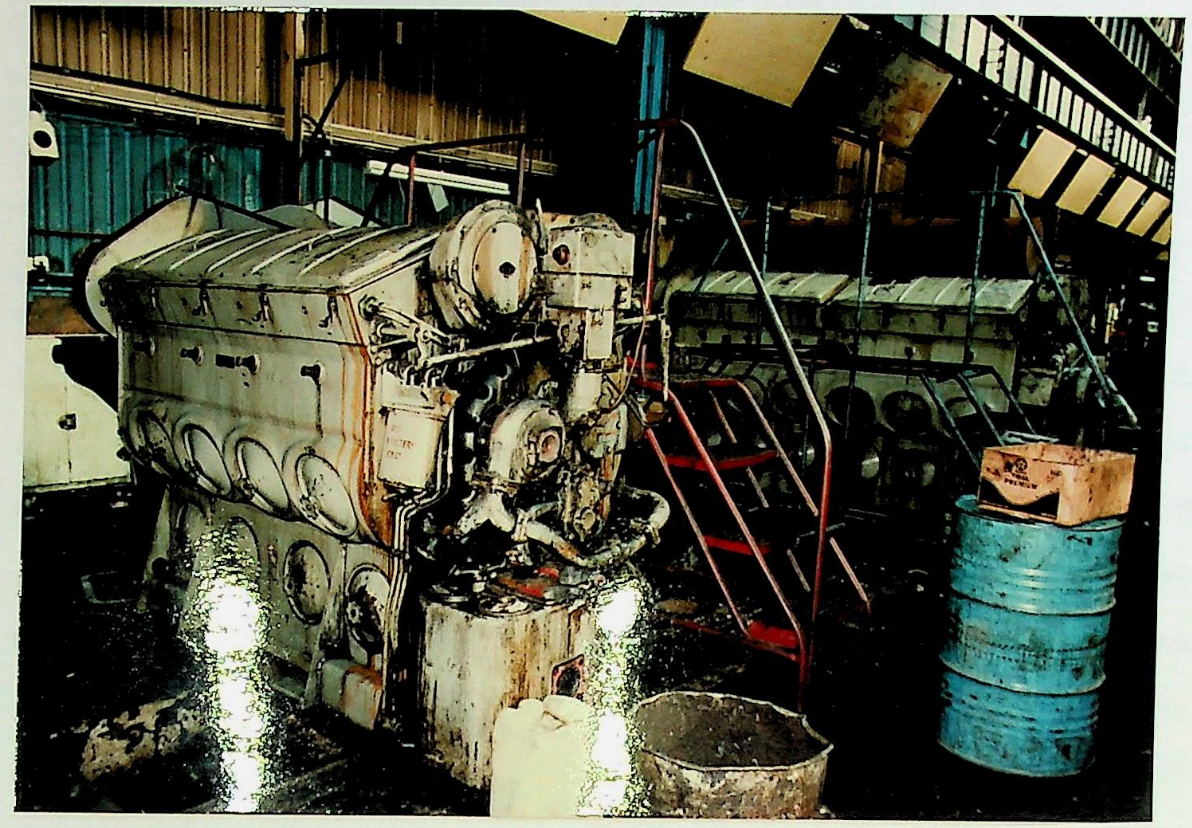
The Baltimore & Ohio (six *E3A's* and six *E3B's*, operated in 3,600 h.p. pairs, pulling the new *Denver Zephyrs* and the *General Pershing Zephyr*)

The City Streamliner Road (two *E2A's* and four *E2B's*, operated in two A-B-B sets, hauling the *The City of Los Angeles* and *The City of San Francisco* and were the most powerful locomotive sets in the world in 1937, at 5,400

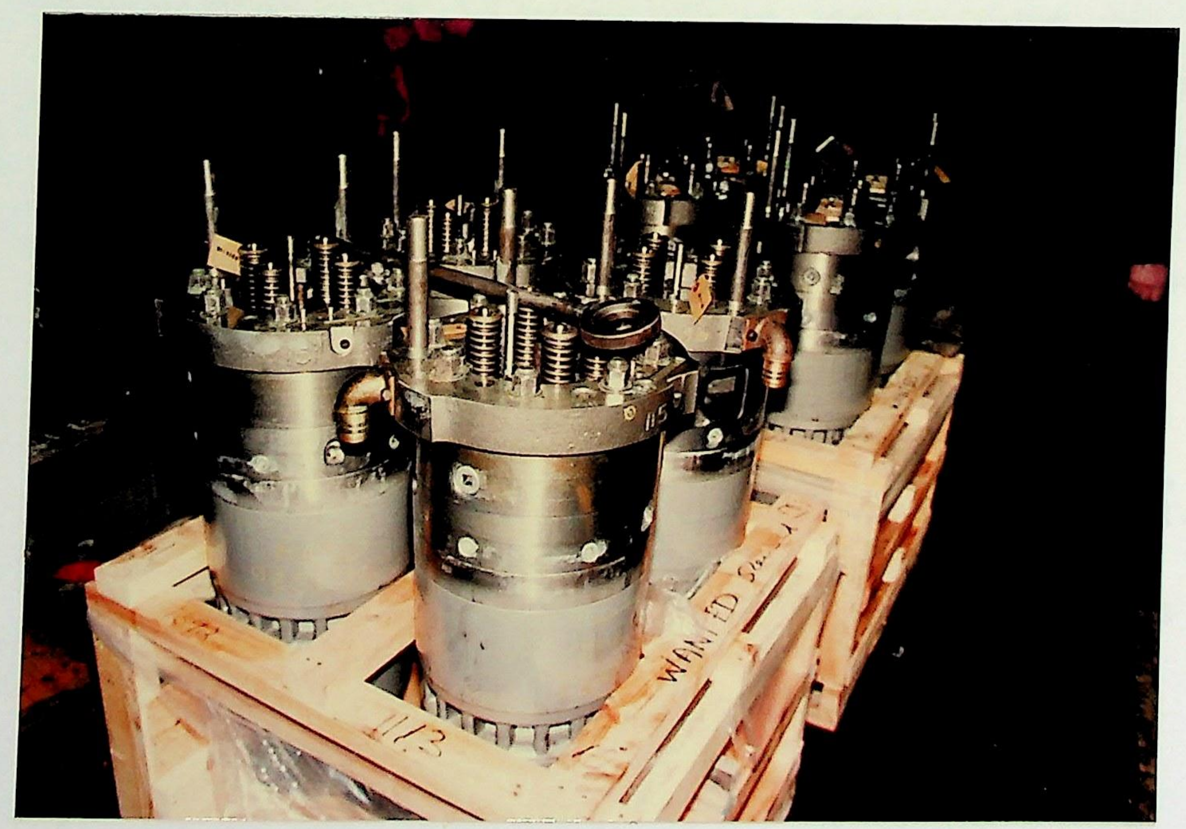
35 Conroy, V. Conversations, January - March 1990

36 Hollingsworth, *Modern Trains*, P. 20

37 Bush, *Streamline Decade*, P. 84



EMD, *567* V-8 and V-12, (Author)



EMD, *567* head/barel/piston/con-rod assemblies Author) h.p.[38]

All these locomotives were an immediate success, not only by their performances, but also by their tiny servicing needs. In multiple unit working, it was possible for some maintenance to be done 'on the road' on the easier stretches, when one engine could be shut down.[39] With servicing assisted in this way, some remarkable feats of endurance were achieved. One of the Baltimore & Ohio's A-B sets completed 365 days of continuous service between Washington and Chicago, covering 282,000 miles. This represents an average speed, including all stops, servicing and bedtime, of 32 m.p.h.[40] This figure was just about beaten by the king of all express passenger steam locomotives, the New York Central's 450 ton, 6,500 h.p. *Niagara* class. One of these achieved 305,000 miles during 1947.[41] EMD's progress was rapid. At 900 h.p. the Winton Engine had reached its limit and a new engine was developed. Called the *567* (the capacity of a cylinder in cubic inches, about 9.5 litres), it was of modular design and was built in eight, twelve and sixteen cylinder versions of 600, 1,000

38 Hollingsworth, *Modern Trains,* P. 23 - 23
Whitehouse, *Great Trains,* P. 27

39 I pity anyone who has had to do this! Inside the engine room of a C.I.E. Metrovick *everything* is covered in oil. Both hearing and standing are impossible.

40 Marshall, *Guinness Book of Rail Facts and Feats,* P. 149

41 Hollingsworth, *Great Trains,* P. 12

General Motors, *E6*, (Modern Trains)

General Motors, *F7*, (Modern Trains)

Mechanic servicing Metrovick, (Author)

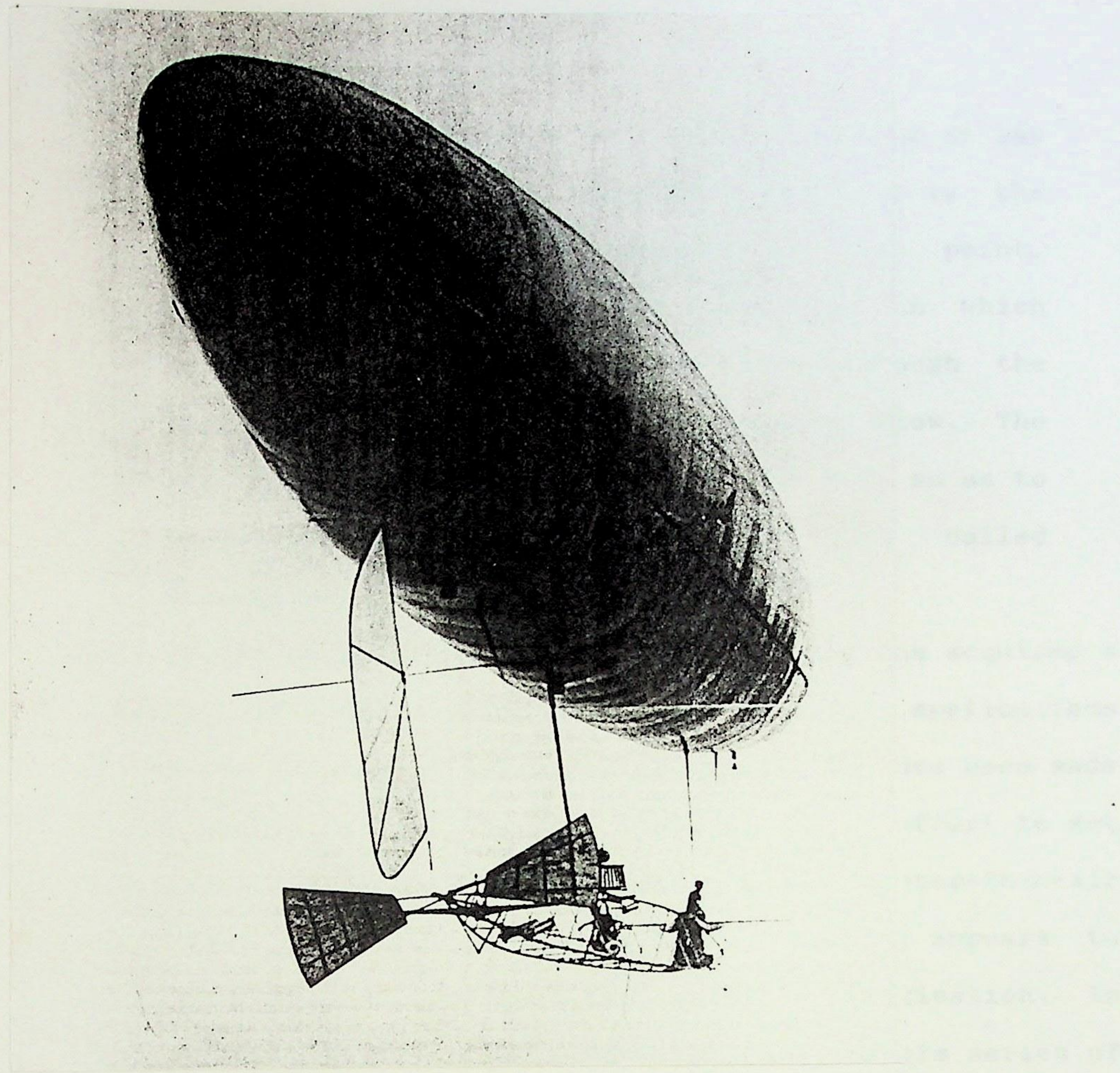
and 1,350 h.p. respectively.[42] At the same time, EMD began to manufacture their own generators, motors and electrical control equipment. This had previously been supplied by General Electric. Until 1939, each railroad's order had incorporated some individual variations - hence the different designations - but EMD aimed to gain the maximum benefits from production line assembly. To this end, individual variations were discouraged. The first of the standard series was the *E6*, which appeared in March 1939. By February 1942, when production was halted by the War Production Board, 118 more or less identical locomotives had been built.[43] In 1939, EMD realised that what the streamliner was doing for the express passenger trains image, it could also do for the freight trains and with the inherent flexibility of the diesel electric locomotive, a true mixed traffic, i.e., freight or passenger locomotive, was possible. Steam locomotives were hopelessly inflexible; passenger locomotives cannot pull heavy freight trains and freight engines run out of steam at 40 m.p.h. The resulting *F* series locomotives were essential similar to the *E* series, the main differences being mechanical (a single 16 cylinder version of the *567* engine and a Bo-Bo wheel arrangement), and a slight change in the nose profile. They retained a streamlined 'monocoque' or 'carbody' type construction, but

42 Tufnell, *Railway Locomotives*, P. 241

43 Whitehouse, *Modern Locomotives*, P. 49

were quite a bit shorter and lighter.[44]

[44] Hollingsworth, *Modern Trains*, P. 11



Alberto Samtos-Dumont, *Airship 2*, (Illustrated History of Aircraft)

6. POST WAR STREAMLINERS

> 'A streamline is a line in a fluid such that at any point in the fluid the tangent to the line is the direction of the fluid's velocity at that point. From this, one can say that fluid flow in which continuous streamlines can be drawn through the fluid about a body is called Streamline Flow. The practice of optimising the shape of a body so as to promote streamline flow about it, is called Streamlining.[45]

As a design principle, however, streamlining has acquired a slightly different meaning. The first practical applications of the new science of Aerodynamics appears to have been made in the second half of the 19th Century, in an effort to get heavier-than-air craft to fly and to make lighter-than-air craft more controllable. It was the latter that appears to have had the most impact on the public's imagination. In 1898, Alberto Santos-Dumont, flew the first of his series of Airships over the Paris suburb of Neuilly-St.James. The 25 metre cigars became a familiar sight over Paris during the following ten years.[46] About the same time, Graf Ferdinand von Zeppelin, built the first of his metal framed dirigible airships. By 1914, the Zeppelin Company was operating scheduled passenger services between major German Cities. In

45 Dainth, (Ed) *Dictionary of Physical Sciences*

46 Gallagher, *An Illustrated History of Aircraft*, P. 31

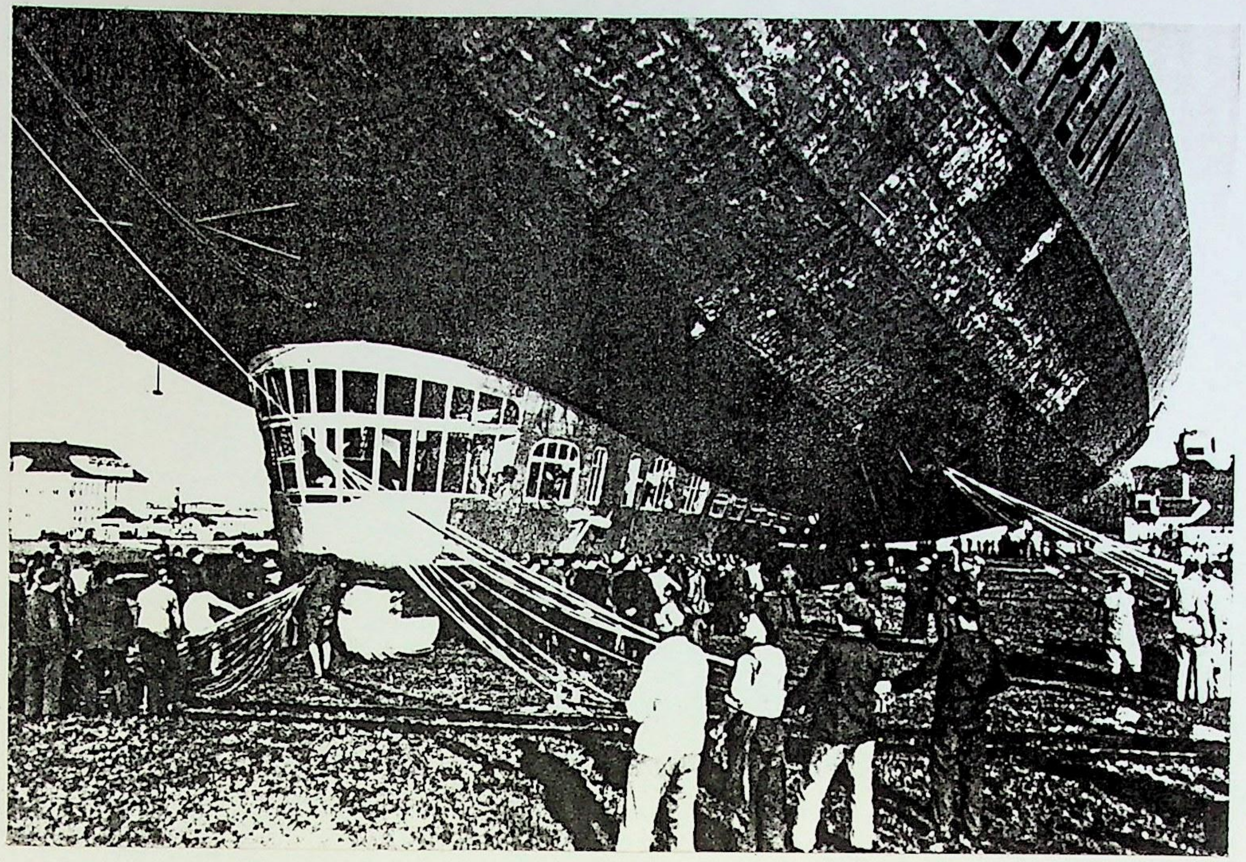
Douglas, *DC-2*, (U.S. Air Force Colours)

the late 1920's and early 1930's, Zeppelins were *the* way to travel long distances. They were fast, luxurious and had a new image. They were aped everywhere, even by aeroplanes. 'Rocket Ships' of the Flash Gordon era were Zeppelins with flames and sparks. The name 'Zeppelin' was very much associated with innovative technology in the 1920's and 1930's, as they were among the world leaders in the use of aluminium.

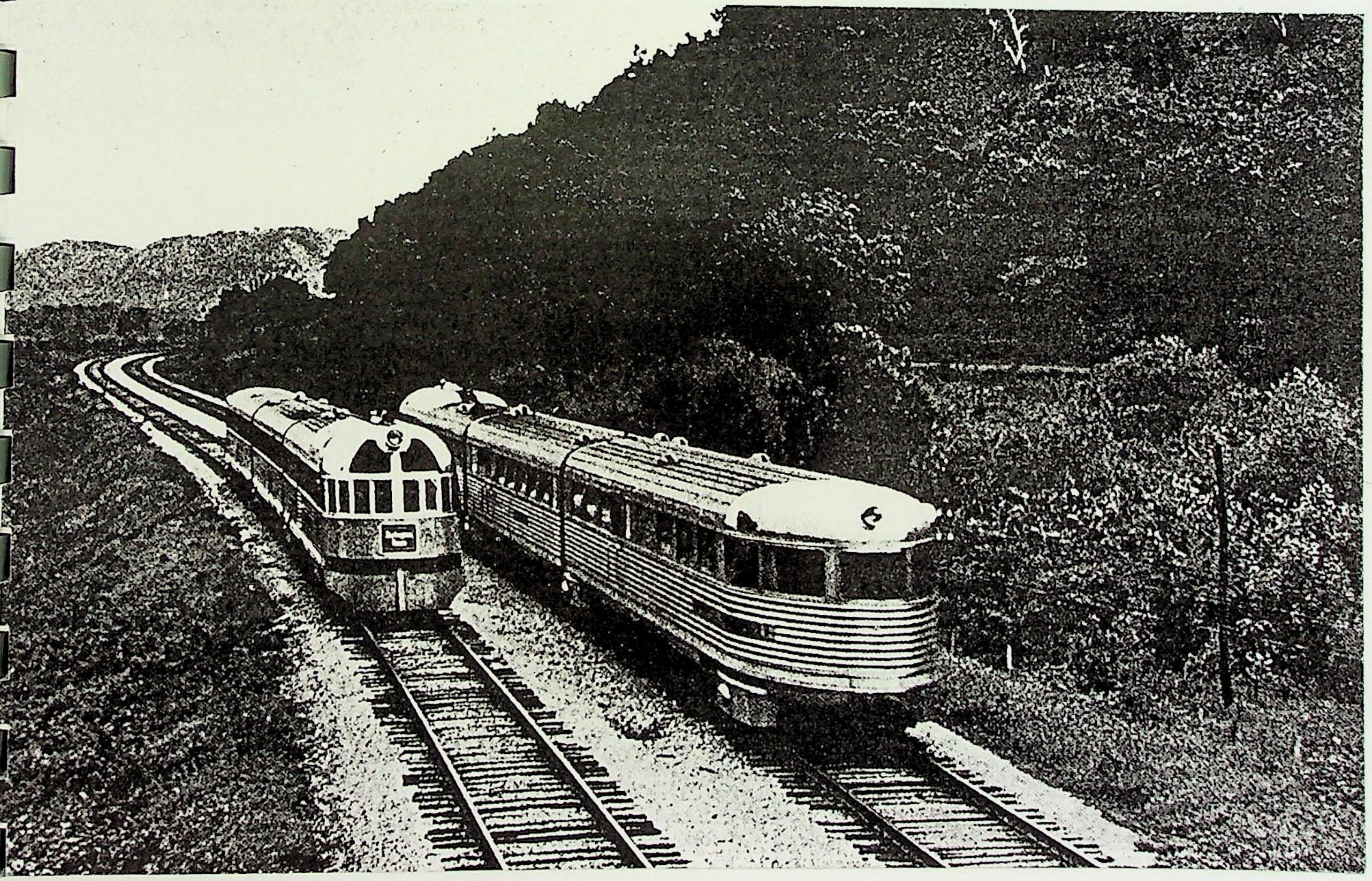
Aluminium was unknown as an engineering material before the advent of cheap industrial electricity (c.1890), as it requires vast quantities of electricity for its production.[47] As a 'new' material, it was seen as a panacea (in much the same way as carbon fibre is seen to-day). It did not corrode or tarnish and had a bright silver appearance. When aluminium powder was added to dope for painting fabric surfaces on aircraft, it was found to prolong the life of the fabric.[48] This was pretty neat, as wood and fabric aeroplanes were instantly indistinguishable from their hi-tech aluminium sisters. This bare metal 'Silver Dream Machine' survived as a hi-tech image right into the 1960's. All this was in strong contrast to the soot and grease, cast iron and steel, and general Christmas tree appearance of a 1930 American Steam-hauled express train. When improvements in aeroplanes, airport lighting and

47 Aluminium Ore is reduced by Electrolysis

48 Bell, *U.S. Air Force Colours, 1926 - 1942*, P. 28

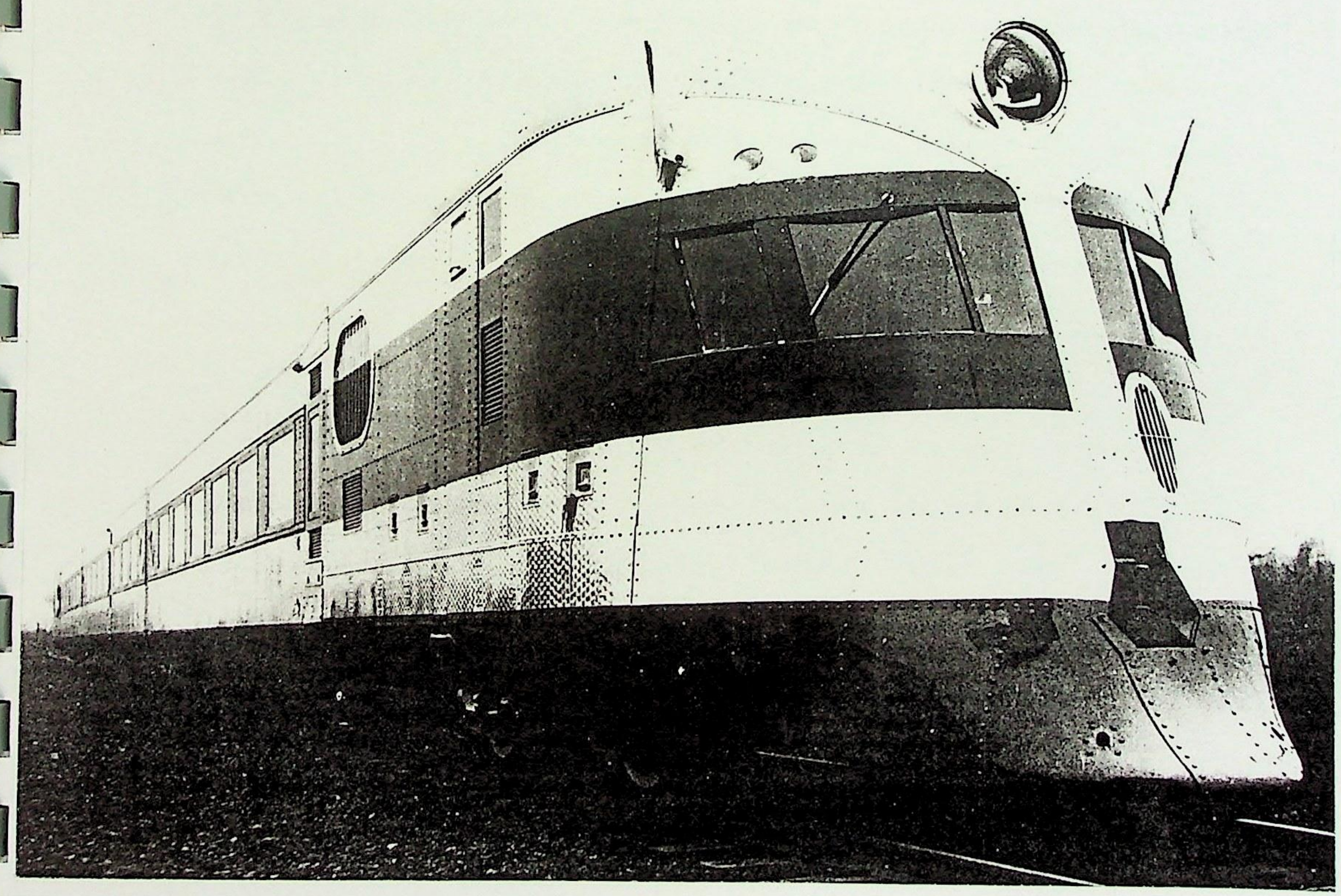


Zeppelin-Straken K.G., *Graf Zeppelin*, (Diamonds in the Sky)



E.G.Budd, *Burlington Zephyr*, (The Locomotive)

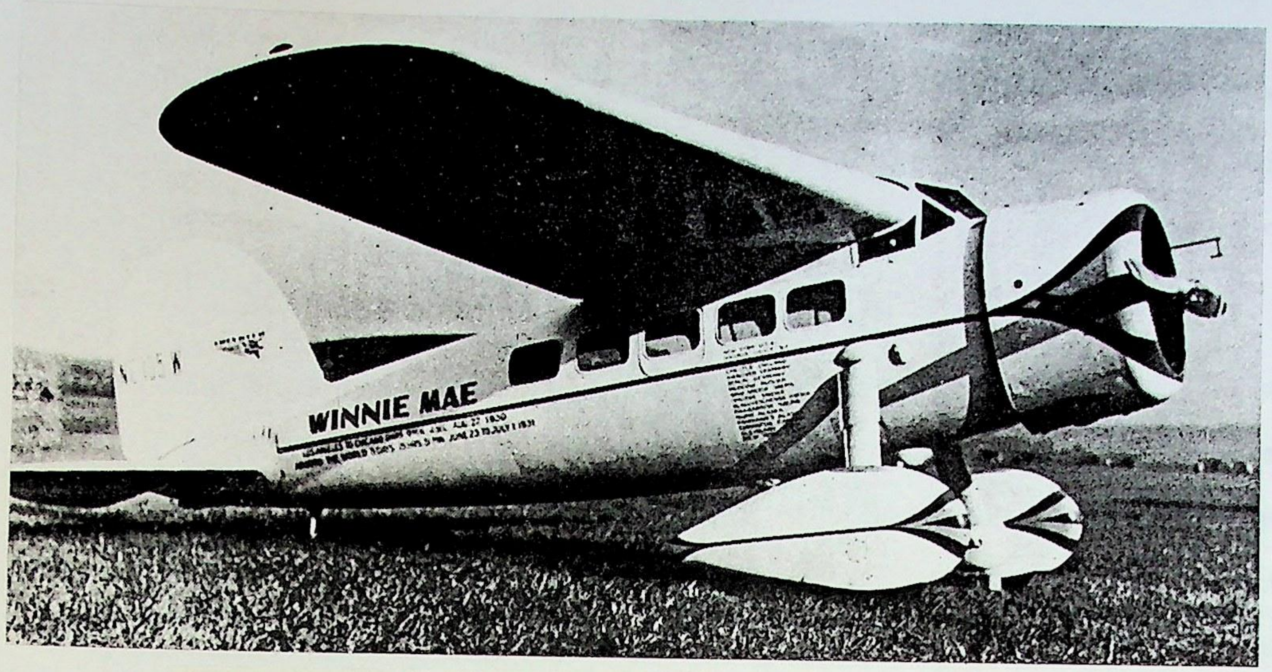
General Electric, *D18B*, (modern Railways)



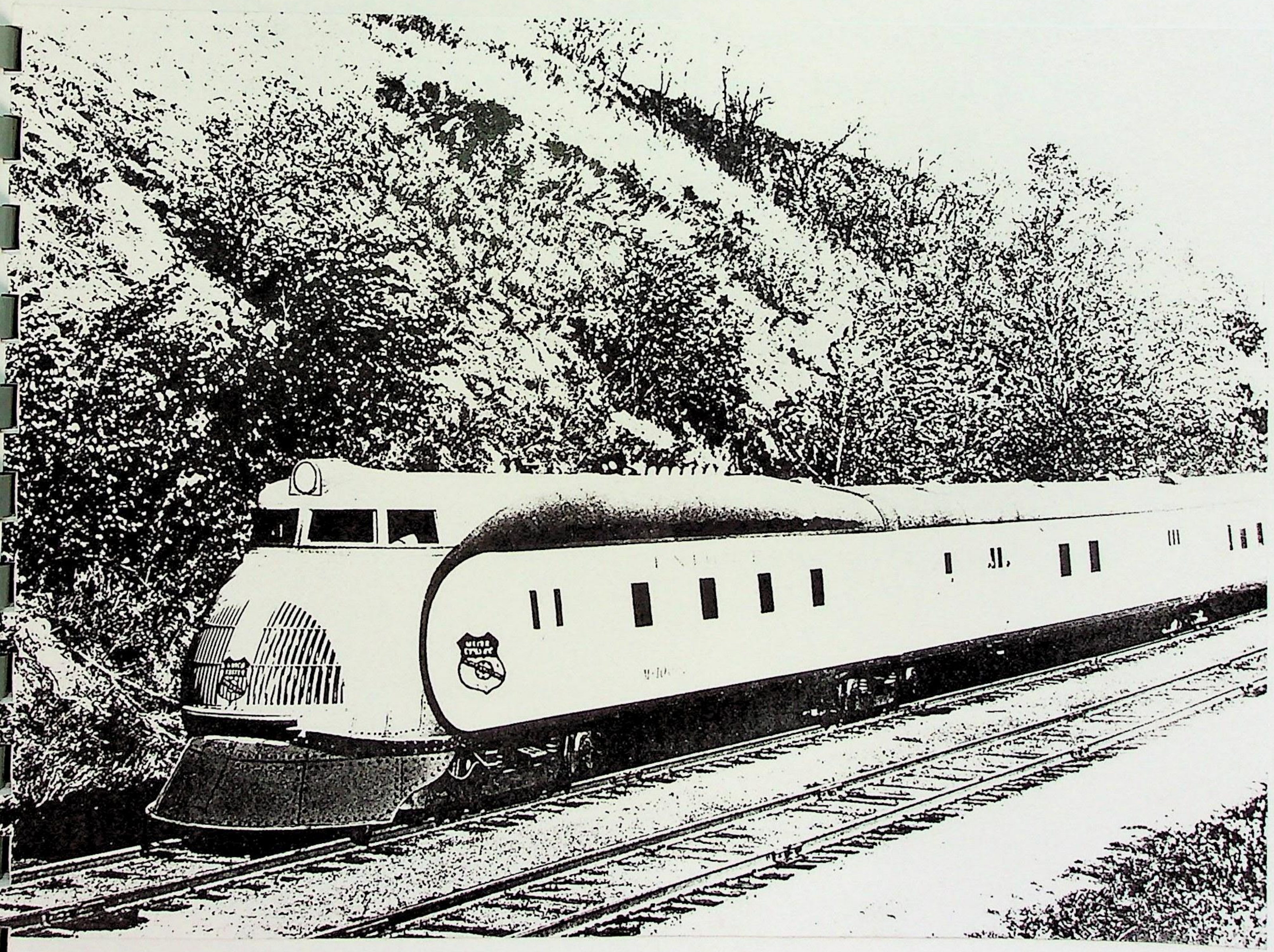
Goodyear Zeppelin, *Comet*, (Streamline decade) navigation equipment made commercial air transport a reality in the early part of the 1930's, forcing railways to compete, they were quick to borrow the Zeppelin image. E.G. Budd's Burlington *Zephyr* was little more than an upturned gondola, complete with hi-tech silver (stainless steel) colouring.

The New York, New Haven and Hartford Railway, was very conscious of the 'Vorsprung durch Technic' image and they chose Zeppelin's American licensee's Good Year, to design and build their streamliner. Not only did it have the name (The Goodyear-Zeppelin Corporation) and the shape, it was also made of the magic material, Aluminium. Perhaps because of the functional no compromise background of the Zeppelin idiom, trains styled in that manner lacked a sense of character. In 1937 Raymond Lowey described the Goodyear *Comet* as having 'an uninviting front end' and the *Zephyr's* appearance as 'far from satisfactory'.[49] In spite of this, the tarnishing of the German image and the destruction of the Hindenburg in 1937, the Gondola form persisted into the late 1940's, though mainly for export. A different sort of front end treatment was chosen for the Union Pacific's *City of Salina*. It's more complicated front end treatment incorporated a large cooling air-intake below the level of the engineer's position. Initially, it bore a close

49 Lowey, *Locomotive*, P. 116



Lockheed, 1928 (Flight



General Motors, M-10,001, (Encyclopaedia of Locomotives) resemblance to the Lockheed *Vega*, a record breaking aircraft of the late 1920's, with its broad rounded nose and high control position. Bulged shoulders of the locomotive echoed the high wing of the *Vega*.

The original *M-10,000* version of the *City of Salina* was quickly replaced by the *M-10,001* which featured more power, more cars and slightly different nose contours.[50] It was felt necessary to fit a much enlarged cow catcher, which did not integrate particularly well with the rest. In 1936, EMD (who had done the re-design work on the *M-10,001* power car) and Pullman Standard, built a mechanically identical train, *The Green Diamond* for Illinois Central Railroad.[51] Visually, there was an attempt to integrate the cow-catcher with a new slanting grill. The window arrangement also changed. The panoramic arrangement was replaced by a front and sides, automobile style. The split screen had been borrowed by the automobile industry from the new generation of air-liners of the mid 1930's. For their own *E* Class, also of 1936, EMD removed the cooling intakes from the nose, further integrated the cow-catcher into the hood and replaced the unicorn headlamp with one buried in the hood. This form drew heavily on the automobile styling of the day and was, in turn, to influence the form of that industry's output for the next 20 years.

50 Tufnell, *Railway Locomotives*, P. 238

51 Bush, *Streamline Decade*, P. 95

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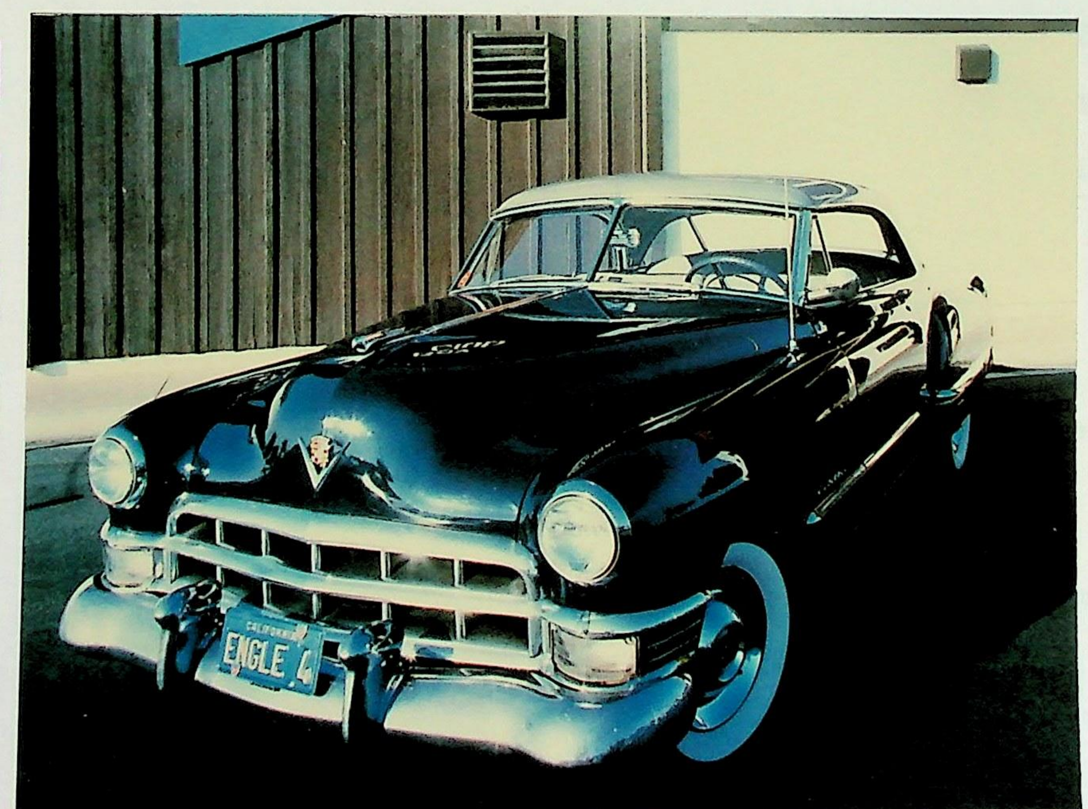
19 Tufnell, Railway Locomotives, P. 238
11 Bush, Streamline Decade, P. 95



^ label

The final change to this form came with EMD's mixed traffic *F* Class in 1939, when the headlight was given a raised surround and the front of the body had its slope changed from 70 to 80 . The rake on the windscreen remained at 70 . This form was adopted for the *E* Class when production re-started in 1945 and remained essentially unchanged until production ceased in 1957 (*F9*) and 1963 (*E9*)[52]

The method of construction of the General Motors' *E's* and *F's* owes a lot to the streamline ethic. Just as the ideal form has no unnecessary complications or additions (these cause parasitic drag in aerodynamics) and ideal construction should have no parasitic elements. By using the aerodynamic skin of the locomotive as an element in the structure, it becomes more than 'nice' cladding, it shares the loads. In many ways, this is how the streamline steam locomotives of the late 1930's fell down. Their aerodynamic exteriors were just cladding and contributed nothing to the function of the locomotive. Norman Zapf claimed in his 1934 thesis that streamlining a 75 m.p.h. passenger train would reduce drag by 91%.[53] This could not, however, be put to much use, as these large locomotives (up to 400 tons) were already speed limited by the rails they ran on. The extra weight of the cladding quite often disimproved performance over slopes

52 Hollingsworth, *Modern Trains*, p. 11 - 27

53 Zapf, *Streamlining a Locomotive*, (*Streamline Decade* P.69)

exterior panelling was removable and a walkway was provided along the exterior on each side. Visibility was much improved by the new narrow body, allowing the engines to be driven either way (initially, it was normal for them to be driven 'engine forward' steam fashion, but drivers soon realised that visibility, and therefore safety, was improved by driving cab forward).[61] All the loads were carried through a massive steel underframe, similar to a truck's.

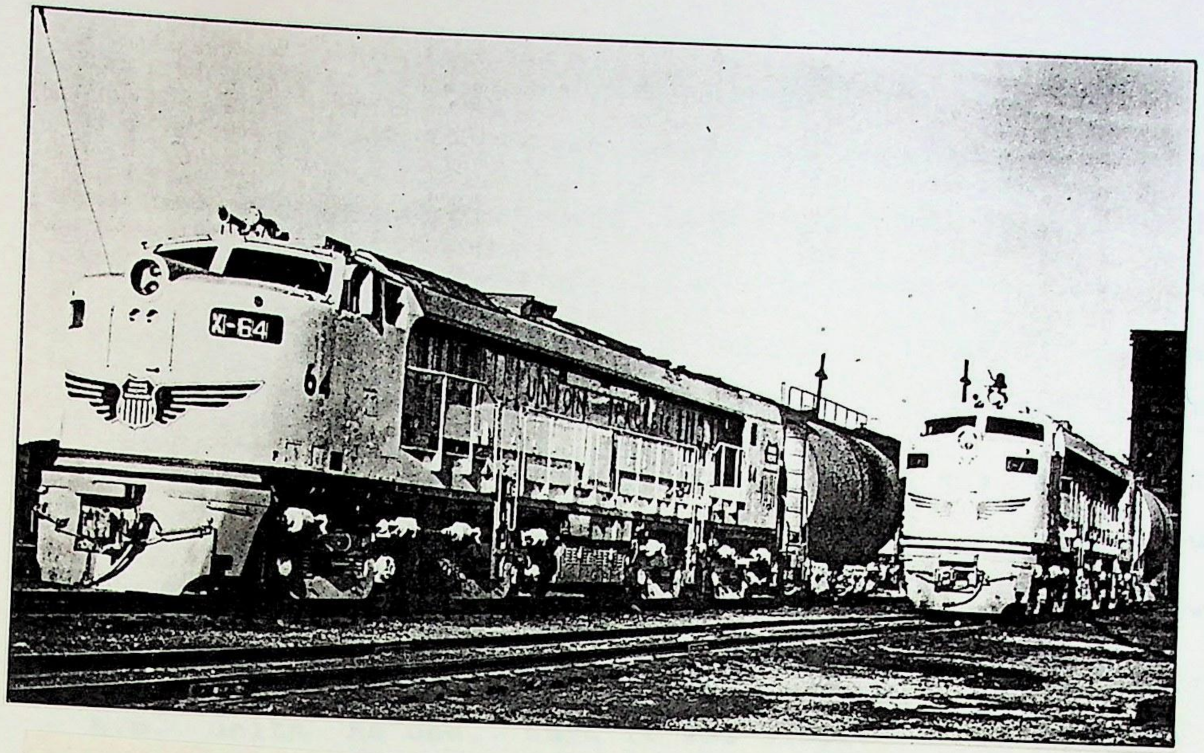
It seems that deliberate effort was put into making these machines ugly. Richard Dilworth, EMD's chief engineer, who was in charge of design of the *GP7*, EMD's equivalent model, said that his aim was to produce a locomotive 'that was so ugly that railroads would be glad to send it to the remotest corners of the system'.[62]

The construction of these locomotives from simple flat or folded steel with simple tooling allowed for easy adaptation of designs for particular circumstances. This went hand in hand with EMD's modular engine design, the *567*, and selection of different bogies allowing them to produce designs tailored to export customers whose railways were much more restricted by low bridges, weight limits and tight turns.

In the United States too there were customers with special

61 Conroy, Conversations, January - March 1990

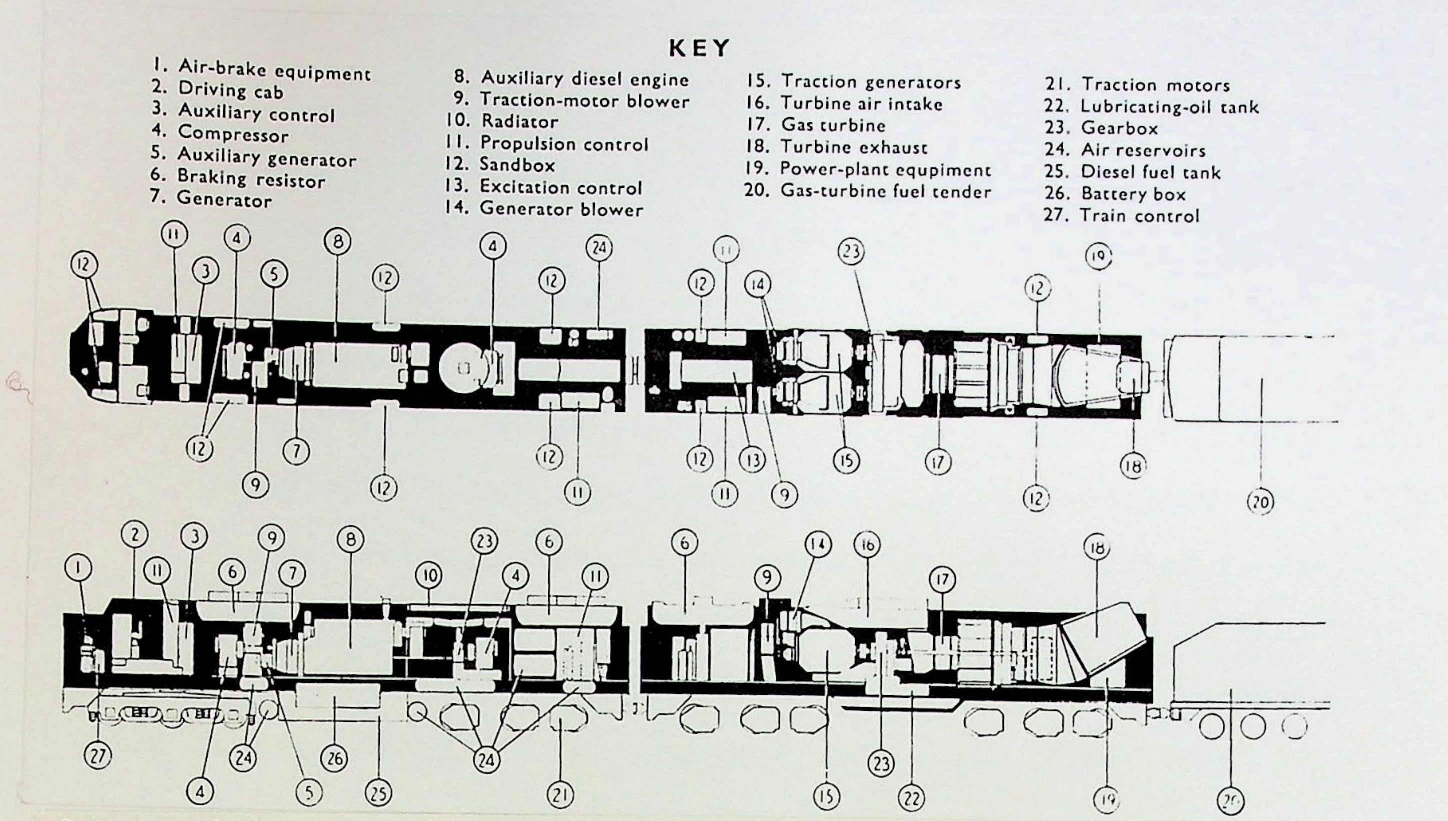
62 A market for diesels still existed in these places.



General Electric, Class X-64, (Illustrated Encyclopaedia of Railway Locomotives) requirements which the first generation of diesels did not meet. With such wide open spaces and long distances between stops, American railroads have tended to run very long freight trans, up to 200 cars being common place. Union Pacific was always the world leader in terms of the most powerful steam locomotives, which it used to haul its freight over the Rockies. The 4,000 class *Big Boys* of 1941 are among the most powerful ever build, with 6500 h.p.[63] When Union Pacific did buy diesels, they looked for more power, reasoning that it made no sense to build and run four 1,500 h.p. units as one, when it was simpler to build just one 6,000 h,p, machine. This provided the impetus for a further, higher, faster style of 'power race' (similar to that which turned into a Space Race in the aircraft industry), which saw ever more powerful engines, peaking in 1955 and again at the end of the 1960's.

After Alco's *415* 1,500 h.p. machine, EMD responded with a 1,500 h.p. *GP7* in 1948 and the 1,750 h.p. *GP9* in 1953. Alco retaliated with a 2,400 h.p. machine in 1954. In 1953, however, General Electric had produced the first of its 4,500 h.p. gas turbine mountain climbing locomotives for Union Pacific. These were 25 special machines which were tailored specifically for Union Pacific and were not intended for full production.

63 Tufnell, *Railway Locomotives*, p. 57



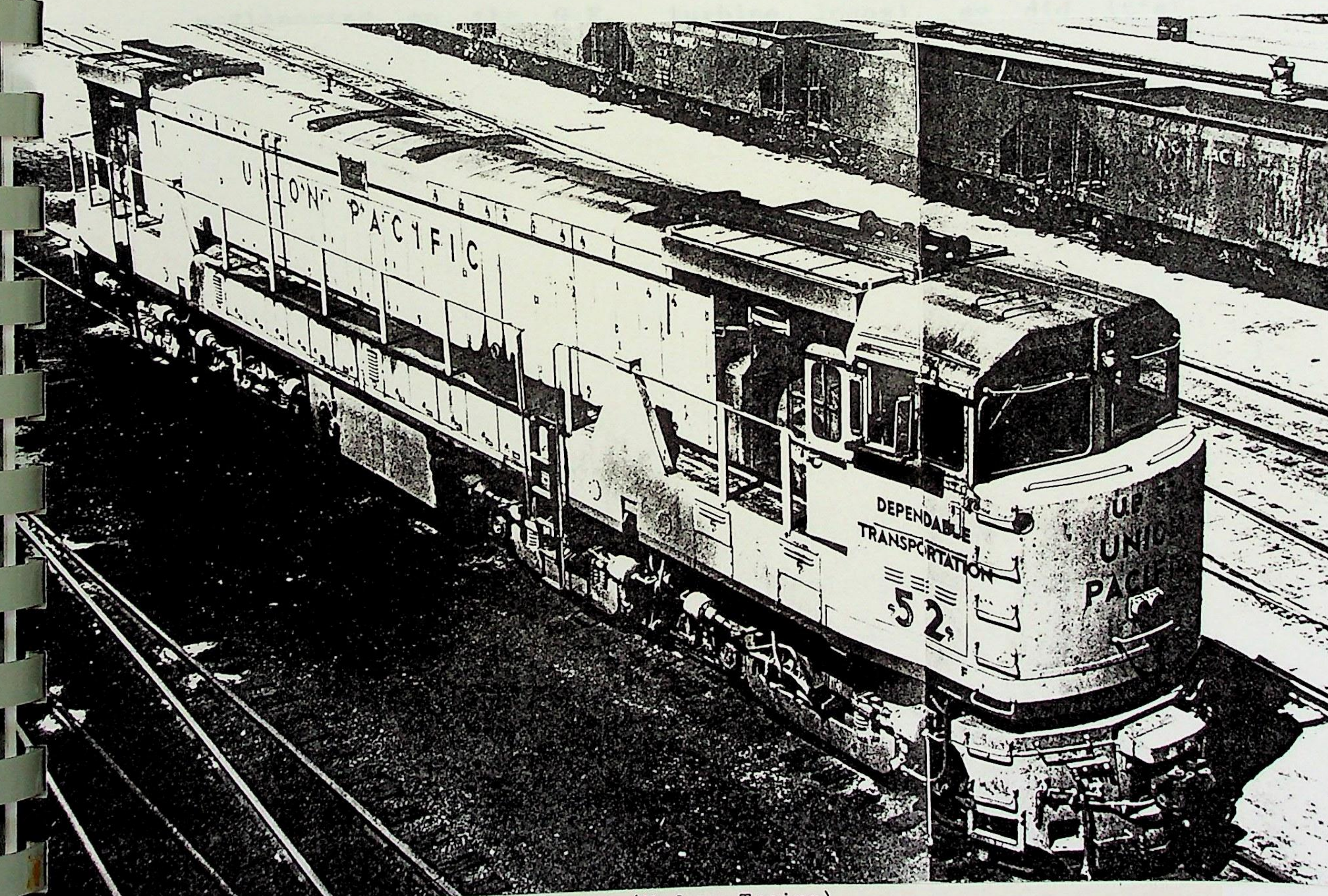
Cutaway of X-1 Class, (Modern Trains)

Gas turbines had been tried as early as 1933 in Sweden. They were found to be efficient only at full output, but railways only need full output about 10% of the time. General Electric fitted the turbine engine, along with a 350 h.p. diesel 'donkey engine' in a massive Bo-Bo-Bo-Bo locomotive, that was half streamliner half switcher, i.e., with an external walkway and removable panels and a streamlined cab. The heavy fuel oil, much like crude oil, was carried in a separate 18,000 U.S. gallon tender. They were used to haul freight trains of up to 5,000 tons over a 480 mile section up Union Pacific's Chicago - San Francisco line over an 8,000 ft. pass. On such steep gradients and heavy loads the gas turbine is at full stretch and is, therefore, working at peak efficiency and at 8,000 ft it suffers none of the power loss a diesel would at such altitude. Once over the summit, the gas turbine was shut down, and the train allowed to coast down the long slope. The Donkey engine provided power for brakes, etc., during the descent.[64]

Union Pacific were not completely satisfied with 4,500 h.p. G.E. responded with the most powerful locomotives of all time, the *X-1* Class, of which 45 were build. These 8,500 h.p. things were far too large to fit into a single unit. The result was a close coupled Co-Co + Co-Co twin unit with a 1,000 h.p. diesel and resistive braking equipment in one

64 Tufnell, *Railway Locomotives*, P. 251.

General Electric, U-25, (Modern Trains)



General Electric, U-50, (Modern Trains)

and the turbine in the other. All the wheels of both units were driven and the tender was enlarged to 25,000 U,S. gallons to cope with the turbines' thirst for tar.

These hi-tech turbine monsters were expensive image-building flagships for U.P. and although nobody else has ever operated anything like them, they did serve to stoke up the power race. By 1960, General Electric had ended its special arrangement with Alco. The commercial might of General Motors had been eating into Alco's 25% market share and G.E. decided that they would have to take on General Motors face to face. Their *U25 'U-Boat'* at 2,500 h.p. was the most powerful diesel in 1960. It was an entirely conventional road switcher unit. It's detailed design owed a lot to previous Also models (Alco had done much of the mechanical engineering on the G.E. turbine locos), as did it's appearance.

Alco bit back in 1962 - 2,600 h.p., a turbocharged V-16 Co-Co. EMD's 1938 *567* engine was at its limit. In turbo-charge form it was stuck at 2,500 h.p. By 1965, Alco was leading again at 3,000 h.p. and were joined by General Electric the following year. Around 1965/1966, Union Pacific were on the look-out for replacements for its gas turbines. EMD sat two of its 2,500 h.p. *GP35* units on a single chasis and gave it two eight wheel Do bogies. To keep length and weight to a minimum, these vehicles were not fitted with a cab, but were operated as booster units. Both Alco and G.E. produced

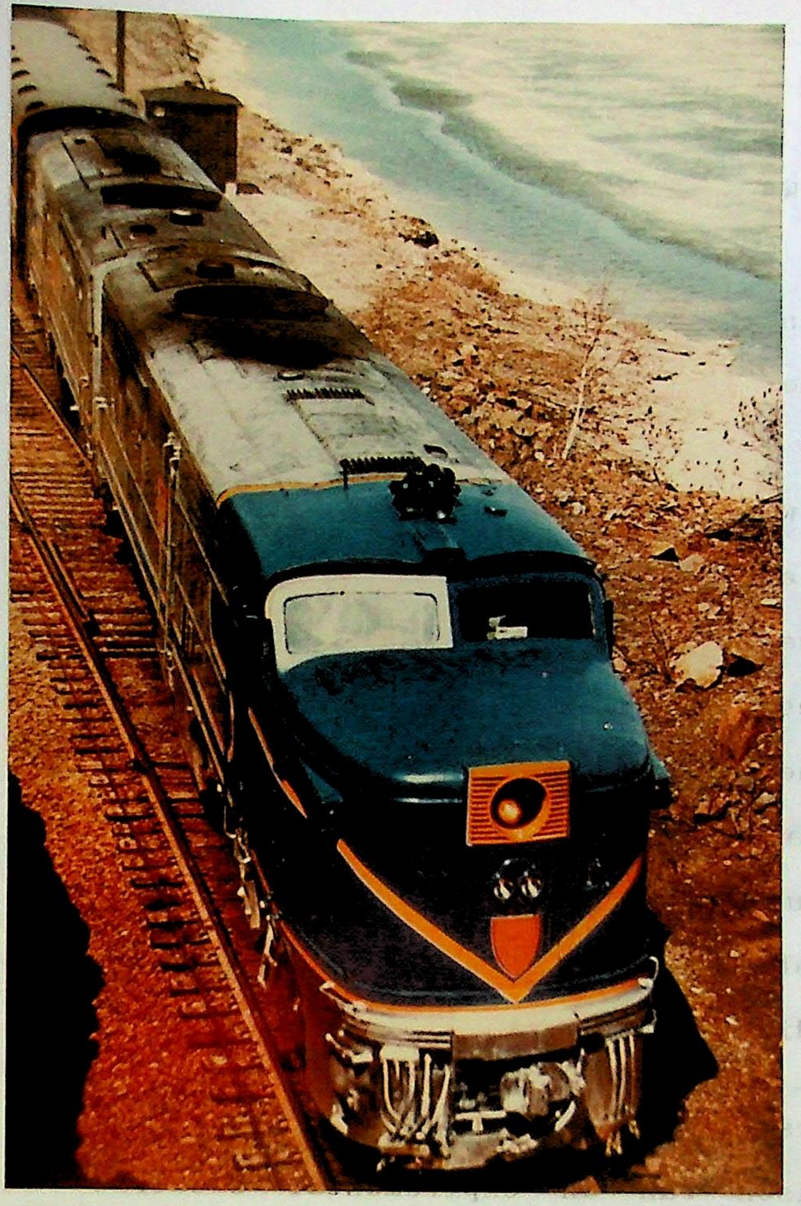
General Motors, DD-40AX, (Modern Trains) similar 5,000 h.p. Siamese units, although, ultimately, they were beaten by EMD's *DD40AX* 6,600 h.p. of 1969. The *DD40AX* is the biggest, longest, most powerful single unit locomotive ever built.[65]

[65] Not all sources have been referenced in the second half of this chapter. All information came from sources previously mentioned.

(the Southern Railway's *Battle of Britain* class was among many to have their 'air smoothed' cladding removed for weight reasons).[54] As well as the fact that it was doing nothing much for the engines, it often severely limited access by the mechanics to the maintenance hungry valve gear and connecting rods.

The diesel streamliner gave American Railroads an entirely modern, 20th Century image of power and speed. It was this image which they pursued right into the 1970's.

54 Tufnell, *Railway Locomotives*, P.104



Alco PA, (Great Trains of the World).

General Motors, GP-9 (Modern Trains)

General Motors, GP-25, (Modern Trains)

7. THE SPACE RACE

Even before the end of World War 11, EMD had resumed full production of their *E* series of express passenger locomotives, production of the *F* having continued uninterrupted through the War.[55] Almost 1,100 *F's* were built at LaGrange between 1939 and 1945 for more than 30 different railroads.[56] Santa Fe was the biggest customer with 320 units. With their long, arid Kansas - California route, they became leaders in a diesel revolution. In 1945, there were 38,852 steam locomotives, 842 electric locomotive and 835 other types (most of the 1,214 *E* and *F* types built by 1945 operated in formations known as 'lash ups', that is, closely coupled or trebled units that function as a single locomotive. This probably accounts for the odd figures). In 1961 there were 28,150 diesels and just 110 steam.[57]

Other locomotive builders had realised there was potential. In 1880, Thomas Eddison ran an expiremental electric locomotive. He later formed with another pioneer, Stephen Field, the Electric Railway Company of America. This Company in turn formed the core of the General Electric Corporation when it formed in 1893[58]. It was natural, therefore, that

55 Hollingsworth, *Modern Trains*, P. 21

56 Marshall, *Guinness Book of Rail Facts and Feats*, P. 149

57 Hollingsworth, *Modern Trains*, P. 21

58 Tufnell, *Railway Locomotives*, P. 29

G.E. should become involved in electric traction. They supplied EMD with all their electrical equipment until 1938, when EMD started making their own. In 1940 General Electric agreed with Alco, the American Locomotive Company that in return for Alco installing only G.E. equipment in their new range of diesel electrics, they would stay out of diesel locomotive production.[59] Both Companies benefited from this arrangement - Alco profited from the expertise of the World leaders in electric traction and G.E. gained almost complete control of the remaining 25% of the market.

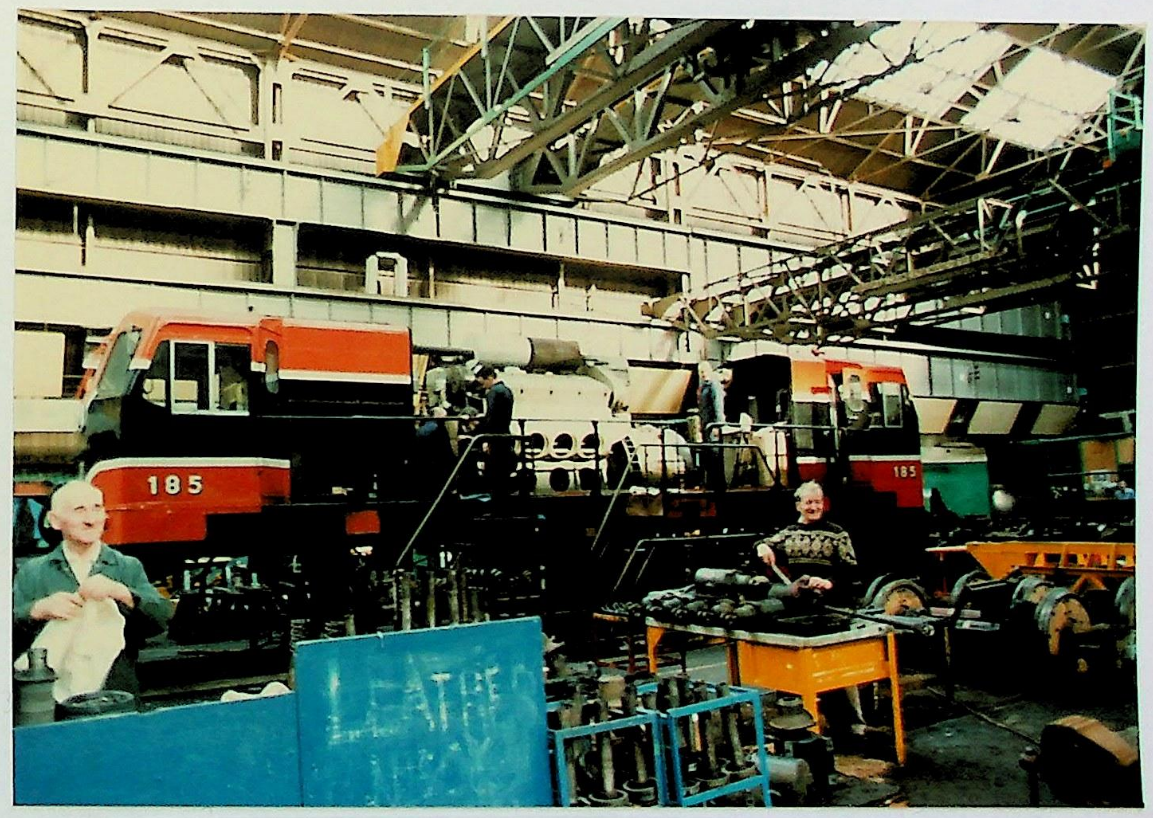
Alco (who with Baldwin-Lima were the only big steam locomotive builders left in 1945) introduced two new diesels to the American market in 1946, the *PA*, a streamliner broadly similar to EMD's streamliners and a large shunting or 'switcher' engine of 1,500 h.p. The latter was intended to haul slow freight trains and was soon referred to as 'the road switcher'.[60]

The construction and appearance of the road switcher was completely different to the streamliner and represented a desire for practicality rather than an ideal form. The ability of mechanics to gain easy access to the working parts was deemed to be more important than providing room to work on them while the vehicle was moving. Almost all the

59 Hollingsworth, *Modern Trains*, P. 96

60 Hollingsworth, *Modern Trains*, P. 126

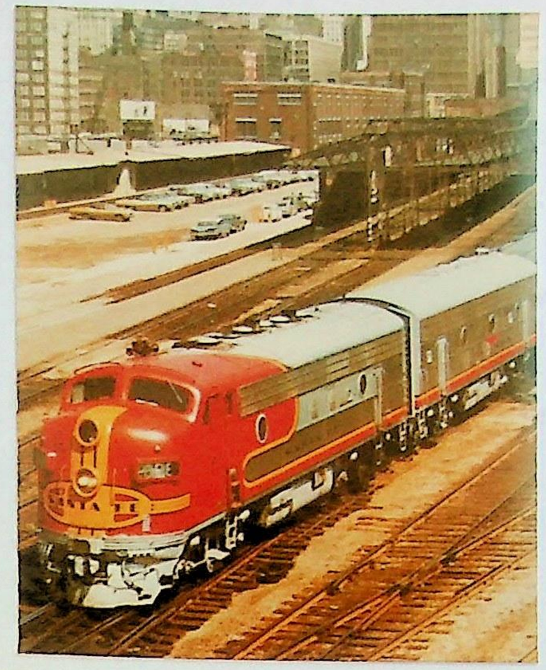
General Motors, Class 121 (Author)



General Motors, Class 151, Road Switcher, (Author)

8. CIRCUS WAGONS.

Black, greasy, dirty and smelly, soot spraying Christmas Trees. American Steam locomotives have always been brutal objects. And *real* steam engines are black! The 40 years following the introduction of diesel power to passenger trains saw several completely different approaches to painting and finishing locomotives and trains in America.



General Motors,E-7, (Modern Trains)

General Motors, SD-40P, (Modern Locomotives)

9. SILVER DREAM MACHINES.

Streamlining as a scientifically inspired design ethic, had many noble ideals.

> Simplicity, unbroken lines, use of pure colours ...[and] honesty in materials: Steel is steel, copper is copper.[66]

Perhaps the strongest trend in trains in this era was the Bare Metal Look. E.G. Budd, who had more or less invested the pressed steel unitary method of construction for automobiles, applied his technology to railway carriages and at the same time developed the technology for spot-welding stainless steel. As a new material, like aluminium, it was taken as a symbol of progress and proudly displayed unpainted. The Burlington *Zephyrs* retained their bare metal finish until 1970, when they were discontinued due to rising costs. [67]When the *Zephyrs* changed to EMD locomotive hauled trains in the late 1930's, the pairs of engines were pained silver (their mild steel bodies would have rusted quickly) and named *Silver King/Silver Queen* and *Silver Knight/Silver Princess.*[68]At one stage, individual even cars were named: *Silver Rifle* was a superdome on the *California Zephyr* during

66 Unknown (*Depression modern* p.32)

67 Whitehouse, *Great Trains* P. 28

68 Whitehouse *Great Trains* P. 27

General Motors, F-3, (Great Trains of the World)

General Motors, F-3, New York Central, (Modern Locomotives).

the late 1960's. [69]

The Acheson Topika and Santa Fe, arriving into the streamline era a little later found a need to alter the stark steel of its Budd built *Super Chief*. Previously, the Santa Fe had used a predominantly blue livery, but underwent a complete change for the *Super*.[70] The cars were left mainly bare metal, but were trimmed with a black/yellow/red stripe and the base. This ran into the locomotive and flared into a red surround to the cab with black and yellow stripes. The remainder of the locomotive was painted silver, including the cow-catcher, wheels, bogies, couplings and fuel tank, turning these items from low-tech steel and cast iron into high-tech aluminium.

The much more conservative New York Central and the Pennsylvania ignored this trend. These two giants of East-Coast railroading stuck with traditional steam locomotive black and dark grey for their locomotives, right up until they merged in 1968. They used strikingly similar bright pin-stripe motifs to aid visibility to workmen. These stripes were first introduced by Loey on his *GG1* Electric locomotive of 1936.[71] These Companies' stealthy black shapes provided a strong/often welcome contrast to the Circus Wagon

69 Whitehouse, *Great Trains*, P. 129

70 Bush, *Streamline Decade*, P. 83

71 Loey, *Industrial Desigh*, P. 61

appearance of some of the schemes which came after the war.

General Motors, GB-25, (Modern Trains)

10. MOBILE BILL-BOARDS

Britain, the second-last bastion of free enterprise, nationalised its railways in 1948, leaving North America with the last remaining railway system in the world in private hands. As if competition between them was not enough, the railroad companies had to worry about (a) the airlines stealing their passengers, and (b) truckers stealing their freight. Through their need to advertise their presence at every opportunity, they provoked some of the brightest and brashest liveries ever.

With arrival of the road switchers in the late 1940's, most of the smoothness that the streamliners had shown went. The EMD *GP7* of 1948, in spite of its brutality and its designer's worst intentions, was a pleasantly proportioned machine, and its large flat areas and simple shape lended themselves well to applied decoration and lettering.

The Santa Fe, which had gone for a warm yellow/red/black/silver scheme for its passenger operations, created a new livery for its freight services, based on its pre-war blue and yellow. 'Santa Fe' was condensed to fit the proportions of the sides of the engine housings. Another bright scheme was that of Union Pacific. In 1934, they had gone for a yellow and brown scheme with black trim. By the 1950's this had simplified to plain yellow with a broadly spaced 'Union Pacific' in a simple red sans serif (as opposed to the grotesque forms that were popular with

General Motors, F-7, Burlington Northern, (Great Trains of the World).

General Motors, F Class, Canadian National, (Great Trains of the World).

General Motors, SD-30, (Illustrated Encyclopaedia of Locmotives)

American Railroads - Santa Fe's was a good example) and a neutral grey roof and cow-catcher.

In the mid and late 1960's, railroad companies were disappearing and merging at a phenomenol rate. Many of the new Corporations thus formed took the brutalist indistrial machine image of the road switcher to its limits. The merger of the Chicago, Burlington and Quincy, the Great Northern, the Northern Pacific and the Spokane Portland and Seattle in 1970, produced America's largest freight system, the Burlington Northern.[72] Their locomotives quickly adopted a stark, bright green and black livery. Both ends of the lomomotives were painted with industrial style diagonal green and white stripes, for high visibility (these stripes were later changed to red and white). In the same year, Canadian National, the government owned Canadian system, adopted an even more abrupt scheme tailored to the road switchers. The engine compartment was painted in broad diagonal black and white stripes, while the cab and the portion forward of it was bright red. Canadian National first used their CN logo type in 1967.[73]

72 Allen, *Modern Railways*, P. 218

73 Marshall, *Guiness Book and Rail Facts and Feats*, P. 91

General Motors, SD-40P, (Modern Locomotives)

11. AMTRAK.

As early as 1915, the Pennsylvania Railroad had operated electric railcars on its suburban lines, South of Philadephia. By 1935, it had electrified the whole of its New York/Washington main line.[74]

In 1966, with backing from the Federal Government, the Pennsylvania placed an order with E.G. Budd for 61 two-car electric train sets. These high speed (160 m.p.h.) lightweight hi-tech *Metroliners* were built of ribbed stainless steel in typical Budd fashion and were left unpainted, also typical. They were fully air-conditioned and were equipped with electrically controlled doors and a public telephone service.[75] Entry into full service was delayed by lots of technical problems, the merger of the Pennsylvania Railroad and the New York Central in 1968 and the bankruptcy of the resultant Penn-Central in 1970.[76]

Amtrak was formed in May 1971 by the U.S. Federal Government to take over the running of passenger rail services in the United States. Initially, it operated stock supplied to it by the railroads (Companies were given the choice 'Give us your gear, or run the service for another two years') with the minimum amount of changes (The Penn-Central *Metroliners*

74 Tufnell, *Railway Locomotives*, P.201.

75 Tufnell, *Railway Locomotives*, P. 213.

76 Allen, *Modern Railways*, P. 221.

were seen running with the P-C logo as late as March 1972). Perhaps in an effort to recall the halcyon days of the Burlington *Zephyr* or the Santa Fe's *Superchief* (or perhaps just out of pragmatism, E.G.Budd built most of the stock they inherited) Amtrak quickly standardised on silver/bare metal with a patriotic red/white/blue cheatline. Reinforcing this image, Amtrak purchased a series of turbine powered, streamlined, unit trains from the United Aircraft Corporation and the French National Railway during the 1970's (the French turbotrains were painted rather than bare metal)

The hi-tech image of these aerospace technology vehicles clashes badly with the dated bare-metal idiom. Whereas aluminium and shiny steel were the finishes of the 1930's, 1940's and 1950's, Nasa and the U.S. Airforce have made black and white the hi-tech colours of the 1970's and 1980's.

12. SEVENTIES AND EIGHTIES.

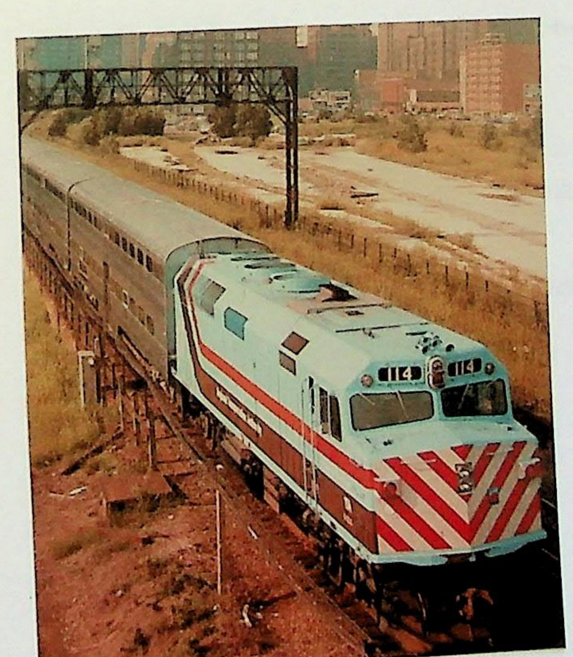
Even though no diesel locomotive of the 1970's or 1980's can approach the *DD40AX's* 6,600 h.p., it would be wrong to think that development stopped in 1970. To-day, there are three major builders in North America;

General Motors EMD, still the strongest by a long way.

General Electric, builders of America's most powerful locomotives of to-day, but concentrating on exports to China, and

Bombardier/MLW, a Canadian former licencee of Alco, who took over most of their business when they bankrupted in 1969.

All three offer a range of broadly similar road switcher units of up to 3,900 h.p., little changed from those of 20 years ago, except in the area of control. Using modern technology, locomotives' pulling power has increased relative to the power of the traction motors. A doppler radar device measures the speed of the locomotive and compares it with the speed of the wheels, allowing the locomotive to pull right to the edge of wheelspin. Other electronics control current fed to the traction motors, braking, diesel engine throttling and many others factors controlling efficiency. EMD is the only manufacturer to-day of passenger locomotives



General Motorsm F-40P, Chicago Transit Authority (Modern Trains) in America.[77]

The last of EMD's passenger carbody units was built at the end of 1963 and with passenger traffic declining rapidly in the U.S.A. the need for special passenger locomotives seemed to have disappeared. Both EMD and its competitors had train heaters as options on some models of road switchers.

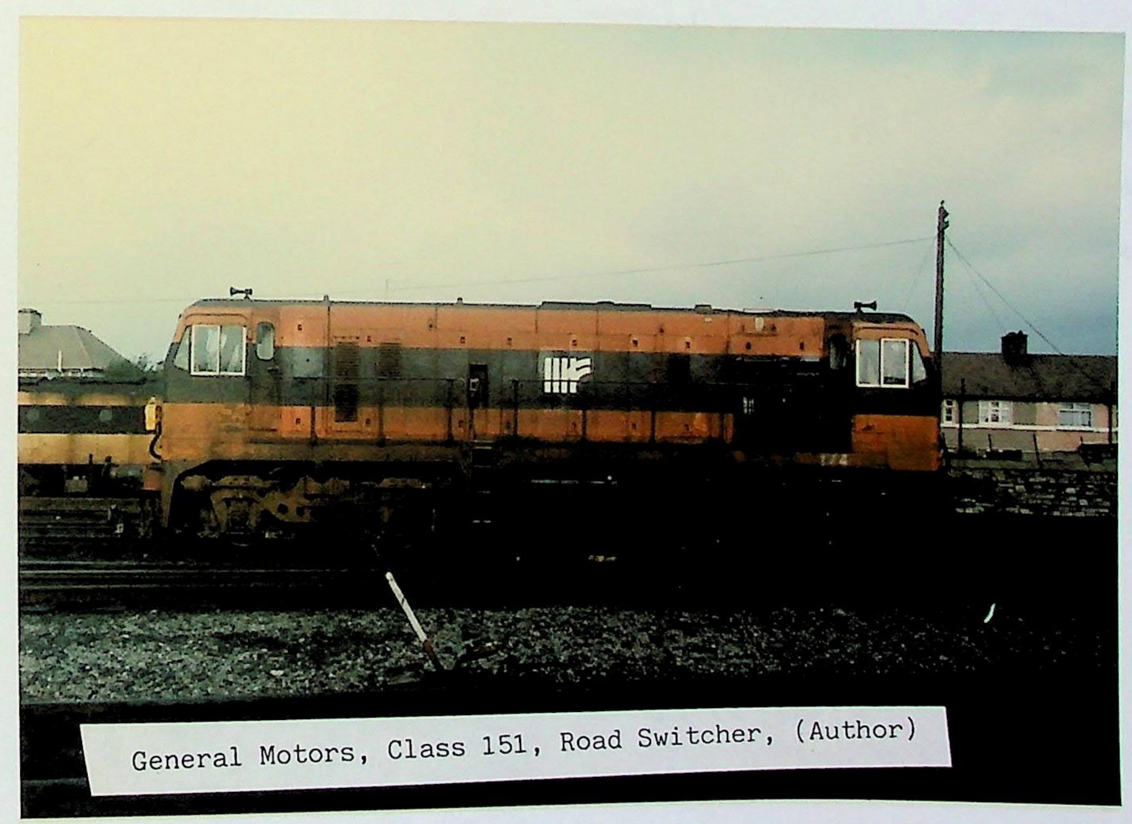
In 1968, at the height of the power race, the Santa Fe, in an effort to revive its passenger service, asked EMD to build some special passenger versions of their Co-Co *SD45* model.[78] Part of the specification was that be given a more acceptable appearance for passenger work and less air resistance than the *SD*. They were geared for high-speed running and given the most powerful engine of the day - the 3,660 h.p. V20 *645 E3 Turbo*, a development of the *567* which powered Santa Fe's original *E1* Streamliner. The new body, a style now referred to as The Cowl, was a simple square box, flat and folded, non-stressed fairing. When Amtrak took over passenger services, these locomotives and the V16 *SPD40's*, which had a slightly modified body, were used to provide motive power for its Western services. Developments of the cowl are still in production to-day, mainly for suburban services.

C.I.E., which had bought its first locomotives from EMD in

77 Foxx, C.J., Telephone Conversations, March 1990.

78 Whitehouse, *Modern Locomotives*, P. 77.

General Motors, Class 121, (Author)



General Motors, Class 151, Road Switcher, (Author)

1961, found a similar image-problem when it used its tiny 950 h.p. road switchers on passenger services. The *141* class of 1962 featured a redesigned cab, which was fitted at both ends, and has since been standard for all EMD locomotives built for C.I.E.[79]

In 1974, when EMD adapted a freight-hauling electric locomotive for use by Amtrak (to replace the 40 year old Raymond Loey *GG1*) on the North East corridor, a cab very similar to the C.I.E. pattern was used, although it was scaled up to match the American proportions.[80]

Amtrak, under pressure from the U.S. Government to improve services, during the 1970's and 1980's, has increasingly turned towards imports for its equipment. As well as the French built *Turbotrain*, and *Turboliner*, streamlined train sets, several Swedish Volvo electric locomotives were bought in 1975 and licensed production of a further 47 was undertaken by G.M.[81]

This policy of buying the best has not been entirely successful - many of the foreign super-locomotives have had trouble dealing with the poorly maintained American railroads, just as the previous domestic equipment had.

79 Conroy, V. Conversations, Jan. - Mar. 1990.

80 Foxx, C.J. Telephone Conversation, Mar. 1990.

81 Allen, *Modern Railways*, P. 201 - 208.

General Motors, Camaro Z-28, (American Dream Machines)

McDonnell Douglas, F-4, (F-4 Phantom 2)

General Motors, GP-30, (An Illustrated Encyclopaedia of Locomotives)

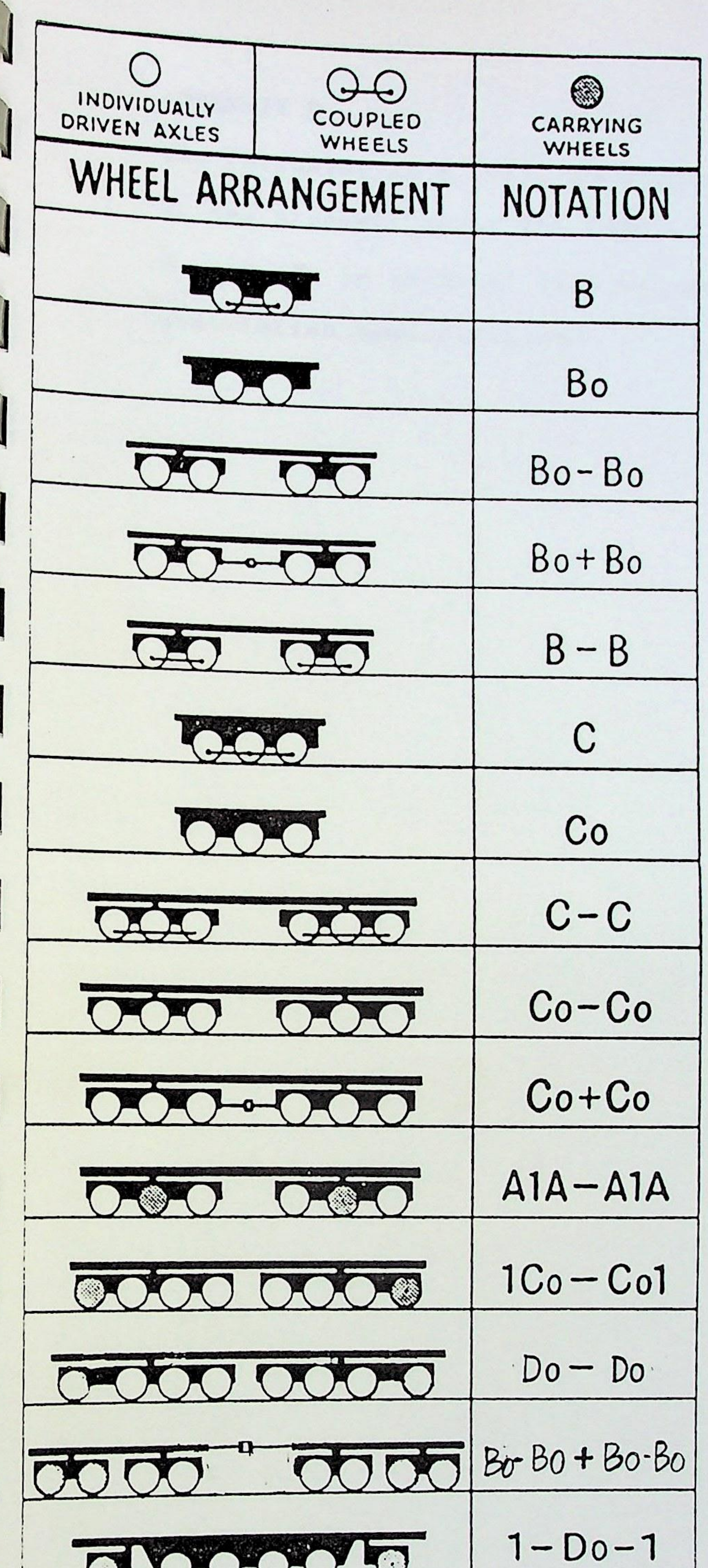
SUMMARY.

The modern diesel locomotive evolved in response to a desire to simplify and streamline the form of the express passenger train during the 1930's. The economies and flexibility inherent in a diesel locomotive ensured its success after the war. A locomotive's job is to provide motive power for its train. There has always been a need perceived by the locomotive builders of America to make engines that are faster, stronger, bigger and more macho than those that went before. After a brief flirtation with streamline forms in the 1930's, the American locomotive industry has pursued an intensely pure, brutalist approach to design. This brutalism peaked at the end of the 1960's, the era of the *Saturn 5* Rocket, the *Z28 Camero*, the *F-4 Phantom*, Agent Orange[82], and Mick Jagger. Even the streamliners of the 1930's and 1940's as an effort to simplify the locomotive form have a brutal purity, an image of power, strength and speed. To-day, the American railway industry is divided, passenger and freight. Amtrak has suffered from politics, politicians and marketing executives and has lost sight of the power image of railways. The remaining commercial railroads have regressed into an isolated position, away from the public eye.

82 A defoliant used by the Americans in Vietnam.

APPENDIX A

WHEEL ARRANGEMENT NOTATION



WHEEL ARRANGEMENTS

The basis of the system used to describe diesel (and electric) locomotive wheel arrangements is that the non-motored, carrying axles are indicated numerically, but that the number of driving axles is shown by letters. Thus, a four-wheel carrying bogie is denoted as '2'; in the driving wheel group, 'A' signifies one motored axle and 'B', two motored axles, etc. Each group of wheels is separated by a dash, except in the case of driving bogies that are not entirely independent of each other, but linked by an articulated joint, or whose axles are connected by cardan shafts to a common engine, when a 'plus' sign is substituted. When the suffix letter 'o' is added to a driving axle group, it indicates that each axle has its own motor.

APPENDIX B

The following is a detailed discription of a typical General Motors streamliner of the 1950's. It lies midway between the *E* and *F* in terms of size and power and was built to an australian specification.

Large Diesel Locomotives for Australia

Clyde-G.M. types of 1,900 b.h.p. now in freight and passenger services on the 4 ft. 8$\frac{1}{2}$ in. gauge lines of the Commonwealth and New South Wales Government Railways

AFTER the original 1,665 b.h.p. (1,500 h.p. traction input to main generator) General Motors type diesel-electric locomotives supplied in 1951-52 by the Clyde Engineering Co. Ltd. to the Commonwealth Railways and the Victorian Railways, the next large locomotives by this builder were five to the Commonwealth Railways and six to the New South Wales Government Railways, which began operation in 1956. The Commonwealth order had meantime been increased by five, making ten in all for the C.R.; and subsequently the Victorian Railways ordered ten which have been introduced during the winter of 1957-58. There are two principal differences between the two batches of 1951-52 and the later units. In the first place, the General Motors type 567-C engine has replaced the 567-B model, and so the b.h.p. is 1,900 instead of 1,665. Secondly, there is a driving cab at one end only, whereas the B-class locomotives of 1952 in Victoria had a cab at each end. In all cases engines, generators, traction motors and electric control equipment were supplied by the Electro-Motive Division of G.M. from La Grange works at Chicago, and the mechanical portions were supplied complete by the Granville works of Clyde.

Differences

The six locomotives for N.S.W.G.R. and the ten for C.R. are basically the same 1,900 b.h.p. design, but the N.S.W. locomotives have dynamic braking and the C.R. not; the Commonwealth locomotives have a slightly pressurised engine room whereas the N.S.W. locomotives have not; the gear ratios are slightly different so that speeds and rated tractive efforts are not quite the same, the C.R. units having 19:58 traction motor gear ratio and 50,000 lb. at 10 m.p.h. continuous rated tractive effort, whereas the N.S.W. units have 16:61 gear ratio and a continuous rated tractive effort of 61,800 lb. at 9 m.p.h. The C.R. units weigh 114 tons, and the N.S.W.G.R. units 116$\frac{3}{4}$ tons; both are of Co-Co wheel notation with 40-in. wheels; the C.R. power has a top speed of 89 m.p.h. and the N.S.W.G.R. locomotives 71 m.p.h. The N.S.W. locomotives also are fitted with air-operated staff exchangers for single-track lines. In both batches a " hostler's controller " is fitted at the back end to facilitate shunting movements. Colour scheme is maroon relieved by yellow bands, with red bands on the N.S.W.G.R. locomotives and white markings on the C.R. units.

Despite the disparity in gear ratios and top speeds it has been the N.S.W. units which up to the moment have been used mainly on passenger workings and the C.R. units on freight turns. The N.S.W. locomotives have been operating the " Brisbane Limited, " a 460-ton train running the 613 miles between Sydney and Brisbane in 16 hr. 8 min. northbound and 16 hr. 28 min. southbound, cuts of 25 to 27 per cent. in the steam-train timings. More recently they have also been used in a southerly direction from Sydney, on the Sydney-Melbourne services as far as the State frontier at Albury; but the locomotives of this 42-Class are now also running on fast freight trains. Though some of the new C.R. locomotives, numbered GM.12 and upwards, have been used on the Trans-Australia Railway, their main duty is on the new

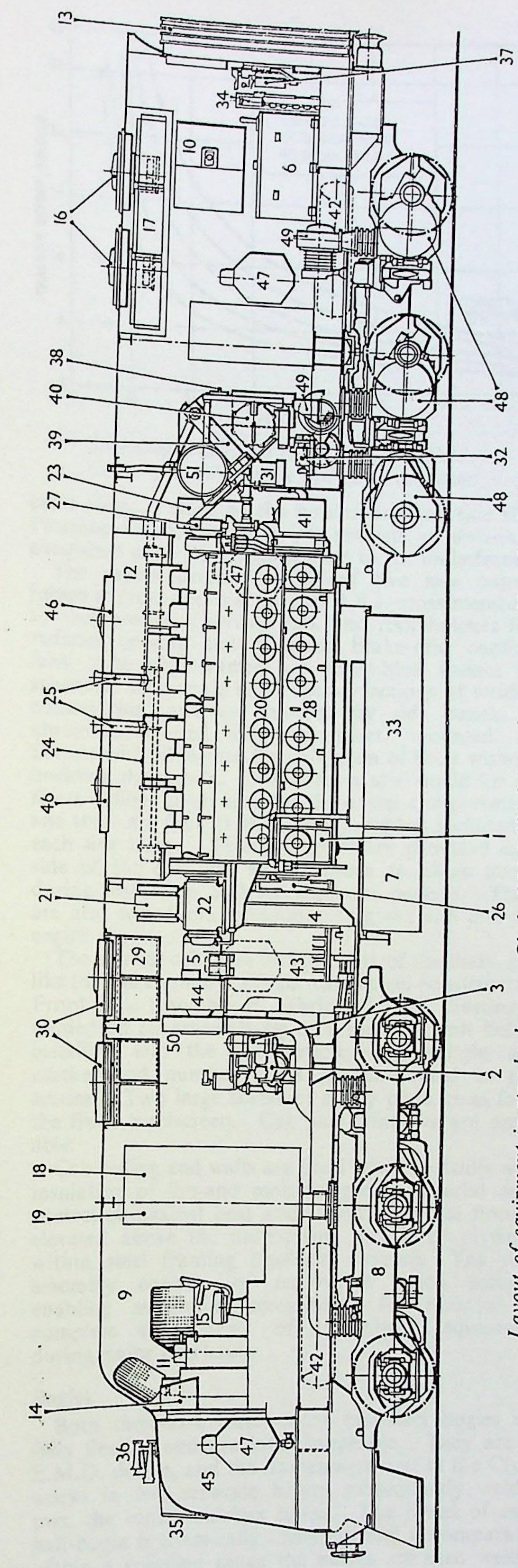
1,900 *b.h.p. Co-Co locomotive of the* 42 *Class heads a fast freight on the N.S.W.G.R.*

Stirling (Port Augusta) to Leigh Creek line, the standard-gauge route replacing the old 3 ft. 6 in. gauge line and built to handle the increasing production of the Leigh Creek coal-field. These locomotives hitherto have been working singly on 2,250/2,600-ton coal trains, but eventually they are to be used in pairs, back-to-back, on 80-wagon coal trains with a trailing weight of 5,000/5,250 tons, hauled over a ruling grade of 1 in 180 southbound, and with returning northbound empties going over a ruling grade of 1 in 120. Timing for the 161-mile run southbound is six hours.

Mechanical Parts

Mechanical portions of both C.R. and N.S.W.G.R. locomotives are almost identical. The locomotive underframe is jig-assembled from rolled steel sections and plates, and the complete assembly is of welded construction throughout. Two 15 in. by 4 in. channel sections run the full length of the frame; these two centre sills are joined to each side frame through cross-members and side sills and serve as the main load carrying structure. Two of the cross-bearers which are welded to the side frame support the fuel tank at approximately the centre of the underframe. The fuel tank is welded construction of heavy-gauge steel with baffle plates, and has a sump with a clear-out plug and non-removable water drain located at the bottom, a vent equipped with a flame arrester, and a filling station and gauge each side.

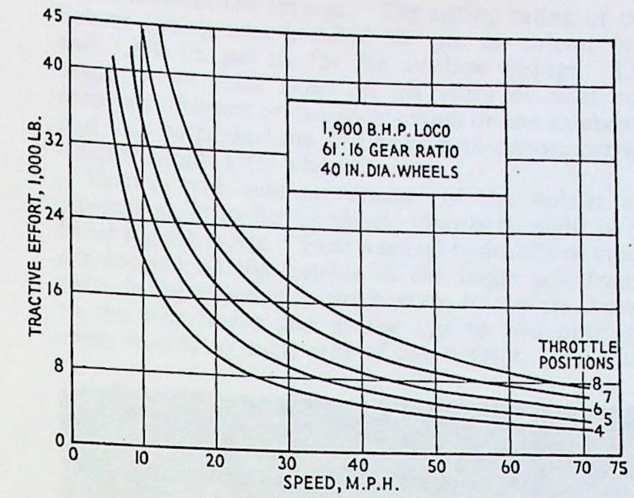
Underframe ends terminate in buffing beams designed and located to accommodate alternate types of buffing and draw gear, and to take the stresses directly on the underframe structure. When centre draft gears are fitted they are located below the main underframe and structure. The C.R. locomotives have centre couplers and the N.S.W.G.R. units have side buffers and screw couplings. The draft gear pockets are of fabricated construction welded integral with the underframe between centre sills. The body centre plates are of cast steel and are bolted to the underframe as part of the basic structure. At front and rear are combination jacking pads and



Layout of equipment in standard-gauge Clyde-GM 1,900 b.h.p. locomotive, New South Wales Government Railways

EQUIPMENT KEY FOR DRAWING ABOVE

1—Air box drain
2—Air compressor
3—Air compressor filter
4—Alternator
5—Auxiliary generator
6—Battery (standard position)
7—Battery (alternative position)
8—Bogie frame
9—Cab
10—Cloak cabinet
11—Controller
12—Cooling-water radiator
13—Diaphragm
14—Driver's control panel
15—Driver's seat
16—Dynamic brake fan
17—Dynamic brake grid
18—Electrical cabinet No. 1
19—Electrical distribution panel
20—Engine
21—Engine air filters
22—Engine blowers
23—Engine control panel
24—Engine exhaust mufflers
25—Engine exhaust stacks
26—Engine flywheel
27—Engine governor
28—Engine lube oil dipstick
29—Engine room air filters
30—Engine room pressurising fans
31—Fuel oil filters
32—Fuel pump
33—Fuel tank
34—Handbrake
35—Headlight
36—Horn
37—Hostler's controller
38—Load regulator
39—Lubricating oil cooler
40—Lubricating oil filter
41—Lubricating oil strainer
42—Main air reservoir
43—Main generator
44—Main generator blower
45—Nose compartment
46—Radiator cooling fans
47—Sandboxes
48—Traction motors
49—Traction-motor blowers
50—Traction-motor blower fan
51—Water tank



Speed-tractive effort curve of Clyde-G.M. Co-Co general-purpose 116-ton locomotive

cable slings, welded to the bolster on each side sill. Flooring in the engine room consists of anti-skid chequered plate ¼ in. thick welded to the underframe.

The superstructure consists of two side panels joined at front and rear by two R.S.J. cross-members to roof profile, a driving cab, and roof hatches for radiator cooling and dynamic brake-grid cooling fans. The side frames are assembled trusses of structural steel angle and channel sections of welded construction, and are covered by side panels of aluminium-covered plywood sheet, mounted on battens with allowance for deflection of body without buckling the panels. Provision is also made for air filters to filter all air entering the power compartment, and there are four fixed circular windows included in each side frame. External doors are provided each side of the cab and engine room to allow access during inspection and maintenance periods. There are also two doors interconnecting the cab and the engine room.

The control cab is an integral part of the body, and like the end frames, is of fabricated steel construction. Front nose assembly of fabricated steel sheeting is welded on an assembly jig as a separate unit before installing into the superstructure. Headlight and marker and number lights are contained in this section. Two large sheets of safety plate glass form the front windscreen. Cab side windows are openable.

Cab ceiling and walls are lined where possible with insulation of fire-and moisture-proof material as a protection against heat and sound; and the floor is elevated above the underframe and is of plywood within steel framing linoleum covered. The roof assembly consists of removable hatch sections enabling maximum accessibility for removal of complete components of locomotive equipment during major overhauls.

Bogies

Both three-axle three-motor cast-steel bogies are fully flexible and are interchangeable. They are of E.M.D. design, and the frames were cast at the Clyde works in two separate halves subsequently welded over the centre axlebox horns. The metal of each half-bogie is chemically analysed, and if comparable within a specified range the halves are then welded and the completed bogie frame is stress-relieved. If the two halves are outside this range they are normalised separately before welding together and are then stress-relieved in a special furnace. All welds are X-rayed for soundness. The bogie is comprised of two side frames, connected together by two cross-members or transoms which are spaced equi-distant from the bogie centre.

Within the frame are four-coil spring pockets, one at each junction of a transom and the side frames. Each of the two transoms has two vertical buffer plates projecting upwards which are contacted by corresponding buffer plates on the bolster with the longitudinal movement of the bolster or bogie frame. Stop plates on the insides of the side frames limit the side travel of the bolster.

Attached to each of the 12 horn cheeks or pedestals, are liners which act as guides and wear-plates for the axleboxes. Between each pair of pedestals in the side frame are pockets for the axlebox coil springs. The pedestals are connected across the bottom by bolted hornstays or pedestal tie bars. On each of the side frames are three brake cylinder mounting pads, one at each end, and one slightly off centre, and the brake hanger bosses are located on each transom and at the four ends of the frame.

Bolster Construction

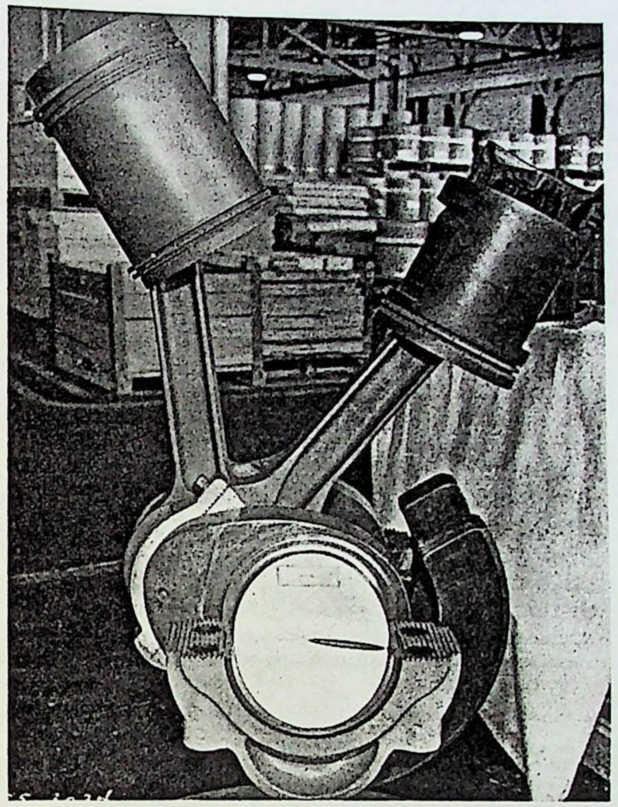
The bolster is also a steel casting and has spring pockets at the end of each arm to support it in the bogie frame. Incorporated in the bolster centre bearing, into which the bogie centre on the locomotive underframe fits, is a renewable steel wear ring and a bronze thrust plate, and fitting around this centre bearing is a felt dust guard to protect against the entry of dust. The bogie side bearers, which are fitted with a renewable wear plate, are located one each side of the bolster, and the bolster is attached to the locomotive underframe by clips bolted to the underframe which hook beneath the bolster outside the side bearers. There are four long safety rods, one on each arm attaching the bolster to the bogie frame.

TABLE I—CLYDE LOCOMOTIVES FOR N.S.W.G.R. AND C.R.

Wheel arrangement	Co-Co
Wheel dia.	40-in.
Bogie wheelbase	13 ft. 2 in.
Bogie pivot pitch	34 ft.
Total wheelbase	47 ft. 2 in.
Length over buffers	62 ft. 6 in.
Overall width	9 ft. 8½ in.
Maximum height	14 ft.
Minimum curve, at slow speed	275 ft.
Fuel capacity	1,500 gal.
Sand capacity	16 cu. ft.
Engine cooling water	175 gal.
Engine lubricating oil	165 gal.
Weights in working order	116¾ tons (N.S.W.) 114 tons (C.R.)
Maximum axle loads	19½ tons (N.S.W.) 19¼ tons (C.R.)
B.H.P.	1,900
Starting tractive effort (30 per cent. adhesion)	76,000 lb.
Continuous rated tractive efforts	61,800 lb. at 9 m.p.h. (N.S.W.) 50,000 lb. at 10 m.p.h. (C.R.)

At the end of the bolster arms and welded to the longitudinal buffers are wear plates, and also provision for the future application of wear plates to the bolster transverse stops. The bolster is suspended at its four corners on the bogie side by heavy-duty coil springs, which not only provide springing for the bolster but also allow a certain amount of restrained side movement. Because of the variation in loaded height of coil springs six spring heights are used, and any variation is compensated by the addition of shims beneath the springs. The spring rating of the bolster spring nest is 6,880 lb. per in. lateral rate and 3,310 lb. per in. for the axlebox springs. The bogie frame itself rides on six pairs of dual coil springs which rest on the spring seats on the axleboxes and may be packed top and bottom to restore correct coupler height after wheel turnings.

Vertical and side movements of the bolster are dampened by hydraulic shock absorbers, eight being fitted to each bogie. Four vertical hydraulic dampers are located on the outside of the bogie side frame, these being attached at the bottom to a plate, bolted to the side frame and at the top to two outrigger arms welded to each arm of the bolster. The side-



Piston and connecting rod assembly of G.M. type 567.C two-stroke engine; $8\frac{1}{2}$-in. piston diameter

ways shocks and movements of the bolster are absorbed by four shock absorbers, two each end of the bolster, attached at approximately 30 deg., and located at the top by brackets welded to the end of the bolster and at the bottom by a bracket welded to the inside of each side frame.

Wheels are of one-piece rolled steel, heat treated, of 40 in. diameter, and provide a clearance of $5\frac{5}{8}$ in. under the gearcase when new. Journal boxes are of cast steel of Clyde manufacture fitted with 6 in. by 11 in. Hyatt roller bearings with two rows of large-diameter solid rollers separated by a spacer ring. The inner ring is shrunk on the journal portion of the axle. Flanges are cast on the sides of the housing frame pedestals, thus allowing free vertical movement of the box under spring action. The pedestal ways are fitted with renewable heat-treated steel liners welded to the box. The thrust bearing consists of steel backing on which is cast a thrust face of bronze which transmits the lateral thrust to a neoprene rubber cone resilient thrust unit, the purpose of which is to cushion and absorb the lateral movement of the axle. Maximum wear limit at the thrust bearing is $\frac{1}{8}$ in., and to compensate for wear there are five $\frac{1}{32}$ in. shims between the housing and the front cover.

Brakes

Both straight and automatic air brakes are provided, and equipment is of Westinghouse type A7EL. The driver's brake valves are mounted in a pedestal on the left-hand side of the driving cab within easy reach of the driver. Where hostler control is fitted equipment is duplicated to allow control of the locomotive from the rear end. Normally the reducing valve is set for 45 lb. per sq. in. maximum, and this represents the maximum brake cylinder pressure available by use of the straight brake. The feed valve supplying the brake pipe is set at 70 lb. per sq. in. and an automatic brake valve admits a corresponding pressure application in the brake cylinders. Each wheel is fitted with 14-in. brake shoes which are actuated by a 9-in. diameter single-acting brake cylinder providing approximately 68 per cent. braking ratio. A hand parking brake is located at the rear of the engine room and is connected to one brake cylinder lever on the trailing bogie.

Air for the operation of the locomotive braking system is supplied by a three-cylinder (one h.p. and two l.p.) two-stage, air-cooled Gardner Denver model WXE compressor, driven from the diesel engine through a flexible coupling. The compressor has a displacement of 60 cu. ft. at engine idling speed (275 r.p.m.) and 186 cu. ft. at 835 r.p.m., and the air is stored in four main reservoirs which have a total capacity of 27 cu. ft. Air is also supplied to the locomotive control system at a pressure of 85 to 95 lb. per sq. in. Main reservoir pressure is 110 to 120 lb. per sq. in. and is controlled by the air compressor governor which acts on unloader pistons to keep the suction valves off their seats and so prevent any compression of air. The maximum demand of the air compressor on the engine is approximately 35 h.p. at 835 r.p.m.

Power Equipment

All power for the operation of the locomotive is developed by a General Motors type 567-C engine with 16 cylinders $8\frac{1}{2}$ in. by 10 in. in two banks with an included angle of 45 deg. and running at a top speed of 835 r.p.m. Dry weight is about $14\frac{1}{2}$ tons, or 17 lb. per b.h.p. A complete description of the 567-C engine was given in our issue of November 1955 and details of construction need not be repeated here. Scavenging is uniflow with air supplied by two gear-driven Roots blowers which deliver 2,900 cu. ft. of air per min. per blower at full engine speed, and at a pressure of approximately 4 lb. per sq. in. All air is drawn in through two 4-in.-thick air filters mounted above and on each blower housing. The engine is started by utilising the main generator as a motor. Special starting fields in the generator are energised by current supplied from the locomotive storage battery, which is of 64 volts with a capacity of 426 amp. hr. Starting speed is 75—100 r.p.m.

Engine Accessories

Water circulation through the engine cooling system is maintained by two centrifugal water pumps mounted on the front end of the engine, and driven by the governor drive gear. The pumps rotate at 2,546 r.p.m. at full engine speed, and each is capable of delivering 200 g.p.m. at approximately 26 lb. per sq. in. discharge pressure. Water from the pumps passes through the engine and into two banks of radiators mounted in parallel in a removable hatch in the roof above the engine. Four electrically-driven cooling fans are also located in this hatch, and each is thermostatically controlled to cut-in or cut-out according to engine water temperature.

Normal operating range of cooling water temperature is 160 to 180 deg. F. A fifth thermostat is so adjusted to protect against over-heating, and closes the circuit to illuminate a warning light and ring the alarm bell when the water temperature reaches 205 deg. F. Water used in the cooling system is specially treated to reduce mineral deposits and resist corrosion. A cooling-water tank is installed at the rear of the locomotive to provide a reservoir for water draining from the radiators when the engine is shut down, and a reserve of water to allow for evaporation. A branch line is installed to a cab heater to provide heating in the cab in cold weather.

Engine lubricating system comprises three individual systems: the engine lubricating system, supplying oil to various moving parts of the engine; the piston-cooling system, supplying oil for piston cooling and piston-pin bearing surface lubrication; and the scavenging oil system which supplies both systems with cooled and filtered oil. The scavenging oil pump is a positive-displacement helical gear-type pump driven by the accessory drive gear, and is capable of delivering 217 g.p.m. at full engine speed.

Oil is drawn from the engine sump through a scavenge strainer and forced through an oil filter containing four elements, and an oil cooler, where heat is extracted by the engine cooling water, before passing into the strainer housing. Filtered and cooled oil is drawn from the strainer housing by the piston-cooling and lubricating-oil pumps, which are contained in one housing but separated by a dividing plate and driven also by the accessory drive gear. The lubricating oil pump can deliver 122 g.p.m. at full engine speed with oil pressure usually from 30 to 50 lb. per sq. in. at full speed and 16 to 25 lb. per sq. in. at idling speed. A mechanism is incorporated in the engine governor to protect against low oil pressure or high suction, and will act to shut down the engine. Warning is given by illumination of a low-oil light on the engine starting panel and ringing of the alarm bell.

Fuel oil is drawn from the fuel tank and passes through suction filters before entering the fuel pump which is driven by a ½ h.p. motor at 1,100 r.p.m. The fuel then passes via a discharge filter and sintered bronze filters to the injectors. A return fuel sight glass on the sintered bronze filter housing has an orifice inlet and maintains a fuel back pressure of approximately 5 lb. per sq. in. on the injectors. In the event of dirty filters a second sight glass shows fuel by-passing the elements and returning to the fuel tank when relief valve pressure of 45 lb. per sq., in. is reached.

TABLE II

Throttle Notch Position	Speed r.p.m.	SOLENOID ENERGISED			
		A + 80 r.p.m.	B + 320 r.p.m.	C + 160 r.p.m.	D —160 r.p.m.
STOP					•
IDLE	275				
1	275				
2	355	•			
3	435			•	
4	515	•		•	
5	595		•	•	•
6	675	•	•	•	•
7	755		•	•	
8	835	•	•	•	

Engine Regulation

The diesel engine is equipped with a Woodward P.G. electro-hydraulic governor which performs four main functions: (1) To give engine speed change, *i.e.* throttle control; (2) To maintain constant engine speed regardless of load; (3) Generator load control; (4) Engine protection in case of lubricating oil pressure failure.

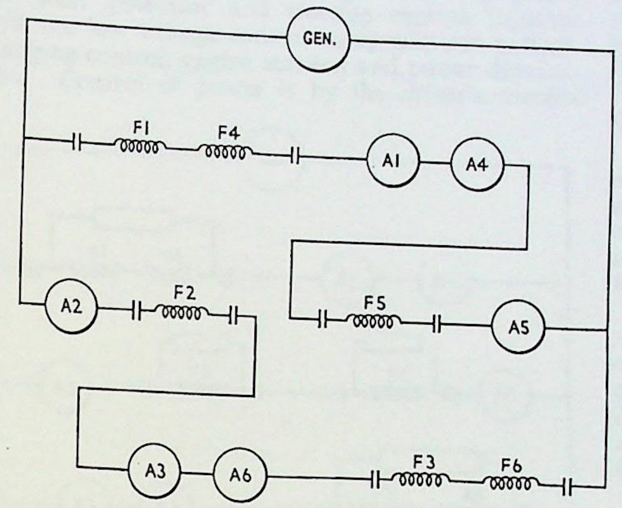
The governor is mounted on the front of the engine and is driven by the governor drive gear of the accessory drive gear train. The main parts of the governor are: a speed-sensing arrangement (speeder spring and flyweights), fuel adjustment control (power piston), compensating mechanism (compensating land integral pilot valve), and an independent oil system (oil sump, oil pump, accumulators and connecting passages). Manipulation of the engineman's throttle controls the speed of the engine by energising four solenoids contained in the governor. When the throttle is opened to notch one, it brings the main generator to life and thus provides current flow to the traction motor. All succeeding seven notches act on the governor solenoids, each notch causing an 80 r.p.m. increment in engine speed with corresponding increases in engine and generator output. Speed variations between 275 and 835 r.p.m. are produced by energising different combinations of the solenoids as shown in Table II.

When the throttle position is changed, *i.e.*, when different solenoids are energised, the position of the speed-setting piston is altered, causing the speeder spring to move the flyweights and change the position of the power piston pilot valve plunger. Because this plunger controls the oil pressure acting under the power piston, its movement causes a resultant movement of the power piston which varies the quantity of fuel supplied by the injectors, thus regulating engine speed to its new value. The new engine speed then causes the flyweights to resume their equilibrium position and centres the plunger and cuts off the oil port to the underside of the power piston.

To prevent hunting of the engine, after the power piston has moved sufficiently to effect the desired speed change, its final movement is controlled by oil leaking past the compensating mechanism. The governor also acts in a similar manner to maintain the particular engine speed irrespective of changes in loading. Simultaneously, the load control mechanism is functioning to change the excitation of the main generator so that the engine will carry the correct amount of load for the particular speed setting.

The resultant movement of the power piston to maintain constant engine speed due to change in generator load causes, by means of a connecting linkage, the position of the load control pilot valve to change, permitting oil to flow from the engine lubricating oil system to a servo-motor operating a load regulator, to change the excitation of, and consequently the demand by, the main generator on the engine. When generator load again equals rated engine output the control pilot valve will assume the balance position, and the load regulator, and hence main generator excitation, will remain at their new setting. The resultant action of the governor on the engine when throttle is untouched is to keep the h.p. output and engine speed constant for a given throttle position.

Incorporated with the load-control mechanism is an over-riding solenoid which over-rides normal pilot



Stage I—Series-parallel grouping for starting and heavy pulling, Clyde-G.M. Co-Co locomotive

valve (load regulator) control and reduces generator excitation during transition, wheel slippage, and when the throttle is returned to idle. When energised, the solenoid permits governor oil to flow from the pump to the underside of an over-riding piston. This piston, together with the load regulator pilot valve, rises and allows engine oil to flow to the load regulators moving it to decrease the excitation of the main generator.

Electric Transmission

The main components of the electric transmission are an Electro-Motive type D.12 main generator, which provides nominal 600-volt direct-current supply to six D.37 type traction motors, grouped:

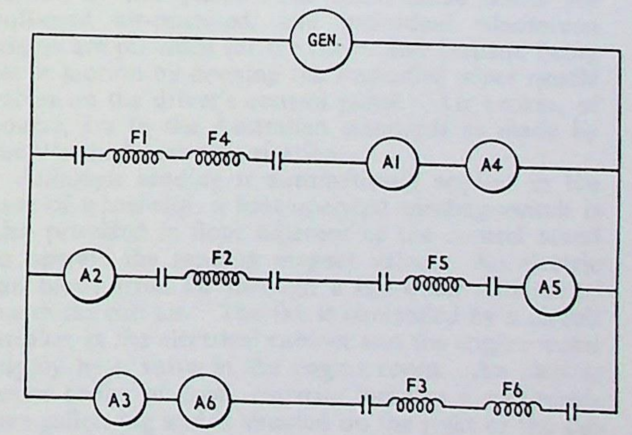
(1) Series-parallel—stage 1, for starting and heavy pulling, two parallel groups of three motors in series.
(2) Series-parallel—stage 2, for normal running, three parallel groups of two motors in series.
(3) Stage 2, series-parallel with 46 per cent. shunting of motor fields, for higher speeds.
(4) Stage 2, series-parallel with 74 per cent. shunting of motor fields, for still higher speeds.

These four types of traction-motor electrical-circuit connections are used so that full power may be obtained at all times from the main generator without exceeding its current and voltage limits. The generator capacity is such that the rated output of the engine, under all conditions, can be transmitted continuously. Transitions are effected automatically. The load regulator is an automatically-operated rheostat connected in series with the main generator exciting field, the battery field (this is a low-voltage 74-volt d.c. externally excited field, current supply being from the auxiliary generator), and operates to create and maintain a pre-determined power output for each throttle position.

The main generator which has a continuous rating of 2,200 amp. is a d.c. machine whose armature is carried by a self-aligning double-row spherical roller bearing in the commutator end housing, and is directly connected to the engine crankshaft through a flexible coupling, being supported at this end by the engine crankshaft rear main bearing. Engine and main generator are mounted directly on to the locomotive underframe, and proper operation of the power plant necessitates careful alignment of generator armature and frame with engine crankshaft, and minimum eccentricity at the coupling is essential. There are six types of field windings, comprising starting, differential, shunt, battery, interpole, and compensating. A coupling flange at the commutator end of the armature serves as the power take-off for the air compressor.

Built integral with the main generator is a D14-type 80-kW 150-volt three-phase 16-pole alternator, which supplies alternating current for driving the 9 h.p. induction motors of engine cooling water fans and 5 h.p. electrically-driven traction motor blowers. The stator assembly is bolted directly to the main generator frame, and the rotor or rotating field assembly directly to the armature spider. This machine is also the source of current supply for the two 9 h.p. motor fans when engine room pressurising is installed as in the Commonwealth Railways locomotives. Both the generator and alternator are force-ventilated, being cooled by an impeller driven by one end of the auxiliary generator shaft. Weight of main generator complete is 17,710 lb.

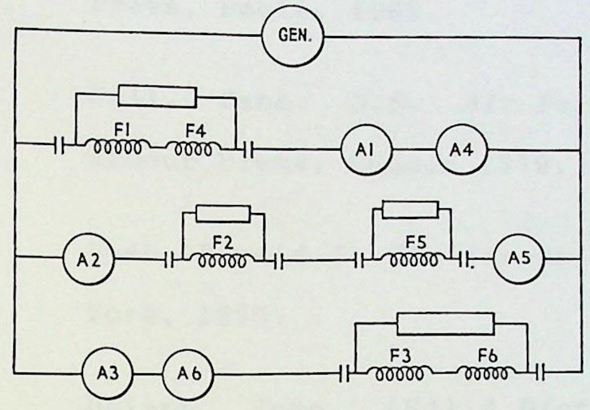
D.37-type traction motors are d.c. nose-suspended series-wound roller-bearing type force-ventilated machines. There are three points of suspension, two of which are the two axle-suspension bearings. These are of the split-shell type and are lubricated by felt wicks, oil being contained in the suspension bearing cap. The third suspension point consists of a nest of suspension springs supported by the truck



Stage II—Series-parallel grouping for normal running frame. Motor pinion and axle gears are contained in a gearcase constructed in two halves which are sealed against ingress of foreign material. Cooling air for the leading bogie traction motors is delivered by a blower directly driven from the diesel engine, whereas the three rear bogie motors are cooled by individual blowers driven by current from the alternator.

Control

The electrical cabinet at the rear of the main driving cab houses the high-voltage control equipment for main generator and traction motors together with the low voltage control equipment for battery-charging control, engine starting and power distribution. Control of power is by the driver's throttle



Series-parallel grouping with 46 per cent. shunt of motor fields, for higher speeds; and, finally, series-parallel grouping with 74 per cent. shunting of motor fields for the highest part of the speed range Clyde-G.M. 1,900 b.h.p. Co-Co locomotive

in two ways. Firstly, when opened to notch one, it completes circuits through the electrical cabinet to bring the main generator to life and allow current to flow to the traction motors. The main generator is connected to the motors by the power contactors, which are pneumatically-operated heavy-duty single-pole switches with a 1,200-volt 800 amp. rating. All succeeding notches increase engine speed and consequently the pulling power of the locomotive.

As engine and locomotive speeds increase, the forward transition changes are initiated automatically by the forward transition relay, which picks up when the main generator output reaches a pre-determined tension of approximately 960 volts. The sequence of events results in a change in power contactors such that the traction motors are connected in parallel with the main generator. Action of control relays is such that all power is automatically reduced momentarily when transition occurs.

As train speed increases and generator voltage again builds up to the pre-determined value a field shunting relay operates to connect shunts across the traction motor field windings. The final stage of field shunting occurs at approximately 38 m.p.h. As locomotive speed is reduced with a corresponding reduction of voltage the field shunting contactors open; and when the current flow from the main generator reaches a pre-determined value, approximately 2,100 amp., the backward transition relay operates and changes the traction motor connections from series-parallel to series.

When dynamic braking is fitted, a second electrical cabinet is located at the rear of the engine room, and houses the rear bogie brake transfer switch. Front bogie transfer switch is housed in the main electrical cabinet. Dynamic brake operation is regulated by a contact lever mounted in the driver's control pedestal. This lever is mechanically interlocked with the throttle so that braking cannot be effected unless the throttle occupies idle position. When moved to brake, the lever acts on the brake-transfer switches and connects the motor armature to the braking grids and establishes braking fields. The degree is then regulated by manipulation of the selector lever.

Cab Equipment

The control stand is located on an elevated section of the main cab floor and locomotive controls are arranged for left-hand driving. There is an upholstered driver's seat with arm rests adjacent to the controller, and a second similar seat at the other side for the assistant driver.

The reversing handle has three positions: forward, neutral, and reverse; and it must be inserted in the controller before operation can be commenced. The controller levers are mechanically interlocked so that: (1) throttle cannot be opened if (*a*) reverser handle is removed; or (*b*) selector lever is in brake position; (2) reverser handle cannot be moved if (*a*) throttle is open or in stop, or (*b*) selector lever is in brake position; (3) reverser handle cannot be removed or inserted unless (*a*) throttle is in idling position and (*b*) selector lever is in off position; (4) selector lever cannot be moved to any position with the throttle open; (5) selector lever cannot be moved to brake position with the reverser handle in neutral.

Mounted on a bracket behind the controller is a speed indicator and recorder driven by a flexible cable from the centre axle of the leading bogie. Located in front of the driver is the Westinghouse A7EL brake pedestal consisting of automatic and straight brake valves. Directly behind this is the driver's control panel, housing traction motor load-indicating meter, Westinghouse air brake gauges, alarm lights for ground relay, brake warning, and wheel-slip indication. Circuit breakers for engine control and locomotive lights are also contained in a section of this panel. The multi-chime horns are pull-cord air-operated, and individual windscreen wipers are provided for the driver and fireman, being set in motion by opening the respective wiper needle valves on the driver's control panel. Air brakes, of course, are to the Australian standards as made by the Westinghouse organisation.

Although sanding is automatically applied in the case of wheel-slip, a foot-operated sanding switch is also provided in floor adjacent to the control stand to operate the sanding magnet valves. An electric fan blows fresh air through a hot-water radiator to warm the cab air. The fan is controlled by a circuit breaker in the electrical cabinet and the engine water supply by a valve in the engine room. An electric water cooler of 2-gal. capacity includes a removable one-gallon jug and is situated on the right of the cab to nose compartment door. The sandboxes are frame-mounted in the nose, and against the side walls.

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