BUS AND COACH DESIGN FOR NEW ZEALAND CONDITIONS

A. J. WILKINSON B.E. (Hons), M.I. Mech.E., M.S.A.E., M.I.R.T.E.N.Z., J.P.

1-1-1 Synopsis

This paper investigates the requirements for coach operation in New Zealand in terms of axle loadings, dimensions, annual distance covered and terrain and compares these with overseas requirements. A detailed investigation is made of the various loadings and components required.

The conclusion drawn is that New Zealand requirements differ markedly from those overseas, and that considerable savings can be made in operating costs by examining New Zealand requirements in detail.

2-1-1 Scope of Paper

Bus and coaches could be roughly divided into 6 catagories:-

1) Light two axle units used for school bus runs and passenger transport in small cities and towns.
2) Mini Buses.
3) Heavy duty urban buses as purchased by the larger cities.
4) Two axle tour coaches.
5) Three axle tour coaches.
6) Combination freight-passenger vehicles - "combi's".

This paper deals with the last three types.

3-1-1 Design Requirements

It is a requirement of the Ministry of Transport regulations that the bus be designed to be legally loaded with all possible combinations of loadings. That is:-

a) Part loaded with passengers.

b) Fully loaded.

c) Part loaded with passengers and freight and/or luggage.

A. J. Wilkinson is Chairman of Directors of Tasman Special Vehicles Limited of Cambridge.

The best way to accommodate the variable loads and to get the best ride is to make the wheelbase as long as possible. This is particularly important with passenger/freight combination units.

4-1-1 Design Loadings

The weight requirements (listed in Table 1, Page 3) have been constructed from a survey made of chassis available in New Zealand.

The bare chassis weights quoted are an average of those commonly available in each class.

In other words, by choosing the right chassis a considerable weight saving can be made.

4-1-2

The second factor which comes into the design is the weight figure used in arriving at the pay load.

In this area some differences occur between the figures specified by the Ministry of Transport in the regulations and those that actually apply.

Although the Ministry of Transport do specify standard figures for weights of passengers and luggage it does not necessarily exempt an operator from being prosecuted should his pay load of passengers and luggage cause the coach to exceed the limits.

4-2-1 Design Weights for Passengers

The Ministry of Transport weight for coaches	=	63.5 kg
The Ministry of Transport weight for omnibuses (including luggage)	=	68.0 kg
The Airline standard figure	=	77.0 kg
The Airline figure for special loads (e.g. a football team)	=	93.0 kg

TABLE No. 1					
DESIGN WEIGHTS					
	TWO AXLE			THREE AXLE	
	M.O.T. REGS		DESIGN WEIGHTS	M.O.T. REGS	DESIGN WEIGHTS
	UNDER 150 KW	OVER 150 KW		-	-
CHASSIS	4,100	5,840	5,840	6,650	6,650
BODY	4,900	5,040	5,040	5,040	5,040
DRIVER	64	64	64	64	64
PASSENGERS	-	-	-	-	-
@ 63.5 kg	-	2,858	-	2,858	-
@ 77.0 kg	-	-	3,465	-	3,465
@ 68.0 kg	3,060	-	-	-	-
LUGGAGE	INCL	605	2,160	605	2,160
TOTAL WEIGHT	12,124	14,407	16,569	15,217	17,379
M.O.T. LIMIT					
CLASS I	13,600	13,600	13,600	17,400	17,400
CLASS II	12,700	12,700	12,700	16,400	16,400

4-2-2 Design Weights for Luggage (per passenger)

The Ministry of Transport	= 13.5 kg
The Airlines allowance - economy	= 22.0 kg
- first class	= 30.0 kg
Ministry of Transport figure (all luggage space)	= 240 kg/m³
The Airlines use for luggage space	= 214 kg/m³
Bundled newspaper weight out at	= 600 kg/m³

The design requirement for luggage space for a tour bus is approximately 9 cubic metres or a pay load of 2160 kg (M.O.T. Figure).

4-4-1 Axle Loadings - Legal

Two Axle Bus

	N.Z. Regs		Overseas
	Class I	Class II	
Front Axle	5,400	5,400	6,000 Approx
Rear Axle	8,200	7,300	10,000 Approx
	13,600	12,700	16,000

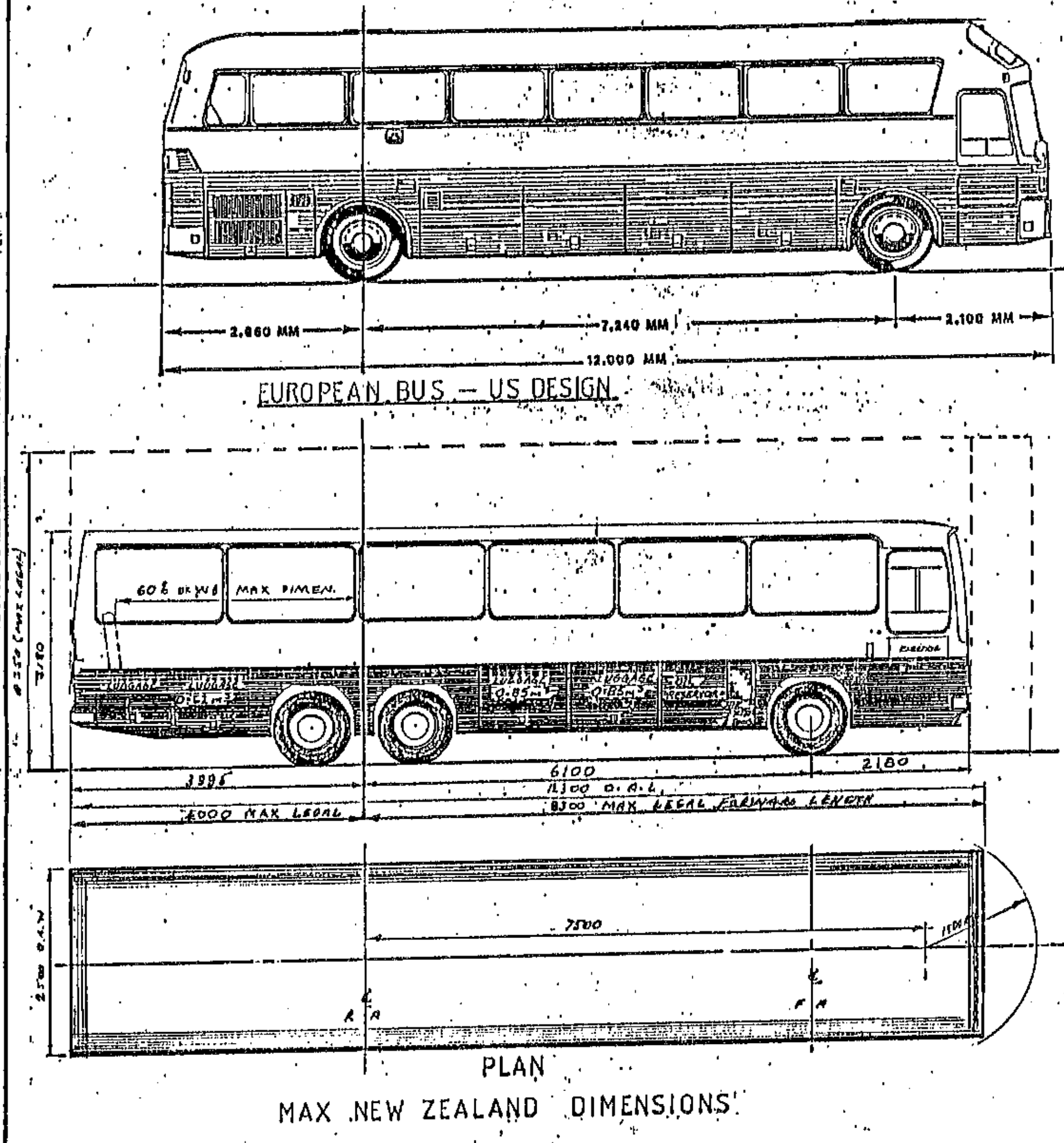
Three Axle Bus (two single tyred, one dual tyred axle)

Front Axle	5,400	5,400
Rear Bogie	12,000	11,000
	17,400	16,400

Dimensional limits are shown on Drawing 1, Page 5.

The table indicates for a 3 axle coach a considerable disparity in design requirements:- (see table 1, Page 3)

a) Strictly to minimum M.O.T. requirements	G.V.M.	15,217 kg
b) To Airline figures and 9m³ luggage capacity		17,379 kg
Possible extra load		2,162 kg



COMPARISON OF
NEW ZEALAND AND OVERSEAS
DIMENSIONAL LIMITATIONS

DRG 1
PAGE 5

DRG Nº
PAGE

The table would indicate that a two axle unit is not practical for tour work, and is only usable when the passenger load is a mixture of adults and children. In other words, if a party of 45 American tourists disembark from a Boeing 747 and climbed into an N.Z. bus, in all probability, the coach could be overloaded by some 2 tonnes.

Certain factors in the design are fixed:-

1. Front overhang (min. of 2100 mm for body builders needs).
2. Rear overhang (4000 to gain maximum length).
3. Wheelbase (long as possible for best ride).
4. Front and rear axle weights (to maximum legal).
5. Body weight (approximately 410 kg/m for a tour coach).
6. Passenger weight (see paragraph 5-2-1).

5-1-1 Operator's Requirements

a) Good profitability.
b) Compliance with all legal requirements.
c) Good passenger appeal.
d) Low first cost.
e) Low running costs.
f) Good fuel costs.
g) Good access for maintenance.

5-2-1 Passengers Requirements

a) Good ride and seating.
b) Good visibility.
c) Quiet.
d) Easy access.

e) Good ventilation.

f) Good luggage storage.

5-3-1 Driver's Requirements

a) Good control.

b) Good visibility.

c) Easy access for daily service routine.

d) Easy access for spare wheel.

e) Easy access for baggage.

6-1-1 Operating Environment

It becomes apparent that the environment in New Zealand is considerably different from most overseas.

The variable factors include:-

1. Axle Loadings. Low legal axle loadings (by overseas standards).

Max. legal Class I 5.4 on single tyred axles.

8.2 on dual tyred axle.

2. Low Annual Mileage. Many buses do fewer than 50,000 kilometres per year, and very few exceed 100,000 kilometres per year.

6-2-1 Terrain

Distances travelled are relatively short, and in parts of the country the roads are steep, narrow and winding, and on many routes unsealed. In the South Island snow and ice is commonly encountered.

High road camber also seems to be a factor particularly on our outback class two roads.

Drawing 1, Page 5 shows the layout of a typical Europe and U.S. Bus as compared with a New Zealand one.

The N.Z. design is shown with a 2 axle rear assembly but the dimensions would not alter for a single axle one.

Front overhang remains the same, the two important differences between the oversea product and ours being the wheelbase and the rear overhang. The wheelbase in New Zealand is restricted to a maximum of approximately 6000 - 6400 mm because of turning circle limitations. The overseas product goes out to over 7000 mm and presumably does not have the same turning restrictions. In the New Zealand case the rear overhang of 4 metres far exceeds that of the U.S. product 2660 mm.

This large rear overhang and low axle loadings require the designer to make the wheelbase as long as possible in order to reduce the effect of variations in loading.

7-1-1 Third Axles

The majority of three axle coaches are fitted with single tyred trailing type tag axles loaded on a 70/30 loading basis. The alternative is to fit the third axle as a pusher.

The advantages of the pusher are as follows:-

1. Reduce rear overhang. That is the driving axle carrying the greater weight is further under the load.
2. Reduced weight transfer under variations of loading.
3. Reduce pitching movements on rough roads.
4. Better ride and traction.

7-2-1

With a trailing type tag axle, because the spring rate of the tag is lower than that of the driving axle, when pitching occurs, then the tag has much less resistance to the pitching movement than the driving axles.

7-3-1

With the axles reversed, that is with the driving axle at the rear, the pitch movement is quickly dampened down.

The disadvantages of the pusher axle are:-

1. More difficulty to achieve turning circle requirements.

2. More expensive installation due to the need to provide a drop centre for the axle to clear the driveshaft.

7-4-1

Drawing No. 2, Page 10, illustrates the situation. The advantages show up particularly on combination freight/passenger units where the road distribution can vary widely.

Table 2, Page 10 shows the difference in loadings on a "combi" unit for pusher or tag axle.

Care should be taken in the design to achieve the correct distribution of weight and of brake balance.

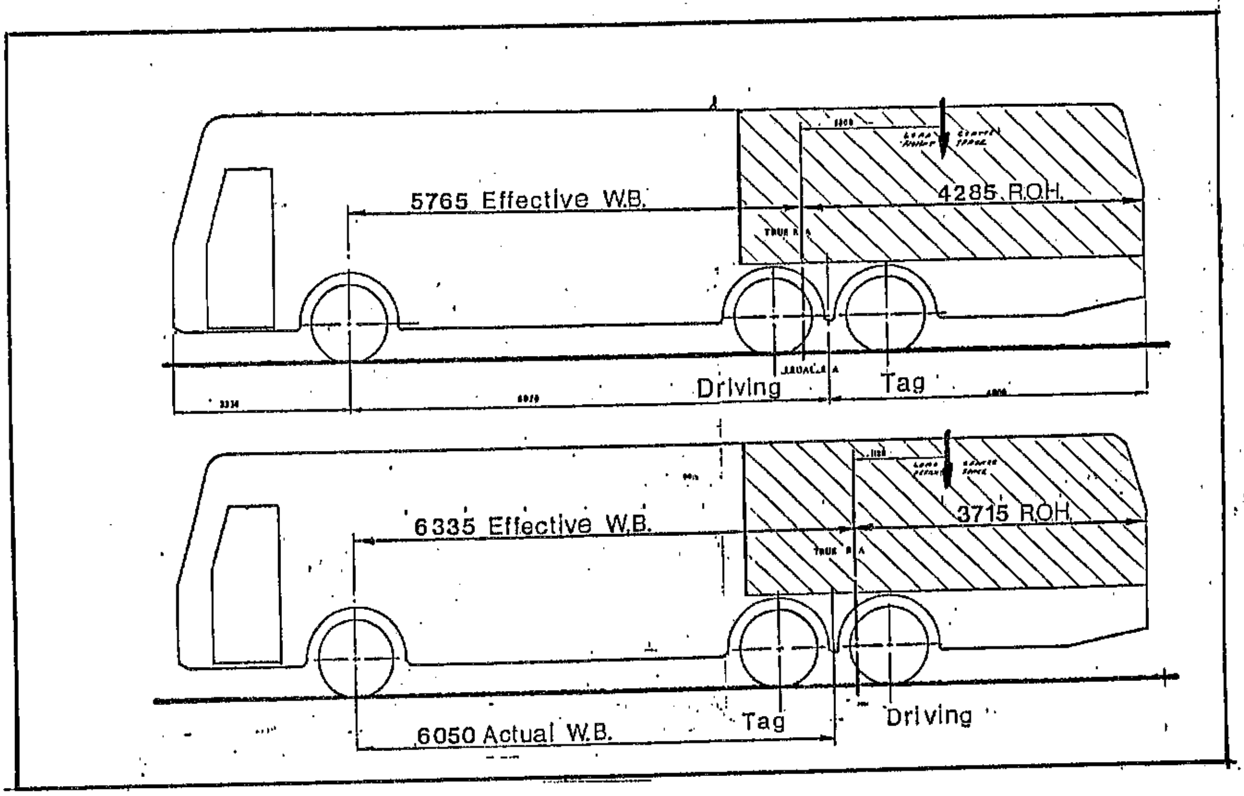


TABLE 2
WEIGHT DISTRIBUTION COMPARISON
THREE-AXLE FREIGHT - PASSENGER COACH

TRAILING THIRD AXLE (30/70 LOADING)	FRONT	REAR	TOTAL
FULLY LADEN	4362	[12637]	16999
NO PASS. ALL FREIGHT	[3305]	[12198]	15503
22 PASS NO FREIGHT	[5639]	6835	12474
LEADING THIRD AXLE (30/70 LOADING)	**FRONT**	**REAR**	**TOTAL**
FULLY LADEN	5098	11900	16999
NO PASS ALL FREIGHT	4000	11499	15503
22 PASS NO FREIGHT	5358	7116	12474
CLASS 1 MAX LOADING	5400	12000	17400

NOTE THIS TABLE WORKED OUT ON THE REQUIREMENT THAT NOT LESS THAN 25% OF G.V.M IS ON FRONT AXLE AT ALL TIMES. THIS FIGURE IS NOW 30%

NOTE FIGURES MARKED THUS [3305] ARE OUTSIDE LEGAL LIMITS

8-1-1 Location of Power Pack

The major components whose location cannot be varied very much in a coach are:-

a) The front and rear axles.

b) The luggage space.

c) The passenger seating.

d) The driver's position.

Five other items, namely engine, transmission, battery, fuel tank and spare wheel can be positioned to the best advantage in weight distribution.

8-2-1

In order to arrive at the best position for these units we have examined weight distribution of a chassis less power train for the following cases, each designed to take 45 passengers and in the case of the three axle units having nine cubic metres of luggage space:-

a) Two axle bus.

b) Three axle unit with mid-mounted engine.

c) Three axle unit with rear mounted engine.

(See Drawing No. 3, Page 12).

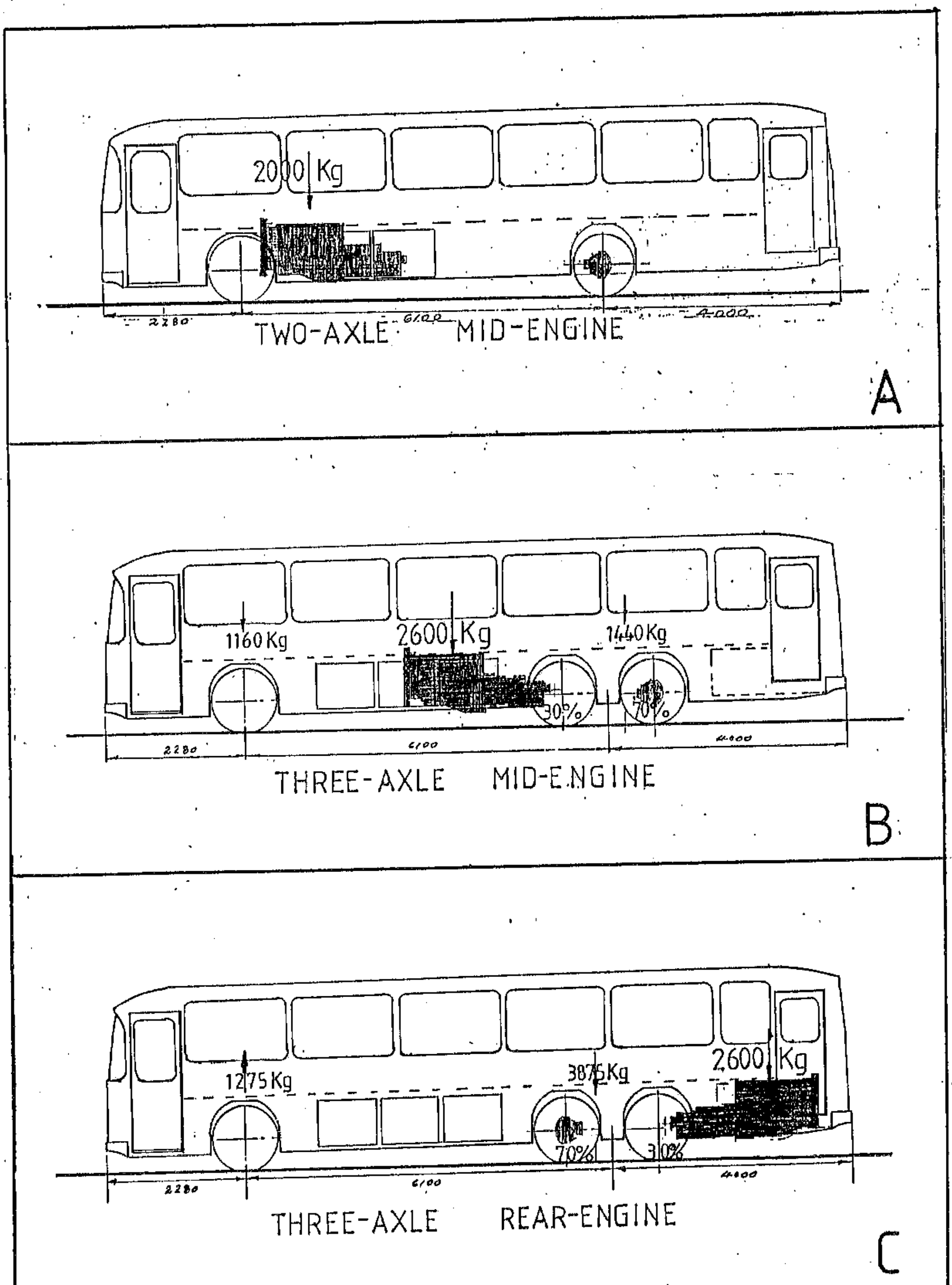
In the case of the mid-mounted unit the design incorporates a leading third axle.

In the case of the rear mounted unit, dimensional limitations dictate that the third axle probably has to be a trailing, being mounted between the driving axle and the transmission.

8-3-1

The calculations indicate as follows:-

1. For the two axle unit the best position for the engine and the transmissions is as close as possible to the steering axle.
2. For the three axle mid-mounted unit the best position for the engine



BEST POWER-PACK LOCATION

DRG 3
PAGE 12

and transmission is as close to the rear axle as possible.

8-4-1

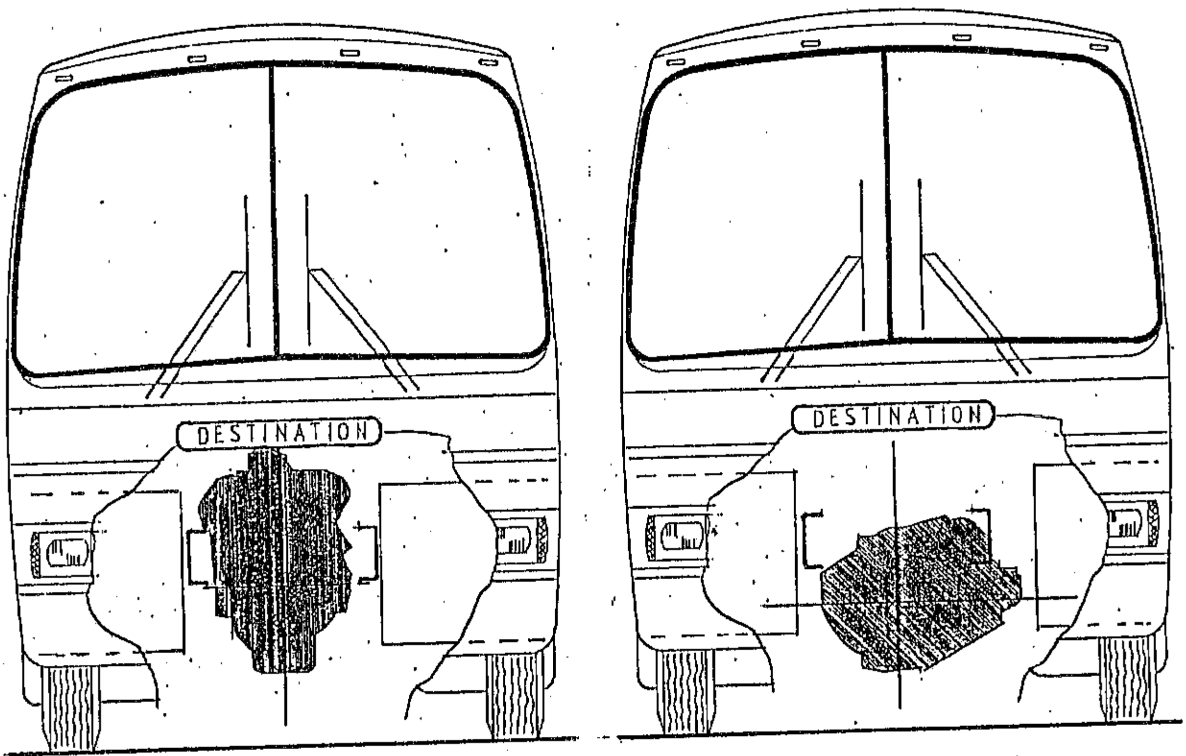
On further examination this turns out to be a very good location for the engine because:-

1. A short single piece driveshaft can be used, reducing weight and vibration problems.
2. The rear of the coach is available for a large walk in the type boot making luggage unloading easy for the driver.
3. Because the heavy mass of the engine and transmission is as close to the centre of gravity of the bus, it helps reduce the variation in axle loadings between empty, part laden and fully laden.
   It also reduces the loads on the suspensions when traversing over undulating roads.
4. Low engine noise in passenger compartment.
5. Reduced steering effort.
6. Better ride because the engine-transmission mass is as close as possible to the pitch centre of the chassis.
7. Because the engine is close to the rear axle, then it can be mounted lower without reducing safe ground clearance and thus permitting a lower floor height.

9-1-1 Vertical or Horizontal Engine

Drawing No. 4, Page 14, is a study showing the same engine (Scania D.S. 9) mounted horizontally and vertically.

It would appear that there is no advantage in service access for the horizontal unit and it intrudes into the locker space on both sides. The vertical engine does appear to have the advantage.



VERTICAL ENGINE HORIZONTAL INSTALLATION

10-1-0 Suspension

10-1-1 Spring Suspension

This had the great advantage of its simplicity and low initial cost. With careful design, spring type suspensions can be made to give a very good ride. However, pressure from tourist operators are requiring that top line coaches be fitted with air suspensions.

10-2-1 Air Suspension

Air suspension does have the advantages in terms of ride because it does not have the interleaf friction of the multi-leaf spring suspension and the rate can be varied easily.

It has the advantages of:-

a) Better insulation between road and chassis.

b) Better ride, particularly over short, sharp bumps.

c) Lower body design height. There is no need to design an additional clearance of 50-100 mm in this body to allow for the difference between unladen and laden height as is necessary with spring suspensions.

d) The ability to raise the coach to give extra clearance over rough terrain.

e) The ability to raise the third axle if it is not required.

10-3-1 Combination Suspension

A third alternative is becoming available in conversion kits.

This is a system whereby the spring type suspensions are converted to semi-air units.

One system involves removing all but the top three leaves of the spring. The spring then acts as a locating device for the axle, and an air bag is included between the axle and the frame in order to provide the springing medium.

Care needs to be taken in designing these units, in order that roll resistance requirements are taken care of. These units when fitted to three axle coaches help improve load sharing between the two rear axles.

11-1-0 Luggage Space

The three axled units can be used for tour and main trunk work. It is the only unit which meets luggage capacity needs of the nine cubic metre of locker space (excluding combination freight-passenger units).

Luggage space can be obtained by:-

a) Side lockers.

b) Through lockers under the body in the case of chassisless construction.

c) Rear boot.

The through lockers are employed in the units with chassisless construction and rear engines. They are not popular with drivers, because stowing and retrieving is slow.

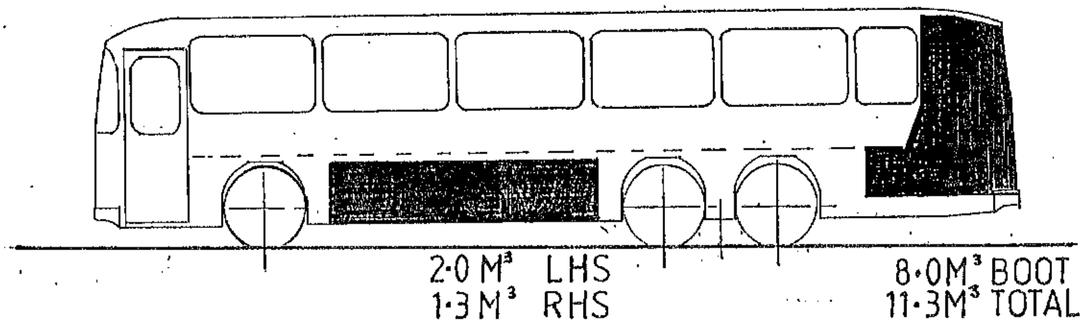
If the major components of the coach are laid out as indicated in Drawing No. 3B, Page 12, (being a mid-mounted unit), leaving the frame rails clear, then it is possible to achieve a 45 passenger and nine cubic metre of luggage space with easy access for the driver without resorting to through type lockers. See Drawing No. 5, Page 17.

The lockers along the left hand side give approximately 2.0 cubic metres. The right hand side 1.4 cubic metres, plus 7.00 m^3 in the boot. A total of 10.40 m^3.

As the depth of the side lockers is important, it is desirable that the body builder builds the back wall of the locker as close to the frame rails as possible.

12-1-1 Floor and Body Height

It appears to be the fashion at the moment to build tour coaches to a deck and one half height.



LOCKER SPACE

DRG 5
PAGE 17

BUS AND COACH DESIGN FOR NEW ZEALAND CONDITIONS - A. J. WILKINSON

As indicated above, it is not necessary to do this in order to achieve the necessary luggage capacity provided the main components of the coach are installed in the right positions.

Good economies can be gained by keeping the floor height as low as possible. These include:-

a) Reduced maintenance. Experience indicates that high buses have more front end maintenance, due possibly to operating on high cambered roads.

b) Better stability in cross winds.

c) Lower drag resistance.

It can be demonstrated that the annual savings in fuel by reducing the height of a coach by 300 mm equates to approximately $ 700.00 in fuel for an annual mileage of 50,000 km.

13-1-1 Entrance Design

The opportunity is available to vastly improve the step design on most coaches.

It should be remembered that the average tourist is often elderly, a little unstable on their feet and wears bifocal glasses.

If the engine is rear or mid-mounted, then there is not reason why a dropped frame cannot be installed at the front which gives the possibility of building in steps on a very easy grade.

The advantage for the operator is that the passengers load and unload quicker - a very important time factor on a tour bus.

14-1-1 Engines

In most cases the chassis is available only with the engine as produced by the chassis manufacturer.

However, in certain instances, engine options are available.

The operators should consider the weight, fuel economy, quietness and availability of spare parts.

Our study shows that the difference in fuel consumption between differing makes of engine can vary by as much as 10%.

This could represent annual savings of $1,600.00 over an annual mileage of 50,000 kilometres.

15-1-1 Brakes

Air braking systems are now virtually universal on heavy duty tour coaches. However, in certain parts of this country retarders are desirable, and a number of options are available, these include:-

a) Cylinder head mounted engine brake.

b) Exhaust pipe slide valve.

c) Electrical drive-line brake.

d) Hydraulic brake built into the transmission.

The last two bear a penalty in terms of weight and cost, and the operator would need to evaluate them carefully.

16-1-1 Rear Axle

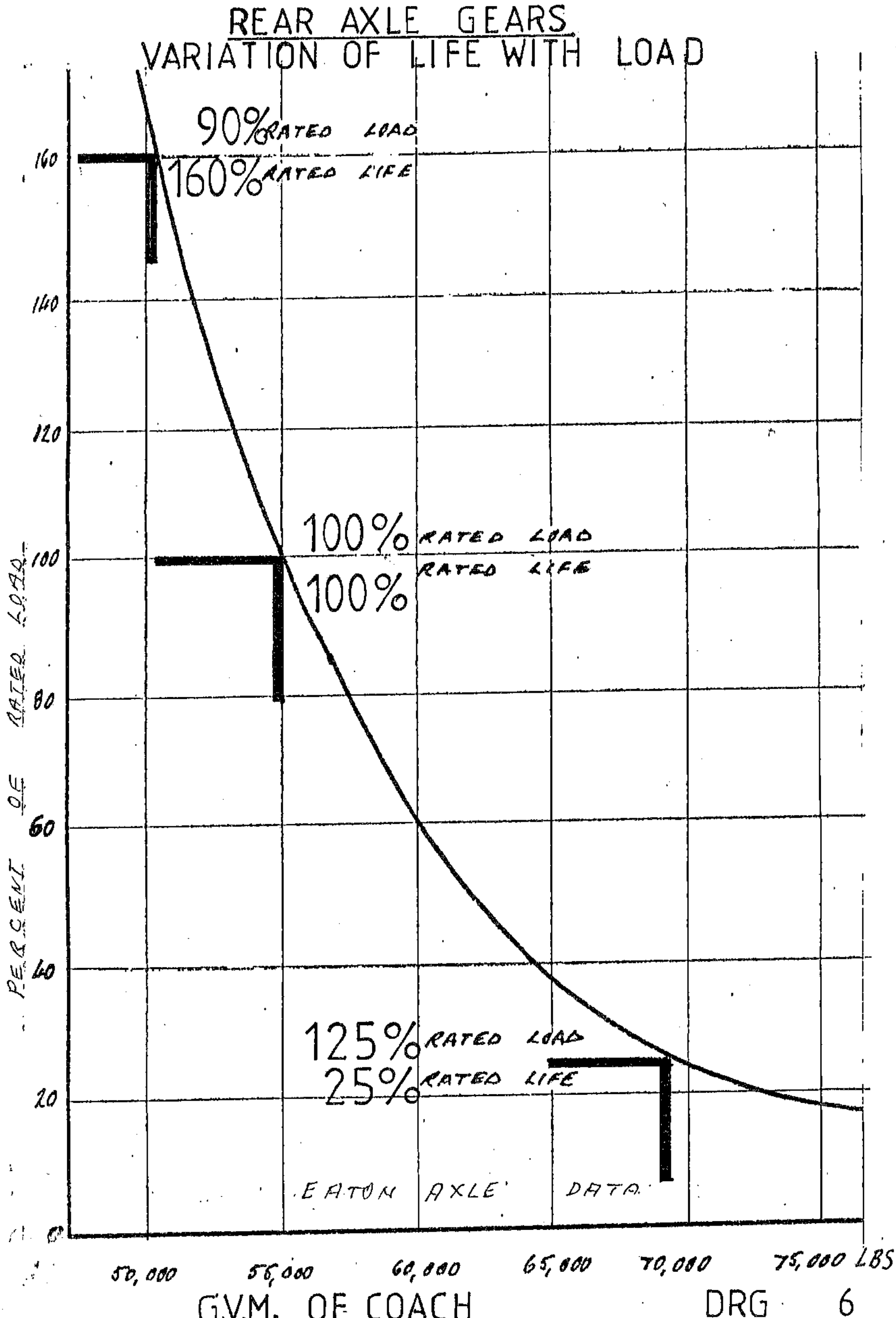
It is most important that the rear axle be correctly sized for the job, neither being undersized nor oversized.

Drawing No. 6, Page 20, is produced by the Eaton Axle Company. It indicates the variation in life of the rear axle assembly in terms of rated load.

It indicates that a 25% overload leads to a 25% life.

The rear axle ratio should be chosen so that the engines can be run at the speed for the best economy under New Zealand speed limitations.

Considerable savings can be made in fuel costs by paying attention to this detail.



REAR AXLE GEARS
VARIATION OF LIFE WITH LOAD
90% RATED LOAD
160% RATED LIFE
100% RATED LOAD
100% RATED LIFE
125% RATED LOAD
25% RATED LIFE
EATON AXLE DATA
PERCENT OF RATED LOAD
160
140
120
100
80
60
40
20
0
50,000
55,000
60,000
65,000
70,000
75,000 LBS
G.V.M. OF COACH

DRG 6
PAGE 20

BUS AND COACH DESIGN FOR NEW ZEALAND CONDITIONS - A. J. WILKINSON

17-1-1 Conclusion

The conclusion which can be drawn from this study is the following:-

17-1-2

That all those that are involved in specing, building and operating coaches should be aware of the fact that their number one priority is to satisfy the customer.

Suggestions have been made in regard to improving access, ride etc. to this end.

17-1-3 Wheelbase

That a wheelbase should be as long as possible because:-

1. It improves ride.
2. Reduces axle load variations.
3. Allows for maximum rows of seats. (See 60% rule, Page 5).

17-1-4

The other point which becomes apparent is that the purchase of a coach chassis and its subsequent fitting up contains a number of important variables all of which can work to the detriment or betterment of the operator's finances.

For example savings can be made as follows:-

	Item	Approx. Annual Savings
a)	Reduced drag from reduced height	$ 700-00
b)	Best fuel consumption from engine	$1,600-00
c)	Reduce weight (1000 kg) fuel savings	$ 900-00
d)	Reduce weight and R.U.C.	$1,665-00
	Total Annual Savings =	$5,865-00

17-1-5

The designer should also look at the design loading figures quoted in Table 1, Page 3.

BUS AND COACH DESIGN FOR NEW ZEALAND CONDITIONS - A. J. WILKINSON

While it may appear that the regulations allow a theoretical figure for the loading of a coach based on the weight of the passenger, the designer and the operator needs to consider other factors which include:-

1. Manufacturer's rating for the axles.
2. Manufacturer's rating for the tyres.
3. Road user license figures.
4. Proportion of weight on the front axle.
5. Braking ability.

A responsible operator will give carful consideration to all the factors mentioned in this paper.