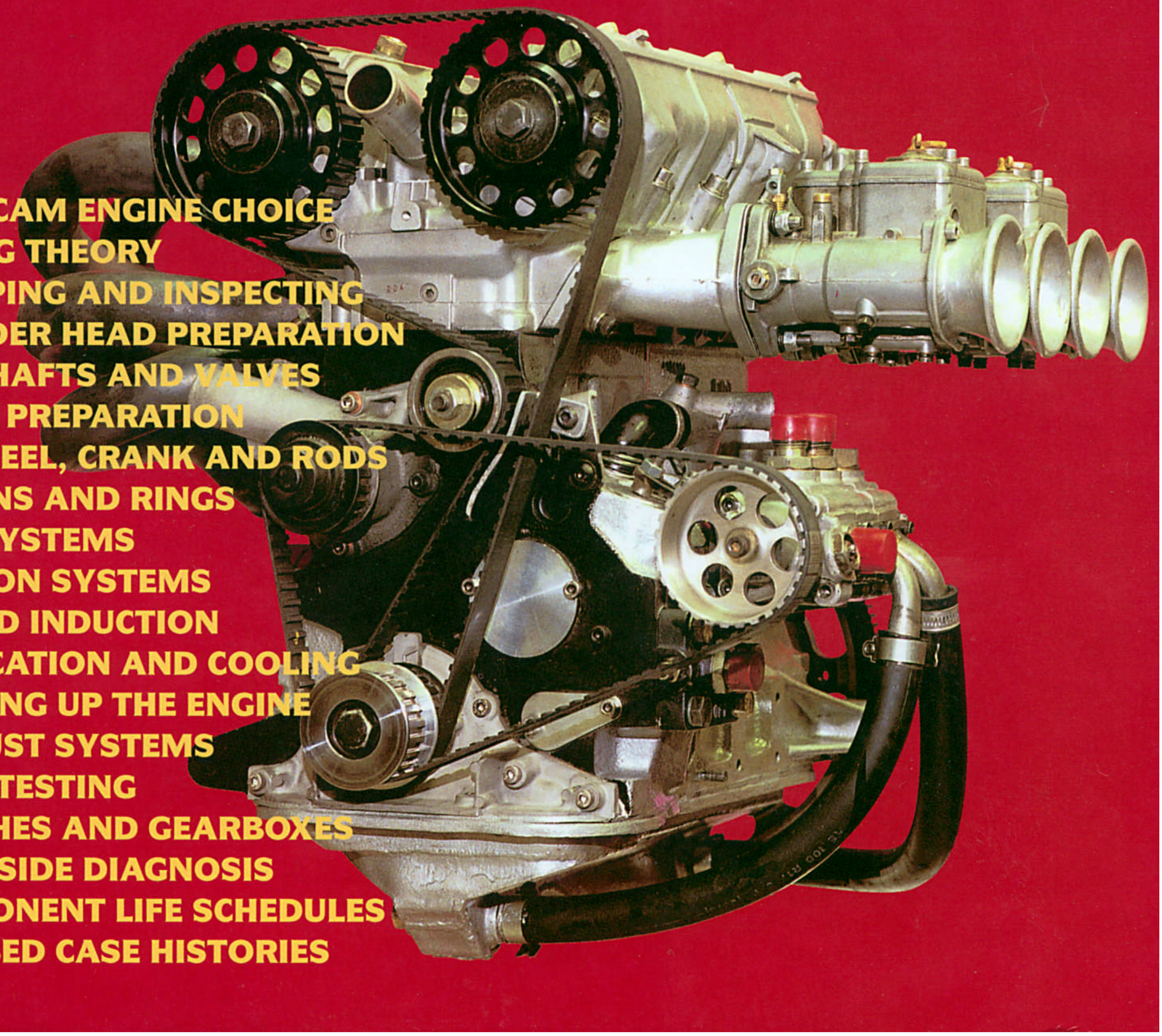
THE Guy CROFT WORKSHOP MANUAL

MODIFYING AND TUNING FIAT/LANCIA TWIN-CAM ENGINES



TWIN-CAM ENGINE CHOICE
TUNING THEORY
STRIPPING AND INSPECTING
CYLINDER HEAD PREPARATION
CAMSHAFTS AND VALVES
BLOCK PREPARATION
FLYWHEEL, CRANK AND RODS
PISTONS AND RINGS
FUEL SYSTEMS
IGNITION SYSTEMS
FORCED INDUCTION
LUBRICATION AND COOLING
BUILDING UP THE ENGINE
EXHAUST SYSTEMS
DYNO TESTING
CLUTCHES AND GEARBOXES
TRACKSIDE DIAGNOSIS
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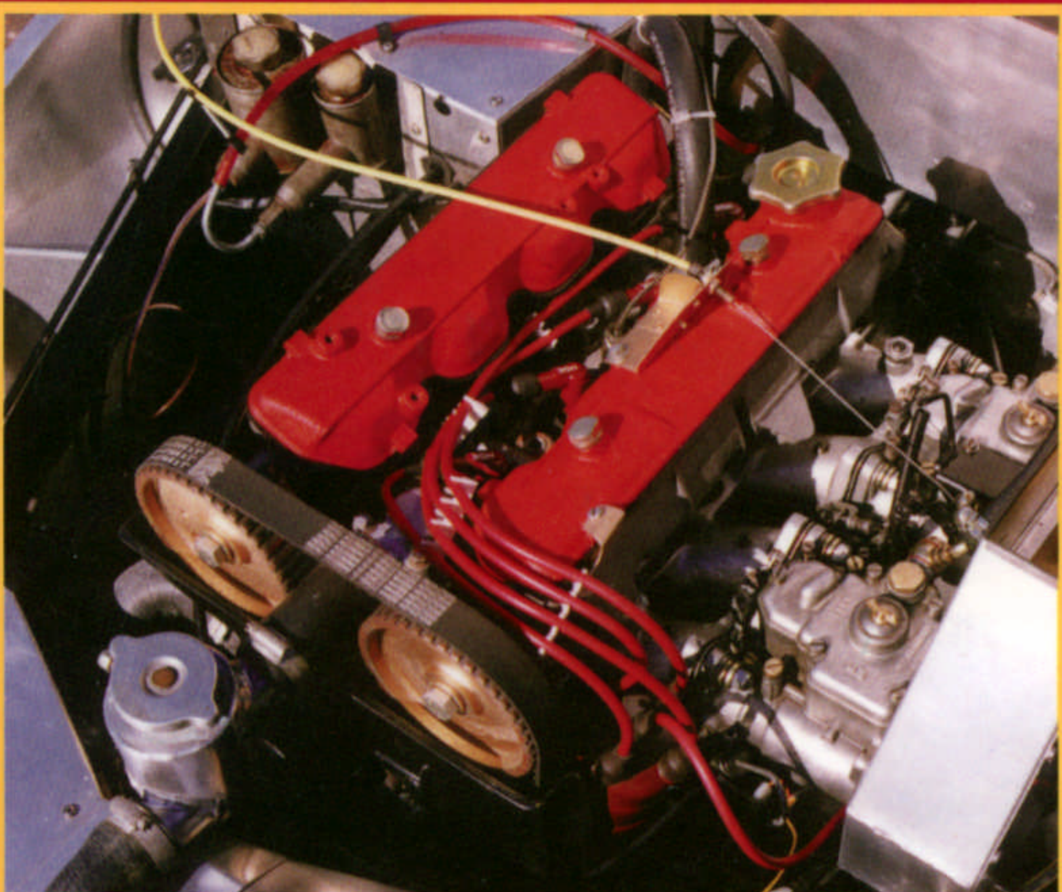

Engine preparation expert GUY CROFT's Fiat and Lancia Twin-Cam engines are renowned across the world for their performance and reliability, having distinguished themselves in motorsport and on the road from the UK to New Zealand. Now, through the pages of this exhaustively detailed manual of engine modification, preparation and tuning, he has made available his years of experience at the sharp end of engine development to all users of Italy's most famous and versatile production engine. He also offers a clear explanation of the fundamentals of high-performance engine tuning, which will be invaluable to anyone seeking the ultimate from their car, whatever the source of its engine. The GUY CROFT WORKSHOP MANUAL is the essential reference source for the serious motorsport competitor.

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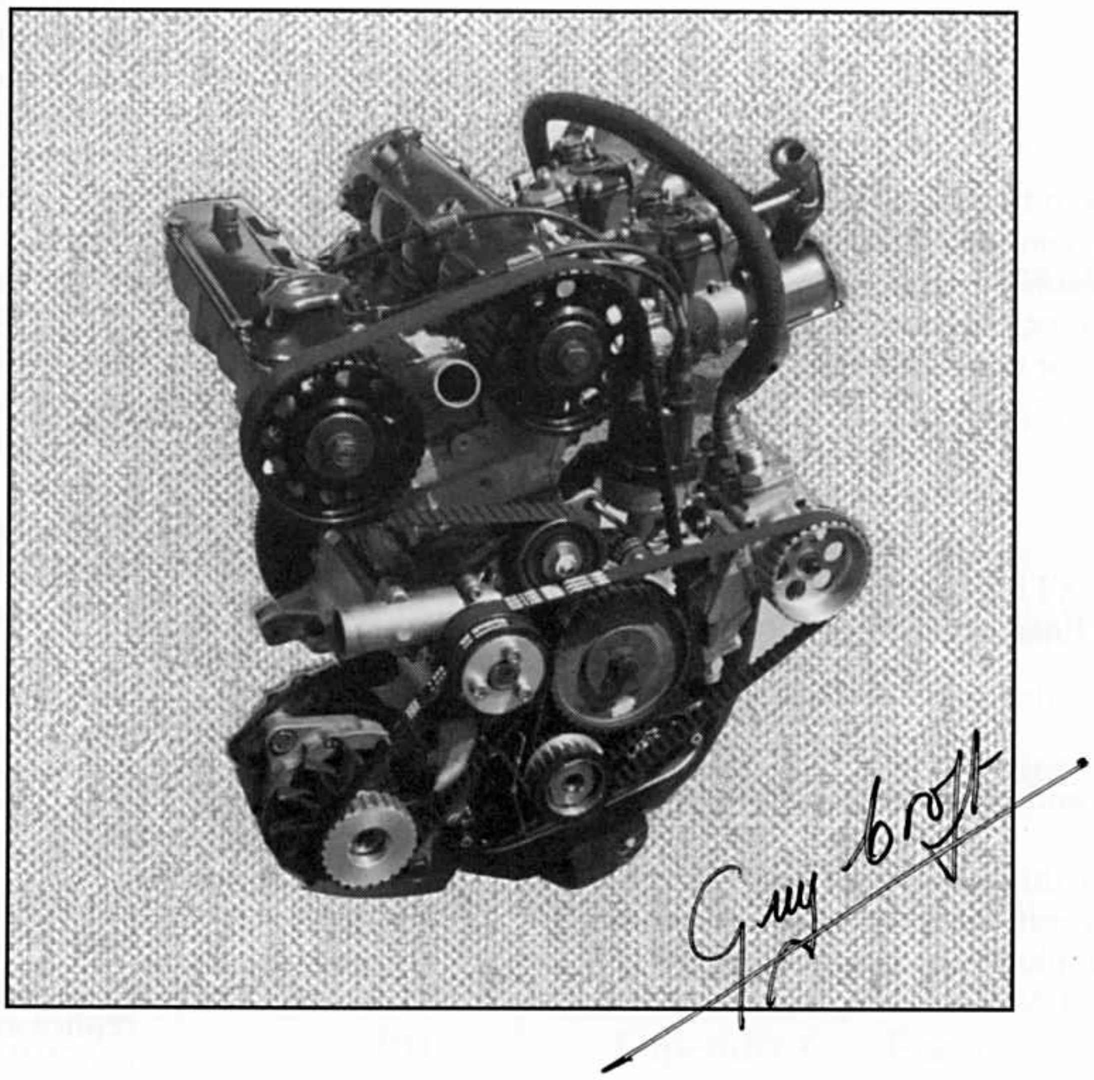

GUY CROFT BSc (Hons)

MOTOR RACING PUBLICATIONS

Introduction

Many years have passed since the forest and tarmac stages of the World Rally Championship echoed to the sound of the Fiat-Abarth 124 and 131 Twin Cams, but such was the success generated by these early cars, in which so many famous drivers made their name, that right up until the official withdrawal of Lancia from the series at the end of 1992, derivatives of those outstanding powerplants were still in use by the works teams. Importantly – as far as we are concerned – this heritage, spanning over two decades, continues to generate enormous interest among motorsport enthusiasts seeking a competitive engine for their clubman car.

This book is not about Abarth; for all their greatness, much of what they did was kept to themselves – perhaps understandably – so little information has ever appeared in print. Life would have been much easier if it had, and of course it would have made fascinating reading! Nearly all the techniques described in this book, therefore, have had to be derived from scratch.

The philosophy behind the work at Guy Croft Tuning over the last nine years has been quite simple – design the parts, test them thoroughly, then make them readily available at an affordable price. A great deal of hard work has gone into extracting the full potential from this remarkable series of engines, and despite the inevitable heartaches along the way, the progress made in establishing the TC as such a formidable and versatile high-performance powerplant has been a reward in itself. We hope that the work at GCT has made a genuine contribution to the recent resurgence of interest in these unique engines and to their popularity amongst both clubman competitors and high-performance road car enthusiasts.

To work in this field is particularly enjoyable. Fiat and Lancia Twin-Cam owners seem to share a common fascination for the intricate technicalities of special tuning; an increasing number of them have asked me: "Can you supply the parts if I build it myself?" My answer has always been "Yes", of course, but the purchase has so often been followed by in-depth, extensive telephone queries relating to the build-up and settings! It was in response to this that, two years ago, I discussed the possibility of this book with publisher John Blunsden, of Motor Racing Publications. John had been pleased with the success of *Fiat and Lancia Twin-Cams*, written by my friend Phil Ward, and to which I had contributed a chapter on special tuning; if there was a criticism, I was told by some readers, it was that 'my' chapter was not big enough.

My broad strategy has been to explain to the reader where to source a suitable engine, how to inspect and prepare it for road and competition use, and how to develop an integrated 'package' to eliminate running problems as far as possible in order that their precious budget is not wasted on an uncompetitive or unreliable engine. All the methods described are those actually used at GCT and are tried and tested. I hope readers will find of interest the technical justifications for the practical tuning methods described and will be suitably impressed by the section on owners' cars, the extent of which offers a clear indication of the wide variety of uses to which the TC can be put.

Acknowledgements

I would particularly like to thank those whose direct assistance in the preparation of this book was invaluable: Sue Mackinnon, manager of Medway Enterprise Centre, who willingly and cheerfully, in her spare time, converted my freehand scrawl into readable text over the course of 1995 – despite not having the vaguest understanding of the contents! My friend Ian Booth, photographer, who produced much of the specialist photographic material essential for a book of this type. Mike Hockley, who consistently supported GCT in every endeavour and whose incisive engineer's approach was a vital asset in bringing 'concepts' to practical reality. Gerard Sauer, for his submissions to the book, encouragement and assistance with queries on technical issues. Tom Casey, Irish Hot Rod Champion, who was the first driver supported by us to be able to supply the consistently accurate feedback needed to make rapid progress with development of a top race engine. Our involvement with Tom took us firmly, and for the first time, into 'super-tuning', where 'every little counts'. Tim Swadkin, racing engine contractor, who freely advised and assisted most generously during our dyno sessions at Warrior Automotive. John Woods, of Gemini Engineering, for his advice on crank balancing. Peter Newton and Giulietta Calabrese, of Fiat Auto (UK) PR, for their kind and persistent efforts to trace available photographs from Archivo Storico in Turin, and for their work in securing permission to reproduce valuable data from Fiat/Lancia workshop manuals. Additionally, GCT could not operate at all without the fullest backing of a first-class Fiat dealership's parts department, and in this respect I would like to record my sincere thanks to the staff at Montroe Motors, of Buckhurst Hill, Essex.

My gratitude, too, to the many companies who supplied important technical data on their products, all of which have been used very successfully by GCT. They include Titan Motorsport, Sachs Automotive, Datum, Fuel System Enterprises, Weber UK, Tran-X, ITG, Pacehigh, Pipercross, Lumenition, Canton-Mecca, Venolia Pistons and Warrior Automotive while *Cars & Car Conversions* magazine and the RAC Motorsports Association have also been most helpful in permitting us to reproduce valuable previously published material. Thanks also to the enthusiastic owners of Fiat/Lancia TCs who sent in photos and details of their cars, and the professional photographers whose work appears in the book. Finally, a special thank you to Richard Clark for his skill in converting such a complicated collection of tables, text and graphics into readable pages, and to John Blunsden for giving this book his fullest support.

Guy Croft
Keel Court
April 1996

Power/torque ratings

Fiat/Lancia bhp ratings are all expressed in DIN; in other words, the outputs are derived on engines fitted with water pump, alternator and silencer. GCT figures are not strictly DIN since in most cases a large-capacity, low-absorption silencer was used for dyno tests, and the alternator removed. Back-to-back tests indicate that for comparative purposes the GC figures may reasonably be assumed to be approximately 3% higher than the equivalent DIN rating.

Unless otherwise stated, all torque and bhp figures quoted are flywheel outputs, corrected to standard atmospheric conditions of humidity, pressure and temperature. This correction is important for comparison since an engine dyno-tested on a cold, damp day will have *corrected* outputs lower than the absolute figure and *vice-versa*.

CONTENTS

About the author

During the course of his 11-year service as an officer in the Royal Engineers, Guy Croft graduated from the Royal Military College of Science with an honours degree in automotive engineering. His interest in Fiat and Lancia Twin-Cams began in earnest in 1985, when the formation of Guy Croft Tuning gave him the opportunity to make a detailed appraisal of the works Group 4 Fiat Spider. His subsequent development work with these engines has given him a vast portfolio of experience, which has been widely sought after for numerous technical articles and publications.

Disclaimer

Whilst every care has been taken to ensure the correctness of the information in this book, all recommendations are made without any guarantee on the part of the author or publisher, who can accept no liability for loss, damage or injury, however caused, resulting from any advice given, or from errors in or omissions from the information provided.

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Cover illustrations

Front:
Completed just prior to publication, latest development GC St IV Fiat for NHRA oval racing. This engine represents the culmination of two years of top-level racing and around 60 hours of dyno-testing. Output was 156lbf ft @ 5750rpm, 200bhp @ 7500rpm, with not less than 146lbf ft torque between 4500–7000rpm. Despite having a flywheel weighing only 4kg, the engine ticked over quite happily at 600rpm and pulled full throttle/full load from 3000rpm. Specification includes: Titan 3-stage dry sump; GC IIID exh cam, IVB inlet (hybrid); 46/40 valves, triple springs, alloy caps, GC alloy verniers, 1" belt; 130 TC head gasket, race bolts, fully ported/blueprinted, 45DCOEs (40 chokes); GC/Venolia forged pistons, 11.5:1 CR (2049cc); production Bosch electronic ignition, NGK B9 EGV plugs; lightened crank, rods; F3 5½" clutch, steel flywheel. Engine was sensationally quick on its debut at Rose Green, Tipperary, and was raced consistently to 9000rpm.

Top rear:
When it comes to Fiat/Lancia conversions, nothing is necessarily what it seems. This '037' is in fact a shortened, highly modified Lancia Monte Carlo fitted with a St II 2l GCT Lancia Twin Cam. Thousands of man-hours (and pounds!) went into building this stunning replica and sourcing original decals, wheels and other details.

Centre rear:
Outstanding National Hot Rod (NHRA) spaceframe raced by Irish Champion Tom Casey. Designed and built by well-known Ford rally specialists Autocross, of Bracknell, with over 20 years of motorsport experience behind them, this tubular-steel/Kevlar vehicle was sensationally quick on its debut. Only six months from prototype to race-ready, the first Autocross car won three races in succession 'out of the box'.

Lower rear:
St II 1600 Fiat installed in Westfield Eleven (see Chapter 18) developing around 145bhp and tuned for sprint/hillclimb events.

CHAPTER 1

TWIN CAM MODELS

Analysis of the engines most commonly used for motorsport

The purpose of this chapter is to identify the key characteristics of the TC engines most commonly used for motorsport and the vehicles in which they may be found. The list, inevitably, is by no means a complete compendium of every single model – that would fill a book by itself. Instead it is a guide for the clubman motorsport enthusiast who wants to know which engine will be suitable for his purpose, and is based on knowledge acquired over the years by Guy Croft Tuning (henceforward referred to as GCT) of the most popular and cost-effective units. While respecting the purist view, *ie* retention of the original engine with the car (and there are many such fine examples within the various Fiat/Lancia Owners' Clubs), it is true that the demise of numerous Fiat and Lancia cars has made available an enormous range of potential powerplants, which have design features so outstanding that their adoption as clubman competition engines is assured for a long time to come.

It may rightly be said that as such the Fiat/Lancia Twin Cam has no equal. With hindsight, it is easy to see that the design concept of these engines probably had motorsport in mind. Fiat's TC designs (later adopted for the Lancia range) dominated World Championship rallying in the Seventies. They were only really matched by the Ford/Cosworth BDA, which by comparison with the Fiat TC was produced in tiny numbers. The Fiat 131/132 2-litre engine, in particular, is one of the classic production engines of all time, and having been conceived with Gp 4 homologation in mind, was essentially a race engine fitted in a production car, a point lost on most owners more preoccupied with corrosion.

For example, few if any volume manufacturers went to the trouble of installing heat-treated forged crankshafts (capable of withstanding the punishing torque of the works 131 cars) in their production vehicles, and few other manufacturers have left such an outstanding fundamental design so little altered in over 20 years. Anyone who takes the trouble to compare the intervals of, say, a 131 2*l* and an Integrale 8v will see this for themselves. The Fiat/Lancia TC truly has an impeccable motorsport pedigree.

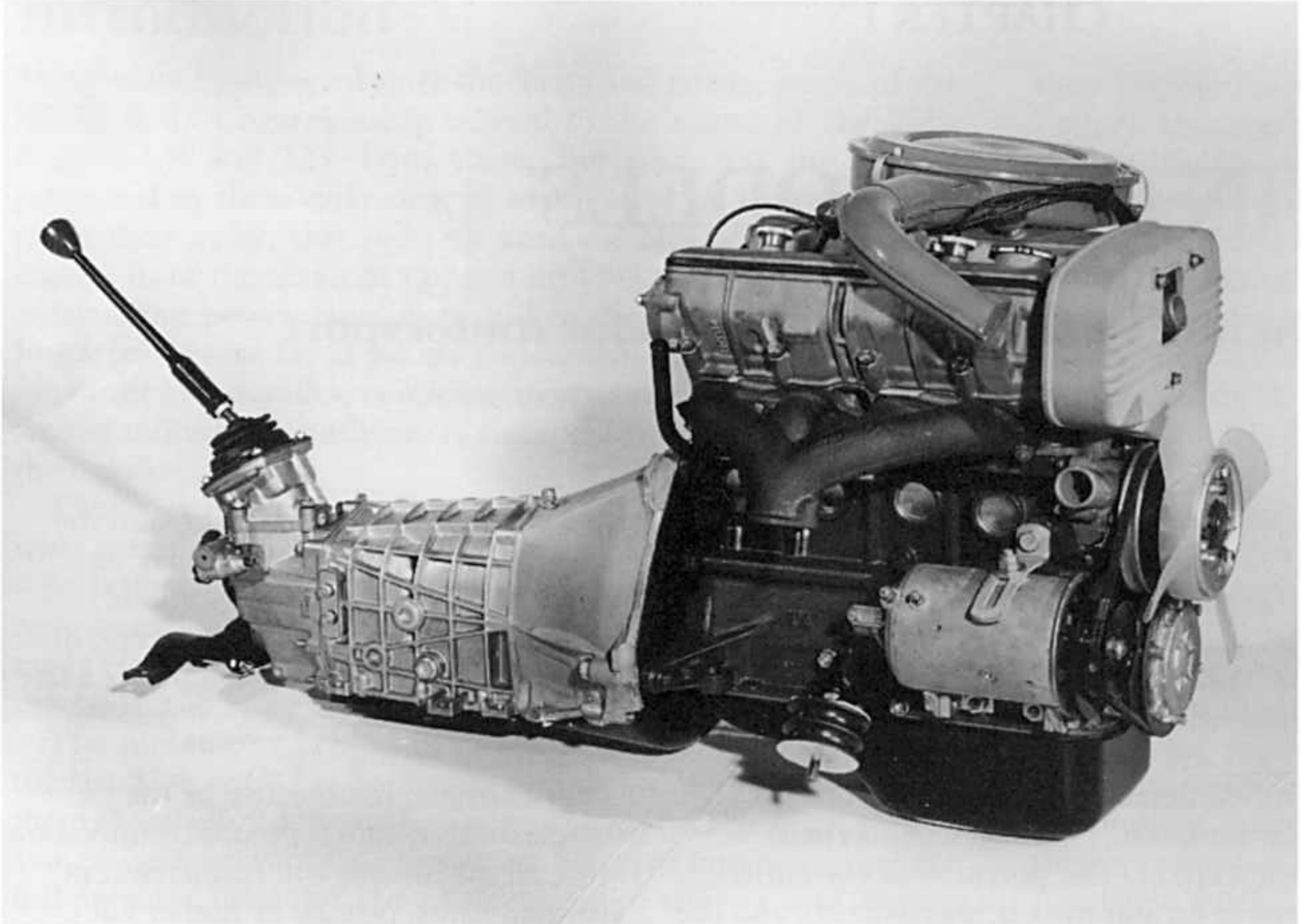
The spin-off from this for the clubman enthusiast is obvious: All the TCs are tried and tested. Design flaws, manufacturing defects and inherent problems are (as far as GCT has been concerned) unheard of. The potential of the entire range for uprating is phenomenal, and the ease with which this may be carried out is quite unique to the Fiat/Lancia TC. No other engine in its class can boast such a multiplicity of good points! The clubman can enjoy an enormous amount of fun with a low-budget 1600 in a modest kitcar, or go all the way and be competitive at National level with a fully prepared 2*l* – using in each case a donor engine bought readily for very low expenditure. Indeed, it is no exaggeration to say that the internals of many Guy Croft engines now winning races and setting records have already spent their former life as the powerplant in a passenger vehicle!

Selecting the key components and offering a grading system for the models listed is extremely hard. All the engines have virtues in their own right, and the ease with which components may be changed, or uprating modifications carried out, is common to all except, of course, that the 'mapped' engine (*ie* a late turbo model) presents its own peculiar problems of setting-up.

For example, irrespective of the standard valve, cam type and compression ratio, all the models will readily accept different cams, pistons of higher CR (normally aspirated versions) and, if the particular model will not accept larger valves on the standard seats, big valve seat inserts can even be fitted up to very large sizes. Other engines do not have this flexibility: the VW and Peugeot engines used extensively for National Hot Rod racing have valve sizes roughly comparable with standard TC items and the valve train layout will not permit bigger; the 2*l* Alfa Romeo is very restricted on valve size, cam lift and port size and lacks the Fiat/Lancia's torsional rigidity. Where the owner of another engine needs more cubic capacity and needs to 'restroke' the crank, the Fiat/Lancia TC owner simply moves from a 1585 to a 1756 or 1995cc model.

The main object of the 'marks out of

1/1: Fiat 124 Sport BC series.



1/2: Early 1608 (125) engine with electrostatic fan and centrifugal oil filter. Gearbox and bellhousing will not fit later 132 type engines, which used a larger flywheel. Box was a weak point anyway.

suitable donor engine in their locality. Specifications of engines from potential donor cars illustrated in this Chapter will be found on pages 13–15.

Further useful reference to and interesting reading about the wide variety of engines fitted to Fiat and Lancia cars can be found in *Fiat and Lancia Twin-Cams* (ISBN 0-947981-57-8), by Phil Ward, and *Lancia Beta: A Collector's Guide* (ISBN 0-947981-62-4), by Brian Long, both published by Motor Racing Publications Ltd.

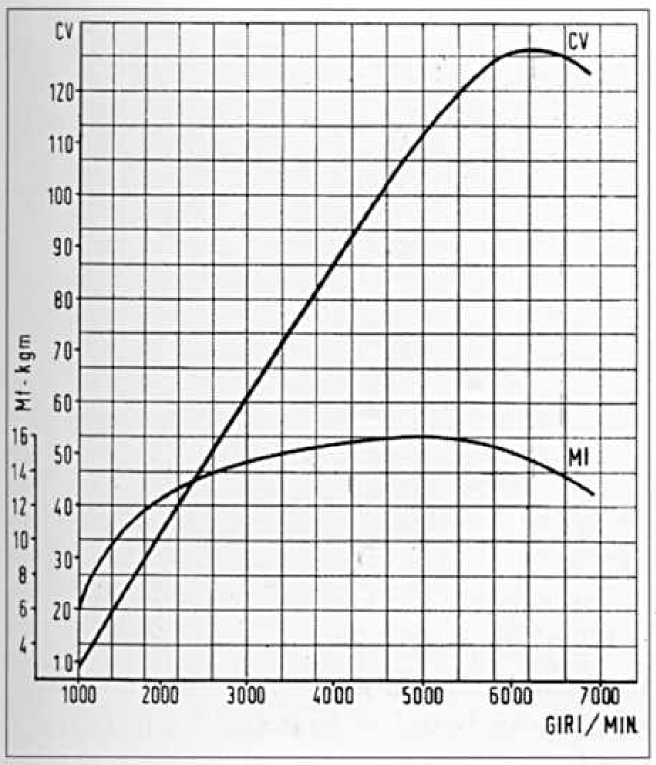
10' scoring system introduced in this book is to identify how much power can be obtained, reliably, from the least expenditure. In this respect, a steel-crank 1600 tends to score more than a cast iron-crank version for reliability reasons (though GCT have never seen a 1585 crank failure, even on a highly tuned Delta Turbo *ie*), and then again, a turbo 1600 may score more than a normally aspirated version because it inherently produces more bhp per £ spent. The reason for scoring the 2*l* normally aspirated versions highly against the 2*l* turbo engines is simply that turbos are usually classed with a cubic capacity equivalence factor of 1.4, taking them into a higher class, and therefore a direct comparison is difficult.

When choosing a powerplant for a road-only vehicle it is obvious that, given the extra expenditure required for the donor engine (plus ancillaries, ECU and harness), the turbo 2*l* versions deliver such blistering performance (because of their phenomenal torque) that they make an obvious choice – if they can be obtained in good condition! The 130 TC scores more than the 131 2*l* because it already comes with twin carbs, big inlet valves, a 4-2-1 tubular exhaust and oil cooler; on the other hand, there are few about.

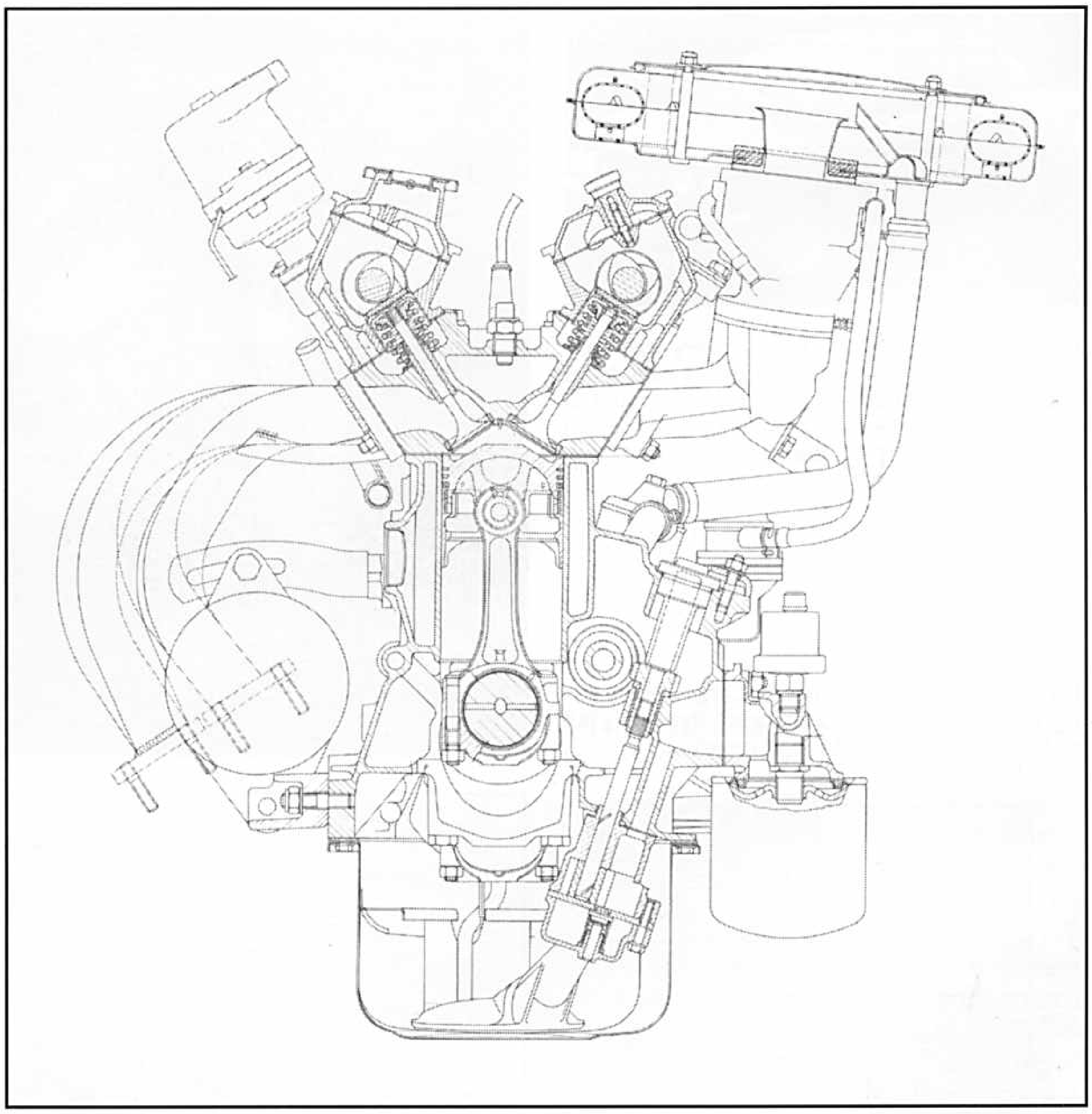
Ultimately, readers who wish to extend themselves beyond the boundary of fitting a standard engine will realize that the choice of powerplant is really only governed by the size of the engine *vis a vis* their particular competition class, the question of normally aspirated/turbo, the budget they wish to commit to the project and, of course, the availability of a

1/3: 1756 Fiat Spider (CS version).

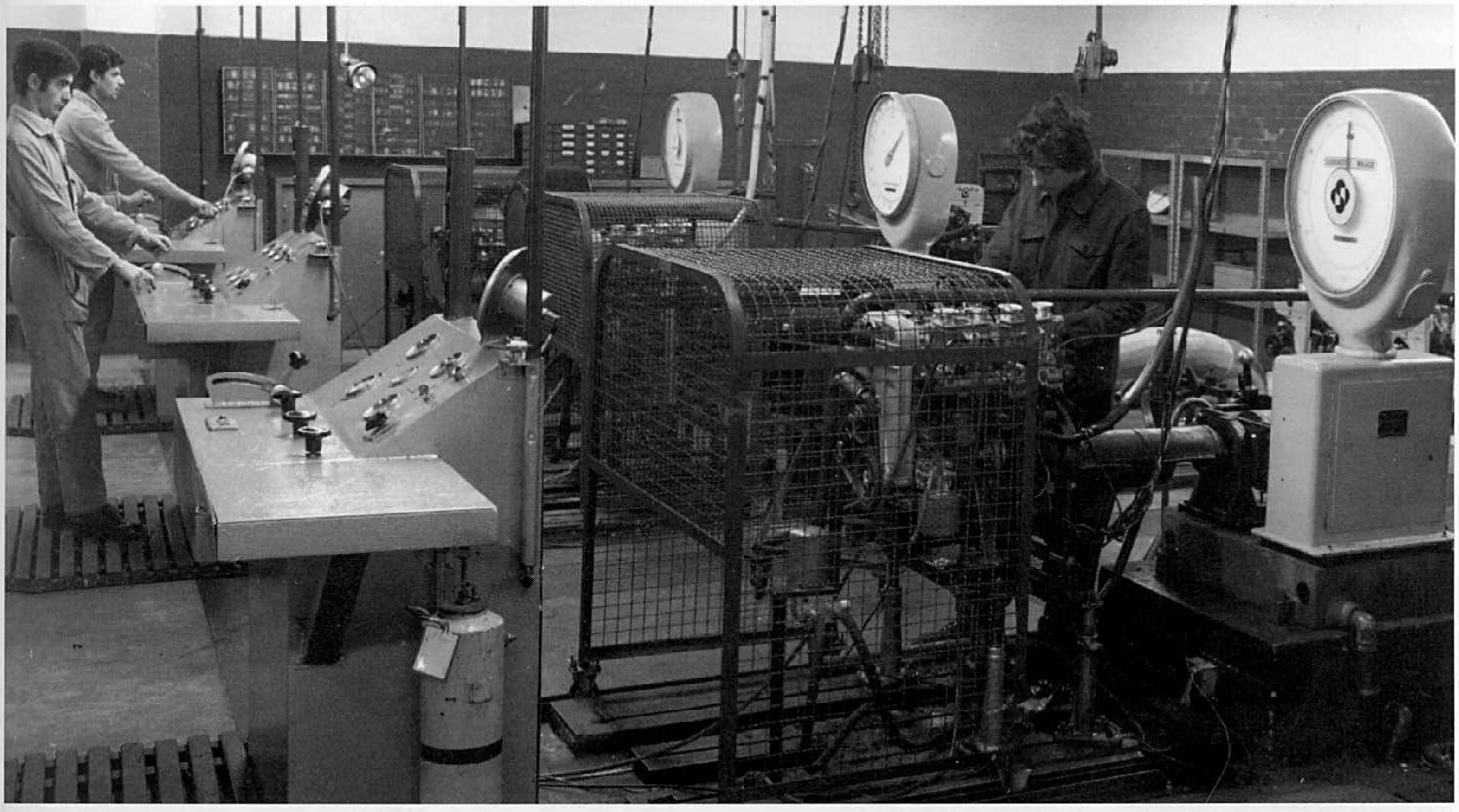
1/4: Author's own 124 Abarth Spider pictured in 1984.



1/5: Power curve for 124 Abarth Spider engine. (Fiat Auto SpA – copyright reserved)

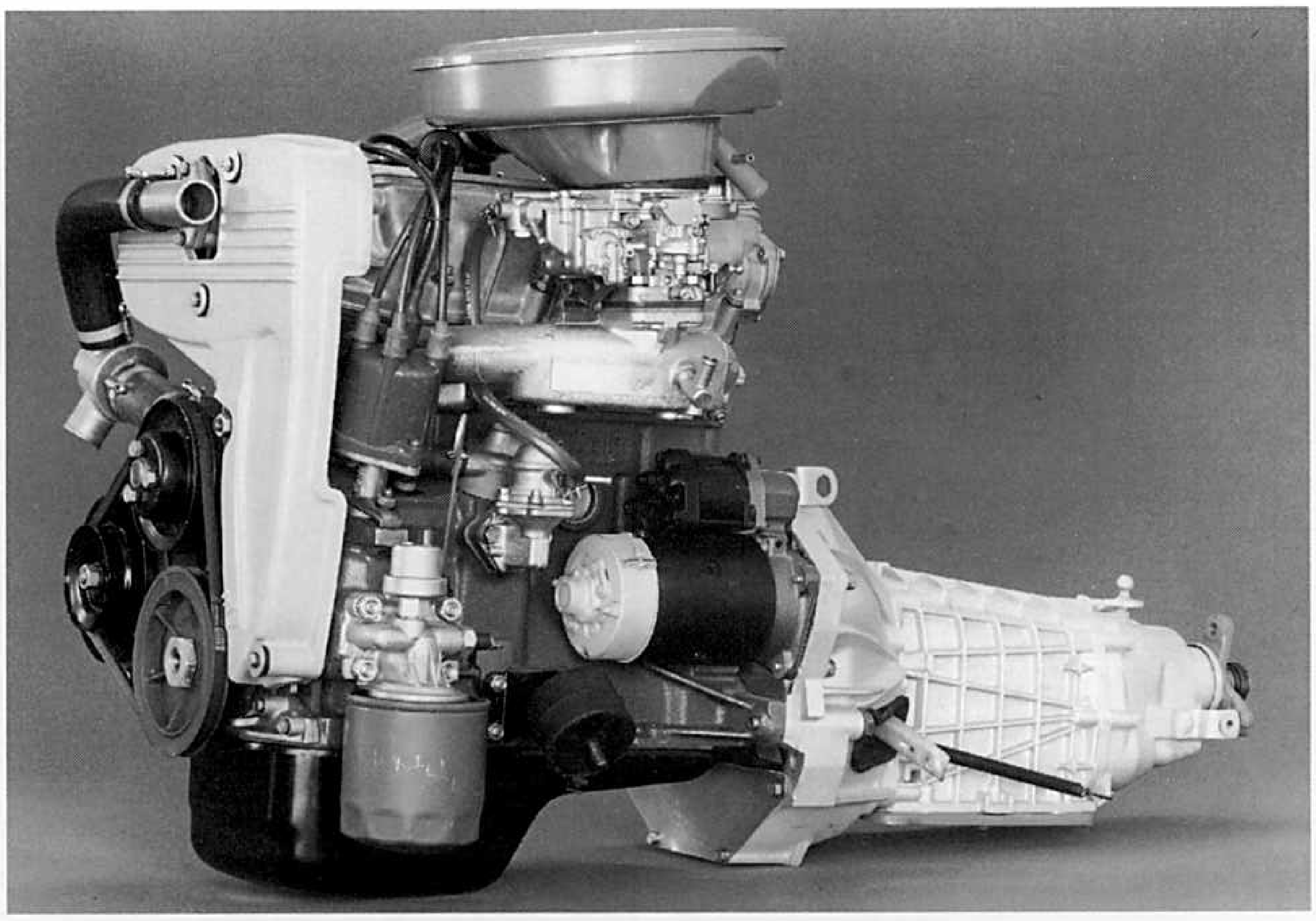


1/6: Extract from Fiat 124 Abarth 1800 manual. (Fiat Auto SpA – copyright reserved)

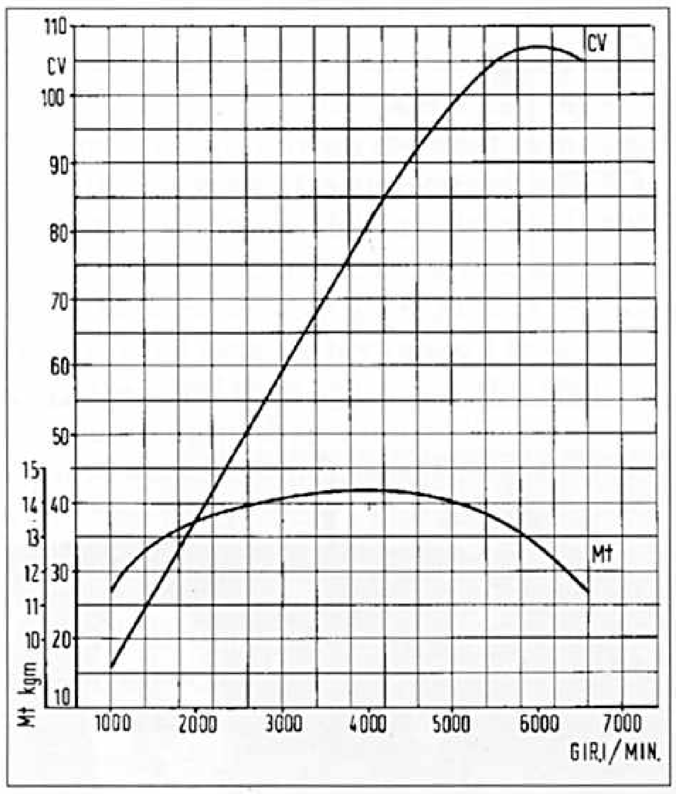


1/7: Rare factory shot of 124 Abarth Spider 8v engines on dyno at Abarth. Centre engine is under load. One of the better jobs in the world, but note the complete absence of soundproofing!

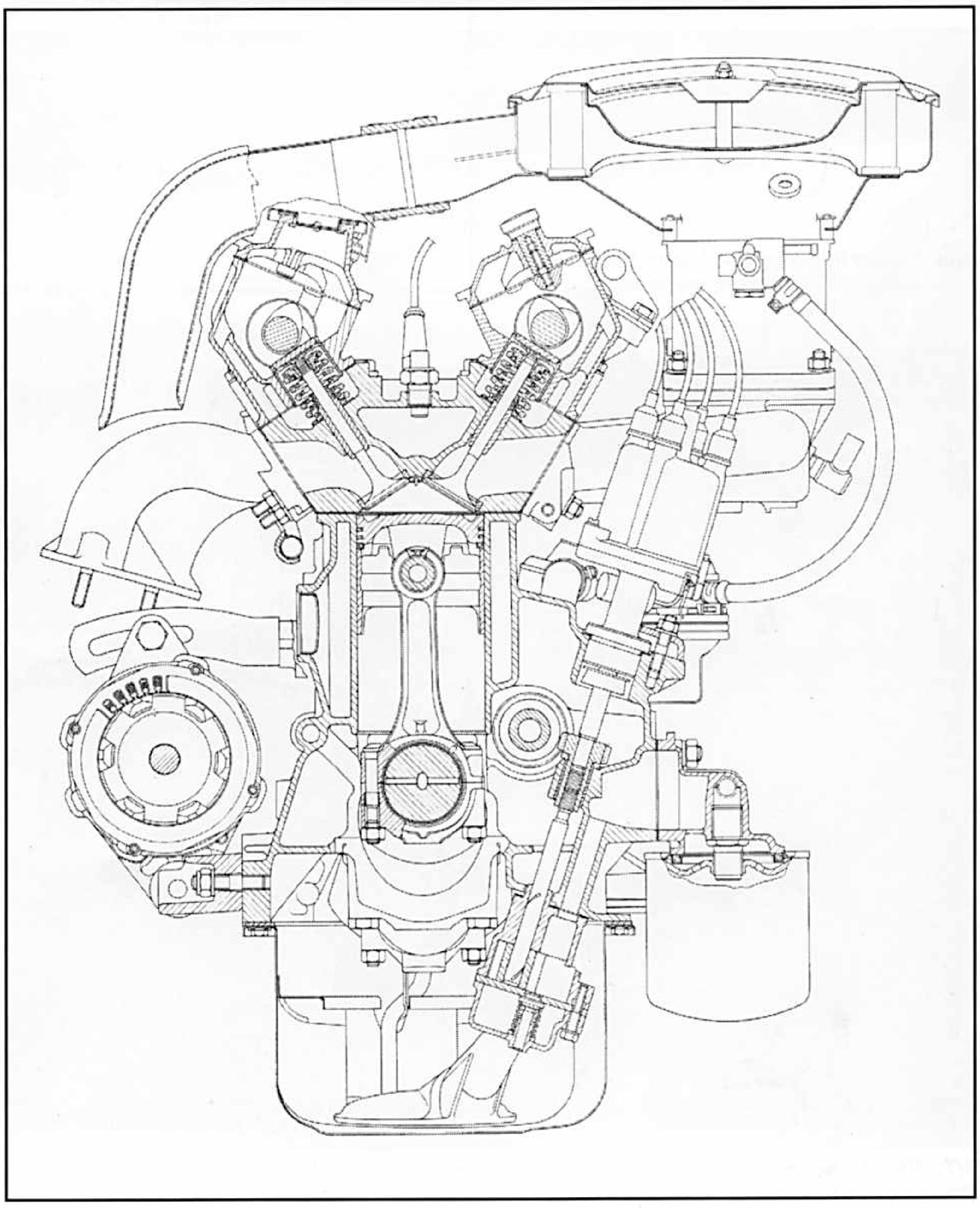
1/8: Fiat 132 (1592cc): boxy, heavy car, nice engine. Unfortunately most of these cars have been crushed. Also available with 1756 and 2l engines. 1592 shares same crank, rods with 1756, ie is in effect same engine but with smaller bores.



1/9: 132 1800 engine (right). Larger bellhousing for 220mm dia (friction face) flywheel, but again weak gearbox (140bhp max!).



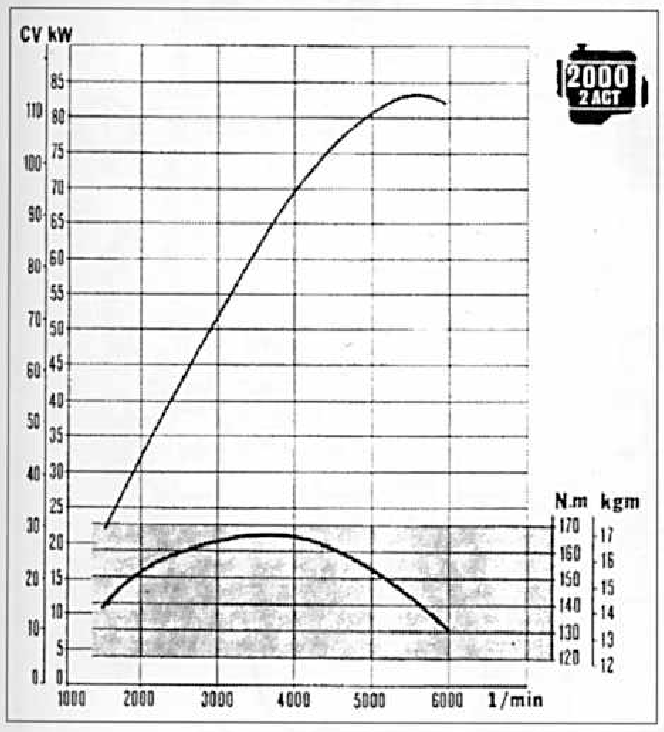
1/10: Power curves of 132 B1000 engine. (Fiat Auto SpA – copyright reserved)

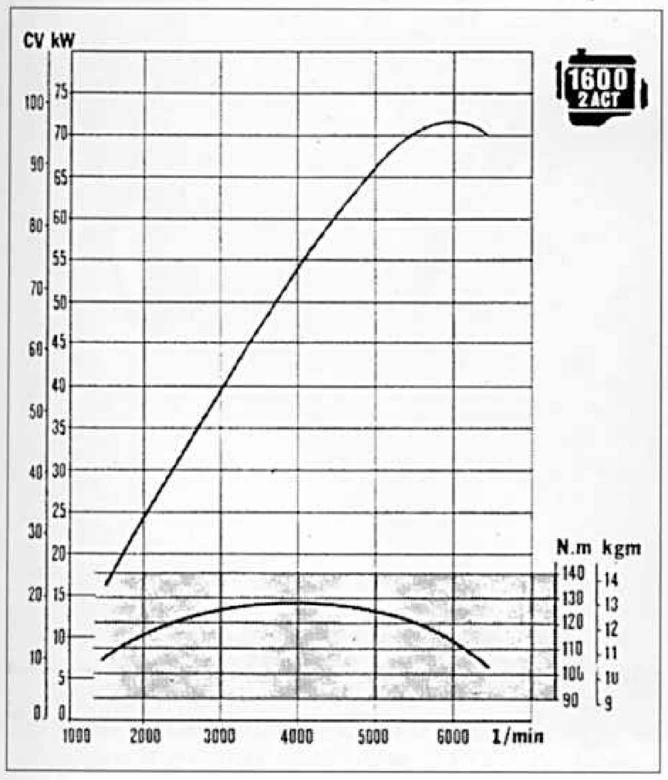


1/11: Cross-section of 132 1800 engine, viewed from the crank nose. Fiat have always produced workshop manual drawings of superb quality. (Fiat Auto SpA – copyright reserved)

1/12: Pristine 131 Sport owned by Houghton, Cambridgeshire solicitor Anthony Fausset.

1/14: Promotional shot of two-door 131 Sport (known as 131 Racing in Europe).

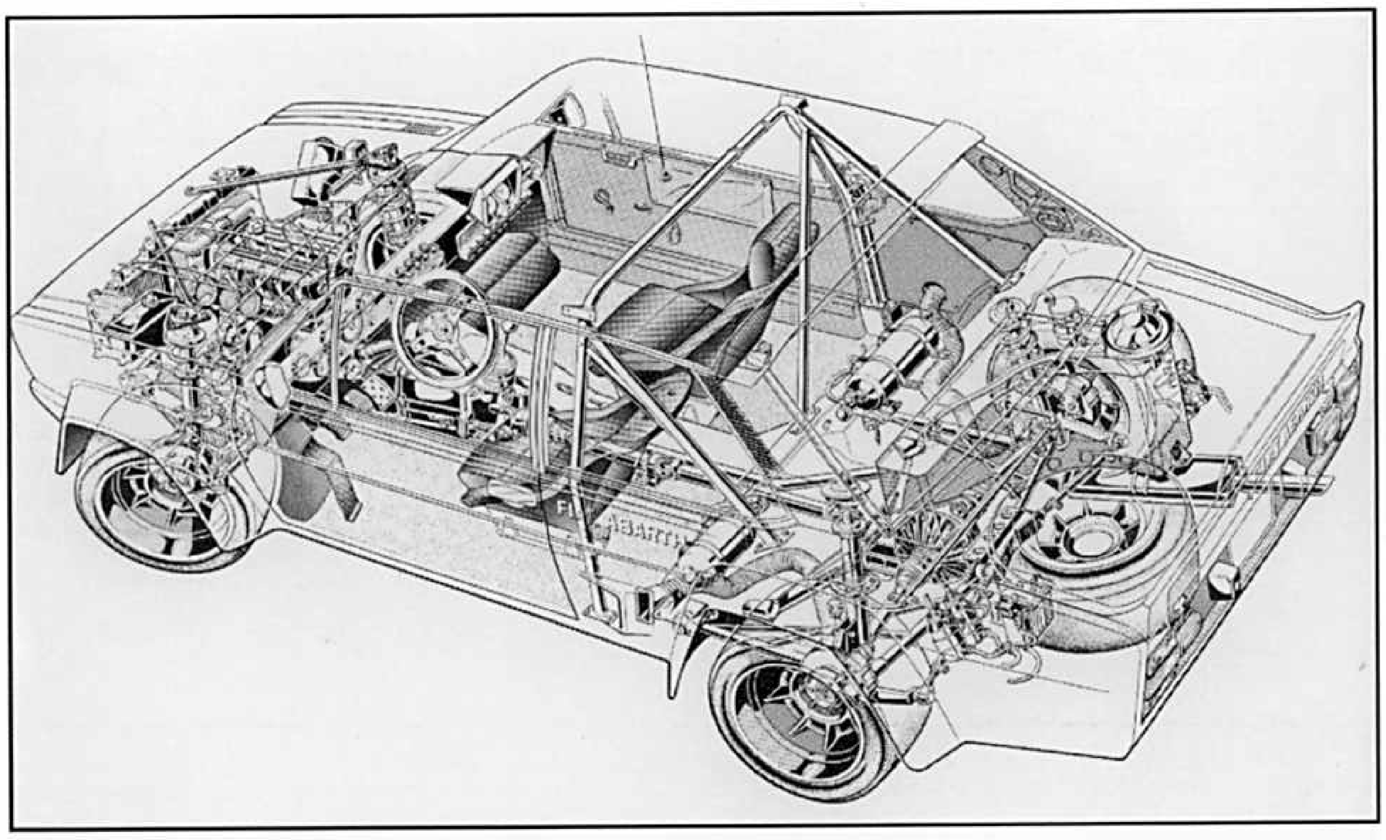




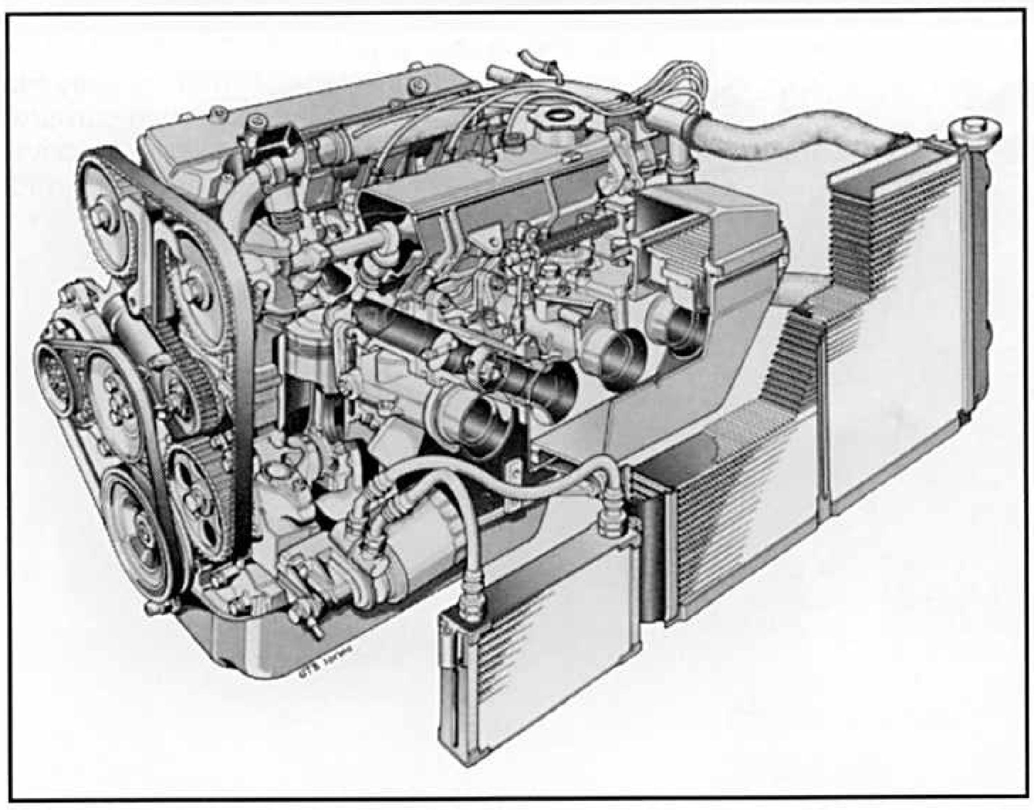
1/13: Power curves for the 2000 and 1600 engines reproduced from the Fiat 131 manual. (Fiat Auto SpA – copyright reserved)

1/15: High on the author's Christmas list – an original, works-prepared 131 Abarth Rally (Gp 4) – arch enemy of the Mk 2 Ford Escort in the '70s!

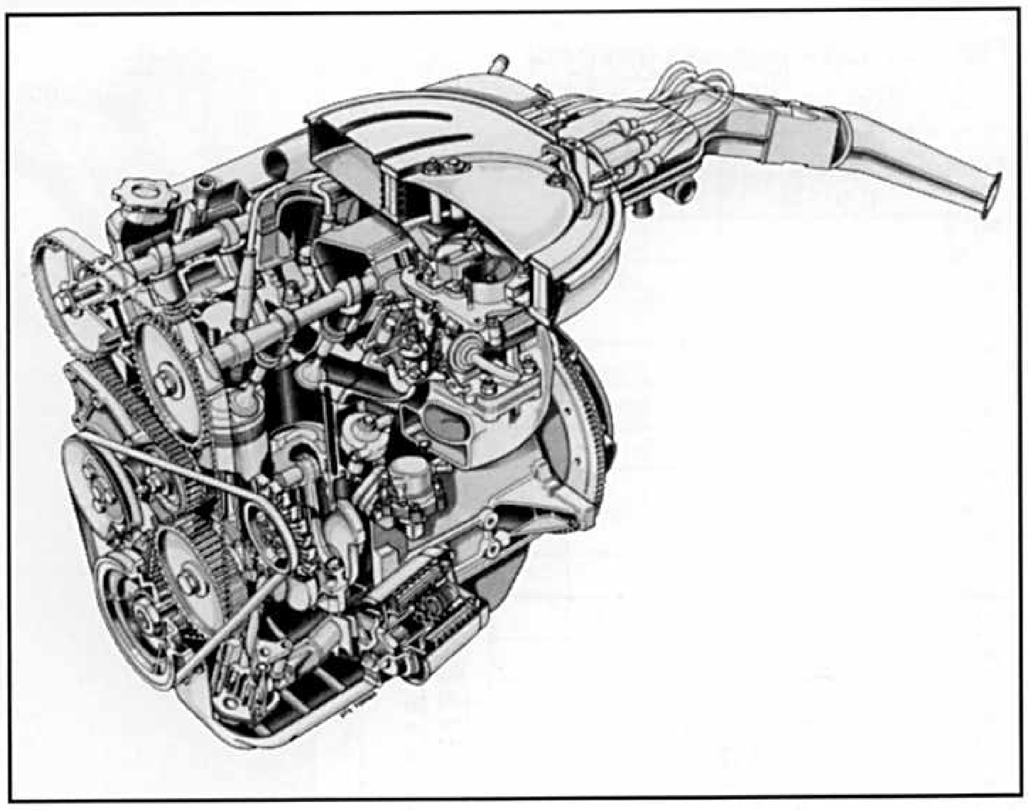
1/16: Preparing a clubman rally car? Cutaway of this works 131 Rally (16v, fuel-injected) shows the way to go...



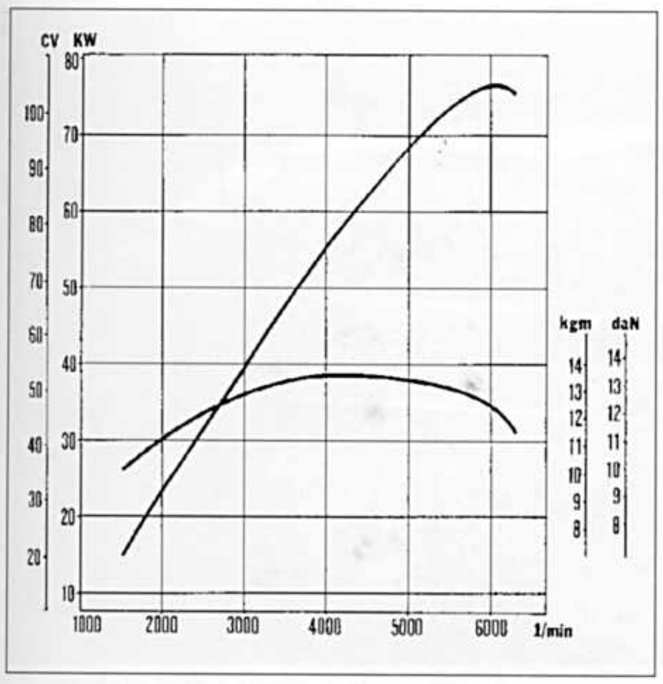
1/17: Fiat Strada Abarth 130 TC.

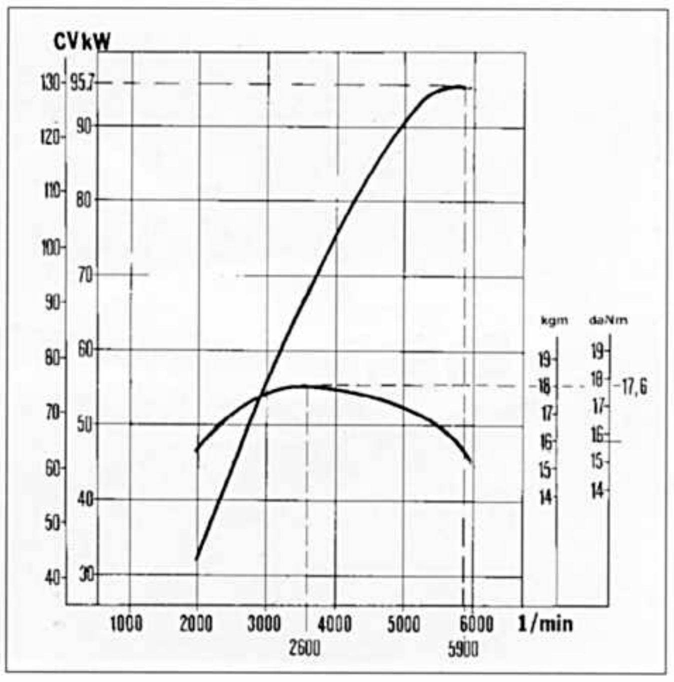


1/18: Fiat Strada Abarth 130 TC engine and ancillaries (one of the last production cars in the world to be produced with twin carbs).

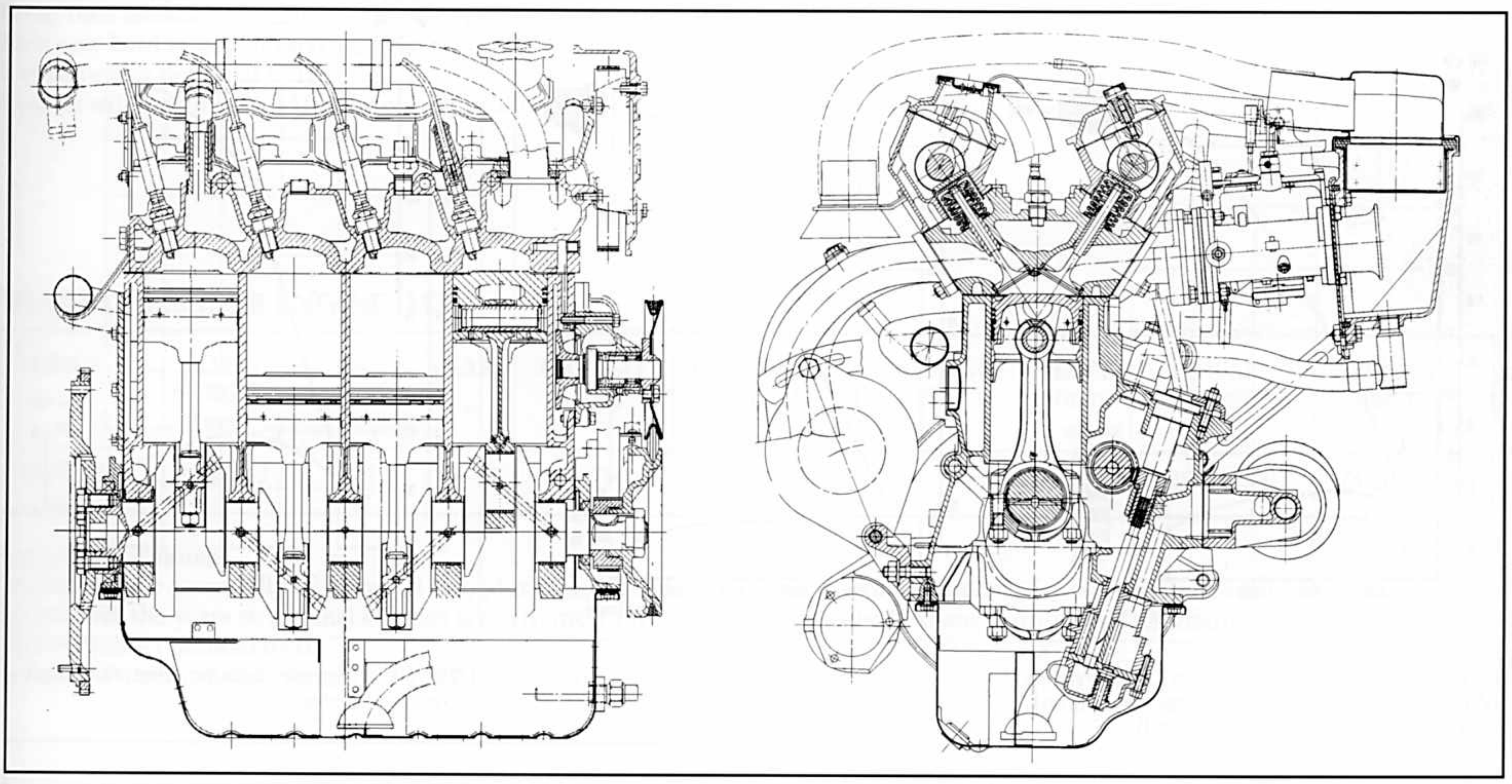


1/19: Regata 100S engine – similar to 105 TC, Delta/Prisma 1600 GT. Note oil pump design, also used on 130 TC and Delta Turbo 1.6 (carb).





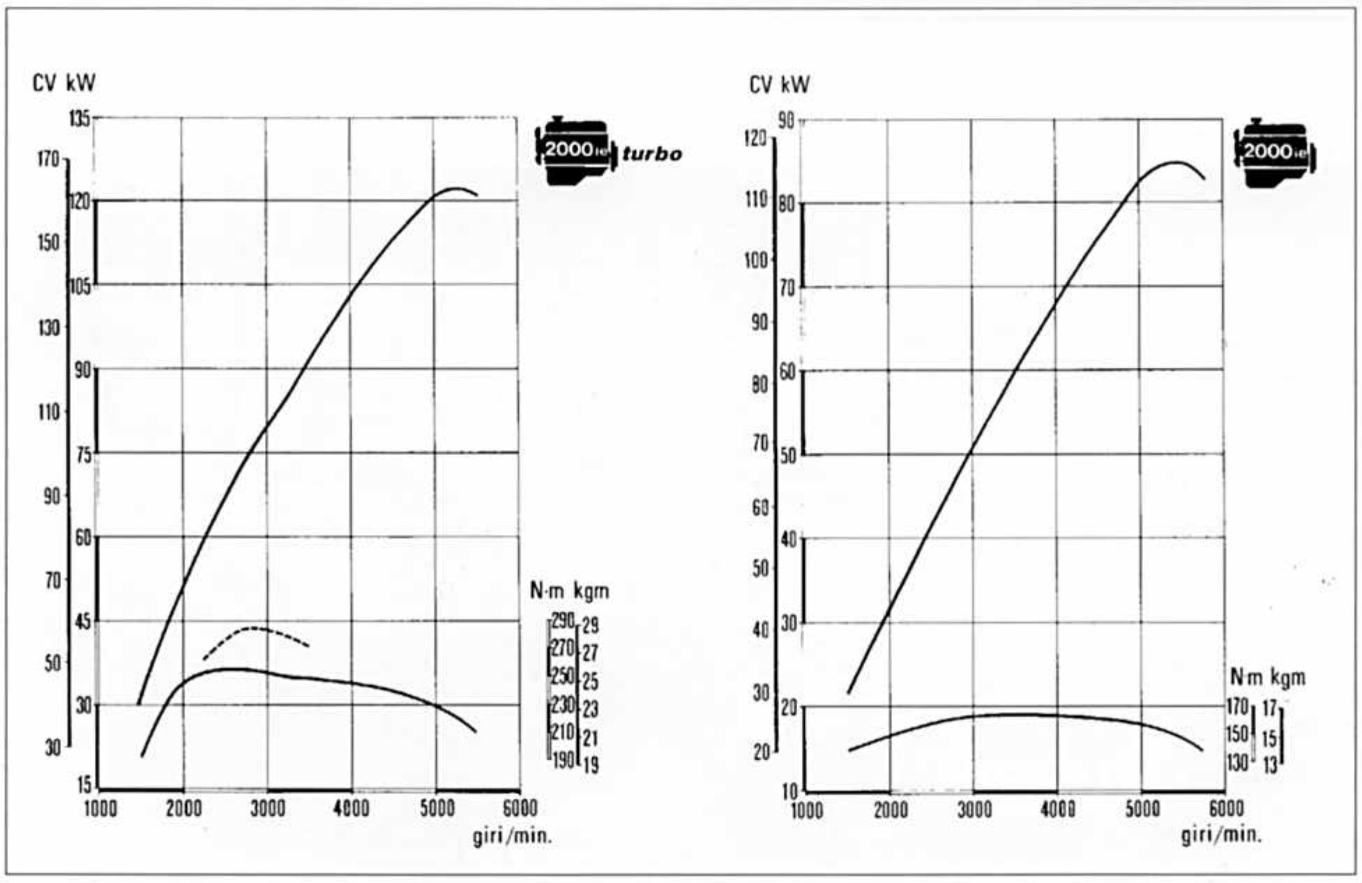
1/20, 1/21: Engine power curves from the 105 and 130 TC workshop manuals. (Fiat Auto SpA – copyright reserved)



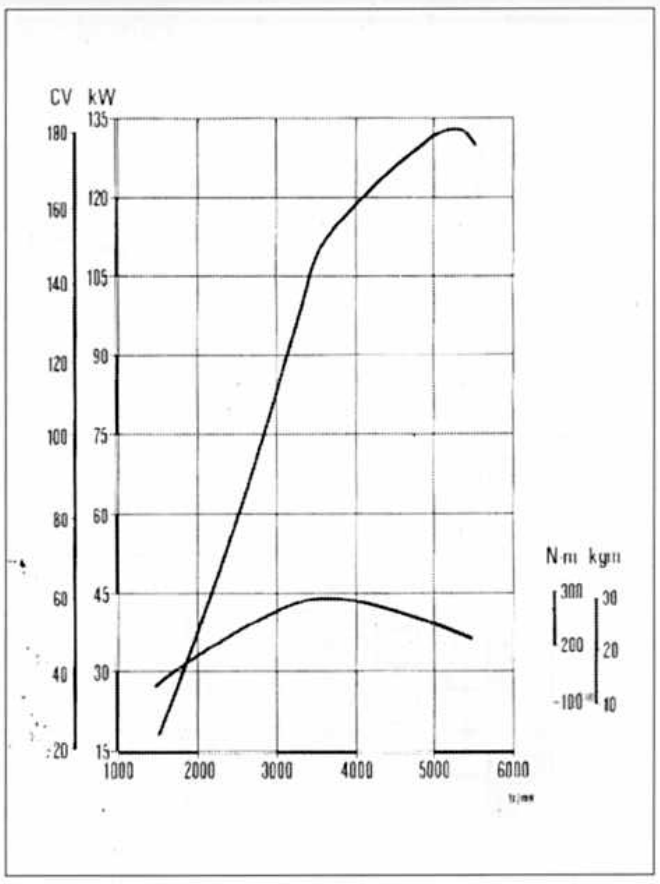
1/22: Cross-sections of 130 TC engine. Note slight upward tilt on carbs. 130 TC is only Fiat model since 124 BC 1608 to use twin carburettors, either Solex or Weber 40s. Distributor driven off inlet camshaft end. Note full-form transverse sump and oil pickup design. Sumps use a 'cruciform' baffle layout and are quite effective. Delta and Prisma versions use remote filter set-up. (Fiat Auto SpA – copyright reserved)

1/23: Lancia 2l Beta Spider owned by Tim Walker. A pristine example of this now rare model.

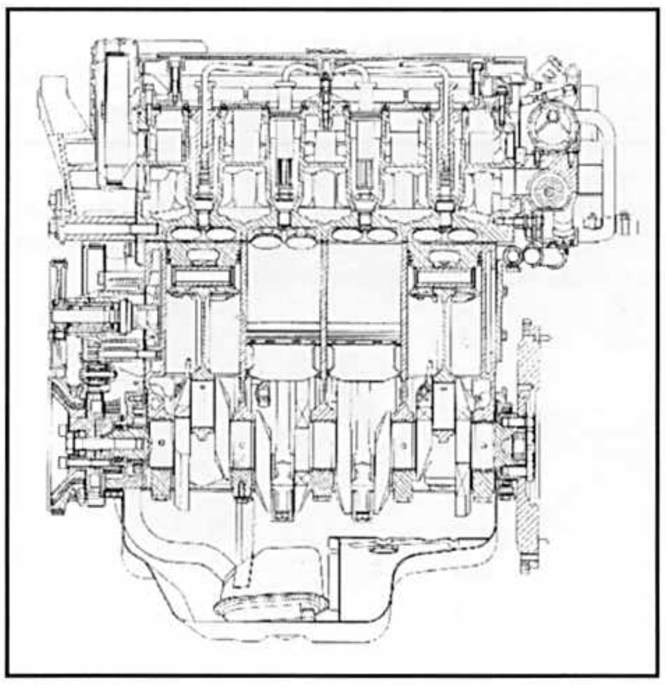
1/24: Works shot of a Gp A Lancia Integrale (16v). These cars dominated World Championship rallying for nine years.



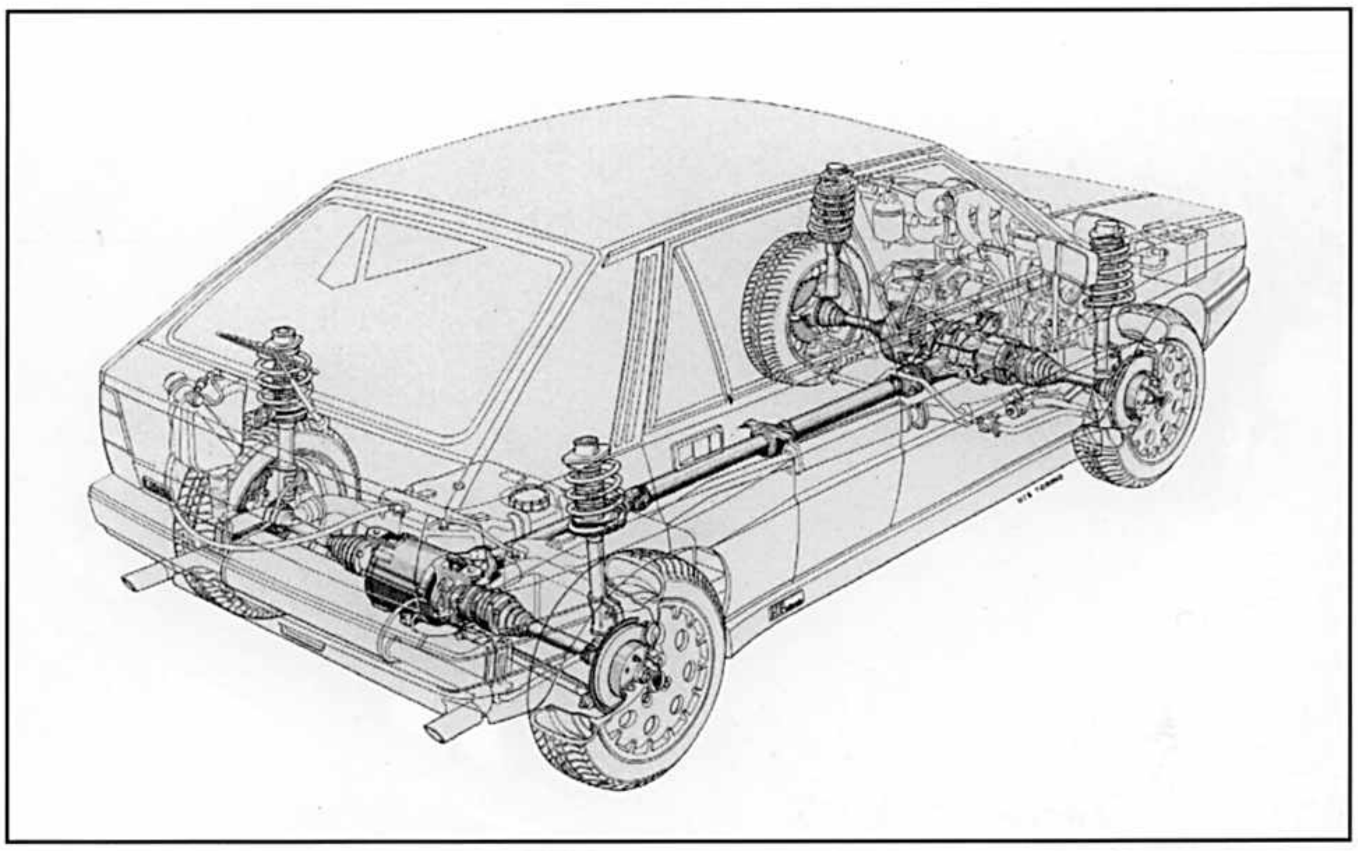
1/25: Power/torque outputs from Delta, Prisma 4WD versions (normally aspirated and turbo). (Fiat Auto SpA – copyright reserved)



1/26: HF Integrale outputs. (Fiat Auto SpA – copyright reserved)



1/27: The 16v 2000 ie engine was available as normally aspirated (eg Thema ie 16v) and turbo (Integrale, Thema turbo) (Fiat Auto SpA – copyright reserved)



1/28: Cutaway of HF Integrale (2l, 8v, turbo) showing drive-train layout. (Fiat Auto SpA – copyright reserved)

DONOR CARS AND ENGINES

Sources and specifications of the engines most commonly used for motorsport

124 SPORT COUPE/SPIDER ENGINE DATA

SERIES	BORE/ STROKE (mm)	CR	YEARS	CAPACITY (cc)	VALVES (mm)	CAM TIMING (deg) IN	EX	LIFT (mm)	POWER (bhp DIN)	TORQUE (lbf ft)
132AC000	80 x 79.2	9.8:1	73–77	1592	42.4/36	12/53	54/11	9.7	108 @ 6000	109 @ 3400
125BC000	80 x 80	9.8:1	70–73	1608	42.4/36	26/66	66/26	9.5	110 @ 6400	103 @ 3800
132AC100	84 x 79.2	9.8:1	73–77	1756	41.8/36	15/55	55/15	9.9	118 @ 6000	

Engine tuning notes:
All models have early con-rod design – race bearings not available. 1592 model has 12mm dia flywheel bolts, others have 10mm.
All models have forged steel crank.
Some 1608 models have exhaust cam-driven distributor, twin 40 IDF.
Parts now hard to get on early models, especially 80mm pistons.
Engine tuning potential 6/10.
Engines will accept later 131 gearbox and bellhousing (but 125 type needs larger 132 type flywheel).

124 ABARTH SPIDER ENGINE DATA

SERIES	BORE/ STROKE (mm)	CR	YEARS	CAPACITY (cc)	VALVES (mm)	CAM TIMING (deg) IN	EX	LIFT (mm)	POWER (bhp DIN)	TORQUE (lbf ft)
132AC4000	84 x 79.2	9.8:1	73–75	1756	41.8/36	15/55	55/15	9.9	128 @ 6200	121 @ 5000

Engine tuning notes:
Original engine essentially 124 Sport 1756, plus twin 44 IDF, 4-2-1 Abarth exhaust manifold system. Numerous Gp 4 parts fitted by owners over the years so original engines are extremely rare. All 8V versions had exhaust cam-driven distributor.
Engine tuning potential 6/10.
Later Gp 4 versions had Abarth 16v head – highly sought after!

FIAT 132 ENGINE DATA

SERIES	BORE/ STROKE (mm)	CR	YEARS	CAPACITY (cc)	VALVES (mm)	CAM TIMING (deg) IN	EX	LIFT (mm)	POWER (bhp DIN)	TORQUE (lbf ft)
132A1000	84 x 79.2	8.9:1	73–75	1756 (1800)	41.8/36	12/53	54/11	9.7	105 @ 6000	104 @ 4200
132B1000	84 x 79.2	8.9:1	75–77	1756	41.8/36	12/53	54/11	9.7	107 @ 6000	104 @ 4200
132C2000	84 x 90	8.9:1	–82	1995 (2*l*)	41.8/36	15/55	57/13	9.9	112 @ 5600	Around 116 @ 3000
132D1000 (Argenta)	84 x 90	9:1	83–85	1995	41.8/36	15/55	57/13	9.9	113 @ 5600	Around 116 @ 3000

Engine tuning notes:
All models have late con-rod design with 12mm dia flywheel bolts.
All models have same flywheel diameter.
All models have forged steel crank, 2*l* versions are Tufftrided/nitrided.
Late gearbox and bellhousing was introduced on 2*l* versions.
Engine tuning potential: 1800 – 7/10; 2*l* – 9/10.

TWIN CAM MODELS

FIAT 131 SUPERMIRAFIORI ENGINE DATA

SERIES	BORE/ STROKE (mm)	CR	YEARS	CAPACITY (cc)	VALVES (mm)	CAM TIMING (deg) IN	EX	LIFT (mm)	POWER (bhp DIN)	TORQUE (lbf ft)
131B1000	84 x 71.5	9:1	77–85	1585	41.8/36	5/53	53/5	9.4	95 @ 6000	98 @ 3800
131B2000	84 x 90	8.9:1	77–82	1995	41.8/36	5/53	53/5	9.9	Around 115 @ 5600	Around 128 @ 3600
131C4000	84 x 90	8.9:1	82–85	1995	41.8/36	5/53	53/5	9.9	Around 115 @ 5600	Around 115 @ 5600

Engine tuning notes:
All models have late pattern con-rods, but 1600 will not accept race bearings.
1600 has smaller (200mm) flywheel than 2*l*.
All models were fitted with late bellhousing and gearbox, 2-door Sport has Abarth remote gearshift.
1600 has cast crank, others are Tufftrided steel forgings.
All models have block-mounted distributor.
Rare 2*l* 16v Gp 4 models highly sought after.
Engine tuning potential: 1585 – 6/10; 8v 2*l* – 9/10.

FIAT 105/130 TC ENGINE DATA

SERIES	BORE/ STROKE (mm)	CR	YEARS	CAPACITY (cc)	VALVES (mm)	CAM TIMING (deg) IN	EX	LIFT (mm)	POWER (bhp DIN)	TORQUE (lbf ft)
138AR000 (105 TC)	84 x 71.5	9.3:1	83–88	1585	43.5/36	10/48	53/5	9.6	105 @ 6100	103 @ 4000
138AR2000 (130 TC)	84 x 90	9.45:1	83–88	1995	43.5/36	7/51	51/8	10	130 @ 5900	136 @ 3600

Engine tuning notes:
105 TC, Regata 100S, Prisma and Delta 1600 GT engines are essentially all the same and use cast crank.
130 TC has nitrided steel crank.
Transverse units can be converted to RWD by change of sump, oil pump and use of bearing in end of crank (input shaft of box may need to be shortened). All engines mounted vertically.
Engine tuning potential: 1585 – 7/10; 2*l* – 9/10.

LANCIA BETA ENGINE DATA (DONOR ENGINES AVAILABLE FROM COUPE, SPIDER, SALOON, HPE)

SERIES	BORE/ STROKE (mm)	CR	YEARS	CAPACITY (cc)	VALVES (mm)	CAM TIMING (deg) IN	EX	LIFT (mm)	POWER (bhp DIN)	TORQUE (lbf ft)
138AR000	84 x 71.5	9.3:1	83–88	1585	43.5/36	10/48	53/5	9.6	105 @ 6100	103 @ 4000
828B000	84 x 71.5	9.4:1	75–84	1585	41.8/36	13/45	49/9	9.4	100 @ 5800	103 @ 3000
828B1000	84 x 90	8.9:1	75–80	1995	41.8/36	13/45	49/9	9.4	115–119 @ 5500	134 @ 2800
828B4000 (*ie* version)	84 x 90	8.9:1	80–84	1995	41.8/36	13/45	49/9	9.4	122 @ 5500	135 @ 2800
828B7000 (Volumex version)	84 x 90	7.5:1	82–84	1995	43.5/36	13/39	37/3	9.2 IN 8.6 EX	135 @ 5500	152 @ 3000

Engine tuning data:
1585 cast crank, others steel. Volumex has sodium-cooled exhaust valves.
134AS Lancia Monte Carlo engine similar to 828B1000, mid-engined layout, others FWD.
Gearboxes all interchangeable, ratios common to all models, final-drive ratios vary. Volumex also used on limited number of 2*l* Spiders (Pininfarina Spider Europa). All engines 20° rear tilt.
Engine tuning potential: 1585 – 6/10; 2*l* (carb) – 9/10; 2*l* (*ie*) – 7/10; Volumex – 10/10.

LANCIA DELTA ENGINE DATA (SEE ALSO 105TC)

SERIES	BORE/ STROKE (mm)	CR	YEARS	CAPACITY (cc)	VALVES (mm)	CAM TIMING (deg) IN	EX	LIFT (mm)	BOOST (Bar-gauge)	POWER (bhp DIN)	TORQUE (lbf ft)
831A7000 Delta HF Turbo (carb)	84 x 71.5	8:1	83–85	1585	41.8/36	0/40	40/0	9.1 IN 8.6 EX	0.52	130 @ 5600	147 @ 3500
831B3000 HF (*ie*)	84 x 71.5	8:1	86–87	1585	43.5/36	0/40	40/0	9.1 IN 8.6 EX	0.8	140 @ 5500	147 @ 3500
831B5000 (Delta 4WD)	84 x 90	8:1	86–87	1995	43.5/36	8/42	41/1	9.1 IN 8.6 EX	0.9	165 @ 5250	196 @ 2500
831C5000 Delta HF Integrale (8v 4WD)	84 x 90	8:1	88–89	1995	43.5/36	8/42	42/1	9.1 IN 8.6 EX	1	185 @ 5300	234 @ 3500
831D5000 Integrale (16v 4WD)	84 x 90	8:1	89–91	1995	34.5/28.5	8/35	30/0	8.6 IN 7.5 EX	1	200 @ 5500	234 @ 3000

Engine tuning notes:
1585 models cast crank, 2*l* forged steel. Port layout changed '86 on.
All models have sodium-cooled exhaust valves. All models except 831A7000 have unleaded ex valve seats.
831A7000 uses Microplex ignition, all others have 'fully mapped' ignition/injection.
831A7000 is vertical, others 20° forward tilt.
2*l* models have larger clutch, *ie* 230mm friction face dia, than early 2*l* normally aspirated models; 1585 types use same dia clutch as 2*l* 131.
Engine tuning potential: 10/10.

'I wonder,' he said to himself presently, 'I wonder if this sort of car starts easily?'

Next moment, hardly knowing how it came about, he found he had hold of the handle and was turning it. As the familiar sound broke forth, the old passion seized on Toad and completely mastered him, body and soul. As if in a dream he found himself, somehow, seated in the driver's seat; as if in a dream, he pulled the lever and swung the car round the yard and out through the archway; and, as if in a dream, all sense of right and wrong, all fear of obvious consequences, seemed temporarily suspended. He increased his pace, and as the car devoured the street and leapt forth on the high road through the open country, he was conscious that he was Toad once more, Toad at his best and highest, Toad the terror, the traffic queller, the Lord of the lone trail, before whom all must give way or be smitten into nothingness and everlasting night. He chanted as he flew, and the car responded with sonorous drone; the miles were eaten up under him as he sped he knew not whither, fulfilling his instincts, living his hour, reckless of what might come to him.

From THE WIND IN THE WILLOWS
by Kenneth Grahame

CHAPTER 2

TUNING THEORY

An engine is often referred to as 'powerful', but what does this mean? In real terms, it usually implies that it gives good acceleration and can sustain a high top speed. Is this high power, or torque? In fact, it is high torque that leads to good performance, both under the transient, accelerative mode, and at steady-state high speed, but the influence of torque is sometimes neglected in discussion. At this early stage, it would be appropriate to state that the 'science' of tuning is to raise the torque output throughout the broadest possible engine speed range. Power is merely a function of torque/rpm, and this relationship will be discussed in detail later. Some definitions at this point are important.

Work

Work is done when a force moves its point of application through a certain distance. No matter how great the force exerted, if there is no movement, there is no work done.

Power

Power is the rate at which work is done. To lift a given weight through a given distance implies a fixed amount of work. To lift it the same distance, but in a shorter time, implies the same work in less time. So more power is used, but for a shorter time to do the same work.

Torque

Torque is the 'twisting effect' in a shaft. When tightening a bolt, the shear effect caused by the twisting depends on the length of the wrench used and the force applied. So Torque = Force applied × Radius of application.

Relationship of torque, speed and power (2/1)

Torque = Force (W) × radius (r),
or T = Wr.

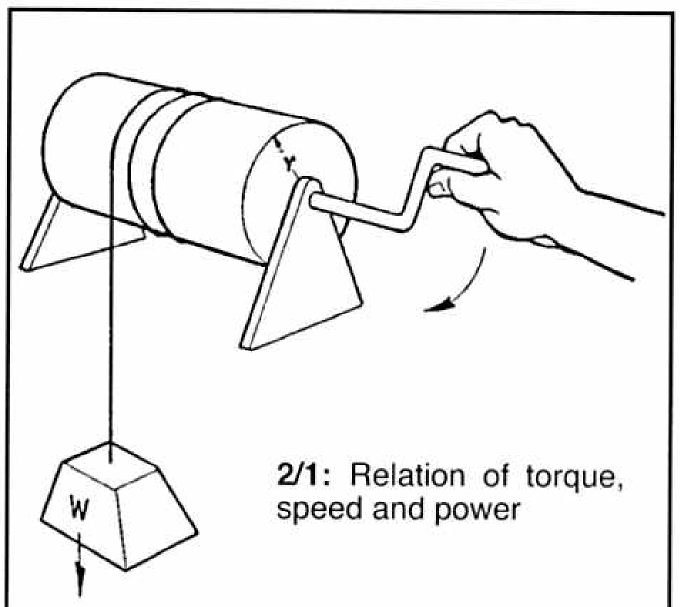
One revolution of the windlass raises the weight a distance of 2π

ie Work done = Force × Distance moved
= $W \times 2\pi r = 2\pi T$

If the windlass is turned through n revolutions in unit time

work in unit time = $2\pi T \times n$

ie Power = $2\pi nT$



2/1: Relation of torque, speed and power

Units

Work (SI)

The standard units are:
mass – kilogram – kg
time – second – s (sec)
length – metre – m
force – Newton – N

where (from the equation Force = mass × acceleration):

$1N = 1kg \times 1m/s^2$

The work unit is 1 Newton operating through 1 metre, giving:
1 Newton metre – 1Nm, which is equivalent to exactly 1 Joule – 1J. Since the Joule is very small, the kiloJoule kJ is normally used.

Work (imperial)

The standard units are:
mass – pound – lb
time – as SI
length – foot – ft
force – pound force – lbf

where $1lbf = 1lb \times 32.18ft/s^2$ ($32.18ft/s^2$ is the acceleration due to gravity).
The work unit is 1 pound force operating through 1 foot, giving 1 foot pound force – lbf ft (or ft lbf).

Power (SI)

The power unit is 1 Joule per second, which is called 1 Watt – 1W. Again the kiloWatt kW is more usual. As explained earlier, the product of power and time is work, thus: 1kW for 1 second = 1kJ and 1kW for 1 hour = 1kW hr (3600kJ). (This is the unit by which electricity is purchased.)

Power (imperial)

The power unit is 550 pound force per second, called 1 horsepower – hp. Since again, the product of power and time is work, 1 horsepower for 1 hour = 1hp hr = 3600hp second = 1.98×10^6lbf ft. Horsepower measured on a dynomometer is referred to as brake horsepower, or bhp.

Useful conversions

Torque	1lbf ft = 1.36Nm
	1Nm = 0.74lbf ft
Power	1bhp = 0.75kW
	1kW = 1.34bhp

Typical example (British units):
If a 2*l* TC develops 198bhp at 7500rpm, what is the torque output?

$$\text{Power} = 2\pi nT\text{, or, rearranging } T = \frac{\text{Power}}{2\pi n} \quad (\pi = 3.142)$$

where: T = Torque, n = engine speed (rev/min)

hence:

$$T = 198 \times \frac{1}{2\pi} \times \frac{1}{7500} = 4.20 \times 10^{-3} \text{ bhp min}$$

or more conventionally:

$$T = 4.2 \times 10^{-3} \text{ bhp min} \times 550 \times 60 = 138.6 \text{ lbf ft}$$

A useful quick form of this calculation to remember is:

$$\text{Power (bhp)} = \frac{T \text{ (lbf ft)} \times n \text{ (rpm)}}{5250}$$

Typical torque (SI units):
If a 2*l* TC develops 130kW at 7400rpm,

$$\text{Power} = 2\pi nT,\ T = \frac{\text{Power}}{2\pi n}$$

where units are: Power – Watts
Speed – rev/sec
T – Nm

$$\text{Torque} = \frac{130\times10^3\times60}{2\pi\times7400} = 167.7 \text{ Nm}$$

Torque or power?
From the equation:

$$P = 2\pi nT$$

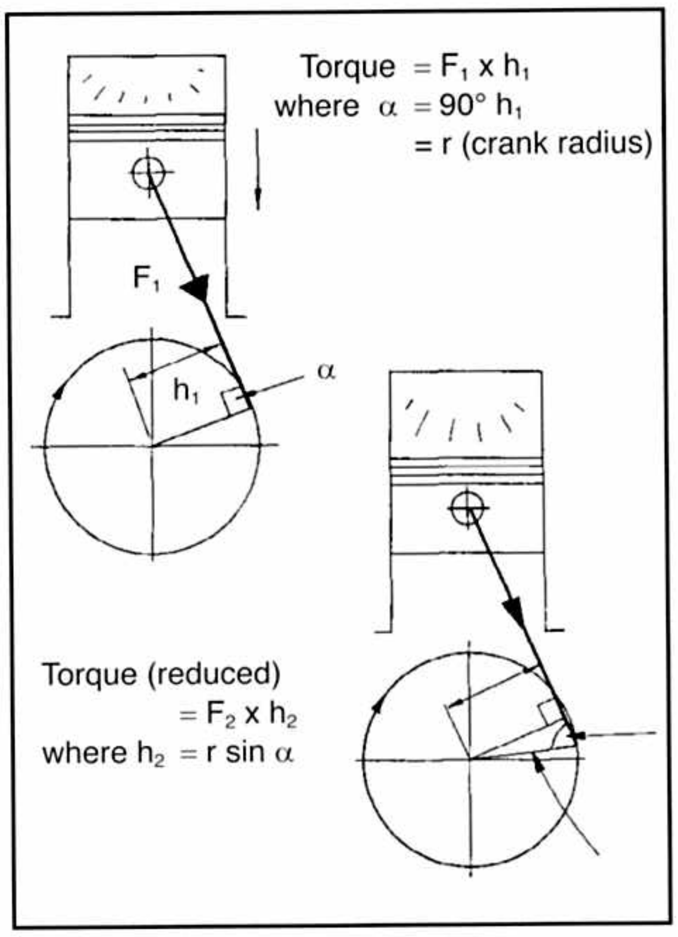
it is obvious that, if torque was constant (*ie* did not vary with rpm), the power output would increase linearly with engine speed. In practice, for reasons which will become clear in due course, the torque output varies with rpm, though to a lesser extent with pressure-charged engines, and the exact power output at any speed will depend on this. Very high torque at low speed may give the same power output as very low torque at very high speed, and similarly modest torque at low speed will give a poor power figure, but this does not imply that acceleration will be poor. Acceleration is produced by torque. To *sustain* a high top speed against the effects of inertia, gradient type, rolling resistance and aerodynamic resistance requires a high rate of work, *ie* high power.

Influences on power/torque output
Torque variation
A brief analysis of the working cycle of the engine shows that fuel/air mixture (petrol/air) is inhaled and burned to produce pressure in the cylinder. This gas pressure acts on the piston to force the assembly downwards in turn giving rise to rotation of the crankshaft. From the equations:

$$\text{Force} = \text{mass} \times \text{acceleration}$$

$$\text{and Gas pressure} = \frac{\text{gas force}}{\text{piston area}}$$

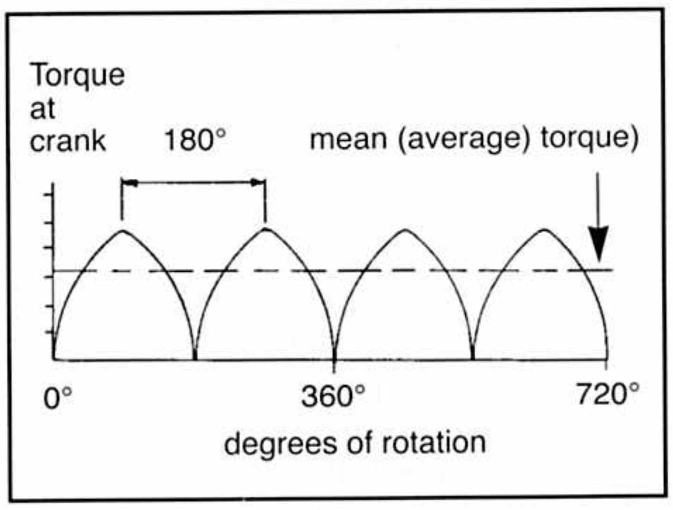
the greater the gas force *(see Chapter 9 – Pistons and Rings for analysis of gas force)* the greater the acceleration of the piston and vehicle as a whole. This process, of course, does not take place entirely unopposed, because to accelerate any body from rest requires a certain proportion of the applied force to be used up in overcoming inertia – the resistance of a mass to motion – and the effects of friction. The net force acting on the piston is the product of gas force minus inertia force and frictional force. What is left (after these deductions) is available to perform 'useful' work.



2/2: Variation of torque arm (h) with crank rotation.

The rotation of the crankshaft being generated by the reciprocating motion of the con-rod, the torque at the crankshaft is determined by the product of this net force acting along the rod axis and the radius at which it is applied **(2/2)**.

Added to the effect of the variation of the length of the torque arm 'h' the gas force 'F' varies. Firstly, the engine inhales a widely varying amount of charge according to its design characteristics and throttle position/speed. Added to this, the net gas force varies with piston position – as the cylinder volume increases the pressure drops, and because of the sinusoidal motion of the piston (it performs a simple harmonic motion) its acceleration varies – even at constant engine speed – so the inertia force (opposing the gas force) changes too. The effect of this is to produce a fluctuating, or cyclical, torque output **(2/3)**.



2/3: Four-cylinder cyclical torque variation.

Since each cylinder of the four-stroke engine fires only once every two crank revolutions, the four-cylinder engine requires 720° of crank rotation for all cylinders to complete their full working cycle. The mean torque output is measured at the flywheel on a brake dynamometer, and it is worth noting at this stage that the flywheel itself has an influence on the mean torque since it can store energy between firing strokes (180° interval on the four-cylinder engine).

Conversion of fuel into power
The net force on the pistons during the firing strokes determines the turning torque transmitted to the flywheel. Shortly after ignition, the cylinder pressure rises to a maximum – peak cylinder pressure – then drops as the piston moves down the bore until, when the exhaust valve opens, the cylinder pressure drops to the point where no further useful work is performed. Peak cylinder pressure depends on a number of interrelated factors, and its measurement is carried out by means of pressure indicator systems which map the pressure-volume relationship in the cylinder. Whilst interesting in itself, the main value of this measurement is to derive a value for the indicated mean effective pressure (imep), which can be used as a basis for calculation and analysis of the engine torque output. There is a variation between the theoretical, *ie* indicated mean effective pressure and the brake mean effective pressure (bmep), which generates usable torque at the flywheel, due to mechanical losses – friction/inertia. In other words, the power output at the flywheel is governed by the following relationship:

Indicated power = brake power + mechanical losses (where the mechanical losses are often referred to as 'friction horsepower', Fhp).

η_{mech}, mechanical efficiency (%)

$$= \frac{\text{brake power}}{\text{indicated power}} \times 100$$

$$= \frac{\text{bp}}{\text{bp}+\text{Fhp}} \times 100$$

Some dynomometers are capable of measuring the 'friction power' (Fhp), and thus the mechanical efficiency (ηmech) of the engine can be calculated; an analysis of ηmech is a useful method of determining just how much usable power is being lost.

Bmep and imep are related to the power output of the engine according to the following equations *(see next page)*:

$$\textbf{indicated power, ip} = \frac{p\,L\,A\,n\,e}{2\pi}\ (kW)$$

$$\text{and } \textbf{brake power, bp} = \eta_{mech} \times \frac{p\,L\,A\,n\,e}{2\pi}\ (kW)$$

where:
p = indicated mean effective pressure (kN/m^2)
L = stroke (m)
A = piston area (m^2)
n = engine speed (radians/sec)
(100 rev/sec = 100 × 2π rad/sec)
e = number of power strokes per revolution
(for the 4-cyl TC e = 2)

$$\text{since } \eta_{mech} = \frac{bp}{ip}\text{, and also } \eta_{mech} = \frac{bmep}{imep}$$

the above equation can be written as:

$$\textbf{brake power} = \frac{bmep \times L\,A\,n\,e}{2\pi}\ kW$$

Thus, if the brake power, L, A, n, e are known, the bmep can be calculated. The peak value will correspond with the speed at which maximum torque is produced, and examination of bmep is useful in the search for more torque (throughout the range) in the sense that the higher the bmep, the better the torque.

The indicated pressure on the piston depends on a number of closely inter-related factors. Firstly, high volumetric efficiency, *ie* good filling of the cylinder with air/fuel mixture, is required – the greater the mass of charge (in the correct ratio of air-fuel) the more energy is available. Secondly, the efficiency of the combustion cycle must be such that this charge is effectively burned to produce as high a pressure as possible. This efficiency depends partly on the design of the combustion chamber and means of ignition initiation (in the right place in the cycle) and partly on the compression ratio (CR) – the relationship between the volume in the cylinder with the piston at TDC and the swept volume of the cylinder. Not only does the CR have a major bearing on the efficiency with which the engine converts fuel into power (thermal efficiency – or η_{th}), it also affects the peak pressure achievable during the firing stroke in that the smaller the volume into which the charge is compressed prior to ignition, the greater the peak pressure that will result. The CR, computed from the dimensions of the clearance and swept volumes, will represent the 'static' compression ratio – on an efficient engine the 'effective' CR may be much higher – and on pressure-charged engines higher still, as the charge enters at a pressure above atmospheric. In this sense, the ability of the engine to inhale fresh charge (volumetric efficiency – or η_{vol}) has an important influence on CR and cylinder pressure as a whole.

INERTIA EFFECTS

During the power stroke, the reciprocating and rotating masses of the engine are accelerated by the force acting on the piston. As the power stroke of each cylinder comes to an end, the momentum generated in these components carries the piston beyond BDC and upwards on the exhaust stroke. On the four-cylinder engine the firing stroke of the next cylinder is just commencing at this point – the more cylinders an engine has, the lower the requirement for this momentum effect to keep the engine running smoothly.

However, no mechanical system is 100% efficient – in other words, the energy returned to the system will always be less than the input amount. If this were not true and there were no losses, a flywheel, once set in motion, would spin forever! It is therefore important that the lightness of these assemblies is carefully matched to the requirements of the engine – GP engines use virtually no flywheel and a very small diameter clutch because their multi-plane (v) crankshaft layout allows the multiple pistons to keep the engine rotating smoothly without the need for external energy storage. Since work is lost, *per se*, in driving these components, albeit that some is returned to the system, overly heavy reciprocating/rotating masses will lead to a torque loss at the flywheel, even at steady speed, against an engine with lighter components.

In addition, much of the time the crankshaft of a competition engine is accelerating in order to achieve a high power output, and the lighter the components, the faster this will take place. It is also worth noting that the heavier the components, the greater will be the frictional losses inside the engine.

Typical bmep
2*l* GCT NHRA Fiat:

$$\text{brake power} = \frac{bmep \times L\,A\,n\,e}{2\pi}\ kW$$

at peak torque, 5000 rev/min,

$$108.4 = bmep \times \frac{0.09 \times 0.0057 \times 83.3 \times 2\pi \times 2}{2\pi}$$

$$= bmep \times 0.09 \times 0.0057 \times 83.3 \times 2$$

$$\text{hence bmep} = \frac{108.4}{0.085} = 1268.3\ kN/m^2\ (184\ lbf/in^2)$$

(*Note:* To convert kN/m^2 to lbf/in^2, convert to N/m^2 (multiply kN/m^2 by 1000) and divide by 6895.)

This may not actually represent the ultimate bmep from an 8v TC, but certainly it is a respectable figure by any standards, which can probably be enhanced by closer attention to volumetric efficiency, CR, combustion efficiency and mechanical losses. A normally aspirated 16v engine of similar dimensions might reasonably give (developing 178lbf ft torque at 5500rpm) $212 lbf/in^2$, principally, GCT believe, due to the high volumetric efficiency of the valve layout, and the superior combustion efficiency of the (low-volume) 16v head.